COMPREHENSIVE LONG-TERM ENVIRONMENTAL ACTION NAVY (CLEAN I)
Northern and Central California, Nevada, and Utah
Contract No. N62474-88-D-5086
Contract Task Order 0235

Prepared for

DEPARTMENT OF THE NAVY
Mr. Stephen Chao, P.E., Remedial Project Manager
Engineering Field Activity West
Naval Facilities Engineering Command

MOFFETT FEDERAL AIRFIELD, CALIFORNIA
(Formerly Naval Air Station Moffett Field)
SITE 5 GROUNDWATER TREATABILITY STUDY
DRAFT TECHNICAL MEMORANDUM

November 18, 1996

Prepared By

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November 19, 1996

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CLEAN Contract Number N62474-88-D-5086 (CLEAN I)
Contract Task Order 0235

Subject: **Site 5 Groundwater Treatability Study Draft Technical Memorandum Moffett Federal Airfield, California**

Dear Messrs. Chao and Chan:

Enclosed please find for your records three copies of the subject technical memorandum. Copies are also being distributed as indicated on the attached distribution list. The memorandum describes the results of the groundwater study conducted at Site 5 between September 1995 and April 1996. During the study, oxygen was introduced to the groundwater, and its fate and transport evaluated.

The technical memorandum presents recommendations for groundwater corrective action at Site 5. These recommendations incorporate the guidance from the California State Water Resources Control Board released in December 1995. The guidance promotes natural attenuation as the preferred corrective action alternative at sites that do not pose an unacceptable risk to human health and the environment. Site 5 specific risks will be assessed under CLEAN II Contract Task Order 79, and, if required, a risk-based corrective action will be selected.

Please call me at (303) 312-8822 or Michael at (303) 312-8857 if you have any questions.

Sincerely,

Willis E. Wilcoxon

Willis Wilcoxon
Task Manager

Michael W. Young

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WW/cmg

Enclosure

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MAY 1996 DRAFT QUARTERLY REPORT
MOFFETT FEDERAL AIRFIELD

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EXECUTIVE SUMMARY

A groundwater treatability study was completed at Site 5 at Moffett Federal Airfield (MFA). Soil and groundwater at the site are contaminated with jet fuel released from on-site bulk fuel storage tanks. The release most likely occurred during routine storage tank maintenance from the 1950s through the 1970s. Jet petroleum 5 (JP-5) is the petroleum contaminant of concern.

The treatability study was completed to evaluate the ability of oxygen release compound (ORC) to decrease concentrations of dissolved-phase JP-5 in shallow groundwater by stimulating aerobic biodegradation. Tests were also conducted to assess hydraulic parameters (flow direction, gradient, and groundwater velocity) at the site during the study period.

Following hydraulic parameter testing, ORC was introduced into groundwater through a previously installed product recovery well. Changes in groundwater concentrations of dissolved oxygen and petroleum contamination were periodically monitored through samples collected from a temporary monitoring point array located directly downgradient of the ORC source well.

Field and laboratory data were analyzed to evaluate changes in petroleum concentrations and dissolved oxygen during the test. The data indicate dissolved oxygen increased by approximately 2 fold at 5 feet downgradient of the ORC source well. Petroleum appeared not to decrease in concentration at downgradient monitoring points, but decreased slightly in the ORC source well.

Close analysis of the chromatograms from the petroleum analysis indicates that the petroleum was severely degraded at the beginning of the study. The degradation byproducts are mostly likely organic acids and alcohols. These byproducts appear on the chromatogram as later-eluting petroleum compounds.

Nitrogen species analysis indicates that nitrogen reduction occurs at the ORC source well. Low levels of nitrate coupled with elevated levels of ammonia indicate that reducing bacteria are anaerobically degrading petroleum. These levels further suggest that alkane molecules are undergoing partial biodegradation. High levels of carbon dioxide in the unsaturated zone (measured just above the water table surface at an adjacent study area) are likely saturating shallow groundwater and inhibiting further biodegradation.

1.0 INTRODUCTION

PRC Environmental Management, Inc. (PRC) completed treatability study field tests to investigate the potential effectiveness of an oxygen-releasing compound to enhance attenuation of petroleum-contaminated groundwater at Moffett Federal Airfield (MFA). This treatability study was conducted as part of Phase I corrective actions at Site 5, a bulk fuel storage area. Test activities were completed between September 1995 and April 1996 under Contract Task Order (CTO) 0235. This treatability study was part of the Comprehensive Long-term Environmental Action Navy (CLEAN I) program for the environmental restoration of Navy facilities.

This technical memorandum describes field activities that were completed and analytical data that were generated to evaluate enhanced attenuation, and presents conclusions and recommendations for implementation of this technology at Site 5 for remediation of groundwater. The document is organized as follows. This introductory section discusses the site background and the project purpose. Section 2.0 summarizes field activities conducted to complete the test. Section 3.0 presents analytical data. Section 4.0 presents the data quality assessment. Section 5.0 presents work plan deviations. Section 6.0 presents test conclusions. Section 7.0 presents recommendations for future activities at the site. Section 8.0 presents references.

1.1 PURPOSE

This treatability study evaluated the ability of magnesium trioxide to enhance biodegradation of dissolved-phase petroleum in groundwater and sorbed-phase petroleum in saturated soils. It is anticipated that biodegradation will be enhanced if dissolved oxygen (DO) levels in groundwater are increased sufficiently to support increased populations of aerobic petroleum-degrading microbes.

When this study was initiated, the Navy was obligated to cleanup extractable-phase hydrocarbons in groundwater to at least 700 micrograms per liter (μg/L). (Section 1.3 further discusses changes in regulatory requirements.) Historical analyses from Site 5 monitoring well samples indicated hydrocarbon contamination above this level at the site. PRC's goal was to evaluate technologies that would promote in situ hydrocarbon biodegradation in groundwater and saturated soils. The most common in situ technology - air sparging and soil vapor extraction - was expensive to operate, had limited effects on groundwater in fine-grained soil, and moderate effectiveness on extractable-phase hydrocarbons.

One alternative was passive introduction of oxygen to the groundwater. Hydrogen peroxide injection is one method of passive oxygen introduction. It, too, has drawbacks, most notably operational and material costs. Another new method of oxygen introduction is placement of magnesium trioxide in the saturated zone. Magnesium trioxide reacts readily with water to release free oxygen in the form of dissolved oxygen.

Regenesis Bioremediation Products, Inc., developed an oxygen release compound (ORC). The ORC is a proprietary mixture of magnesium trioxide and portland cement that controls the rate of oxygen release from magnesium trioxide. The manufacturer indicated that the compound released DO at a fairly continuous rate over a several month period. The increased DO would, theoretically, stimulate growth of petroleum-degrading microbes, which would reduce petroleum concentrations in groundwater and saturated soils through biodegradation. PRC anticipated that such a passive system would control operational and maintenance expenses associated with cleanup costs, since the only operational costs would be periodic replacement of the spent ORC.

Therefore, two performance characteristics were evaluated: (1) increases in groundwater DO directly downgradient of an ORC source; and (2) changes in groundwater petroleum concentrations downgradient of the ORC source that are attributable to the ORC. Specific quantitative values have not been set as target levels in the selection of this technology; rather, professional judgment will be used to evaluate the effectiveness of this technology.

1.2 SITE BACKGROUND

This subsection briefly summarizes the operational history, physical setting, and hydrogeology of MFA and Site 5, and describes previous investigations conducted at Site 5. Much of the information presented here was obtained from the Additional Petroleum Sites Investigation Technical Memorandum (PRC 1995a) and the Petroleum Sites Corrective Action Plan (CAP) (PRC 1994a).

1.2.1 Physical Setting

MFA is located near the southwestern edge of San Francisco Bay in Santa Clara County, California (Figure 1). It is bordered by salt evaporation ponds on the north, Lockheed Missile and Space Company's Lockheed Aerospace Center on the east, U.S. Highway 101 on the south, and Stevens Creek on

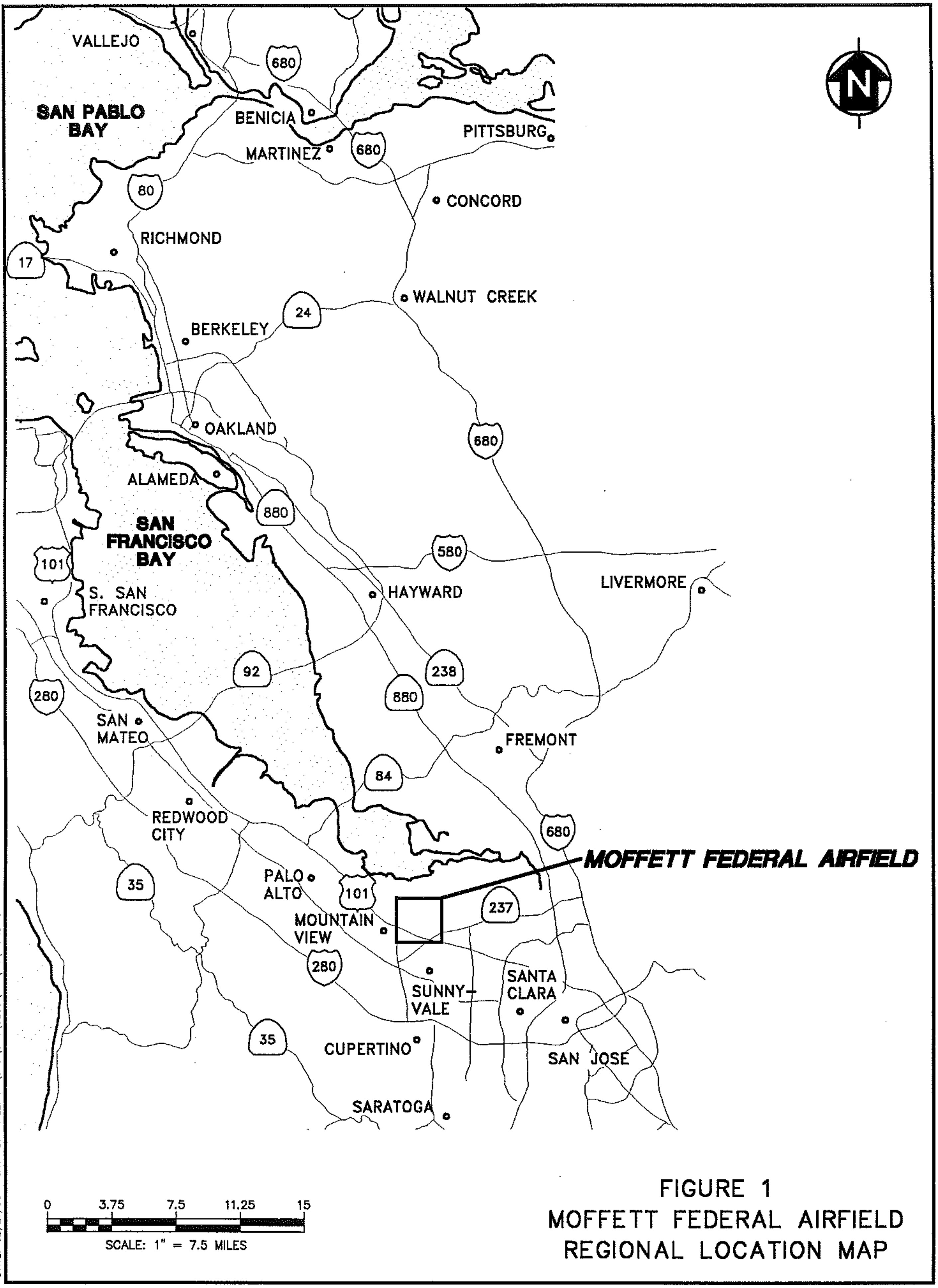


FIGURE 1
MOFFETT FEDERAL AIRFIELD
REGIONAL LOCATION MAP

the west. MFA also borders the cities of Mountain View and Sunnyvale, California. Sunnyvale is located east of Mountain View, and both cities are adjacent to the southern portion of MFA. The National Aeronautics and Space Administration (NASA) Ames Research Center is located west and north of MFA.

Historically, tidal salt marsh and mud flats covered extensive areas of the southern portion of the San Francisco Bay near MFA; most of these areas, however, have been eliminated or greatly altered by fill material. The large area north and northeast of MFA was diked and is now used as commercial salt evaporation ponds. Coyote Creek and Guadalupe Slough drain into San Francisco Bay east of MFA, and Stevens Creek drains into the bay on the western side of MFA. About 40 acres of wetlands located along the northern portion of MFA are the only natural surface water features at MFA. Another wetland area consisting of approximately 80 acres lies north of the Ames Research Center. These areas provide habitat for various mammals, birds, and other species.

1.2.2 Installation History

MFA was continuously operated by the U.S. military since it was commissioned in April 1933 to support the West Coast dirigible program. In October 1935, the station was transferred to the Army Air Corps for use as a training base. Ames Aeronautical Laboratory was granted a permit in 1939 to use part of the station.

In April 1942, the base was returned to Navy control and was renamed Naval Air Station (NAS) Moffett Field. In 1949, the station became home to the Military Air Transport Service Squadron. By 1950, NAS Moffett Field was the largest naval air transport base on the West Coast and became the first all-weather naval air station. In 1953, the station became home to all Navy fixed-wing, land-based antisubmarine craft. A weapons department was formed on the base in 1954. In February 1966, the base activated its high-speed refueling facilities. During reorganization of the station in 1973, it became the headquarters of the Commander Patrol Wings, U.S. Pacific Fleet.

During the 1980s and early 1990s, the mission of NAS Moffett Field was to support antisubmarine warfare training and patrol squadrons. The station supported more than 70 tenant units, including the Commander Patrol Wings, U.S. Pacific Fleet, and the California Air National Guard. At one point, NAS Moffett Field was the largest P-3 base in the world, with nearly 100 P-3C Orion patrol aircraft. These aircraft were assigned to nine squadrons supported by 5,500 military, 1,500 civilian, and 1,000 reservist personnel. No heavy manufacturing or major aircraft maintenance was conducted at NAS Moffett Field, but a significant amount of unit- and intermediate-level maintenance occurred. In April 1991, the station was designated for closure as an active military base under the Department of Defense Base Realignment and Closure (BRAC) program. MFA was closed as an active military base and transferred to NASA in July 1994. At that time, NAS Moffett Field was renamed MFA. The Navy plans to continue environmental restoration activities and remains responsible for remediating contamination caused by Navy operations in accordance with a memorandum of understanding between the Navy and NASA.

1.2.3 Site History

Site 5 was developed to manage bulk fuel storage and distribution at MFA. Four jet petroleum number 5 (JP-5) bulk fuel underground storage tanks (USTs) were constructed during 1952 in an area surrounded by Macon Road and two unnamed patrol roads. Each tank has a capacity of 567,000 gallons. Figure 2 illustrates the location of the four storage tanks.

Five french drains were constructed adjacent to the tanks. The drains were used to dispose of residual fuel, sediment, and water that was periodically pumped from the tank bottoms as part of tank maintenance. Navy records indicate that each drain consisted of an 8-foot deep by 8-foot wide cylinder of crushed rock. A drain line connected the tank sumps to the drains. During storage tank maintenance, the drains were filled until water/fuel began to puddle at the surface; then, an adjacent drain was filled until the tank sumps were adequately emptied (PRC 1994b). According to the Initial Assessment Study by the Naval Energy and Environmental Support Activity (1984), this practice of using french drains was initiated in 1951 and stopped in the mid-1960s.

1.3 REGULATORY BACKGROUND

Petroleum corrective action requirements changed dramatically during the study period. When the field work plan was developed, the San Francisco Bay Regional Water Quality Control Board (RWQCB) and the Navy had negotiated a groundwater cleanup level of 700 μg/L for extractable-phase total petroleum hydrocarbons (TPH-e). Historically, groundwater TPH-e contaminant concentrations at Site 5 had been greater than 700 μg/L, and TPH-e contaminant concentrations were above this cleanup level at other sites on MFA.

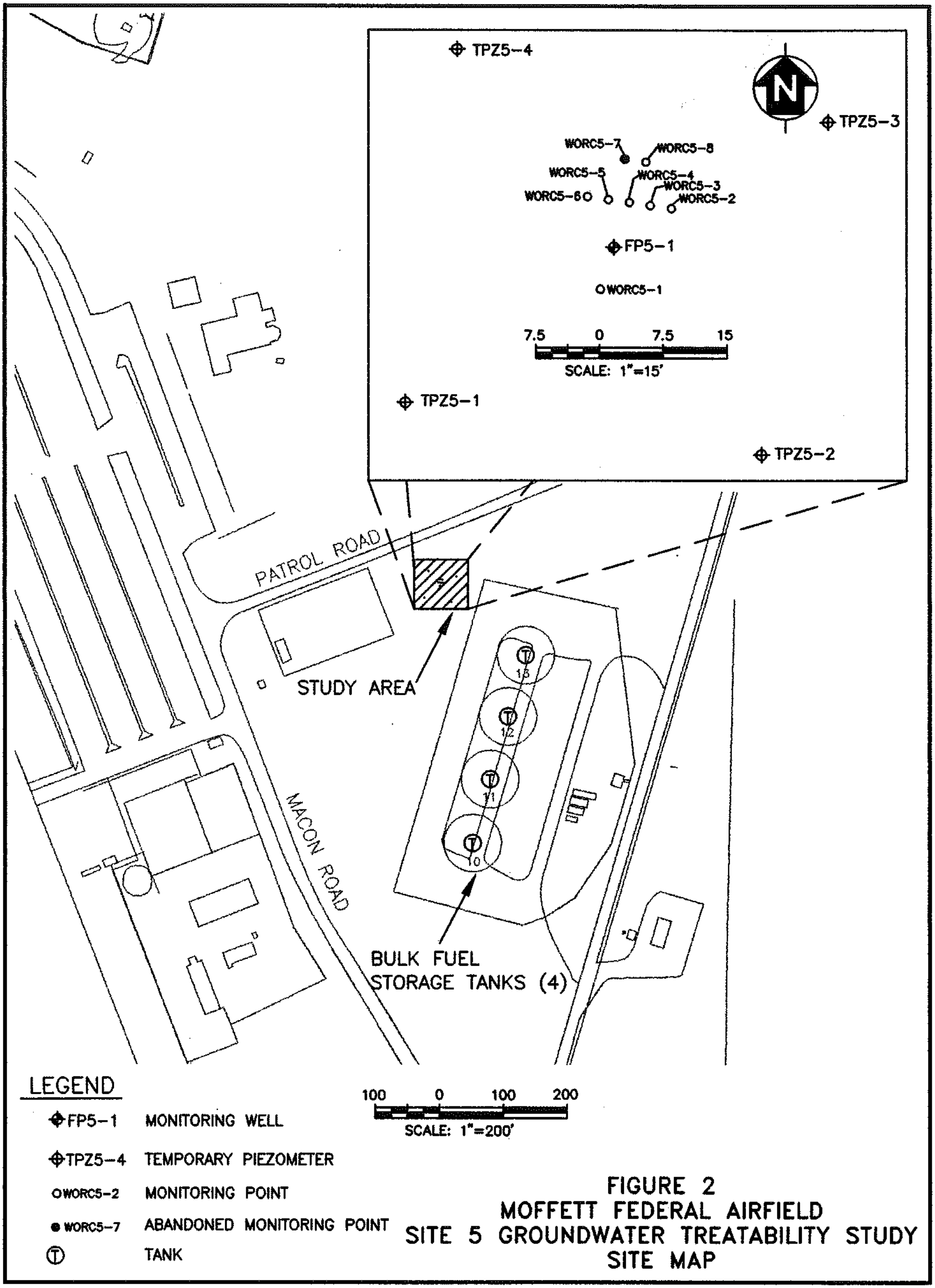


FIGURE 2
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
SITE MAP

DATE: 06-20-96 TWL DN FILENAME: C:\PROJECT\MOFFETT\SITESRD\FIG2.DWG

In October 1995, Lawrence Livermore National Laboratory (LLNL) presented its Recommendations to Improve the Cleanup Process for California's Leaking Underground Fuel Tanks (Rice and others 1995). The report recommended the following major regulatory policy revisions: (1) evaluate petroleum spill sites for risk to human health and the environment; and (2) select natural attenuation over active remedial systems (such as groundwater pump and treatment systems) as the corrective action alternative when the release does not present an unacceptable current risk.

The State Water Resources Control Board (SWRCB) accepted the LLNL recommendations and recommended that each RWQCB close low-risk soil cases, and that long-term groundwater monitoring replace active remediation in low-risk groundwater cases (SWRCB 1995). It recommended that the American Standards for Testing and Materials (ASTM) risk assessment method (ASTM 1995) be used to evaluate risks to human health

The San Francisco Bay RWQCB presented supplemental instructions to the SWRCB interim guidance (RWQCB 1996). The supplement provided definitions of low-risk soil and low-risk groundwater cases, and provided a question and answer fact sheet. It recommended that soil-only cases be closed if they do not present an unacceptable risk, and "managing low-risk groundwater impact cases utilizing natural bioremediation as the preferred remedial alternative."

These recommendations represented a substantial change in management of petroleum spill sites. The recommendations were labeled interim guidance, and were subject to change pending forthcoming State of California legislation (state bill 1764) and revisions to SWRCB Resolution 92-49. (Both the legislation and the revised resolution are anticipated to be approved in 1996.) Since the guidance was interim, and organized environmental groups were expected to object to the proposed changes, the study was continued.

1.4 GEOLOGY

Geologic information provided below has been compiled from the Geology and Hydrogeology Technical Memorandum (PRC and James M. Montgomery [JMM] 1992a). This document provides additional information regarding MFA geology.

1.4.1 Area Geology

MFA is located at the northern end of Santa Clara Valley Basin. The land is relatively flat, ranging from 2 feet below to 36 feet above mean sea level (msl). The Santa Clara Valley Basin is a Pliocene age, northwest-trending structural depression between the San Andreas and Hayward faults. The valley is bordered on the west by the Santa Cruz Mountains and on the east by the Diablo Range.

Regionally, the Santa Clara Valley contains up to 1,500 feet of interbedded alluvial, fluvial, and estuarine deposits (Iwamura 1980). Locally, these sediments consist of varying combinations of clay, silt, sand, and gravel that represent interfingering of estuarine and fluvial depositional environments during the late Pleistocene and Holocene epochs. The interfingering of fluvial and estuarine sediments in southern San Francisco Bay is related to world-wide fluctuations in sea level during glacial and interglacial episodes of the late Quaternary period (PRC and JMM 1992a). The fluvial sediments were derived from the Santa Cruz highlands west and south of the basin and deposited on an alluvial plain bounded by alluvial fan deposits to the west and baylands to the northeast (Iwamura 1980). Iwamura's surface geologic maps indicate that alluvial fan deposits extend toward the basin approximately to U.S. Highway 101, which forms the southern boundary of MFA. Shallow deposits in the area around MFA are anastomosing (branching) river and flood plain deposits. Estuarine deposits are found at the extreme northern end of MFA.

A geologic map of the Santa Clara Valley (Helley and others 1979) shows that MFA lies between two primary (trunk) stream channels. Stevens Creek is an active channel. The outline of an abandoned channel east of MFA can also be discerned. The areas between these channels consist of flood plain and fresh water marsh environments that were repeatedly dissected by secondary (distributary) channels and crevasse splay deposits. The distributary channel and crevasse splay deposits were formed during floods when water breached the levees of established streams and spread across the adjacent floodplain. Lenticular or stringer-like sand and gravel bodies are deposited along the path of the most concentrated flow, while thin sheets of silty and clayey sands (crevasse splay deposits) radiate from where the levee was breached.

