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PHASE 2 WORK PLAN

Pilot Test to Evaluate Enhancement of Product Recovery

U.S. Naval Station Roosevelt Roads Ceiba, Puerto Rico

Prepared for:
Department of the Navy,
Atlantic Division
Naval Facilities Engineering Command
Norfolk, Virginia
and
J.A. Jones Environmental Services

January 20, 2000

SCIENCE : STRATEGY : TECHNOLOGY : SOLUTIONS

McLaren Hart, Inc.

January 24, 2000

Tracking No. JPDGN-4519-0009-Be
Project No. 945809

Mr. Christopher Penny, Code 1823
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VIA Overnight Service

RE: TRANSMITTAL
PHASE 2 WORK PLAN: PILOT TEST TO EVALUATE ENHANCEMENT OF PRODUCT RECOVERY USING PNEUMATIC FRACTURING AND PUMPING TECHNIQUES
TOW WAY FUEL FACILITY, NAVAL STATION ROOSEVELT ROADS, CEIBA, PUERTO RICO
CONTRACT NO. N62470-93-D-3033, TASK ORDER #9

Dear Mr. Penny:

Enclosed is one copy of the Phase 2 Work Plan prepared by McLaren/Hart, Inc. to conduct pilot tests to enhance the performance of a product recovery system at the Tow Way Fuel Facility, U.S. Naval Station Roosevelt Road, Puerto Rico.

Phase 1 of the Work Plan was submitted on January 13, 2000. This current Phase 2 Work Plan describes the details and mechanics of the proposed pilot test and also includes the recommendations and modifications to the Draft Work Plan. Together these two work plans constitute the pilot test program at the Tow Way Fuel Facility.

A response to the comments for the Draft Work Plan is attached as Appendix A in this Phase 2 Work Plan. Additionally, the figures, tables, and appendices had been bolded in the text of this document to enable the reader to locate them before reading the respective sections.

If you have any questions regarding this transmittal or the project in general, please do not hesitate to contact me.

Respectfully submitted,

Terrd Ring for

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PHASE 2 WORK PLAN ADDENDUM
TASK ORDER # 9

PILOT TEST TO EVALUATE
ENHANCEMENT OF PRODUCT RECOVERY
USING
PNEUMATIC FRACTURING TECHNOLOGY AND PRODUCT RECOVERY METHODS

AT
TOW WAY FUEL FACILITY
U.S. NAVAL STATION ROOSEVELT ROADS
CEIBA, PUERTO RICO

January 20, 2000

Project No. 945809

Prepared for:
Department of the Navy
Atlantic Division
Contract No. N62470-93-0-3033
POLRAC
Naval Facilities Engineering Command
Norfolk, Virginia
and
J.A. Jones Environmental Services

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EXECUTIVE SUMMARY

This Work Plan describes an approach to performing a pilot test to evaluate the enhancement of product recovery from the Tow Way Fuel Facility (TWFF), U.S. Naval Station, Roosevelt Roads, Ceiba, Puerto Rico. The site contains 7 fuel tanks. Since 1957, spills, leaks, and sludge disposal have resulted in an estimated release of over one million gallons of total petroleum hydrocarbons (Bunker C fuel, Diesel fuel, JP-5 fuel).

For the pilot test, two permutations of pneumatic fracturing (PF) technology and two product recovery methods will be evaluated. Additionally, a product recovery interceptor trench will be installed at the site and evaluated as a product recovery system. This Phase 2 Work Plan describes the details for designing, installing, and performing the pilot test. A Phase 1 Work Plan, submitted to the Navy Technical Team on January 13, 2000, describes the baseline program for the Phase 2 activities.

The pilot tests will be conducted at the RW-1 and the PW-6 areas of the TWFF. The approximate area of the pilot test areas is 880 ft^2 and 1080 ft^2 respectively, and the anticipated treatment zone is 16 to 30 ft. bgs. These locations were selected because free product is known to be present and information on subsurface conditions from previous investigations and pilot tests, as well as historical information on product recovery, is available. Well RW-1 is an existing product recovery well and Well PW-06 has been used for product recovery in the past.

