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DRAFT OXYGEN RELEASE COMPOUND GROUNDWATER REMEDIATION REPORT SITE
13 NAB LITTLE CREEK VA
6/1/2002
CH2MHILL

DRAFT

ORC™ Groundwater Remediation Report

Site 13

**Naval Amphibious Base Little Creek
Virginia Beach, Virginia**



Prepared for:

**Department of the Navy
Atlantic Division
Naval Facilities Engineering Command
Norfolk, Virginia**

**Under Contract No. N62470-95-D-6007
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Virginia Beach, Virginia

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Introduction

This Groundwater Remediation Report presents the results of a pilot scale Oxygen Release Compound (ORC™) groundwater treatability study completed at Site 13, the Public Works PCP Dip Tank and Wash Rack at the Naval Amphibious Base Little Creek, Virginia Beach, Virginia. The treatability study is described in a Work Plan submitted by CH2M HILL in October 2000 to Naval Facilities Engineering Command (NAVFACENGCOM) LANTDIV as part of Navy Contract N62470-95-D-6007, Navy Comprehensive Long-Term Environmental Action Navy (CLEAN), District III, Contract Task Order 0098. The treatability study was completed on Contract Task Order 0183.

The treatability test was conducted to evaluate an in-situ approach to enhance the bioremediation of contaminants in the groundwater. The test involved the injection of an aerobic enhancement agent, ORC™, into the subsurface to help degrade pentachlorophenol (PCP) in the soil and groundwater. ORC™ has been developed by Regenesys Bioremediation Products of San Juan Capistrano, California.

PCP has been shown to degrade under both aerobic and anaerobic conditions. The selection of the aerobic enhancement agent that was used (ORC™), was based on the results of a 3-month-long bench scale microcosm test conducted for the United States Navy (the Navy) by Regenesys. The ORC™ was injected via Geoprobe throughout the saturated zone of the shallow (unconfined) aquifer beneath the site.

The objectives of the treatability test at Site 13 were to 1) Install and sample a system of monitoring wells to determine baseline water quality; 2) Inject ORC™ into the saturated zone and capillary fringe of the water table aquifer at a hot-spot below the location of a former PCP dip tank, to enhance the degradation rate of PCP; and 3) Collect sufficient data to evaluate groundwater remediation success.

Little Creek is on the National Priorities List (NPL), and Site 13 is being investigated and remediated under CERCLA authority.

1.1 Site History and Location

NAB Little Creek is located in the Tidewater area of southwestern Virginia in the northwest corner of the City of Virginia Beach. The western portion of the base is located in the City of Norfolk (Figure 1-1). Site 13-Public Works PCP Dip Tank and Wash Rack, is located near the intersection of 7th and F Streets, in the eastern portion of NAB Little Creek (Figure 1-2). Site 13 consists of the location of a former dip tank that had been used to treat wood with a mixture of PCP, diesel fuel and kerosene, and an adjacent area that had contained drying racks for PCP-treated wood, an open area formerly used by the Public Works Department for storage of supplies and equipment, and a concrete wash rack at the southwestern end of the area.

The PCP dip tank was located in the southwest corner of the fenced compound behind (west of) Building 3165E (Figure 1-3). It was used from the early 1960s until 1974.

According to a former public works supervisor, the tank was constructed of metal, had an estimated capacity of 1,500 gallons, and was partially set into the ground approximately two feet. It was a cylindrical tank laid on its axis. The top third of the tank was cut off and replaced with a metal cover. Initial oral accounts stated that the tank held 10,000 gallons; however, follow-up interviews with former employees in 1998 provided estimated tank dimensions of 20 feet long and a five foot diameter. A full tank of this size would hold 3,000 gallons. An open-top tank would likely hold a maximum of 1,500 gallons.

The contents of the tank were a mixture of one part PCP to ten parts diesel and kerosene. Wood was dipped into the tank and either set on racks for drying or placed directly on trucks for delivery to where it was to be used on base. The drying racks were located immediately east of the dip tank between the tank and Building 3165E. A pump was located at the south end of the tank, outside the fenced compound. This pump was used to keep the contents of the tank mixed and to empty the contents of the tank into 55-gallon drums when it became spent. The dip tank was cleaned out approximately every six months, at which time the approximately 55 gallons of PCP sludge generated are believed to have been removed from the tank and hauled away for disposal. All remaining PCP solution and associated sludges were removed from the tank in 1975. The tank itself was dismantled in 1982. The area formerly containing the PCP dip tank and drying racks has since been paved with asphalt and converted to a Public Works Department storage area. Subsequent soil and groundwater sampling in this area indicated that PCP was present in both media.

1.1.1 Source, Nature, and Extent of Contamination—Groundwater

Contaminants that were found in the groundwater at Site 13 that are above USEPA Region III Risk-Based Contaminant Levels (MCLs) include PCP, tetrachloroethene (PCE), trichloroethene (TCE), 1,2-dichloroethene total (1,2-DCE), and vinyl chloride. There appear to be two separate but overlapping plumes at the site, each with their own source area.

One plume is characterized by PCP, and its source is apparently the former PCP dip tank and the contaminated soil in the vicinity of the former dip tank. The PCP plume is the focus of this treatability test. The extent of the PCP plume is shown in Figure 1-4. The highest historic concentrations of PCP found in the groundwater occurred in Well LS13-MW08S, which was screened from 3 to 13 feet below ground surface (bgs) directly within the area formerly occupied by the aforementioned PCP dip tank and pump. Concentrations in this well ranged from 320 to 2,300 ug/L from 1996 to 1999. Concentrations of PCP in Well LS13-MW08D, which was screened in the lower portion of the aquifer (from 22.5 to 24.5 feet bgs) at the same location as LS13-MW08S ranged from 9 to 500 ug/L (all in 1998). Both of these monitoring wells were removed as part of the soil removal action at Site 13 in 1999 (Section 1.1.3). The closest downgradient well LS13-MW03T, which is 60 feet downgradient (southwest) of the former location of LS13-MW08S and D, had PCP concentrations ranging from 83 to 100 ug/L from 1996 to 1999. Therefore, it appears that the most significant PCP concentrations in groundwater are in the upper portion of the aquifer within relatively close proximity to the location of the former dip tank and pump.

The second plume is defined by chlorinated organic compounds (PCE, TCE, etc.) and appears to have a source south of the former PCP dip tank. The highest concentrations are in wells LS13-MW11S and D which are located 275 feet southwest of the former PCP dip

tank. A specific ongoing source (area of contaminated soil or non-aqueous phase liquid (NAPL) has not been identified for this plume). While these contaminants and concentrations are a concern, they were not the focus of this treatability study.

It should be noted that the lateral extent of both the PCP and the other chlorinate organic compound plumes have been determined, and neither plume appears to extend more than 600 feet downgradient from the former dip tank. Monitoring wells have been installed at the downgradient edges of the plumes and the nearest potential surface water discharge point is more than 1,200 feet beyond the edge of the plumes. A supplemental remedial investigation and risk assessment was prepared that documented the nature and extent of, and risks associated with these groundwater plumes.

1.1.2 Source, Nature, and Extent of Contamination - Soil

The primary contaminant found in the soil at concentrations above risk-based guidance levels (USEPA Region III RBCs for residential soil and for industrial soil) is PCP. Several PAHs have also been detected above the soil RBC for both residential and industrial use. The greatest concentrations of PCP and PAHs are centered around the former location of the PCP dip tank and the associated circulation pump. The greatest concentrations have consistently been found in the soil above the water table and typically in the upper two feet below the surface. The maximum concentration found to date is 890 mg/kg. The area of greatest soil contamination coincides with the head of the PCP-contaminated groundwater plume and the greatest concentrations found in the groundwater. Lesser concentrations (generally less than 10 mg/kg) of PCP have been detected in the soil in other areas around the former wood treatment compound. The belief is that the PCP-contaminated soil near the former tank and pump may act as a continuing source of contamination to the groundwater.

All soil containing PCP at concentrations greater than 36 mg/kg has since been removed as part of a soil removal action. In April 1999, the PCP-contaminated soil in the area beneath the former dip tank was excavated to depths ranging from 6 to 8 feet. The environmental investigation and removal action are discussed in greater detail in Section 1.1.3.

The wash rack and associated storage area, which are approximately 60 feet south of the dip tank and west of Building 3165E, continue to be used by the Public Works Department. The PCP in the groundwater is not associated with the wash rack or storage area.

1.1.3 Soil Removal Action

A soil removal action has been completed at the location of the former dip tank and pump area where the treatability testing was performed. The removal action consisted of removing all soil above the water table (5.3 bgs) at PCP concentrations greater than 16 mg/kg, and also removing one to three feet of soil below the water table. The 16 mg/kg action level was established in the Engineering Evaluation and Cost Assessment (EE/CA) (CH2M Hill, March 1999) and represented a concentration that would no longer present a leachable source of groundwater contamination that would pose a risk under an industrial use scenario.

The overall area of soil excavated in this removal action measured 46.5 feet by 17 feet, with excavation depths of 6 feet and 8 feet. A clay layer was encountered at depths ranging from

5.5 to 8 feet bgs that served as an effective barrier. Once the clay layer was removed, water entered the excavation area as the depth was below the water table. The excavated area was backfilled with sand and covered with bituminous concrete. The location of the excavated area is shown on Figure 1-5.

Confirmation sampling on the bottom and sides of the excavation showed concentrations that were all below 16 mg/kg of PCP, with the highest concentration in soil left in place at about 9.6 mg/kg of PCP. However, pre-excavation in-situ sampling detected soil contamination as high as 36 mg/kg at 10 ft bgs at the south end of the excavated area, indicating the possible presence of soil contamination potentially not removed by the excavation, at concentrations that may represent a source of potential contamination to groundwater in that area.

1.2 Site Description – Surface Features & Hydrogeology

The majority of the ground surface at Site 13 is asphalt-covered, with a small grass-covered area located immediately north of the location of the former dip tank. Paved storage areas surround the site, and an access road to Building 3165 is located immediately east of the former dip tank location. Ground surface elevation for Site 13 is approximately 8 feet amsl across the site. The area surrounding the site drains north via sheet flow to a storm water ditch that parallels 7th Street.

The upper 23 feet of geology in the vicinity of the former dip tank at Site 13 is primarily composed of fine to medium sands with some fines and occasional gravels. Interbedded, discontinuous layers of clay, ranging in thickness from approximately 2 to 5 feet occur at shallow depths in the western portion of the site. Boring logs indicate the occurrence of many discontinuous interbedded layers within the sands immediately underlying this site. A clay layer of undetermined thickness is present approximately 23 feet below ground surface (bgs) and is believed to be the Yorktown confining unit. Due to a lack of deep borings at the site, the full extent and thickness of this clay layer is unknown; but based on borings conducted at other IR Sites within NAB Little Creek (Sites 11 and 12), the clay layer is assumed to be present throughout the base and is likely to be 25 to 35 feet thick. The depth to the water table at the former dip tank is 5 to 6 feet.

The aforementioned shallow unconsolidated sand layers with discontinuous, interbedded clay lenses serve as an unconfined aquifer at Site 13. The thin (approximately 17 to 18 feet thick) water table aquifer in the Columbia Group is underlain by a confining clay layer in the upper Yorktown Formation. A semi-confined aquifer, the Yorktown aquifer, underlies this clay layer. The flow direction of the shallow water table (Columbia) aquifer at the site is predominantly to the southwest (Figure 1-6).

The average depth-to-water measured varied by only 0.1 ft between September 1998 (5.55 ft) and January 2001 (5.45 ft). The fluctuation in water levels at the site averaged approximately 0.20 ft between the September 1998 and January 2001 measurements. Horizontal gradients across the site were relatively flat and were approximately 0.0010 ft/ft in September 1998 and January 2001.

A pumping test conducted at nearby Site 12 indicated an average hydraulic conductivity (K) of 110 ft/day. Slug test data at Site 12 indicated an average K of 2.7×10^{-4} ft/sec. Although no

pumping tests were conducted at Site 13, K was estimated from slug test data to be 3.0×10^{-4} ft/sec. These similar results (along with similar subsurface soil properties) provide justification for using the K (110 ft/day) from Site 12 at Site 13. The effective porosity was estimated to be 0.35. Therefore, the groundwater flow velocity at Site 13 was estimated to be 0.3 ft/day (*Draft Supplemental Remedial Investigation for Site 13; CH2M HILL, June 2001*) using Darcy's Law,

$$V = Ki/n_e$$

V = groundwater velocity, ft/day

K = average hydraulic conductivity, ft/day

i = hydraulic gradient (dimensionless)

n_e = effective porosity (dimensionless)"

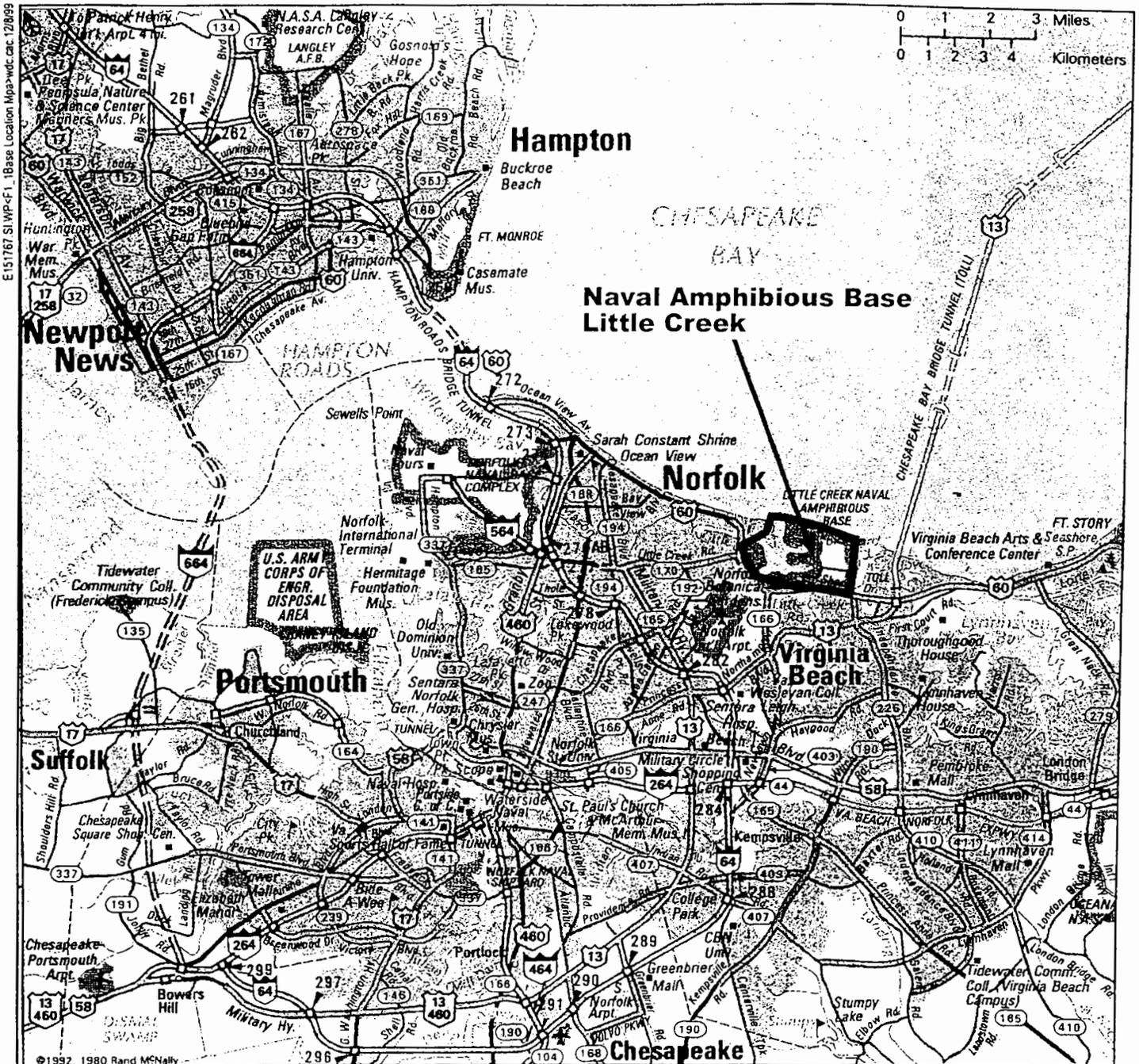


Figure 1-1
REGIONAL LOCATION MAP
NAB Little Creek
Virginia Beach, Virginia

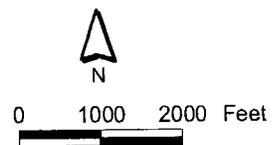
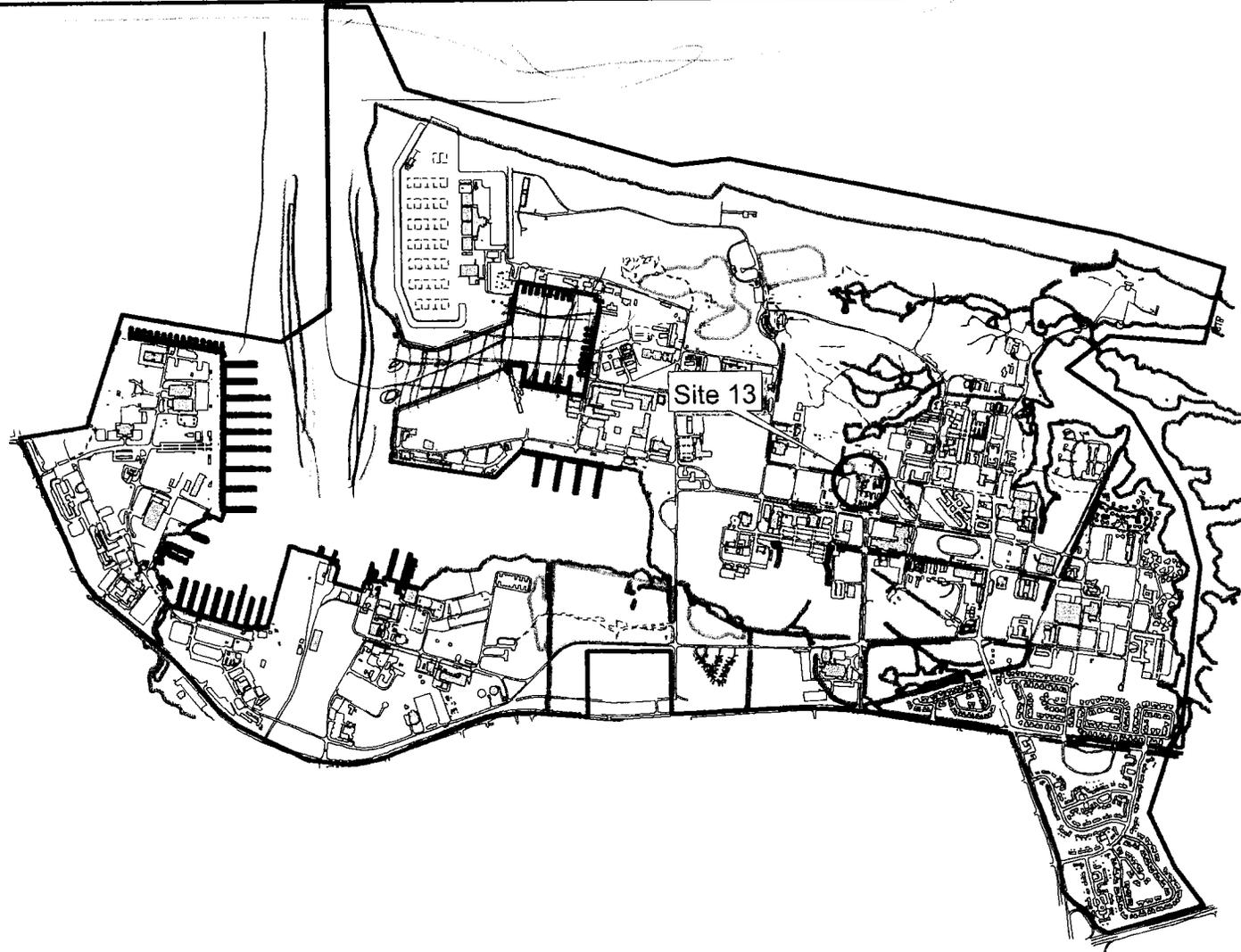
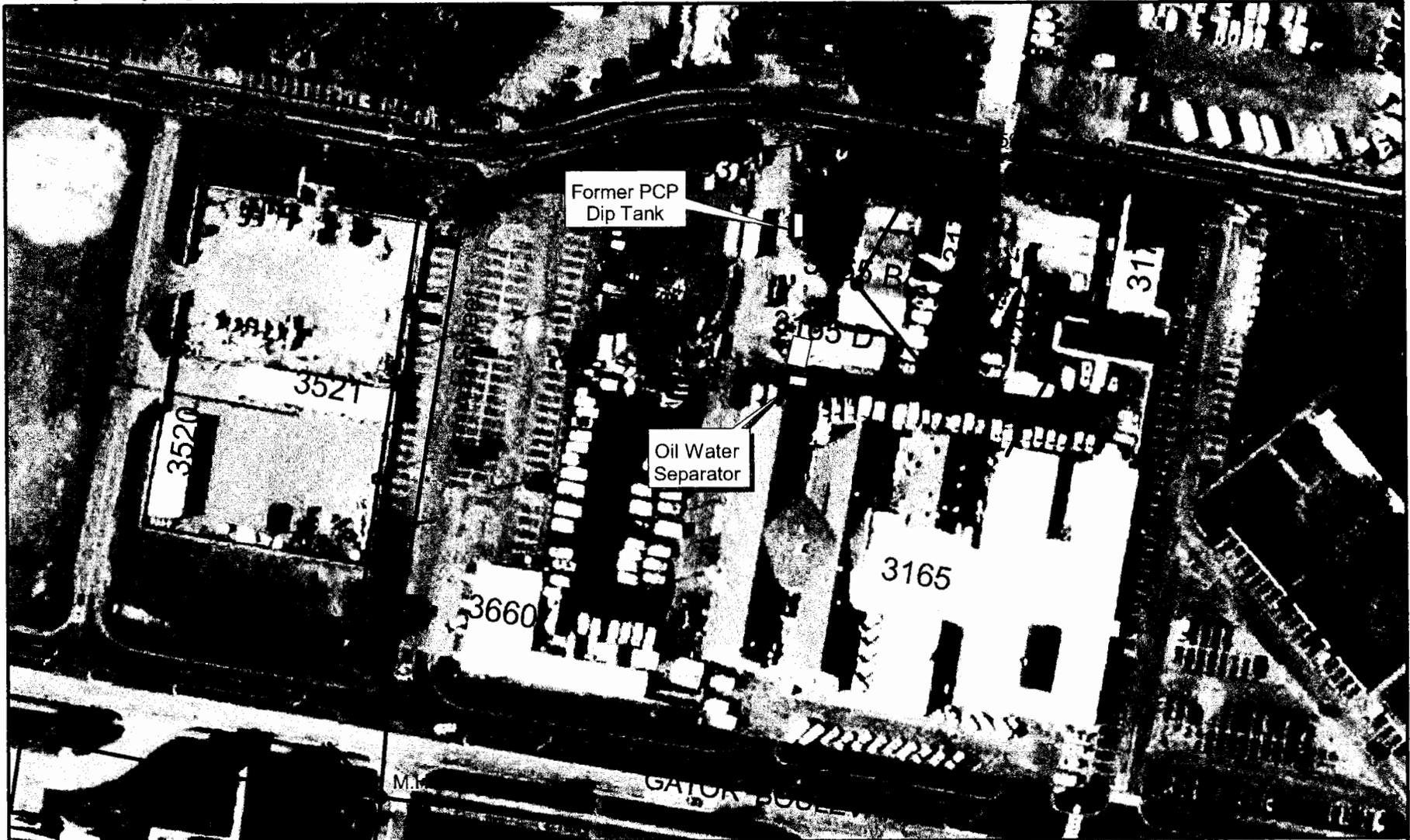


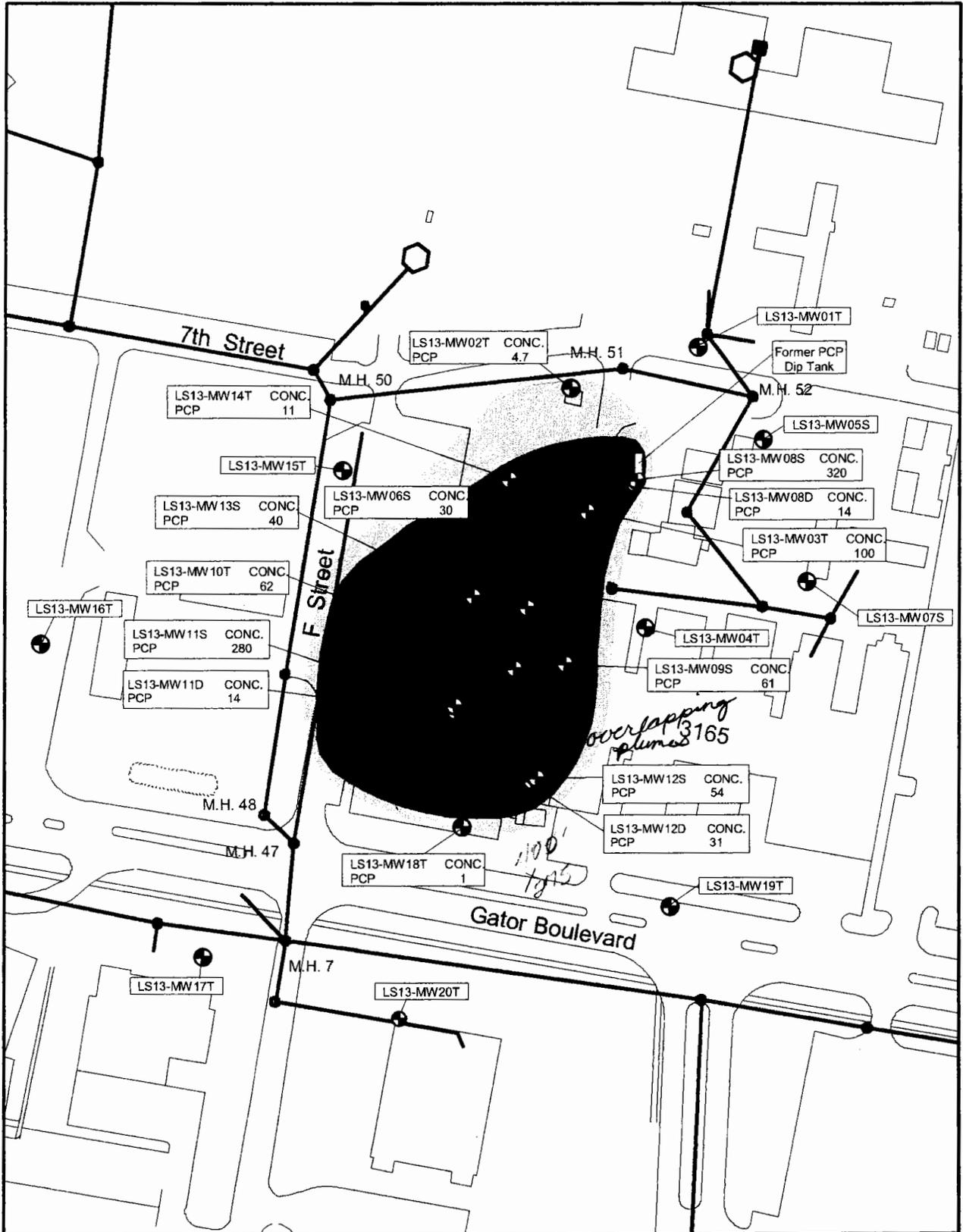
Figure 1-2
Site 13 Location Map
Site 13 ORC Summary Report
NAB Little Creek



LEGEND
~ Sanitary Sewer Lines
○ Manhole



Figure 1-3
Site Map
Site13 ORC Summary Report
NAB Little Creek



LEGEND

- 1-10 ug/L
- 10-100 ug/L
- 100+ ug/L

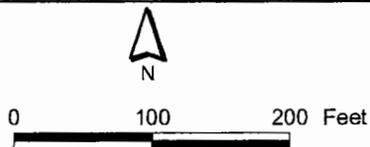
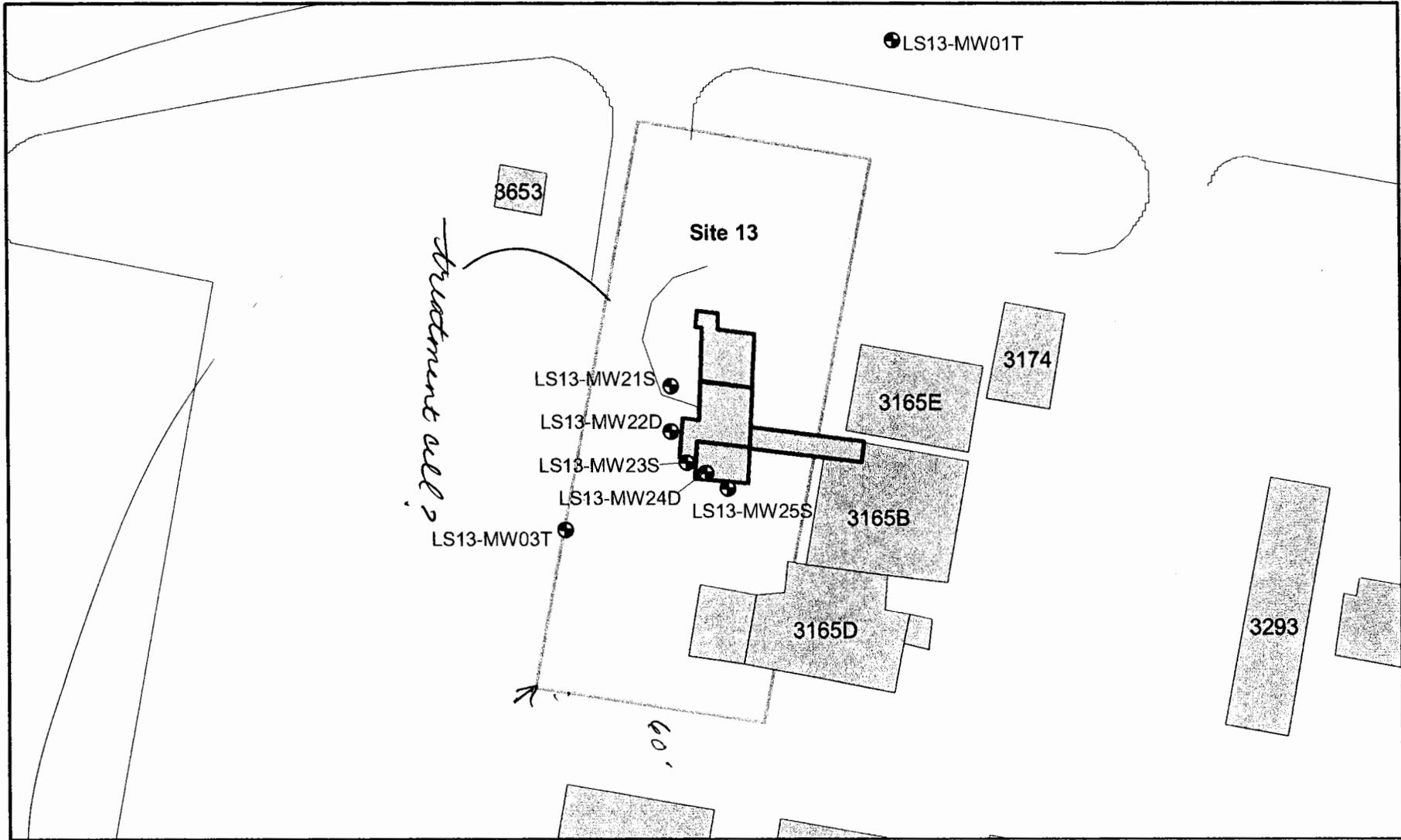


Figure 1-4
 PCP Isoconcentration Map
 For Columbia Aquifer, September 1998
 Site 13 ORC Summary Report
 NAB Little Creek



LEGEND

-  Excavation Areas
-  Building
-  IR Sites

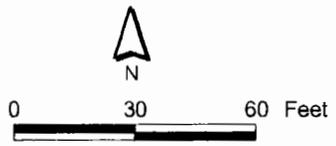
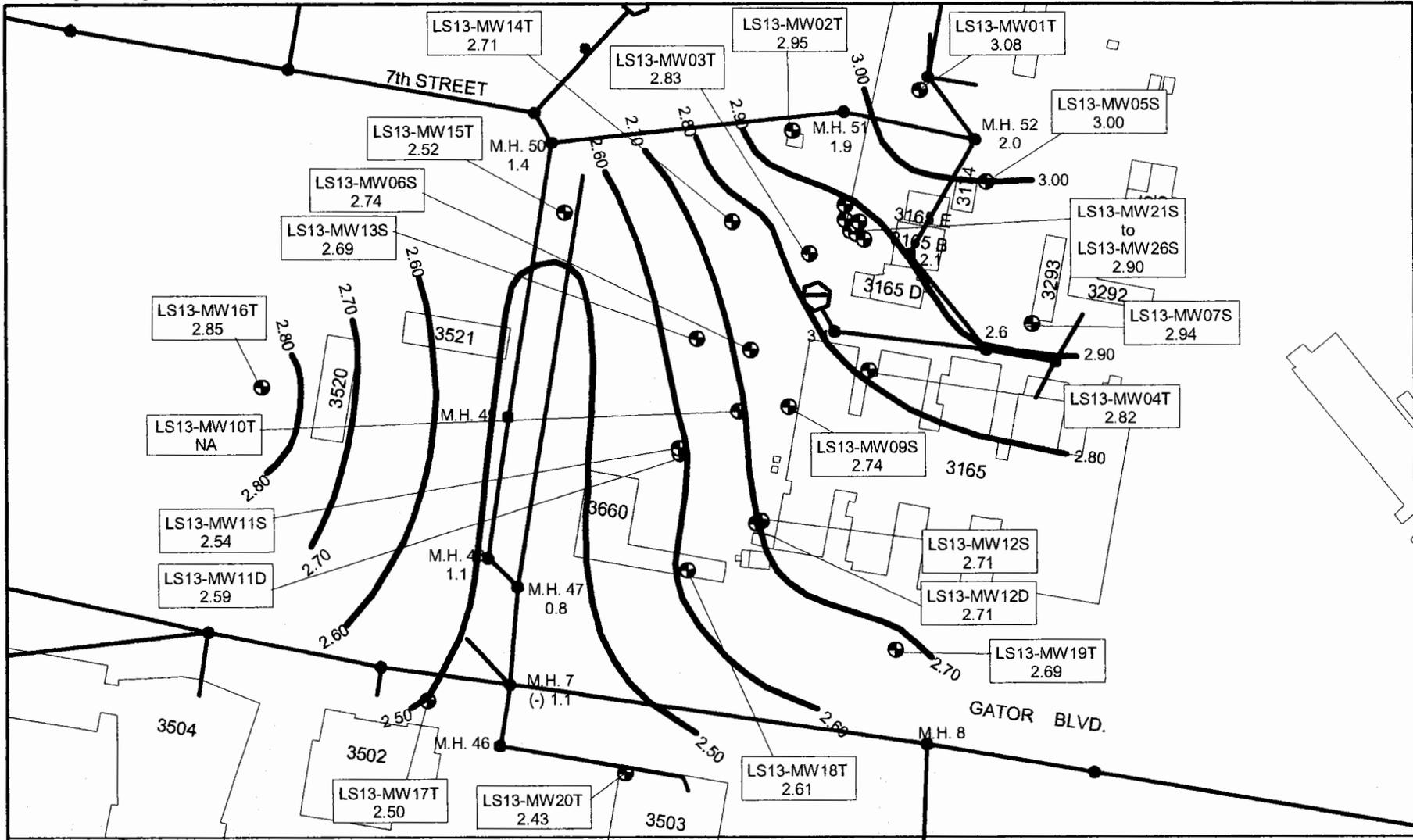


Figure 1-5
Extent of Soil Removal Action at Site 13
Site 13 ORC Summary Report
NAB Little Creek

12



LEGEND

- Monitoring Wells
- Sanitary Sewer Lines
- M.H. 48 - Manhole Number
1.1 - Invert Elevation
- LS13-MW01T
2.36 Water Level in MSL
- 2.10 — Line of Equipotential in MSL

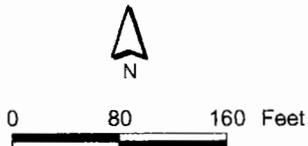


Figure 1-6
 April 2001 Water Level Data
 Site 13 ORC Summary Report
 NAB Little Creek

ORC™ Pilot Study Bench Scale Testing

A series of test tube microcosm tests were conducted to determine if reagent-enhanced aerobic or anaerobic conditions could enhance the biodegradation of PCP at Site 13. In these bench-scale tests, the Regensis products Hydrogen Release Compound (HRC) and Oxygen Release Compound (ORC™) were used to determine which, if either, of these two products would be applied in the treatability test. HRC™, a polyacetate ester made from reduced sugars and lactic acid, results in the release of hydrogen in the environment via metabolism of the lactic acid. This hydrogen is available to promote the conversion of chlorinated hydrocarbons to dechlorinated hydrocarbons (Regensis, HRC™ Technical Bulletin 1.1.3 in Appendix A). ORC™ is a patented formation of magnesium peroxide, MgO_2 , which slowly releases oxygen when moist.

The tests were conducted over a 3-month period under idealized conditions and were designed to provide a relative determination of the ORC™ versus the HRC™ effectiveness and applicability for use at Site 13. The complete results of the bench scale testing and all preliminary work completed for the pilot study is documented in the *Final Implementation for a Groundwater Treatability Study at Site 13, NAB Little Creek (CH2M HILL, October 2000)*, which is included as Appendix A.

2.1 Mechanisms of PCP Degradation

PCP has been shown to degrade both anaerobically (without the presence of oxygen) and aerobically (using oxygen as an electron acceptor). Appendix A presents a paper titled *Bioremediation of Pentachlorophenol, Literature Survey of Metabolic Pathways and Rate Constants*, by Pelorus Environmental & Biotechnology Corporation, June 4, 1997. This paper provides a detailed discussion of the various potential anaerobic and aerobic degradation pathways of PCP. These are briefly summarized below.

2.1.1 Anaerobic Biodegradation of PCP

PCP has been observed to degrade anaerobically by reductive dechlorination. Anaerobic degradation is a much slower process than aerobic because each chlorine molecule acts as an electron acceptor and is replaced by hydrogen producing first tetrachlorophenol (TeCP), then trichlorophenol (TCP), dichlorophenol (DCP), and finally chlorophenol (CP) before the phenol ring is broken relatively late in the process. To complicate matters, there are three isomers of TeCP, five isomers of TCP, six isomers of DCP, and three isomers of CP. The pathway that is followed appears to depend on the type of microorganism present in the system. It is possible that almost any of the isomers potentially could be involved, but the literature suggests that for a given system a certain limited number of breakdown products tend to predominate. However, it appears to be difficult to predict what the predominant pathway will be before testing. One reference offers the comment that unacclimated microbial consortia tend to preferentially remove chlorines from the ortho position (i.e., $PCP \rightarrow 2,3,4,5\text{-TeCP} \rightarrow 3,4,5\text{-TCP}$), whereas acclimated consortia may attack the meta or para position chlorines. It is also possible that under some conditions (and with some

microorganisms), the degradation pathway may not reach completion and may result in the generation and accumulation of one or more of the intermediate isomers.

While the literature seems to indicate that PCP is more toxic than any of its potential breakdown isomers, several of them are still considered to represent risks to human health. PCP and six of its 18 possible breakdown intermediates have been assigned human health risk-based concentrations (RBCs) for drinking water by EPA Region III. These are shown in Table 2-1. In order for anaerobic degradation of PCP to occur, highly anaerobic conditions must exist in the aquifer; dissolved oxygen levels below 0.5 mg/l are necessary in the groundwater.