1.4.2 Site 5 Geology

The shallow lithology at Site 5 consists primarily of alluvial silt and clay with minor fine sand. The sand occurs as thin stringers or mixed within the silt and clay matrix. This lithology is typical of distal alluvial deposits or crevasse splay deposits found adjacent to the southern border of the San Francisco Bay.

Previous investigations have identified two shallow sand and gravel channels at Site 5. The channels have been traced from the southern end of the four bulk fuel USTs to the Moffett golf course north and northwest of the USTs. Both channels are positioned in the shallow saturated zone. The upper channel appears variably saturated, depending on the piezometric head of the water table. The lower channel is slightly deeper (approximately 12 to 16 feet below ground surface [bgs]). It is not clear whether the channels are hydraulically connected.

The upper channel passes through the west side of the study area. A sandy gravel interval was observed at 8 to 9 feet bgs in cores collected at the site. The gravel appears to extend laterally across the study area. Sustained yield in a product recovery test indicates the gravel is in hydraulic connection with the upper channel. The deeper channel appears not to cross through the study area.

1.5 HYDROGEOLOGY

Hydrogeologic information provided below has been adapted from the Petroleum Sites CAP (PRC 1994a), which was compiled from the Geology and Hydrogeology Technical Memorandum (PRC and JMM 1992a), the Operable Unit 4 (OU4) Feasibility Study (FS) report (PRC 1992), and the OU5 FS report (PRC 1995b). These documents provide additional information regarding MFA hydrogeology.

The hydrogeologic setting at MFA consists of alluvial sand and gravel aquifers separated by low permeability silt and clay aquitards. In the interior part of the Santa Clara Valley, the numerous aquifers have been divided into two broad zones or sequences: the upper-aquifer sequence (A and B aquifers) and the lower-aquifer sequence (C aquifer). The upper-aquifer sequence is generally unconfined, although it is semiconfined in places. The lower-aquifer sequence is confined under a laterally extensive clay aquitard at depths of 140 to 200 feet bgs. Water-bearing materials in the upper zone are generally thin and discontinuous. Aquifer materials range from silty to fine sand to coarse gravel.

The A aquifer has been divided into two zones: a shallow 5- to 35-foot deep zone referred to as the A1-aquifer zone, and the deeper 35- to 65-foot deep zone referred to as the A2-aquifer zone. Predominant lithologies include fine-grained silt and clay within these zones. Permeable units that comprise the productive parts of these aquifer zones are thin (3 to 20 feet thick) discontinuous channels and lenses of sand and gravel. These sediments were deposited by a branching fluvial channel system that traversed alluvial plain and marsh environments, creating discontinuous, lenticular sand bodies that are surrounded by finer-grained deposits.

Groundwater in the A and B aquifers generally flows northward toward San Francisco Bay. The horizontal groundwater flow gradient averages about 0.004 to 0.005 feet per foot in the A and B aquifers (PRC and JMM 1992a). Hydraulic conductivity values estimated from aquifer tests (Harding Lawson and Associates [HLA] 1988; PRC 1992) are greater in the A aquifer (ranging from 5.7 to 420 feet per day [ft/day]) than in the B aquifer (0.35 to 36 ft/day). This difference is consistent with the overall coarsening upward of sediment grain size observed from the B aquifer to the A aquifer. The vertical gradients between the B and overlying A aquifers are variable but are generally upward, and probably result from localized confining conditions (PRC 1992).

Site 5 hydrogeology is consistent with general hydraulic conditions observed at MFA. Most of the soil observed in borehole cores consist of silt and clay with varying amounts of fine sand. Coarse sand and gravel channel deposits are limited in lateral and vertical extent. Groundwater velocity is most likely several orders of magnitude higher in these channel deposits than in the surrounding silt and clay materials, and groundwater migration is subsequently controlled by the distribution of these channel deposits.

1.6 NATURE AND EXTENT OF CONTAMINATION

Information regarding the nature and extent of contamination at Site 5 has been adapted from the Additional Petroleum Sites Investigation Technical Memorandum (PRC 1995a). Discussion on the extent of contamination has been restricted to the shallow aquifer, since the primary contaminant of concern is lighter than water.

This technical memorandum discusses petroleum contamination at Site 5 and refers to established cleanup levels for groundwater. Cleanup levels were negotiated with and accepted by the California Department of Toxic Substances Control (DTSC) and the San Francisco Bay Area RWQCB. The negotiated cleanup level for extractable-phase petroleum is 150 milligrams per kilogram (mg/kg) in soil and 700 μg/L in groundwater.

In December 1995, the state of California modified its standard cleanup policy to incorporate suggestions provided in a report completed by LLNL (SWRCB 1995). The suggestions included natural attenuation of petroleum hydrocarbons in soil and groundwater at sites where the petroleum release does not pose an immediate human or environmental threat. The study also suggests that human health and environmental risk from exposure to specific petroleum compounds be assessed at each site, and corrective action tailored to manage the assessed risk. The study concluded that natural attenuation should be the selected corrective action alternative at most petroleum spill sites.

The San Francisco Bay Area RWQCB recommended that the Navy use the negotiated cleanup levels as a benchmark for cleanup levels, or alternatively, evaluate human health and environmental risks at petroleum spill sites and establish corrective action plans that mitigate unacceptably high risk levels (RWQCB 1996).

The Navy has the option to use the negotiated cleanup levels as default concentrations, or evaluate the human health and environmental risks from exposure to specific petroleum constituents and mitigate unacceptable risks. This decision is beyond the scope of this technical memorandum, but is further discussed in Section 7.0.

1.6.1 Soil Contamination

Site 5 encompasses the areas adjacent to and including the active fuel farm on the eastern side of MFA (see Figure 2). The majority of fuel-contaminated soils are adjacent to four above-described bulk fuel USTs in the northern portion of Site 5. Tanks 10 and 11 held aviation gasoline (AVGAS) and Tanks 12 and 15 held jet petroleum (JP)-4 until 1962. From 1962 to 1973, all four tanks were used to store JP-4. From 1973 until 1994, the tanks were used to store JP-5. In July 1994, the Department of Defense Fuel Supply assumed operation and responsibility for the fuel storage and delivery system at MFA. From June 1995 to the present, the tanks have been used to store JP-8.

Subsurface soils at Site 5 have been contaminated by fuel-and-water mixtures disposed of in the french drains, fuel spills, and possibly from leaking pipes and USTs. Contamination primarily resides in the capillary fringe zone at depths of about 6 to 10 feet bgs. Figure 3 shows the estimated extent of soil contamination associated with the bulk fuel storage tanks at Site 5 as indicated from analysis of soil samples collected during previous investigations (PRC 1995a).

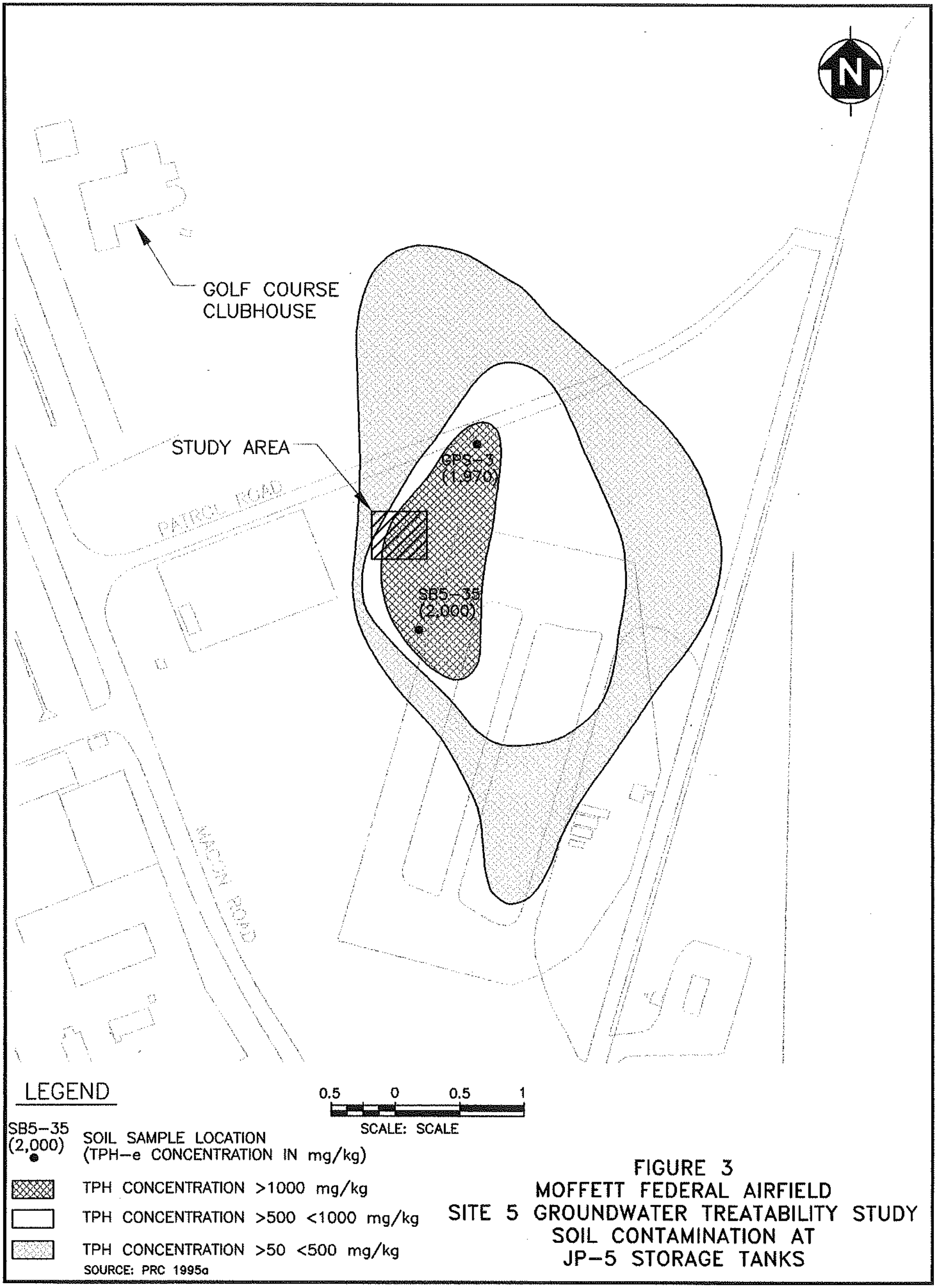


FIGURE 3
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
SOIL CONTAMINATION AT
JP-5 STORAGE TANKS

As indicated in Figure 3, most contaminated soils at Site 5 reside just north and northwest of USTs 10 through 13. Numerous soil samples in this vicinity exhibit TPH-e concentrations in excess of 1,000 mg/kg, including a sample containing 2,000 mg/kg TPH-e at boring SB5-35 and 1,970 mg/kg TPH-e at Geoprobe coring location GP5-3. Since the majority of fuel resulting in soil contamination was likely released to the subsurface many years ago, fuel in soil samples is highly degraded; analytical laboratory sample chromatograms do not adequately match fresh JP-5 fuel standard chromatograms to allow certain identification of constituents. Consequently, the laboratories quantify most soil contamination as TPH-e as other heavy components rather than TPH-e as JP-5.

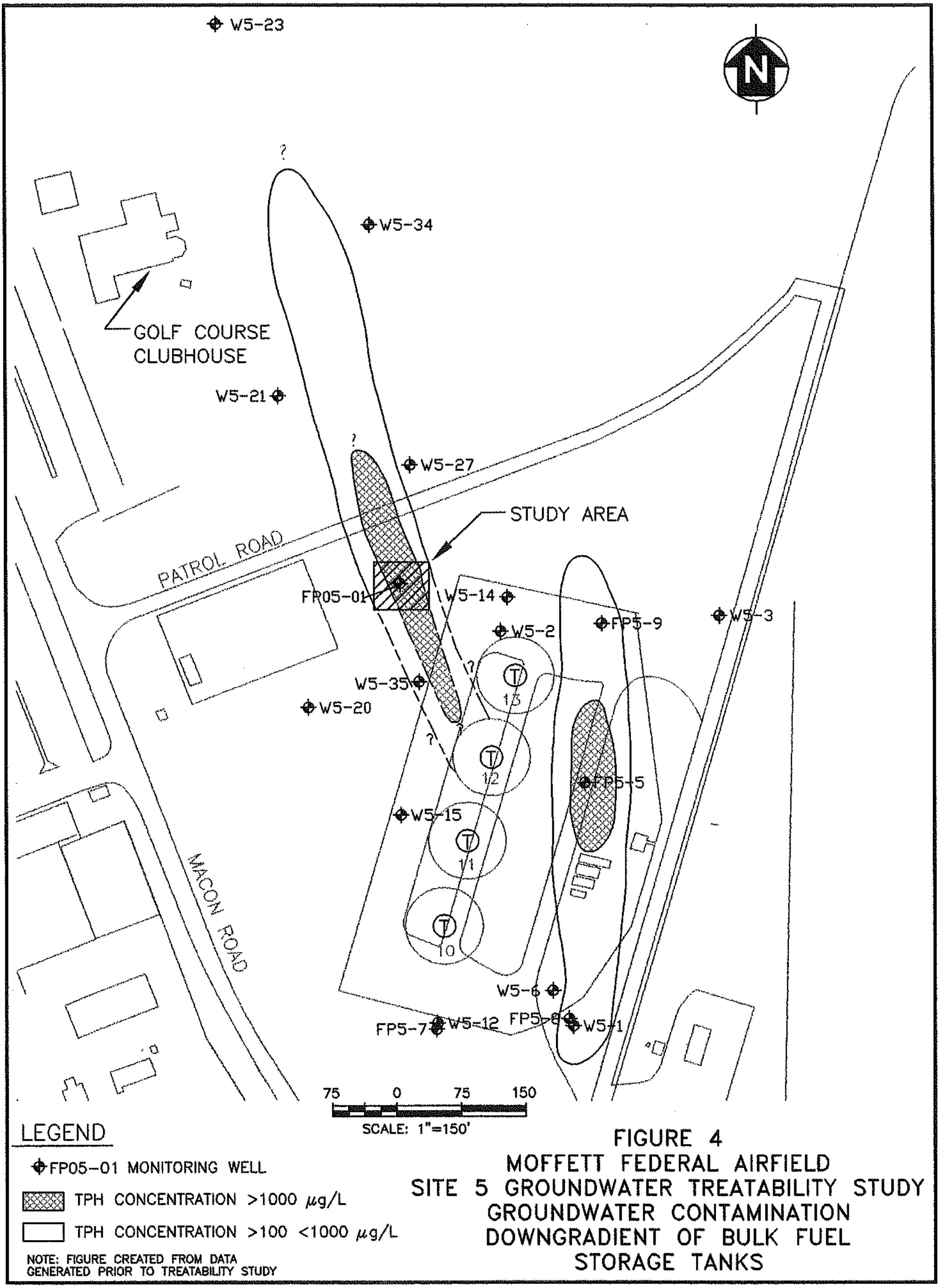
1.6.2 Groundwater Contamination

Petroleum-contaminated groundwater in the A1-aquifer zone exists near the four USTs, as illustrated in Figure 4. The groundwater plume appears to originate near the tanks and extends north beneath the MFA golf course. Two isolated water samples collected from the southern portion of Site 5 contained TPH-e levels in excess of the 700 μg/L cleanup level; however, no concentrations observed above the detection limits for TPH-e in samples from nearby locations indicates a very limited extent of contamination. As with soils, the contaminant of concern in groundwater is JP-5. Most TPH-e detections in groundwater have been qualified as TPH-e as other heavy components because the weathered fuel in the samples does not adequately match fresh JP-5 standard chromatograms.

The A2-aquifer zone appears to be uncontaminated by petroleum compounds. Groundwater elevations at several A1-A2 aquifer zone well pairs across MFA indicate a flat to upward hydraulic gradient. The A1 and A2 aquifers are discontinuously separated by a clay aquitard. Since the soluble components that make up JP-5 are lighter than water, it is unlikely that the A2 aquifer has been affected by JP-5 releases.

Water samples collected from Site 5 monitoring well FP5-1 have historically contained up to 2,000 mg/L TPH-e, and all samples collected from this well prior to the ORC treatability study had concentrations above 1,000 μg/L TPH-e. Also, a thin layer of floating product was detected on the water surface within the well for about an 18-month period. This product layer was removed during a product recovery test conducted in 1994, and the free product layer dissipated after the test was completed.

Analysis of groundwater samples collected shortly after the product removal test indicated much lower concentrations and fluctuating concentrations with time. Pre-ORC concentrations dropped to their lowest value (1.8 mg\L) in a sample collected in May 1994. The last two samples (collected in September 1994



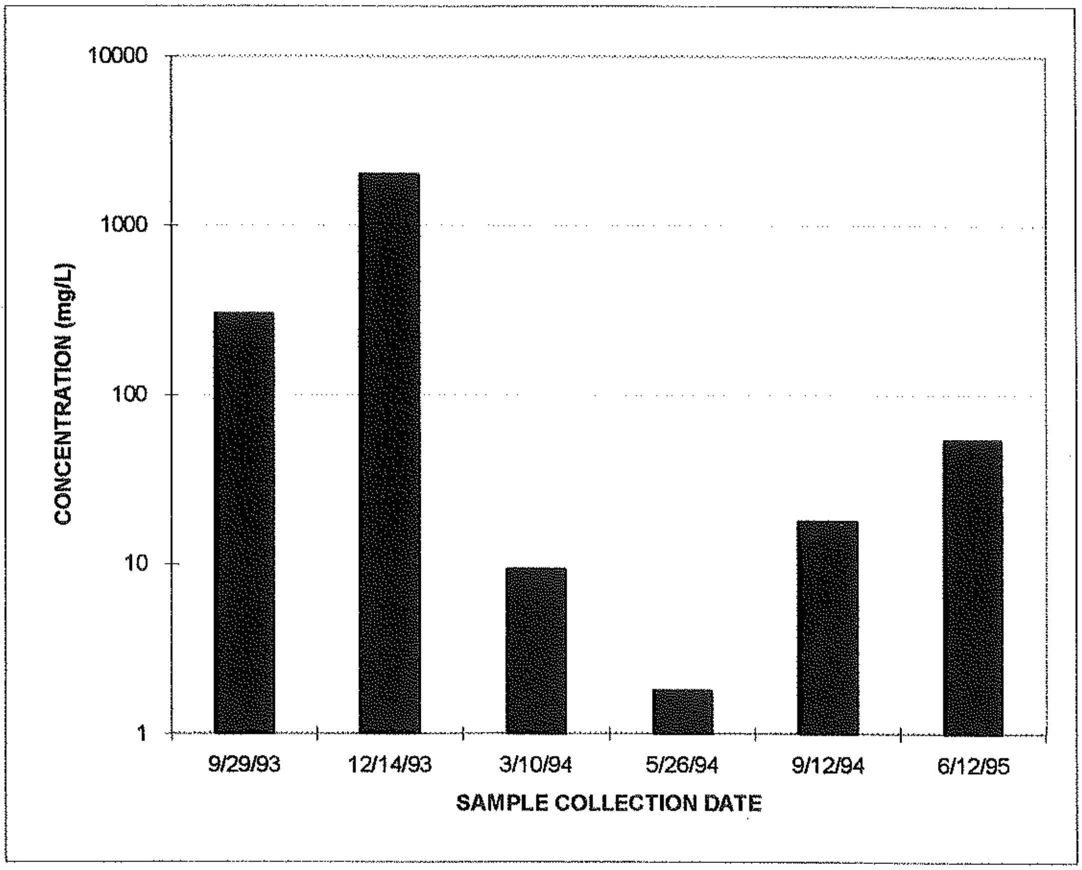
NOTE: FIGURE CREATED FROM DATA GENERATED PRIOR TO TREATABILITY STUDY

FIGURE 4
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
GROUNDWATER CONTAMINATION
DOWNGRADIENT OF BULK FUEL
STORAGE TANKS

and June 1995) indicated sharply increasing concentrations. No free-phase fuel has been detected in well FP5-1 since PRC removed product during the product recovery test in May 1994. Figure 5 illustrates concentration changes with respect to time for samples collected from FP5-1.

These data indicate changing conditions over time at the study area. TPH-e concentrations, however, were continuously above the agency approved action levels for TPH-e in groundwater. The Navy was, therefore, required under the action level agreement with RWQCB to remediate groundwater that was contaminated with TPH-e at levels above the approved action level. In general, groundwater contamination appears to follow the upper shallow permeable channel that trends north from western side of the bulk fuel USTs. The channel has been traced north beneath the southern part of the MFA golf course. Fuel contamination in groundwater has been detected in samples approximately 600 feet downgradient (north) of the USTs, as illustrated in Figure 4.

FIGURE 5
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
SUMMARY OF PETROLEUM CONTAMINATION IN GROUNDWATER SAMPLES FROM FP5-1



2.0 SUMMARY OF FIELD ACTIVITIES

Field activities were conducted from September 1995 until early April 1996 to evaluate the performance of ORC to enhance petroleum degradation. Field activities can be subdivided into the following (chronologically arranged) tasks:

- Piezometer installation-September 11, 1995
- Gradient evaluation-September 12, 1995
- Monitoring point installation-September 12 and 13, 1995
- Biological sample collection-September 25, 1995
- Tracer testing-September 26 through October 12, 1995
- Baseline sample collection-October 19, 1995
- ORC installation-October 20, 1995
- Groundwater sample collection-November 3 and 17 and December 1 and 15, 1995; January 12, February 8, March 8, and April 5, 1996
- ORC removal-March 8, 1996

The following sections describe these activities.

2.1 PIEZOMETER INSTALLATION

Four piezometers were installed in a square pattern around monitoring well FP5-1 to evaluate flow direction of the shallow groundwater in the ORC test area (Figure 2). Each piezometer was installed 3 to 4 feet into the first saturated interval, which was observed at approximately 5 feet bgs. The piezometers were constructed of 1-inch diameter polyvinyl chloride (PVC) pipe that was slotted with a saw on the bottom 12 inches. The PVC pipe was installed in a corehole created by the Geoprobe soil coring system (SCS). The annular space between the corehole wall and the tubing was filled with sand to the piezometric surface, and with granular bentonite from the top of the sand to the ground surface.

Following installation, the casing of each piezometer was marked with a pen at the same elevation as the top of the protective casing on well FP5-1. A manometer was used to measure and mark the elevation of each piezometer relative to well FP5-1. One end of the manometer was placed so the bottom of the meniscus of the water in the manometer tubing was level with the reference point (the top of the FP5-1 protective casing); the other end of the manometer tubing was placed successively next to each piezometer, and a mark was placed on each piezometer casing that corresponded to the bottom of the manometer meniscus. The piezometer casing was then cut off at this mark.

2.2 GROUNDWATER GRADIENT EVALUATION

Groundwater within the piezometers was allowed to equilibrate, then its elevation was measured. The measurements were used to determine groundwater gradient direction. Groundwater flow direction was assumed to be perpendicular to lines of equal elevation, and string lines were laid out to mark the measured flow direction. Table 1 presents measured groundwater levels in the piezometers and in FP5-1.

During the ORC portion of the study, groundwater elevations were measured prior to each sample collection event. The data were collected to evaluate change in gradient direction and magnitude. Section 3.0 summarizes the data, and Section 5.0 discusses conclusions drawn from data analysis.