In the RW-1 area, three wells will be tested as product recovery wells and six boreholes will be installed and pneumatically fractured. The boreholes will be located radially around the existing product recovery wells and will be radially and directionally fractured to enhance these systems. One of the radial boreholes will be converted into a recovery well after fracturing. The evaluation program will consist of pre-fracture baseline product recovery measurements using a total fluids pneumatic pumping system. After fracturing, these tests will be repeated for 90 to 120 days to determine if any change in product recovery rates or hydraulic parameters has occurred.

In the PW-6 area, three wells will be tested as product recovery wells. Three fracture boreholes will be installed and pneumatically fractured (radially and directionally) to enhance the performance of an existing well. Additionally, a proppant will be installed into specific product zones and the boreholes will be converted into two types of extended radius wells. Each of these wells will then be evaluated as product recovery wells. For the evaluation of the total fluid product recovery method, a system utilizing a pneumatic pump and a vacuum pump will be tested. The testing procedure will be similar to the program developed and described for the RW-1 area.

For this pilot test , the proper local and state authorities will be notified, and storage of gases on site will follow appropriate protocols and procedures. The necessary permits have been identified and will be acquired from the respective agencies. Ad addendum to the site-specific health and safety plan has been prepared and is included as Appendix D of this document.

Following the completion of the pilot testing activities, Volume 2 of the final report will be submitted to the Navy for review. It will supplement the findings of Volume 1 (test procedures for the two pilot test areas, the construction of the recovery trench, discuss the results from each pilot test, evaluate the effectiveness of PF to enhance the performance of the existing system, evaluate various well types, and evaluate the performance of the two total fluids product recovery methods to improve the removal of product from the formation) by including the results of the long-term product evaluation program and evaluating the overall performance of the pilot test and the product recovery trench. It will also propose recommendations for a full scale design.

1.0 INTRODUCTION

McLaren/Hart appreciates the opportunity to submit this Phase 2 Work Plan to conduct pilot tests at the Tow Way Fuel Facility (TWFF) to evaluate enhancement of product recovery using pneumatic fracturing and pumping techniques. This Work Plan describes the procedure for implementing and evaluating a program to enhance product recovery using pneumatic fracturing and pumping techniques. on January 13, 2000, a Phase 1 Work Plan describing a baseline program for the pilot tests was submitted to the Navy and is still under review.

McLaren/Hart (M/H) is a team sub-contractor with J.A. Jones Environmental Services (JAJES) on the Petroleum, Oils and Lubricants Remedial Action Contract (POLRAC) operating in the Navy's Atlantic Division. McLaren/Hart is currently operating and maintaining the Interim Remedial Measures, Free Product Recovery System commissioned in 1997 at the TWFF.

This pilot test program will be conducted as part of the pre-design activities for the Product Recovery System at the TWFF. The Work Plan is submitted as an Addendum to the approved Task Order (TO) # 9 Work Plan (Installation of a Free Product Recovery System at the Tow Way Fuel Facility", submitted August 16, 1996 [1]) and will be performed under the existing POLRAC contract.

During the period 1957 to 1986 approximately one million gallons of diesel and jet fuel leaked from tanks and pipelines at the US Naval Station – Roosevelt Roads Site (Site), and this discharge has impacted soil and groundwater at the site. The cumulative volume of free product recovered since product recovery remediation activities commenced in 1994 is 15,600 gallons (Quarterly Summary Progress Report Number 8, dated February 26, 1999).

The single-phase product-only recovery system which was installed in 1997 has removed approximately 974 gallons of product in 1997, 675 gallons in 1998 and 360 gallons in 1999. The performance of the system is poor and appears to be limited by the heterogeneity of the formation which is very dense and a hard inconsistency.

The objectives of the pilot study at the site are two fold. The primary objective is to evaluate the effectiveness of Pneumatic Fracturing (PF) technology to enhance product recovery at two different soil locations at the site. The secondary objective is to evaluate product recovery methods. Although this pilot study will be conducted at the Roosevelt Roads Site, it is also intended to evaluate enhancement of product recovery systems on a program-wide basis for use at other US Naval Station sites.