2.1.2 Aerobic Biodegradation of PCP

In aerobic degradation, the phenol ring is broken during an early stage of the process and complete mineralization to carbon dioxide, water and chloride occurs much more quickly than through the anaerobic pathway. Initial intermediate products that form prior to breaking the phenol ring may include tetrachlorocatechol, tetrachlorohydroquinone (TeCHQ), tetrachlorobenzoquinone (TeCBQ), trichlorohydroxylbenzoquinone (TCBHQ), TCHQ, DCHQ, and CHQ. However, these intermediate products have been found to be relatively innocuous. None of these intermediate products are listed in EPA Region III RBC tables. Also, none are listed in EPA's Integrated Risk Information System (IRIS) and Health Effects Assessment Summary Tables (HEAST) data bases. Because these breakdown products have fewer chloride atoms than PCP and because they degrade quickly by cleavage of the phenol ring and are short-lived (they have not been found to accumulate in the environment at similar sites), it is assumed that the risk they pose is significantly less than PCP (see Appendix A).

The intermediate compounds of aerobic degradation of PCP are not on the TCL for semivolatile organics. The EPA Region III Tap Water RBCs for PCP and its breakdown products are listed in Table 2-1. Tentatively identified compounds were listed on the analysis results and compared to the anticipated breakdown products for identification, however past research indicated that these compounds were not been found to accumulate and were not likely to be detected.

For aerobic oxidation to occur, a dissolved oxygen concentration in the groundwater of at least 2 mg/l is typically required. Under ideal conditions, aerobic oxidation is considered to be a much faster process than anaerobic dechlorination. When PCP-contaminated wastes are treated above ground it has typically been found to be much faster and less costly to degrade the contaminant under aerobic rather than anaerobic conditions. The drawback is that it can be difficult and very expensive to create sufficiently aerobic conditions in the subsurface.

2.2 Results of the Test Tube Microcosm ORC™ Test

Two types of tests were run with addition of ORC™: tests with a low ORC™ dose (0.25 grams) and tests with a high ORC™ dose (0.75 grams). The test was run for three months with samples analyzed once a month. One control sample to which no ORC™ was added

was also run. Finally, an attempt was made to run a "sterile" sample using sterile sand as opposed to site soil and no ORCTM addition. The results were as follows:

10 ppm
PCP

1. After 30 days, PCP detected in the sample with the high ORCTM dose was reduced to 0.20 mg/l PCP (98% reduction). After 60 days, no PCP was detected.
2. PCP detected in the samples with the low ORCTM dose steadily declined over the test period and was reduced to an average of 0.93 mg/l PCP (91% reduction) by the end of 90 days.
3. At both 30 days and 60 days, the PCP in the control sample was about 6 mg/l (40% reduction). Results from the control samples at the 90-day mark were unavailable. Similar to the control sample, results in the "sterile" sample at 60 days and at 90 days were about 6 mg/l.
4. No 2,4-DCP and very little 2,4,6-TCP was detected in any of the samples, with the exception of a spike of 2.14 mg/l of 2,4,6-TCP at 30 days. 2,4,6-TCP was also detected in the 90-day samples at concentrations at or below 0.20 mg/l.

TM

10 ppm
PCP

2.3 Results of the Test Tube Microcosm HRCTM Test

A parallel series of tests using the same procedures and contaminant concentrations were run to test the effect of HRCTM addition. As with the ORCTM tests, two levels of HRCTM addition were tested (0.25 grams and 0.75 grams). The results of the HRCTM tests were as follows:

1. PCP in the sample with the high HRCTM dose was detected at 1.98 mg/l (80% reduction) at 30 days, 2.29 mg/l at 60 days, and 0.321 mg/l (97% reduction) at 90 days.
2. PCP in the sample with the low HRCTM dose was detected at 1.61 mg/l (84% reduction) at both 30 days and 60 days, and 0.672 mg/l (93% reduction) at 90 days.
3. The control and "sterile" samples were the same as those of the ORCTM test.
4. No 2,4-DCP and very little 2,4,6-TCP was detected in any of the samples. 2,4,6-TCP was detected in the 90-day samples at concentrations at or below 0.22 mg/l.

2.4 Selection of ORCTM as the Remedy

These results indicated that both HRCTM and ORCTM will degrade PCP under laboratory conditions. ORCTM was selected as the preferred method for the test plot because it was shown to degrade PCP to a greater extent during the 90-day test.

2.4.1 Summary of Treatability "Design"

This treatability test focused on the application of ORCTM within the hot spot of the contaminated groundwater to reduce contaminant mass. This was believed to provide the best opportunity to observe measurable declines in the groundwater concentrations. The soil at the groundwater interface has been addressed through the soil removal action and

2.4.3 Calculations for ORCTM Application Rates

The data collected at the site and presented in Table 2-2 show that there is a significant difference in the TPH and PCP concentrations in the upper portions of the aquifer compared to the lower portion (i.e. concentrations are greater in the upper portion of the aquifer). In order to reduce the amount of ORC™ needed, different application rates were calculated for the upper (6 to 15 feet bgs) and lower (15 to 23 feet bgs) halves of the aquifer.

The mass of PCP and TPH in the groundwater and saturated soil was calculated based on the following conservative assumptions:

- The concentration of PCP in the soil and groundwater throughout the treatment area was assumed to be 36 mg/kg and 2 mg/l respectively in the upper 9 feet and 0.4 mg/kg and 0.5 mg/l respectively in the lower 8 feet.
- The concentration of TPH in the soil and groundwater throughout the treatment area was assumed to be 39 mg/kg and 1.5 mg/l respectively in the upper 9 feet and 0.4 mg/kg and 1 ug/L respectively in the lower 8 feet.
- The volume of aquifer that was treated extended from the water table (at approximately 6 feet bgs) to the top of the Yorktown Clay (at approximately 23 feet bgs) and the aerial extent encompassed the entire excavation (17 by 46.5 feet). Total volume of the treatment area in the upper portion of the aquifer was 7,114 cubic feet. Total volume of the treatment area in the lower portion of the aquifer was 6,324 cubic feet
- The dry weight of the soil was 100 pounds per cubic foot.
- The porosity was assumed to be 0.3.

The theoretical (stoichiometry-based) oxygen demands for the aerobic degradation of PCP and TPH were as follows:

- Three pounds of oxygen (30 lbs. of ORC™) are required to completely degrade one pound of hydrocarbon.
- 0.54 pounds of oxygen (5.4 lbs. of ORC™) are required to completely degrade one pound of PCP.

If ORC™ were to be placed uniformly throughout the upper 9 feet of the aquifer, the total amount of ORC™ required would be:

$$\text{PCP in soil: } (7,114 \text{ ft}^3) \times (100 \text{ lbs/ft}^3) \times (0.000036 \text{ lbs. PCP/lb soil}) \times (5.4 \text{ lbs ORC}^{\text{TM}}/\text{lb PCP}) = 138 \text{ lbs.}$$

$$\text{PCP in gw: } (7,114 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.000002 \text{ lbs. PCP/lb. water}) \times (5.4 \text{ lbs. ORC}^{\text{TM}}/\text{lb. PCP}) = 1 \text{ lb.}$$

$$\text{TPH in soil: } (7,114 \text{ ft}^3) \times (100 \text{ lbs/ft}^3) \times (0.000039 \text{ lbs TPH/lb soil}) \times (30 \text{ lbs ORC}^{\text{TM}}/\text{lb TPH}) = 832 \text{ lbs.}$$

$$\text{TPH in gw: } (7,114 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.0000015 \text{ lbs. TPH/lb. water}) \times (30 \text{ lbs. ORC}^{\text{TM}}/\text{lb. TPH}) = 5 \text{ lbs.}$$

$$\text{Total ORC}^{\text{TM}} \text{ requirements in the upper portion of the aquifer} = 976 \text{ lbs.}$$

In order to maintain the dosage below the recommended maximum of 7 pounds ORC™/linear foot (recommended by Regenesys based on equipment limitations from past experience in sandy aquifers) over a 9 foot depth, the ORC™ was injected into the 17 direct push points shown in Figure 2-1, at a rate of 6.3 pounds ORC™ per foot.

If ORC™ were to be placed uniformly throughout the lower 8 feet of the aquifer, the total amount of ORC™ required would be:

$$\text{PCP in soil: } (6324 \text{ ft}^3) \times (100 \text{ lbs/ft}^3) \times (0.0000004 \text{ lbs. PCP/lb. soil}) \times (5.4 \text{ lbs. ORC}^{\text{TM}}/\text{lb. PCP}) = 1.5 \text{ lb.}$$

$$\text{PCP in gw: } (6324 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.0000005 \text{ lbs. PCP/lb. water}) \times (5.4 \text{ lbs. ORC}^{\text{TM}}/\text{lb. PCP}) = 0.5 \text{ lb.}$$

$$\text{TPH in soil: } (6324 \text{ ft}^3) \times (100 \text{ lbs/ft}^3) \times (0.00002 \text{ lbs. TPH/lb. soil}) \times (30 \text{ lbs. ORC}^{\text{TM}}/\text{lb. TPH}) = 379 \text{ lbs.}$$

$$\text{TPH in gw: } (6324 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.000001 \text{ lbs. TPH/lb. water}) \times (30 \text{ lbs. ORC}^{\text{TM}}/\text{lb. TPH}) = 3 \text{ lbs.}$$

$$\text{Total ORC}^{\text{TM}} \text{ requirements in the lower portion of the aquifer} = 384 \text{ lbs.}$$

The ORC™ was injected into the lower portion of the aquifer using the same 17 direct push points as for the upper portion of the aquifer. The injection rate for the lower portion was about 3 pounds ORC™ per foot. Using injection rates of 6.3 (upper portion) and 3 (lower portion) pounds per foot, the total ORC™ requirement was 1,384 pounds.

Table 2-1
Site 13 ORC Groundwater Remediation Report
RBCs for PCP and its Breakdown Products

Compound	EPA Region III RBC for Tap Water
PCP	0.56 ug/l
2,3,4,6-TeCP	1,100 ug/l
2,4,5-TCP	3,700 ug/l
2,4,6-TCP	6.1 ug/l
2,4-DCP	110 ug/l
2-CP	180 ug/l
phenol	22,000 ug/l

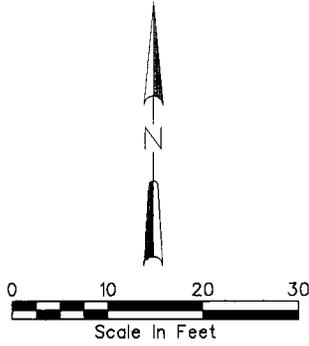
*Anaerobic
Degradation*

Table 2-2
 Site 13 ORC Groundwater Remediation Report
 Maximum Concentrations of Selected Parameters in the Treatment Area
 (After Excavation of Hot Spot Soil)

Media and Depth	PCP	TPH	TOC	DO	NO3	Fe+2	SO4	BOD	COD
Shallow Soil - mg/kg (10-12 feet)	36	39	3,540	NA	NA	NA	NA	249	11,600
Deep Soil - mg/kg (> 18 feet)	<0.4	<20	140	NA	NA	NA	NA	NA	NA
Shallow Groundwater - ug/l (5-15 feet)	2,000	<1,500	1,400	1,000	190	940	18,400	NA	NA
Deep Groundwater - ug/l (15-25 feet)	500	<1,000	2,700	1,300	550	500	27,000	<20,000	NA

Note:
 NA - Not Analyzed

*1 mg/L → 2.0 mg/L
 required*



LEGEND

- AREA OF ORC APPLICATION
- ORC INJECTION POINT
- SHALLOW MONITORING WELL (5-15' bgs)
- DEEP MONITORING WELL (13-23' bgs)
- GROUNDWATER FLOW DIRECTION

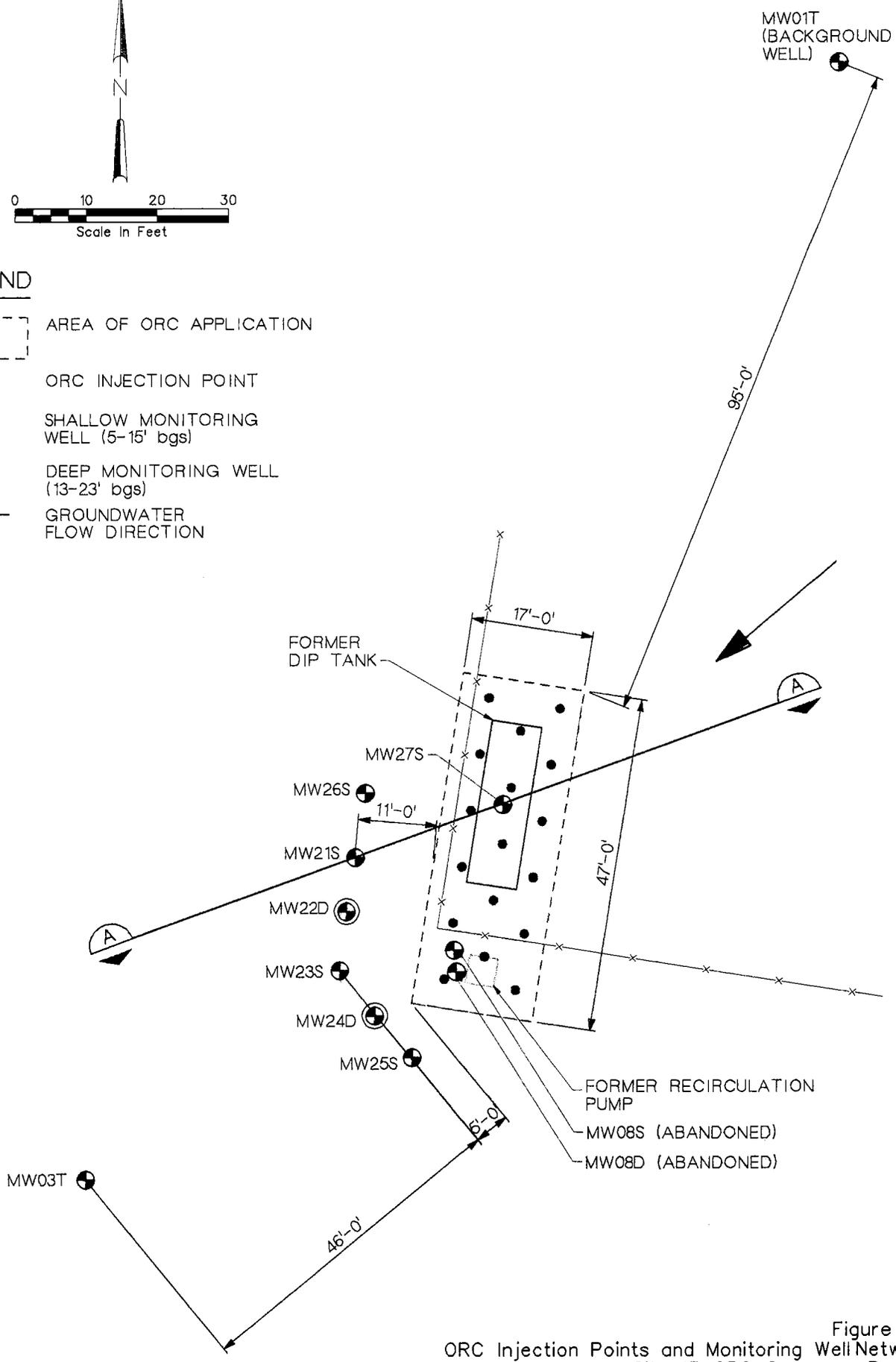
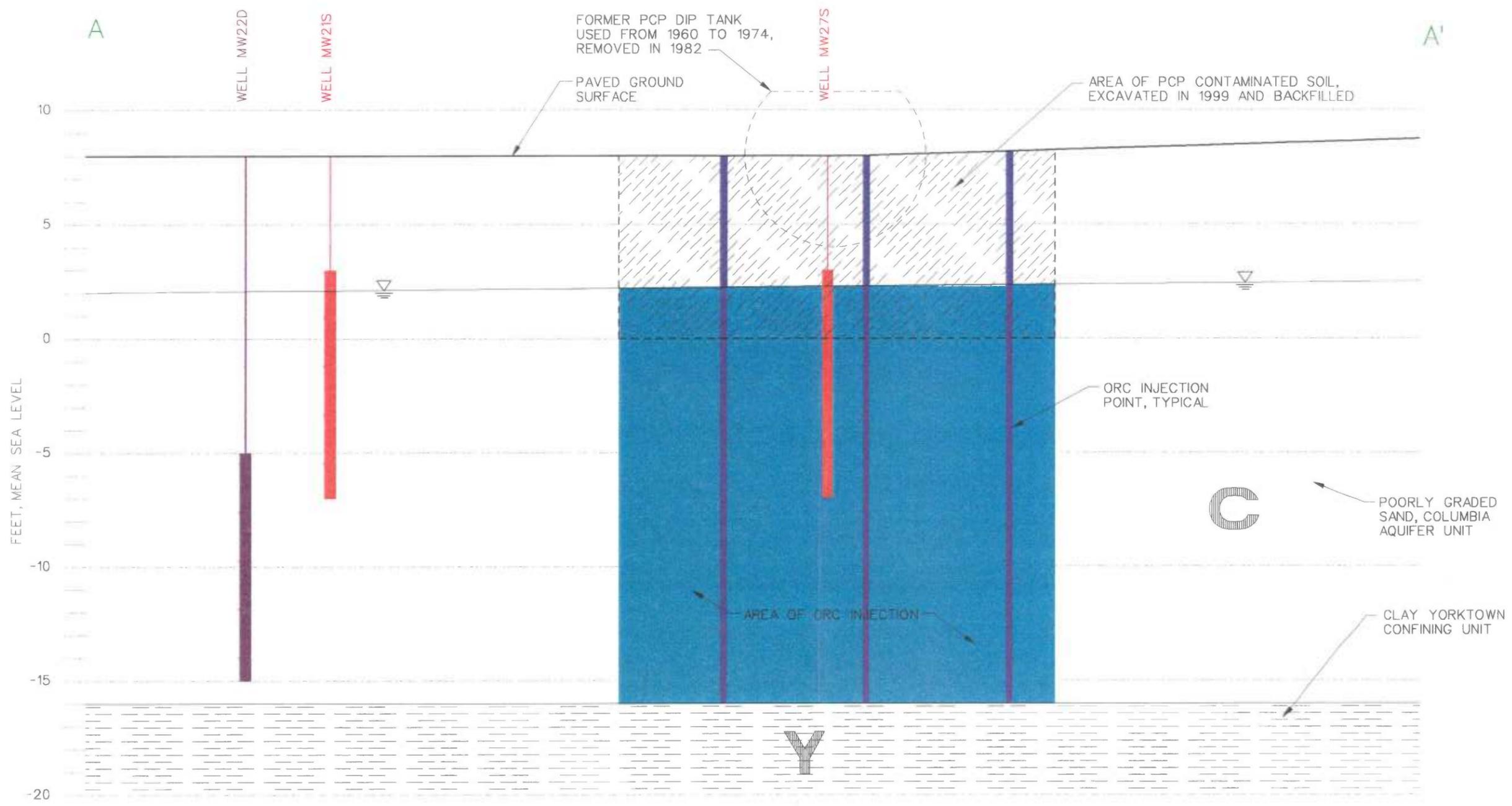


Figure 2-1
ORC Injection Points and Monitoring Well Network
Site 13 ORC Summary Report
NAB Little Creek



CROSS SECTION A-A'
THROUGH ORC INJECTION AREA
VERTICAL AND HORIZONTAL SCALE 1"=5'

Figure 2-2
Cross Section of Former Dip Tank Relative to Injection Area
Site 13 ORC Summary Report
NAB Little Creek

Pilot Study

1.1 Monitoring Well Network Installation

On August 21 and 22, 2000, five new monitoring wells were installed downgradient of the former PCP tank location. Three of the new wells are shallow (15 ft) and three are deep (25 ft): wells LS13-MW21S, LS13-MW22D, LS13-MW23S, LS13-MW24D, and LS13-MW25S. Two additional shallow monitoring wells, LS13-MW26S and LS13-MW27S, were installed during the pilot study to provide additional information on the effectiveness of the ORC™. The new wells were drilled using continuous-flight hollow-stem augers and constructed of 2-inch inner-diameter PVC with threaded joints and a flush mount cover. Wells were constructed with ten foot screens. A summary of the construction of the monitoring wells is provided in Table 3-1.

1.2 Baseline Groundwater Sample Collection

In August 2000, groundwater samples were collected from seven site wells (Figure 2-1), including the five newly installed wells and two existing wells (LS13-MW01T and LS13-MW03T). This sampling activity was conducted in order to determine baseline aquifer characteristics and water quality prior to the injection of ORC™. Measurements of pH, conductivity, turbidity, dissolved oxygen, and temperature were collected in the field using a Horiba U-10 water quality indicator. Dissolved oxygen measurements were confirmed with a Chemets® dissolved oxygen test kit. All sampling observations and measurements were recorded in a field logbook. Samples were collected from each of the seven wells for target compound list (TCL) semivolatile organic compounds (SVOCs), alkalinity, chloride, total organic carbon (TOC), ferrous iron, and carbon dioxide as listed in Table 3-2. Samples were collected for TCL volatile organic compound (VOC) analysis at two wells, LS13-MW03T and LS13-MW23S. Samples were collected for target analyte list (TAL) metals at four wells, LS13-MW24D, LS13-MW23S, LS13-MW01T, and LS13-MW03T. Samples were collected with a Grundfos® submersible pump using standard low flow sampling protocol. Samples collected in shallow wells were drawn at approximately ten feet below ground surface (bgs). Samples collected in deep wells were drawn approximately two feet above the bottom of the well (~22' bgs). Samples were transferred immediately into laboratory prepared sample containers and were packed on ice for overnight shipment to Katahdin Analytical, Westbrook, ME (through Round 3) and Compuchem, Inc. of Cary, NC (for Rounds 4 to 6) for laboratory analysis. All sampling procedures were conducted in accordance with Standard Operating Procedures (SOPs) in the *Master Project Plans Naval Amphibious Base Little Creek*.

The groundwater samples collected from each of the seven wells (at the time of baseline monitoring, MW26S and MW27s were not installed) in the monitoring network are shown in Table 3-1. Analytical parameters for baseline groundwater sampling are tabulated in Table 3-2.

While it was unlikely that the treatability test would affect metals concentrations in the groundwater to the extent that additional risks would be introduced to the site, dissolved and total metals analyses were analyzed for in samples from four wells in the baseline round (1T, 23S, 24D, and 3T). The parameters on the TCL for SVOCs are listed in Table 3-3 along with their method detection limits. All TCL and TAL analyses were performed in a fixed-base laboratory. One duplicate and one field blank were collected for QA/QC.

1.3 ORCTM Injection

During the week of October 16, 2000, approximately 1,400 lbs of ORCTM compound was injected into the surficial aquifer at the site. As discussed in Section 2.4.3, calculations for aquifer ORCTM requirements computed in CH2M HILL's *Implementation for a Groundwater Treatability Study at Site 13, NAB Little Creek* (Appendix A) indicated a requirement of approximately 1,000 lbs of ORCTM for remediation of the upper nine feet of the aquifer and 400 lbs of ORCTM for the lower eight feet of the aquifer. ORCTM was injected into the 17 direct push locations shown in Figure 2-1. The ORCTM was injected into the upper portion of the aquifer at a rate of approximately 6.3 pounds ORCTM per vertical foot. The injection rate for the lower aquifer was maintained at approximately 3 pounds ORCTM per vertical foot.

Prior to the commencement of injection, three direct-push groundwater samples were collected from locations illustrated in Figure 2-1. The direct-push sample locations were positioned to provide information for delineating the extent of contamination west of the excavation area. Elevated PCP levels were detected in monitoring well LS13-MW21S during the baseline investigation, therefore direct-push samples were analyzed for PCP only. Analytical results of these groundwater samples are presented in Table 3-4. Photographs of the ORCTM injection are attached as Appendix B.

1.4 Post-Injection Groundwater Monitoring

1.4.1.1 Round 1:

One additional monitoring well, LS13-MW26S was installed after the baseline investigation in the proximity of Geoprobe location LS13-GP302-05 due to an elevated PCP concentration of 1,300 ug/L in the groundwater sample obtained from this location. This well was then sampled as part of the Round 1 sampling event. The well was set at approximately 15 bgs and installation methods were consistent with the first series of well installations.

A summary of field sampling parameters (pH, Eh, temperature, and DO), by round, is provided in Tables 3-5 through 3-8. PCP results for each sampling round are summarized in Table 3-9. Graphical presentations of variations in dissolved oxygen and PCP concentrations are presented on Tables 3-8 and 3-9, respectively. The discussion of the post-injection monitoring results in this section is limited to that of PCP. Additional parameters analyzed during the pilot study were not found to fluctuate from round to round, nor were significant detections of any other parameters observed that were likely to influence the results of the pilot study. Complete analytical results for all parameters sampled during each round of the pilot study are included in Appendix C.

The wells sampled during the baseline sampling event and the newly installed LS13-MW26S were sampled between December 11 and 13, 2000 to collect Round 1 of post-injection samples in accordance with the Treatability Study Implementation Plan. Monitoring well LS13-MW26S was sampled for TCL VOCs, TCL SVOCs, carbon dioxide, alkalinity, chloride, ferrous iron, and TOC. All of the previously sampled wells were sampled for the same parameters as the baseline event, with the exception of LS13-MW01T and LS13-MW03T, which were not sampled for TAL total and dissolved metals, and LS13-MW24D and LS13-MW01T which were not sampled for TCL VOCs. Sampling procedures for the Round 1 sampling event were identical to the baseline sampling procedures.

The primary contaminant of concern during this pilot study was pentachlorophenol, which was detected in six of the seven wells sampled in the baseline sampling event. Pentachlorophenol was also detected in seven of the eight groundwater samples collected in the Round 1 sampling event. Pentachlorophenol was not detected in the upgradient sample from LS13-MW01T during either sampling event.

Increases in pentachlorophenol concentrations over baseline concentrations were evident in samples from wells LS13-MW21S and LS13-MW25S. All other wells demonstrated slight decreases in pentachlorophenol concentrations. At the completion of Round 1 of post-injection monitoring, concentrations did not appear to be consistent with well locations or proximity to ORC™ injection, and analytical results were inconclusive regarding the effectiveness of the ORC™.

Dissolved oxygen (DO) concentrations increased by a nominal amount in monitoring wells LS13-MW21S, LS13-MW25S, and LS13-MW03T between baseline and Round 1 monitoring. The remaining wells demonstrated slight decreases in DO. Concentrations ranged from 0.5 mg/L (LS13-MW01T and LS13-MW24D) to 2.0 mg/L (LS13-MW21S and LS13-MW25S). As discussed in Section 2.1.2, a DO concentration of at least 2 mg/L is typically required for aerobic oxidation to occur.

Complete analytical results for TCL SVOCs (all wells), TCL VOCs and TAL (total and dissolved) metals, and wet chemistry parameters for Round 1 and each subsequent round of post-injection monitoring are included in Appendix C. Samples were collected from each well during both sampling rounds for ferrous iron, alkalinity, chloride, TOC, and CO₂. The purpose of these analyses is to determine changes in oxygenation of the groundwater.

A comparison of baseline to Round 1 sampling analytical results demonstrated no apparent change in concentrations resulting from the October 2000 ORC™ injection. However, the injection process (ORC™ mixed with water into a slurry) may have caused transport of contamination from the source area to the surrounding wells. Additionally, the six week period between injection and sampling may not have allowed enough time for remediation to occur.

1.4.1.2 Round 2:

The second round of monitoring was conducted on January 16 and 17, 2001, approximately 13 weeks after the injection of ORC™ at the site. At this time, the PCP concentrations still had not shown the expected decrease in concentrations due to the injection. The speculated reasons for this were the same as those following Round 1. Complete analytical results for Round 2 sampling are summarized in Appendix C.

DO concentration increased significantly in monitoring well LS13-MW23S from Round 1 to Round 2 (1 mg/L to 8 mg/L). Increases were also observed in LS13-MW22D, LS13-MW24D, and LS13-MW03T. The remaining wells demonstrated a decrease in DO concentration. The range of DO measured in the field during Round 2 was from 0.42 mg/L (MW21S) to 8 mg/L (MW23S). Only MW23S and MW03T exhibited DO concentrations above the 2 mg/L typically required for the aerobic oxidation.

In order to further evaluate the effectiveness of the pilot study in subsequent monitoring rounds, it was proposed to install two additional monitoring wells at the site. These two wells were located within the "hot spot" at the site (within the actual ORC™ injection area) to determine PCP concentration immediately at the injection, and nearly west of monitoring well LS13-MW26S to provide additional downgradient data on the extent of the plume from the injection area. Based upon water level measurements, it appeared there may have been some component of groundwater flow in a more westerly direction than was anticipated prior to the installation of the monitoring wells.

Only one of these monitoring wells, MW27S, located directly within the ORC™ injection area, was installed on April 4, 2001 to provide additional information on the groundwater within the injection area.

Additionally, it was proposed to discontinue sampling monitoring well MW24D and one of either MW23S or 25S after completion of Round 2. After discussion with the Little Creek Partnering Team, it was decided to continue sampling all wells through Round 3 of post-injection monitoring, and determine if any wells could then be eliminated based upon this data.

1.4.1.3 Round 3:

The third round of monitoring was conducted on April 10 and 11, 2001, approximately 25 weeks after the injection of Oxygen Release Compound (ORC™) at the site.

After this third round of groundwater sampling, pentachlorophenol (PCP) concentrations were still not demonstrating the expected decrease in concentrations. As suggested after the second round of groundwater sampling, this could have been caused by slower movement of the PCP contamination than groundwater flow rates, or by a slight change in the groundwater flow direction that may have been initiated by the ORC™ injection. These reasons were still believed to be affecting the pilot study at the completion of Round 3. As a result, the monitoring was extended for an additional two rounds to obtain additional data on the effectiveness of the injection. Complete analytical results for Round 3 sampling are summarized in Appendix C.

All monitoring wells were sampled for the same constituent list as the previous two rounds during this monitoring event. Recently installed MW27S contained PCP at 460 ug/L, which was the second highest detected concentration during Round 3. This was, however, a decrease from the 760 ug/L detected during Round 2 monitoring. The concentration of PCP in MW26S at 880 ug/L was the highest observed concentration during the pilot study. Table 3-9 contains a graph demonstrating the PCP concentration in selected monitoring wells.

The DO concentrations measured during Round 3 were not usable due to equipment malfunction. As such, DO concentrations for Round 3 are not presented in this summary report.

Based upon the results of the third round of post-ORC™ injection monitoring, it was suggested that MW24D be eliminated from the monitoring network in subsequent monitoring rounds since it had not shown concentrations of PCP above the detection limit since the pilot study was initiated. The remaining monitoring would continue to be sampled for the same constituents through the remaining monitoring rounds.

1.4.1.4 Round 4:

This round of monitoring was conducted July 16 and 17, 2001 (approximately 40 weeks after the injection of ORC™ at the site). After Round 3, it was recommended to discontinue sampling from monitoring well MW24D. Therefore, MW24D was not sampled in Round 4 or in subsequent rounds. The remaining monitoring wells were continued to be sampled and analyzed for the same constituents through the remaining monitoring events. Complete analytical results for Round 4 sampling are summarized in Appendix C.

The highest detected PCP concentration in Round 4 was 250 J ug/L at MW26S. PCP concentrations at MW21S and the recently installed MW27S were 140 J ug/L. In Round 3 the highest historical PCP concentrations occurred at MW26S (880 ug/L) and the recently installed MW27S (460 ug/L). The highest concentration of PCP at MW21S was 760 ug/L in Round 1. This data obtained through Round 4 demonstrated the first significant decrease in PCP concentrations since the initiation of the pilot study. Figure 3-1 presents the groundwater concentrations of PCP per monitoring well location by round. Table 3-9 contains a graph demonstrating the PCP concentration in selected monitoring wells (MW01T, MW03T, MW21S, MW26S, and MW27S).

PCP concentrations at MW01T had been non-detect since Round 1 and the results at MW22D and MW23S exhibited non-detections during Rounds 3 and 4. There was a decrease in PCP concentration at MW25S from Round 3 to Round 4, and the results from MW03T were the only concentrations to show a slight increase in PCP during this time period.

The PCP results demonstrated a decrease in concentrations at six of the eight wells sampled, in comparison to the Round 3 results. The PCP concentrations at MW26S and MW27S were reduced approximately 70% from Round 3 to Round 4. MW21S results exhibited an approximate 80% reduction in PCP concentration from Round 1 to Round 4.

At the completion of Round 4, the DO concentrations were continuing to show a significant fluctuation from round to round, and only monitoring wells MW21S, MW23S, and MW22D were demonstrating an increase compared to baseline conditions. MW27S, which was installed prior to the collection of Round 3 samples (DO was not recorded during Round 3), indicated a DO concentration of 5 mg/L, which was the highest recorded concentration during Round 4. The monitoring wells demonstrating the elevated DO (concentrations ranged from 2.5 mg/L (MW21S) to 5 mg/L (MW27S)), also exhibited significant decreases in PCP concentrations (above 2 mg/L) for the first time during the pilot study. The average increase over baseline concentrations in the three monitoring wells demonstrating elevated

DO levels was 342% (range 208% to 471%). Data, including graphs, for PCP and DO are included in Tables 3-8 and 3-9, respectively.

1.4.1.5 Round 5:

The fifth round of post-injection monitoring was conducted on October 23 and 24, 2001 (approximately 53 weeks after the injection of Oxygen Release Compound (ORC™) at the site).

The highest detected PCP concentration during Round 5 of post-injection monitoring was 160 ug/L at MW21S. PCP concentrations in the remaining monitoring wells ranged from an estimated concentration (below laboratory detection limits) of 2 J ug/L (MW25S) up to 70 ug/L (MW26S). The concentration of PCP in MW26S decreased to 70 ug/L (an approximate 92% reduction) in the time between Round 3 and Round 5 sampling events (approximately 28 weeks). Table 3-9 contains a graph demonstrating the PCP concentration in selected monitoring wells over the duration of the pilot study.

PCP concentrations in MW01T had been non-detect since Round 1 and the results at MW22D and MW23S exhibited concentrations at or below detection limits during the pilot study, with the exception of a detection of 27 ug/L in MW23S during the baseline monitoring event. MW25S has also exhibited PCP concentrations below the detection limits in all sampling events except for Round 2 (49 ug/L) and Round 3 (33J ug/L). Additionally, MW03T demonstrated only one PCP detection above the detection limit, at 43J ug/L during Round 4.

The PCP results demonstrated a decrease in concentrations at five of the eight wells sampled as part of this pilot study (excluding comparison of estimated concentrations below detection limits to detection limits). The percent reduction from the maximum to minimum detected PCP concentrations in each of the monitoring wells through Round 5 is demonstrated in Table 3-10.

Dissolved oxygen concentrations remained elevated (over the baseline monitoring event) in six of the eight monitoring wells sampled during the pilot study at the completion of Round 5. The two wells that had not shown an increase in dissolved oxygen levels (MW25S and MW24D) showed minimal concentrations of PCP throughout the evaluation period. These wells were likely located slightly side-gradient of the PCP plume. Due to the lack of PCP detections, MW24D had not been sampled since Round 3. The remaining monitoring wells continued to demonstrate dissolved oxygen levels ranging from 170% (MW27S) to approximately 1,400% (MW22D) over the values determined during the baseline sampling event. It should be noted that dissolved oxygen is a field measurement subject to operator instrument readings, equipment variations, and calibration during each monitoring event. The results varied over the duration of this evaluation; however a general upward trend can be observed in the data. Table 3-8 presents the results, including a graph, of the dissolved oxygen measurements taken during the pilot study in select monitoring wells.

As determined after Round 4, the most significant PCP reductions corresponded to the monitoring wells with elevated (>2 mg/L) DO concentrations.

Evaluation of the data through round five of post-injection monitoring provided approximately one year worth of data regarding the effectiveness of this pilot study. Based

upon the extent of reductions in PCP concentrations and the sustained dissolved oxygen levels over the duration of this pilot study, the ORC™ injection appeared to have worked successfully. Further rounds of monitoring data were not likely to provide additional information to evaluate the effectiveness of the ORC™ injection. As a result, it was recommended to discontinue sampling each of these monitoring wells as part of this pilot study. However, it was suggested that selected wells (MW03T, MW21S, MW26S, and MW27S) be sampled on a periodic basis to monitor further reductions in PCP concentrations and to determine dissolved oxygen levels in the surficial aquifer as the ORC™ continues to flush out of the groundwater monitoring network. This additional information was also thought to be helpful in evaluating options for the feasibility study at Site 13.

The decision to continue the post-injection ORC™ monitoring at Site 13 to Round 6 was determined through discussion by the Little Creek Partnering Team, and included a modified sampling program for only PCP and DO in monitoring wells MW21S, MW26S, MW27S, and MW03T.

1.4.1.6 Round 6:

This round of monitoring was conducted on January 9, 2002 (approximately 65 weeks after the injection of ORC™ at the site). The sampling program was modified for this round of sampling to include analysis for pentachlorophenol (PCP) in monitoring wells MW21S, MW26S, MW27S, and MW03T only. Field measurements of dissolved oxygen were also taken at each monitoring well during the sampling event.

This modified round of sampling was conducted to confirm the reduction of PCP concentrations in groundwater samples through Round 5 after the data was reviewed by the NAB Little Creek Tier I Partnering team. Results of the modified Round 6 groundwater monitoring indicate the ORC™ is continuing to degrade the PCP. This is demonstrated by both reduced PCP concentrations and increased dissolved oxygen readings (as compared to baseline monitoring). These select monitoring wells had contained both the highest initial PCP concentration and greatest percent reduction in concentration during the pilot study, combined with sustained elevated DO readings.

The highest detected PCP concentration during Round 6 of post-injection monitoring in the selected monitoring wells was 130 ug/L at MW21S. PCP concentrations in the remaining monitoring wells ranged from an estimated concentration (below laboratory detection limits) of 2 J ug/L (MW25S) up to 110 ug/L (MW26S). Figure 3-1 presents the Round 6 groundwater detections by monitoring well location. Historically, the highest concentration of PCP was 880 ug/L (MW26S) in Round 3. MW26S was installed in December 2000 to provide additional data on the effectiveness of the ORC™ injection.

The concentration of PCP in LS13-MW26S decreased to 110 ug/L (an approximate 88% reduction) in the time between Round 3 and Round 6 sampling events (approximately 40 weeks). Table 3-9 contains a graph demonstrating the PCP concentration in selected monitoring wells over the duration of the pilot study.

The PCP results have demonstrated a decrease in concentrations at five of the eight wells sampled as part of this pilot study (excluding comparison of estimated concentrations below detection limits to detection limits). The percent reduction from the maximum to minimum

detected PCP concentrations in each of the monitoring wells is demonstrated in Table 3-10. The range of PCP reduction in MW21S, MW26S, and MW27S (the monitoring wells with the highest concentration of PCP throughout the pilot study) ranged from 81.6% to 98.3% and averaged 90.6%. MW23S and MW 25S also demonstrated significant decreases in PCP concentration, but had a considerably lower highest concentration during the pilot study.

Dissolved oxygen concentrations have remained elevated (over the baseline monitoring event) in six of the eight monitoring wells sampled during the Pilot Study. The monitoring wells sampled during Round 6 continue to demonstrate an average dissolved oxygen increase of 202%. Only MW26S contained a dissolved oxygen level lower than baseline conditions (23% of baseline during Round 6). This includes a 90% reduction between Rounds 5 and 6, which could indicate the ORC™ has been depleted around this monitoring well (located within the injection area). The results have varied over the duration of this evaluation; however a general upward trend can still be observed in the data. Table 3-8 presents the results, including a graph, of the dissolved oxygen measurements taken during the pilot study in the monitoring wells.