2.3 MONITORING POINT INSTALLATION

Seven monitoring points were installed around well FP5-1 to complete an aquifer tracer test and monitor groundwater chemistry during the ORC test. One point (WORC5-1) was positioned 5 feet directly upgradient of well FP5-1. Five temporary monitoring points (WORC5-2, WORC5-3, WORC5-4, WORC5-5, and WORC5-6) were positioned in a row perpendicular to the calculated groundwater flow direction, 5 feet downgradient of well FP5-1. The seventh point (WORC5-8) was positioned 10 feet downgradient of well FP5-1 and 6 inches perpendicular to an imaginary line that extended directly downgradient of well FP5-1. Figure 2 illustrates monitoring point positions.

Each monitoring point was installed in a Geoprobe SCS corehole. The Geoprobe SCS was used to minimize disruption to the saturated zone formation, and hence, minimize changes to in situ groundwater hydraulics and chemistry. Each point typically was constructed of a 5-feet long PVC screen section and PVC casing. The annular space between the screen and the corehole wall was filled with coarse sand to the top of the screen, and the remainder of the corehole was filled with granular bentonite. An attempt was made to install each screen completely within the first saturated interval; however, sloughing sand and gravel in the saturated zone prevented installation of the screen to completely span the desired depth in some monitoring points. Table 2 summarizes the monitoring point screen intervals.

TABLE 1

MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER FEASIBILITY STUDY
WATER LEVEL DATA

MEASUREMENT DATE	WATER LEVELS (Depth in feet below top of casing)				
	TP-25	TP-25	TP-25	TP-25	FP5-1
September 11, 1995	10.73	10.74	10.84	10.85	ND
September 25, 1995	10.65	10.64	10.74	10.75	10.67
September 26, 1995	10.66	10.65	10.76	10.77	ND
September 29, 1995	10.67	10.68	10.81	10.82	10.72
January 12, 1996	ND	9.62	9.75	9.72	9.67
February 9, 1996	ND	8.25	8.29	8.35	8.28
March 8, 1996	ND	8.75	8.82	8.87	8.81
April 5, 1996	ND	9.40	9.48	9.50	9.48

Notes:

ND	no data

TABLE 2

MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
MONITORING POINT SCREEN INTERVALS

WELL DATA	MONITORING POINT DESIGNATION							
	FP5-1	WORC 5-1	WORC 5-2	WORC 5-3	WORC 5-4	WORC 5-5	WORC 5-6	WORC 5-8
Screen Top (feet, bgs)	3.0	7.0	8.6	8.3	7.0	8.6	7.3	7.2
Screen Bottom (feet, bgs)	13.0	12.0	13.6	13.3	13.5	13.6	12.3	12.2

Two pieces of 0.25-inch diameter polyethylene tubing were placed within each monitoring point to monitor two intervals within the screened monitoring zone. The shorter piece of tubing was positioned so that its open end was approximately 9.5 feet bgs, and the longer piece of tubing was positioned so that its open end was approximately 12 feet bgs. Each tubing was marked with a unique identifier. Figure 6 illustrates a typical monitoring point setup.

2.4 TRACER TEST

The tracer test was conducted to determine the groundwater travel time in the first saturated interval at the study area. This information would be used to select the sample collection interval after the ORC was installed in the source well, evaluate transverse dispersion in the aquifer, and help analyze such DO transport properties as consumption and retardation.

Bromine (in the form of crystalline potassium bromide) was used as the tracer chemical. The benefits of bromine include: low toxicity, high solubility, nonsorptive (conservative) properties , economical cost, detectable in low concentrations with field tests, and very low background concentrations in groundwater at Site 5.

The potassium bromide was dissolved in 5 gallons of distilled water in the PRC field trailer. At the same time, a single junction ion-selective probe for bromide ions (Cole Parmer Model H-27502-54) was calibrated against field-prepared standards according to the probe manufacturer's instructions. The probe was operated with an Orion Model 290A combination pH and ion concentration meter at a work station that was set up in the field trailer.

2.4.1 Tracer Injection

The bromide tracer solution was injected into monitoring well FP5-1 with a peristaltic pump. The tracer was injected into the midpoint of the screened interval that was below the piezometric surface, at approximately 2.5 gallons per hour. This rate did not cause a measurable increase in the static water level in the well. This precaution was taken to minimize interruption of the natural groundwater gradient and, consequently, the groundwater velocity across the site.

A second peristaltic pump was set up to withdraw water from the bottom of the screened interval and return it into the top of the screened interval of the injection well. This circulation action promoted uniform mixing of the tracer in the injection well water column and minimized gravity separation in the water column due to the high density of the bromide ion.

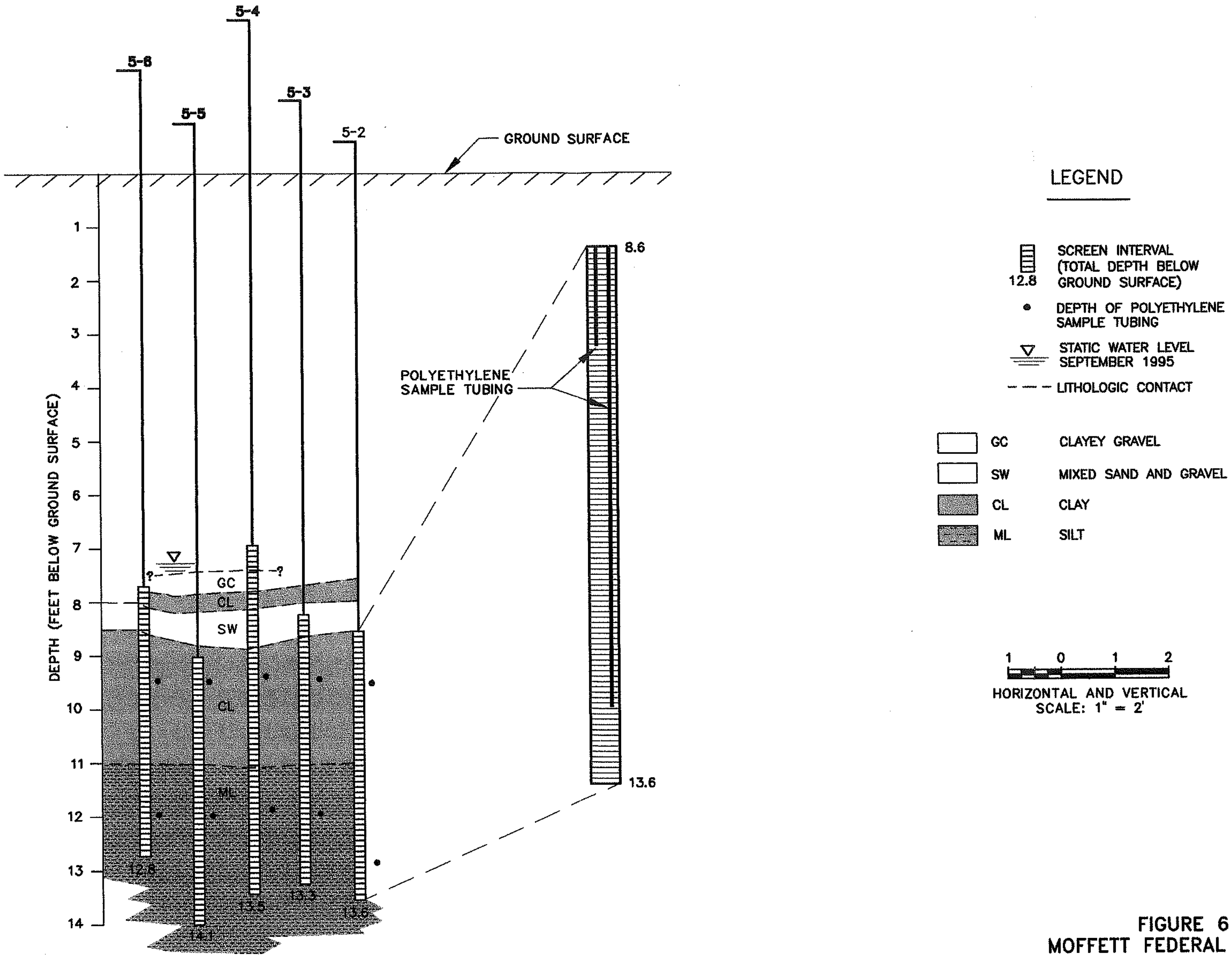


FIGURE 6
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
SCHEMATIC OF MONITORING POINT DESIGN

DATE: 10/08/96 JAY DN FILE NAME: R:CAD\044\02235\IRR\DPS\FIG6.DWG

Water samples were collected from the injection well during the injection period and analyzed with the ion-specific probe for bromide concentration. Samples were collected from the bottom and top of the water column. Initial analyses indicated the bromide was uniformly distributed throughout the water column in the well. Appendix A presents bromide analytical results.

2.4.2 Tracer Monitoring

As soon as the tracer solution was completely injected, groundwater samples were periodically collected from the seven monitoring points and from the injection well. Samples were withdrawn from the monitoring points with a peristaltic pump, through the previously installed polyethylene tubing. Prior to each sample collection, the tubing was purged of approximately two volumes of water. Samples were collected in uniquely labeled 40-milliliter vials, transported to the field trailer, and analyzed for bromide ion concentration.

Samples were collected from each monitoring point and from the injection well every 2 hours for the first 24 hours. After 24 hours of sampling at 2-hour intervals, the sampling interval was increased to 4-hour increments. After approximately 36 hours of sampling at 4-hour intervals, the sampling interval was increased to 8-hour increments. Six days after the tracer was injected, the sampling interval was increased to 12-hour increments. Sample collection continued until the slug of bromide-enriched groundwater passed the array of monitoring points and the measured bromide concentration in the monitoring points dropped to background concentrations (16 days).

The bromide probe was calibrated prior to analyzing each analytical group, and then it was rechecked in one standard following sample analyses to evaluate instrument drift. Instrument readings tended to drift upward during analysis of a given group of samples. The drift, however, did not appear to result in uninterpretable data, since the data were used to observe a relative maximum bromide concentration, rather than a quantified bromide value. The probe was stored in a weak bromide solution between analyses to maintain its condition and minimize instrument drift.

2.5 BASELINE GROUNDWATER SAMPLE COLLECTION

Immediately prior to the tracer test, samples were collected from well FP5-1 and monitoring points WORC5-1, WORC5-4, and WORC5-8 and analyzed for selected biological and chemical constituents.

Analyses included a comparative enumeration assay, and nutrient and cation metal concentrations. Each sampling point was purged of 1 gallon of water prior to sample collection.

One week after completion of tracer testing, samples were collected from well FP5-1 and each monitoring point (WORC5-1 through WORC 5-8) and analyzed for chemical constituents. Analyses included TPH-e, dissolved metals, major anions, nutrients, chemical oxygen demand (COD), and biochemical oxygen demand (BOD). Prior to sample collection, the polyethylene tubing at each sampling point was purged of 250 milliliters (ml) (approximately two volumes) of water. At the end of purging, a sample was collected and field analyzed for DO.

Each sample was collected from the lower sampling tube in the monitoring points, and from the midline sampling tube in well FP5-1. Each sample was given a unique identification number, stored in an ice-chilled cooler, and sent to the analytical laboratory under standard chain-of-custody procedures.

2.6 ORC INSTALLATION

After the baseline samples were collected, the ORC "socks" were installed in well FP5-1. The ORC consists of a proprietary powdered mixture of magnesium trioxide and Portland cement. A 1-foot-long tubular cloth sock holds the powdered mixture. Once the sock is placed in water, the cement sets up, thereby controlling the rate of oxygen release.

Seven socks were attached to each other with polyethylene rope and suspended in the water column in the well, so the ORC assembly extended through the entire saturated interval (8 to 13 feet bgs).

2.7 GROUNDWATER SAMPLE COLLECTION

Following ORC installation, groundwater samples were periodically collected from well FP5-1 and the monitoring points and analyzed for DO and petroleum contamination. Sample collection frequency was based on the tracer velocity observed during the tracer test. The first sample set was collected 2 weeks after the ORC was installed. Three additional sets of samples (the second, third, and fourth sets) were collected at 2-week intervals after the first sampling interval. The fifth and sixth sample sets were collected at 4-week intervals beginning 4 weeks after the four sample set. The ORC array was removed from well FP5-1 after the sixth sample set was collected. The seventh (final) sample set was collected 4 weeks after the ORC was removed. Table 3 summarizes the sample collection schedule and DO results.

TABLE 3

MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER FEASIBILITY STUDY
DISSOLVED OXYGEN CONTENT IN GROUNDWATER SAMPLES

SAMPLE ID	MEASURE-MENT METHOD	MEASUREMENT DATE								
		Oct 20, 1995[1]	Nov 3, 1995	Nov 17, 1995	Dec 1, 1995	December 15, 1995	Jan 12, 1996	Feb 9, 1996	Mar 8, 1996	April 5, 1996
		MEASURED DISSOLVED OXYGEN VALUES (mg/L)								
FP5-1	Horiba	1.20	>20	ND	ND	17.15	13.10	ND	7.75	0.71
	Hach	ND	ND	*	*	17	13	9	8	0.8
WORC5-1	Horiba	1.26	1.32	ND	ND	0.78	1.18	ND	0.81	0.62
	Hach	ND	ND	1.0	0.8	0.8	1.0	0.4	0.6	0.6
WORC5-2	Horiba	1.23	1.38	ND	ND	0.93	0.98	ND	0.87	0.74
	Hach	ND	ND	0.8	1.0	1.0	1.0	0.8	1.0	1.2
WORC5-3	Horiba	1.19	1.37	ND	ND	1.51	0.92	ND	0.60	0.85
	Hach	ND	ND	0.8	1.8	1.6	1.0	0.8	0.6	1.0
WORC5-4	Horiba	1.18	1.10	ND	ND	1.93	0.95	ND	0.74	0.81
	Hach	ND	ND	1.0	1.8	1.8	1.0	0.6	0.8	1.0
WORC5-5	Horiba	1.12	1.08	ND	ND	1.57	0.87	ND	0.69	0.83
	Hach	ND	ND	0.8	1.8	1.6	1.0	0.8	0.8	1.0

TABLE 3 (Continued)

MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER FEASIBILITY STUDY
DISSOLVED OXYGEN CONTENT IN GROUNDWATER SAMPLES

SAMPLE ID	MEASUREMENT METHOD	MEASUREMENT DATE								
		Oct 20, 1995[1]	Nov 3, 1995	Nov 17, 1995	Dec 1, 1995	December 15, 1995	Jan 12, 1996	Feb 9, 1996	Mar 8, 1996	April 5, 1996
		MEASURED DISSOLVED OXYGEN VALUES (mg/L)								
NALF Crows Landing WORC5-6	Horiba	1.09	1.23	ND	ND	1.04	0.91	ND	0.76	0.85
	Hach	ND	ND	0.8	1.0	1.0	0.8	1.0	1.0	1.0
WORC5-8	Horiba	1.86	1.55	ND	ND	0.87	1.10	ND	0.93	0.69
	Hach	ND	ND	1.2	1.0	1.0	1.2	0.8	1.2	0.8

[1] ORC installed immediately after sample calculation.

Samples were collected and handled in the same manner as the samples collected for baseline analysis. The polyethylene tubing in each sampling point was purged and groundwater at each sampling point was field analyzed for DO prior to sample collection.

DO measurements were completed following two field methods. First, the DO content of each sample was measured with an Horiba dissolved oxygen meter. Then, the DO content of each sample was measured with a Hach DO measurement kit. Results are discussed in Section 3.0.

3.0 ANALYSIS AND DATA SUMMARY

The following sections summarize the analyses, present and discuss the data that were collected to complete this treatability study, and assess laboratory data quality. Data types include groundwater data generated in the field and data generated in analytical laboratories.

3.1 TRACER TEST ANALYSIS AND DATA SUMMARY

There were 38 groundwater sampling events over an 18-day period during the tracer test. Samples were collected from two elevations (shallow and deep) at each monitoring point and from three elevations (shallow, intermediate, and deep) at well FP5-1. Each sample was analyzed for bromide ion concentration with a ion-specific probe. Appendix A presents the bromide data.

The analysis was completed by inserting the probe halfway into the sample vial and agitating the water in the vial with the probe until the concentration meter indicated a stable reading. (The meter indicated a stable reading with a beep.) Prior to analyzing each sample group, the probe was calibrated to five standards that bracketed the anticipated concentration range. The probe was recalibrated after half of the samples were analyzed. Also, once daily, the slope of the meter was checked to verify that it was within the acceptable range specified by the manufacturer.

For each well, time versus bromide concentration was plotted. The difference between the measured bromide concentrations in samples collected from the shallow sampling tubes and the deep sampling tubes appeared to be random. Thus, to reduce the severity of instrument variation, the bromide concentration values for samples collected from shallow and deep sampling tubes for each monitoring point were averaged.

A graphical comparison of the average of bromide concentrations for samples from all of the monitoring points revealed considerable instrument drift between sampling events. To calculate the net observed peak concentration, data from each of the wells were normalized by calculating the average of bromide concentration values over the test period from all of the monitoring points except WORC5-4 and WORC5-5 (the monitoring points through which the bromide appeared to pass). This average baseline value was then subtracted from the bromide concentration readings from each well. The result was a normalized concentration value less subject to error from positive or negative instrument drift.

The normalized bromide values were then plotted against time. Data for samples collected from monitoring points WORC5-4 and WORC5-5 showed significant increases in the bromide concentration. The maximum normalized bromide concentration was 3.78 milligrams per liter (mg/L) at 12.3 days in WORC5-4 and 9.49 mg/L at 11.3 days in WORC5-5. Nonlinear numerical regression using a fourth order polynomial equation was calculated to closely approximate the plotted data for WORC5-4 and WORC5-5 (Figure 7). The correlation coefficient (R^2), which quantifies the relative closeness between the regressed curve and the data curve (goodness of fit), was found to be 0.76 for WORC5-4 and 0.86 for WORC5-5. These coefficient values indicate a fair correlation between the data and the regressed curves.

The maxima of each of these regressed curves was determined to provide an estimate of the tracer travel time. (This determination assumes that the maximum calculated bromide value represents center of the bromide mass and, therefore, the average groundwater velocity.) The average travel time from well FP5-1 to point WORC5-4 was 9.9 days and from well FP5-1 to point WORC5-5 11.8 days, yielding groundwater velocities of 0.505 ft/day and 0.432 ft/day, respectively. The average groundwater velocity was then calculated to be 0.469 ft/day. This averaged value was used to select the sample collection interval during the ORC sample collection.

The bromide values for samples collected from the source well (FP5-1) were plotted against time on a semilogarithmic scale (see Figure 8). The plotted values yield a nearly straight line, indicating that the decreasing bromide concentration observed in samples from well FP5-1 followed an exponential decay and that the bromide moved as a slug of solute through the aquifer. The R^2 value for the exponential curve fit is 0.98, indicating not only a strong correlation, but also a nearly perfect fit. The nearly perfect fit indicates steady state groundwater flow during the test period.

The bromide mass balance was calculated to estimate the percentage of bromide that passed throughout the monitoring points during the test. The following assumptions were made to calculate the mass:

- The concentration found in each well was consistent for a 1-foot, cross-sectional width (6 inches on either side of the monitoring point).
- All bromide traveled through a 1.3-foot thick sandy gravel interval that was bound above by sandy silt and below by silty clay.
- The groundwater velocity during the test was 0.45 feet per day. That is, the bromide tracer was not retarded, and reflected the actual groundwater velocity value.

FIGURE 7
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
BROMIDE CONCENTRATIONS
IN MONITORING POINTS

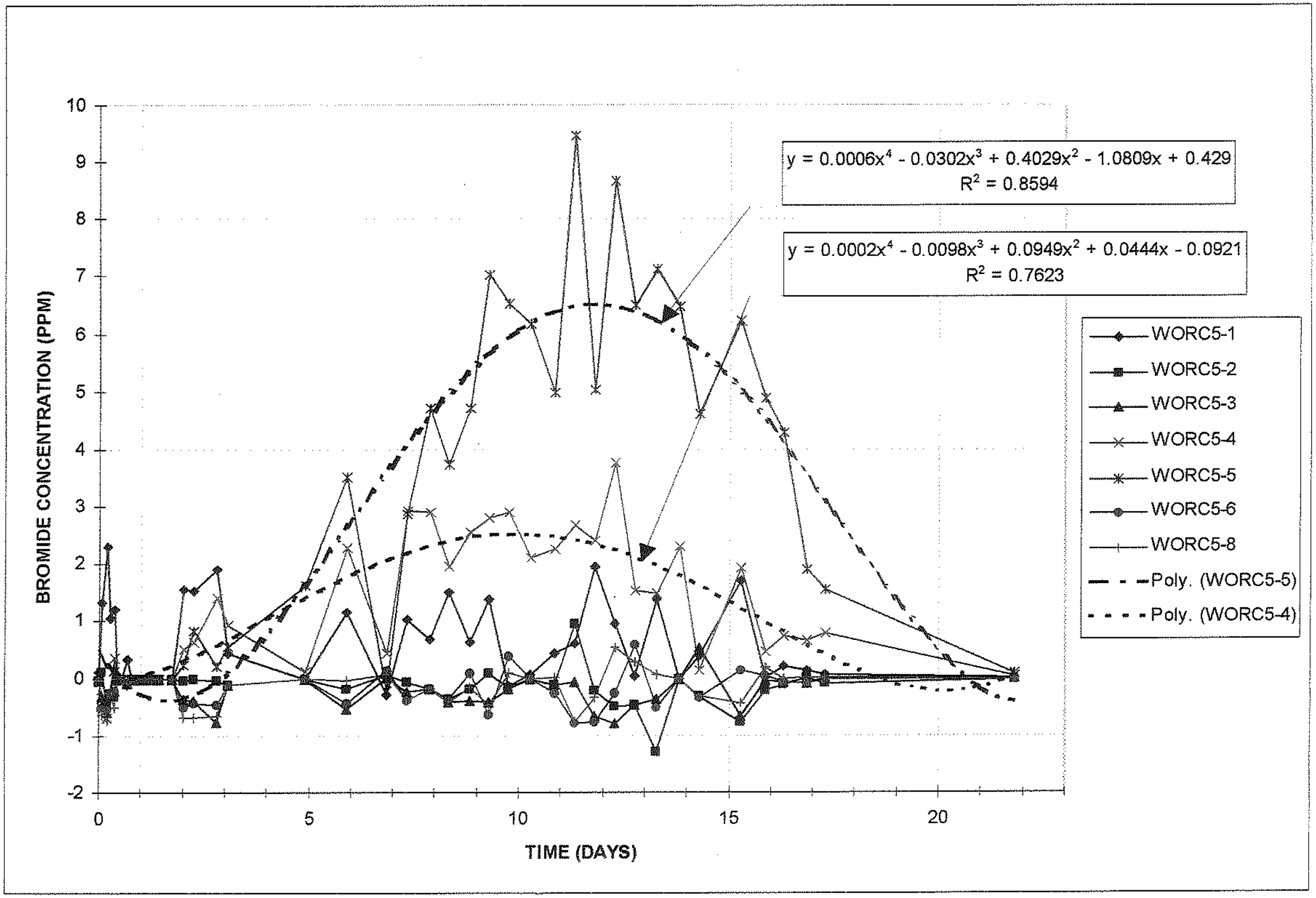
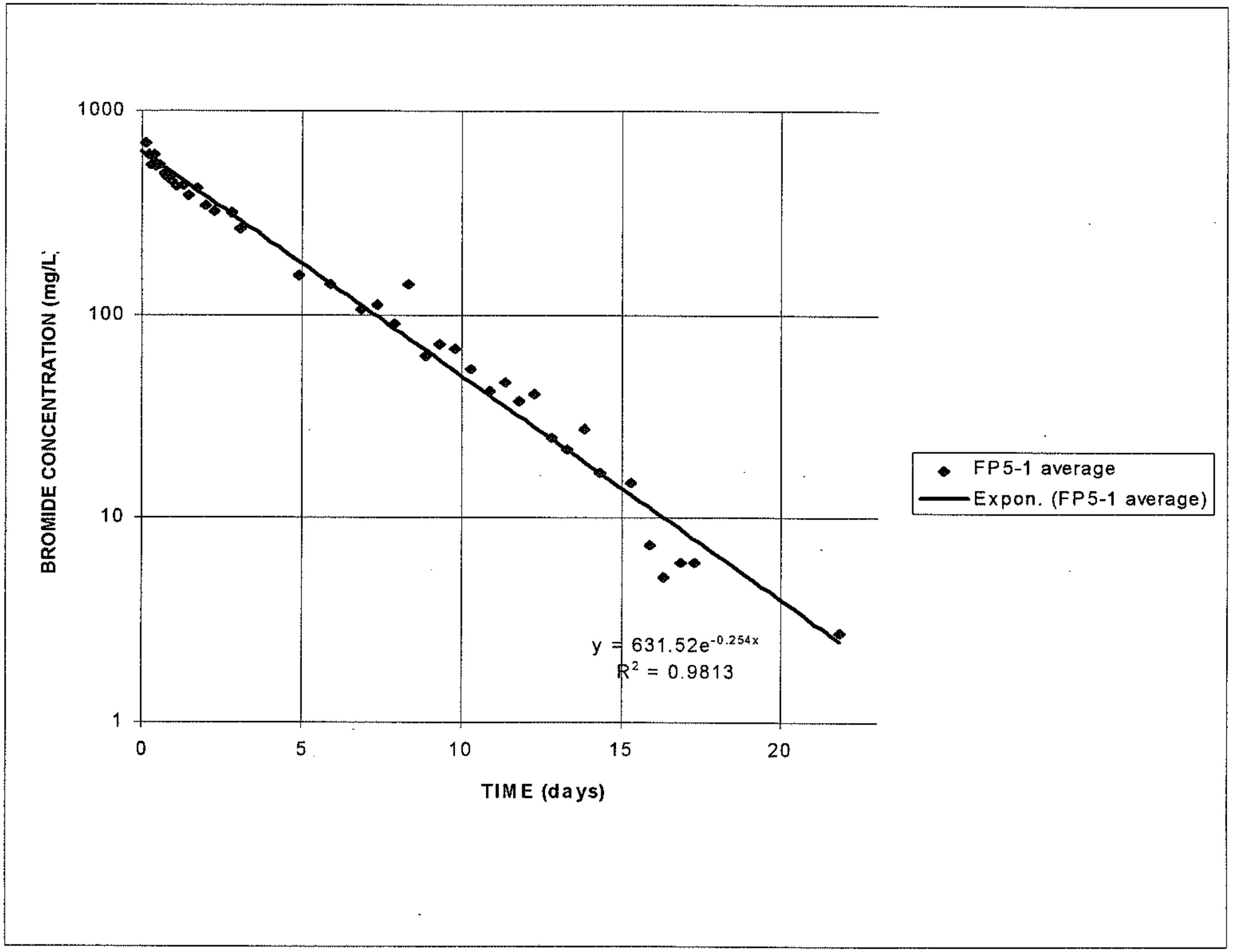