[1] 1. McLaren/Hart (Formerly PDG Environmental Services, Inc.), Work Plan D.O.# 0009, Free Product Recovery System for the Tow Way Fuel Facility, Project 945809, Contract No. N62470-93-D-3033, August 16, 1996.

To accomplish the first objective, M/H will:

1) Fracture soils around two existing product recovery wells
2) Fracture soils around an existing monitoring well, and then convert to a product recovery well
3) Fracture an open borehole and then convert to a product recovery well
4) Install extended radius wells (ERWs) at two locations and then convert to product recovery wells

The new wells (*i.e.,* open boreholes, ERWs) will be located where there is an accumulation of product in the formation. The fracturing process will be designed to shorten advective distances and to create a network of interconnected fractures around the fracture- and recovery-wells. The accumulated effect is expected to result in an increased production from the product recovery wells.

To accomplish the second objective, two types of product recovery methods will be evaluated and compared in short- and longer-term pumping tests. These tests will be designed to determine if free product recovery rates can be significantly increased over the current, product only (i.e., single phase) pumping system.

1.1 OVERVIEW OF THE TECHNOLOGIES

The following sections describe the three main technologies which will be used during the pilot test. They are: pneumatic fracturing, extended radius wells, and two product recovery methods.

1.1.1 Pneumatic Fracturing

PF is a patented process that was developed in the late 1980s to increase pneumatic permeability of geologic formations. The PF process has received intensive laboratory and bench scale testing and development at the New Jersey Institute of Technology (NJIT). The process uses pressurized gas at controlled pressures and flow rates to initiate and propagate a network of fractures in low permeability soil and rock formations. **FIGURE 1** shows a schematic of the Pneumatic Fracturing Concept in both soil and rock formations. PF in overconsolidated soil formations creates a network of horizontal fractures that radiate from the fracture well. In rock formations, PF opens up, cleans out, and interconnects existing discontinuities in the formation.

In addition to permeability enhancement, PF can improve homogeneity in the formation and access pockets of free product or contaminants previously unattainable. Since the first PF patent in 1992, PF technology has been extended to include the addition of liquid and solid amendments. To date, over 70 sites have been treated throughout the United States. Thirty of these sites have been pneumatically fractured to enhance subsurface permeability for various remedial options, including soil vapor extraction, dual phase extraction, product recovery, and pump and treat systems.

1.1.2 Extended Radius Wells

Extended radius wells have evolved from the original PF concept and are designed to extend the effective radius of a pumped well. An ERW is created by injecting supplemental media (*e.g.*, dry media, proppant) into the subsurface at a specified depth. The injection creates conductive lenses which radiate outward from the well. They have a conductivity which is significantly greater than that of the native soil, thus increasing the recovery of liquids and vapors from the formation. The media are injected into the formation through the use of an injection nozzle which is capable of creating conductive lenses in various directions and at multiple elevations.

The concept of an ERW and comparison of it with a standard recovery well are depicted on Figure 2. Traditional wells possess high permeability zones only adjacent to the well as part of the sand pack. In contrast, the ERW has high permeability lenses which extend outward from the sand pack into the formation, which greatly increases the effective diameter of the well. The lateral extent of the ERW will, of course, depend on the site specific soil properties, as well as injection flow rates and pressures.

1.1.3 Product Recovery Methods

A total fluid recovery system is a conventional pumping method used to simultaneously recover groundwater and Non-Aqueous Phase Liquid (NAPL) from the formation. Because they pump water, these pumps lower the water column in the well and induce product migration to the well. Therefore, they may enhance produce accumulation in the well and thus accelerate product removal. Use of total fluid pumps requires an oil/water separation step after the total fluids are recovered.

The two types of total fluid recovery pumping systems include a pumping only system which uses a pneumatic pump and a vacuum enhanced recovery (VER) system which uses a drop tube or a pneumatic pump plus a vacuum pump.