Table 3-1
 Site 13 ORC Groundwater Remediation Report
 Treatability Test Monitoring Well Network

Sampling Point	Diameter (inches)	Total Depth (feet bgs)	Depth of Screened Interval (feet bgs)
Background Wells			
LS13-MW01T (existing)	2	15.5	5.5 to 15.5
Downgradient Wells			
LS13-MW22D	2	25	15 to 25
LS13-MW23S	2	15	5 to 15
LS13-MW03T (existing)	2	15.5	5.5 to 15.5
LS13-MW21S	2	15	5 to 15
LS13-MW24D	2	25	15 to 25
LS13-MW25S	2	15	5 to 15
Additional Wells			
LS13-MW26S	2	15	5 to 15
LS13-MW27S	2	15	5 to 15

Table 3-2
 Site 13 ORC Groundwater Remediation Report
 Summary of Analytical Parameters for Baseline and Post-Injection Monitoring at Site 13

Sampling Point	Method	Method/Reference
All Wells (9)	TCL LC SVOCs and tics	Method OLCO2
All Wells (9)	Redox potential	A2580B
All Wells (9)	pH	Field probe
All Wells (9)	Temp	Field probe
All Wells (9)	Specific Conductance	Field probe
All Wells (9)	TOC	SW846-9060
All Wells (9)	Alkalinity	310.1
All Wells (9)	CO2	RSK-175
All Wells (9)	Fe2+	
All Wells (9)	Chloride	A44500-Cl-
All Wells (9)	DO	Field probe
BL: 4 wells (1T, 23S, 24D, 3T) Other Rds: 2 wells (23S, 24D)	TAL Metals (total)	Method ILM04
4 wells (1T, 23S, 24D, 3T) Other Rds: 2 wells (23S, 24D)	TAL Metals (dissolved)	Method ILM04
4 wells (1T, 23S, 24D, 3T) Other Rds: 2 wells (23S, 3T)	TCL LC VOCs	Method OLC02

Table 3-3
 Site 13 ORC Groundwater Remediation Report
 Analytical Parameters and Quantitation Limits
 Semivolatile Organic Compounds on Target Compounds List (TCL) (Method OCL02)

Analyte	Water ug/L	Analyte	Water ug/L
1,2-Dichlorobenzene	10	2,4-Dinitrophenol	25
1,3-Dichlorobenzene	10	4-Nitrophenol	25
1,4-Dichlorobenzene	10	Dibenzofuran	10
Phenol	10	2,4-Dinitrotoluene	10
bis-(2-Chloroethyl)ether	10	Diethylphthalate	10
2-Chlorophenol	10	4-Chlorophenyl-phenylether	10
2-Methylphenol	10	Fluorene	10
2,2'-oxybis(1-Chloropropane)	10	4-Nitroaniline	25
4-Methylphenol	10	4,6-Dinitro-2-methylphenol	25
N-Nitroso-di-n-propylamine	10	N-Nitrosodiphenylamine	10
Hexachloroethane	10	4-Bromophenyl-phenylether	10
Nitrobenzene	10	Hexachlorobenzene	10
Isophorone	10	Pentachlorophenol	25
2-Nitrophenol	10	Phenanthrene	10
2,4-Dimethylphenol	10	Anthracene	10
bis-(2-Chloroethoxy)methane	10	Di-n-butylphthalate	10
2,4-Dichlorophenol	10	Carbazole	10
1,2,4-Trichlorobenzene	10	Fluoranthene	10
Naphthalene	10	Pyrene	10
4-Chloroaniline	10	Butylbenzylphthalate	10
Hexachlorobutadiene	10	3,3'-Dichlorobenzidine	10
4-Chloro-3-methylphenol	10	Benzo(a)anthracene	10
2-Methylnaphthalene	10	Chrysene	10
Hexachlorocyclopentadiene	10	bis-(2-Ethylhexyl)phthalate	10
2,4,6-Trichlorophenol	10	Di-n-octylphthalate	10
2,4,5-Trichlorophenol	25	Benzo(b)fluoranthene	10
2-Chloronaphthalene	10	Benzo(k)fluoranthene	10
2-Nitroaniline	25	Benzo(a)pyrene	10
Dimethylphthalate	10	Indeno(1,2,3-cd)pyrene	10
Acenaphthylene	10	Dibenz(a,h)anthracene	10
2,6-Dinitrotoluene	10	Benzo(g,h,i)perylene	10
3-Nitroaniline	25	Acenaphthene	10

Table 3-4
 Site 13 ORC Groundwater Remediation Report
 Geoprobe® Groundwater Sample Results for PCP

Sample ID				LS13-GP-303-05	LS13-GP-303-05	LS13-GP-303-05
Sample Date				10/18/2000	10/18/2000	10/18/2000
Semi-volatile Organic Compounds (ug/L)	Frequency	Max Value	Max Location			
Pentachlorophenol	3/3	1,300	LS13-GP302-05	25	1,300	420

Table 3-5
Site 13 ORC Groundwater Remediation Report
pH

Round Number	Baseline	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6
Date	08/29/2000	12/13/2000	01/16/2001	04/10/2001	07/16/2001	10/25/2001	1/9/2002
Elapsed time (days)	0	55	89	173	278	379	455
LS13-MW01T	5.96	6.9	6.18	6.25	6.73	6.91	N/S
LS13-MW21S	4.89	5.4	5.41	5.19	5.32	4.92	5.13
LS13-MW23S	5.74	5.7	5.74	5.78	5.76	5.33	N/S
LS13-MW25S	5.41	6.0	5.65	5.4	5.75	5.33	N/S
LS13-MW26S	N/S	5.6	5.4	5.38	5.54	5.46	5.37
LS13-MW27S	N/S	N/S	N/S	5.53	5.6	5.66	5.56
LS13-MW22D	5.27	6.0	6.0	5.51	5.9	5.44	N/S
LS13-MW24D	5.1	5.6	5.34	5.35	N/S	N/S	N/S
LS13-MW03T	5.91	6.1	6.09	5.87	6.03	6.39	6.48

Note:

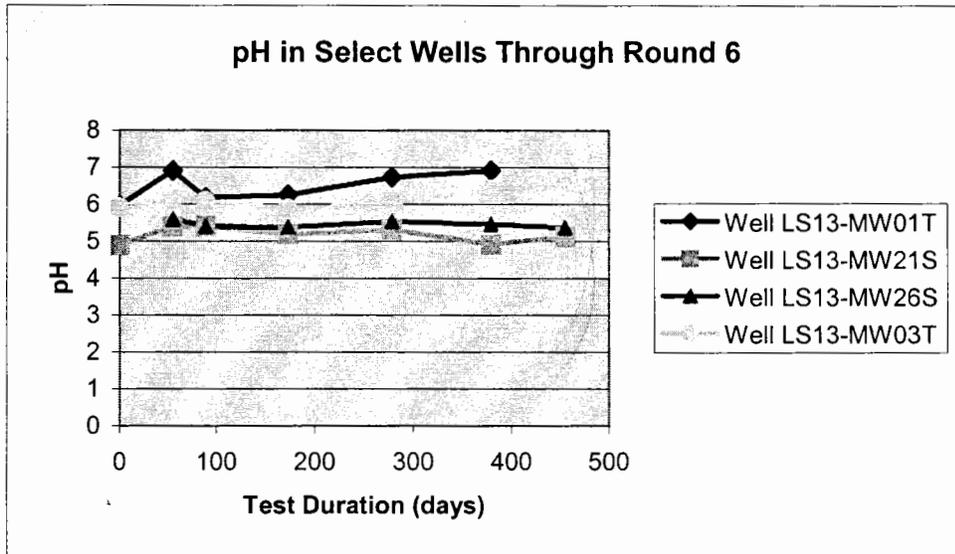


Table 3-6
Site 13 ORC Groundwater Remediation Report
Redox Potential (mV)

Round Number	Baseline	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6
Date	08/29/2000	12/13/2000	01/16/2001	04/10/2001	07/16/2001	10/25/2001	1/9/2002
Elapsed time (days)	0	55	89	173	278	379	455
LS13-MW01T	N/S	-144	-195	-135	-185	-127	N/S
LS13-MW21S	N/S	159	114	111	133	207	178
LS13-MW23S	N/S	110	123	135	165	238	N/S
LS13-MW25S	N/S	81	34	0	29	109	N/S
LS13-MW26S	N/S	22	63	67	33	106	98
LS13-MW27S	N/S	N/S	N/S	101	181	265	5.56
LS13-MW22D	N/S	68	76	122	198	307	N/S
LS13-MW24D	N/S	162	162	212	N/S	N/S	N/S
LS13-MW03T	N/S	73	42	40	37	14	96

Note:

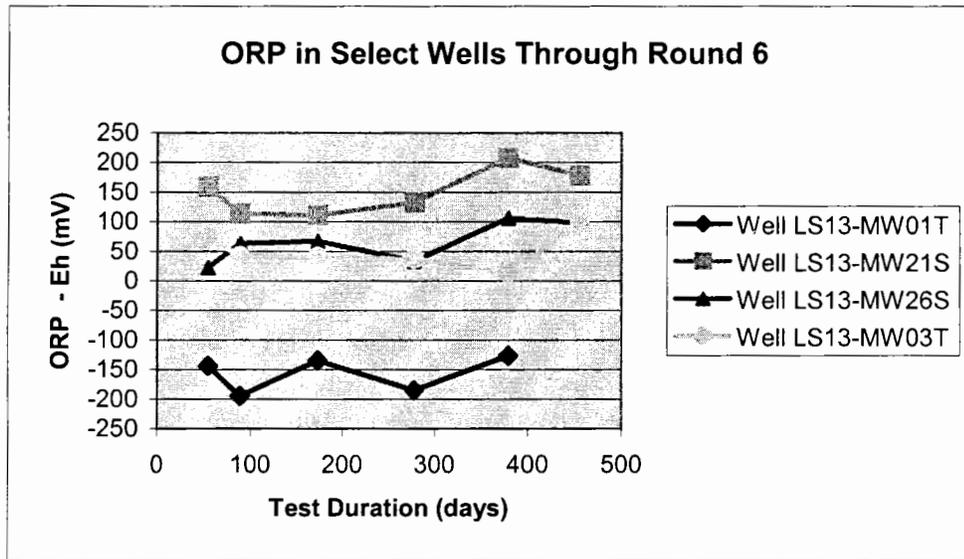


Table 3-7
 Site 13 ORC Groundwater Remediation Report
 Temperature (Degrees C)

Round Number	Baseline	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6
Date	08/29/2000	12/13/2000	01/16/2001	04/10/2001	07/16/2001	10/25/2001	1/9/2002
Elapsed time (days)	0	55	89	173	278	379	455
LS13-MW01T	26.1	23.9	19.9	19.9	30.1	27.9	N/S
LS13-MW21S	26.1	22	17.7	19	32.6	26.6	21.1
LS13-MW23S	24.4	22.4	18.3	17.7	26.9	25.7	N/S
LS13-MW25S	22.7	20.6	17.3	17.1	24	24.1	N/S
LS13-MW26S	N/S	24.8	17.4	18.6	29.9	27.1	19.8
LS13-MW27S	N/S	N/S	N/S	20	29.7	27.6	20.6
LS13-MW22D	22.7	24.2	19.9	19.2	25	24.2	N/S
LS13-MW24D	22.0	22.1	19.7	18.9	N/S	N/S	N/S
LS13-MW03T	26.4	23.4	18.3	18.7	29.6	27.9	15.2

Note:
 N/S - Parameter not sampled or monitoring well was not installed at time of sampling.

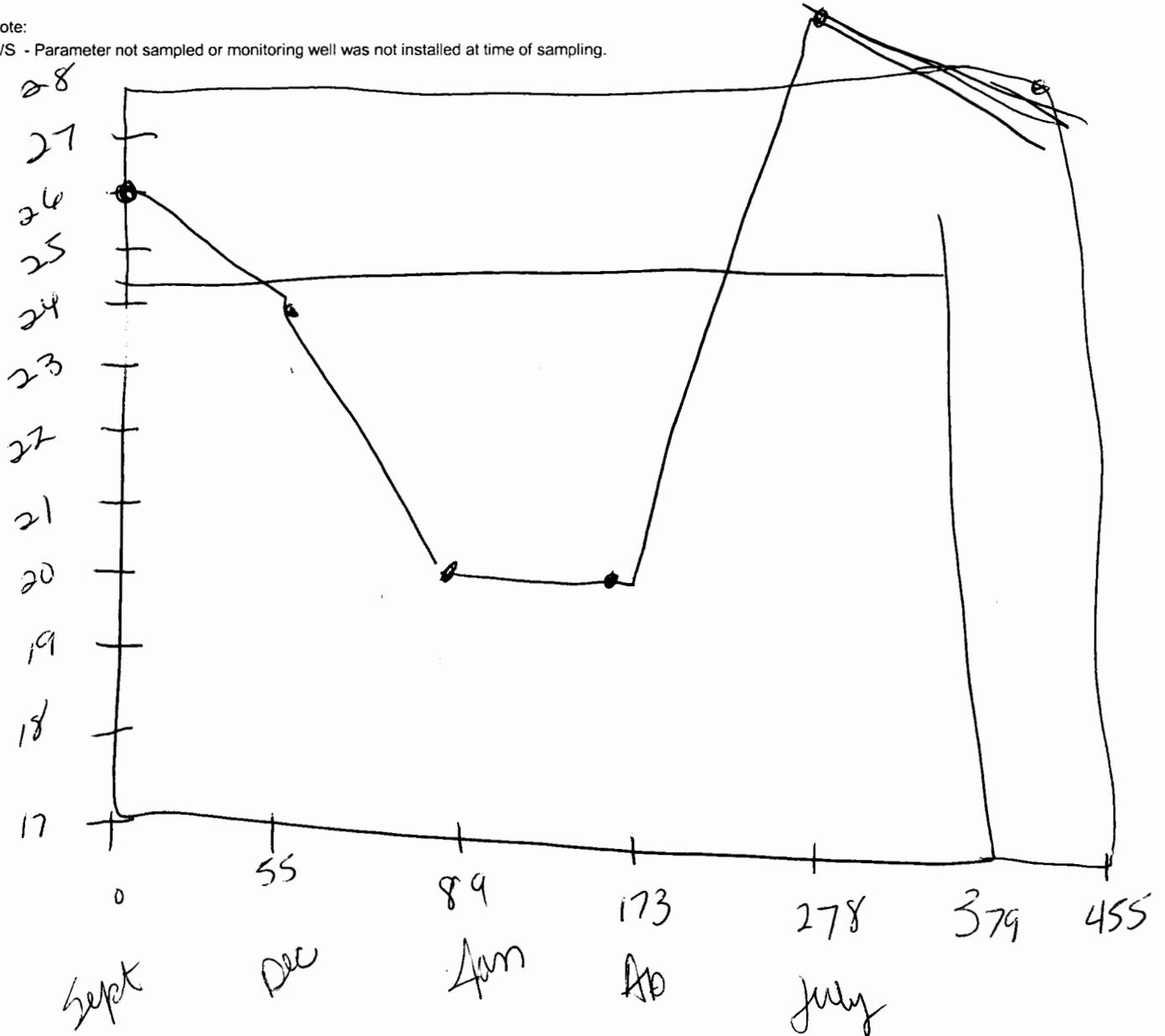


Table 3-8
 Site 13 ORC Groundwater Remediation Report
 Dissolved Oxygen Concentrations (mg/L)

Round Number	Baseline	Round 1	Round 2	Round 4	Round 5	Round 6
Date	08/29/2000	12/13/2000	01/16/2001	07/16/2001	10/25/2001	1/9/2002
Elapsed time (days)	0	55	89	278	379	455
LS13-MW01T	0.85	0.5	1	0.31	1.06	N/S
LS13-MW21S	1.2	2.0	0.42	2.5	3	4
LS13-MW23S	1.15	1.0	8	4	4	N/S
LS13-MW25S	1.43	2.0	0.58	0.3	0.9	N/S
LS13-MW26S	N/S	1.3	1	0.7	3	0.3
LS13-MW27S	N/S	N/S	N/S	5	8.5	11.84
LS13-MW22D	0.85	0.7	1	4	12	N/S
LS13-MW24D	1.2	0.5	0.89	N/S	N/S	N/S
LS13-MW03T	0.93	1.7	3	0.6	3.5	2

Note:

DO readings for Round 3 were erroneous.

DO readings for Round 5 are from the Chemet, if measured.

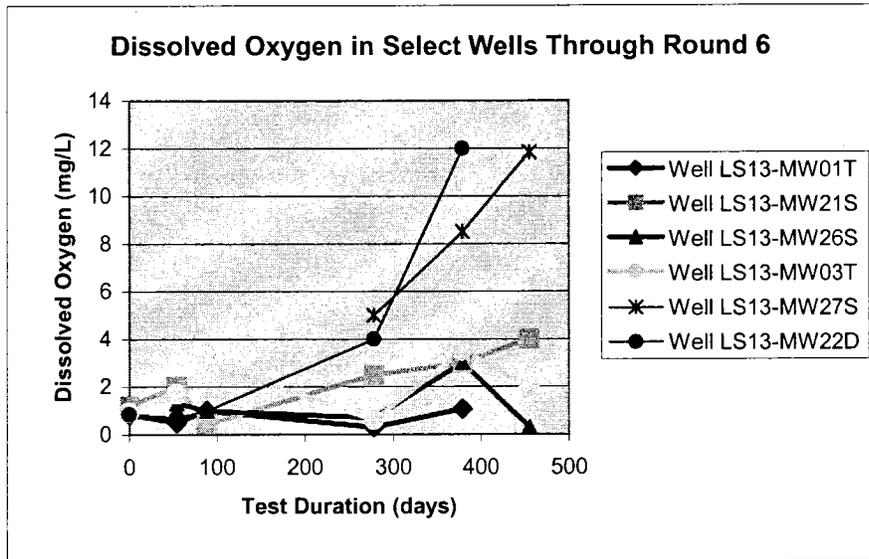


Table 3-9
 Site 13 ORC Groundwater Remediation Report
 Pentachlorophenol Concentrations (ug/L)

Round Number	Baseline	Round 1	Round 2	Round 3	Round 4	Round 5	Round 6
Date	08/29/2000	12/13/2000	01/16/2001	04/10/2001	07/16/2001	10/25/2001	1/9/2002
Elapsed time (days)	0	55	89	173	278	379	455
LS13-MW01T	19U	20 U	20U	20U	18 U	19 U	N/S
LS13-MW21S	450	760	460	360	140 J	160	130 D
LS13-MW23S	27	4J	2J	20U	18 U	19 U	N/S
LS13-MW25S	8J	49	33J	15J	4 J	2 J	N/S
LS13-MW26S	N/S	730	790	880	250 J	70	110
LS13-MW27S	N/S	N/S	N/S	460	140 J	8 J	19 U
LS13-MW22D	9J	3J	20U	N/S	18 U	19 U	N/S
LS13-MW24D	8J	2J	20U	20 U	N/S	N/S	N/S
LS13-MW03T	3J	1J	20U	2J	43 J	6 J	2 J

Note:

- U - Not Detected. The associated number indicates approximate sample concentration necessary to be detected.
- D - Result came from a diluted sample
- J - Analyte Present. Reported value may not be accurate or precise.

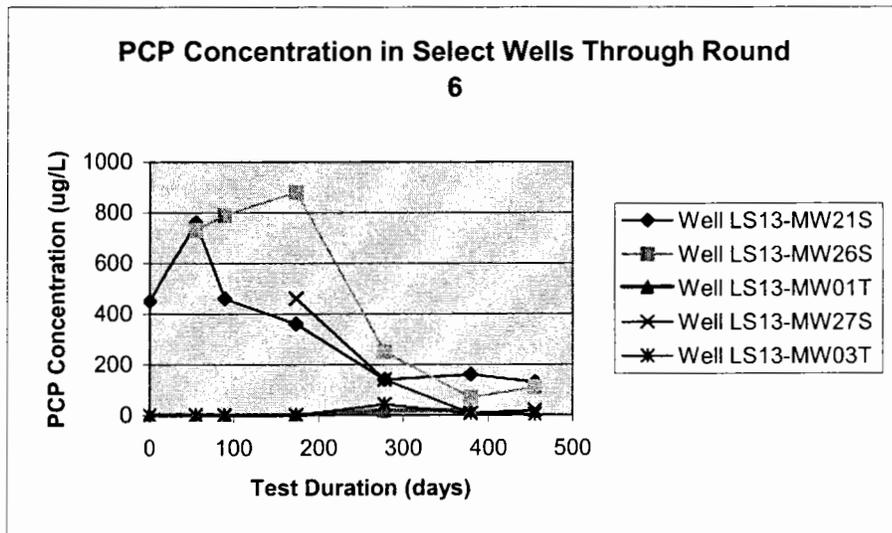
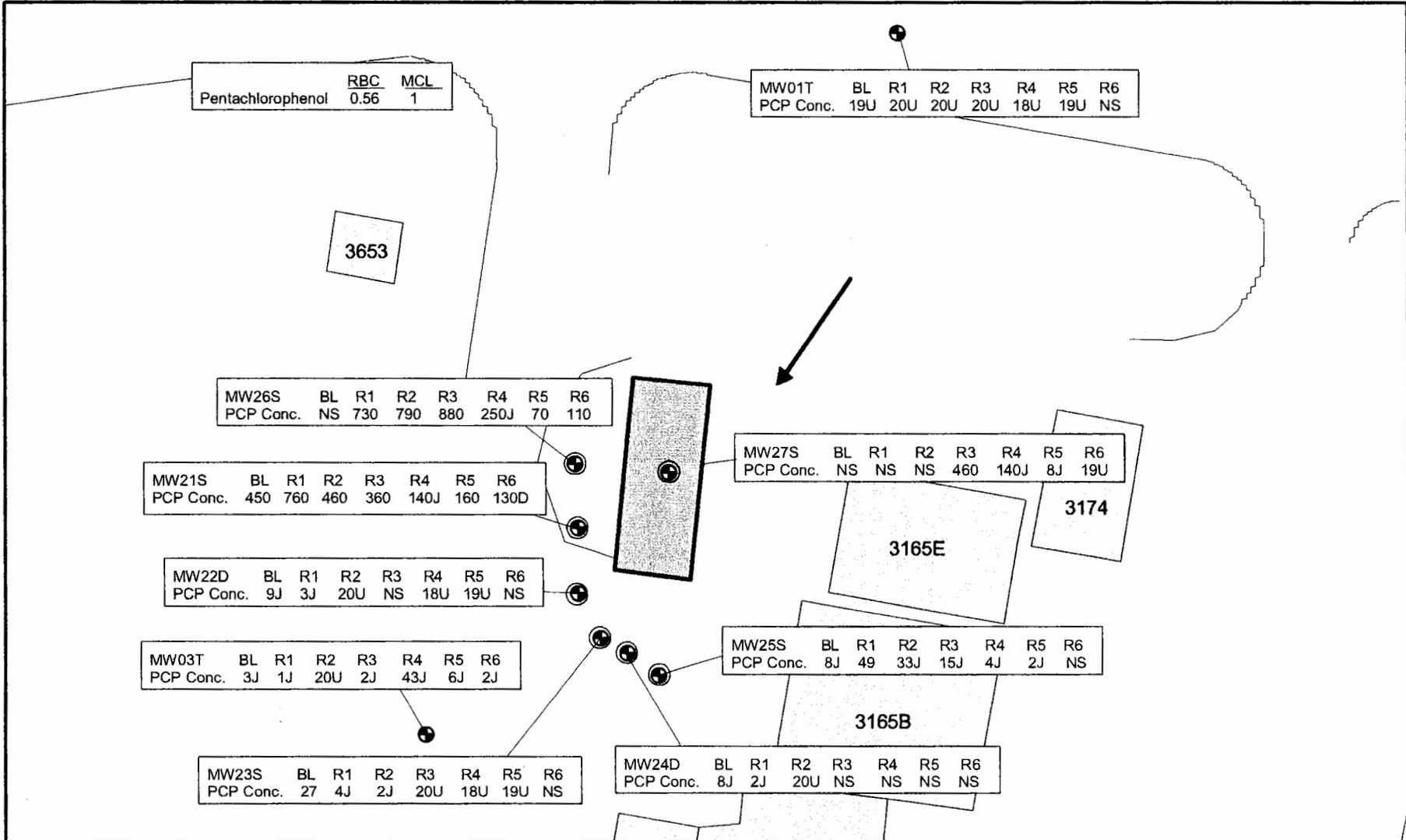


Table 3-10
 Site 13 ORC Groundwater Remediation Report
 Effectiveness of ORC™ in Reducing PCP Concentrations

Monitoring Well	Maximum Concentration (ug/L)	Minimum Concentration (ug/L)	Percent Reduction
MW01T	19U	18U	Non-Detect
MW21S	760	140J	81.60%
MW22D	19U	18U	Non-Detect
MW23S	27	18U	33.30%
MW24D	20U	2J	Non-Detect
MW25S	49	2J	95.90%
MW26S	880	70	92.00%
MW27S	460	8J	98.30%
Average MW21S, MW26S, and MW27S			90.63%

Note: Maximum and minimum as observed during pilot study. Concentrations shown were not collected during the same monitoring event.



LEGEND

- Monitoring Well Network Well (Exist Well)
- ⊕ Monitoring Well Network Well (New Well Installed for Pilot Study)
- ▭ Area of ORC Injection
- ← Groundwater Flow Direction

Note: Concentrations in ug/L.
NS = Not sampled

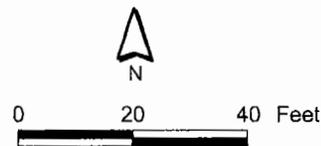


Figure 3-1
Groundwater PCP Concentrations by Round
Site 13
Site 13 ORC Summary Report
NAB Little Creek

Conclusions and Recommendations

Evaluation of the data through round six of post-injection monitoring provides over one year worth of data regarding the effectiveness of this pilot study. Based upon the extent of reductions in PCP concentrations and the sustained dissolved oxygen levels over the duration of this Pilot Study, the ORC™ injection appears to have worked successfully. The Round 6 sampling event completed the ORC™ Pilot Study at Site 13.

The apparent time frame for the PCP to aerobically degrade during the ORC™ pilot study was considerably slower than was anticipated from bench scale testing conducted with Site 13 soils. As observed by slowly increasing DO concentrations that correspond to decreasing PCP concentrations from round to round, the ORC™ did not appear to show significant effects until approximately 40 weeks after the injection was completed. At completion of Round 6 monitoring (65 weeks after the injection), the DO concentrations indicate the ORC™ is continuing to affect the oxygenation of groundwater at Site 13, and therefore, continuing to further degrade the PCP.

The immediate effectiveness of the ORC™ may have been underestimated due to a significant lack of data within the immediate area of the injection during the first four months of the test. If well MW27S had been installed prior to the test, a much greater initial concentration may have been observed and hence a much greater and more immediate decrease in PCP concentration at that well.

There are several factors that may have influenced the time frame in which the remediation of PCP occurred, including (but not limited to):

- Groundwater flow rates that were slower than those predicted from slug tests at Site 13.
- Potential impacts to groundwater flow caused by differences between the backfill sand used during the removal action at Site 13 and/or impacts caused by the smearing of fine-grained soils during the installation and removal of sheet piling used to hold the excavation open during the removal action.
- Differences in the velocity of the PCP plume compared to groundwater flow rate.
- Localized groundwater flow directions in the immediate area near the pilot study that varied from those observed at Site 13 when viewed as a whole.

Selected wells (MW03T, MW21S, MW26S, and MW27S) should continue to be sampled on a periodic basis to monitor further reductions in PCP concentrations and to determine dissolved oxygen levels in the surficial aquifer as the ORC™ continues to flush out of the groundwater monitoring network. This additional information will be helpful in evaluating options for the feasibility study at Site 13.

A feasibility study (FS) will be conducted for the groundwater (and soil) at Site 13. As part of the FS process, preliminary remediation goals (PRGs) will be developed for each of the site-related contaminants found in the groundwater. The PRGs will be compared to the current (post pilot study) site conditions to determine if and where additional or continued

remedial actions might be warranted. If warranted, a range of alternatives will be evaluated to further remediate the groundwater. Proposed alternatives would likely include the continued monitoring of the current ORC™ injection until it is evident that the reactions have run their course or concentrations have reached PRGs, as well as the injection of additional ORC™.

Appendix A
Final Implementation Plan for a Groundwater
Treatability Study at Site 13



CH2MHILL

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October 11, 2000

151767
00-431

Commander
LANTNAVFACENCOM
Attention: Code 18222 Mr. Bob Schirmer
Lafayette Annex, Building A
6506 Hampton Boulevard
Norfolk, VA 23508

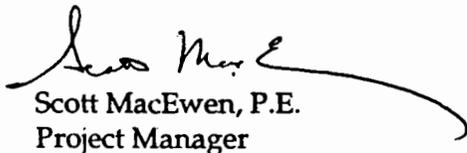
Dear Mr. Schirmer:

Subject: Contract N62470-95-D-6007
Navy CLEAN II Program Contract Task Order 0098

Enclosed for your use and records are four copies of the final implementation plan for the ORC treatability test at Site 13 at Naval Amphibious Base Little Creek, Virginia Beach, Virginia. Copies are also being sent to Mr. Randy Sawyer at NWS Yorktown, Mr. Robert Weld at VDEQ, and Mr. Bruce Beach at USEPA Region III as outlined on the distribution list below. The plan has been revised from the previous draft version to address comments from EPA in accordance with the enclosed comment response letter dated July 31, 2000. Any questions can be directed to me at (703) 471-6405, extension 4332.

Sincerely,

CH2M HILL


Scott MacEwen, P.E.
Project Manager

cc: Mr. Randy Sawyer/NWS Yorktown (1 copy)
Mr Robert Weld/VDEQ (1 copy)
Mr. Bruce Beach/USEPA Region III (4 copies)
Ms. Lee Anne Rapp/LANTDIV Code 18312 (cover letter only)
Mr. Rollie Burford/LANTDIV (cover letter only)
Frances Fadullon/CH2M HILL
Paul Landin/CH2M HILL
Program Files

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Final Implementation Plan for a Groundwater Treatability Study at Site 13 Naval Amphibious Base Little Creek, Virginia Beach, Virginia



Prepared for

Department of the Navy
Atlantic Division
Naval Facilities Engineering Command
Norfolk, Virginia

Contract No. N62470-95-D-6007
CTO-0098

October 2000

Prepared by

CH2MHILL

Baker
Environmental, Inc.

CDM
Federal Programs Corp.

Final
Implementation Plan for a Groundwater Treatability Study
at Site 13

Naval Amphibious Base Little Creek,
Virginia Beach, Virginia

CTO Task Order - 098
October 2000

Prepared for
Department of the Navy
Atlantic Division
Naval Facilities Engineering Command

Under the
LANTDIV CLEAN II Program
Contract N62470-95-D-6007

Prepared by
 **CH2MHILL**

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1.0 Introduction

This implementation plan addresses a proposed groundwater treatability test at Site 13, the Public Works PCP Dip Tank and Wash Rack at the Naval Amphibious Base (NAB) Little Creek in Virginia Beach, Virginia. The treatability test is being conducted to evaluate an in-situ approach to enhance the bioremediation of contaminants in the groundwater. The treatability test will involve the injection of an aerobic enhancement agent, Oxygen Release Compound (ORC), into the subsurface to help degrade pentachlorophenol (PCP) in the soil and groundwater. ORC has been developed by Regenesis Bioremediation Products of San Juan Capistrano, California.

PCP has been shown to degrade under both aerobic and anaerobic conditions. The selection of the aerobic enhancement agent to be used (ORC) was made based on the results of a 3-month-long bench scale microcosm test conducted for the Navy by Regenesis. The ORC will be injected via Geoprobe throughout the saturated zone of the shallow (unconfined) aquifer beneath the site.

The objectives of the treatability test at Site 13 are to:

- Install and sample a system of monitoring wells to determine baseline water quality,
- Inject ORC into the saturated zone and capillary fringe of the water table aquifer at a hot-spot below the location of a former PCP dip tank, to enhance the removal rate of PCP, and
- Collect sufficient data to evaluate groundwater remediation success.

Little Creek is on the National Priorities List (NPL), and Site 13 is being investigated and remediated under CERCLA authority.

1.1 Site Location and History

Site 13—Public Works PCP Dip Tank and Wash Rack, is located near the intersection of 7th and F Streets, in the eastern portion of NAB Little Creek (see Figure 1). Site 13 consists of the location of a former dip tank that had been used to treat wood with a mixture of PCP, diesel fuel and kerosene, an adjacent area that had contained drying racks for PCP-treated wood, an open area formerly used by the Public Works Department for storage of supplies and equipment, and a concrete wash rack at the southwestern end of the area.

The PCP dip tank was located in the southwest corner of the fenced compound behind (west of) Building 3165E (see Figure 2). It was used from the early 1960s until 1974. According to a former public works supervisor, the tank was constructed of metal, had an estimated capacity of 1,500 gallons, and was partially set into the ground approximately two feet. It was a cylindrical tank laid on its axis. The top third of the tank was cut off and replaced with a metal cover. Initial oral accounts stated that the tank held 10,000 gallons; however, follow-up interviews with former employees in 1998 provided estimated tank

dimensions of 20 feet long and a 5 foot diameter. A full tank of this size would hold 3,000 gallons. An open-top tank would likely hold a maximum of 1,500 gallons.

The contents of the tank were a mixture of one part PCP to ten parts diesel and kerosene. Wood was dipped into the tank and either set on racks for drying or placed directly on trucks for delivery to where it was to be used on base. The drying racks were located immediately east of the dip tank between the tank and Building 3165E. A pump was located at the south end of the tank, outside the fenced compound. This pump was used to keep the contents of the tank mixed and to empty the contents of the tank into 55-gallon drums when it became spent. The dip tank was cleaned out approximately every 6 months, at which time the approximately 55 gallons of PCP sludge generated are believed to have been removed from the tank and hauled away for disposal. All remaining PCP solution and associated sludges were removed from the tank in 1975. The tank itself was dismantled in 1982. The area formerly containing the PCP dip tank and drying racks has since been paved with asphalt and converted to a Public Works Department storage area.

Subsequent soil and groundwater sampling in this area indicated that PCP was present in both media. In April 1999, the PCP-contaminated soil in the area beneath the former dip tank was excavated to depths ranging from 6 to 8 feet. The environmental investigation and removal action are discussed in greater detail in Section 1.3

The wash rack and associated storage area, which are approximately 60 feet south of the dip tank and west of Building 3165D, continue to be used by the Public Works Department. The PCP in the groundwater is not associated with the wash rack or storage area.

1.2 Site Geology and Hydrogeology

The upper 23 feet of geology in the vicinity of the former dip tank at Site 13 is primarily composed of fine to medium sands with some fines and occasional gravels. Interbedded, discontinuous layers of clay, ranging in thickness from approximately 2 to 5 feet occur at shallow depths in the western portion of the site. Boring logs indicate the occurrence of many discontinuous interbedded layers within the sands immediately underlying this site. A clay layer of undetermined thickness is present approximately 23 feet below ground surface (bgs) and is believed to be the Yorktown confining unit. Due to a lack of deep borings at the site, the full extent and thickness of this clay layer is unknown; but based on borings conducted in other areas of Little Creek (Site 12), the clay layer is assumed to be present throughout the base and is likely to be 25 to 35 feet thick. The depth to the water table at the former dip tank is 5 to 6 feet.

The aforementioned shallow unconsolidated sand layers with discontinuous, interbedded clay lenses serve as an unconfined aquifer at Site 13. The thin (approximately 17 to 18 feet thick) water table aquifer in the Columbia Group is underlain by a confining clay layer in the upper Yorktown Formation. A semi-confined aquifer, the Yorktown aquifer, underlies this clay layer. The flow direction of the shallow water table (Columbia) aquifer at the site is predominantly to the southwest (see Figure 2). The hydraulic conductivity has been estimated via pumping tests at Site 12 to be 100 ft/day and is likely to be similar at Site 13. The average gradient at Site 13 is 0.00146 ft/ft. Using an effective porosity of 0.3, the groundwater flow velocity in the Columbia Aquifer at Site 13 is estimated to be approximately 0.5 ft/day.

1.3 Source, Nature, and Extent of Contamination

1.3.1 Groundwater

Contaminants that were found in the groundwater at Site 13 that are above USEPA Region III Risk-Based Concentrations (RBCs) for tap water or Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs) include PCP, tetrachloroethene (PCE), trichloroethene (TCE), 1,2-dichloroethene total (1,2-DCE), and vinyl chloride. There appear to be two separate but overlapping plumes at the site, each with their own source area.

One plume is characterized by PCP, and its source is apparently the former PCP dip tank and the contaminated soil in the vicinity of the former tank. The PCP plume is the focus of this treatability test. The extent of the PCP plume is shown in Figure 3. The highest historic concentrations of PCP found in the groundwater have always occurred in Well LS13-MW08S, which is screened from 3 to 13 feet below ground surface (bgs) directly within the area formerly occupied by the aforementioned PCP dip tank and pump. Concentrations in this well have ranged from 320 to 2,300 ug/l since 1996. Concentrations of PCP in well LS13-MW08D, which is screened in the lower portion of the aquifer (from 22.5 to 24.5 feet bgs) at the same location as LS13-MW08S have ranged from 9 to 500 ug/l (all in 1998). The closest downgradient well LS13-MW03T, which is 60 feet downgradient (southwest) of LS13-MW08S and D, has had PCP concentrations ranging from 83 to 100 ug/l since 1996. Therefore it appears that the most significant PCP concentrations in groundwater are in the upper portion of the aquifer within relatively close proximity to the former dip tank and pump.

The second plume is defined by chlorinated organic compounds (PCE, TCE, etc.) and appears to have a source south of the former PCP dip tank (see Figure 4). The highest concentrations are in wells LS13-MW11S and D which are located 275 feet southwest of the former PCP dip tank. A specific ongoing source (area of contaminated soil or non-aqueous-phase liquid (NAPL)) has not been identified for this plume. While these contaminants and concentrations are a concern, they are not the focus of this treatability study.

It should be noted that the lateral extent of both the PCP and the PCE/TCE/etc. plumes have been determined, and neither plume extends more than 600 feet downgradient from the former dip tank. Monitoring wells have been installed at the downgradient edges of the plumes and the nearest potential surface water discharge point is more than 1,200 feet beyond the edge of the plumes. A supplemental remedial investigation and risk assessment is being prepared that documents the nature and extent of, and risks associated with, these groundwater plumes.

1.3.2 Soil

The primary contaminant found in the soil at concentrations above risk-based guidance levels (USEPA Region III RBCs for residential soil and for industrial soil) is PCP. Several PAHs have also been detected above the soil RBC for both residential and industrial use. The greatest concentrations of PCP and PAHs are centered around the former location of the PCP dip tank and the associated circulation pump. The greatest concentrations have consistently been found in the soil above that water table and typically in the upper two feet below the surface. The maximum concentration found to date is 890 mg/kg. The area of greatest soil contamination coincides with the head of the PCP-contaminated groundwater

plume and the greatest concentrations found in the groundwater (see Figure 2). Lesser concentrations (generally less than 10 mg/kg) of PCP have been detected in the soil in other areas around the former wood treatment compound. The belief is that the PCP-contaminated soil near the former tank and pump may act as a continuing source of contamination to the groundwater.

All soil containing PCP at concentrations greater than 36 mg/kg has since been removed as part of the soil removal action discussed in Section 1.3.3.