FIGURE 8
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
BROMIDE CONCENTRATIONS IN FP5-1
DURING TRACER TEST



The mass of bromide that traveled through each well was calculated by the following formula:

bromide mass = thickness of sandy gravel x travel path width x groundwater velocity x sum of measured concentration x total observed travel time of bromide

The sum of measured concentration was calculated by finding the area under the curve for measured bromide concentrations in points WORC5-4 and WORC5-5. The area was estimated by using the trapezoidal rule.

Using the above described formula, the total mass of bromide that passed through monitoring points WORC5-4 and WORC5-5 was approximately 1.6 grams. Approximately 9.45 grams of bromide were injected into FP5-1; therefore, approximately 17 percent of the injected bromide mass was observed to pass through the monitoring points.

3.2 GROUNDWATER ANALYSIS AND DATA SUMMARY

Before the ORC was installed, a baseline round of groundwater samples was analyzed for TPH-e contamination, several inorganic chemical constituents, DO, and biological activity. After the ORC was installed, eight rounds of samples were analyzed for TPH-e contamination.

Baseline groundwater samples were analyzed for TPH-e contamination and chemical constituents following U.S. Environmental Protection Agency (EPA) and California-modified EPA protocol. Chemical analyses included TPH-e (as JP-5), chemical oxygen demand, biological oxygen demand, nitrogen as ammonia, orthophosphate, total anions, and dissolved metals. The baseline analyses for TPH-e were completed in triplicate for each sample.

Baseline groundwater samples were also analyzed for total microbe and petroleum degrader microbe population counts. The laboratory that completed the biological analyses also analyzed the samples for available nutrients (Kjeldahl nitrogen, ammonia, nitrate, phosphorous, and potassium), total minerals, and heavy metals (arsenic, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, nickel, selenium, and zinc). Appendix B presents chemical and biological data.

The eight rounds of samples collected following ORC installation were analyzed for TPH-e as JP-5. All sample rounds included matrix spike and matrix spike duplicate (MS/MSD) sample pairs collected from monitoring point WORC5-8, and field duplicate samples collected from monitoring point WORC5-1. Groundwater elevations were also measured during each sample collection period.

3.2.1 Baseline Data Summary

Groundwater data generated over a 2-year period for samples collected from well FP5-1 indicate decreasing TPH-e concentrations initially, then increasing concentrations just before the to ORC was introduced. Concentrations dropped from an high of 2,000 mg/L (from a sample collected on December 14, 1993) to a low of 1.8 mg/L (from the baseline sample collected on May 26, 1994) then back to 54 mg/L (from a sample collected on June 12, 1995). Figure 5 illustrates historical TPH-e concentrations for samples collected from well FP5-1 prior to initiating this treatability study. Table B1 (Appendix B) presents these data.

Baseline sample analyses indicated slightly heterogeneous baseline TPH-e concentrations across the study area. The baseline sample from monitoring point WORC5-1 contained the highest TPH-e concentration (860 μg/L), and baseline samples from monitoring points WORC5-2 and WORC5-4 contained the lowest TPH-e concentrations (140 μg/L). The average baseline concentration for all monitoring point and source well samples is 304 μg/L. Table B2 (Appendix B) presents baseline TPH-e data.

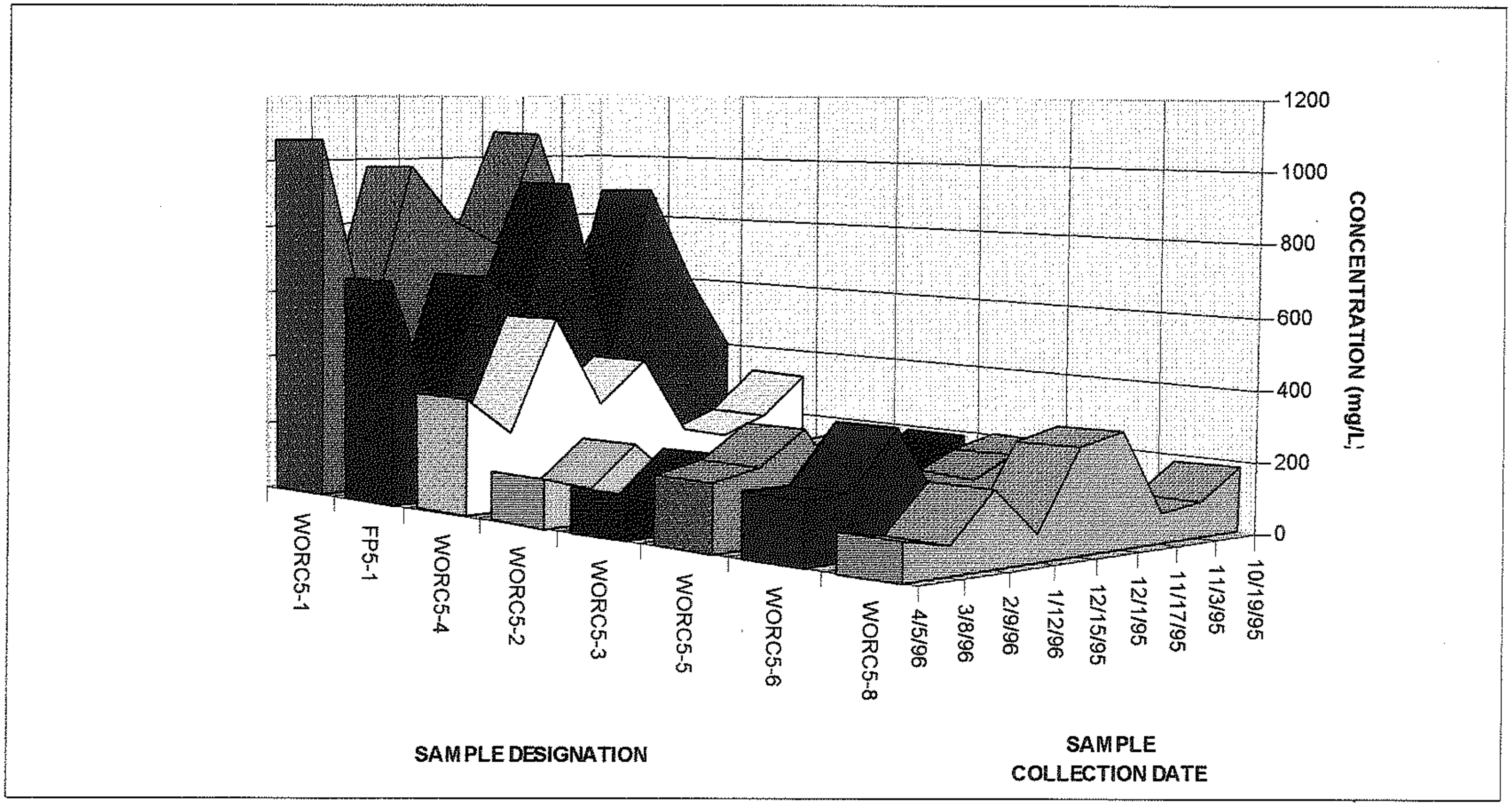
3.2.2 ORC Test Data Summary

Groundwater samples were analyzed for TPH-e to evaluate ORC effects on TPH-e concentrations in groundwater. Samples were analyzed by a California-certified laboratory following gas chromatography procedures described the NAS Moffett Field quality assurance project plan (QAjPP) (PRC and JMM 1992b). The laboratory compared each sample area to a standard response for all extractable fuels (diesel, kerosene, JP-5, and motor oil), which resulted in a variety of values for the various fuel standards.

PRC recalculated concentrations to compare sample area to JP-5 standards only, since JP-5 is the only contaminant of concern that has been detected in groundwater samples from Site 5. Concentrations were recalculated by dividing the chromatographic response area by the JP-5 standard response factor. Table B2 (Appendix B) presents TPH-e as JP-5 values for samples collected during this treatability study.

Figure 9 presents a graph of measured TPH-e concentrations for each collection period. The graph indicates high concentration variability across the test site during the test period. Concentrations range from 1,080 μg/L (WORC5-1 sampled on December 1, 1995) to 75 μg/L (WORC5-2 sampled on

FIGURE 9
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
EXTRACTABLE TPH CONCENTRATION TRENDS
IN MONITORING POINTS



December 15, 1995). For samples collected beginning 2 weeks after the ORC was installed, monitoring point WORC5-1 also contained the highest average concentration (806 μg/L), followed by well FP5-1 (619 μg/L), and points WORC5-4 (298 μg/L), WORC5-5 (181 μg/L), WORC5-8 (159 μg/L), WORC5-6 (154 μg/L), WORC5-2 (117 μg/L), and WORC5-3 (112 μg/L). Percent standard deviations ranged from 27.4 percent (WORC5-1) to 62.7 percent (WORC5-8). The highest percent standard deviation occurred generally in wells downgradient of FP5-1 (the ORC source well).

3.2.3 DO Analysis and Data Summary

DO was measured in samples collected from each monitoring point and from well FP5-1 during the study. Measurements were made with an Horiba DO meter and with an Hach DO measurement kit. The baseline measurements and first round of measurements following ORC installation were made with the Horiba meter, only. The second and third rounds of samples collected following ORC installation were made with the Hach measurement kit. Measurements during the remaining rounds were made with both measurement systems, except the sixth round. It was completed with the Hach measurement kit only, due to sensor failure on the Horiba equipment. Overall, measured DO concentration differences between the Horiba meter and Hach kit were negligible. Therefore, the DO measurement method did not appear to influence the data.

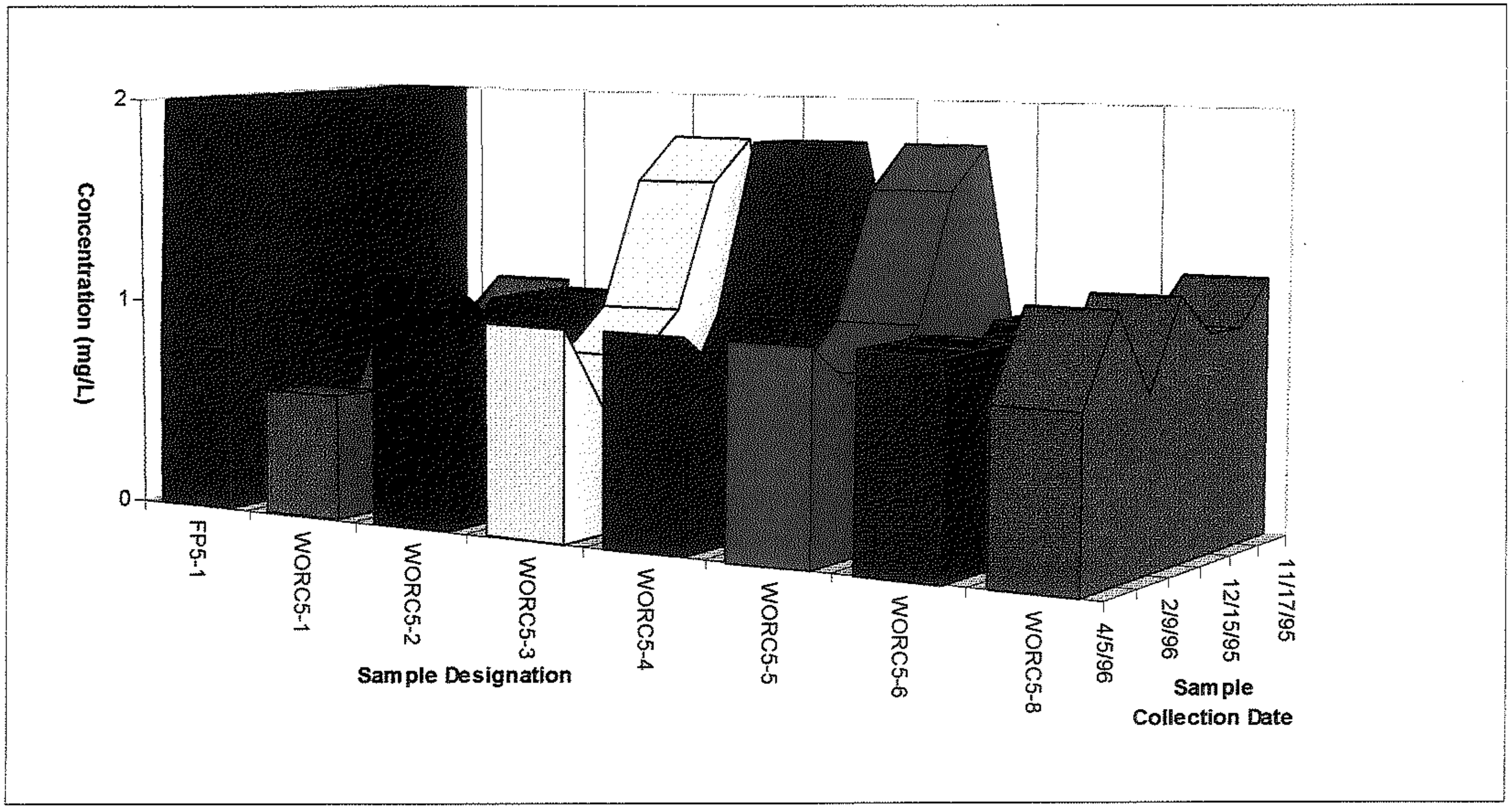
Initially, DO concentrations in samples from well FP5-1 were above the upper detection limits for both the Horiba meter and the Hach kits, so the sample was diluted with a measured volume of distilled water. (The DO content of the distilled water was measured before it was added to the groundwater sample.) The DO content of the diluted sample was measured, and the DO content of the original sample was calculated.

Figure 10 illustrates DO concentrations with respect to time for samples collected from the monitoring locations. The data indicate approximately a two-fold increase in DO concentration in monitoring points WORC5-3, WORC5-4, and WORC5-5 during the two measurement periods in December 1995. The data also indicated a significant drop in DO concentration in monitoring point WORC5-1 (the background monitoring point) that began in February 1996 and continued throughout the remainder of the test period. Appendix C presents DO data.

3.2.4 Groundwater Elevation Data

Groundwater elevation was measured in each temporary piezometer and in monitoring well FP5-1 during each sample collection event. The accuracy of the data collected during the baseline sampling event and

FIGURE 10
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
DISSOLVED OXYGEN CONCENTRATIONS
DURING STUDY PERIOD



the first four rounds of ORC test sampling, however, was insufficient to allow adequate interpretation. Measurements during the remaining rounds were of sufficient accuracy to interpret flow direction and gradient magnitude through the study area.

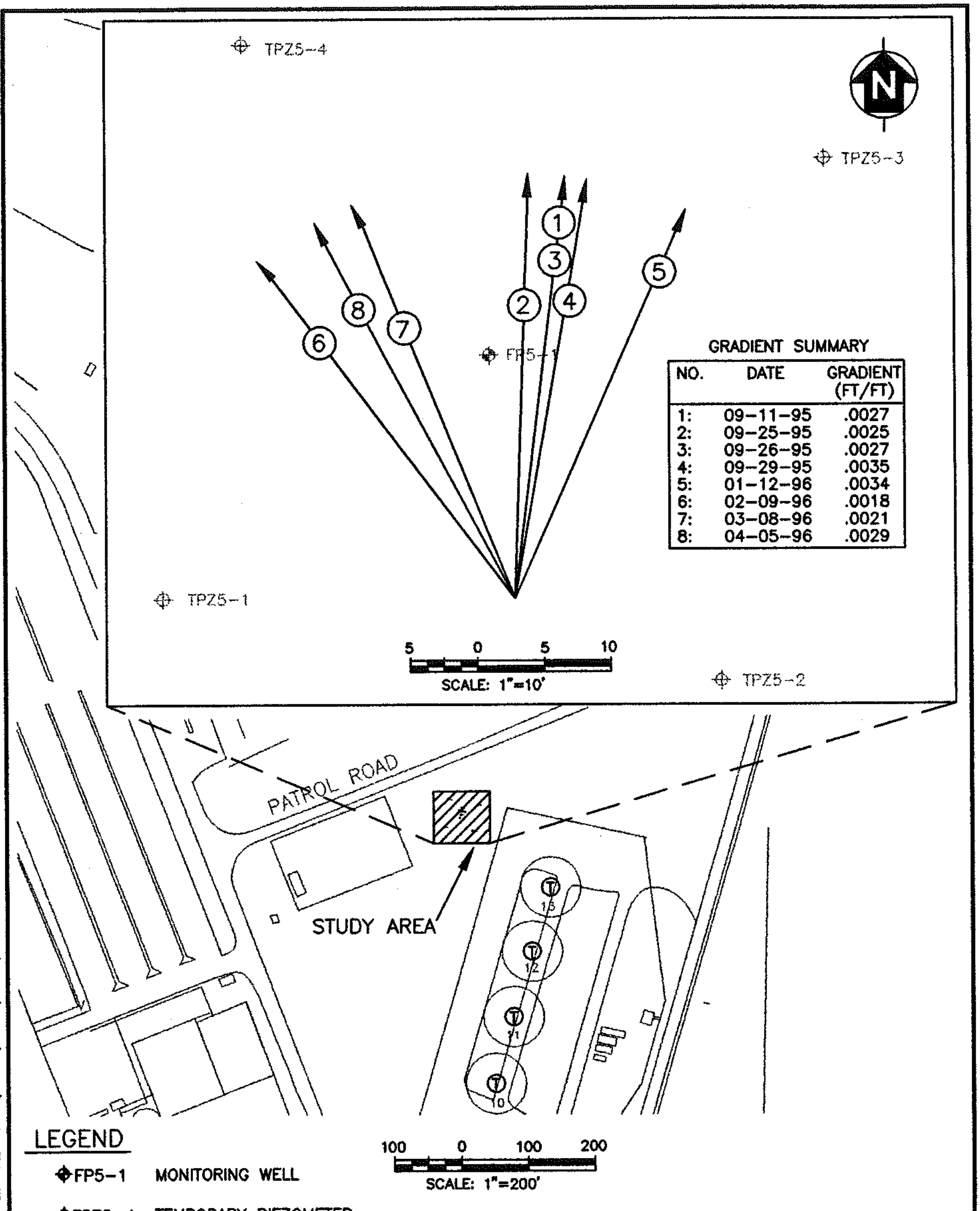
Initially, water elevations were measured at the four temporary piezometers at the site and at FP5-1. One piezometer (TPZ5-1) was damaged prior to the December 15, 1995 sampling event. As a result, subsequent measurement data from this piezometer were not usable.

Water elevation data indicate a stable gradient but changing flow direction during the test period. The average gradient for eight measurements during the study period was 0.0027 foot per foot with a standard deviation of 0.0006. This gradient compares favorably with MFA-wide gradients.

Plots of data collected throughout September 1995 indicate that the flow direction remained constant and the gradient magnitude slightly increased at the end of the month. Figure 11 illustrates estimated flow directions and presents calculated gradients from measurements collected during the study period. A plot of the data collected on January 12, 1996, indicates an eastward flow direction shift of approximately 15 degrees. However, these data may not accurately reflect the true site-wide groundwater flow direction. The site received abundant rainfall during December and January, and standing water was observed at the site during sample collection in December. Some of this surface water may have preferentially infiltrated the annular space of one or more piezometers and biased the piezometric surface.

A plot of data from the February 1996 sampling event indicates a westward flow direction shift of approximately 45 degrees. Plots of data from March and April 1996 sampling events indicate minor continued change to the west.

The calculated gradient magnitude also changed slightly during the study period. In September 1995, the average gradient magnitude was 0.0029 foot per foot with a standard deviation of 0.00044. In January 1996, the calculated gradient magnitude increased slightly to 0.0034, then decreased to 0.0018 in February 1996. Calculated gradients from March and April 1996 data were 0.0021 and 0.0029 foot per foot, respectively.



GRADIENT SUMMARY

NO.	DATE	GRADIENT (FT/FT)
1:	09-11-95	.0027
2:	09-25-95	.0025
3:	09-26-95	.0027
4:	09-29-95	.0035
5:	01-12-96	.0034
6:	02-09-96	.0018
7:	03-08-96	.0021
8:	04-05-96	.0029

FIGURE 11
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
GRADIENT SUMMARY

DATE: 06-20-96 TWL DN FILENAME: C:\PROJECT\MOFFETT\SITESRD\FIG11.DWG

4.0 LABORATORY DATA QUALITY ASSESSMENT

This section discusses the results of data review, achievement of data quality objectives, and compound identification and quantitation during the Site 5 groundwater treatability study at MFA. Sampling was conducted from October 1995 through April 1996. A total of 94 water samples were collected during nine sampling events.