The application of a multi-phase (air and water) extraction system can be achieved with a single or two-pump configuration. In a single pump configuration, a single drop tube is used to remove liquid and vapor from a recovery well. Practically, this configuration is limited to depths less than 30 ft. bgs. This depth limitation can be overcome with a two-pump configuration. This system (commonly known as a vacuum-enhanced recovery [VER] system) uses a submersible pump for groundwater recovery in conjunction with a separate vacuum applied at the wellhead. In this configuration, liquid and vapor streams are separate at the well head and the respective streams are managed by independent air and NAPL treatment systems.

Historically, VER systems have been the standard approach for dewatering low permeability sediments and for speeding the dewatering of more permeable sediments. VER is a multi-phase extraction process which uses high vacuums on recovery wells and the geologic formation to enhance the recovery of total fluids from the well. In the process, air and water are used as carriers for the removal of contaminants from unsaturated and saturated zones. The extraction process is applied to recovery wells with some portion of the well screen extending above the water table and into the unsaturated zone. The applied vacuum increases the effective drawdown

at the pumping well, extracts soil vapor, and enhances groundwater recovery. Liquid flow rates are increased due to the increased negative pressure gradient applied on the system. The applied vacuum enhances the volatilization and mobility of trapped product in the unsaturated zone, thereby accelerating the cleanup process and reducing the number of recovery wells required to achieve the same process

1.2 PRODUCT RECOVERY EXPERIENCE

For product recovery applications, the technology has been applied at two Air Force bases - one in Oklahoma and the other in New Jersey.

1.2.1 Oklahoma Site

At the Oklahoma site, a total fluids product recovery system was installed in 1991 and 1992. The geology of the formation was a weak cemented red sandstone, which classified texturally as a fine Sand. The depth of fracturing for product recovery enhancement was 26.7-28.7 ft. below ground surface (bgs). The results of the pilot test showed that PF technology increased the performance of the existing product recovery system. During pre-fracture pump tests, the product represented only 12% of the total fluid (product plus water) recovered. After fracturing this increased to 74% of the total fluid recovered. One month after fracturing the system had been adjusted so that more than 90% of the fluid recovered was product[2]. Information on the current status of the system is unavailable from the Air Force.

1.2.2 New Jersey Site

The geology of the formation at the New Jersey site was silty fine Sand. Prior to PF, several product recovery systems had been evaluated to recover free product from a migrating plume. These systems included: single phase free product recovery pumping, vacuum enhanced free-product recovery (bioslurping), and installation of two (50 ft and 100 ft) recovery trenches. The performance of these systems was poor and product recovery rates were low.

In April 1998, a pilot test was performed to evaluate if PF could improve the recovery of free product in these cohesionless soils at depths ranging from 9 ft – 13-ft bgs. The test was designed to install extended radius wells (ERWs) by two delivery methods. One method involved injecting a proppant into the formation using a directional nozzle. The second method involved the creation of ERWs using a newly designed helical nozzle. **FIGURE 2** shows the concept of a conventional well verses an ERW.

The results of the pilot test showed that product recovery rates were increased by both PF delivery systems and that ERWs could be installed in cohesionless soil formations. Product recovery rates were increased by 325% for the directional ERW system and by 225% for the helical ERW system. Based on the results of this pilot study, the Air Force has selected product recovery ERWs as the preferred option for the product recovery system.

[2] *Pneumatic Fracturing Demonstration, Tinker Air Force Base, Oklahoma City, OK.* Oct. 1994. Project Report prepared by HSMRC of NJIT, NJ; Accutech Remedial Systems, NJ; Battelle Memorial Institute, OH; and Battelle Pacific NW Labs, WA.

1.3 REPORT ORGANIZATION

The organization of this Workplan is as follows:

- Section 2.0 presents an overview of the project background and objectives; this includes an understanding of site geology, hydrogeology and project objectives
- Section 3.0 details the pre-pilot test preparation activities
- Section 4.0 details the pilot test program
- Section 5.0 discusses the pilot test data interpretation and reporting format
- Section 6.0 presents a project organization chart and
- Section 7.0 presents a project schedule

All tables, figures and appendices are provided at the end of this report.