1.3.3 Soil Removal Action

A soil removal action has been completed at the location of the former dip tank and pump area where the proposed treatability testing will be carried out. The removal action consisted of removing all soil above the water table (5.3 feet bgs) at PCP concentrations greater than 16 mg/kg, and also removing one to three feet of soil below the water table. The 16 mg/kg action level was established in the Engineering Evaluation and Cost Assessment (EE/CA) (CH2M HILL, March 1999) and represents a concentration that will no longer represent a leachable source of groundwater contamination that would pose a risk under an industrial use scenario.

The overall area of soil excavated in this removal action measured 46.5 feet by 17 feet, with excavation depths of 8 feet and 6 feet. A clay layer was encountered at depths ranging from 5.5 to 8 feet bgs that served as an effective barrier. Once the clay layer was removed water entered the excavation area as the depth was below the water table. The excavated area was backfilled with sand and covered with bituminous concrete. The location of the excavated area is shown on Figure 5.

Confirmation sampling on the bottom and sides of the excavation showed concentrations that were all below 16 mg/kg of PCP, with the highest concentration in soil left in place at about 9.6 mg/kg of PCP. However, pre-excavation in situ sampling detected soil contamination as high as 36 mg/kg at 10 ft bgs at the south end of the excavated area, indicating the possible presence of soil contamination potentially not removed by the excavation, at concentrations that may represent a source of potential contamination to groundwater in that area.

2.0 Mechanisms of PCP Degradation

PCP has been shown to degrade both anaerobically (without the presence of oxygen) and aerobically (using oxygen as an electron acceptor). Appendix A presents a paper titled *Bioremediation of Pentachlorophenol, Literature Survey of Metabolic Pathways and Rate Constants*, by Pelorus Environmental & Biotechnology Corporation, June 4, 1997. This paper provides a detailed discussion of the various potential anaerobic and aerobic degradation pathways of PCP. These are briefly summarized below.

2.1 Anaerobic Biodegradation of PCP

PCP has been observed to degrade anaerobically by reductive dechlorination. Anaerobic degradation is a much slower process than aerobic because each chlorine molecule acts as an electron acceptor and is replaced by hydrogen producing first tetrachlorophenol (TeCP), then trichlorophenol (TCP), dichlorophenol (DCP), and finally chlorophenol (CP) before the phenol ring is broken relatively late in the process. To complicate matters, there are three isomers of TeCP, five isomers of TCP, six isomers of DCP, and three isomers of CP. The pathway that is followed appears to depend on the type of microorganism present in the system. It is possible that almost any of the isomers potentially could be involved, but the literature suggests that for a given system a certain limited number of breakdown products tend to predominate. However, it appears to be difficult to predict what the predominant pathway will be before testing. One reference offers the comment that unacclimated microbial consortia tend to preferentially remove chlorines from the ortho position (i.e., $PCP \rightarrow 2,3,4,5\text{-TeCP} \rightarrow 3,4,5\text{-TCP}$), whereas acclimated consortia may attack the meta or para position chlorines. It is also possible that under some conditions (and with some microorganisms), the degradation pathway may not reach completion and may result in the generation and accumulation of one or more of the intermediate isomers.

While the literature seems to indicate that PCP is more toxic than any of its potential breakdown isomers, several of them are still considered to represent risks to human health. PCP and six of its 18 possible breakdown intermediates have been assigned human health risk-based concentrations (RBCs) for drinking water by EPA Region III. These are shown in Table 1. In order for anaerobic degradation of PCP to occur, highly anaerobic conditions must exist in the aquifer; dissolved oxygen levels below 0.5 mg/l are necessary in the groundwater.

2.2 Aerobic Biodegradation of PCP

In aerobic degradation, the phenol ring is broken during an early stage of the process and complete mineralization to carbon dioxide, water and chloride occurs much more quickly than through the anaerobic pathway. Initial intermediate products that form prior to breaking the phenol ring may include tetrachlorocatechol, tetrachlorohydroquinone (TeCHQ), tetrachlorobenzoquinone (TeCBQ), trichlorohydroxylbenzoquinone (TCBHQ), TCHQ, DCHQ, and CHQ. However, these intermediate products have been found to be relatively innocuous. None of these intermediate products are listed in EPA Region III RBC

tables Also, none are listed in EPA's IRIS and HEAST data bases. Because these breakdown products have fewer chloride atoms than PCP and because they degrade quickly by cleavage of the phenol ring and are shortlived (they have not been found to accumulate in the environment at similar sites), it is assumed that the risk they pose is significantly less than PCP. (See Appendix A Section II.B).

Compound	EPA Region III RBC for Tap Water
PCP	0.56 ug/l
2,3,4,6-TeCP	1,100 ug/l
2,4,5-TCP	3,700 ug/l
2,4,6-TCP	6.1 ug/l
2,4-DCP	110 ug/l
2-CP	180 ug/l
phenol	22,000 ug/l

These intermediate compounds of aerobic degradation of PCP are not on the TCL for semivolatile organics. As specified in Section 5, tentatively identified compounds will be listed on the analysis results and compared to the anticipated breakdown products for identification, however past research has indicated that these compounds have not been found to accumulate and are not likely to be detected.

For aerobic oxidation to occur, a dissolved oxygen concentration in the groundwater of at least 2 mg/l is typically required. Under ideal conditions, aerobic oxidation is considered to be a much faster process than anaerobic dechlorination. When PCP-contaminated wastes are treated above ground it has typically been found to be much faster and less costly to degrade the contaminant under aerobic rather than anaerobic conditions. The drawback is that it can be difficult and very expensive to create sufficiently aerobic conditions in the subsurface.

In the studies reviewed during the preparation of this work plan, no conclusive evidence has been found to indicate that nitrogen may be a limiting factor of aerobic PCP degradation at Site 13. In a series of bench-scale tests conducted by Vernalia et.al. on PCP-contaminated soil in 1997, side by side aerobic tests showed no significant difference in degradation rate between cells inoculated with fertilizer (10,000 mg/kg of TKN) and those not inoculated (200 mg/kg TKN). The bench-scale test conducted with the Site 13 soil by APC (see Section 3) did not include nitrogen or phosphorous amendments. These tests showed complete removal of PCP.

3.0 Scope of Test Tube Microcosm Tests

A series of test tube microcosm tests were conducted to determine if reagent-enhanced aerobic or anaerobic conditions could enhance the biodegradation of PCP at Site 13. In these bench-scale tests, the Regenesis products Hydrogen Release Compound (HRC) and Oxygen Release Compound (ORC) were used to determine which if either of these two products would be applied in the proposed treatability test. HRC, a polyacetate ester made from reduced sugars and lactic acid, results in the release of hydrogen in the environment via metabolism of the lactic acid. This hydrogen is available to promote the conversion of chlorinated hydrocarbons to dechlorinated hydrocarbons (Regenesis, HRC Technical Bulletin 1.1.3.). ORC is a patented formulation of magnesium peroxide, MgO_2 , which slowly releases oxygen when moist.

The tests were conducted over a 3-month period under idealized conditions and were designed to provide a relatively quick go/no go response. The protocol for the test tube tests is provided in Appendix C. Summaries of the results from the 3-month test are provided in Appendix D.

Each test used 150 ml of a 10 mg/l solution of PCP mixed with 10 grams of soil collected from the upper portion of the Columbia aquifer in the vicinity of well LS13-MW08S. Standard microbial counts were performed for each test, where possible.

Two types of tests were run with addition of ORC: tests with a low ORC dose (0.25 grams) and tests with a high ORC dose (0.75 grams). The test was run for three months with samples analyzed once a month. One control sample to which no ORC was added was also run. Finally, an attempt was made to run a "sterile" sample using sterile sand as opposed to site soil and no ORC addition. The results were as follows:

1. After 30 days, PCP detected in the sample with the high ORC dose was reduced to 0.20 mg/l PCP (98% reduction). After 60 days, no PCP was detected.
2. PCP detected in the sample with the low ORC dose steadily declined over the test period and was reduced to an average of 0.93 mg/l PCP (91% reduction) by the end of 90 days.
3. At both 30 days and 60 days, the PCP in the control sample was about 6 mg/l (40% reduction). Results from the control sample at the 90-day mark were unavailable. Similar to the control sample, results in the "sterile" sample at 60 days and at 90 days were about 6 mg/l.
4. No 2,4-DCP and very little 2,4,6-TCP was detected in any of the samples, with the exception of a spike of 2.14 mg/l of 2,4,6-TCP at 30 days. 2,4,6-TCP was also detected in the 90-day samples at concentrations at or below 0.20 mg/l.

A parallel series of tests using the same procedures and contaminant concentrations were run to test the effect of HRC addition. As with the ORC tests, two levels of HRC addition were tested (0.25 grams and 0.75 grams). The results of the HRC tests were as follows:

1. PCP in the sample with the high HRC dose was detected at 1.98 mg/l (80% reduction) at 30 days, 2.29 mg/l at 60 days, and 0.321 mg/l (97% reduction) at 90 days.
2. PCP in the sample with the low HRC dose was detected at 1.61 mg/l (84% reduction) at both 30 days and 60 days, and 0.672 mg/l (93% reduction) at 90 days.
3. The control and "sterile" samples were those of the ORC test above.
4. No 2,4-DCP and very little 2,4,6-TCP was detected in any of the samples. 2,4,6-TCP was detected in the 90-day samples at concentrations at or below 0.22 mg/l.

These results indicate that both HRC and ORC will degrade PCP under laboratory conditions. ORC was selected as the preferred method for the proposed test plot because it was shown to degrade PCP to a greater extent during the 90-day test.

4.0 Use of Oxygen Release Compounds and Potential Impacts to the Environment

Oxygen Release Compound (ORC) is a patented formulation of magnesium peroxide, MgO_2 , which slowly releases oxygen when moist. The hydrated product is magnesium hydroxide, $Mg(OH)_2$. ORC also contains some magnesium oxide (MgO), which hydrates to form $Mg(OH)_2$. The hydrated product is a solid form of ordinary Milk of Magnesia. The ORC product also contains a few percent of food grade potassium phosphate. The phosphates are the same material that is sometimes used to support microbial growth for bioremediation.

The oxygen release rate is dependent upon the level of the contaminant flux. Generally, the product will continue to release oxygen for about 6 months. Most studies on in situ bioremediation have found that 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.

ORC works by slowly releasing oxygen into the water in a dissolved form (i.e.: it does not bubble oxygen out in a gaseous form that then equilibrates into the groundwater and vadose zone). CH2M HILL's experience at two BTEX sites has shown that resultant dissolved oxygen levels have been in the 2 to 3 mg/l level. A separate study conducted by IT and the Army COE on a BTEX plume recorded dissolved oxygen concentrations increasing from 0.3 mg/L before injection to a maximum of 1.6 mg/L during treatment. Regenesis has stated that they would not expect to see oxygen levels increase in the vadose zone.

ORC will not harm an aquifer. It is virtually insoluble. Biofouling is inhibited by an elevated, but localized pH. pH within the ORC mass has been found to be in the range of 9, however, based on actual site data, background pH levels are expected to return within 10 feet downgradient of the injection area. Iron fouling is avoided, particularly when compared to air sparging, by the long, gentle release of dissolved oxygen that is dispersed widely. Several studies have been done by the University of Waterloo and North Carolina State University to determine the impacts of ORC on magnesium and phosphate concentrations in aquifers. These studies showed no significant increase in either magnesium or phosphate concentrations in the groundwater within or surrounding the treatment area. Brief descriptions of these findings are presented in Appendix B.

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. (Regenesis, ORC Technical Bulletin 1.3.1). Appendix B also presents a technical bulletin that describes the process of aerobic degradation of PCP using ORC in further detail.

5.0 Technical Scope of Proposed Treatability Test

This treatability test focuses on the application of ORC within the hot spot of the contaminated groundwater to reduce contaminant mass. This will provide the best opportunity to observe measurable declines in the groundwater concentrations. The soil at the groundwater interface has been addressed through the soil removal action and the downgradient edge of the plume has been defined and will be addressed in the groundwater feasibility study for the site.

The proposed field treatability test will involve:

- Providing an adequate groundwater monitoring network consisting of existing and new monitoring wells
- Collecting baseline groundwater parameters
- Injecting the ORC
- Monitoring the groundwater for selected parameters
- Evaluating and reporting of results

There is no plan to monitor PCP concentrations in the soil gas during the test. Because PCP is a semivolatile with a vapor pressure of 1×10^{-4} mm Hg, which is similar to PCBs and many PAHs such as fluorene and phenanthrene, it is not expected that PCP would volatilize under atmospheric conditions. Also, because oxygen is released from the ORC at a very slow rate, the ORC would not be expected to provide any additional driving force for volatilization over current conditions.

5.1 Groundwater Monitoring Network

The effectiveness of the treatability study will be determined by collecting and analyzing groundwater samples from selected wells prior to, and throughout the duration of, the treatability test. The groundwater-monitoring network will consist of seven wells located upgradient, downgradient and side-gradient of the proposed treatment area. The network will be made up of both existing and new wells. Table 2 and Figure 6 identify the wells that make up the monitoring network. The two wells that historically had been the closest to the proposed treatment area, LS13-MW08S and LS13-MW08D, were abandoned during the soil removal action. These wells will be replaced with three shallow (15 foot) wells and two deep (23 foot) wells situated along the west and south (downgradient) sides of the former tank location: wells LS13-MW21S, LS13-MW22D, LS13-MW23S, LS13-MW24D, and LS13-MW25S. The new wells will be drilled using continuous-flight hollow-stem augers and constructed of 2-inch inner-diameter PVC with threaded joints and flush mount cover. The methods for drilling and installation of the monitoring wells are documented in the attached SOPs (see Appendix E). If, as the test proceeds, it is determined that data from

other wells are needed to fully understand the effectiveness of the pilot test, other wells, such as LS13-MW13S, LS13-MW14S, and LS13-MW06S may be added to the monitoring network. The new wells will be installed prior to the proposed injection of ORC.

During well installation, two soil samples will be collected from the upper portion of the aquifer (5-7 feet bgs) and two soil samples will be collected from the lower portion of the aquifer (15-17 feet). These samples will be analyzed for nitrite, nitrate and phosphate to help determine available nutrient concentrations in the subsurface.

5.2 Baseline Groundwater Sampling

Groundwater samples will be collected from each of the seven wells in the monitoring network shown in Table 2 to determine baseline aquifer characteristics and water quality. This will be done prior to the injection of ORC and at least 24 hours after the new wells have been installed. All monitoring wells shall be purged at a low-flow discharge using a Grundfos® Redi-Flo II pump. Groundwater sampling methods are documented in the attached SOPs (see Appendix E). Analytical parameters for baseline groundwater sampling are tabulated in Table 3.

Sampling Point	Diameter (inches)	Total Depth (feet bgs)	Depth of Screened Interval (feet bgs)
Background Wells			
LS13-MW01T (existing)	2	15.5	5.5 to 15.5
Downgradient Wells			
LS13-MW22D (proposed)	2	25	15 to 25
LS13-MW23S (proposed)	2	15	5 to 15
LS13-MW03T (existing)	2	15.5	5.5 to 15.5
Side-gradient Wells			
LS13-MW21S (proposed)	2	15	5 to 15
LS13-MW24D (proposed)	2	25	15 to 25
LS13-MW25S (proposed)	2	15	5 to 15

All groundwater samples will be analyzed using Method OLC02 for low concentration target compound list (TCL) semivolatile organic compounds (SVOCs) during the treatability study. Analytical reporting will include a library search of tentatively identified compounds (tics) which will be compared to the known aerobic and anaerobic breakdown products of PCP.

While no VOCs were detected above the 1 ug/l detection limit in the two former wells near the dip tank excavation, a total of 8.8 ug/l were detected in well 3T (the downgradient well to be used in the test). This included 4.5 ug/l of cis-DCE and 4.3 ug/l of TCE. The

increased dissolved oxygen would help to degrade the cis-DCE if it were to reach the well, and would likely not affect the TCE. Low concentration VOCs will be analyzed for in four wells: 3T, 23S, 24D, and 3T. The primary mass of VOCs is at well 11S (600ug/l), about 300 feet downgradient of the pilot study location. It is not expected that the test will increase dissolved oxygen concentrations that far away from the injection point.

With the exception of dissolved iron, metals have only been sampled for in three wells at the site during the 1996 SRI. These are 9S, 10T, and 11S, located in the area where VOCs were found. The only dissolved metal found above tap water RBCs was manganese (844 ug/l). Dissolved iron concentrations were extremely low (100 ug/l) compared to total concentrations (approximately 100,000 ug/l) in these three wells. Dissolved iron detected near the former PCP tank ranged from 940 ug/l in Well 8S to 500 ug/l in Well 8D. Increasing dissolved oxygen in the aquifer would tend to desolubilize both manganese and iron as well as other common risk drivers such as arsenic.

While it is unlikely that the treatability test will affect metals concentrations in the groundwater to the extent that additional risks will be introduced to the site, dissolved and total metals analyses will be analyzed for in samples from four wells in the baseline round (1T, 23S, 24D, and 3T). The parameters on the TCL for SVOCs are listed in Table 4 along with their method detection limits. All TCL and TAL analyses will be performed in a fixed-base laboratory. One duplicate and one field blank will be collected for QA/QC.

Sampling Point	Method	Method/Reference
All Wells (7)	TCL LC SVOCs and tics	Method OLCO2
All Wells (7)	Redox potential	A2580B
All Wells (7)	pH	Field probe
All Wells (7)	Temp	Field probe
All Wells (7)	Specific Conductance	Field probe
All Wells (7)	TOC	SW846-9060
All Wells (7)	Alkalinity	310.1
All Wells (7)	CO ₂	RSK-175
All Wells (7)	Fe ²⁺	
All Wells (7)	Chloride	A44500-Cl ⁻
All Wells (7)	DO	Field probe
BL: 4 wells (1T, 23S, 24D, 3T) Other Rds: 2 wells (23S, 24D)	TAL Metals (total)	Method ILM04
4 wells (1T, 23S, 24D, 3T) Other Rds: 2 wells (23S, 24D)	TAL Metals (dissolved)	Method ILM04
4 wells (1T, 23S, 24D, 3T) Other Rds: 2 wells (23S, 3T)	TCL LC VOCs	Method OLC02

TABLE 4
Analytical Parameters and Quantitation Limits

Semivolatile Organic Compounds on Target Compound List (TCL) (Method OLC02)			
Analyte	Water µg/L	Analyte	Water µg/L
1,2-Dichlorobenzene	10	2,4-Dinitrophenol	25
1,3-Dichlorobenzene	10	4-Nitrophenol	25
1,4-Dichlorobenzene	10	Dibenzofuran	10
Phenol	10	2,4-Dinitrotoluene	10
bis-(2-Chloroethyl)ether	10	Diethylphthalate	10
2-Chlorophenol	10	4-Chlorophenyl-phenylether	10
2-Methylphenol	10	Fluorene	10
2,2'-oxybis(1-Chloropropane)	10	4-Nitroaniline	25
4-Methylphenol	10	4,6-Dinitro-2-methylphenol	25
N-Nitroso-di-n-propylamine	10	N-Nitrosodiphenylamine	10
Hexachloroethane	10	4-Bromophenyl-phenylether	10
Nitrobenzene	10	Hexachlorobenzene	10
Isophorone	10	Pentachlorophenol	25
2-Nitrophenol	10	Phenanthrene	10
2,4-Dimethylphenol	10	Anthracene	10
bis-(2-Chloroethoxy)methane	10	Di-n-butylphthalate	10
2,4-Dichlorophenol	10	Carbazole	10
1,2,4-Trichlorobenzene	10	Fluoranthene	10
Naphthalene	10	Pyrene	10
4-Chloroaniline	10	Butylbenzylphthalate	10
Hexachlorobutadiene	10	3,3'-Dichlorobenzidine	10
4-Chloro-3-methylphenol	10	Benzo(a)anthracene	10
2-Methylnaphthalene	10	Chrysene	10
Hexachlorocyclopentadiene	10	bis-(2-Ethylhexyl)phthalate	10
2,4,6-Trichlorophenol	10	Di-n-octylphthalate	10
2,4,5-Trichlorophenol	25	Benzo(b)fluoranthene	10
2-Chloronaphthalene	10	Benzo(k)fluoranthene	10
2-Nitroaniline	25	Benzo(a)pyrene	10
Dimethylphthalate	10	Indeno(1,2,3-cd)pyrene	10
Acenaphthylene	10	Dibenz(a,h)anthracene	10
2,6-Dinitrotoluene	10	Benzo(g,h,i)perylene	10
3-Nitroaniline	25	Acenaphthene	10

5.3 Injection of ORC

The treatability test will involve the injection of ORC into the aquifer in a slurry form using direct push (Geoprobe) technology at depths ranging from approximately 6 to 23 feet bgs (from the water table to the clay layer).

An ORC slurry composed of a dilute mixture of water and a fine ORC powder will be injected into the saturated zone of the shallow aquifer. When hydrated, the powder forms a

fine granular slurry that amounts to some additional silt content in the aquifer (generally less than 1 percent of the aquifer pore space). When the slurry is injected through a probe, it is pushed out into the aquifer to a radius of three to ten feet. At Site 13 an estimate of a five-to-eight foot radius from each injection point is anticipated. The area to be addressed corresponds to the footprint of the previous soil excavation (17 by 46.5 feet). Seventeen direct push injection points will be used to cover this area as shown in Figure 6.

5.4 Application Rates

The treatability test ORC application rates are designed based on the maximum concentrations found in the treatment area over the past 4 years (since the Phase I SRI in 1996) in the groundwater and in soil below the excavation area. The design concentrations are presented in Table 5.

Media and Depth	PCP	TPH	TOC	DO	NO3	Fe+2	SO4	BOD	COD
Shallow Soil - mg/kg (10-12 feet)	36	39	3,540	na	na	na	na	249	11,600
Deep Soil - mg/kg (> 18 feet)	<0.4	<20	140	na	na	na	na	na	na
Shallow Groundwater - ug/l (5-15 feet)	2,000	<1,500	1,400	1,000	190	940	18,400	na	na
Deep Groundwater - ug/l (15-25 feet)	500	<1,000	2,700	1,300	550	500	27,000	<20,000	na
na: not analyzed									

While ORC treats the contaminants in the aqueous phase, the application rate calculated below is based on the maximum concentration of PCP and TPH for the sorbed phase in the saturated soil, which will take into consideration the future leaching of these contaminants from the soil into the groundwater. This approach is suggested by Regenesis (see technical bulletin 2.2.2.4 in Appendix B). Applying the maximum soil concentration throughout the treatment area (as opposed to some mean concentration) is a very conservative assumption, however the intent is to minimize the need of having to return for a repeat injection later on. The concentration of other oxygen-demanding factors such as dissolved iron and TOC are relatively low at this site and would not expect to significantly increase the amount of oxygen needed.

The oxygen requirements for degrading PCP and TPH are based on straight stoichiometry and have been provided in Regenesi's technical papers (see technical bulletin 2.2.2.4 in Appendix B).

ORC Application Rates

The data collected at the site and presented in Table 5 show that there is a significant difference in the TPH and PCP concentrations in the upper portions of the aquifer

compared to the lower portion (i.e.: concentrations are greater in the upper portion of the aquifer). In order to reduce the amount of ORC needed, different application rates have been calculated for the upper (6 to 15 feet bgs) and lower (15 to 23 feet bgs) halves of the aquifer.

The mass of PCP and TPH in the groundwater and saturated soil is calculated based on the following conservative assumptions:

- The concentration of PCP in the soil and groundwater throughout the treatment area is assumed to be 36 mg/kg and 2 mg/l respectively in the upper 9 feet and 0.4 mg/kg and 0.5 mg/l respectively in the lower 8 feet.
- The concentration of TPH in the soil and groundwater throughout the treatment area is assumed to be 39 mg/kg and 1.5 mg/l respectively in the upper 9 feet and 0.4 mg/kg and 1 ug/l respectively in the lower 8 feet.
- The volume of aquifer to be treated extends from the water table (at approximately 6 feet bgs) to the top of the Yorktown Clay (at approximately 23 feet bgs) and the aerial extent encompasses the entire excavation (17 by 46.5 feet). Total volume of the treatment area in the upper portion of the aquifer is 7,114 cubic feet. Total volume of the treatment area in the lower portion of the aquifer is 6,324 cubic feet
- The dry weight of the soil is 100 pounds per cubic foot.
- The porosity is assumed to be 0.3.

The theoretical (stoichiometry-based) oxygen demands for the aerobic degradation of PCP and TPH are as follows:

- Three pounds of oxygen (30 lbs. of ORC) are required to completely degrade one pound of hydrocarbon.
- 0.54 pounds of oxygen (5.4 lbs. of ORC) are required to completely degrade one pound of PCP.

If ORC were to be placed uniformly throughout the upper 9 feet of the aquifer, the total amount of ORC required would be:

$$\text{PCP in soil: } (7,114 \text{ ft}^3) \times (100 \text{ lbs./ft}^3) \times (0.000036 \text{ lbs PCP/lb soil}) \times (5.4 \text{ lbs ORC/lb PCP}) = 138 \text{ lbs.}$$

$$\text{PCP in gw: } (7,114 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.000002 \text{ lbs. PCP/lb. water}) \times (5.4 \text{ lbs. ORC/lb. PCP}) = 1 \text{ lb.}$$

$$\text{TPH in soil: } (7,114 \text{ ft}^3) \times (100 \text{ lbs./ft}^3) \times (0.000039 \text{ lbs TPH/lb soil}) \times (30 \text{ lbs ORC/lb TPH}) = 832 \text{ lbs.}$$

$$\text{TPH in gw: } (7,114 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.0000015 \text{ lbs. TPH/lb. water}) \times (30 \text{ lbs. ORC/lb. TPH}) = 5 \text{ lbs.}$$

$$\text{Total ORC requirements in the upper portion of the aquifer} = 976 \text{ lbs.}$$

In order to maintain the dosage below the recommended maximum of 7 pounds ORC/linear foot (recommended by Regenesys based on equipment limitations from past experience in sandy aquifers) over a 9 foot depth, the ORC would be injected into the 17 direct push points shown in Figure 5, at a rate of 6.3 pounds ORC per foot.

If ORC were to be placed uniformly throughout the lower 8 feet of the aquifer, the total amount of ORC required would be:

PCP in soil: $(6324 \text{ ft}^3) \times (100 \text{ lbs./ft}^3) \times (0.0000004 \text{ lbs. PCP/lb. soil}) \times (5.4 \text{ lbs. ORC/lb. PCP}) = 1.5 \text{ lb.}$

PCP in gw: $(6324 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.0000005 \text{ lbs. PCP/lb. water}) \times (5.4 \text{ lbs. ORC/lb. PCP}) = 0.5 \text{ lb.}$

TPH in soil: $(6324 \text{ ft}^3) \times (100 \text{ lbs./ft}^3) \times (0.00002 \text{ lbs. TPH/lb. soil}) \times (30 \text{ lbs. ORC/lb. TPH}) = 379 \text{ lbs.}$

TPH in gw: $(6324 \text{ ft}^3) \times (0.3 \text{ ft}^3 \text{ water/ft}^3) \times (57 \text{ lbs. water/ft}^3) \times (0.000001 \text{ lbs. TPH/lb. water}) \times (30 \text{ lbs. ORC/lb. TPH}) = 3 \text{ lbs.}$

Total ORC requirements in the lower portion of the aquifer = 384 lbs.

The ORC would be injected into the lower portion of the aquifer using the same 17 direct push points as for the upper portion of the aquifer. The injection rate for the lower portion would be about 3 pounds ORC per foot. Using injection rates of 6.3 and 3 pounds per foot, the total ORC requirements would be 1,384 pounds.

5.5 Groundwater Monitoring

Five rounds of groundwater sampling are proposed for the treatability study to evaluate the performance of the ORC on reducing concentrations of PCP and its daughter products in groundwater. Sampling will be conducted prior to the injection of the ORC, and then at 6, 12, 24, and 36 weeks after the injection of the ORC.

Groundwater velocity is estimated to be 0.5 feet per day in the sandy portion of the surficial aquifer. Therefore groundwater is expected to flow approximately 125 feet in the 36-week test period. Contaminant transport is often attenuated with respect to groundwater flow. However, the 5 and 50 foot spacings should permit an assessment of the effects of ORC injection over the expected 36-week duration of the treatability study. The study period will be extended if groundwater and contaminant transport velocity is slower than estimated. The seven monitoring wells identified in Table 2 will be sampled.

All groundwater samples will be analyzed for the parameters summarized in Table 3. Chemical analyses will be performed in a fixed-base laboratory with a 28-day turn around time.

5.6 Reporting

CH2M HILL will prepare progress memos for submission to the Little Creek Partnering Team. These will include a memo on the baseline groundwater study findings and three memos that summarize site activities and progress at weeks 6, 12, and 24. A draft report for ORC groundwater remediation will be prepared for the Little Creek Partnering Team for review and comment. This report will summarize the contents of the memorandums, document all field activities and analytical results from groundwater monitoring, and evaluate groundwater remediation using the implemented technology. A final report will be prepared based on the comments received.

6.0 Schedule

Approximate relative schedule dates for the major milestones of the treatability study are listed below. Upon review and issuance of the final implementation plan, these dates will be defined.

- Approval of draft work plan and RTC– August 16, 2000
- Additional well installation – August 28, 2000
- Baseline groundwater sampling (prior to injection of ORC) – September 4, 2000
- ORC injection – October 16, 2000
- 6-wk Milestone and quarterly monitoring – Nov 27, Jan 8, Apr 2, Jun 25
- Final Reporting – Aug 25, 2001

7.0 References

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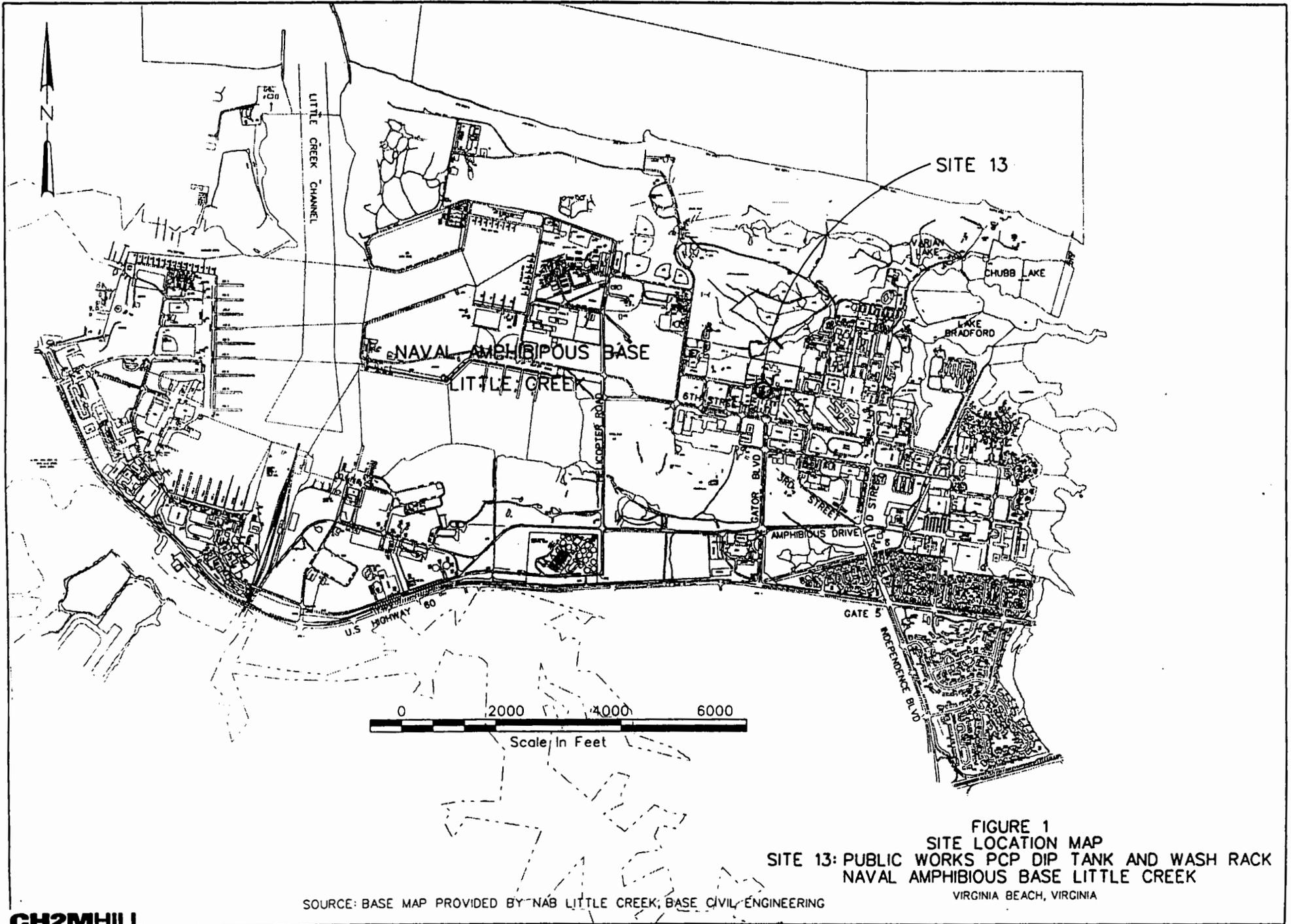


FIGURE 1
 SITE LOCATION MAP
 SITE 13: PUBLIC WORKS PCP DIP TANK AND WASH RACK
 NAVAL AMPHIBIOUS BASE LITTLE CREEK
 VIRGINIA BEACH, VIRGINIA

SOURCE: BASE MAP PROVIDED BY NAB LITTLE CREEK, BASE CIVIL ENGINEERING

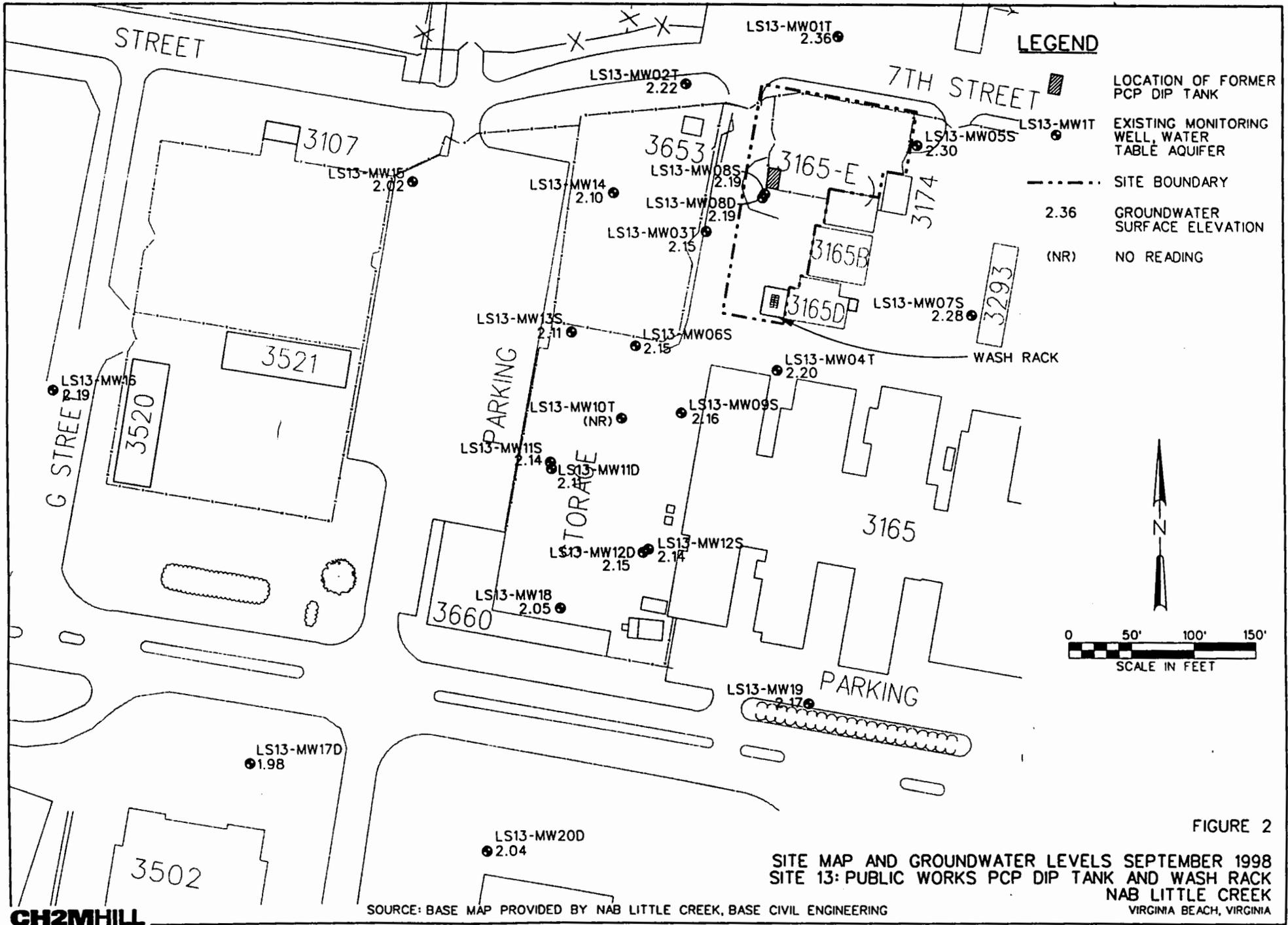


FIGURE 2

SITE MAP AND GROUNDWATER LEVELS SEPTEMBER 1998
 SITE 13: PUBLIC WORKS PCP DIP TANK AND WASH RACK
 NAB LITTLE CREEK
 VIRGINIA BEACH, VIRGINIA