All samples collected during the nine sampling events were analyzed for TPH-e. Laboratory reported TPH-e data from the ORC investigation is presented in Table B3. Samples FP5-1, WORC5-1, and WORC5-8 collected on October 19, 1995 were also analyzed for EPA Contract Laboratory Program (CLP) dissolved metals, anions (fluoride, chloride, bromide, nitrate, sulfate and orthophosphate) by EPA Methods 300.0 and 341.2, BOD by EPA Method 405.1, COD by EPA Method 410.1, and total Kjeldahl nitrogen (TKN) by EPA Method 351.3. Non-TPH-e data were not reviewed for this data quality assessment, but are presented in tables B4, B5, and B6, located in Appendix B.

Samples were also collected on September 24, 1995, before the ORC test began. The samples were analyzed for microbial populations (American Water Works Association, modified Method 9215C), nutrients by EPA Methods 351.1, 350.1, 365.2, and 352.1, pH, and metals by EPA Method 6010. The data generated for the sampling date were not reviewed as part of this data quality assessment, but are presented in tables B7, B8, and B9.

4.1 DATA REVIEW

Data review is the systematic and independent verification of data quality. The data review process provides information on analytical limitations of data based on specific quality control (QC) criteria established in the following document:

> U.S. Environmental Protection Agency Contract Laboratory Program (CLP) National Functional Guidelines for Organic Data Review (EPA 1994a)

The reviewer verified that the proper analytical method was conducted and laboratory requirements achieved for TPH-e analysis. PRC reviewed 17 of the 94 samples for TPH-e analysis only; all other TPH-e results were reviewed for compliance with QC limits. Cursory review of TPH-e data was conducted on 100 percent of the fully reviewed data, while full review was conducted on 10 percent of all reviewed data. The reviewed QC criteria were as follows:

- Method compliance
- Holding times (verify from time of collection)
- Calibration (initial and continuing)
- Method blanks
- Surrogate recovery
- MS/MSDs
- Laboratory control samples (LCS)
- Sample duplicates
- Other laboratory QC specified by the method

The following subsections summarize results of the review of TPH-e data.

4.1.1 Method Compliance

All samples were prepared and analyzed correctly using protocols established in the following documents:

- CLEAN Laboratory Basic Ordering Agreement (BOA) (PRC 1994c)
- Leaking underground fuel tank (LUFT) field manual (State of California 1989)

No method deviations were encountered.

4.1.2 Holding Times

Samples were reviewed using limits found in the LUFT field manual (State of California 1989). QC limits for holding time are 7 days to extraction and 40 days to analysis. All holding times were within these established limits; therefore, no qualification of data was necessary.

4.1.3 Calibrations

For initial calibrations, the percent relative standard deviation (RSD) of the five calibration points must be less than 20 percent. For continuing calibrations, the relative percent difference (RPD) between the continuing calibration standard and the calibration factor must be less than 15 percent. The following equations were used for calibration calculations:

$$\%\ RSD = \frac{\left[\left(\sum_{i=1}^{5} (RF_i - \overline{RF})^2 \right) / n-1 \right]^{\frac{1}{2}}}{\overline{RF}} \ x\ 100$$

$$\% \; RPD = \frac{\left| (RF_c - \overline{RF}) \right|}{\left(\frac{RF_c + \overline{RF}}{2} \right)} \; x \; 100$$

where,

Rf_x = response factor, initial calibration
RF = mean response factor
n = number of calibration points
Rf_c = response factor, continuing calibration

All initial and continuing calibrations were within established QC limits; therefore, no qualification of data was necessary.

4.1.4 Blanks

Method blanks should be free of contamination. All method blanks were found to be within this QC limit; therefore, no qualification of data was necessary.

4.1.5 Surrogates

All samples are spiked with surrogate compounds to assess method performance in the laboratory by determining the percent recovery (R) of the surrogate compounds. The percent R must be 60 to 140 percent of the spiked amount. Surrogate percent recovery is calculated using the following equation:

%R = [sample amount/spike amount] X 100

All surrogate recoveries met these established QC limit; therefore, no qualification of data was necessary.

4.1.6 MS/MSDs

The percent recovery for MS and MSD samples must be 50-150 percent. The RPD between the MS and MSD must be less than 50 percent RPD. The percent R and RPD are calculated using the following equations:

$$\% \ R = \left[\frac{(\mathit{Spiked\ \ Sample Concentration} - \mathit{Original\ Sample\ Concentration})}{\mathit{Spike\ Amount}} \right]$$

$$RPD = \left[\frac{(\%R(MS) - \%R(MSD))}{\left(\frac{\%R(MS) + \%R(MSD)}{2} \right)} \right] x\ 100$$

All MS/MSD percent recover and RPDs met established QC limits.

4.1.7 Laboratory Control Samples

The QC limit for laboratory control sample recovery is 60 to 140 percent. All LCSs met these QC limits.

4.1.8 Sample Duplicates

Sample duplicates were collected for six of nine sampling events. For all sampling events, the sample ID was WORC5-1 and the duplicate ID was WORC5-99. RPD values were calculated from the laboratory results of these two samples and then compared to the RPD limits for water. RPDs for sample duplicates are calculated using the following equation:

$$RPD = \left[\frac{(\mathit{Sample\ Result} - \mathit{Duplicate\ Result})}{\left(\frac{\mathit{Sample\ Result} - \mathit{Duuplicate\ Result}}{2} \right)} \right] x\ 100$$

All samples and duplicates met the RPD limit of less than 25 percent with the following exceptions:

Sample Date	Constituent	Sample Concentration (μg/L)	Duplicate Concentration (μg/L)	Percent Deviation
1/12/96	Kerosene	400	260	42%
4/5/96	Diesel	1400	900	44%
4/5/96	Motor Oil	370	190	64%

Organic data are not qualified based upon field duplicate criteria alone. The RPD is not calculated for samples with results which are undetected or below the contract required quantitation limit (CRQL).

4.1.9 Other Quality Control Specified by the Method

All other laboratory QC specified by the appropriate methods have been reported and found to be within established QC limits for the reviewed samples.

4.2 DATA QUALITY OBJECTIVES

The quality of data needed to achieve informed decisions depends upon the scientific validity and integrity of the data. Data validity is assessed based on comparison of the analytical and QC results to the data quality objectives (DQOs) for the project. The integrity of the data is maintained by observing procedures designed to minimize errors and loss of data during manipulation and transfer.

4.2.1 PARCC Parameters

A comparison of the MFA results to project DQOs as defined in the basewide QAPjP (PRC 1992) formed the basis for evaluating the quality of the analytical data. As described in the QAPjP, analytical data must be of a known and acceptable quality to be used to evaluate the presence of chemicals. Determination of data quality was based on evaluation of the precision, accuracy, representativeness, comparability, and completeness (PARCC) characteristics of the data. Once these characteristics were evaluated, a determination was made as to whether the data were acceptable for their intended use.

Sections 4.2.2 through 4.2.6 discuss the results of the following QC samples: field duplicates, MS/MSD samples, method blanks, trip blanks, and equipment rinsates. Section 4.2.7 summarizes the overall comparability and completeness of the sampling effort.

4.2.2 Field Duplicates

Field duplicates are two samples collected at the same time and from the same source and are used to evaluate combined sampling and analytical precision through the calculation of RPD values. Field duplicate samples were scheduled to be collected for 10 percent of the total number of samples. The acceptance criterion for the precision of field duplicates for water samples was set at an RPD value less than 25 percent (PRC 1992).

Fulfillment of QC Duplicate Sampling Objectives

The fulfillment of QC sampling objectives was measured by calculating the actual number of duplicate samples collected and analyzed, dividing by the total number of real samples collected and analyzed, and then multiplying by 100 to obtain a percentage. Field duplicates were collected at a frequency of 6.4 percent for this investigation, which is below the target goal of 10 percent.

Results and Evaluation of DQOs

RPD values were calculated using reviewed TPH-e data. All field duplicates met the QC limits of 25 percent for precision with the exceptions noted in Section 4.1.7.

4.2.3 Matrix Spike and Matrix Spike Duplicate Samples

The precision and accuracy of an analytical method for a particular environmental sample matrix were determined by analyzing two samples to which was added an equal and known concentration of a target analyte. These samples, the MS and MSD, were collected in the field to be representative of a real sample matrix. The recoveries of the spiked analytes from the MS/MSD samples measure the accuracy of the analytical method for those analytes. RPD values for the MS/MSD pair are calculated to evaluate the analytical precision of the method.

MS/MSD samples were to be collected for 5 percent of the total number of samples collected. The acceptance criteria for recoveries and RPDs were established by the analytical procedures for the TPH-e method and by laboratory-established control limits for non-CLP methods. Acceptable recoveries and RPDs have been established for each target analyte (EPA 1993).

Fulfillment of QC MS/MD Sampling Objectives

The fulfillment of QC sampling objectives was measured by calculating the number of MS/MSD samples collected and analyzed, dividing by the total number of real samples collected and analyzed, and then multiplying by 100 to obtain a percentage. The QC sampling objective for MS/MSD samples is 5 percent of the total number of samples. For the overall ORC investigation a 9.5 percent MS/MSD frequency was achieved. However, for the November 3, 1995 sampling event, 24 samples were collected, while only 1 MS/MSD pair was analyzed. The MS/MSD frequency for this sampling date was 4.1 percent, which is below the QC sampling objective of 5 percent.

Results and Evaluation of MS/MD DQOs

All MS/MSD RPD and percent recovery results were within the QC acceptance criteria for precision and accuracy.

4.2.4 Method Blanks

Method blanks consisting of laboratory pure water were prepared and processed in the same manner as a field sample. Method blanks are used to evaluate laboratory accuracy by identifying whether laboratory procedures, equipment, or reagents introduced contamination that might affect the analytical results of field samples.

The frequency of analysis of method blanks was determined by the laboratory based on guidance provided in the LUFT field manual (State of California 1989). The acceptance criterion for method blank results was for all reported values to be less than the CRQL for each organic analyte of interest (PRC and JMM 1992b).

Fulfillment of Analytical QC Objectives

Laboratory compliance with established guidance for the frequency of analysis of method blanks was evaluated by the reviewers of the data. The reviewers determined that the laboratory fulfilled the analytical QC objectives.

Results and Evaluation of DQOs

No analytes were detected in the method blanks above the CRQL.

4.2.5 Trip Blanks

The purpose of trip blanks is to determine if field storage and transportation procedures introduces volatile organic contamination to field samples. Trip blanks were not analyzed because field samples were not analyzed for volatile components.

4.2.6 Equipment Rinsates

Equipment rinsates are collected and analyzed to determine if equipment cleaning and decontamination procedures were effective in removing contaminants that may have been present from the collection of field samples. Equipment rinsates are taken between collection of field samples, typically immediately before of a field sample is collected. All water sampling was conducted using disposable sampling equipment. Therefore, no equipment rinsates were collected for water samples.

4.2.7 Comparability and Completeness Summary

Comparability was promoted through the use of standard units of measurement in reporting the analytical data and the selection of analytical methods. The units of measurement and the analytical methods used were comparable to those used by previous investigations at Moffett Federal Airfield.

Completeness is a measure of the percentage of project-specified data that are deemed valid. All data that are not rejected ("R" qualified data) through the review process will be deemed valid. For TPH-e results, the DQO of 90 percent completeness was met for this project.

4.3 COMPOUND IDENTIFICATION AND QUANTITATION

Precision is evaluated based on the RPD of field duplicates and the RPD of MS/MSD samples. Accuracy is evaluated based on the percent recovery of MS and MSD samples, percent recovery of LCS samples, and the results of method blanks, trip blanks, and equipment rinsates. Table B2 presents the requantified TPH-e concentrations, and Table B3 presents the laboratory-reported concentrations. Additionally, data reported as motor oil from sampling on November 17, 1995, December 1, 1995, December 15, 1995, January 12, 1996, March 8, 1996 and April 8, 1996 appear to represent a mixture of petroleum degradation products (primarily organic acids and alcohols), rather than a petroleum product. Therefore, the motor oil chromatographic responses for these dates were not included in the calculations of the TPH-e values. Section 6.2.3 provides an additional discussion of compound identification.

For the November 3, 1995 sampling event, PRC collected triple sample volumes for triplicate analyses at the request of Regenesis. Table B10 (Appendix B) presents the triplicate sample concentrations, the calculated mean, and the standard deviation of the triplicate concentrations. If the TPH-e concentration was below the detection limit, a value equal to one-half of the quantitation limit was used to compute the mean and standard deviation. If the TPH-e concentration was below the detection limit in all three analyses, the mean and standard deviation were not calculated.

5.0 WORK PLAN DEVIATIONS

The following sections detail work plan deviations. Typically, deviations occurred when more favorable alternatives were discovered or unforseen events developed in the field.

5.1 MONITORING POINT INSTALLATION

Nine monitoring points were proposed in the work plan. Eight points were proposed in two arrays downgradient and perpendicular to the groundwater flow direction. The ninth point was proposed upgradient of well FP5-1. The monitoring points were installed as proposed in the work plan; however, the Geoprobe equipment broke after the seventh monitoring point was installed. The number of monitoring points that had been installed prior to equipment failure was sufficient to conduct the test, and vehicle repair would have resulted in one or more weeks of delay. Therefore, the additional two monitoring points were not installed.

5.2 SAMPLE COLLECTION FREQUENCY

The work plan proposed collection of samples on a 1-week interval following ORC installation. This proposal was based on the assumption that groundwater velocity at the site was on the order of 2 feet per day. (This assumption was based on interpretation of the pump recovery data collected at Site 5 during previous field activities.) The tracer test indicated that groundwater at the site moved at approximately 0.45 feet per day. To adequately evaluate the effect of ORC on groundwater contamination, sample collection intervals were extended.

5.3 ANALYTICAL DEVIATIONS

Laboratory analyses were completed as planned; however, interpretation of the TPH-e chromatograms was modified. The interpretative protocol established in the statement of work between the analytical laboratory and PRC required that the laboratory compare sample chromatograms to several extractable-phase petroleum standards. The standards that most closely match the sample chromatographic pattern are used to quantify the type of TPH-e in each sample.

In several samples, the standards that most closely matched the sample chromatographic pattern were diesel, motor oil, and kerosene. However, because historical evidence indicates that only JP-4, JP-5, and

AVGAS were stored in the four bulk storage tanks adjacent to the study area, and chromotograms evaluated by PRC chemists were determined be degraded JP-5. PRC requantified each sample chromatographic response against the JP-5 standard only. Both sets of data are presented in Appendix B. Table B3 presents laboratory-reported TPH-e values, and Table B2 presents requantitated TPH-e data.

6.0 CONCLUSIONS

The following sections present conclusions based on data collected during this treatability study. Although conclusions presented here are specific to Site 5 at MFA, the information presented in this report should be considered when evaluating use of this technology at other hydrocarbon-contaminated sites at MFA.

6.1 GEOLOGY

Observation of cores collected during this study indicates a continuous permeable sandy gravel interval throughout the study area. This interval occurs between 8 and 9 feet bgs. Previous data collected at Site 5 indicate that this gravel is part of a continuous fluvial channel deposit that extends north toward the San Francisco Bay. Figure 12 presents a fence diagram of the shallow subsurface lithology of the study area.

6.2 GROUNDWATER HYDROLOGY

Site-specific groundwater hydrologic data were collected as a part of this study to help evaluate the efficacy of ORC to increase DO concentrations in groundwater. Hydrologic data included groundwater gradient, velocity, and flow direction. These data were used to approximate transport characteristics of the shallow saturated zone and evaluate observed petroleum concentration changes during the test period.

6.2.1 Hydraulic Parameters

Site-specific data indicate gradient changes during the study period. Water level measurements in the piezometers at the site indicate that the site-specific gradient decreased by nearly 50 percent (from approximately 0.0033 to approximately 0.0017) from the time the ORC was introduced until the time it was removed. The groundwater velocity also decreased by nearly 50 percent during this period, assuming (1) groundwater velocity is directly proportional to gradient, and (2) the other input values in the velocity equation (hydraulic conductivity and porosity) remained constant over the study period.

This range of gradient values compares favorably with calculated facility-wide gradients during the study period. MFA quarterly reports present MFA-wide quarterly water level measurements and groundwater potentiometric maps. Maps presented in the November 1994, February 1995, and May 1995 (PRC 1995c, 1995d, 1995e) quarterly reports indicate a 0.002 foot per foot groundwater gradient and a north to

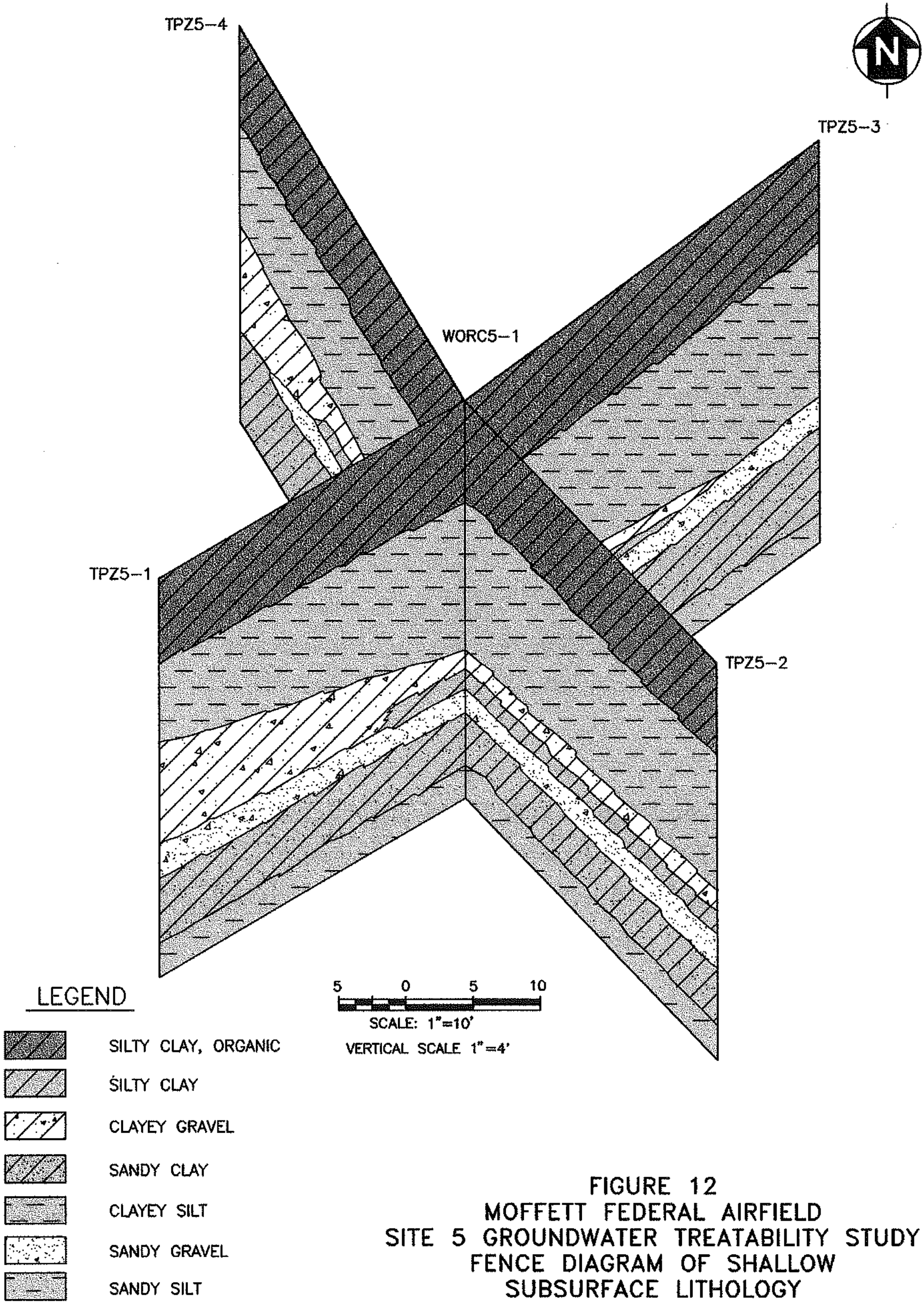


FIGURE 12
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
FENCE DIAGRAM OF SHALLOW
SUBSURFACE LITHOLOGY

north-northwest flow direction in the vicinity of Site 5. Site-specific hydraulic conductivity (calculated from the tracer test-measured velocity value of 0.47 feet per day, assumed porosity of 0.3, and measured gradient of 0.0033) compares favorably to the hydraulic conductivity value calculated from well recovery test data (PRC 1994d) when the thickness of the aquifer is limited to the thickness of the coarse material (approximately 1.0 foot of sand and gravel). Hydraulic conductivity is inversely proportional to aquifer thickness by the following formula (Kruseman and de Ridder 1991):

$$\Delta s = 2.3Q/4\pi KD$$

where,

Δs = recovery (in feet) over one log cycle
Q = averaged discharge rate (in feet^3 per day)
K = hydraulic conductivity (in feet per day)
D = aquifer thickness (in feet)

Using this formula, the value of hydraulic conductivity (as calculated from the pump recovery test data [PRC 1994d]) is 55.1 feet per day. The hydraulic conductivity value can also be estimated from the tracer test-measured velocity (0.47 feet per day) by the formula (Fetter 1988):

$$v = KI/\rho.$$

where,

v = groundwater velocity (in feet per day)
K = hydraulic conductivity (in feet per day)
I = aquifer gradient (in horizontal feet per vertical feet)
ρ = porosity (unitless)

Using this formula, the value of hydraulic conductivity (as calculated from the tracer test data) is 42.7 feet per day. The two comparable conductivity values indicate that the 1-foot thick gravel interval acts as a preferential pathway for groundwater and solute transport, and the overlying and underlying adjacent fine-grained material does not transport a significant volume of water or mass of solute.

Previously collected data from Site 5 and from the western side of MFA support this preferential pathway conclusion. For instance, a groundwater sample that was collected from a shallow subsurface channel (possibly a continuation of the channel material at the study site) approximately 300 feet north of the treatability study area exhibited a substantially elevated TPH-e concentration relative to samples collected nearby, but from finer-grained material. Also, analysis of groundwater samples collected from the monitoring network on the western side of MFA indicate petroleum and chlorinated solvent contaminants are migrating along similar types of naturally occurring, preferential subsurface channel pathways.

The apparent flow direction changes at the study area have been observed at other sites at MFA. Quarterly groundwater level measurements completed as part of the groundwater monitoring program at MFA indicate flow direction changes of more than 25 degrees on the western side of the base. A stormwater lift station on the north side of the base influences groundwater flow across the northern half of MFA. Rainfall at MFA is controlled in part by a system of stormwater collection basins and pipeline. This system diverts, channelizes, and transfers rainfall to a holding basin on the northern MFA boundary. Studies at MFA (PRC 1995f) indicate that this system loses water along its course. These losses likely influence the gradient and flow direction of shallow groundwater during periods of rainfall.

Since the gradient and groundwater flow direction changed significantly during the sample collection period, the data cannot be used to quantify transverse dispersivity of the DO. However, research by Robertson and others (1991) indicate low to very low transverse dispersivity in coarse-grained aquifers. Observed bromide concentrations in monitoring points during the tracer test indicate some dispersion during the test; however, the width of the injected slug of bromide cannot be ascertained since the degree of mixing between solute in the casing and water in the filter pack was not determined. The solution within the source well casing was mixed with a peristaltic pump during the first 2 days of the tracer test, and the amount of incidental mixing between the casing and surrounding sandpack could not be measured.