2.0 BACKGROUND AND PROJECT OBJECTIVES

2.1 SITE LOCATION AND BACKGROUND

The Site is an active U.S. Naval Station and is located near the town of Ceiba on the eastern end of Puerto Rico. A site location map is presented as **FIGURE 3**. The approximate location of the Naval Station is 18°15' 00' latitude and 65° 39' 30" longitude.

Seven fuel storage tanks constitute the TWFF. Since 1957, spills, leaks, and sludge disposal have resulted in an estimated release of over one million gallons of product. This discharge has impacted soil and groundwater at the site, and there is currently a migrating plume of free product moving south of the upper TWFF and south-east along Forrestal Drive.

Free product recovery operations began in 1994 with the installation of a small-scale pilot test product recovery system. From 1994 to 1995, approximately 12,600 gallons of product and water were recovered. In April 1997, a larger system was installed, consisting of seven product recovery wells. In July 1998, the system was expanded to include two additional recovery wells. Historically, four of the nine recovery wells were operated at a time. This product recovery system is a skimming system (i.e., single phase). From April 1997 until January 1999, the total volume of free product recovered by this system was only 2,650 gallons. The total amount of product recovered in the 6 years of operation is estimated to be 15,600 gallons.

An analysis of the lack of recovery indicates that the primary reasons are the severe heterogeneities in the soil and fill material and the low permeabilities of the formation. Review of product thickness maps indicates that the product has accumulated at select locations, possibly due to the subsurface heterogeneities. To improve performance of the free product recovery system, a method is needed to improve the subsurface conditions by allowing easier flow of the viscous oil through the overburden and shallow bedrock.

2.2 SITE GEOLOGY

The site geology is taken from the Quarterly Summary Progress Report Number 8, dated February 26, 1999. The surficial lithology from 0 to 42 ft. bgs is predominantly clay with varying amounts of weathered volcanic rock fragments. The clays are primarily grayish-green, yellowish-brown, grayish-brown, and olive-brown as based on color matching with the Munsell soil color chart. Intermixed with the primary colors are shades of red, grayish-brown, olive-gray and bluish-gray. The clays are cohesive, stiff, and range from dry to moist. A review of boring logs from several of the recovery wells indicates that much of the near-surface geology consists of silt and clays, and that at one location (RW-4), the bedrock is fairly close to the surface.

2.3 SITE HYDROGEOLOGY

The site hydrogeology information is taken from the Quarterly Summary Progress Report Number 8, dated February 26, 1999. The hydrogeology is controlled by elevation differences between the Upper and Lower TWFFs. The average hydraulic gradient is 0.012 ft/ft towards the southwest. The dense nature of the volcanic rock and slow recharge rates observed in monitoring wells indicate that the permeability of the rock is very low, causing it to behave as a confining or semi-confining unit.

2.4 PROJECT OBJECTIVES

The pilot test will be conducted in two areas of the TWFF site where product recovery wells are currently being operated. The proposed locations for the pilot test areas are shown on Figure **4**; anticipated treatment depths range from 16 to 30 ft. bgs. Both wells in these locations, RW-1 and PW-06, are skimming product from a weathered volcanic rock formation which is classified as inorganic clays of low to high plasticity, Gravely and Sandy Clays.

The goals of this pilot test are to evaluate a program to enhance the removal of free product from these two locations and to prepare a report for the Navy on the procedure and findings of the pilot test. This will involve application of PF technology to increase the permeability of the soil formation in the test areas and conductance of short term pump tests in both existing and new product recovery wells. During these tests, product removal will be monitored at the recovery wells, and product levels in the surrounding wells will be monitored. Based on the results of the short term tests, a longer-term product removal and monitoring program will be performed at selected wells. This program could last for 3 to 4 months, during which time the long-term performance of the enhanced system will be evaluated.

The objectives of this pilot test are:

1) Establish baseline conditions for the test areas. This will be done by conducting short term product recovery tests, followed by 20 to 30 day longer term tests. A Phase 1 Work Plan has been submitted to the Navy (dated 1/13/00) describing the procedure for these evaluations.

2) Evaluation of the change in product recovery rates after fracturing in both test plots. This evaluation will involve conversion of selected fracture boreholes to recovery wells and repeating the baseline short term tests in various product recovery wells. Based on the findings from these tests, longer term product recovery testing will be performed.