SOURCE: BASE MAP PROVIDED BY NAB LITTLE CREEK, BASE CIVIL ENGINEERING

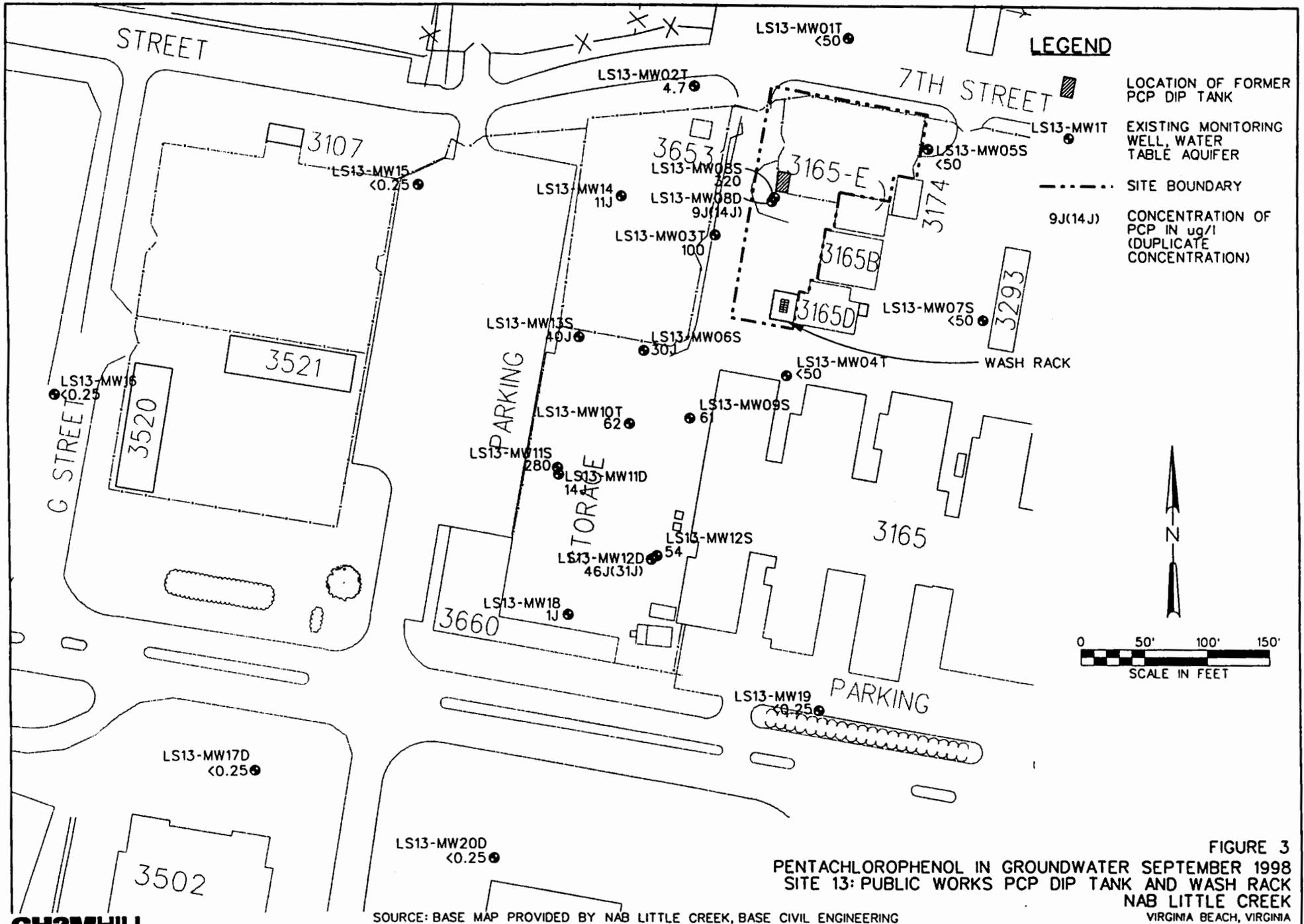
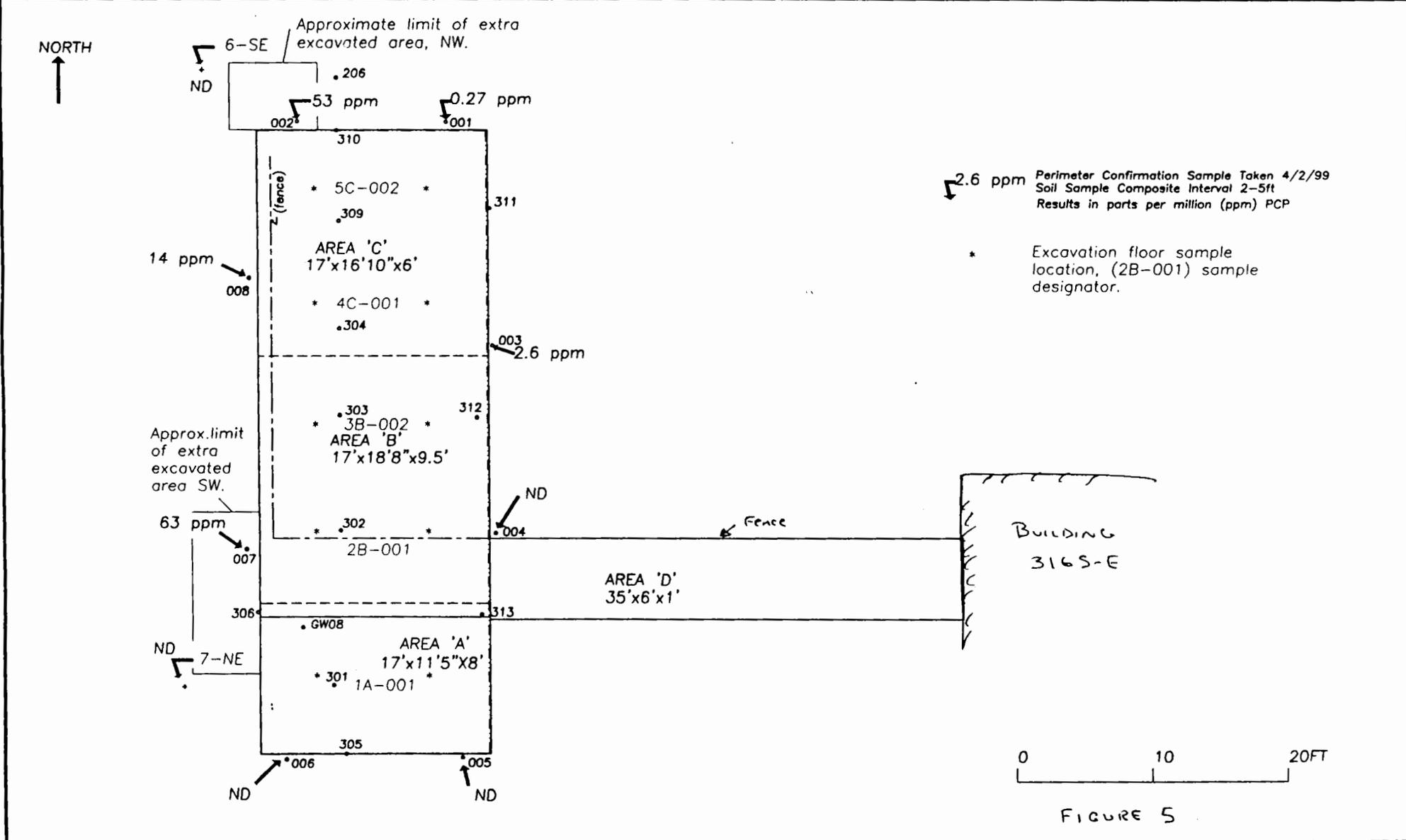


FIGURE 3
PENTACHLOROPHENOL IN GROUNDWATER SEPTEMBER 1998
SITE 13: PUBLIC WORKS PCP DIP TANK AND WASH RACK
NAB LITTLE CREEK
VIRGINIA BEACH, VIRGINIA

SOURCE: BASE MAP PROVIDED BY NAB LITTLE CREEK, BASE CIVIL ENGINEERING

PLOT DATE: 6/3/99
 FORMAT REVISION 3/25/99

IMAGE	X-REF	OFFICE	DRAWING
---	---	Trenton, NJ	NUMBER 777941-A6



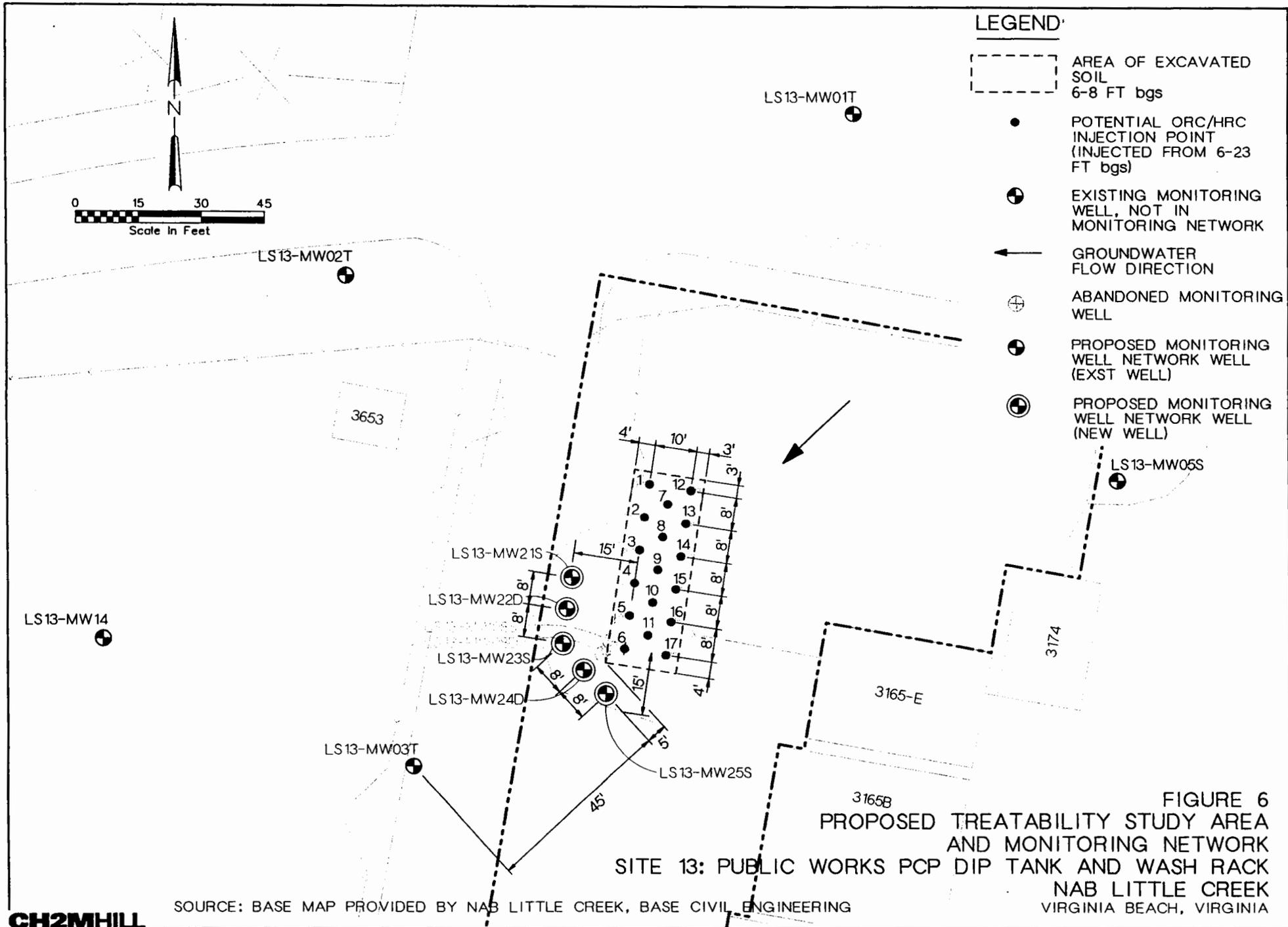
SHEET I.D.	DEPARTMENT OF THE NAVY	NAVAL FACILITIES ENGINEERING COMMAND
	NAVAL STATION	ATLANTIC DIVISION
	NAVAL AMPHIBIOUS BASE - LITTLE CREEK	NORFOLK, VIRGINIA
	NAVAL AMPHIBIOUS BASE - VIRGINIA BEACH, VIRGINIA	
CONSTR. CONTRACT NO.	SITE 13 - AMPHIBIOUS BASE	
CONTRACT ORDER NO.	PCP CONTAMINATED SOIL REMOVAL/EXCAVATION	
SCALE: AS SHOWN	EXCAVATION LIMITS/ SAMPLE POINTS	



OHM Remediation Services Corp.
 PROJECT NO. 777941

DESIGNED BY	PTS	4/13/99	CHECKED BY	T. Sword	5/99
DRAWN BY	PTS	4/13/99	APPROVED BY	T. Sword	5/99

REV	DATE	BY	CHK'D	APR'VD	DESCRIPTION/ISSUE



LEGEND:

- AREA OF EXCAVATED SOIL
6-8 FT bgs
- POTENTIAL ORC/HRC INJECTION POINT
(INJECTED FROM 6-23 FT bgs)
- ⊕ EXISTING MONITORING WELL, NOT IN MONITORING NETWORK
- ← GROUNDWATER FLOW DIRECTION
- ⊕ ABANDONED MONITORING WELL
- ⊕ PROPOSED MONITORING WELL NETWORK WELL (EXST WELL)
- ⊕ PROPOSED MONITORING WELL NETWORK WELL (NEW WELL)

FIGURE 6
PROPOSED TREATABILITY STUDY AREA
AND MONITORING NETWORK
SITE 13: PUBLIC WORKS PCP DIP TANK AND WASH RACK
NAB LITTLE CREEK
VIRGINIA BEACH, VIRGINIA

SOURCE: BASE MAP PROVIDED BY NAB LITTLE CREEK, BASE CIVIL ENGINEERING

Appendix A
Palorus's Paper on PCP Bioremediation

BIOREMEDIATION OF PENTACHLOROPHENOL

Literature Survey of Metabolic Pathways and Rate Constants

Submitted to

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CH2M HILL
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Prepared by

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June 4, 1997

I. INTRODUCTION

Pentachlorophenol (PCP) is a herbicide and fungicide which has been used extensively throughout the wood producing regions of the United States for wood preservation. As a result of wood treating operations surficial and groundwater contamination has occurred at a number of former wood treating sites. Over the years a number of scientists and engineers have investigated methodologies for remediating PCP contaminated soil and groundwater. The most common practice for treating surficial soils has been to apply landfarming techniques which optimize the naturally occurring biodegradative activity of soil microorganism's through the management of soil moisture, inorganic nutrients, and aeration (e.g. tilling). With respect to groundwater contamination the most common practice had been to use pump and treat methods to achieve plume control with treatment of produced waters using either carbon adsorption or some form of aqueous bioreactor. Recently, the process of Natural Attenuation of groundwater plumes has been receiving a great deal of support from industry as well as government agencies (US/EPA, 1996). Under a natural attenuation scenario, the contaminant plume has reached an equilibrium condition in which the natural rates of contaminant dissipation have been retarded through the nondestructive mechanisms of chemical adsorption, dispersion, dilution, volatilization and through the destructive mechanism of biodegradation. Support of the natural attenuation mechanism requires that the proponent must scientifically demonstrate that degradation of site contaminants is occurring at rates sufficient to be protective of human health and the environment. Often this entails a detailed site characterization to collect data which can be used in a site specific groundwater flow and contaminant transport model. Using the site specific model a preliminary screening of potential remedial options can be performed by inputting the reaction rates for the various treatment methods. Using a range of published literature values one can simulate performance over a range of operating conditions and assess those with the highest probability of success.

This literature review has been undertaken to establish basic information with respect to Pentachlorophenol biodegradation that can be used as a basis for evaluating the intrinsic biodegradation component of natural attenuation processes at the site. As such our literature review has been focused on collecting rate data for aerobic and anaerobic biodegradation of PCP. Rate data is very difficult to extract from many of the publications on microbial degradation of organic pollutants. This is because the experiments performed or the field data collected, were not designed in a manner which generates such information. In other instances the rate information is expressed in uncommon units (e.g. mg/hr/cell), or in a manner that it can not be adequately interpreted with out making broad assumptions. When ever it was possible to use the information presented in a particular reference for making rate estimates then standard chemical reaction rate equations where employed for zero and first order rate approximations.

Following are the zero and first order rate equations and the corresponding equation for half life ($t_{1/2}$) approximations.

Zero Order Rate Expression:

$$k = (C_0 - C_t) / t$$

Where:

- k = Rate Constant (ppm/day)
- t = Time (day)
- C_0 = Initial substrate concentration
- C_t = Substrate concentration at time (t)
- $t_{1/2}$ = $C_0 / 2k$

First Order Rate Expression:

$$k = \ln(C_t / C_0) / t$$

Where:

- k = Rate Constant (day⁻¹)
- t = Time (day)
- C_0 = Initial substrate concentration
- C_t = Substrate concentration at time (t)
- $t_{1/2}$ = $(\ln 2) / k$

In addition to the rate data, information has been collected on the pathways by which PCP is biodegraded, Particular emphasis has been placed on the anaerobic biodegradation mechanisms. The emphasis on the anaerobic degradative pathway is driven by the fact that this process is one of sequential dechlorination of PCP which results in a number of potential chlorophenol's being produced and accumulating in the system. Since some of the less chlorinated phenol's are more mutagenic than PCP itself it is important to understand the potential for these chlorophenolic's to be produced under various site conditions.

II. BIODEGRADATION PATHWAYS

A. *Anaerobic Mechanisms.*

Anaerobic biodegradation of PCP occurs by reductive dechlorination, a process by which chlorine's are sequentially replaced with hydrogen. Degradation is dependent upon characteristics of the compound, the microbial consortium, and environmental factors (e.g. organic carbon, redox, inorganic electron acceptors). Studies of the distribution and fate of PCP in Japanese rice paddy fields provide some of the earliest information concerning the anaerobic biotransformation (i.e. dehalogenation) of chlorinated phenols (Ide et al., 1972). Much of the research on anaerobic degradation mechanisms has been performed using laboratory enrichment cultures with either consortium of bacteria or pure cultures. For the most part these studies reveal the same general patterns of reductive dehalogenation in both acclimated and unacclimated anaerobic sewage sludge's, sediments, soils and aquifers (Figure 1). Chlorine's in positions which are *ortho* to the hydroxyl group were removed more readily than those in the *meta* or *para* positions, a phenomenon verified in a number of studies (Mikesell et al., 1986 and Woods et al., 1989).

Biotransformation pathways vary with the characteristics of the microbial consortium. Sludge's acclimated to 2-chlorophenol (2-CP) were to degrade 4-CP and 2,4-DCP but not 3-CP and that those acclimated 3-CP are incapable of degrading 2-CP (Boyd et al. 1984). In addition, sludge's acclimated to individual monochlorophenol's yield different initial PCP degradation products as evident by the accumulation of *meta* and *para* dechlorination products as seen in Figure 1. Furthermore, reductive dechlorination pathways for have been determined for organisms acclimated to 2,4-DCP or 3,4-DCP . These studies have shown that the 2,4-DCP cultures produce *ortho* dechlorination products, while the 3,4-DCP cultures produced *para* dechlorination products. The data presented in Figure 1 suggests that environments exposed to PCP over a long period may yield a large number of metabolites and a complex PCP biotransformation pathway.

It is a well known fact that anaerobic bacteria are rich in organo metallic cofactors such as cobalt corrinoid compounds, nickel porphinoic coenzymes and iron porphyrin heme, which catalyze reductive dehalogenation reactions. A recent study reported that vitamin B₁₂ catalyzed the reductive dechlorination of PCP at only the *meta* and *para* positions (Gantzer, C.J., et al. (1991). The fact that anaerobic microorganism can release these organo metallic cofactors into the environment sets up the potential for "abiotic" reductive dehalogenation reactions to occur. The process by which these reductive dehalogenation reactions occur can be best classified as a biologically mediated (i.e. cofactor production

and release) abiotic process. It is only the vitamin B₁₂, which has been reduced Co(I), which can mediate the reactions of aryl halide dehalogenation. Figure 2 illustrates a summary of the reactions known to be mediated by vitamin B₁₂ (Smith et al. 1994). This aspect of reductive dechlorination is an important factor to consider when performing and evaluating microcosm tests in which abiotic controls are being used. It is quite likely that such controls would show evidence of reductive dehalogenation, however the specificity of the reaction products would be a clue that the process is occurring. It is also an important consideration when evaluating the potential migration of contaminants from the source area of plume moving down gradient. Since these organo metallic cofactors would be very water soluble they may move readily in the aquifer and contribute to abiotic transformations of contaminants downgradient. Thus the absence of a significant microbial population downgradient may not be an indicator that degradation or attenuation can not occur.

Increasingly a significant body of information on PCP reductive dehalogenation pathways is being collected using pure culture studies. Figure 3 is an illustration of the preferential *ortho*-dechlorination pathway exhibited by *Desulfotobacterium dehalogenans* (Utkin, et al. 1995). It is clear that this organism has a specificity for *ortho* dechlorination and differs significantly from the *meta*-dechlorination pathway demonstrated in *Desulfomonile tiedjei* which as a gram negative sulfate reducing bacterium. The fact that different microorganisms possess different substrate and regiospecificity in dehalogenation reactions suggests that consortium of microorganisms are of most importance to the operation of these mechanisms in situ. Furthermore, extreme care must be exercised when evaluating the published literature for reaction rates of reductive dehalogenation. The history of the source material and the enrichment procedures of the study can have a profound effect on the results one observes.

B. Aerobic Mechanisms.

There is a significant body of information on the isolation and characterization of aerobic PCP degrading pure cultures of microorganisms. In addition many studies have been performed at bench scale and field scale which evaluated the bioremediation of PCP through landfarming practices, which are by nature "aerobic" treatment systems. The mechanisms of aerobic degradation are substantially more limited by the fact the PCP is a highly oxidized molecule to begin with and is severely hindered sterically for attack by an oxygen via an oxygenase enzyme system. Therefore there does not appear to have been a systematic study to elucidate a definitive metabolic pathway for aerobic PCP degradation. However as illustrated in Figure 4, the information available from a number of independent investigators using simultaneous adaptation studies provides support the proposed mechanism. The substitution of the *para*-chlorine with an hydroxyl group generates the tetrachloro-*para*-hydroquinone. The resonance structure of this

intermediate is such that one of the *meta*- chlorine substituent could be chemically or enzymatically eliminated quite easily. A number of aerobic dehalogenases have been described that can mediate chlorine release from the aromatic nucleus of chlorophenolic compounds. Once the aromatic ring has 2 hydroxyl substituents inserted it can be ring cleaved by a ring cleavage oxygenase and completely mineralized to carbon dioxide, water and free chloride. Very few metabolic intermediates, other than chloride have been shown to accumulate in systems which aerobically degrade PCP (Rochkind, et al. 1986 and Klecka et al. 1985). This is probably due to the fact that the organisms degrading the PCP must expend significant energy to initiate degradation. Unless the substrate can be readily metabolized through ring fission it is not likely that populations will develop to appreciable cell densities to effect PCP degradation nor release intermediates.

III. PCP Degradation Rate Constants.

A focused but by no means exhaustive review of the literature was performed to collect rate data for PCP biodegradation under aerobic and anaerobic conditions. As can be seen in the tables presented in Appendix B, there is an extremely wide range of both aerobic and anaerobic rate constants. The lowest aerobic rates were reported by McGinnis et al (1995) for soils which had PCP concentrations 10^3 to 10^4 ppm. At such high concentrations one must consider the high probability of PCP toxicity to the soil microorganisms which creates somewhat of a bacteriostatic condition, where the organisms grow under very stressed conditions. The highest aerobic rate was reported by Mueller et al (1992) in an aqueous phase bioreactor with high acclimated biomass retention which was achieved through inoculation of the system with proprietary bacteria. Edgehill (1995) also reported high aerobic rates of PCP degradation in inoculated and uninoculated soils. This study, while biased by the fact that soils were spiked with PCP, still illustrates some trends and factors which are important to the bioremediation of PCP. First there is clearly an initial concentration dependent effect on the rate constant. As concentrations increase (93 -175 ppm) up to some threshold value, the rate constant increases as well. At the threshold one reaches concentrations (e.g. 400 ppm) which become inhibitory to the reaction. The second feature of these studies is the fact that increasing specific contaminant biodegrading biomass has the effect of increasing the rates of reaction., suggesting that in some instances biomass may be the rate limiting factor. Thus environments which possess a high level of acclimated biomass should show the highest rates of contaminant degradation.

Anaerobic rate data in the literature suffers from the same limitations as the aerobic data. The range of rate constants is quite large and is obviously influenced by the manner in which the studies were performed. Generally studies with the highest anaerobic PCP degradation rates were those in which

anaerobic bioreactor's were used and contained high levels of acclimated biomass or were pure culture studies. These results once again highlight the importance of the acclimated biomass component and the levels of that biomass on the rates of degradation in a system or environment. Supplemental carbon source was also shown to be an important rate determining factor for anaerobic treatment systems (Hendriksen et al. 1992). Supplemental carbon provides the potential energy for reductive dehalogenation by generating, through fermentation of the substrate, a source of reducing equivalents in the form of hydrogen. Hydrogen is a critical cosubstrate in the reductive dehalogenation process since it is used to replace chlorine on the chlorinated compound with release of free chloride. The studies performed by Godsy (1986), Hendriksen (1992) and Harmsen (1991) provide the most reliable rate information for the anaerobic PCP degradation process.

IV. Literature Cited.

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- Utkin, I., et al. (1995). *Appl. Env. Microbiol.* 61: 346.
- Rochkind, M. L., et al.(1986). U.S. Envi. Prot. Agency, Cincinnati, OH. Report No. EPA-600/2-86/090.
- Klecka, G.M., et al. (1985). *Appl. Env. Microbiol.* 49: 46.

APPENDIX A

Figures 1 - 4

FIGURE 1.

Pathway for the reductive dehalogenation of Pentachlorophenol with granular sludge from an anaerobic digestors supplemented with carbon and PCP as sole carbon sources. Ortho- and para- dechlorinations are the thermodynamically favored reactions for polychlorinated phenolic compounds.

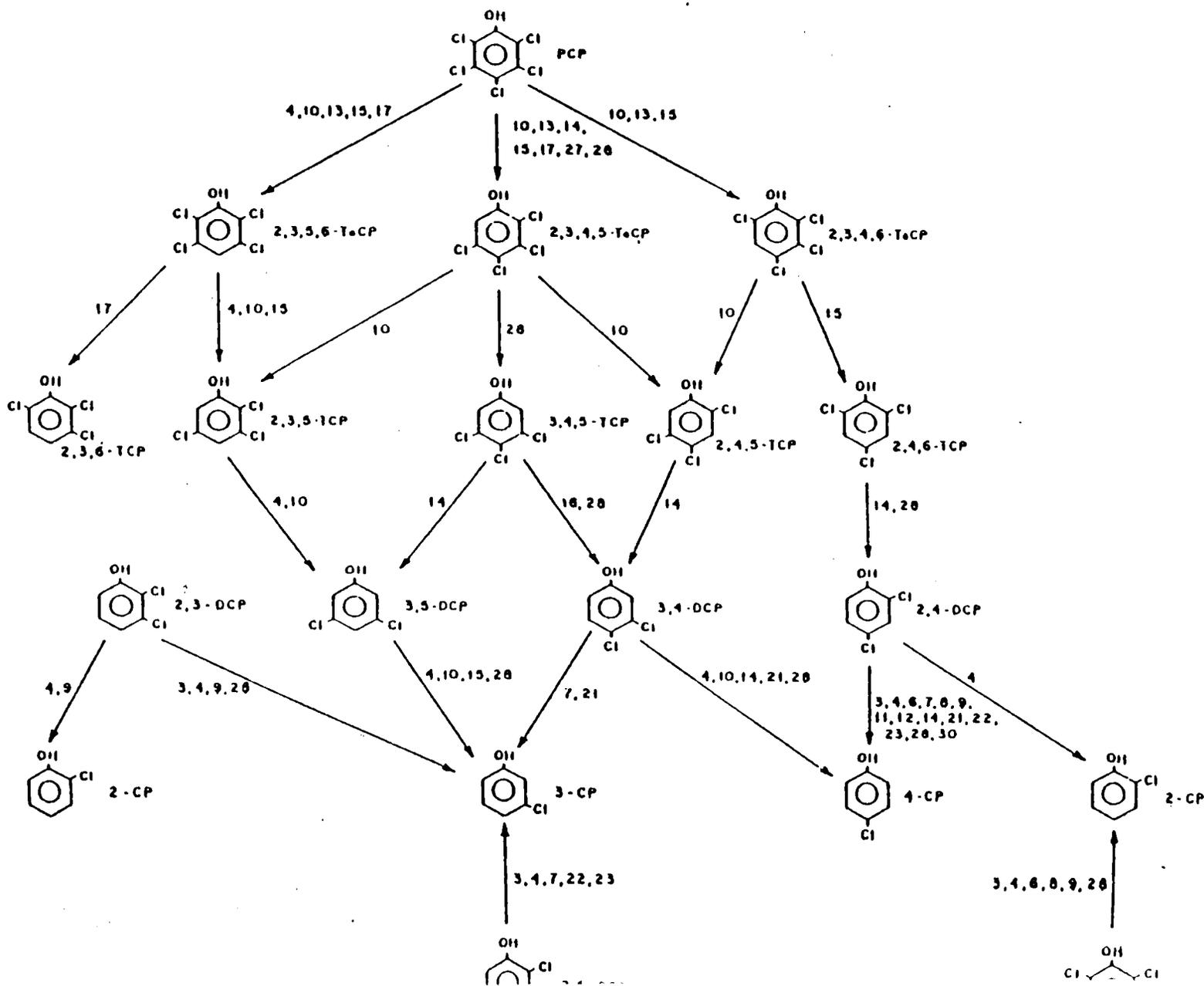


FIGURE 2. Anaerobic bacteria are rich in organo metallic cofactors which catalyze reductive dehalogenation reactions. Acetogenic and methanogenic bacteria are especially rich in corrinoids. Representative of these corrinoids is Vitamin B₁₂ which can exist in one of three oxidation states. The cobalt cofactor Co(III) can be sequentially reduced to Co(I) which is one of the most powerful nucleophiles known. Under the appropriate conditions, PCP, can be cometabolized by corrinoids released into an aqueous system by anaerobic bacteria. In this case reductive dehalogenation is mediated extracellularly. The pathway below represents the corrinoids (B₁₂) mediated pathwat for PCP dehalogenation.

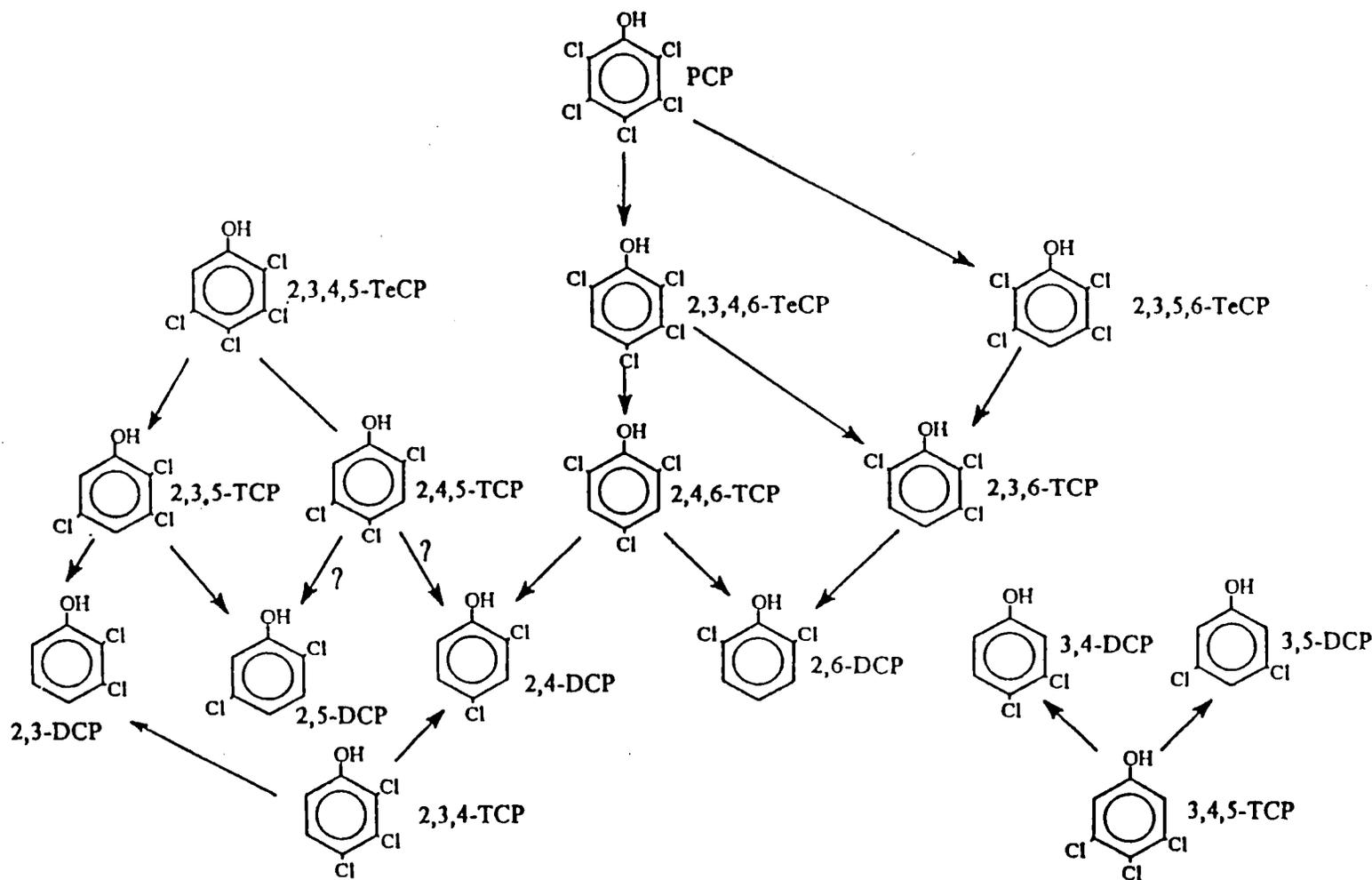
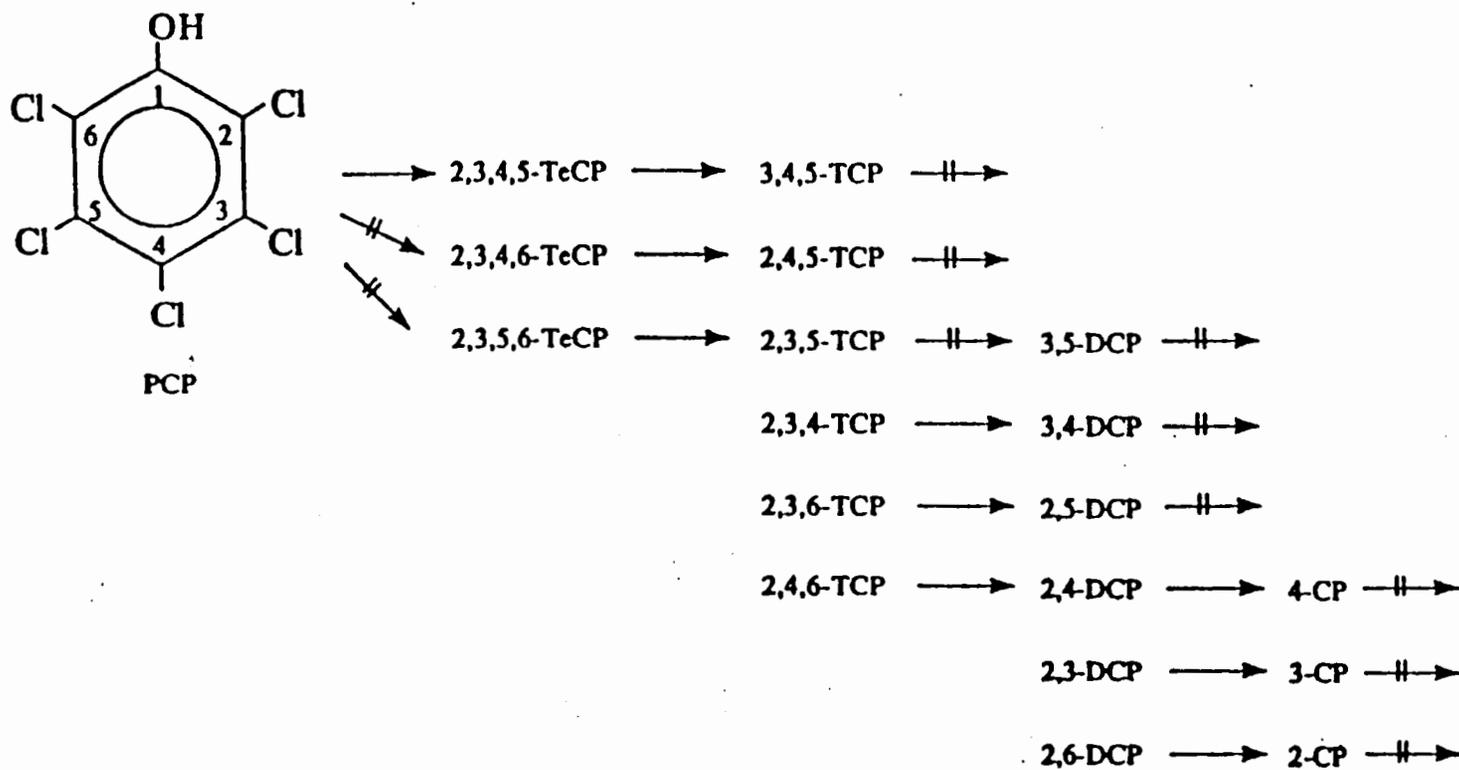


FIGURE 3. General scheme for the reductive ortho dechlorination of PCP by *Desulfitobacterium dehalogenans*. The figure illustrates with solid arrows the products which appear to accumulate to the highest extent, while the hatched arrows indicate intermediates which transiently accumulate at low levels. While not definitively proven, it is believed that the metabolites which accumulate to the highest extent probably do not represent intermediates which are central to the degradative pathway. Stated in another way, those intermediates which are identified at the lowest levels represent compounds which are more important to the growth and survival of the microbes, and are therefore metabolized a faster rates.



APPENDIX B

PCP Rate Tables

PENTACHLOROPHENOL DEGRADATION RATES

COMPOUND	C ₀ (ppm)	First Order Rate		Zero Order Rate		Matrix	Reference
		Aerobic	Anaerobic	Aerobic	Anaerobic		
Pentachlorophenol	5.00		2.6 x 10 ⁻³		1.1 x 10 ⁻²	Water	Godsy et al.(1986) Bull.Env.Tox. 36:271
	1500.00			5.4		Soil	Mahaffey et al. (1989) Ecova Milestone Report for UPRR Laramie Tie Treating Site
	15.00	1.97 x 10 ⁻²		208		Aqueous Bioreactor	Mueller et al. (1992) 4th Forum Innov. Haz. Waste Treat. Tech: Domestic & Intl. Nov. 17-19, San Fransisco
	120.00			2		Soil	McGinnis et al. (1987). Technology Completion Report. US Dept. Inter. Project #G1234-03
	40.00	7.3 x 10 ⁻¹		13		Pure Culture	Radehaus et al. (1992). Appl. Env. Microbiol. 58(9): 2879
	150.00	5.6 x 10 ⁻¹		24			
	10.00			2.5		Pure Culture	Stanlake et al (1982). Appl. Env. Microbiol. 44: 1421
	130.00			3.6			
	2.20		6.1		8.4	Pure Culture	Mohn et al. (1992). Appl. Env. Microbiol. 58(4): 1367
	12 to 20	8.4 x 10 ⁻¹				Chemostat	Rutgers et al. (1993). Appl. Env. Microbiol. 59(10): 3373
	30.00	1.6 x 10 ⁻¹		1.1		Soils	Miethling et al. (1996). Appl. Env. Microbiol. 62(12): 4361
	1.50				0.6	Anaerobic Digester	Hendriksen et al. (1992). Appl. Env. Microbiol. 58(1): 365
	3.00				2.2	" w/ Carbon Supplement	
					1.6	"	
	40.00				20	Anaerobic Digester	Wu et al (1993). Appl. Env. Microbiol. 59(2): 389

PENTACHLOROPHENOL DEGRADATION RATES

COMPOUND	C ₀ (ppm)	First Order Rate		Zero Order Rate		Matrix	Reference
		Aerobic	Anaerobic	Aerobic	Anaerobic		
Pentachlorophenol	100.00	1.35 x 10 ⁻²	6.78 x 10 ⁻³	7.41 x 10 ⁻¹	5.10 x 10 ⁻¹	Soil	Harmsen (1991). ON-SITE BIORECLAMATION. Processes for Xenobiotic and Hydrocarbon Treatment. p 255.
	50.00			3.4 x 10 ¹		Aqueous Pure culture	Panneton et al. (1995). Microbial Processes for Bioremediation. 3(8): 205. Third Int'l In-Situ and On-Site Bio.Symp. Battelle Press, Columbus, OH. NOTE: Rates transformed from published values by assuming biomass levels of 10 ¹² cells/liter.
	200.00			9.1 x 10 ⁰			
	500.00			3.2 x 10 ¹			
	93.00	8.3 x 10 ⁻²		6.8		Soil Uninoculated (SU)	Edgehill (1995). Bioaugmentation for Site Remediation. 3(3): 85. Third Int'l In-Situ and On-Site Bio.Symp. Battelle Press, Columbus, OH.
	93.00	4.9 x 10 ⁻¹		20		Soil Inoculated (SI)	
	175.00	4.2 x 10 ⁻²		6.6		SU	
	175.00	5.0 x 10 ⁻¹		42.5		SI	
	259.00	1.1 x 10 ⁻¹		22.75		SU	
	259.00	0.4 x 10 ⁻⁰		51.75		SI	
	400.00	8.7 x 10 ⁻²		28.2		SU	
	400.00	2.8 x 10 ⁻¹		60		SI	
	115.00	1.92 x 10 ⁻²		1.15		LTU Soil Lift 2	Huling et al. (1995). Bioremediation of Recalcitrant Organics. 3(7): 101. Third Int'l In-Situ and On-Site Bio.Symp. Battelle Press, Columbus, OH.
	119.00			3.01		LTU Soil	
	17116.00			8.9 x 10 ⁻³			McGinnis et al. (1991). BIOREMEDIATION: Fundamentals & Effective Applications. 3rd Ann. Symp. Gulf Coast Haz. Subst. Res. Ctr. February 21
	14600.00			7.3 x 10 ⁻³			
	7255.00			2.1 x 10 ⁻²			
	3900.00			4.9 x 10 ⁻³			

Appendix B
Regenesis's Technical Bulletins

ORC TECHNICAL BULLETIN # 1.3.5**Field Study on the Disposition of Compounds**

At present there are three field studies where magnesium has been measured. One of the studies also studied free phosphate levels.