6.3 ORC PERFORMANCE

Chemical data reviewed to evaluate ORC performance included DO and TPH-e concentrations directly downgradient of the ORC source well, as well as chemical demands on oxygen from inorganic sources. The following sections discuss conclusions based on chemical data reduction and analysis.

6.3.1 Changes In Dissolved Oxygen Concentration

DO measurements of groundwater samples collected from the monitoring points installed at Site 5 indicate increased oxygen concentration downgradient of the ORC source well. DO concentrations appear to have increased nearly twofold over observed background concentrations. The graph in Figure 10 illustrates measured DO concentrations in the ORC source well and monitoring points. The graph indicates that the DO concentrations increased in monitoring points WORC5-3, WORC5-4, and WORC5-5 in December, and returned to background levels in January. This observation indicates that the flow direction did not change from September through December.

Elevated DO concentrations were first measured in monitoring points WORC5-3, WOPRC5-4, and WORC5-5 (located 5 feet downgradient of the ORC source well) on December 1, 1995 (42 days following ORC installation). Measurement in these same wells on November 17, 1995 (28 days following ORC installation) indicated no increased DO. Therefore, DO velocity was greater than 0.12 feet per day, but less than 0.18 feet per day. DO concentrations measured on December 1 were equal to the maximum concentrations measured from those monitoring points for the duration of the study.

The measured DO concentration in the monitoring points five feet downgradient of the DO source seems low, relative to the measured concentration in the source itself. However, recent research by Fry and others (1995, 1996) indicates that oxygen retardation can be as high as 10 (water being unity or 1). Their research shows that DO retardation rate is a function of the amount of trapped oxygen gas in the saturated zone.

Trapped oxygen can be formed when DO, at or above saturation concentrations, exsolves out of solution. The trapped oxygen will retard transport of the DO through mass transfer of oxygen between the mobile dissolved phase and the trapped gas phase. The degree of retardation will be a function of the difference between the DO concentration and the partial pressure of gas-phase oxygen, and the gas-phase oxygen will continue to act as a sink for dissolved gas until equilibrium is reached (Fry and others 1995).

The above-described site-specific velocity range is an averaged range over the distance between the injection point and the monitored points. Measurements in monitoring point WORC5-8 indicate the DO retardation approximates a nonlinear equation. If retardation of DO was linear, then elevated concentrations of DO should have been measured in monitoring point WORC5-8 (located 10 feet downgradient of the ORC source well) sometime between 56 days (10 feet at 0.18 feet per day) and 83 days (10 feet at 0.12 feet per day) following ORC installation. Elevated DO concentrations were not observed in monitoring point WORC5-8 at any time after ORC was installed in the source well. At least three measured points are required to define a nonlinear equation; therefore, a nonlinear retardation rate for the site cannot be calculated from these data.

If linear retardation is assumed between the source well and the first row of monitoring points, its value range is 2.5 to 3.8. This range is determined by dividing the measured groundwater velocity (0.45 feet per day) by the range of measured DO velocities (0.12 and 0.18 feet per day). The retardation between the first row of monitoring points and point WORC5-8 appears to be infinite, since no increased DO was measured in WORC5-8. The amount of retardation due to oxygen exsolution versus biological consumption was not determined, and is beyond the scope of this study.

Analysis of samples from each of these monitoring points also indicated a decrease in ground water DO in February to the minimum value for the study period at the site. This decrease coincides with a decrease in background DO concentrations, as observed in the sample from point WORC5-1, and a decrease in the calculated groundwater gradient to the minimum calculated value for the study period. The rise in piezometric head suggests that surface water is infiltrating from the ground surface to the first saturated zone. The corresponding decrease in background DO indicates that the oxygen is being consumed during infiltration. Stumm and Morgan (1981) report that DO in surface water is consumed and replaced by carbon dioxide (CO_2) as it infiltrates the unsaturated zone. Through aerobic respiration, oxygen is utilized by bacteria that consume organic matter in the soil horizon. Observations of core collected at the site during monitoring point installation (and at the biovent site immediately upgradient) indicate substantial petroleum contamination (and therefore an abundant source of organic matter) in the capillary fringe of the first saturated zone. The DO in infiltrating surface water would be utilized by aerobic bacteria as they consume the hydrocarbons.

The resultant oxygen-depleted infiltrating water would mix with in-place groundwater. The surface water that infiltrates through soil contamination at Site 5 passes through a carbon-rich zone (the petroleum-contaminated zone just above the saturated interval). This zone likely has an elevated microbe population that could utilize most of the DO in infiltrating surface water. When this DO-depleted infiltrating water mixes with groundwater, it would dilute (and thus reduce) the DO concentration in the groundwater.

6.3.2 Ion-Oxygen Interactions

Groundwater samples analyzed for COD during the baseline sampling event indicate the potential for oxidation of organic material and oxidizable inorganic substances. There appears to be a correlation between COD and TPH-e concentration; COD values are highest in samples that also have the highest TPH-e values (as expected). Measured COD in groundwater at Site 5 appears to be sufficiently high (measured values ranged from less that 5 to 14 mg/L to affect calcium carbonate equilibrium; observations at two other treatment system sites located on MFA (Site 14 recirculating in situ treatment [RIST] system and the Site 9 source control system) indicate substantial calcium carbonate precipitation in treatment systems that aerate groundwater during treatment. Treatment systems at Sites 9 and 14 aerate groundwater, and both systems have sufficient calcium carbonate precipitation to require special maintenance procedures or treatment systems to control precipitate buildup.

The increased DO probably results in decreased dissolved CO_2 partial pressure in groundwater and subsequent calcium carbonate precipitation. Data collected during the Site 5 biovent test indicate elevated CO_2 (2 to 10 percent) and depressed oxygen (1 to 10 percent) concentrations in unsaturated zone soil gas just above the capillary fringe. This phenomenon was also observed in the unsaturated zone at another petroleum contamination site (Site 14) during soil-gas analysis (PRC 1990).

A high concentration of CO_2 in the deep vadoze zone would result in shallow groundwater at Site 5 being saturated or even supersaturated with CO_2. The addition of DO to groundwater (via ORC) would raise the reduction oxidation potential (redox). In a bicarbonate-rich aqueous environment, this increase in DO would result in calcium carbonate precipitation (through the process described in the previous paragraph). Krauskopf (1979) reports that in general, many groundwaters are near saturation with respect to calcium carbonate.

Groundwater samples from Site 5 groundwater wells were previously analyzed for alkalinity as calcium carbonate, and three samples from ORC monitoring points were analyzed for calcium ion concentration. The averaged value from 6 alkalinity analyses was 543 mg/L, and the averaged value for calcium ion concentration was 114 mg/L. A plot of these averaged values on nomographs in Hem's *Study and Interpretation of the Chemical Characteristics of Natural Waters* (1989) indicates that bicarbonate is near saturation with respect to calcium carbonate. Under these conditions, subsequent displacement of dissolved carbon dioxide with dissolved oxygen would raise the pH, and carbonate ions would bond with calcium ions to form solid-phase calcium carbonate. This conclusion is supported by observations at Site 9 and Site 14 treatment systems.

Stumm and Morgan (1981) report that bacterial aerobic respiration results in increased concentrations of CO_2 in surface water as it infiltrates through the unsaturated zone. Biodegradation of the abundant organic matter (the petroleum contamination) in the capillary fringe could result in high concentrations of CO_2 in soil gas, and CO_2 approaching saturation in shallow groundwater. Subsequent addition of oxygen (by the ORC) would result in precipitation of calcium carbonate.

No calcium carbonate precipitation was observed in cores collected during this investigation. However, chemical analyses indicate sufficient ionic species in groundwater at the site to support calcium carbonate precipitation.

Calcium carbonate precipitation around the ORC source well would reduce aquifer porosity and permeability. Reduced permeability would hinder oxygen advection and dispersion, and thus hinder enhanced aerobic degradation.

6.3.3 Changes in Petroleum Contaminant Concentrations

Groundwater extractable-phase petroleum concentrations changed significantly prior to the test period. Two years prior to the test, TPH-e concentrations as high as 2,000 mg/L were detected in samples collected from well FP5-1, and a thin layer of free-phase fuel (approximately 1 to 2 inches thick) was detected on the water surface in the well during sample collection. The concentration in a sample collected in June 1995 dropped to 54 mg/L, and no free-phase fuel was observed during sampling. However, this concentration was above the agency-negotiated action level for groundwater contamination at MFA, and within the ORC manufacturer's recommended operable range. Figure 5 illustrates concentration changes with time for samples collected prior to the test period.

Analysis of the baseline sample collected from well FP5-1 indicates a substantial drop in TPH-e concentration from the previously analyzed sample. The difference in sample collected methods may account for the twofold increase in TPH-e concentration between the sample collected in June 1995 and the baseline sample collected in October 1995. Prior to the treatability study, groundwater samples from well FP5-1 were collected with a bailer after the well was purged of, at a minimum, a quantity of water equal to three casing and sandpack volumes. Samples from well FP5-1 and the monitoring points for this treatability study were collected through dedicated polyethylene tubing with a peristaltic pump after purging 250 milliliters (ml) (two tubing volumes) of water from the well. Samples collected with a bailer are a composite of the column of water through which the bailer passes, whereas samples collected through a peristaltic pump represent the water that surrounds the intake of the pump tubing. Since sorbed-phase and residual nonaqueous-phase petroleum that contaminates the groundwater resides at the water table capillary fringe (the smear zone), the aqueous-phase petroleum should exhibit a gradient of decreasing concentration with depth.

Although site-specific DO and biological data indicate conditions suitable for increased petroleum degradation in Site 5 groundwater, TPH-e suggest little or no bioremediation of fuel during the study. The most probable explanation for the lack of biological activity is that the JP-5 had been previously biodegraded by native fuel-degrading micro-organisms. The following discussion of the chemical alteration associated with the JP-5 bioremediation process and the effect of changes on the chromatographic analysis of the fuel shows the JP-5 was previously biodegraded.

As described in the background section, Site 5 operational information suggests JP-5 is the most probable petroleum contamination present in groundwater at the site. However, gas chromatograms of groundwater samples collected from the study area contained fewer resolved peaks and a larger unresolved hydrocarbon hump; the hump appears to be shifted to a later retention time compared to the JP-5 laboratory standard. These features are characteristic of a biodegraded fuel.

JP-5 is a complex mixture of straight, branched, cyclic, and aromatic hydrocarbons. Figure 13 illustrates the chromatogram for analysis of a JP-5 standard (300 nanogram) by flame ionization detection (FID). During analysis, the chromatographic column in the analytical equipment separates the individual JP-5 hydrocarbon components based on the boiling point of the hydrocarbon. Ideally, each component is separated and is represented as a peak with the height (or area) the measure of its concentration. The aromatic content of JP-5 is reported to be 16 percent (Smith and others 1981), but may vary depending on the source of crude oil used to make the fuel. Thus, the majority of JP-5 is made up of straight, branched, and cyclic hydrocarbons, and the largest peaks associated with the JP-5 analysis are straight chain hydrocarbons (alkanes) ranging in size from 9 (n-nonane) to 16 (n-hexadecane) carbons.

Preferential biodegradation of petroleum products including JP-5 has been observed in many environments. Generally, the shorter alkanes (n-C_{10} to n-C_{20}) are degraded first, followed by the branched and cyclic compounds, and finally the aromatic hydrocarbons (Jordan and Payne 1980). Biodegradation studies of alkanes by various bacteria, yeasts, and fungi have shown that biodegradation occurs by oxidation at the terminal methyl group and subsequent formation of an alcohol. The alcohol is further oxidized, eventually being converted to the corresponding carboxylic acid by the following reaction sequence:

$$RCH_2CH_3 \text{ --> } RCH_2CH_2OH \text{ --> } RCH_2CH \text{ --> } RCHCOOH$$

where R = unspecified hydrocarbon

Aromatic hydrocarbons may degrade by a similar mechanism. For example, p-xylene may be oxidized to the corresponding dimethylpyrocatechol. In both cases, the oxidation of the hydrocarbons will modify the chemical makeup of the fuel and increase its molecular weight. These changes will be evident during chromatographic analysis of the biodegraded fuel.

A chromatogram of a biodegraded JP-5 will contain small or missing alkane peaks. In addition, a large unresolved hydrocarbon hump will replace the resolved peaks. The hump results from the inability of the

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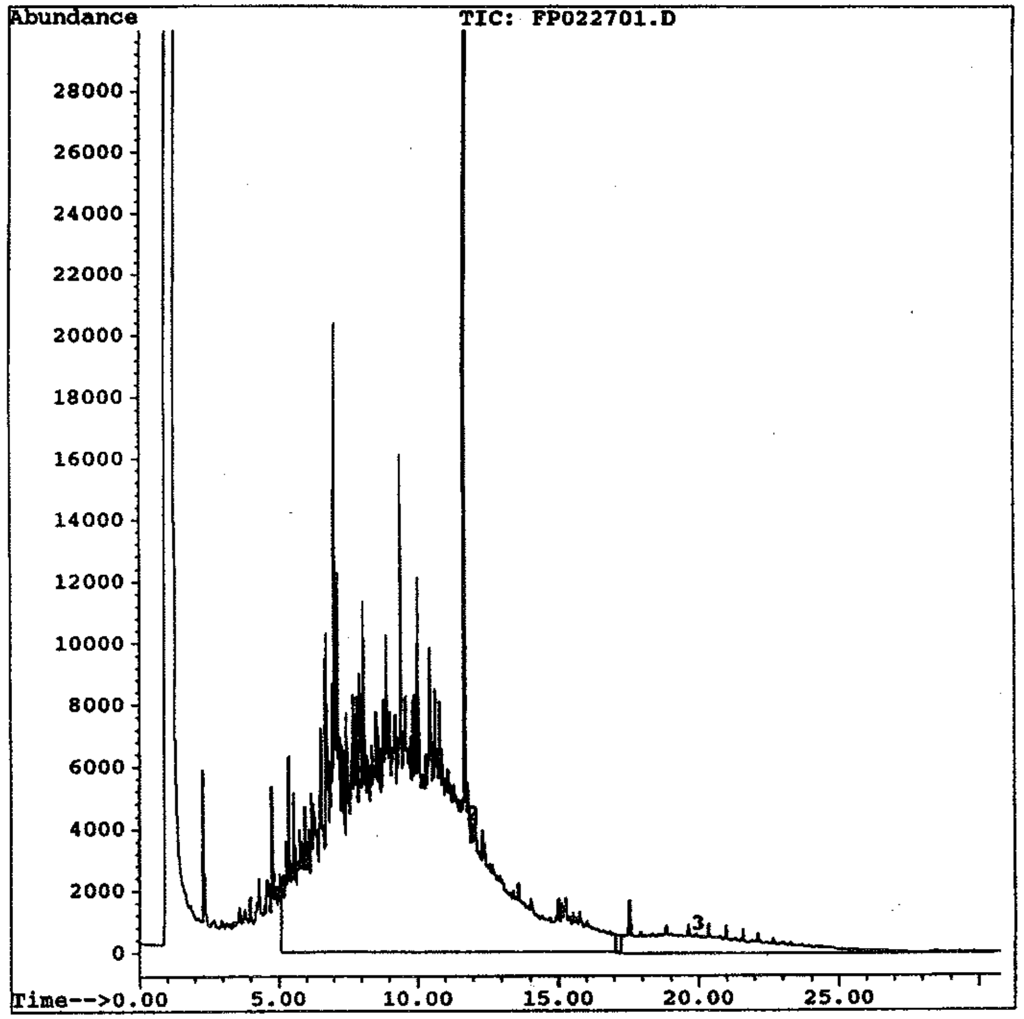
                    Quantitation Report

Data File : J:\GCTPH\HP27\DATA\27O20F1A\FP022701.D
Acq On    : 21 Oct 95  03:44 AM                              Oper: ARP
Sample    : 9510227-01                                       Vial: 15
Misc      :                                                  Mult: 1.0
Quant Time: Oct 21 14:53 1995

Method       : J:\GCTPH\HP27\METHODS\27L12FXW.M
Title        : TPHd  - Anametrix, Inc
Last Update  : Sat Oct 21 14:50:05 1995
Response via : Multiple Level Calibration

Volume Inj.  : 3 uL              Instrument ID  : HP27
Signal Phase : DB-5
Signal Info  : 0.53mm
```



```
FP022701.D  27L12FXW.M        Sat Oct 21 15:07:21 1995        HP27     Page 2
```

Chromatogram of water Sample
from FP5-1 (October 21, 1995)

```
                    Quantitation Report

Data File : J:\GCTPH\HP27\DATA\27F26F1A\SF26A1F6.D
Acq On    : 27 Feb 96  03:39 AM                              Oper: ARP
Sample    : JP-5 300NG #A003930                              Vial: 19
Misc      :                                                  Mult: 1.0
Quant Time: Feb 27 11:05 1996

Method       : J:\GCTPH\HP27\METHODS\27F26F1W.M
Title        : TPHd  - Anametrix, Inc
Last Update  : Wed Feb 28 10:51:19 1996
Response via : Multiple Level Calibration

Volume Inj.  : 3 uL              Instrument ID  : HP27
Signal Phase : DB-5
Signal Info  : 0.53mm
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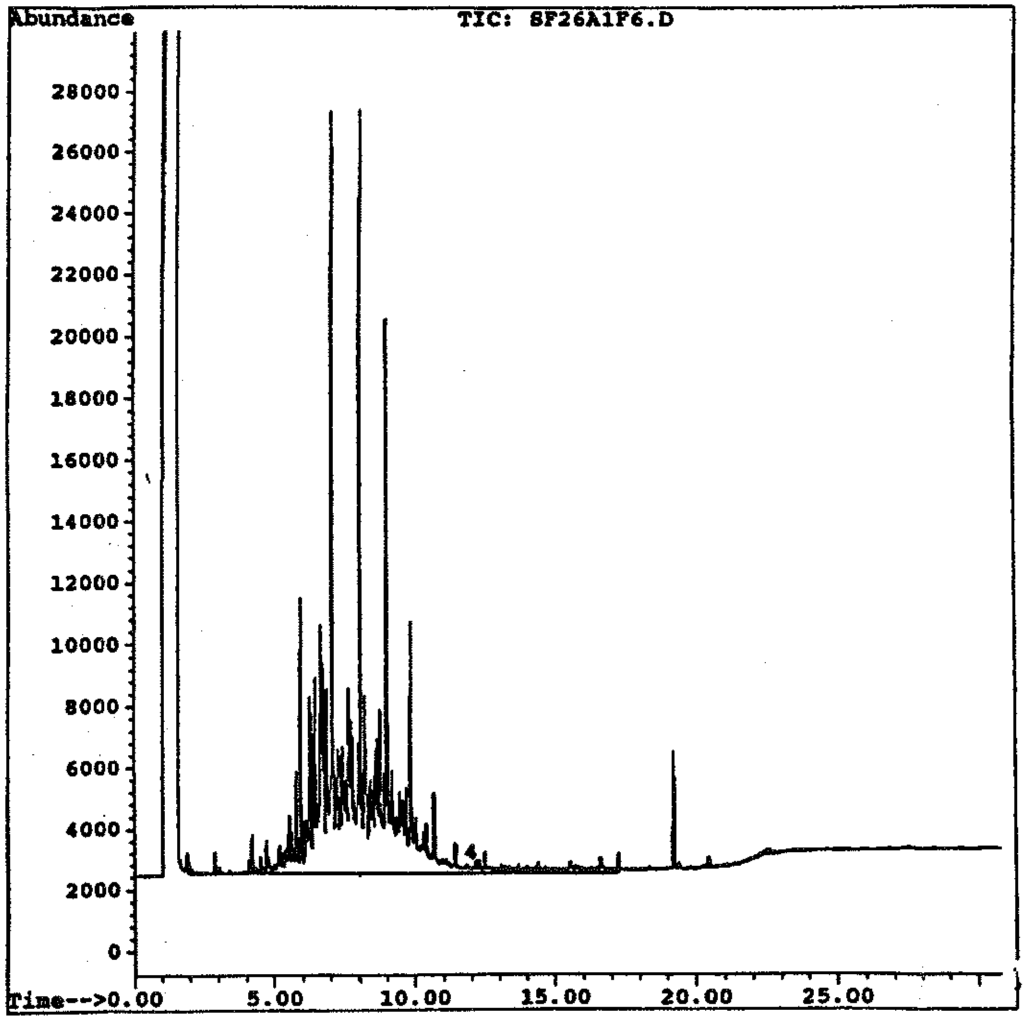

```
SF26A1F6.D  27F26F1W.M        Fri Mar 01 16:48:53 1996                 Page 2
```

Chromatogram of JP- Laboratory
Standard - 300 mg

FIGURE 13
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
CHROMATOGRAPHIC COMPARISON OF DEGRADED JP-5 AND JP-5 STANDARD

DATE: 07-24-96 DDJ DN FILE NAME: 0441\0235\RR\DP5\QUAN-RPT.DS4 gas chromatograph to separate or resolve the oxidation products into distinct peaks. Finally, the increased molecular weight of degraded fuel components will cause the JP-5 to elute later than the undegraded fuel.

Figure 13 shows a chromatogram of a JP-5 laboratory standard and a chromatogram of a water sample from well FP5-1. A close comparison of these two chromatograms shows the fuel in the well FP5-1 groundwater sample is substantially degraded. The water sample chromatogram contains few of the equally spaced resolved peaks that are present in the laboratory standard; this indicates that the alkanes in the water sample have been removed or altered.

Additionally, the water sample chromatogram contains a large unresolved hydrocarbon hump that is displaced about 2 minutes later than the corresponding envelope in the JP-5 standard. The two-minute displacement is roughly equal to the increase in mass (29 atomic mass units) expected by the oxidation of the alkanes. This oxidation reaction combined with the nearly complete loss of the lower molecular weight fraction of the fuel in the water sample suggest the fuel has been substantially degraded.

Thus, it appears the ORC oxidation process did not stimulate biodegradation of the Site 5 fuel contamination because the fuel had been previously biodegraded by native petroleum degrading microorganisms. Although fuels have been shown to be biodegraded to CO_2 in numerous laboratory and field studies, it appears the native petroleum degraders at Site 5 are not able to further degrade the JP-5, or that the process is very slow. Typically, further biodegradation of the oxidized fuel compounds can occur (via beta-oxidation of the fatty acids); however, this process does not appear to be overly active in the Site 5 petroleum-degrading microbes. Elevated dissolved CO_2 concentrations in groundwater and CO_2 high partial pressures in the unsaturated zone just above the petroleum smear zone may inhibit beta-oxidation of fatty acids to CO_2.

6.3.4 Biological Activity

BOD concentrations were unexpectedly low. The samples apparently did not contain sufficient DO initially to allow accurate measurement of BOD. The COD analyses do indicate that sufficient material (both organic and inorganic) is available in the groundwater to utilize oxygen.

Historical groundwater analytical data from Site 5 indicate a sufficient concentration of soluble-phase petroleum to support microbes. However, microbial data from samples collected during baseline sampling indicate total heterotrophic microbe populations between 6,000 and 130,000 colony-forming units per milliliter of groundwater (cfu/ml), and jet fuel-specific microbe populations between 175 and 4,850 cfu/ml. These values indicate marginal populations of hydrocarbon-consuming bacteria that, without increased populations, would not rapidly degrade the fuel.

As discussed in Section 6.2.3, the TPH-e analysis chromatograms indicate that petroleum had degraded before this study was completed. The increased DO concentrations, however, did not appear to influence the biodegradation rate during the study period.