University of Waterloo:

The following quote is from Dr. Gino Bianchi on his observations pertaining to a very limited migration of magnesium from ORC deposition wells. He is the lead author of an ORC based oxygen barrier study published in GWMR, Winter 1994.

"It is unlikely that sufficient magnesium would be dissolved to create scaling or reduced permeability problems in the aquifer. The increase in magnesium during the (3 month long) Borden experiment (a reference to Canadian Forces Base Borden) was very localized; the concentration increased from approximately 5 mg/L (background for the site) to approximately 20 mg/L within 1 m downgradient of the ORC. The magnesium concentration decreased to 5 mg/L, 1.5 m downgradient of the ORC."

North Carolina State University:

Magnesium samples were taken at a number of wells both outside and inside the ORC treatment zone. There was no significant difference in magnesium content for any of the samples with respect to the baseline levels. In fact, magnesium levels remained at between .5 and .67 mg/L in the ORC source well itself during the time it was measured (102 days). The average level in U.S. drinking water is 60 mg/L (in a range of 10 to 100 mg/L). Also, commercial mineral waters actually advertise the presence of percent levels of magnesium.

Phosphate levels were completely unchanged from background in response to contact with ORC. All phosphate levels at the site were below .5 ppm. Even if several ppm are being released in proximity to the well, it is apparently able to be consumed rather quickly by the microbes present.

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Iron Fouling

Given the fact that ORC produces both oxygen and an elevated pH there is a concern for iron fouling that will interfere with oxygen distribution. The degree to which this becomes an issue is a function of several things including, 1) the amount of soluble (ferrous) iron present, 2) the pH of the aquifer, 3) the fate of precipitated iron and 4) the ability to rehabilitate a problem should it arise. Also, it must be recognized that if the soluble iron is excessive and generates difficulties in an oxygenated environment, then any technology that attempts to foster aerobic bioremediation may become problematic as has been observed with air sparging.

Given the choices to provide oxygen in such an environment, ORC would have a distinct advantage in that it generates small amounts of oxygen over an extended period of time and would therefore minimize any potential problems. Also, iron hydroxide precipitates would have a tendency to deposit on the ORC filter sock which provides a mechanism to "capture" and remove them. Unless the sock is literally "electroplated" with metals, which is not likely, this process would not interfere with oxygen release. The precipitates can form directly at a higher pH, and thus be removed with the ORC. In the vicinity of the ORC, the pH will increase depending on the buffering capacity of the water.

In measurements with tap water in a closed system, the pH increases to about 9 inside the filter sock and drops to 7.5 to 8 a few inches from the outer edge of the material. Field data from the University of Waterloo study indicate that pH is restored to ambient values between 1 and 1.5 meters from the source.

The conclusion drawn from both theoretical calculations and the field results to date indicate that, regardless of the precipitation mechanism, only a minor amount of ferric hydroxide will form in a high iron aquifer under the influence of ORC, and it will largely do so on the surface of the removable ORC filter sock.

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Microbial Fouling

Microbial Biofouling

In highly oxygenated environments, microbes which can drive the bioremediation process will flourish. Consequently, microbial biomass will increase dramatically under the enriched conditions. The biological growth can clog well screens and packing that are designed to allow groundwater flow to pass through the well.

The use of ORC in an Oxygen Barrier easily combats the problem of biofouling by generating a highly localized, elevated pH. Microbial growth is inhibited in these environments. The use of ORC does not raise pH levels throughout an entire treatment area which could jeopardize the success of bioremediation. pH is elevated and highly localized at the ORC source alone thus allowing microbes to thrive elsewhere in the treatment zone.

Iron Fouling

In oxygenated environments dissolved metals, such as iron, can oxidize and precipitate as hydroxides. The oxidized metals will deposit on the well casings and create blockages which inhibit the efficacy of oxygen distribution. This problem usually occurs when the soluble (ferrous) iron content of the treatment area is fairly high. Even in these cases, it is easily remedied by pretreatment technologies, such as the use of polyphosphates, or various cleaning methods, such as the use of hydrochloric acid, which remove the precipitates.

Since ORC releases oxygen very slowly, the possibility of iron fouling is markedly reduced when compared to other oxygen delivery systems. The use of hydrogen peroxide, for example, would be difficult to use under high iron conditions. It should be noted that where oxygen induced fouling is severe, the general feasibility of using aerobic remediation methods would be in question.

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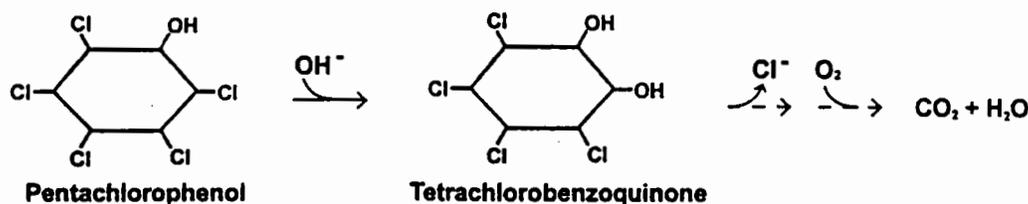
ORC TECHNICAL BULLETIN # 2.2.2.4

Remediation of Pentachlorophenol (PCP)

Pentachlorophenol (PCP) is a biocide used widely in the wood preservation industry. Laboratory results have successfully demonstrated bioremediation in soils and groundwater contaminated with pentachlorophenol. In fact, bioremediation has been recommended for implementation at numerous abandoned wood treatment sites (Dasappa, S.M. and R.C. Loehr, 1991). Oxygen Release Compound (ORC[®]) has been demonstrated to stimulate the rate of pentachlorophenol degradation and offers a unique alternative for PCP remediation.

Biodegradation of Pentachlorophenol

PCP degradation proceeds via a complex series of biochemical reactions beginning with an aerobic step that results in the formation of tetrachlorobenzoquinone (Spain, 1997). Subsequent dechlorination steps yield intermediate compounds susceptible to aerobic ring cleavage. The oxidative sequence ultimately ends in the formation of carbon dioxide.



Laboratory results indicate that PCP degradation occurs rapidly under aerobic conditions with half lives ($T_{1/2}$) less than 48 hours. (Maritinson et al., 1984). Furthermore, field demonstrations in certain contaminated soils show half lives less than 15 days (Crawford and Hohn, 1985).

Pentachlorophenol Treatment with ORC

ORC provides a slow, steady supply of oxygen that can stimulate the aerobic degradation of pentachlorophenol. Results from a field study at a Region 9 USEPA wood treatment site show that soils amended with ORC achieved a PCP biodegradation half life ($T_{1/2}$) of 37 days compared to the aerobic control (contaminated soils not treated with ORC but exposed to air) which showed a PCP degradation half life of 210 days (Vernalia, et al., 1997).

A pilot study in which ORC filter socks are being used to enhance the remediation of PCP-contaminated groundwater has produced promising results. The following data were collected after 2.5 months of treatment with ORC.

Well No.	Distance Downgradient	Initial Concentration (ppb)	Concentration after 2.5 Months (ppb)
1	30	400	7
2	5	7	0.3
3	30	54	1.7
4	30	16	1.2

Full scale implementation of enhanced in situ bioremediation with ORC is currently under consideration at several wood treatment facilities with PCP contaminated soils and groundwater. ORC presents a passive, cost effective approach to the remediation of PCP, without the costs associated with highly engineered systems.

ORC Installation Design Parameters

The theoretical mass ratio of oxygen to PCP required for the aerobic degradation of the contaminant is 0.54 to 1.0. Thus, 0.54 pounds of oxygen are required to degrade one pound of PCP.

The sorption coefficient (K_{oc}) for pentachlorophenol is $5.30E+4$ ml/g, suggesting that the compound has a stronger tendency to sorb to the aquifer matrix relative to petroleum hydrocarbons (e.g., benzene $K_{oc} = 8.30E+01$ ml/g). Therefore, when designing groundwater treatment systems employing ORC it is recommended that the aquifer matrix is sampled for PCP concentration. Such considerations will allow for more accurate indications of the oxygen demand imparted by the sorbed fraction of contamination.

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Spain, J. 1997. Synthetic Chemicals with Potential for Natural Attenuation. *Bioremediation Journal* 1:1-9.

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Appendix C

Test Tube Microcosm Test Protocol

Protocol for the testing of ORC remediation in small closed systems

January 12, 1999

Sponsor: Steve Koenigsberg
Regenesis
27130 A Paseo Espada, Suite 1407
San Juan Capistrano, CA 92675

Testing Facility: Applied Power Concepts, Inc
1738 N. Neville Street
Orange, CA 92865

Purpose of Study: To determine if the CH2M HILL soil site contaminated with pentachlorophenol is a candidate for remediation with ORC.

Test System: Each experiment will be conducted in a 38 X 200-mm glass airtight test tube. The tube will contain (according to each experiment defined below) a known amount of PCP solution and contaminated soil. A second tube 1.5 X 15-mm will hold a known amount of ORC. This second tube will be placed into the first test tube and the oxygen generated will enter the microcosm through the top of the tube.

Proposed Start Date and End Date: The test tube experiments will begin after completion of the PCP methodology and the approval of the protocol. The first set of experiments (experiment A) will last 25 days. At the end of this set of experiment, samples from the larger tube will be plated and maintained and held 10 days for growth, bringing the total time of the experiment to approximately 35 days. In order to reduce the time before the report is issued, the samples will also be plated two weeks into the test tube experiment. If the results are satisfactory the test will end at the 25 days. If the results are not satisfactory at this point, the test tube solutions will be plated again at the end of the experiment. The second set of experiments (experiment B) will have a duration of at least 3 months. At the end of this set of experiments the samples will be plated, adding 10 days to the duration of the test.

The Type and Frequency of Tests, Analysis and Measurements to be Made:

In experiment A, the test tubes will be analyzed on a weekly basis for 25 days. At the conclusion of the study the test tube solutions will be plated to determine their exact bacterial concentration. In experiment B, the test tubes will be analyzed on a monthly basis for three months. The test tubes in both experiments are analyzed for the following information:

1. Degradation of PCP and its daughter products will be monitored by gas chromatography using a PID or a FID detector using the APC method developed for measuring PCP.
2. Colony Forming Units (Cfu)/ml will be determined using the APC method for plating and counting field soil and water samples. The plate counts will include anaerobic, aerobic and Sulfur Reducing Bacteria counts.

Outline of Test: The two experiments involve testing one level of PCP (10 mg/L) and two different levels of ORC (0.25 grams and 0.75 grams). The difference between experiment A and experiment B is the duration of the test. Not including plating, experiment A is 25 days in duration and experiment B is at least 3 months in duration. Experiment A and experiment B will each consist of two sets of triplicate test tubes as outlined in 1 and 2 below. Four test tubes will be used as controls for both experiments as outlined in 3 below, as well as for the two experiments using HRC in place of ORC.

1. Three test tubes will contain 10 grams of soil, 0.25 grams of ORC and 150 ml of 10 ppm of PCP.
2. Three test tubes will contain 10 grams of soil, 0.75 grams of ORC and 150 ml of 10 ppm of PCP.
3. Four test tubes will be used as a control for both experiment A and experiment B. They will also be used as the set of controls for the HRC experiment with PCP (See protocol for the testing of HRC remediation in small closed system for PCP). They will each contain 10 grams of soil and 150 ml of 10 ppm of PCP with no ORC or HRC present. One test tube will be sampled three times over the 25 day period and then plated. The other three will be sampled three times over the 25 days, two months and three months and then plated. This will enable the control to apply to both experiment A and experiment B.

In addition three sterile test tubes will be set up with 10 grams of sterile sand and 150 ml of 10 ppm of PCP. The test tubes will be sampled at 25 days, 2 months and 3 months time intervals. This set will be used to examine if there is any loss in PCP due to sampling. This same set will be used for the PCP study using HRC instead of ORC.

These experiments will determine if the contaminated site is a candidate for bioremediation with Regensis's ORC product.

Final Report: At the conclusion of experiment A, APC will issue a confidential report to Regensis that will include raw data presented in tabular form in an Excel program. Copies of all raw data from the chemist's notebook will also be submitted. The final and any subsequent reports will include APC's interpretation of the raw data and specific

Protocol for the testing of HRC remediation in small closed systems

January 12, 1999

Sponsor: Steve Koenigsberg
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Testing Facility: Applied Power Concepts, Inc
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Purpose of Study: To determine if the CH2M HILL soil site contaminated with pentachlorophenol is a candidate for remediation with HRC.

Test System: Each experiment will be conducted in a 38 X 200-mm glass airtight test tube. The tube will contain (according to each experiment defined below) a known amount of PCP, HRC and the contaminated soil sample.

Proposed Start Date and End Date: The test tube experiment will begin after completion of the PCP methodology and approval of the protocol. The first set of experiments (experiment A) will last 25 days. At the end of this set of experiments, samples will be plated and maintained and held 10 days for growth, bringing the total time of the experiment to approximately 35 days. In order to reduce the time before the report is issued, the samples will also be plated two weeks into the test tube experiment. If the results are satisfactory the test will end at the 25 days. If the results are not satisfactory at this point, the test tube solutions will be plated again at the end of the experiment. The second set of experiments (experiment B) will have a duration of at least 3 months. At the end of this set of experiments the samples will be plated, adding 10 days to the duration of the test.

The Type and Frequency of Tests, Analysis and Measurements to be Made:
In experiment A, the test tubes will be analyzed on a weekly basis for 25 days. At the conclusion of the study the test tube solutions will be plated to determine their exact bacterial concentration. In experiment B, the test tubes will be analyzed on a monthly basis for at least three months. The test tubes in both experiments are analyzed for the following information:

1. Lactic acid, pyruvic acid and acetic acid will be analyzed by liquid chromatography using the APC method for the above acids.

2. Degradation of PCP will be monitored by gas chromatography using a PID or a FID detector using the APC method for measuring PCP (to be validated before this protocol begins).
3. Colony Forming Units (Cfu)/ml will be determined using the APC method for plating and counting field soil and water samples. The plate counts will include anaerobic, aerobic and Sulfur Reducing Bacteria counts.

Outline of Test: The two experiments involve testing one level of PCP (10 mg/L) and two different levels of HRC (0.25 grams and 0.75 grams). The difference between experiment A and experiment B is the duration of the test. Not including plating, experiment A is 25 days in duration and experiment B is 3 months in duration. Experiment A and experiment B will each consist of two sets of triplicate test tubes as outlined in 1 and 2 below. Four test tubes will be used as controls for both experiments as outlined in 3 below, as well as the two experiments using ORC in place of HRC.

1. Three test tubes will contain 10 grams of soil, 0.25 grams of HRC and 150 ml of 10 ppm of PCP.
2. Three test tubes will contain 10 grams of soil, 0.75 grams of HRC and 150 ml of 10 ppm of PCP.
3. Four test tubes will be used as a control for both experiment A and experiment B. They will also be used as the set of controls for the ORC experiment with PCP (See protocol for testing ORC remediation in small closed systems). They will each contain 10 grams of soil and 150 ml of 10 ppm of PCP with no HRC or ORC present. One test tube will be sampled three times over the 25 day period and then plated. The other three will be sampled three times, at 25 days, and then again at two months and three months and then plated. This will enable the control to apply to both experiment A and experiment B.

These experiments will determine if the contaminated site is a candidate for bioremediation with Regenesi's HRC product.

Final Report: At the conclusion of experiment A, APC will issue a confidential report to Regenesi that will include raw data presented in tabular form in an Excel program. Copies of all raw data from the chemist's notebook will also be submitted. The final and any subsequent reports will include APC's interpretation of the raw data and specific recommendations for future studies conducted with the ASV unit. The final report will be issued within 30 days of completion of experiment B.

Appendix D
3 Month Test Results

Treatability Study
CH2M HILL PCP-ORC STUDY

For
Regenesis Bioremediation Products, Inc.

by

Applied Power Concepts, Inc.
1738 N. Neville Street
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July 28, 1999

FINAL REPORT

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Reported by: Tracy Palmer

Summary:

A soil sample from a CH2M Hill site was studied using the Protocol for the Regenesis Bench Scale Experiments. The purpose of the study is to determine whether the site is a candidate for aerobic remediation of chlorinated hydrocarbons specifically PCP and its degradation products. The initial concentration of PCP added to the test tubes was 10 mg/L. The soil samples sent were contaminated with PCP.

The bench scale test provides an accelerated response to aerobic remediation. The focus is on the determination of whether the soil contains a population of bacteria that a) are suitable to perform the remediation and b) respond to an increase in both the carbon compound biochemical energy and the oxygen generated from ORC.

Typically the test is run for 20-25 days, in this case the test was run for three months with samples analyzed once a month. By the end of the first month the PCP in the high level ORC were reduced to 0.20 mg/L. By the end of the test the sample set that began with a low ORC dose (0.25 grams) had been reduced to an average of 0.93 mg/L of PCP. The concentration at the end of the test of 2,4-DCP and 2,4,6-TCP were 0 mg/L and 0.20 mg/L respectively. The sample set with a high ORC dose (0.75 grams) had been reduced to 0 mg/L of PC. The concentration at the end of the test of 2,4-DCP and 2,4,6-TCP were 0 mg/L and 0.18 mg/L respectively.

The control sample at the 90-day period was unavailable, at 60 days the average value for PCP was 6.33 mg/l, 0 mg/l of 2,4-DCP and 0 mg/L of 2,4,6-TCP, essentially no change from the 30 days. The sterile sample contained 6.29 mg/L of PCP and 0.18 mg/L of 2,4,6-TCP at the end of the test. When the samples were analyzed for microbial counts, microorganisms were found in the sterile sample. The sterile samples were made following the protocol for the bench scale test for CH2M Hill. The samples were made using clean materials but they were not actually sterilized. The sterile samples could have been inoculated with bacteria from the soil during sampling even though clean (but not sterile) implements are used. PCP is not volatile and is not lost after sampling as shown in the 25 day study on PCP.

Based on comparison to other sites we conclude that this site is a candidate for a pilot field test. The higher levels of ORC work at a much faster rate than the samples with the lower levels of ORC.

Experimental Methods:

The experiment involved testing one level of PCP (10 mg/L) and two different levels of ORC (0.25 grams and 0.75 grams). The soil samples are homogenized by manual stirring and a 10 gram aliquot is added to each of the 8 test tubes of approximately 200 ml total volume. In three of the test tubes 150 ml of distilled water containing 10 mg/L of PCP is added along with 0.25 grams of ORC. In three of the test tubes 10 mg/L of a PCP solution is added along with 0.75 grams of ORC. One test tube is the microbe control and only distilled water is added to the contaminated soil. A final test tube is used as a sterile test tube, containing 10 grams of sterile sand and 150 ml of 10-mg/L solution of PCP.

The samples from each of the PCP test tubes are analyzed for PCP using liquid chromatography with a Retek C18 column and an UV detector. Xylene is used as the internal standard for PCP.

Bacterial counts are made using standard plate pour techniques. Three populations are measured. The first population is aerobic total plate counts (TPC) based on a glucose nutrient agar plate. This is the normal test used for groundwater. The results are reported as the number of Colony Forming Units per ml. We use the same test media for anaerobes but incubate the plates anaerobically under nitrogen. These counts are reported as anaerobic TPC. Finally we also use the standard AWWA test for sulfate reducing bacteria to measure the SRB content in the soil water. This later test is usually of use in anaerobic remediation of chlorinated hydrocarbons because it has been found that SRBs thrive at a redox potential that is close to the optimum for dechlorination. In this aerobic test the same three sets of bacteria were measured to be able to compare the microbial distribution with the distribution from the same soil treated under anaerobic conditions.

Complete detailed methods are on file for all of the procedures used at APC. Also available are GLP Protocols even though they are not required. APC generally follows GLP methodology. The Regensis protocols do not require a GLP study for each of the treatability. This reduces administrative time and costs and allows more flexibility in sample collection, duration of the tests, etc.

Results and Discussion:

We began the treatability test on the CH2M Hill site sample on 3/17/99. By the end of the test there was evidence of remediation. The data from the test are given in Table 1.

The systems were sampled for microbial counts. The counts for each sample are given in Table 2. In the Tables a "spreader" is a plate that has become so overgrown that colonies merge making identification of individual colonies impossible. This usually occurs when the sample contains an organism that will grow rapidly when provided an adequate carbon source. In the Tables a "TNTC" (Too Numerous Too Count) is a plate that has so many individual colonies making it impossible to count. A contaminated plate is easy to identify since invariably contamination in plating is due to fungus that overgrows the plate. This is not the case in spreaders that have microbes clearly growing into the agar.

The microbial counts for the aerobic test are shown in Table 2. The aerobic counts are increased over the counts in the same system that had been exposed to anaerobic conditions. Facultative organisms can show up in both aerobic and anaerobic conditions even though organisms will reproduce more quickly to become a visible colony in the conditions it favors most. The large number of anaerobic TPC and SRB counts indicates that the organisms that are effective at dechlorination may be facultative. They can function under aerobic conditions or anaerobic conditions but grow most rapidly in culture under anaerobic conditions. We usually find that the nature of the colonies changes during the course of these studies. Control colonies are usually spreaders. The large number of bacteria of essentially the same nature in the sterile samples indicates that the sterile samples were contaminated during sampling. This is the first time the same study was run both anaerobically and aerobically. The facultative nature of the dechlorinating bacteria has been suspected and noted in the literature. These results support the hypothesis that the dechlorinating bacteria are facultative.

Conclusions and Recommendations:

The CH2M Hill site is a candidate for either an ASV trial or a field trial using ORC. The test tube experiments are encouraging.

In actual field trials ORC has shown for other compounds that can be remediated aerobically that it can provide an increase in remediation rate over background.

Table 1
PCP Data for CH2M Hill

PCP	Days			
	0	30	60	90
Lo ORC	10.00	4.18	1.59	0.93
Hi ORC	10.00	0.20	0.00	0.00
Control	10.00	6.05	6.33	NA
Sterile	10.00	8.21	6.29	6.29
2,4-DCP	0	30	60	90
Lo ORC	0.00	0.00	0.00	0.00
Hi ORC	0.00	0.00	0.00	0.00
Control	0.00	0.00	0.00	NA
Sterile	0.00	0.00	0.00	0.00
2,4,6-TCP	0	30	60	90
Lo ORC	0.00	2.14	0.00	0.20
Hi ORC	0.00	0.00	0.00	0.18
Control	0.00	0.00	0.00	NA
Sterile	0.00	0.00	0.16	0.184

Table 2
Microbial Counts for CH2M Hill

	Aerobic	Anaerobic	
<u>Sample</u>	<u>TPC</u>	<u>TPC</u>	<u>SRB</u>
LoORCA1	9	4	41
LoORCB1	Spreader	Spreader	TNTC
LoORCC1	0	0	TNTC
HiORCA2	416	Spreader	TNTC
HiORCB2	82	44	896
HiORCC2	260	224	TNTC
Control	146	Spreader	TNTC
Control	496	Spreader	TNTC
Control	63	42	TNTC
Sterile	20	Spreader	TNTC
Sterile	75	Spreader	TNTC
Sterile	103	Spreader	TNTC

Treatability Study
CH2M HILL PCP-HRC STUDY

For
Regenesis Bioremediation Products, Inc.

by

Applied Power Concepts, Inc.
1738 N. Neville Street
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July 27, 1999

FINAL REPORT

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Reported by: Tracy Palmer

Summary:

A soil sample from a CH2M Hill site was studied using the Protocol for the Regenesis Bench Scale Experiments. The purpose of the study is to determine whether the site is a candidate for anaerobic remediation of chlorinated phenols specifically PCP and its degradation products. The initial concentration of the contaminate PCP was 10 mg/L.

The bench scale test provides an accelerated response to anaerobic remediation. The focus is on the determination of whether the soil contains a population of bacteria that a) are suitable to perform the remediation and b) respond to an increase in both the carbon compound biochemical energy and the hydrogen generated from HRC.

This particular test was three months in length. By the end of the first month significant reductions in PCP were seen in the low level HRC test tubes as well as the high level HRC test tubes. By the end of the test the sample set that began with a low HRC dose (0.25 grams) had been reduced to an average of 0.672 mg/L of PCP. The concentration of 2,4-DCP was 0 mg/L and the concentration of 2,4,6-TCP was 0.22 mg/L. The sample set with a high HRC dose (0.75 grams) had been reduced to an average value of 0.321 mg/L of PCP. The concentration of 2,4-DCP was 0 mg/L and the concentration of 2,4,6-TCP was 0.20 mg/L.

The control sample at the 90-day period was unavailable, at 60 days the average value for PCP was 6.33 mg/L, 0 mg/L of 2,4-DCP and 0 mg/L of 2,4,6-TCP, essentially no change from 30 days. The sterile sample contained 6.29 mg/L of PCP and 0.18 mg/L of 2,4,6-TCP at the end of the test. When the samples were analyzed for microbial counts, microorganisms were found in the sterile sample. The sterile samples were made following the protocol for the bench scale test for CH2M Hill. The samples were made using clean materials but they were not actually sterilized.

Based on comparison to other sites we conclude that this site is a candidate for a pilot field test. In this case HRC expedited the remediation of PCP.

Experimental Methods:

The experiment involved testing one level of PCP (10 mg/L) and two different levels of HRC (0.25 grams and 0.75 grams). The soil samples are homogenized by manual stirring and a 10-gram aliquot is added to each of 12 test tubes of approximately 200-ml total volume. In three of the test tubes 150 ml of distilled water containing 10 mg/L of PCP is added along with 0.25 grams of Sorbitol Polylactate (SPL) HRC. In three of the test tubes 10 mg/L of a PCP solution is added along with 0.75 grams of SPL HRC. Three test tubes are the microbe controls and only distilled water is added to the contaminated soil. Final three test tubes are used as sterile test tubes, containing 10 grams of sterile sand and 150 ml of 10-mg/L solution of PCP.

The test was run for three months with samples taken and analyzed every month. The samples from each of the PCP test tubes are split and analyzed for both PCP and organic acid content. The control and sterile sample are only analyzed for PCP.

The organic acids and PCP are measured using liquid chromatography with a Retek C18 column and an UV detector. Citric acid is used as the internal standard for lactic acid and xylene is used as the internal standard for PCP.

Bacterial counts are made using standard plate pour techniques. Three populations are measured. The first population is aerobic total plate counts (TPC) based on a glucose nutrient agar plate. This is the normal test used for groundwater. The results are reported as the number of Colony Forming Units per ml. We use the same test media for anaerobes but incubate the plates anaerobically under nitrogen. These counts are reported as anaerobic TPC. Finally we also use the standard AWWA test for sulfate reducing bacteria to measure the SRB content in the soil water. The rationale for this test is that the SRBs thrive at a redox potential that is close to the optimum for dechlorination. Although the dechlorinators are not necessarily SRBs, the presence of SRB indicates that aquifer conditions may be suitable for reductive dechlorination. One must be aware, however, that a high SRB count also indicates a high level of competition for hydrogen so that more HRC will be required.

Complete detailed methods are on file for all of the procedures used at APC. Also available are GLP Protocols even though they are not required. APC generally follows GLP methodology. The Regeneration protocols do not require a GLP study for each of the treatability. This reduces administrative time and costs and allows more flexibility in sample collection, duration of the tests, etc.

Results and Discussion:

We began the treatability test on the CH2M Hill site sample on 3/16/99. By the end of the test there was evidence of significant remediation. The data from the test are given in Table 1.

The comparable lactic acid data are given in Table 2. Note that the fourth significant digit is kept in the report for completeness although the method should only be relied upon for 3 significant digits.

These small closed systems should not be run past 3 months due to the increasing amount of head space that makes it more and more difficult to maintain the anaerobic environment as the system is sampled. The systems were sampled for microbial counts. The counts for each sample are given in Table 3. In the Tables a "spreader" is a plate that has become so overgrown that colonies merge making identification of individual colonies impossible. This usually occurs when the sample contains an organism that will grow rapidly when provided an adequate carbon source. In the Tables a "TNTC" (Too Numerous Too Count) is a plate that has so many individual colonies making it impossible to count. A contaminated plate is easy to identify since invariably contamination in plating is due to fungus that overgrows the plate. This is not the case in spreaders that have microbes clearly growing into the agar.

The microbial counts for CH2M Hill are shown in Table 3. The aerobic and anaerobic microbial counts are virtually zero. In this case it appears the SRB's are the microbes involved in the bioremediation. Facultative organisms can show up in both counts although an organism will reproduce more quickly to become a visible colony in the conditions it favors most. Reasonable SRB counts are to be expected given the nature of the dechlorinating bacteria that prefer a redox environment similar to SRBs. This is one of the few cases where we have seen a deficiency of organisms that will grow on sugar. Glucose is the carbon source in both the aerobic and anaerobic media. The bacteria in this soil require nutrients such as iron and sulfate found only in the SRB media. These results indicate that SRB are key to the reduction of PCP. This result is quite different than for "CAH'S" compounds.

Conclusions and Recommendations:

The CH2M Hill site is a candidate for either an ASV trial or a field trial. The test tube experiments are very encouraging.

In actual field trials HRC, as well as lactic acid, have shown they can provide a large increase in remediation rate over background.

Table1
PCP Data for CH2M Hill

PCP	Days			
	0	30	60	90
Lo HRC	10.00	1.61	1.61	0.672
Hi HRC	10.00	1.98	2.29	0.321
Control	10.00	6.05	6.33	NA
Sterile	10.00	8.206	6.29	6.29
2,4,-DCP	0	30	60	90
Lo HRC	0.00	0.00	0.00	0.00
Hi HRC	0.00	0.00	0.00	0.00
Control	0.00	0.00	0.00	NA
Sterile	0.00	0.00	0.00	0.00
2,4,6-TCP	0	30	60	90
Lo HRC	0.00	0.14	0.00	0.22
Hi HRC	0.00	0.13	0.00	0.198
Control	0.00	0.00	0.00	NA
Sterile	0.00	0.00	0.160	0.184

Table 2
Lactic Acid Data for CH2M Hill

Days	0	30	60	90
Lactic Acid				
Lo HRC	0	1688	1006	1030
Hi HRC	0	1762	2138	1926

Table 3
Microbial Counts for CH2M Hill

	Aerobic	Anaerobic	
<u>Sample</u>	<u>TPC</u>	<u>TPC</u>	<u>SRB</u>
LoHRCA1	3	7	32
LoHRCB1	0	6	Spreader
LoHRCC1	4	11	Spreader
HiHRCA2	4	2	Spreader
HiHRCB2	0	0	496
HiHRCC2	0	0	184
Control	146	Spreader	TNTC
Control	496	Spreader	TNTC
Control	63	42	TNTC
Sterile	20	Spreader	TNTC
Sterile	75	Spreader	TNTC
Sterile	103	Spreader	TNTC

Appendix E
Standard Operating Procedures

Field Measurement of Dissolved Oxygen

I. Purpose

To provide general guidelines for the calibration and use of the Dissolved Oxygen (DO) meter.

II. Scope

This is a general guideline for the field use of a DO meter. For specific instructions, refer to the operations manual.

III. Equipment and Materials

- Operations manual
- A DO probe and readout/control unit with batteries
- Electrolyte solution (KCl dissolved in deionized water) and probe membrane

IV. Procedures and Guidelines

A. Calibration

Calibrate prior to initial daily use before any readings are taken. Clean probe according to manufacturer's recommendations.

1. Prepare DO probe according to manufacturer's recommended procedures using electrolyte solution.
2. In the off position, set the pointer to zero using the screw in the center of the meter panel.
3. Turn function switch to red line and adjust using red line knob until the meter needle aligns with red mark at the 31 degrees C position.
4. Turn function switch to zero and adjust to zero using the zero control knob.
5. Attach prepared probe and adjust retaining ring finger tight.
6. Allow 15 minutes for optimum probe stabilization (when meter is off or during disconnection of the probe).
7. Place probe in hollow stopper that is supplied for use with the YSI Calibration Chamber.

VI. Key Checks and Items

- Battery check
- Calibration

VII. Preventive Maintenance

- Refer to operation manual for recommended maintenance.
- Check batteries, have replacement set on hand.

Groundwater Sampling from Monitoring Wells

I. Purpose and Scope

This procedure presents guidelines for the collection of groundwater samples from monitoring wells.

II. Equipment and Materials

- Probe box; box with inlet/outlet ports for purged groundwater and watertight ports for each probe
- pH meter; Orion Model SA250 or equivalent
- Temperature/conductivity meter; YSI Model 33 or equivalent
- In-line disposable 0.45 μ filters; QED FF8100 or equivalent
- Grundfos® Redi-Flo2 Pump
- Peristaltic Pump with Tubing (capable of yielding 2 gpm)
- Submersible Pump

III. Procedures and Guidelines

A. Setup and Purging

1. For the well to be sampled, information is obtained on well location, diameter(s), depth, and screened interval(s), and the method for disposal of purged water.
2. A pump will be used for well purging. The expected mechanism is a submersible pump with dedicated purge pipe for each well.
3. Instruments are calibrated according to manufacturer's instructions.
4. The well number, site, date, and condition are recorded in the field logbook.
5. Plastic sheeting is placed on the ground, and the well is unlocked and opened.
6. Water level measurements are collected in accordance with SOP Water Level Measurements, and the total depth of the well is measured.

repeatedly bailed dry to obtain a minimum of three well volumes, and allowed to recover before sampling.

12. Three to five well volumes are purged (more may be purged if parameters do not stabilize). Purging is stopped when field parameters have stabilized over two consecutive well volumes. Field parameters are considered stabilized when pH measurements agree within 0.5 units, temperature measurements agree within 1°C, and specific conductance measurements agree within 10 percent (e.g., 100 units for readings of 1,000 $\mu\text{mhos/cm}$).

B. Sample Collection

Once purging has been completed, the well is ready to be sampled. The elapsed time between completion of purging and collection of the groundwater sample from the well should be minimized. Typically, the sample is collected immediately after the well has been purged, but this is also dependent on well recovery.

Samples will be placed in bottles that are appropriate to the respective analysis and that have been cleaned to laboratory standards. Each bottle typically will have been previously prepared with the appropriate preservative, if any.

The following information, at a minimum, will be recorded in the log book:

1. Sample identification (site name, location, and project number; sample name/number and location; sample type and matrix; time and date; sampler's identity)
2. Sample source and source description
3. Field observations and measurements (appearance, volatile screening, field chemistry, sampling method), volume of water purged prior to sampling, number of well volumes purged, and field parameter measurements
4. Sample disposition (preservatives added; laboratory sent to, date and time sent; laboratory sample number, chain-of-custody number, sample bottle lot number)
5. Additional remarks

The steps to be followed for sample collection are as follows:

1. The cap is removed from the sample bottle, and the bottle is tilted slightly.
2. The sample is slowly discharged from the pump so that it runs down the inside of the sample bottle with a minimum of splashing. Samples may be field filtered before transfer to the sample bottle. Filtration must occur in the field immediately upon collection. Inorganics, including metals, are to be collected and preserved in the filtered form as well as the unfiltered form. The recommended

STANDARD OPERATING PROCEDURE

Field Measurement of pH and Eh

I. Purpose and Scope

The purpose of this procedure is to provide a guideline for field measurement of pH and Eh.

II. Equipment and Materials

pH buffer solution for pH 4, 7, and 10

Deionized water in squirt bottle

pH/Eh meter, calibration sheet, and instructions

pH and redox electrodes

Beakers

Glassware that has been washed with soap and water, rinsed twice with hot water, and rinsed twice with deionized water

4 M KCl saturated with Ag/AgCl solution, electrode filling solution.

III. Procedures and Guidelines

A. Calibration

Calibrate unit prior to initial daily use. There are no calibration procedures for the redox electrode. Calibrate with at least two solutions. Clean the probe according to the manufacturer's recommendations. Duplicate samples should be run once every 10 samples. The order of calibration solutions will be based on the instrument manufacturer's recommendation.

Place electrode in pH 7 buffer solution.

Allow meter to stabilize, and then turn calibration dial until a reading of 7.0 is obtained.

Rinse electrode with deionized water and place it in a pH 4 or pH 10 buffer solution.

Allow meter to stabilize again and then turn slope adjustment dial until a reading of 4.0 is obtained for the pH 4 buffer solution or 10.0 for the pH 10 buffer solution.

Rinse electrode with deionized water and place in pH 7 buffer. If meter reading is not 7.0, repeat sequence.

B. Procedure

Before going out into the field:

- a. Check batteries.
- b. Do a quick calibration at pH 7 and 4 to check electrode.
- c. Obtain fresh calibration solutions.

Refer to operation manual for recommended maintenance.

Field Measurement of Specific Conductance and Temperature

I. Purpose and Scope

The purpose of this procedure is to provide a general guideline for field measurement of specific conductivity and temperature of groundwater samples.

II. Equipment and Materials

- Conductivity meter and electrode
- Distilled water in squirt bottle
- Standard potassium chloride (KCl) solution (0.01 N)

III. Procedures and Guidelines

- A. **Technical:** Detection limit = 1 $\mu\text{mho/cm}$ @ 25°C; range = 0.1 to 100,000 $\mu\text{mho/cm}$
- B. **Calibration:** Calibrate prior to initial daily use with standard solution. The standards should have different orders of conductance. Clean probe according to manufacturer's recommendations. Duplicates should be run once every 10 samples. Calibration procedure:
1. With mode switch in OFF position, check meter zero. If not zeroed, set with zero adjust.
 2. Plug probe into jack on side of meter.
 3. Turn mode switch to red line and turn red line knob until needle aligns with red line on dial. If they cannot be aligned, change the batteries.
 4. Immerse probe in 0.01 N standard KCl solution. Do not allow the probe to touch the sample container.
 5. Set the mode control to TEMPERATURE. Record the temperature on the bottom scale of the meter in degrees C.
 6. Turn the mode switch to appropriate conductivity scale (i.e., x100, x10, or x1). Use a scale that will give a midrange output on the meter.
 7. Wait for the needle to stabilize. Multiply reading by scale setting and record the conductivity.

V. Key Checks and Preventative Maintenance

- Check battery.
- Calibrate meter.
- Clean probe with deionized water when done.
- When reading results, note sensitivity settings.
- Refer to operations manual for recommended maintenance.
- Check batteries, and have a replacement set on hand.

General Guidance for Monitoring Well Installation

I. Purpose

To provide site personnel with a review of the well installation procedures that will be performed. These procedures are to be considered general guidelines only and are in no way intended to supplement or replace the contractual specifications in the driller's subcontract.

II. Scope

Bedrock well installations and shallow unconsolidated well installations are planned.

III. Equipment and Materials

IV. Procedures and Guidelines

1. Wells will be installed in accordance with standard EPA procedures. Note that USEPA Region III requires any well penetrating a confining layer to be double cased.
2. The threaded connections will be water-tight.
3. Shallow well screens will be constructed of 0.010 slot Schedule 40 PVC and will be 5 to 10 feet in length depending on saturated thickness of unconsolidated sediments. The exact length will be determined by the field team supervisor.
4. Wells will be surrounded by four concrete-filled, 4-inch diameter guard posts.
5. A record of the finished well construction will be compiled.
6. All soils and liquids generated during well installations will be drummed for proper disposal.

- Pipes and pumps must not be fitted with foot valves or other devices that might inhibit the return flow of water to the well.
- Surging should continue throughout the development process.
- The air lift method will be used to pump materials out of the well. The air compressor will be fitted with filters to remove all oil and the air lift hose used will be made of inert materials.
- Well development will continue until the water produced is free of turbidity, sand, and silt.
- Development water will be considered hazardous and placed in sealed 55-gallon U.S. DOT approved steel drums supplied by CH2M HILL. CH2M HILL will label and date the drums, and transport the drums to a designated site for storage.

V. Attachments

None.

VI. Key Check and Items

Selection of the filter pack and well screen intervals for the shallow monitoring wells shall be made in the field. Based on lithologic samples previously obtained at the site, and comparison with samples to be obtained in the well borings, standard well screen slot of 0.010-inch and silica sand gradations conforming to Morie No. 1 are anticipated.

A primary sand pack (Morie No. 1) consisting of clean silica sand will be placed around the well screen. The sand will be placed into the borehole at a uniform rate, in a manner that will allow even placement of the sand pack. The augers will be raised gradually during sand pack installation to avoid caving of the borehole wall; at no time will the augers be raised higher than the top of the sand pack during installation. During placement of the sand, the position of the top of the sand will be continuously sounded. The primary sand pack will be extended from the bottom of the borehole to a minimum height of 2 feet above the top of the well screen. A secondary, finer-grained, sand pack will be installed for a minimum of 1 foot above the coarse sand pack. Heights of the coarse and fine sand packs and bentonite seal may be modified in the field to account for the shallow water table and small saturated thickness of the surficial aquifer.

A bentonite pellet seal at least 2 feet thick will be placed above the sand pack. The pellets will be placed into the borehole in a manner that will prevent bridging. The position of the top of the bentonite seal will be verified using a weighted tape measure. If all or a portion of the bentonite seal is above the water table, clean water will be added to hydrate the bentonite. A hydration period of at least 30 minutes will be required following installation of the bentonite seal.

Above the bentonite seal, an annular seal of cement-bentonite grout will be placed. The cement-bentonite grout will be installed continuously in one operation from the bottom of the space to be grouted to the ground surface through a tremie pipe. The tremie pipe must be plugged at the bottom and have small openings along the sides of the bottom 1-foot length of pipe. This will allow the grout to diffuse laterally into the borehole and not disturb the bentonite pellet seal.

For monitoring wells that will be completed above-grade, a locking steel protective casing set in a concrete pad will be installed. The steel protective casing will extend at least 3 feet into the ground and 2 feet above ground but should not penetrate the bentonite seal. The concrete pad will be square or round, with a minimum radius of approximately 3.5 feet. The concrete will be sloped away from the protective casing.

Guard posts may be installed in high-traffic areas for additional protection. Four steel guard posts will be installed around the protective casing, within the edges of the concrete pad. Guard posts will be concrete-filled, at least 2 inches in diameter, and will extend at least 2 feet into the ground and 3 feet above the ground. The protective casing and guard posts will be painted with an epoxy paint to prevent rust.

For monitoring wells with flush-mount completions, Morrison 9-inch or 12-inch 519 manhole cover or equivalent, with a rubber-sealed cover and drain will be installed. The top of the manhole cover will be positioned approximately 1 inch above grade. A square concrete pad, approximately 3

Installation of Shallow Monitoring Wells

I. Purpose and Scope

The purpose of this guideline is to describe methods for drilling and installation of shallow monitoring wells and piezometers in unconsolidated or poorly consolidated materials. Methods for drilling and installing bedrock monitoring wells are presented in SOP Installation of Bedrock Monitoring Wells.

II. Equipment and Materials

Drilling

Drilling rig
Hollow-stem augers

Well Riser/Screen

Polyvinyl chloride (PVC), Schedule 40, minimum 2-inch ID, flush-threaded riser; alternatively, stainless steel riser
PVC, Schedule 40, minimum 2-inch ID, flush-threaded, factory slotted screen; alternatively, stainless steel screen.

Bottom Cap

PVC, threaded to match the well screen; alternatively, stainless steel
Centering Guides (if used)

Well Cap

Above-grade well completion: PVC, threaded or push-on type, vented
Flush-mount well completion: PVC, locking, leak-proof seal
Stainless steel to be used as appropriate

Sand

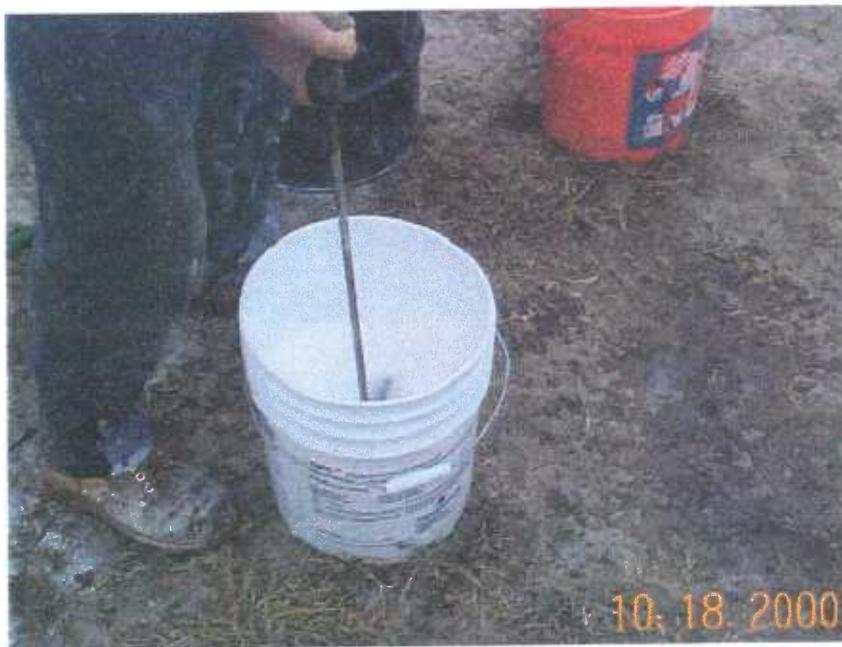
- Clean silica sand, provided in factory-sealed bags, well-rounded, containing no organic material, anhydrite, gypsum, mica, or calcareous material; primary (coarse) filter pack, and secondary (fine) filter pack. Grain size determined based on sediments observed during drilling.

Bentonite

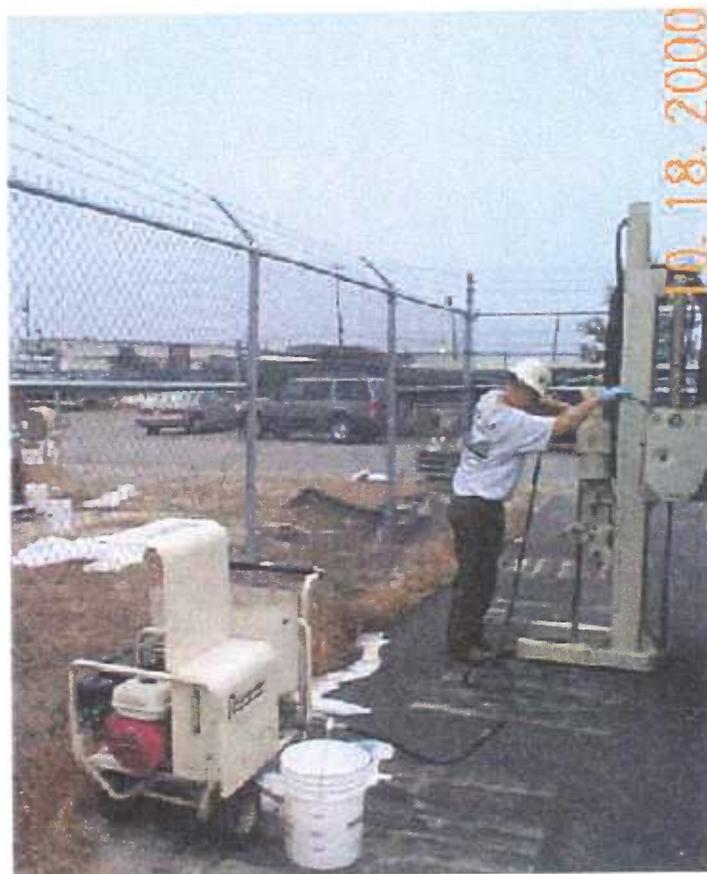
- Pure, additive-free bentonite pellets
- Pure, additive-free powdered bentonite
- Coated bentonite pellets; coating must biodegrade within 7 days
- Cement-Bentonite Grout: proportion of 6 to 8 gallons of water per 94-pound bag of Portland cement; 3 to 6 pounds of bentonite added per bag of cement to reduce shrinkage

Protective Casing

Appendix B
Photographs of ORC™ Injection



Mixing of ORC™ Slurry



Injection of ORC™ Slurry



Setup for Geoprobe® Groundwater Sampling



Collection of Geoprobe® Groundwater Samples



ORC™ Injection Grid Layout



Bulk Shipment of ORC™

Appendix C
Complete Analytical Results

Appendix C 1-A
Site 13 ORC Groundwater Remediation Report
Round 1 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S		LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-00D-R1	LS13-MW03T-00D-R1	LS13-MW21S-00D-R1	LS13-MW22D-00D-R1	LS13-MW23S-00D-R1	LS13-MW23S-00D-R1P	LS13-MW24D-00D-R1	LS13-MW25S-00D-R1	LS13-MW26S-00D-R1
Sample Date	12/12/00	12/12/00	12/11/00	12/12/00	12/13/00	12/13/00	12/12/00	12/11/00	12/12/00
Chemical Name									
Volatle Organic Compounds (UG/L)									
1,1,1-Trichloroethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,1,2,2-Tetrachloroethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,1,2-Trichloroethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,1-Dichloroethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,1-Dichloroethene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,2,4-Trichlorobenzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,2-Dibrom-3-chloropropane	NA	1 UJ	NA	NA	1 UJ	1 UJ	NA	NA	1 UJ
1,2-Dibromoethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,2-Dichlorobenzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,2-Dichloroethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,2-Dichloropropane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,3-Dichlorobenzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
1,4-Dichlorobenzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
2-Butanone	NA	5 U	NA	NA	5 U	5 U	NA	NA	5 U
2-Hexanone	NA	5 UJ	NA	NA	5 UJ	5 UJ	NA	NA	5 UJ
4-Methyl-2-pentanone	NA	5 U	NA	NA	5 U	5 U	NA	NA	5 U
Acetone	NA	3 B	NA	NA	5 B	5 B	NA	NA	7 B
Benzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Bromochloromethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Bromodichloromethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Bromofom	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Bromomethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Carbon disulfide	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Carbon tetrachloride	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Chlorobenzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Chloroethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Chloroform	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Chloromethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Dibromochloromethane	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Ethylbenzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	0.6 J
Methylene chloride	NA	2 UJ	NA	NA	2 UJ	1 B	NA	NA	2 UJ
Styrene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Tetrachloroethene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Toluene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Trichloroethene	NA	0.8 J	NA	NA	1 U	1 U	NA	NA	1 U
Vinyl chloride	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Xylene, total	NA	1 U	NA	NA	1 U	1 U	NA	NA	11
cis-1,2-Dichloroethene	NA	1	NA	NA	1 U	1 U	NA	NA	1 U
cis-1,3-Dichloropropene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
trans-1,2-Dichloroethene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
trans-1,3-Dichloropropene	NA	1 U	NA	NA	1 U	1 U	NA	NA	1 U
Semi-volatile Organic Compounds (UG/L)									
2,2'-Oxybis(1-chloropropane)	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2,4,5-Trichlorophenol	20 U	20 U	20 U	24 U	20 U	20 U	20 U	20 U	20 U
2,4,6-Trichlorophenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U

Appendix C 1-A
Site 13 ORC Groundwater Remediation Report
Round 1 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S		LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-00D-R1	LS13-MW03T-00D-R1	LS13-MW21S-00D-R1	LS13-MW22D-00D-R1	LS13-MW23S-00D-R1	LS13-MW23S-00D-R1P	LS13-MW24D-00D-R1	LS13-MW25S-00D-R1	LS13-MW26S-00D-R1
Sample Date	12/12/00	12/12/00	12/11/00	12/12/00	12/13/00	12/13/00	12/12/00	12/11/00	12/12/00
Chemical Name									
2,4-Dichlorophenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2,4-Dimethylphenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2,4-Dinitrophenol	20 UJ	20 UJ	20 UJ	24 UJ	20 UJ	20 UJ	20 UJ	20 UJ	20 UJ
2,4-Dinitrotoluene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2,6-Dinitrotoluene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2-Chloronaphthalene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2-Chlorophenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2-Methylnaphthalene	5 U	5 U	26	6 U	5 U	5 U	5 U	0.8 J	24
2-Methylphenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
2-Nitroaniline	20 U	20 U	20 U	24 U	20 U	20 U	20 U	20 U	20 U
2-Nitrophenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
3,3'-Dichlorobenzidine	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
3-Nitroaniline	20 U	20 U	20 U	24 U	20 U	20 U	20 U	20 U	20 U
4,6-Dinitro-2-methylphenol	20 U	20 U	20 U	24 U	20 U	20 U	20 U	20 U	20 U
4-Bromophenyl-phenylether	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
4-Chloro-3-methylphenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
4-Chloroaniline	5 R	5 R	44 R	6 R	5 R	5 R	24 R	5 R	95 R
4-Chlorophenyl-phenylether	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
4-Methylphenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
4-Nitroaniline	20 U	20 U	20 U	24 U	20 U	20 U	20 U	20 U	20 U
4-Nitrophenol	20 U	20 U	20 U	24 U	20 U	20 U	20 U	20 U	20 U
Acenaphthene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Acenaphthylene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Anthracene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Benzo(a)anthracene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Benzo(a)pyrene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Benzo(b)fluoranthene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Benzo(g,h,i)perylene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Benzo(k)fluoranthene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Butylbenzylphthalate	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Chrysene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Di-n-butylphthalate	5 U	5 U	0.7 J	0.6 J	5 U	5 U	5 U	5 U	5 U
Di-n-octylphthalate	5 UJ	5 UJ	5 UJ	6 UJ	5 UJ	5 UJ	5 UJ	5 UJ	5 UJ
Dibenz(a,h)anthracene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Dibenzofuran	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Diethylphthalate	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Dimethyl phthalate	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Fluoranthene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Fluorene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Hexachlorobenzene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Hexachlorobutadiene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Hexachlorocyclopentadiene	5 UJ	5 UJ	5 UJ	6 UJ	5 UJ	5 UJ	5 UJ	5 UJ	5 UJ
Hexachloroethane	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Indeno(1,2,3-cd)pyrene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Isophorone	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Naphthalene	5 U	5 U	43	6 U	5 U	5 U	5 U	0.9 J	32
Nitrobenzene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U

Appendix C 1-A
Site 13 ORC Groundwater Remediation Report
Round 1 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S		LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-00D-R1	LS13-MW03T-00D-R1	LS13-MW21S-00D-R1	LS13-MW22D-00D-R1	LS13-MW23S-00D-R1	LS13-MW23S-00D-R1P	LS13-MW24D-00D-R1	LS13-MW25S-00D-R1	LS13-MW26S-00D-R1
Sample Date	12/12/00	12/12/00	12/11/00	12/12/00	12/13/00	12/13/00	12/12/00	12/11/00	12/12/00
Chemical Name									
Pentachlorophenol	20 U	1 J	760	3 J	4 J	4 J	2 J	49	730
Phenanthrene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Phenol	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Pyrene	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
bis(2-Chloroethoxy)methane	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
bis(2-Chloroethyl)ether	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
bis(2-Ethylhexyl)phthalate	0.9 B	0.6 B	2 B	2 B	5 U	5 U	160	0.7 B	5 U
n-Nitroso-di-n-propylamine	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
n-Nitrosodiphenylamine	5 U	5 U	5 U	6 U	5 U	5 U	5 U	5 U	5 U
Total Metals (UG/L)									
Aluminum	NA	NA	NA	NA	1,840 J	598 J	794 J	NA	NA
Antimony	NA	NA	NA	NA	2.96 U	2.96 U	2.96 U	NA	NA
Arsenic	NA	NA	NA	NA	2.46 U	2.46 U	2.46 U	NA	NA
Barium	NA	NA	NA	NA	24.2 J	22.8 J	17.5 J	NA	NA
Beryllium	NA	NA	NA	NA	0.5 B	0.5 B	0.3 U	NA	NA
Cadmium	NA	NA	NA	NA	0.28 U	0.28 U	3.13 U	NA	NA
Calcium	NA	NA	NA	NA	16,700	17,300	10,300	NA	NA
Chromium	NA	NA	NA	NA	4.8 B	1.6 B	13.4 B	NA	NA
Cobalt	NA	NA	NA	NA	1.1 J	0.88 U	3.45 U	NA	NA
Copper	NA	NA	NA	NA	1.4 J	1.29 U	1.92 U	NA	NA
Iron	NA	NA	NA	NA	2,100	1,270	1,420	NA	NA
Lead	NA	NA	NA	NA	1.86 U	1.86 U	1.86 U	NA	NA
Magnesium	NA	NA	NA	NA	2,420 J	2,450 J	2,770 J	NA	NA
Manganese	NA	NA	NA	NA	162	170	383	NA	NA
Mercury	NA	NA	NA	NA	0.03 U	0.03 U	0.03 U	NA	NA
Nickel	NA	NA	NA	NA	4.2 B	2 B	12.6 B	NA	NA
Potassium	NA	NA	NA	NA	2,890 J	2,960 J	2,710 J	NA	NA
Selenium	NA	NA	NA	NA	2.39 U	2.39 U	2.39 U	NA	NA
Silver	NA	NA	NA	NA	1.07 U	1.07 U	3.09 U	NA	NA
Sodium	NA	NA	NA	NA	7,600	8,110	6,240	NA	NA
Thallium	NA	NA	NA	NA	5.12 U	5.12 U	5.12 U	NA	NA
Vanadium	NA	NA	NA	NA	2.2 J	0.83 U	3.81 U	NA	NA
Zinc	NA	NA	NA	NA	6.8 B	6.5 B	7.4 B	NA	NA
Dissolved Metals (UG/L)									
Aluminum	NA	NA	NA	NA	43 B	44.6 B	15.7 UJ	NA	NA
Antimony	NA	NA	NA	NA	2.96 U	2.96 U	2.96 U	NA	NA
Arsenic	NA	NA	NA	NA	2.46 U	2.46 U	2.46 U	NA	NA
Barium	NA	NA	NA	NA	20 J	19.4 J	13.7 J	NA	NA
Beryllium	NA	NA	NA	NA	0.54 B	0.47 B	0.3 U	NA	NA
Cadmium	NA	NA	NA	NA	0.28 U	0.28 U	3.13 U	NA	NA
Calcium	NA	NA	NA	NA	17,300	17,200	10,400	NA	NA
Chromium	NA	NA	NA	NA	0.92 U	0.92 U	4.14 U	NA	NA
Cobalt	NA	NA	NA	NA	0.88 U	0.88 U	4.5 J	NA	NA
Copper	NA	NA	NA	NA	1.29 U	1.29 U	1.92 U	NA	NA
Iron	NA	NA	NA	NA	773	705	107 B	NA	NA

Appendix C 1-A
 Site 13 ORC Groundwater Remediation Report
 Round 1 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S		LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-00D-R1	LS13-MW03T-00D-R1	LS13-MW21S-00D-R1	LS13-MW22D-00D-R1	LS13-MW23S-00D-R1	LS13-MW23S-00D-R1P	LS13-MW24D-00D-R1	LS13-MW25S-00D-R1	LS13-MW26S-00D-R1
Sample Date	12/12/00	12/12/00	12/11/00	12/12/00	12/13/00	12/13/00	12/12/00	12/11/00	12/12/00
Chemical Name									
Lead	NA	NA	NA	NA	1.86 U	1.86 U	1.86 U	NA	NA
Magnesium	NA	NA	NA	NA	2,420 J	2,360 J	2,780 J	NA	NA
Manganese	NA	NA	NA	NA	163	165	385	NA	NA
Mercury	NA	NA	NA	NA	0.03 U	0.03 U	0.03 U	NA	NA
Nickel	NA	NA	NA	NA	4 B	2.4 B	10.9 B	NA	NA
Potassium	NA	NA	NA	NA	2,940 J	3,230 J	2,620 J	NA	NA
Selenium	NA	NA	NA	NA	2.39 U	2.4 J	2.39 U	NA	NA
Silver	NA	NA	NA	NA	1.07 U	1.07 U	3.09 U	NA	NA
Sodium	NA	NA	NA	NA	8,010	7,950	6,460	NA	NA
Thallium	NA	NA	NA	NA	5.12 U	5.12 U	5.12 U	NA	NA
Vanadium	NA	NA	NA	NA	0.83 U	0.83 U	3.81 U	NA	NA
Zinc	NA	NA	NA	NA	7.2 B	6.1 B	7.2 B	NA	NA
Wet Chemistry (MG/L)									
Alkalinity	80	50	20	40	20 U	NA	20 U	40	20
Carbon dioxide	24	63	150	83	36	37	38	75	110
Chloride	29	25	21	36	8	NA	6	27	10
Cyanide	NA	NA	NA	NA	0.01 U	0.01 U	0.01 U	NA	NA
Ferrous Iron	4.3	1.8	4	1.1	0.8	NA	0.2	7.8	7.5
Total organic carbon (TOC)	7	9	16	6	6	NA	4	7	14

Notes:
 U - Not Detected
 J - Analyte Present. Result may not be accurate or precise.
 B - Possible Blank Contamination
 R - Sample was rejected
 NA - Not analyzed

Appendix C 1-B
 Site 13 ORC Groundwater Remediation Report
 Round 1 Detections

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S		LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-00D-R1	LS13-MW03T-00D-R1	LS13-MW21S-00D-R1	LS13-MW22D-00D-R1	LS13-MW23S-00D-R1	LS13-MW23S-00D-R1P	LS13-MW24D-00D-R1	LS13-MW25S-00D-R1	LS13-MW26S-00D-R1
Sample Date	12/12/00	12/12/00	12/11/00	12/12/00	12/13/00	12/13/00	12/12/00	12/11/00	12/12/00
Chemical Name									
Volatile Organic Compounds (UG/L)									
Ethylbenzene	NA	1 U	NA	NA	1 U	1 U	NA	NA	0.6 J
Trichloroethene	NA	0.8 J	NA	NA	1 U	1 U	NA	NA	1 U
Xylene, total	NA	1 U	NA	NA	1 U	1 U	NA	NA	11
cis-1,2-Dichloroethene	NA	1	NA	NA	1 U	1 U	NA	NA	1 U
Semi-volatile Organic Compounds (UG/L)									
2-Methylnaphthalene	5 U	5 U	28	6 U	5 U	5 U	5 U	0.6 J	24
Di-n-butylphthalate	5 U	5 U	0.7 J	0.6 J	5 U	5 U	5 U	5 U	5 U
Naphthalene	5 U	5 U	43	6 U	5 U	5 U	5 U	0.8 J	32
Pentachlorophenol	20 U	1 J	760	3 J	4 J	4 J	2 J	49	720
bis(2-Ethylhexyl)phthalate	0.9 B	0.6 B	2 B	2 B	5 U	5 U	180	0.7 B	5 U
Total Metals (UG/L)									
Aluminum	NA	NA	NA	NA	1,840 J	598 J	784 J	NA	NA
Barium	NA	NA	NA	NA	24.2 J	22.8 J	17.5 J	NA	NA
Calcium	NA	NA	NA	NA	16,700	17,300	10,300	NA	NA
Cobalt	NA	NA	NA	NA	1.1 J	0.88 U	3.45 U	NA	NA
Copper	NA	NA	NA	NA	1.4 J	1.29 U	1.92 U	NA	NA
Iron	NA	NA	NA	NA	2,100	1,270	1,420	NA	NA
Magnesium	NA	NA	NA	NA	2,420 J	2,450 J	2,770 J	NA	NA
Manganese	NA	NA	NA	NA	162	170	383	NA	NA
Potassium	NA	NA	NA	NA	2,890 J	2,990 J	2,710 J	NA	NA
Sodium	NA	NA	NA	NA	7,800	8,110	6,240	NA	NA
Vanadium	NA	NA	NA	NA	2.2 J	0.83 U	3.81 U	NA	NA
Dissolved Metals (UG/L)									
Barium	NA	NA	NA	NA	20 J	19.4 J	13.7 J	NA	NA
Calcium	NA	NA	NA	NA	17,300	17,200	10,400	NA	NA
Cobalt	NA	NA	NA	NA	0.88 U	0.88 U	4.5 J	NA	NA
Iron	NA	NA	NA	NA	773	705	107 B	NA	NA
Magnesium	NA	NA	NA	NA	2,420 J	2,360 J	2,780 J	NA	NA
Manganese	NA	NA	NA	NA	163	165	383	NA	NA
Potassium	NA	NA	NA	NA	2,840 J	3,230 J	2,620 J	NA	NA
Selenium	NA	NA	NA	NA	2.39 U	2.4 J	2.39 U	NA	NA
Sodium	NA	NA	NA	NA	8,010	7,850	6,480	NA	NA
Wet Chemistry (MGL)									
Alkalinity	80	50	20	40	20 U	NA	20 U	40	20
Carbon dioxide	24	83	150	83	36	37	38	75	110
Chloride	29	25	21	38	8	NA	6	27	10
Ferrous iron	4.3	1.8	4	1.1	0.8	NA	0.2	7.8	7.5
Total organic carbon (TOC)	7	9	16	6	6	NA	4	7	14

Notes:

- J - Indicates Detection
- U - Not Detected
- J - Analyte Present. Result may not be accurate or precise.
- B - Possible Blank Contamination
- R - Sample was rejected
- NA - Not analyzed

Appendix C 2-A
 Site 13 ORC Groundwater Remediation Report
 Round 2 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T		LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01A-R2	LS13-MW03T-01A-R2	LS13-MW03T-01A-R2P	LS13-MW21S-01A-R2	LS13-MW22D-01A-R2	LS13-MW23S-01A-R2	LS13-MW25S-01A-R2	LS13-MW26S-01A-R2
Sample Date	01/17/01	01/16/01	01/17/01	01/17/01	01/17/01	01/16/01	01/17/01	01/16/01
Chemical Name								
Volatile Organic Compounds (UG/L)								
1,1,1-Trichloroethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,1,2,2-Tetrachloroethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,1,2-Trichloroethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,1-Dichloroethane	NA	0.2 J	0.2 J	NA	NA	1 U	NA	1 U
1,1-Dichloroethene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,2,4-Trichlorobenzene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,2-Dibromo-3-chloropropane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,2-Dibromoethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,2-Dichlorobenzene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,2-Dichloroethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,2-Dichloropropane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,3-Dichlorobenzene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
1,4-Dichlorobenzene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
2-Butanone	NA	5 U	5 U	NA	NA	5 U	NA	5 U
2-Hexanone	NA	5 U	5 U	NA	NA	5 U	NA	5 U
4-Methyl-2-pentanone	NA	5 U	5 U	NA	NA	5 U	NA	5 U
Acetone	NA	5 U	5 U	NA	NA	5 B	NA	6 B
Benzene	NA	0.5 J	0.6 J	NA	NA	1 U	NA	1 U
Bromochloromethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Bromodichloromethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Bromoform	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Bromomethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Carbon disulfide	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Carbon tetrachloride	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Chlorobenzene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Chloroethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Chloroform	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Chloromethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Dibromochloromethane	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Ethylbenzene	NA	1 U	1 U	NA	NA	1 U	NA	0.4 J
Methyl-tert-butyl ether (MTBE)	NA	62	61	NA	NA	1 U	NA	3
Methylene chloride	NA	0.4 B	0.4 B	NA	NA	0.4 B	NA	0.4 B
Styrene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Tetrachloroethene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Toluene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Trichloroethene	NA	1 J	1	NA	NA	1 U	NA	1 U
Vinyl chloride	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Xylene, total	NA	1 U	1 U	NA	NA	1 U	NA	4
cis-1,2-Dichloroethene	NA	2	2	NA	NA	1 U	NA	1 U
cis-1,3-Dichloropropene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
trans-1,2-Dichloroethene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
trans-1,3-Dichloropropene	NA	1 U	1 U	NA	NA	1 U	NA	1 U
Semi-volatile Organic Compounds (UG/L)								
2,2'-Oxybis(1-chloropropane)	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2,4,5-Trichlorophenol	94 U	190 U	190 U	20 U	190 U	20 U	190 U	20 U

Appendix C 2-A
Site 13 ORC Groundwater Remediation Report
Round 2 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T		LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01A-R2	LS13-MW03T-01A-R2	LS13-MW03T-01A-R2P	LS13-MW21S-01A-R2	LS13-MW22D-01A-R2	LS13-MW23S-01A-R2	LS13-MW25S-01A-R2	LS13-MW26S-01A-R2
Sample Date	01/17/01	01/16/01	01/17/01	01/17/01	01/17/01	01/16/01	01/17/01	01/16/01
Chemical Name								
2,4,6-Trichlorophenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2,4-Dichlorophenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2,4-Dimethylphenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2,4-Dinitrophenol	94 U	190 U	190 U	20 U	190 U	20 U	190 U	20 U
2,4-Dinitrotoluene	24 UL	46 U	46 U	5 UL	47 UL	5 U	47 UL	5 U
2,6-Dinitrotoluene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2-Chloronaphthalene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2-Chlorophenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2-Methylnaphthalene	24 U	46 U	46 U	20	47 U	5 U	47 U	17
2-Methylphenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
2-Nitroaniline	94 U	190 U	190 U	20 U	190 U	20 U	190 U	20 U
2-Nitrophenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
3,3'-Dichlorobenzidine	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
3-Nitroaniline	94 U	190 U	190 U	20 U	190 U	20 U	190 U	20 U
4,6-Dinitro-2-methylphenol	94 U	190 U	190 U	20 U	190 U	20 U	190 U	20 U
4-Bromophenyl-phenylether	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
4-Chloro-3-methylphenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
4-Chloroaniline	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
4-Chlorophenyl-phenylether	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
4-Methylphenol	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
4-Nitroaniline	94 U	190 U	190 U	20 U	190 U	20 U	190 U	20 U
4-Nitrophenol	94 U	190 U	190 U	20 U	190 U	20 U	190 U	20 U
Acenaphthene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Acenaphthylene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Anthracene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Benzo(a)anthracene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Benzo(a)pyrene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Benzo(b)fluoranthene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Benzo(g,h,i)perylene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Benzo(k)fluoranthene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Butylbenzylphthalate	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Chrysene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Di-n-butylphthalate	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Di-n-octylphthalate	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Dibenz(a,h)anthracene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Dibenzofuran	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Diethylphthalate	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Dimethyl phthalate	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Fluoranthene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Fluorene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Hexachlorobenzene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Hexachlorobutadiene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Hexachlorocyclopentadiene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Hexachloroethane	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Indeno(1,2,3-cd)pyrene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Isophorone	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Naphthalene	24 U	46 U	46 U	21	47 U	5 U	47 U	23

Appendix C 2-A
Site 13 ORC Groundwater Remediation Report
Round 2 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T		LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01A-R2	LS13-MW03T-01A-R2	LS13-MW03T-01A-R2P	LS13-MW21S-01A-R2	LS13-MW22D-01A-R2	LS13-MW23S-01A-R2	LS13-MW25S-01A-R2	LS13-MW26S-01A-R2
Sample Date	01/17/01	01/16/01	01/17/01	01/17/01	01/17/01	01/16/01	01/17/01	01/16/01
Chemical Name								
Nitrobenzene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Pentachlorophenol	94 U	190 U	190 U	460	190 U	2 J	33 J	790
Phenanthrene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
Phenol	24 U	46 U	46 U	47 R	47 U	5 U	47 U	50 R
Pyrene	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
bis(2-Chloroethoxy)methane	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
bis(2-Chloroethyl)ether	24 U	46 U	46 U	5 U	47 U	5 U	47 U	5 U
bis(2-Ethylhexyl)phthalate	5 J	46 U	46 U	0.6 J	47 U	5 U	47 U	5 U
n-Nitroso-dl-n-propylamine	24 U	46 UL	46 UL	5 U	47 U	5 UL	47 U	5 UL
n-Nitrosodiphenylamine	24 U	46 UL	46 UL	5 U	47 U	5 UL	47 U	5 UL
Total Metals (UG/L)								
Aluminum	NA	NA	NA	NA	NA	3,840	NA	13,400
Antimony	NA	NA	NA	NA	NA	3.65 U	NA	3.65 U
Arsenic	NA	NA	NA	NA	NA	2.53 U	NA	3.3 J
Barium	NA	NA	NA	NA	NA	28.6 J	NA	51.5 J
Beryllium	NA	NA	NA	NA	NA	0.43 B	NA	0.34 B
Cadmium	NA	NA	NA	NA	NA	0.24 U	NA	0.24 U
Calcium	NA	NA	NA	NA	NA	16,100	NA	8,840
Chromium	NA	NA	NA	NA	NA	6.3 B	NA	16.4 B
Cobalt	NA	NA	NA	NA	NA	1 B	NA	5.3 B
Copper	NA	NA	NA	NA	NA	0.84 U	NA	3.2 B
Iron	NA	NA	NA	NA	NA	3,340	NA	17,200
Lead	NA	NA	NA	NA	NA	2.9 B	NA	5 B
Magnesium	NA	NA	NA	NA	NA	2,420 J	NA	5,030
Manganese	NA	NA	NA	NA	NA	126	NA	536
Mercury	NA	NA	NA	NA	NA	0.03 U	NA	0.03 U
Nickel	NA	NA	NA	NA	NA	3.5 B	NA	8.4 B
Potassium	NA	NA	NA	NA	NA	2,290 B	NA	1,170 U
Selenium	NA	NA	NA	NA	NA	3.04 U	NA	3.04 U
Silver	NA	NA	NA	NA	NA	1.03 U	NA	1.03 U
Sodium	NA	NA	NA	NA	NA	6,830	NA	7,840
Thallium	NA	NA	NA	NA	NA	4.74 U	NA	4.74 U
Vanadium	NA	NA	NA	NA	NA	5.7 J	NA	20 J
Zinc	NA	NA	NA	NA	NA	8.7 B	NA	23.8 B
Dissolved Metals (UG/L)								
Aluminum	NA	NA	NA	NA	NA	29.5 U	NA	29.5 U
Antimony	NA	NA	NA	NA	NA	3.65 U	NA	3.65 U
Arsenic	NA	NA	NA	NA	NA	2.53 U	NA	2.53 U
Barium	NA	NA	NA	NA	NA	17.7 J	NA	11.2 J
Beryllium	NA	NA	NA	NA	NA	0.18 U	NA	0.18 U
Cadmium	NA	NA	NA	NA	NA	0.24 U	NA	0.24 U
Calcium	NA	NA	NA	NA	NA	15,600	NA	8,210
Chromium	NA	NA	NA	NA	NA	0.57 U	NA	0.57 U
Cobalt	NA	NA	NA	NA	NA	0.92 U	NA	2.9 B
Copper	NA	NA	NA	NA	NA	0.84 U	NA	0.84 U

Appendix C 2-A
 Site 13 ORC Groundwater Remediation Report
 Round 2 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T		LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01A-R2	LS13-MW03T-01A-R2	LS13-MW03T-01A-R2P	LS13-MW21S-01A-R2	LS13-MW22D-01A-R2	LS13-MW23S-01A-R2	LS13-MW25S-01A-R2	LS13-MW26S-01A-R2
Sample Date	01/17/01	01/16/01	01/17/01	01/17/01	01/17/01	01/16/01	01/17/01	01/16/01
Chemical Name								
Iron	NA	NA	NA	NA	NA	415 B	NA	6,640
Lead	NA	NA	NA	NA	NA	1.48 U	NA	1.48 U
Magnesium	NA	NA	NA	NA	NA	2,100 J	NA	3,910 J
Manganese	NA	NA	NA	NA	NA	120	NA	455
Mercury	NA	NA	NA	NA	NA	0.03 U	NA	0.03 U
Nickel	NA	NA	NA	NA	NA	1.7 B	NA	0.97 B
Potassium	NA	NA	NA	NA	NA	2,250 B	NA	1,690 B
Selenium	NA	NA	NA	NA	NA	3.04 U	NA	3.1 B
Silver	NA	NA	NA	NA	NA	1.03 U	NA	1.03 U
Sodium	NA	NA	NA	NA	NA	6,700	NA	8,680
Thallium	NA	NA	NA	NA	NA	4.74 U	NA	4.74 U
Vanadium	NA	NA	NA	NA	NA	0.52 U	NA	0.57 B
Zinc	NA	NA	NA	NA	NA	6.1 B	NA	8.6 B
Wet Chemistry (MGL)								
Alkalinity	40	70	NA	20 U	40	20 U	40	20
Carbon dioxide	25	76	NA	100	87	42	90	110
Chloride	20	30	NA	20	40	10	30	20
Cyanide	NA	NA	NA	NA	NA	0.01 U	NA	NA
Ferrous Iron	12	5.1	NA	3.9	0.7	0.4	7.1	6.7
Total organic carbon (TOC)	37	3	NA	5	3	4	6	5

- Notes:
 U - Not Detected
 J - Analyte Present. Result may not be accurate or precise.
 B - Possible Blank Contamination
 R - Sample was rejected
 NA - Not analyzed
 L - Reported value may be biased low.

Appendix C 2-B
Site 13 ORC Groundwater Remediation Report
Round 2 Detections

Station ID	LS13-MW01T	LS13-MW03T		LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01A-R2	LS13-MW03T-01A-R2	LS13-MW03T-01A-R2P	LS13-MW21S-01A-R2	LS13-MW22D-01A-R2	LS13-MW23S-01A-R2	LS13-MW25S-01A-R2	LS13-MW26S-01A-R2
Sample Date	01/17/01	01/19/01	01/17/01	01/17/01	01/17/01	01/16/01	01/17/01	01/16/01
Chemical Name								
Volatile Organic Compounds (UG/L)								
1,1-Dichloroethane	NA	0.2 J	0.2 J	NA	NA	1 U	NA	1 U
Benzene	NA	0.5 J	0.8 J	NA	NA	1 U	NA	1 U
Ethylbenzene	NA	1 U	1 U	NA	NA	1 U	NA	0.4 J
Methyl-tert-butyl ether (MTBE)	NA	82	61	NA	NA	1 U	NA	3
Trichloroethene	NA	1 J	1	NA	NA	1 U	NA	1 U
Xylene, total	NA	1 U	1 U	NA	NA	1 U	NA	4
cis-1,2-Dichloroethene	NA	2	2	NA	NA	1 U	NA	1 U
Semi-volatile Organic Compounds (UG/L)								
2-Methylnaphthalene	24 U	46 U	46 U	20	47 U	5 U	47 U	17
Naphthalene	24 U	46 U	46 U	21	47 U	5 U	47 U	23
Pentachlorophenol	94 U	190 U	190 U	480	190 U	2 J	33 J	790
bis(2-Ethylhexyl)phthalate	5 J	46 U	46 U	0.8 J	47 U	5 U	47 U	5 U
Total Metals (UG/L)								
Aluminum	NA	NA	NA	NA	NA	3,840	NA	13,400
Arsenic	NA	NA	NA	NA	NA	2.53 U	NA	3.3 J
Barium	NA	NA	NA	NA	NA	28.6 J	NA	61.5 J
Calcium	NA	NA	NA	NA	NA	18,100	NA	8,840
Iron	NA	NA	NA	NA	NA	3,340	NA	17,200
Magnesium	NA	NA	NA	NA	NA	2,420 J	NA	6,030
Manganese	NA	NA	NA	NA	NA	128	NA	536
Sodium	NA	NA	NA	NA	NA	8,830	NA	7,840
Vanadium	NA	NA	NA	NA	NA	5.7 J	NA	20 J
Dissolved Metals (UG/L)								
Barium	NA	NA	NA	NA	NA	17.7 J	NA	11.2 J
Calcium	NA	NA	NA	NA	NA	15,800	NA	8,210
Iron	NA	NA	NA	NA	NA	415 B	NA	8,840
Magnesium	NA	NA	NA	NA	NA	2,100 J	NA	3,910 J
Manganese	NA	NA	NA	NA	NA	120	NA	465
Sodium	NA	NA	NA	NA	NA	8,700	NA	8,680
Wet Chemistry (MG/L)								
Alkalinity	40	70	NA	20 U	40	20 U	40	20
Carbon dioxide	25	78	NA	100	87	42	90	110
Chloride	20	30	NA	20	40	10	30	20
Ferrous iron	12	5.1	NA	3.9	0.7	0.4	7.1	8.7
Total organic carbon (TOC)	37	3	NA	5	3	4	6	5

Notes:

- J - Analyte Present. Result may not be accurate or precise
- U - Not Detected
- B - Possible Blank Contamination
- R - Sample was rejected
- NA - Not analyzed
- L - Reported value may be biased low.