The results of baseline microbial counts on groundwater samples collected during baseline activities indicate populations of both total heterotrophs and petroleum degraders increases somewhat from well FP5-1 to the most downgradient monitoring point. The lowest concentration of total heterotrophs and petroleum degraders was found in the sample from well FP5-1 and the highest counts were found in the sample from monitoring point WORC5-8. Samples collected from monitoring points between WORC5-8 and FP5-1 had intermediate populations. Although microbial counting techniques are variable, the trend of these results is sufficiently consistent within the data set to suggest that the results do represent subsurface conditions. Higher bacterial populations downgradient of well FP5-1 suggest that the immediate area around this well may be oxygen limited.

The low levels of DO, decreased levels of nitrate, low aerobic micro-organism counts, and slightly higher levels of ammonia in groundwater from well FP5-1 (relative to monitoring points WORC5-1 and WORC5-8) suggest microbial nitrate reduction occurs at FP5-1.

Generally, nitrate reduction occurs in anaerobic or low oxygen environments, and the reduced nitrogen compounds produced are either used by the micro-organisms to make proteins (assimilatory) or released to the environment (dissimilatory). According to Atlas and Bartha (1987), in the dissimilatory nitrate reduction process, nitrate is reduced to various reduced nitrogen species with the simultaneous oxidation of organic material (such as JP-5 hydrocarbons). The addition of oxygen to this environment would inhibit continued nitrate reduction.

7.0 RECOMMENDATIONS

The data gathered during this study do not indicate increased petroleum degradation during introduction of increased oxygen to groundwater. The measured TPH-e concentrations changed, but no clear trends developed during the study period. The chromatograms suggest that the fuel has undergone substantial degradation during its residence time in the subsurface, but degradation is a long-term process for the larger hydrocarbon molecules. It is not clear from the collected data that the additional DO supplied by the ORC supported increased microbial populations. It is possible that the test period was too short to allow the aerobic microbe populations to increase and further degrade the fuel. It is also possible that insufficient carbon source (fuel) exists to support an increased microbe population.

Use of ORC to reduce TPH-e concentrations at Site 5 is not warranted for the following reasons. First, the results of this test do not indicate a correlation between TPH-e reduction and placement of ORC in the source well. Second, data did not indicate significant oxygen transport downgradient of the ORC source well. Third, the petroleum contamination appears to have undergone substantial degradation under intrinsic conditions.

In light of the recent policy revisions by the State of California agencies that regulate petroleum corrective actions, use of an active medium (such as ORC) to enhance degradation of petroleum contamination in groundwater at this site is not warranted. The recently published study led by LLNL (Rice and others 1995) indicates acceptable rates of petroleum biodegradation without enhancement.

Data from this treatability study indicate that intrinsic remediation should be the selected corrective action for petroleum-contaminated groundwater at Site 5. Examination of chromatograms for samples collected from the site demonstrated that the fuel is currently being degraded. Microbe enumeration surveys also indicate that microbial populations reside in the subsurface. There is no apparent current or near-future potential human receptor pathway for dissolved-phase petroleum, since groundwater is not currently used at MFA. Therefore, long-term corrective action through natural attenuation should adequately protect the groundwater resource at this site.

To confirm the above described risk assumption, groundwater at the site will be evaluated for human health risks under the protocol described in the MFA facility-wide petroleum risk assessment technical memorandum (currently being prepared). This assessment will be conducted under another CTO.

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APPENDIX A

FIELD DATA

TABLE A1
MOFFETT FEDERAL AIRFIELD
SITES GROUNDWATER TREATABILITY STUDY
BROMIDE DATA SUMMARY
(concentration in parts per million)

DATE	TIME	WORC5-1 SHALLOW	WORC5-1 DEEP	WORC5-2 SHALLOW	WORC5-2 DEEP	WORC5-3 SHALLOW	WORC5-3 DEEP	WORC5-4 SHALLOW	WORC5-4 DEEP
9/26/95	13:30:00	0.34	0	0	0	0.0235	0	0	0
9/26/95	15:30:00	2.86	1.26	0.984	0.692	0.521	0.316	0.416	0.405
9/26/95	18:20:00	5.18	0.879	0.408	0.158	0.256	0.0301	0.674	0.323
9/26/95	20:00:00	1.92	0.729	0	0	0	0	0	0
9/26/95	22:30:00	2.68	2.19	0.811	1.05	1.08	0.965	1.68	1.48
9/27/95	00:20:00	0.174	0	0	0	0	0	0	0
9/27/95	02:20:00	0	0	0	0	0	0	0	0
9/27/95	06:00:00	0.844	0	0	0	0	0	0	0
9/27/95	08:00:00	0	0	0	0	0	0	0	0
9/27/95	10:00:00	0	0	0	0	0	0	0	0
9/27/95	12:00:00	0	0	0	0	0	0	0	0
9/27/95	16:00:00	0	0	0	0	0	0	0	0
9/27/95	20:00:00	0	0	0	0	0	0	0	0
9/28/95	00:10:00	0	0	0	0	0	0	0	0
9/28/95	07:30:00	0	0	0	0	0	0	0	0
9/28/95	13:30:00	4.78	3.85	2.68	2.76	2.27	2.5	3.24	3.28
9/28/95	19:20:00	3	2.06	1.16	0.785	0.599	0.599	1.08	2.2
9/29/95	08:15:00	5.26	4.75	3.25	2.88	2.17	2.54	4.72	4.32
9/29/95	15:30:00	0.523	0.601	0	0	0	0	0.865	1.25
10/1/95	11:30:00	0	0	0	0	0	0	0.155	0.0872
10/2/95	11:00:00	2.55	0.88	0.391	0.345	0	0	2.83	2.81
10/3/95	10:00:00	3.65	4.65	4.5	4.49	4.42	4.47	4.93	4.82
10/3/95	21:30:00	1.42	1.38	0.45	0.162	0.162	0.124	4.08	2.54
10/4/95	11:00:00	1.21	0.51	0	0	0	0	2.78	3.36
10/4/95	21:05:00	3.52	1.37	1.14	0	0.456	0.617	3.39	2.4
10/5/95	10:00:00	2.24	1.53	1.17	0.981	0.908	0.867	3.44	4.17
10/5/95	20:30:00	4.63	2.42	2.36	2.07	1.7	1.72	4.54	5.3

TABLE A1 (Continued)
MOFFETT FEDERAL AIRFIELD
SITES GROUNDWATER TREATABILITY STUDY
BROMIDE DATA SUMMARY
(concentration in parts per million)

DATE	TIME	WORC5-1 SHALLOW	WORC5-1 DEEP	WORC5-2 SHALLOW	WORC5-2 DEEP	WORC5-3 SHALLOW	WORC5-3 DEEP	WORC5-4 SHALLOW	WORC5-4 DEEP
10/6/95	08:00:00	1.12	1	1.1	0.979	0.859	1.19	3.92	4.31
10/6/95	20:00:00	0.197	0	0	0	0	0	2.5	1.78
10/7/95	09:45:00	1.36	0.942	0.621	0.58	0.6	0.595	2.9	3.03
10/7/95	21:10:00	2.63	1.65	2.59	2.36	1.22	1.69	3.91	4.46
10/8/95	08:30:00	4.9	2.95	2.03	1.49	1.4	1.23	4.1	4.63
10/8/95	20:15:00	3.92	3.18	2.07	2.11	1.78	1.8	6.41	6.31
10/9/95	08:00:00	1.03	0.891	0.538	0.35	0.45	0.436	2.17	2.71
10/9/95	20:00:00	5.59		0.123	0.126	1.52	0.611	2.98	2.8
10/10/95	09:00:00	0	0	0	0	0	0	2.28	2.34
10/10/95	20:15:00	1.56	0	0.19	0	1.88	0	0	1.1
10/11/95	20:15:00	4.46	1.52	0.435	0.636	1.11	0.158	2.86	3.6
10/12/95	10:00:00	0.621	0.303	0.232	0.226	0.215	0.612	0.982	0.831
10/12/95	20:35:00	0.678	1.1	0.647	0.491	0.447	0.772	0.925	1.87
10/13/95	10:00:00	0.682	0.402	0.435	0.422	0.385	0.275	1.02	1.13
10/13/95	20:30:00	0.421	0.314	0.222	0.222	0.399	0.243	0.961	1.23
10/18/95	08:35:00	0.0103	0.0482	0.0119	0.0108	0.0391	0.0103	0.0638	0.0568

TABLE A1 (Continued)
MOFFETT FEDERAL AIRFIELD
SITES GROUNDWATER TREATABILITY STUDY
BROMIDE DATA SUMMARY
(concentration in parts per million)

DATE	TIME	WORC5-5	WORC5-5	WORC5-6	WORC5-6	WORC5-8	WORC5-8	FP5-1	FP5-1	FP5-1
		SHALLOW	DEEP	SHALLOW	DEEP	SHALLOW	DEEP	SHALLOW	MIDDLE	DEEP
9/26/95	13:30:00	0	0	0.0331	0	0.0331	0			
9/26/95	15:30:00	0.338	0.156	0.305	0.156	0.0952	0.125	695		
9/26/95	18:20:00	0.0934	0.0301	0.391	0	0	0	589	641	592
9/26/95	20:00:00	0	0	0	0	0	0	582	565	483
9/26/95	22:30:00	1.31	1.43	1.08	0.956	0.837	0.623	622	593	619
9/27/95	00:20:00	0	0	0	0	0	0	598	527	479
9/27/95	02:20:00	0	0	0	0	0	0	566	557	510
19/27/95	06:00:00	0	0	0	0	0	0	515	513	441
9/27/95	08:00:00	0	0	0	0	0	0	504	504	431
9/27/95	10:00:00	0	0	0	0	0	0	504	484	432
9/27/95	12:00:00	0	0	0	0	0	0	462	447	445
9/27/95	16:00:00	0	0	0	0	0	0	435	426	407
9/27/95	20:00:00	0	0	0	0	0	0	447	428	426
9/28/95	00:10:00	0	0	0	0	0	0	423	408	329
9/28/95	07:30:00	0	0	0	0	0	0	440	464	346
9/28/95	13:30:00	2.66	3.33	2.44	2.03	2.07	2.08	349	338	340
9/28/95	19:20:00	2.2	1.47	0.731	0.362	0.388	0.206	330	325	313
9/29/95	08:15:00	3.25	3.41	2.54	2.77	2.34	2.58	344	340	260
9/29/95	15:30:00	0.575	0.759	0	0	0	0	296	257	240
10/1/95	11:30:00	1.45	1.83	0	0	0	0	187	145	131
10/2/95	11:00:00	3.49	4.66	0.233	0	0	1.02	159	129	132
10/3/95	10:00:00	3.52	4.92	4.59	4.55	4.56	4.45	122	117	79
10/3/95	21:30:00	3.36	3.15	0	0	0	0	ND	109	115
10/4/95	11:00:00	4.14	5.65	0	0	0	0	102	72.5	93.9
10/4/95	21:05:00	4.88	4.49	0.775	0.399	0.492	0.581	137	155	132
10/5/95	10:00:00	5.48	6.47	1.35	1.33	1.22	0.987	78.7	52.7	55.7
10/5/95	20:30:00	9.87	8.47	1.73	1.28	1.53	1.83	87.2	64.3	63.9
10/6/95	08:00:00	7.21	8.3	1.85	1.36	1.32	1.26	86.6	69.4	47.1

TABLE A1 (Continued)
MOFFETT FEDERAL AIRFIELD
SITES GROUNDWATER TREATABILITY STUDY
BROMIDE DATA SUMMARY
(concentration in parts per million)

DATE	TIME	WORC5-5	WORC5-5	WORC5-6	WORC5-6	WORC5-8	WORC5-8	FP5-1	FP5-1	FP5-1
		SHALLOW	DEEP	SHALLOW	DEEP	SHALLOW	DEEP	SHALLOW	MIDDLE	DEEP
10/6/95	20:00:00	6.24	6.2	0	0	0	0	80.2	47.8	34.9
10/7/95	09:45:00	7.2	4.18	0.372	0.524	0.711	0.749	61.9	38.4	26.9
10/7/95	21:10:00	10.6	11.4	0.732	0.749	0.691	0.83	69.5	38.1	33.1
10/8/95	08:30:00	7.54	6.49	1.13	1.31	1.73	1.53	54.5	31.5	26.8
10/8/95	20:15:00	11.7	10.8	2.4	2.26	3.16	3.08	56	36.5	29.5
10/9/95	08:00:00	8.24	6.61	2.15	0.845	1.64	0.745	38	18.6	17.7
10/9/95	20:00:00	8.61	8.51	1.03	0.761	0.959	1.98	29.1	18.4	17.8
10/10/95	09:00:00	6.6	6.36	0	0	0	0	39.7	26.4	16.1
10/10/95	20:15:00	4.57	5.46	0	0.152	0.19	0	22.5	15.4	12.4
10/11/95	20:15:00	7.36	7.7	1.46	1.42	0.907	0.8	22.2	11.5	11
10/12/95	10:00:00	4.91	5.77	0.612	0.365	0.794	0.5	11.8	5.37	4.73
10/12/95	20:35:00	5.01	4.91	0.721	0.48	0.699	0.617	5.04	5.03	5.27
10/13/95	10:00:00	2.43	2.21	0.351	0.281	0.415	0.423	10.6	3.79	3.61
10/13/95	20:30:00	2.23	1.49	0.354	0.222	0.327	0.332	9.83	4.92	3.36
10/18/95	08:35:00	0.131	0.0717	0.0069	0.0006	0.005	0.0027	2.73		

TABLE A2
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
DISSOLVED OXYGEN DATA
(Concentrations in mg/L)

SAMPLE ID	SAMPLE DATE							STATISTICAL ANALYSIS		
	11/17/95	12/1/95	12/15/95	1/12/96	2/9/96	3/8/96	4/5/96	AVERAGE	STANDARD DEVIATION	PERCENT STANDARD DEVIATION
FP5-1	29	22	17	13	9	8	0.8	14.1	9.44	66.8
WORC5-1	1	0.8	0.8	1	0.4	0.6	0.6	0.7	0.22	30.0
WORC5-2	0.8	1	1	1	0.8	1	1.2	1.0	0.14	14.2
WORC5-3	0.8	1.8	1.6	1	0.8	0.8	1	1.1	0.45	41.0
WORC5-4	1	1.8	1.8	1	0.6	0.8	1	1.1	0.47	41.3
WORC5-5	0.8	1.8	1.6	1	0.8	0.8	1	1.1	0.41	37.2
WORC5-6	0.8	1	1	0.8	1	1	1	0.9	0.10	10.4
WORC5-8	1.2	1	1	1.2	0.8	1.2	0.8	1.0	0.18	17.5
AVERAGE	0.9	1.3	1.3	1.0	0.7	0.9	0.9			
STANDARD DEVIATION	0.16	0.46	0.40	0.12	0.19	0.22	0.19			
PERCENT STANDARD DEVIATION	17.2	35.0	31.4	11.5	25.6	26.0	20.2			

Notes:

mg/L Milligrams per liter

APPENDIX B

CHEMICAL DATA

TABLE B1
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
SUMMARY OF HISTORICAL
TPH DATA FROM FP5-1
(Concentrations in μg/L)

Sample Date	Diesel		JP-5		Kerosene		Motor Oil		Other TPH	
	Concentration	Qualifier	Concentration	Qualifier	Concentration	Qualifier	Concentration	Qualifier	Concentration	Qualifier
9/29/93	2,500	U	2,500	U	300,000		25,000	U	2,500	U
12/14/93	15,000	U	15,000	U	2,000,000		150,000	UJ-K	15,000	U
3/10/94	50	U	50	UJ-K	9,400	J-K	500	U	50	U
5/26/94	50	UJ-K	50	U	50	U	500	U	1,800	Y
9/12/94	200	UJ-K	18,000		200	U	2,000	U	200	U
6/12/95	500	UJ-S	500	UJ-S	500	UJ-S	5,000	UJ-S	54,000	YJ-S

Notes:

J = Estimated
K = Calibration was outside quality control limits
S = Surrogate compound recovery was outside quality control limits
U = Undetected
Y = Assembles a typical fuel pattern but pattern match is less than 90 percent chromotographic pattern

TABLE B2
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
REQUANTITATED TPH[1]
DATA SUMMARY
(Concentrations in μg/L)

Sample Date	Sample Designation								
	WORC5-1	WORC5-2 99	FP5-1	WORC5-2	WORC5-3	WORC5-4	WORC5-5	WORC5-6	WORC5-8
10/19/93[1]	860	NA	400	140	190	320	200	140	180
11/3/95	630	NA	610	130	97J	210	170	130	100
11/17/95	680	NA	900	89J	78J	160	110	94J	86J
12/1/95	1080	540	390	100	110	190	150	110	320
12/15/95	730	690	930	75J	100	410	180	79J	290
1/12/96	810	670	570	89J	84J	290	120	120	78J
2/9/96	980	860	660	210	210	550	310	340	210
3/8/96	470	500	230	100	90J	230	220	180	80J
4/5/96	1070	670	660	140	130	340	190	180	110

Notes:

1	All results were recalculated as TPH using the JP5 standard from the original laboratory results
2	Duplicate of WORC5-1
3	These data represent baseline concentrations
J	Estimated value, concentration is below the CRQL
NA	Not analyzed
μg/L	micrograms per liter

TABLE B3
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
LABORATORY-REPORTED TPH DATA
(Concentrations in $\mu g/L$)

Sample Date	Contaminant Standard	Sample Identification							
		WORC5-1	FP5-1	WORC5-2	WORC5-3	WORC5-4	WORC5-5	WORC5-6	WORC5-8
10/19/95[1]	Diesel	100U	380	100U	67J	140	84J	130	73J
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	100U	100U	100U	100U	100U	100U	100U	100U
	JP-5	860	100U	140	120	170	110	100U	100
11/3/95	Diesel	613	593	127	94J	210	160	127	97J
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	66J	69J	56J	100U	62J	117	100U	100U
	JP-5	100U	100U	100U	100U	100U	100U	100U	100U
11/17/95	Diesel	180	150	90JY	79JY	160Y	110	95J	84J
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	100U	100U	100U	100U	100U	100U	100U	100U
	JP-5	500	750	100U	100U	100U	100U	100U	100U

TABLE B3 (Continued)
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
LABORATORY-REPORTED TPH DATA
(Concentrations in $\mu g/L$)

Sample Date	Contaminant Standard	Sample Identification							
		WORC5-1	FP5-1	WORC5-2	WORC5-3	WORC5-4	WORC5-5	WORC5-6	WORC5-8
12/1/95	Diesel	300	230	60J	60J	110	82J	110	86J
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	820	100U	100U	100U	100U	100U	100U	100U
	JP-5	220	160	100U	100U	79J	68J	100U	230
12/15/95	Diesel	430	470	76J	100	410	180	80J	290
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	53J	100U	100U	100U	100U	100U	100U	100U
	JP-5	310	460	100U	100U	100U	100U	100U	100U
1/12/96	Diesel	510	280	65J	65J	250	95J	140	59J
	Kerosene	400	370	100U	100U	74J	100U	100U	100U
	Motor Oil	57J	100U	100U	100U	100U	100U	100U	100U
	JP-5	100U	100U	100U	100U	100U	100U	100U	100U

TABLE B3 (Continued)
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
LABORATORY-REPORTED TPH DATA
(Concentrations in μg/L)

Sample Date	Contaminant Standard	Sample Identification							
		WORC5-1	FP5-1	WORC5-2	WORC5-3	WORC5-4	WORC5-5	WORC5-6	WORC5-8
2/9/96	Diesel	690	450	120	120	390	200	250	140
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	70J	220	86J	86J	140	82J	88J	61J
	JP-5	310	110	100U	100U	100	74J	54J	100U
3/8/96	Diesel	630	310	130	120	320	290	250	110
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	140Y	120Y	ND	82JYZ	100Y	110Y	120YZ	62JYZ
	JP-5	100U	100U	100U	100U	100U	100U	100U	100U
4/5/96	Diesel	1,400	890	190	180	450	260	250	150
	Kerosene	100U	100U	100U	100U	100U	100U	100U	100U
	Motor Oil	370ZY	130ZY	110Z	120Z	120ZY	120ZY	140ZY	57JZ
	JP-5	100U	100U	100U	100U	100U	100U	100U	100U

Notes:

1	Samples collected on this date represent baseline conditions prior to installation of ORC into 2P-1
U	Undetected
ND	Not Detected
J	Estimated, concentration is below the CRQL
JP-5	Jet Petroleum Number 5
Y, Z	Samples chromatographic response does not resemble a typical fuel pattern
μg/L	Micrograms per liter

TABLE B4
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
DISSOLVED METALS DATA SUMMARY[1]
(Concentrations in $\mu g/L$)

Analyte	Sample Designation		
	FP5-1	WORC5-1	WORC5-8
Aluminum	32.6B	26.6B	32.5B
Antimony	3.0U	3.0U	3.0U
Arsenic	2.8U	2.8U	2.8U
Barium	171B	173B	155B
Beryllium	0.10U	0.10U	0.10U
Cadmium	0.20U	0.20U	0.20U
Calcium	111,000	113,000	119,000
Chromium	0.50U	10.50U	0.50U
Cobalt	0.50U	0.78B	0.50U
Copper	4.2B	3.1B	4.8B
Iron	227	1500	13.9B
Lead	1.2U	1.2U	1.2U
Magnesium	72,700	76,200	71,500
Manganese	412	1080	140
Mercury	0.10UN	0.10UN	0.12BN
Molybdenum	4.0B	3.6B	8.0
Nickel	4.5B	6.2B	5.7B
Potassium	2540B	484U	578B
Selenium	3.9U	3.9U	3.9U
Silver	0.70UN	0.70UN	0.70UN
Sodium	72,600	77,300	72,800
Thallium	6.7	4.4B	1.9U
Vanadium	2.7B	1.5B	3.8B
Zinc	23.1	20.4	30.1

Notes:

[1] Samples collected October 19, 1995

U = Undetected
B = Reported value is less than the Contract Required Detection Limit (CRQL) but greater than the Instrument Detection Limit (IDL)
N = Spiked sample recovery is not within control limits

TABLE B5
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
MAJOR ANION NUTRIENT DATA SUMMARY
(Concentrations in μg/L)

Analyte	Sample Designation		
	FP5-1	WORC5-1	WORC5-8
Ammonia-Nitrogen	0.05	0.04	0.03
Bromide	2.6	0.26	0.62
Chloride	31.9	30.8	32.7
Fluoride	0.26	0.33	0.32
Nitrate-Nitrogen	0.41	1.2	1.7
Phosphate	1.0 U	0.05 U	0.05 U
Sulfate	77.4	72.4	97.6

Notes:

[1] Sample collected on October 19, 1995

U Undetected
μg/L milligrams per liter

TABLE B6
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
OXYGEN CONSUMPTION ANALYSIS DATA SUMMARY

Analyte	Concentration (mg/L)							
	FP5-1	WORC5-1	WORC5-2	WORC5-3	WORC5-4	WORC5-5	WORC5-6	WORC5-8
BOD	2U	2U	2U	2U	2U	2U	2U	2U
COD	14	12	5U	5U	7	5U	5U	5U
TKN	0.24U	0.24U	NA	NA	NA	NA	NA	0.24U

Notes:

[1] Samples collected on October 19, 1995

U	Undetected
NA	Not analyzed
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
TKN	Total Kjeldahl Nitrogen

TABLE B7
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
COMPARATIVE ENUMERATION ASSAY SUMMARY[1]

Growth Media	FP5-1		WORC5-1		WORC5-4		WORC5-8	
	Mean (cfu/mL)	95% Confidence Range	Mean (cfu/mL)	95% Confidence Range	Mean (cfu/mL)	95% Confidence Range	Mean (cfu/mL)	95% Confidence Range
Total Populations: Simple Carbon Compounds	6,410	5,720 to 7,140	41,900	36,200 to 48,100	54,900	48,500 to 61,900	132,000	121,000 to 142,000
Degrader Populations: JP-5	175	142 to 217	943	849 to 1,040	397	339 to 456	4,850	4,220 to 5,470

Notes:

[1] Analysis completed by BioRenewal Technologies, Inc., Madison, Wisconsin

cfu/ml colony-forming units per milliliter

TABLE B8
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
NUTRIENT DATA SUMMARY[1]

Parameter	Units	FP5-1	WORC5-1	WORC5-4	WORC5-8
TKN	ppm	1.6	1.5	3.8	2.0
NH_4-N	ppm	0.5U	0.5U	0.5U	0.5U
Available Phosphurus	ppm	0.1	0.2	0.2	0.2
Available Potassium	ppm	0.5	1.0	1.0	0.5
pH	pH units	7.5	7.4	7.5	7.5
Nitrates Nitrogen	ppm	0.5U	1.0	0.5U	0.5U

Notes:

[1] Samples collected in September 24, 1995
Analyses completed by BioRenewal Technologies, Inc., Madison, Wisconsin

U	Undetected
TKN	Total Kjadehl nitrogen
NH_4-N	Ammonia as nitrogen
ppm	parts per million

TABLE B9
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
METALS DATA SUMMARY[1]
(Concentrations in μg/L)

Analyte	Sample Designation			
	FP5-1	WORC5-1	WORC5-4	WORC5-8
Aluminum	0.35U	0.35U	0.35U	0.35U
Arsenic	0.279U	0.279U	0.279U	0.279U
Barium	0.75	0.88	0.82	0.78
Cadmium	0.010U	0.010U	0.010U	0.010U
Calcium	103.1	104.7	102.0	102.0
Chromium	0.017U	0.017U	0.017U	0.017U
Cobalt	0.018U	0.018U	0.018U	0.018U
Copper	0.03U	0.03U	0.03U	0.03U
Iron	0.03	0.07	0.04	0.01U
Lead	0.111U	0.111U	0.111U	0.111U
Lithium	0.025U	0.025U	0.025U	0.025U
Magnesium	68.31	70.95	68.68	71.45
Manganese	0.313	0.730	0.792	0.617
Molybdenum	0.021U	0.021U	0.021U	0.021U
Nickel	0.037U	0.037U	0.037U	0.037U
Phosphorus	0.22U	0.22U	0.22U	0.22U
Potassium	0.62U	0.62U	0.62U	0.62U
Selenium	0.190U	0.190U	0.190U	0.190U
Sodium	76.70	80.48	77.80	75.69
Sulfur	30.84	29.49	28.48	26.78
Zinc	0.01U	0.01U	0.01U	0.01U

Notes:

[1] Samples collected on September 24, 1995. Analysis completed by BioRenewal Technologies, Inc., Madison, Wisconsin

U	Undetected
μg/L	milligrams per liter

TABLE B10
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
STATISTICAL SUMMARY OF TRIPLICATE SAMPLE DATA
NOVEMBER 3, 1995
(Concentrations in μg/L)

Sample ID	Diesel		Motor Oil		Kerosene		JP-5	
	Concentration	Mean ± Standard Deviation	Concentration	Mean ± Standard Deviation	Concentration	Mean ± Standard Deviation	Concentration	Mean ± Standard Deviation
WORC5-1A	740	613 ± 95	69J	66 ± 3	100U	NA	100U	NA
WORC5-1B	590		61J		100U		100U	
WORC5-1C	510		67J		100U		100U	
FP5-1A	550	593 ± 31	78J	69 ± 8	100U	NA	100U	NA
FP5-1B	610		70J		100U		100U	
FP5-1C	620		58J		100U		100U	
WORC5-2A	130	127 ± 5	100U	56 ± 8	100U	NA	100U	NA
WORC5-2B	130		100U		100U		100U	
WORC5-2C	120		68J		100U		100U	
WORC5-3A	95J	94 ± 6	100U	NA	100U	NA	100U	NA
WORC5-3B	86J		100U		100U		100U	
WORC5-3C	100		100U		100U		100U	

TABLE B10(Continued)
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
STATISTICAL SUMMARY OF TRIPLICATE SAMPLE DATA
(Concentrations in $\mu g/L$)

Sample ID	Diesel		Motor Oil		Kerosene		JP-5	
	Concentration	Mean ± Standard Deviation	Concentration	Mean ± Standard Deviation	Concentration	Mean ± Standard Deviation	Concentration	Mean ± Standard Deviation
WORC5-4A	220	210 ± 22	66J	62 ± 9	ND	NA	ND	NA
WORC5-4B	180		ND		ND		ND	
WORC5-4C	230		71J		ND		ND	
WORC5-5A	160	160 ± 0	130	117 ± 50	ND	NA	ND	NA
WORC5-5B	160		170		ND		ND	
WORC5-5C	160		ND		ND		ND	
WORC5-6A	120	127± 5	ND	NA	ND	NA	ND	NA
WORC5-6B	130		ND		ND		ND	
WORC5-6C	130		ND		ND		ND	
WORC5-8A	92J	97± 4	ND	NA	ND	NA	ND	NA
WORC5-8B	100		ND		ND		ND	
WORC5-8C	100		ND		ND		ND	

Notes:

1.	A,B and C are aliquots of the associated sample point
J	Estimated Value, concentration is below the CRQL
U	Undetected
NA	Not Applicable
$\mu g/L$	micrograms per liter

APPENDIX C

BORELOGS

BOREHOLE LOG

PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:

Borehole Designation: WORC5-01

Client: U.S. Navy

Surface Elevation: Not Surveyed

Site: Moffett Federal Airfield Subsite: Site 5

Geologist: Steve Broering

Drilling Date (s): September 12, 1995

Well Installation Date (s):

Drilling Company: PRC Personnel: W. Wilcoxon, D. Berestka

Drilling Method: Geoprobe

Borehole Diameter: ______ Latitude: ______ Longitude: ______

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		4/4				0-3	CL	SILTY CLAY; very dark gray (10YR 3/1), low plasticity, dry to damp, stiff, trace roots
								Color lightens with depth
						3-4	ML	CLAYEY SILT; light brownish gray (10YR 6/2), low plasticity, damp, stiff, trace sand
5		4/4				4-7.6	CL	SILTY CLAY; light brownish gray (10YR 6/2), low plasticity, damp, stiff, trace sand
		4/4				7.6-7.9	GC	CLAYEY GRAVEL; pale brown (10YR 6/3), gravel is fine, saturated, loose, trace sand, little silt
						7.9-8.3	CL	SILTY CLAY; brown (10YR 5/3), low plasticity, saturated, stiff, trace sand, trace concretions
						8.3-8.9	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), gravel is fine, saturated, loose, trace silt
10						8.9-10.6	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, saturated, very stiff
						10.6-12	ML	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, soft
								Total depth of borehole 12 feet bgs
15								

BOREHOLE LOG

PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:
Client: U.S. Navy
Site: Moffett Federal Airfield Subsite: Site 5
Drilling Date (s): September 12, 1995

Borehole Designation: WORC5-02
Surface Elevation: Not Surveyed
Geologist: Steve Broering
Well Installation Date (s):

Drilling Company: PRC Personnel: W. Wilcoxon, D. Berestka
Drilling Method: Geoprobe
Borehole Diameter: Latitude: Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		4/4				0-3	CL	SILTY CLAY; very dark gray (10YR 3/1), low plasticity, dry to damp, stiff, fine roots
		4/4				3-7.6	ML	CLAYEY SILT; light brownish gray (10YR 6/2), low plasticity, damp, stiff, trace sand
5								Clay content decreases with depth, color changes to pale brown (10YR 6/3), moisture increases with depth
								Trace of gravel
		4/4				7.6-8	CL	SILTY CLAY; brown (10YR 5/3), low plasticity, saturated, stiff, trace gravel and sand, trace concretions
						8-8.5	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), gravel is fine, loose, saturated, trace silt
10						8.5-11	CL	SANDY CLAY; dark yellowish brown (10YR 5/2), low plasticity, very stiff, saturated
						11-12	ML	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, soft
								Total depth of borehole 12 feet bgs
15								

BOREHOLE LOG

PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:

Borehole Designation: WORC5-03

Client: U.S. Navy

Surface Elevation: Not Surveyed

Site: Moffett Federal Airfield Subsite: Site 5

Geologist: Steve Broering

Drilling Date (s): September 12, 1995

Well Installation Date (s):

Drilling Company: PRC Personnel: W. Wilcoxon, D. Berestka

Drilling Method: Geoprobe

Borehole Diameter: Latitude: Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		0/4				0-4		No recovery, no sample description
5		4/4				4-8.1		CLAYEY SILT; light brownish gray (10RY 6/2),low plasticity, damp, stiff, petroleum odor, trace sand
							ML	Moisture increases with depth
								Clay content decreases with depth
								Trace to minor gravel
10		0/3				8.1-11		No recovery, no sample description
		4/4				11-12.6		SANDY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, soft
						12.6-15	ML	CLAYEY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, stiff
15								Total depth of borehole 15 feet bgs

BOREHOLE LOG

PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:
Client: U.S. Navy
Site: Moffett Federal Airfield Subsite: Site 5
Drilling Date (s): September12, 1995
Borehole Designation: WORC5-04
Surface Elevation: Not Surveyed
Geologist: Steve Broering
Well Installation Date (s):
Drilling Company: PRC Personnel: W. Wilcoxon, D. Berestka
Drilling Method: Geoprobe
Borehole Diameter: Latitude: Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		0/4				0-4		No recovery, no sample description
5		4/4				4-7.4	ML	CLAYEY SILT; pale brown (10YR 6/3), damp increasing to moist with depth, low plasticity, trace sand, petroleum odor.
						7.4-7.8	GC	CLAYEY GRAVEL; pale brown (10YR 6/3), gravel is fine, loose, saturated, little sand, trace silt, petroleum odor
		4/4				7.8-8.1	CL	SILTY CLAY; brown (10YR 5/3), low plasticity, saturated, stiff, trace sand, trace concretions
						8.1-8.9	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), gravel is fine, loose, saturated, trace silt
10						8.9-11.1	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, very stiff, saturated
						11.1-12.2	ML	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, soft
15		4/4				12.2-16		CLAYEY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, stiff

BOREHOLE LOG *PRC* **ENVIRONMENTAL MANAGEMENT, INC.**

Job Number: 044-0235IRRDP5 Well Designation:
Borehole Designation: WORC5-05
Client: U.S. Navy
Surface Elevation: Not Surveyed
Site: Moffett Federal Airfield Subsite: Site 5
Geologist: Steve Broering
Drilling Date (s): September 13, 1995
Well Installation Date (s):
Drilling Company: PRC Personnel: W. Wilcoxon, D. Berestka
Drilling Method: Geoprobe
Borehole Diameter: Latitude: Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		0/4				0-4		No sample recovery, no description
5		4/4				4-7.5	ML	CLAYEY SILT; pale brown (10YR 6/3), low plasticity, damp increasing to moist with depth
		4/4				7.5-7.9	GC	CLAYEY GRAVEL; pale brown (10YR 6/3), gravel is fine, loose, trace silt, little sand, saturated, petroleum odor
						7.9-8.2	CL	SILTY CLAY; brown (10YR 5/0), low plasticity, saturated, stiff, trace sand, trace concretions
						8.2-8.8	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), gravel is fine, loose, saturated, trace silt
10						8.8-11.1	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, very stiff
		2/2				11.1-12.2	ML	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, soft
						12.2-14		CLAYEY SILT; yellowish brown (10YR 5/4), low plasticity, stiff, saturated
15								Borehole total depth 14 feet bgs

BOREHOLE LOG

PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:

Client: U.S. Navy

Site: Moffett Federal Airfield Subsite: Site 5

Drilling Date (s): September 13, 1995

Borehole Designation: WORC5-06

Surface Elevation: Not Surveyed

Geologist: Steve Broering

Well Installation Date (s):

Drilling Company: PRC

Personnel: W. Wilcoxon, D. Berestka

Drilling Method: Geoprobe

Borehole Diameter:

Latitude:

Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		0/4					☒	No sample recovery, no description
		0/4					☒	
5							☒	
		4/4				8-8.5	GW	GRAVELLY SAND; light brownish gray (10YR 6/2), gravel is fine, loose, saturated, trace silt
						8.5-11	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, stiff, saturated
10								
						11-12.2	ML	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, soft
		2/2				12.2-14		CLAYEY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, stiff
								Borehole total depth 14 feet bgs
15								

Page 1 of 1

BOREHOLE LOG

PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:
Borehole Designation: WORC5-08
Client: U.S. Navy
Surface Elevation: Not Surveyed
Site: Moffett Federal Airfield Subsite: Site 5
Geologist: Steve Broering
Drilling Date (s): September 13, 1995
Well Installation Date (s):
Drilling Company: PRC
Personnel: W. Wilcoxon, D. Berestka
Drilling Method: Geoprobe
Borehole Diameter:
Latitude:
Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		0/4				0-4		No sample recovery, no description
5						4-7.5	ML	CLAYEY SILT; pale brown (10YR 6/3), low plasticity, stiff, damp increasing to moist with depth, trace sand
						7.5-7.8	GC	CLAYEY GRAVEL; pale brown (10YR6/3), gravel is fine, saturated, loose, little sand, trace silt, petroleum odor
		4/4				7.8-8.1	ML	SILTY CLAY; brown (10YR 5/3), low plasticity, saturated, stiff, trace sand, concretions
						8.1-8.9	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), gravel is fine, loose, trace of silt
10						8.9-11.2	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, stiff
						11.2-12	ML	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, stiff
								Borehole total depth 12 feet bgs
15								

BOREHOLE LOG **PRC ENVIRONMENTAL MANAGEMENT, INC.**

Page 1 of 1

Job Number: 044-0235IRRDP5 Well Designation:

Borehole Designation: TPZ5-01

Client: U.S. Navy

Surface Elevation: Not Surveyed

Site: Moffett Federal Airfield Subsite: Site 5

Geologist: Steve Broering

Drilling Date (s): September 11, 1995

Well Installation Date (s):

Drilling Company: PRC Personnel: W. Wilcoxon, D. Berestka

Drilling Method: Geoprobe

Borehole Diameter: ______ Latitude: ______ Longitude: ______

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		4/4				0-2.5	CL	SILTY CLAY; very dark gray (10YR 3/1), low plasticity, dry to damp, stiff, trace roots
						2.5-5	ML	CLAYEY SILT; light brownish gray (10YR 6/2), low plasticity, damp, stiff, trace sand
		4/4				4-8		Decreasing clay content, color changes to pale brown (10YR 6/3)
5						5-8	GC	CLAYEY GRAVEL; pale brown (10YR 6/3), fine, saturated, loose, little sand, petroleum odor
		4/4				8-9.2 8-12	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), fine, loose, saturated, trace silt
						9.2-12	CL	SANDY CLAY; dark yellowish brown (10YR 6/2), low plasticity, saturated, stiff to very stiff
10								
								Decrease in clay, increase in silt content
								Total depth of borehole 12 feet bgs
15								

BOREHOLE LOG

PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:

Borehole Designation: TPZ5-02

Client: U.S. Navy

Surface Elevation: Not Surveyed

Site: Moffett Federal Airfield Subsite: Site 5

Geologist: Steve Broering

Drilling Date (s): September 11, 1995

Well Installation Date (s):

Drilling Company: PRC

Personnel: W. Wilcoxon, D. Berestka

Drilling Method: Geoprobe

Borehole Diameter:

Latitude:

Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		4/4				0-3	CL	SILTY CLAY; very dark gray (10YR 3/1), low plasticity, dry to damp, stiff, trace fine roots
5		4/4				3-7	ML	SILTY CLAY; light brownish gray (10YR 6/2), low plasticity, damp, stiff, trace sand
						7-7.5	GC	CLAYEY GRAVEL; pale brown (10YR 6/3), fine, saturated, loose, trace silt, little sand, petroleum odor
						7.5-8	CL	SILTY CLAY; brown (10YR 5/3), low plasticity, saturated, stiff, trace sand, trace concretions
		4/4				8-8.9	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), fine, saturated, loose, trace silt
10						8.9-11	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, saturated, very stiff
						11-12	ML	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, oh so soft
								Total depth of borehole 12 feet bgs
15								

BOREHOLE LOG **PRC ENVIRONMENTAL MANAGEMENT, INC.** *Page 1 of 1*

Job Number: 044-0235IRRDP5 Well Designation:
Client: U.S. Navy
Site: Moffett Federal Airfield Subsite: Site 5
Drilling Date (s):
Borehole Designation: TPZ5-03
Surface Elevation: Not Surveyed
Geologist: Steve Broering
Well Installation Date (s):
Drilling Company: PRC Personnel: W. Wilcoxon, D. Berestka
Drilling Method: Geoprobe
Borehole Diameter: Latitude: Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		4/4				0-3	CL	SILTY CLAY; very dark gray (10YR 3/1), low plasticity, dry to damp, stif, trace fine roots
5		4/4				3-7.5	MC	CLAYEY SILT; light brownish gray (10YR 6/2), low plasticity, damp, stiff, trace sand Clay content decreases with depth, color changes to pale brown (10YR 6/3), moisture increases, petroleum odor Becomes gravelly
		4/4				7.5-8.5	GW	SANDY GRAVEL; light brownish gray (10YR 6/2), gravel is fine, loose, saturated, trace silt
10						8.5-11	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, saturated, stiff to very stiff
						11-12	MS	SANDY SILT; yellowish brown (10YR 5/4), low plasticity, saturated, soft
15								Total depth of borehole 12 feet bgs

BOREHOLE LOG PRC ENVIRONMENTAL MANAGEMENT, INC.

Job Number: 044-0235IRRDP5 Well Designation:

Borehole Designation: TPZ5-04

Client: U.S. Navy

Surface Elevation: Not Surveyed

Site: Moffett Federal Airfield Subsite: Site 5

Geologist: Steve Broering

Drilling Date (s): September 11, 1995

Well Installation Date (s):

Drilling Company: PRC

Personnel: W. Wilcoxon, D. Berestka

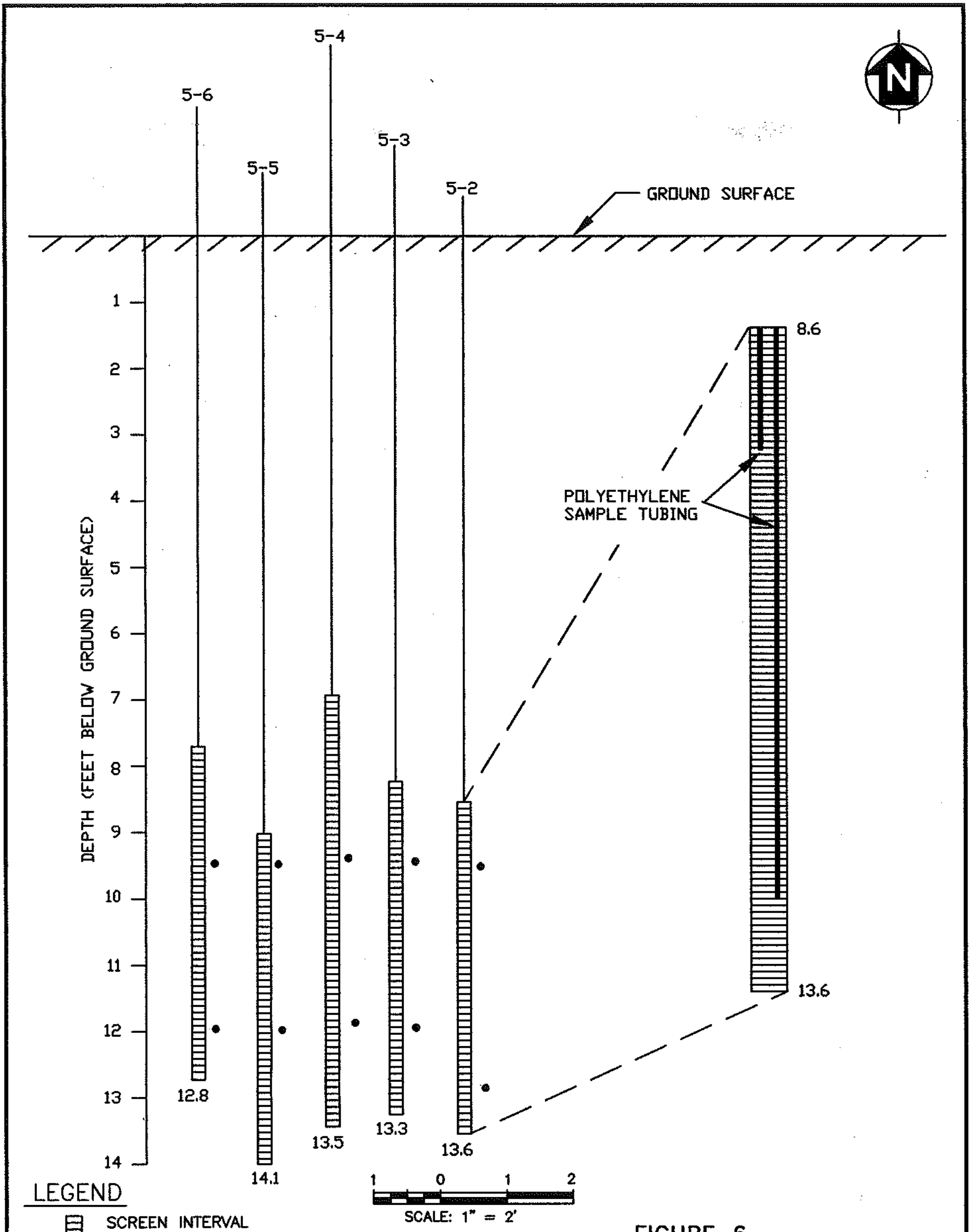
Drilling Method: Geoprobe

Borehole Diameter:

Latitude:

Longitude:

DEPTH (FT)	BLOWS/FT	RECOVERY	TIME	FIELD SCREENING	ANALYSIS	CORE INTERVAL	GRAPHIC LOG	SOIL DESCRIPTION
		4/4				0-2.8	CL	SILTY CLAY; very dark gray (10YR 3/1), low plasticity, dry to damp, stiff, trace roots
								Color lightens with depth to very dark grayish brown (10YR 3/2).
		4/4				2.8-6	ML	CLAYEY SILT; light brownish gray (10YR 6/2), low plasticity, damp, stiff, trace sand
5								Decreasing clay content, color changes to pale brown (10YR 6/3)
		4/4				6-9	GC	CLAYEY GRAVEL; pale brown (10YR 6/3), gravel is fine, saturated at depth, loose, little to trace sand, petroleum odor
10						9-12	CL	SANDY CLAY; dark yellowish brown (10YR 5/3), low plasticity, very stiff, saturated
15								Total depth of borehole 12 feet bgs



LEGEND

▤ SCREEN INTERVAL (TOTAL DEPTH BELOW
12.8 GROUND SURFACE)

● DEPTH OF POLYETHYLENE SAMPLE TUBING

FIGURE 6
MOFFETT FEDERAL AIRFIELD
SITE 5 GROUNDWATER TREATABILITY STUDY
SCHEMATIC OF MONITORING POINT DESIGN

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