Appendix C 3-A
 Site 13 ORC Groundwater Remediation Report
 April 2001 Round 3 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01B-R3	LS13-MW03T-01B-R3	LS13-MW21S-01B-R3	LS13-MW22D-01B-R3	LS13-MW23S-01B-R3	LS13-MW24D-01B-R3	LS13-MW25S-01B-R3	LS13-MW26S-01B-R3
Sample Date	04/10/01	04/11/01	04/10/01	04/10/01	04/11/01	04/11/01	04/10/01	04/11/01
Chemical Name								
Volatile Organic Compounds (UG/L)								
1,1,1-Trichloroethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,1,2,2-Tetrachloroethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,1,2-Trichloroethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,1-Dichloroethane	NA	0.3 J	NA	NA	1 U	NA	NA	1 U
1,1-Dichloroethene	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,2,4-Trichlorobenzene	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,2-Dibromo-3-chloropropane	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,2-Dibromoethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,2-Dichlorobenzene	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,2-Dichloroethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,2-Dichloropropane	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,3-Dichlorobenzene	NA	1 U	NA	NA	1 U	NA	NA	1 U
1,4-Dichlorobenzene	NA	1 U	NA	NA	1 U	NA	NA	1 U
2-Butanone	NA	5 U	NA	NA	5 U	NA	NA	5 U
2-Hexanone	NA	5 U	NA	NA	5 U	NA	NA	5 U
4-Methyl-2-pentanone	NA	5 U	NA	NA	5 U	NA	NA	5 U
Acetone	NA	5 U	NA	NA	8 B	NA	NA	8 B
Benzene	NA	0.4 J	NA	NA	1 U	NA	NA	1 U
Bromochloromethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
Bromodichloromethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
Bromoform	NA	1 U	NA	NA	1 U	NA	NA	1 U
Bromomethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
Carbon disulfide	NA	1 U	NA	NA	1 U	NA	NA	1 U
Carbon tetrachloride	NA	1 U	NA	NA	1 U	NA	NA	1 U
Chlorobenzene	NA	1 U	NA	NA	1 U	NA	NA	1 U
Chloroethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
Chloroform	NA	1 U	NA	NA	1 U	NA	NA	1 U
Chloromethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
Dibromochloromethane	NA	1 U	NA	NA	1 U	NA	NA	1 U
Ethylbenzene	NA	1 U	NA	NA	1 U	NA	NA	0.9 J
Methyl-tert-butyl ether (MTBE)	NA	34	NA	NA	1 U	NA	NA	3
Methylene chloride	NA	0.5 B	NA	NA	0.4 B	NA	NA	0.6 B
Styrene	NA	1 U	NA	NA	1 U	NA	NA	1 U
Tetrachloroethene	NA	1 U	NA	NA	1 U	NA	NA	1 U
Toluene	NA	1 U	NA	NA	1 U	NA	NA	1 U
Trichloroethene	NA	0.7 J	NA	NA	1 U	NA	NA	1 U
Vinyl chloride	NA	1 U	NA	NA	1 U	NA	NA	1 U
Xylene, total	NA	1 U	NA	NA	1 U	NA	NA	9
cis-1,2-Dichloroethene	NA	1	NA	NA	1 U	NA	NA	1 U
cis-1,3-Dichloropropene	NA	1 U	NA	NA	1 U	NA	NA	1 U
trans-1,2-Dichloroethene	NA	1 U	NA	NA	1 U	NA	NA	1 U
trans-1,3-Dichloropropene	NA	1 U	NA	NA	1 U	NA	NA	1 U
Semi-volatile Organic Compounds (UG/L)								
2,2'-Oxybis(1-chloropropane)	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2,4,5-Trichlorophenol	20 U							
2,4,6-Trichlorophenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2,4-Dichlorophenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	1 J
2,4-Dimethylphenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2,4-Dinitrophenol	20 U							
2,4-Dinitrotoluene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2,6-Dinitrotoluene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2-Chloronaphthalene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2-Chlorophenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2-Methylnaphthalene	5 U	5 U	17	5 U	5 U	5 U	5 U	14
2-Methylphenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2-Nitroaniline	20 U							

Appendix C 3-A
Site 13 ORC Groundwater Remediation Report
April 2001 Round 3 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01B-R3	LS13-MW03T-01B-R3	LS13-MW21S-01B-R3	LS13-MW22D-01B-R3	LS13-MW23S-01B-R3	LS13-MW24D-01B-R3	LS13-MW25S-01B-R3	LS13-MW26S-01B-R3
Sample Date	04/10/01	04/11/01	04/10/01	04/10/01	04/11/01	04/11/01	04/10/01	04/11/01
Chemical Name								
2-Nitrophenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
3,3'-Dichlorobenzidine	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
3-Nitroaniline	20 U							
4,6-Dinitro-2-methylphenol	20 U							
4-Bromophenyl-phenylether	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
4-Chloro-3-methylphenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
4-Chloroaniline	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
4-Chlorophenyl-phenylether	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
4-Methylphenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
4-Nitroaniline	20 U							
4-Nitrophenol	20 U							
Acenaphthene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Acenaphthylene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Anthracene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Benzo(a)anthracene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Benzo(a)pyrene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Benzo(b)fluoranthene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Benzo(g,h,i)perylene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Benzo(k)fluoranthene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Butylbenzylphthalate	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Chrysene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Di-n-butylphthalate	5 U	5 U	5 U	0.9 U	5 U	0.9 J	0.6 J	5 U
Di-n-octylphthalate	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Dibenz(a,h)anthracene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Dibenzofuran	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Diethylphthalate	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Dimethyl phthalate	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Fluoranthene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Fluorene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Hexachlorobenzene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Hexachlorobutadiene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Hexachlorocyclopentadiene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Hexachloroethane	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Indeno(1,2,3-cd)pyrene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Isophorone	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Naphthalene	5 U	5 U	15	5 U	5 U	5 U	5 U	24
Nitrobenzene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Pentachlorophenol	20 U	2 J	360 J	0.9 J	20 U	20 U	15 J	880 J
Phenanthrene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Phenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Pyrene	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
bis(2-Chloroethoxy)methane	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
bis(2-Chloroethyl)ether	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
bis(2-Ethylhexyl)phthalate	2 B	5 B	0.7 B	2 B	5 U	8 B	0.8 B	5 B
n-Nitroso-di-n-propylamine	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
n-Nitrosodiphenylamine	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
Total Metals (UG/L)								
Aluminum	NA	NA	NA	NA	5,680	171 B	NA	NA
Antimony	NA	NA	NA	NA	3.65 U	3.65 U	NA	NA
Arsenic	NA	NA	NA	NA	2.53 U	2.53 U	NA	NA
Barium	NA	NA	NA	NA	31.7 B	16.3 J	NA	NA
Beryllium	NA	NA	NA	NA	0.18 U	0.18 U	NA	NA
Cadmium	NA	NA	NA	NA	0.24 U	0.24 U	NA	NA
Calcium	NA	NA	NA	NA	13,900	9,040	NA	NA
Chromium	NA	NA	NA	NA	11.2	6.2 J	NA	NA
Cobalt	NA	NA	NA	NA	16.2 J	38 J	NA	NA
Copper	NA	NA	NA	NA	4.1 B	0.86 B	NA	NA

Appendix C 3-A
Site 13 ORC Groundwater Remediation Report
April 2001 Round 3 Analytical Results

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01B-R3	LS13-MW03T-01B-R3	LS13-MW21S-01B-R3	LS13-MW22D-01B-R3	LS13-MW23S-01B-R3	LS13-MW24D-01B-R3	LS13-MW25S-01B-R3	LS13-MW26S-01B-R3
Sample Date	04/10/01	04/11/01	04/10/01	04/10/01	04/11/01	04/11/01	04/10/01	04/11/01
Chemical Name								
Cyanide	NA	NA	NA	NA	10 U	10 U	NA	NA
Iron	NA	NA	NA	NA	4,470	191 B	NA	NA
Lead	NA	NA	NA	NA	2.8 B	1.48 U	NA	NA
Magnesium	NA	NA	NA	NA	1,950 J	2,440 J	NA	NA
Manganese	NA	NA	NA	NA	72.3	293	NA	NA
Mercury	NA	NA	NA	NA	0.05 B	0.03 U	NA	NA
Nickel	NA	NA	NA	NA	6.4 B	5.8 B	NA	NA
Potassium	NA	NA	NA	NA	3,440 B	2,840 B	NA	NA
Selenium	NA	NA	NA	NA	3.04 U	3.04 U	NA	NA
Silver	NA	NA	NA	NA	1.03 U	1.03 U	NA	NA
Sodium	NA	NA	NA	NA	5,180	7,820	NA	NA
Thallium	NA	NA	NA	NA	4.74 U	4.74 U	NA	NA
Vanadium	NA	NA	NA	NA	7.5 J	0.52 U	NA	NA
Zinc	NA	NA	NA	NA	9.8 B	12.6 B	NA	NA
Dissolved Metals (UG/L)								
Aluminum	NA	NA	NA	NA	50.3 B	29.5 U	NA	NA
Antimony	NA	NA	NA	NA	3.65 U	3.65 U	NA	NA
Arsenic	NA	NA	NA	NA	2.53 U	2.53 U	NA	NA
Barium	NA	NA	NA	NA	16.3 B	15.6 B	NA	NA
Beryllium	NA	NA	NA	NA	0.18 U	0.18 U	NA	NA
Cadmium	NA	NA	NA	NA	0.24 U	0.24 U	NA	NA
Calcium	NA	NA	NA	NA	14,300	8,930	NA	NA
Chromium	NA	NA	NA	NA	1.8 B	1.2 B	NA	NA
Cobalt	NA	NA	NA	NA	31.9 J	21.9 J	NA	NA
Copper	NA	NA	NA	NA	1.5 B	0.84 U	NA	NA
Iron	NA	NA	NA	NA	173 B	16.5 U	NA	NA
Lead	NA	NA	NA	NA	1.48 U	1.48 U	NA	NA
Magnesium	NA	NA	NA	NA	1,740 J	2,330 J	NA	NA
Manganese	NA	NA	NA	NA	63.6	273	NA	NA
Mercury	NA	NA	NA	NA	0.03 U	0.03 B	NA	NA
Nickel	NA	NA	NA	NA	5.6 B	3.5 B	NA	NA
Potassium	NA	NA	NA	NA	3,230 B	2,800 B	NA	NA
Selenium	NA	NA	NA	NA	3.04 U	3.04 U	NA	NA
Silver	NA	NA	NA	NA	1.03 U	1.03 U	NA	NA
Sodium	NA	NA	NA	NA	5,440	7,670	NA	NA
Thallium	NA	NA	NA	NA	4.74 U	5.9 B	NA	NA
Vanadium	NA	NA	NA	NA	0.52 U	0.52 U	NA	NA
Zinc	NA	NA	NA	NA	3.9 B	6.9 B	NA	NA
Wet Chemistry (MG/L)								
Alkalinity	110	60	20 U	40	20	20 U	40	20 U
Carbon dioxide	4.60E-05	8.30E-05	7.60E-05	8.50E-05	3.70E-05	6.60E-05	9.90E-05	8.40E-05
Chloride	40	29	7	30	6	10	25	8
Ferrous iron	9.7	3	2	0.3	0.2	0.1 U	7.8	7.6
Total organic carbon (TOC)	5.6	2	4	17	6	2	5	4

Notes:
 B - Not detected substantially above the level reported in laboratory or field blanks- Possible blank contamination
 J - Analyte present. Reported may not be accurate or precise
 NA - Not analyzed
 U - Not Detected

Appendix C 3-A
 Site 13 ORC Groundwater Remediation Report
 April 2001 Round 3 Analytical Results

Station ID	LS13-MW27S	
	Sample ID	Sample ID
Sample Date	LS13-MW27S-01B-R3	LS13-MW27S-01B-R3P
Chemical Name	04/11/01	04/11/01
Volatile Organic Compounds (UG/L)		
1,1,1-Trichloroethane	1 U	1 U
1,1,2,2-Tetrachloroethane	1 U	1 U
1,1,2-Trichloroethane	1 U	1 U
1,1-Dichloroethane	1 U	1 U
1,1-Dichloroethene	1 U	1 U
1,2,4-Trichlorobenzene	1 U	1 U
1,2-Dibromo-3-chloropropane	1 U	1 U
1,2-Dibromoethane	1 U	1 U
1,2-Dichlorobenzene	1 U	1 U
1,2-Dichloroethane	1 U	1 U
1,2-Dichloropropane	1 U	1 U
1,3-Dichlorobenzene	1 U	1 U
1,4-Dichlorobenzene	1 U	1 U
2-Butanone	5 U	5 U
2-Hexanone	5 U	5 U
4-Methyl-2-pentanone	5 U	5 U
Acetone	7 B	6 B
Benzene	1 U	1 U
Bromochloromethane	1 U	1 U
Bromodichloromethane	1 U	1 U
Bromoform	1 U	1 U
Bromomethane	1 U	1 U
Carbon disulfide	1 U	1 U
Carbon tetrachloride	1 U	1 U
Chlorobenzene	1 U	1 U
Chloroethane	1 U	1 U
Chloroform	0.8 J	0.7 J
Chloromethane	1 U	1 U
Dibromochloromethane	1 U	1 U
Ethylbenzene	1 U	1 U
Methyl-tert-butyl ether (MTBE)	0.6 B	0.3 B
Methylene chloride	0.7 B	0.7 B
Styrene	1 U	1 U
Tetrachloroethene	1 U	1 U
Toluene	1 U	1 U
Trichloroethene	1 U	1 U
Vinyl chloride	1 U	1 U
Xylene, total	0.2 J	0.4 J
cis-1,2-Dichloroethene	1 U	1 U
cis-1,3-Dichloropropene	1 U	1 U
trans-1,2-Dichloroethene	1 U	1 U
trans-1,3-Dichloropropene	1 U	1 U
Semi-volatile Organic Compounds (UG/L)		
2,2'-Oxybis(1-chloropropane)	5 U	5 U
2,4,5-Trichlorophenol	20 U	20 U
2,4,6-Trichlorophenol	5 U	5 U
2,4-Dichlorophenol	5 U	5 U
2,4-Dimethylphenol	0.6 J	0.6 J
2,4-Dinitrophenol	20 U	20 U
2,4-Dinitrotoluene	5 U	5 U
2,6-Dinitrotoluene	5 U	5 U
2-Chloronaphthalene	5 U	5 U
2-Chlorophenol	5 U	5 U
2-Methylnaphthalene	5 U	5 U
2-Methylphenol	5 U	5 U
2-Nitroaniline	20 U	20 U

Appendix C 3-A
 Site 13 ORC Groundwater Remediation Report
 April 2001 Round 3 Analytical Results

Station ID	LS13-MW27S	
	Sample ID	Sample ID
Sample Date	LS13-MW27S-01B-R3	LS13-MW27S-01B-R3P
Chemical Name	04/11/01	04/11/01
2-Nitrophenol	5 U	5 U
3,3'-Dichlorobenzidine	5 U	5 U
3-Nitroaniline	20 U	20 U
4,6-Dinitro-2-methylphenol	20 U	20 U
4-Bromophenyl-phenylether	5 U	5 U
4-Chloro-3-methylphenol	5 U	5 U
4-Chloroaniline	5 U	5 U
4-Chlorophenyl-phenylether	5 U	5 U
4-Methylphenol	5 U	5 U
4-Nitroaniline	20 U	20 U
4-Nitrophenol	20 U	20 U
Acenaphthene	5 U	5 U
Acenaphthylene	5 U	5 U
Anthracene	5 U	5 U
Benzo(a)anthracene	5 U	5 U
Benzo(a)pyrene	5 U	5 U
Benzo(b)fluoranthene	5 U	5 U
Benzo(g,h,i)perylene	5 U	5 U
Benzo(k)fluoranthene	5 U	5 U
Butylbenzylphthalate	5 U	5 U
Chrysene	5 U	5 U
Di-n-butylphthalate	5 U	0.6 J
Di-n-octylphthalate	5 U	5 U
Dibenz(a,h)anthracene	5 U	5 U
Dibenzofuran	5 U	5 U
Diethylphthalate	5 U	5 U
Dimethyl phthalate	5 U	5 U
Fluoranthene	5 U	5 U
Fluorene	5 U	5 U
Hexachlorobenzene	5 U	5 U
Hexachlorobutadiene	5 U	5 U
Hexachlorocyclopentadiene	5 U	5 U
Hexachloroethane	5 U	5 U
Indeno(1,2,3-cd)pyrene	5 U	5 U
Isophorone	5 U	5 U
Naphthalene	5 U	5 U
Nitrobenzene	5 U	5 U
Pentachlorophenol	460	440
Phenanthrene	5 U	5 U
Phenol	5 U	5 U
Pyrene	5 U	5 U
bis(2-Chloroethoxy)methane	5 U	5 U
bis(2-Chloroethyl)ether	5 U	5 U
bis(2-Ethylhexyl)phthalate	0.8 B	2 B
n-Nitroso-di-n-propylamine	5 U	5 U
n-Nitrosodiphenylamine	5 U	5 U
Total Metals (UG/L)		
Aluminum	2,000	2,370
Antimony	3.65 U	3.65 U
Arsenic	2.53 U	2.53 U
Barium	35.4 B	35.9 B
Beryllium	0.18 U	0.18 U
Cadmium	0.24 U	0.24 U
Calcium	17,600	17,600
Chromium	5.9 B	6.2 J
Cobalt	9.4 J	7.3 J
Copper	1.3 B	1.6 B

Appendix C 3-A
 Site 13 ORC Groundwater Remediation Report
 April 2001 Round 3 Analytical Results

Station ID	LS13-MW27S	
	LS13-MW27S-01B-R3	LS13-MW27S-01B-R3P
Sample ID		
Sample Date	04/11/01	04/11/01
Chemical Name		
Cyanide	10 U	10 U
Iron	3,870	4,480
Lead	1.48 U	2 B
Magnesium	5,200	5,240
Manganese	449	449
Mercury	0.04 B	0.04 B
Nickel	4.4 B	4.1 B
Potassium	3,980 B	4,040 B
Selenium	3.04 U	3.04 U
Silver	1.03 U	1.03 U
Sodium	19,100	19,300
Thallium	4.74 U	4.74 U
Vanadium	2.9 J	3 J
Zinc	8.6 B	8.2 B
Dissolved Metals (UG/L)		
Aluminum	77.8 B	61.6 B
Antimony	3.65 U	3.65 U
Arsenic	2.53 U	2.53 U
Barium	31.6 B	30.4 B
Beryllium	0.18 U	0.18 U
Cadmium	0.24 U	0.24 U
Calcium	18,400	17,800
Chromium	1.1 B	0.75 B
Cobalt	11.8 J	7.2 J
Copper	0.86 B	0.84 U
Iron	1,790	2,060
Lead	1.48 U	1.48 U
Magnesium	5,360	5,300
Manganese	475	454
Mercury	0.03 U	0.04 B
Nickel	3.4 B	2.8 B
Potassium	4,070 B	3,990 B
Selenium	3.04 U	3.3 B
Silver	1.03 U	1.03 U
Sodium	20,300	20,200
Thallium	4.74 U	4.74 U
Vanadium	0.52 U	0.52 U
Zinc	5.6 B	5.6 B
Wet Chemistry (MG/L)		
Alkalinity	40	NA
Carbon dioxide	1.30E-04	NA
Chloride	22	NA
Ferrous iron	2.2	NA
Total organic carbon (TOC)	9	NA

Notes:
 B - Not detected substantially above the level reported in lat
 J - Analyte present. Reported may not be accurate or precise
 NA - Not analyzed
 U - Not Detected

Appendix C 3-B
Site 13 ORC Groundwater Remediation Report
Round 3 Detections

Station ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW23S	LS13-MW24D	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01B-R3	LS13-MW03T-01B-R3	LS13-MW21S-01B-R3	LS13-MW22D-01B-R3	LS13-MW23S-01B-R3	LS13-MW24D-01B-R3	LS13-MW25S-01B-R3	LS13-MW26S-01B-R3
Sample Date	04/10/01	04/11/01	04/10/01	04/10/01	04/11/01	04/11/01	04/10/01	04/11/01
Chemical Name								
Volatile Organic Compounds (UG/L)								
1,1-Dichloroethane	NA	0.3 J	NA	NA	1 U	NA	NA	1 U
Benzene	NA	0.4 J	NA	NA	1 U	NA	NA	1 U
Chloroform	NA	1 U	NA	NA	1 U	NA	NA	1 U
Ethylbenzene	NA	1 U	NA	NA	1 U	NA	NA	0.9 J
Methyl-tert-butyl ether (MTBE)	NA	34	NA	NA	1 U	NA	NA	3
Trichloroethene	NA	0.7 J	NA	NA	1 U	NA	NA	1 U
Xylene, total	NA	1 U	NA	NA	1 U	NA	NA	9
cis-1,2-Dichloroethene	NA	1	NA	NA	1 U	NA	NA	1 U
Semi-volatile Organic Compounds (UG/L)								
2,4-Dichlorophenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2,4-Dimethylphenol	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
2-Methylnaphthalene	5 U	5 U	17	5 U	5 U	5 U	5 U	14
Di-n-butylphthalate	5 U	5 U	5 U	0.9 J	5 U	0.8 J	0.8 J	5 U
Naphthalene	5 U	5 U	15	5 U	5 U	5 U	5 U	24
Pentachlorophenol	20 U	2 J	360 J	0.9 J	20 U	20 U	15 J	880 J
Total Metals (UG/L)								
Aluminum	NA	NA	NA	NA	5,880	171 B	NA	NA
Barium	NA	NA	NA	NA	31.7 B	16.3 J	NA	NA
Calcium	NA	NA	NA	NA	13,900	9,040	NA	NA
Chromium	NA	NA	NA	NA	11.2	6.2 J	NA	NA
Cobalt	NA	NA	NA	NA	16.2 J	36 J	NA	NA
Iron	NA	NA	NA	NA	4,470	191 B	NA	NA
Magnesium	NA	NA	NA	NA	1,950 J	2,440 J	NA	NA
Manganese	NA	NA	NA	NA	72.3	283	NA	NA
Sodium	NA	NA	NA	NA	5,180	7,820	NA	NA
Vanadium	NA	NA	NA	NA	7.5 J	0.52 U	NA	NA
Dissolved Metals (UG/L)								
Calcium	NA	NA	NA	NA	14,300	8,930	NA	NA
Cobalt	NA	NA	NA	NA	31.9 J	21.9 J	NA	NA
Iron	NA	NA	NA	NA	173 B	16.5 U	NA	NA
Magnesium	NA	NA	NA	NA	1,740 J	2,330 J	NA	NA
Manganese	NA	NA	NA	NA	63.8	273	NA	NA
Sodium	NA	NA	NA	NA	5,440	7,870	NA	NA
Wet Chemistry (MG/L)								
Alkalinity	110	50	20 U	40	20	20 U	40	20 U
Carbon dioxide	4.80E-05	6.30E-05	7.60E-05	8.60E-05	3.70E-05	6.50E-05	8.90E-05	8.40E-05
Chloride	40	29	7	30	6	10	25	8
Ferrous iron	9.7	3	2	0.3	0.2	0.1 U	7.6	7.6
Total organic carbon (TOC)	5.6	2	4	17	6	2	3	4

Notes:

- J - Indicates Detection
- B - Not detected substantially above the level reported in laboratory or field blanks- Possible blank contamination
- J - Analyte present. Reported may not be accurate or precise
- NA - Not analyzed
- U - Not Detected

Appendix C 3-B
Site 13 ORC Groundwater Remediation Report
Round 3 Detections

Station ID	LS13-MW27S	
	LS13-MW27S-01B-R3	LS13-MW27S-01B-R3P
Sample ID		
Sample Date	04/11/01	04/11/01
Chemical Name		
Volatile Organic Compounds (UG/L)		
1,1-Dichloroethane	1 U	1 U
Benzene	1 U	1 U
Chloroform	0.8 J	0.7 J
Ethylbenzene	1 U	1 U
Methyl-tert-butyl ether (MTBE)	0.6 B	0.3 B
Trichloroethene	1 U	1 U
Xylene, total	0.2 J	0.4 J
cis-1,2-Dichloroethene	1 U	1 U
Semi-volatile Organic Compounds (UG/L)		
2,4-Dichlorophenol	5 U	5 U
2,4-Dimethylphenol	0.6 J	0.6 J
2-Methylnaphthalene	5 U	5 U
Di-n-butylphthalate	5 U	0.6 J
Naphthalene	5 U	5 U
Pentachlorophenol	480	440
Total Metals (UG/L)		
Aluminum	2,000	2,370
Barium	35.4 B	35.9 B
Calcium	17,800	17,800
Chromium	5.9 B	6.2 J
Cobalt	9.4 J	7.3 J
Iron	3,670	4,480
Magnesium	5,200	5,240
Manganese	449	449
Sodium	19,100	19,300
Vanadium	2.9 J	3 J
Dissolved Metals (UG/L)		
Calcium	18,400	17,800
Cobalt	11.6 J	7.2 J
Iron	1,790	2,060
Magnesium	5,380	5,300
Manganese	476	454
Sodium	20,300	20,200
Wet Chemistry (MG/L)		
Alkalinity	40	NA
Carbon dioxide	1.30E-04	NA
Chloride	22	NA
Ferrous iron	2.2	NA
Total organic carbon (TOC)	9	NA

Notes:

Indicates Detection
 B - Not detected substantially above the level reported in la
 J - Analyte present. Reported may not be accurate or prec
 NA - Not analyzed
 U - Not Detected

Appendix C 4-A
Site 13 ORC Groundwater Remediation Report
Round 4 Analytical Results

Well ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW22D	LS13-MW23S	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01C-R4	LS13-MW03T-01C-R4	LS13-MW21S-01C-R4	LS13-MW22D-01C-R4	LS13-MW22DP-01C-R4	LS13-MW23S-01C-R4	LS13-MW25S-01C-R4	LS13-MW26S-01C-R4
Sample Date	7/17/2001	7/18/2001	7/18/2001	7/17/2001	7/17/2001	7/18/2001	7/17/2001	7/18/2001
Chemical Name								
Semi-volatile Organic Compounds (UG/L)								
1,1-BIPHENYL	NA	10 U	55 U	NA	NA	NA	NA	10 U
2,2-OXYBIS(1-CHLOROPROPANE)	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2,4,5-TRICHLOROPHENOL	18 U	25 U	140 U	18 U	18 U	18 U	18 U	25 U
2,4,6-TRICHLOROPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2,4-DICHLOROPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2,4-DIMETHYLPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2,4-DINITROPHENOL	18 U	25 U	140 U	18 U	18 U	18 U	18 U	25 U
2,4-DINITROTOLUENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2,6-DINITROTOLUENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2-CHLORONAPHTHALENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2-CHLOROPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2-METHYLNAPHTHALENE	5 U	10 U	14 J	5 U	5 U	5 U	5 U	1 J
2-METHYLPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
2-NITROANILINE	18 U	25 U	140 U	18 U	18 U	18 U	18 U	25 U
2-NITROPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
3,3'-DICHLOROBENZIDINE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
3-NITROANILINE	18 U	25 U	140 U	18 U	18 U	18 U	18 U	25 U
4,6-DINITRO-2-METHYLPHENOL	18 U	25 U	140 U	18 U	18 U	18 U	18 U	25 U
4-BROMOPHENYL PHENYL ETHER	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
4-CHLORO-3-METHYLPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
4-CHLOROANILINE	5 UK	10 U	55 U	5 UK	5 UK	5 UK	5 UK	10 U
4-CHLOROPHENYL PHENYL ETHER	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
4-METHYLPHENOL	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
4-NITROANILINE	18 U	25 U	140 U	18 U	18 U	18 U	18 U	25 U
4-NITROPHENOL	18 U	25 U	140 U	18 U	18 U	18 U	18 U	25 U
ACENAPHTHENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
ACENAPHTHYLENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
ACETOPHENONE	NA	10 U	55 U	NA	NA	NA	NA	10 U
ANTHRACENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
ATRAZINE	NA	10 U	55 U	NA	NA	NA	NA	10 U
BENZALDEHYDE	NA	10 U	55 U	NA	NA	NA	NA	10 U
BENZO(A)ANTHRACENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
BENZO(A)PYRENE	5 UL	10 U	55 U	5 UL	5 UL	5 UL	5 UL	10 U
BENZO(B)FLUORANTHENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
BENZO(G,H,I)PERYLENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
BENZO(K)FLUORANTHENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
BIS(2-CHLOROETHOXY)METHANE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
BIS(2-CHLOROETHYL)ETHER	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
BIS(2-ETHYLHEXYL)PHTHALATE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	3 B
BUTYL BENZYL PHTHALATE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
CAPROLACTAM	NA	10 U	55 U	NA	NA	NA	NA	10 U
CARBAZOLE	NA	10 U	55 U	NA	NA	NA	NA	10 U
CHRYSENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
DIBENZO(A,H)ANTHRACENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
DIBENZOFURAN	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
DIETHYL PHTHALATE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
DIMETHYL PHTHALATE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
DI-N-BUTYL PHTHALATE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
DI-N-OCTYL PHTHALATE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
FLUORANTHENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
FLUORENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
HEXACHLOROENZENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
HEXACHLOROBUTADIENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
HEXACHLOROCYCLOPENTADIENE	5 UJ	10 U	55 U	5 UJ	5 UJ	5 UJ	5 UJ	10 U
HEXACHLOROETHANE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
INDENO(1,2,3-CD)PYRENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
ISOPHORONE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U

Appendix C 4-A
 Site 13 ORC Groundwater Remediation Report
 Round 4 Analytical Results

Well ID	LS13-MW01T	LS13-MW03T	LS13-MW21S	LS13-MW22D	LS13-MW22D	LS13-MW23S	LS13-MW25S	LS13-MW26S
Sample ID	LS13-MW01T-01C-R4	LS13-MW03T-01C-R4	LS13-MW21S-01C-R4	LS13-MW22D-01C-R4	LS13-MW22DP-01C-R4	LS13-MW23S-01C-R4	LS13-MW25S-01C-R4	LS13-MW26S-01C-R4
Sample Date	7/17/2001	7/18/2001	7/18/2001	7/17/2001	7/17/2001	7/18/2001	7/17/2001	7/18/2001
Chemical Name								
NAPHTHALENE	5 U	10 U	13 J	5 U	5 U	5 U	5 U	3 J
NITROBENZENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
N-NITROSO-DI-N-PROPYLAMINE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
N-NITROSODIPHENYLAMINE(1)	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
PENTACHLOROPHENOL	18 U	43 J	140 J	18 U	18 U	18 U	4 J	250 J
PHENANTHRENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U
PHENOL	5 UL	10 U	55 U	5 UL	5 UL	5 UL	5 UL	10 U
PYRENE	5 U	10 U	55 U	5 U	5 U	5 U	5 U	10 U

Notes:

- NA - not analyzed
- U - undetected
- J - estimated
- K - biased high
- L - biased low

Appendix C 4-A
 Site 13 ORC Groundwater Remediation Report
 Round 4 Analytical Results

Well ID	LS13-MW27S
Sample ID	LS13-MW27S-01C-R4
Sample Date	7/18/2001
Chemical Name	
Semi-volatile Organic Compounds (UG/L)	
1,1'-BIPHENYL	55 U
2,2'-OXYBIS(1-CHLOROPROPANE)	55 U
2,4,5-TRICHLOROPHENOL	140 U
2,4,6-TRICHLOROPHENOL	55 U
2,4-DICHLOROPHENOL	55 U
2,4-DIMETHYLPHENOL	55 U
2,4-DINITROPHENOL	140 U
2,4-DINITROTOLUENE	55 U
2,6-DINITROTOLUENE	55 U
2-CHLORONAPHTHALENE	55 U
2-CHLOROPHENOL	55 U
2-METHYLNAPHTHALENE	55 U
2-METHYLPHENOL	55 U
2-NITROANILINE	140 U
2-NITROPHENOL	55 U
3,3'-DICHLOROBENZIDINE	55 U
3-NITROANILINE	140 U
4,6-DINITRO-2-METHYLPHENOL	140 U
4-BROMOPHENYL PHENYL ETHER	55 U
4-CHLORO-3-METHYLPHENOL	55 U
4-CHLOROANILINE	55 U
4-CHLOROPHENYL PHENYL ETHER	55 U
4-METHYLPHENOL	55 U
4-NITROANILINE	140 U
4-NITROPHENOL	140 U
ACENAPHTHENE	55 U
ACENAPHTHYLENE	55 U
ACETOPHENONE	55 U
ANTHRACENE	55 U
ATRAZINE	55 U
BENZALDEHYDE	55 U
BENZO(A)ANTHRACENE	55 U
BENZO(A)PYRENE	55 U
BENZO(B)FLUORANTHENE	55 U
BENZO(G,H,I)PERYLENE	55 U
BENZO(K)FLUORANTHENE	55 U
BIS(2-CHLOROETHOXY)METHANE	55 U
BIS(2-CHLOROETHYL)ETHER	55 U
BIS(2-ETHYLHEXYL)PHTHALATE	55 U
BUTYL BENZYL PHTHALATE	55 U
CAPROLACTAM	55 U
CARBAZOLE	55 U
CHRYSENE	55 U
DIBENZO(A,H)ANTHRACENE	55 U
DIBENZOFURAN	55 U
DIETHYL PHTHALATE	55 U
DIMETHYL PHTHALATE	55 U
DI-N-BUTYL PHTHALATE	55 U
DI-N-OCTYL PHTHALATE	55 U
FLUORANTHENE	55 U
FLUORENE	55 U
HEXACHLOROBENZENE	55 U
HEXACHLOROBUTADIENE	55 U
HEXACHLOROCYCLOPENTADIENE	55 U
HEXACHLOROETHANE	55 U
INDENO(1,2,3-CD)PYRENE	55 U
ISOPHORONE	55 U

Appendix C 5-B
 Site 13 ORC Groundwater Remediation Report
 Round 5 Detects

Well ID	LS13-MW011 LS13-MW011-01D-R5 10/24/2001	LS13-MW037 LS13-MW037-01D-R5 10/24/2001	LS13-MW219 LS13-MW219-01D-R5 10/23/2001	LS13-MW220 LS13-MW220-01D-R5 10/23/2001	LS13-MW235 LS13-MW235-01D-R5 10/23/2001	LS13-MW255 LS13-MW255-01D-R5 10/23/2001	LS13-MW265 LS13-MW265-01D-R5 10/23/2001	LS13-MW275 LS13-MW275-01D-R5 10/24/2001	LS13-MW275 LS13-MW275-01D-R5 10/24/2001
Volatiles Organic Compounds (UG/L)									
CIS-1,2-DICHLOROETHENE	NA	0.7 J	NA	1 U	NA	NA	0.1 J	1 U	1 U
METHYLENE CHLORIDE	NA	2 U	NA	2 U	NA	NA	2 U	2 U	0.6 B
TETRACHLOROETHENE	NA	0.3 J	NA	1 U	NA	NA	1 U	1 U	1 U
TOLUENE	NA	0.2 B	NA	0.2 B	NA	NA	0.3 B	1 U	0.2 B
TRICHLOROETHENE	NA	0.9 J	NA	1 U	NA	NA	1 U	1 U	1 U
Semi-volatile Organic Compounds (UG/L)									
2-METHYLNAPHTHALENE	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U
BIS(2-ETHYLHEXYL)PHTHALATE	5 U	5 U	8 B	5 U	5 U	5 U	0.3 J	5 U	5 U
NAPHTHALENE	19 U	6.3	100	19 U	18 U	2 J	70	8 J	8 J
PENTACHLOROPHENOL									
Total Metals (UG/L)									
ALUMINUM	NA	NA	NA	NA	94	NA	NA	841	875
ARSENIC	NA	NA	NA	NA	3.2 J	NA	NA	3.1 J	3 U
BARIUM	NA	NA	NA	NA	27.8 J	NA	NA	18.8 J	14.8 J
CALCIUM	NA	NA	NA	NA	14,300	NA	NA	7,710	7,440
CHROMIUM	NA	NA	NA	NA	5.1 B	NA	NA	2.9 B	3 B
IRON	NA	NA	NA	NA	853	NA	NA	762	777
MAGNESIUM	NA	NA	NA	NA	1,920 J	NA	NA	5,020	4,770 J
MANGANESE	NA	NA	NA	NA	78.5	NA	NA	30	28.8
NICKEL	NA	NA	NA	NA	3.6 B	NA	NA	1.7 B	1.7 B
POTASSIUM	NA	NA	NA	NA	3,350 J	NA	NA	1,950 B	1,860 J
SODIUM	NA	NA	NA	NA	16,500	NA	NA	12,000 B	11,800
VANADIUM	NA	NA	NA	NA	2.9 J	NA	NA	0.9 U	1 J
Dissolved Metals (UG/L)									
BARIUM	NA	NA	NA	NA	25.5 J	NA	NA	12 J	12.2 J
CALCIUM	NA	NA	NA	NA	14,700	NA	NA	6,900	7,200
MAGNESIUM	NA	NA	NA	NA	1,880 J	NA	NA	4,560 J	4,780 J
MANGANESE	NA	NA	NA	NA	77	NA	NA	22.4	23.3
POTASSIUM	NA	NA	NA	NA	3,430 J	NA	NA	1,720 J	1,800 J
SODIUM	NA	NA	NA	NA	6,570	NA	NA	11,400	11,800
VANADIUM	NA	NA	NA	NA	13 J	NA	NA	0.9 U	0.9 U
ZINC	NA	NA	NA	NA	7.6 B	NA	NA	6.2 B	5.3 B
Wet Chemistry (MGL)									
ALKALINITY	78	73	18	28	22	34	29	28	28
CARBON DIOXIDE	44	84	84	69	40	79	69	65	65
CHLORIDE	1.3	14.9	10.3	27.8	4.8	13.3	14	7.9	7.2
TOTAL ORGANIC CARBON	5.5	5 U	5 U	5 U	5 U	5 U	5 U	5 U	5 U

Notes:
 Indicates Detection
 U - undetected
 J - estimated
 B - blank contaminated
 L - biased low
 NA - not analyzed