3) Evaluation of various product recovery well construction techniques. Four types of recovery well scenarios will be evaluated:

    - Enhancement of existing recovery wells with PF
    - Enhancement of an existing monitoring well with PF

- Installation of dry media (proppant) into two PF open borehole and conversion to two types of recovery wells.
- Installation of recovery well in a PF open borehole after fracturing has occurred

4) Determination if product recovery performance can be increased by using a different recovery method (e.g., total fluids system, which will hydraulically stress the formation) compared to the current single-phase system.

5) Compare pilot test results with the predictions from the recently developed software, PF Model.

6) Obtaining site-specific engineering design data necessary for a full-scale system design.

In the period preceding and during the Pilot Studies, operation of the existing Free Product Recovery System will be suspended in the pilot test areas. This will allow product levels of the recovery and monitoring wells to stabilize and present a more representative picture of the true subsurface, groundwater and free product conditions at the site.

3.0 PRE-PILOT TEST PREPARATION ACTIVITIES

The objective of the pre-pilot test preparation activities is to ensure that the design of the pilot test will be efficient and cost effective. Test preparation activities include the following: 1) site visit by a PF engineer, 2) implementation of a reconnaissance soil boring program, 3) conducting a product assessment in the proposed pilot test areas, 4) conducting a geotechnical analysis on selected soil samples, and 5) determining permit and health and safety issues.

3.1 SITE VISIT

In September 1999, the McLaren/Hart, Inc. project manager and a PF engineer conducted a site visit to obtain first hand knowledge of the site and pilot test area. They saw the layout of the site; selected two potential pilot test areas; located a soil boring grid for split spoon sample collection; looked at soil samples from the two areas; evaluated free product levels in existing monitoring wells; determine drilling requirements and performance; and identified general pilot test requirements.

During this visit they also met with representatives from the U.S Naval Station environmental staff and field staff of J.A. Jones Management Services Company which is currently monitoring the product recovery system at the site. Information on permit requirements, access requirements by pilot test personnel (see **APPENDIX B** for Naval Base Access Requirements), utility requirements and general site protocol was also obtained.

3.2 SOIL SAMPLING PROGRAM AND RESULTS

The location of the proposed pilot test areas RW-1 (named after Recovery Well 1) and PW-6 (named after Pumping Well 6) are shown on **FIGURE 4**. Both areas are located in the Upper TWFF and are approximately 250 ft. apart. A reconnaissance soil-boring program was performed to evaluate the soil conditions at the site and to identify product zones to a depth of 30-ft bgs. This program involved the collection of 101 split spoon samples from eight soil boring locations within the two pilot test areas.

Samples were collected by driving a 2-ft. by 2-in. diameter split spoon sampler into the undisturbed formation with a 140-pound drop hammer. Once the sample was retrieved, a 2.5-in. hollow stem auger was advanced to the sample depth and the sampling process repeated.

Samples were visually inspected for the evidence of product and were lithologically described using the Burmister Soil Classification System. Shear strengths of the samples were determined using a pocket penetrometer or from the hammer blow counts. On completion of soil classifications, the samples were carefully packaged and shipped to NJIT, in New Jersey, USA for further inspection and for the determination of selected geotechnical parameters.

3.2.1 RW-1 Area

In September 1999, sixty-five split spoon soil samples were collected from five soil boring locations. **FIGURE 5** shows the soil boring locations in the RW-1 pilot test area. The boring identifications were: MH-SB-2, MH-SB-5, MH-SB-6, MH-SB-7, MH-SB-8 and DP-31A, and the sample identifications were S-#s. Copies of the soil boring logs are included as **APPENDIX C**.

FIGURE 6 shows a geologic cross-section location map and **FIGURE 7** shows two stratigraphic cross sections which are representative of the geology in the RW-1 pilot test area. These cross-sections were developed using boring logs from the Mantech Environmental well installation program, the McLaren/Hart reconnaissance soil boring program and the RW-1 well installation log.

Cross-section AA' is a north to south trend of the area and cross-section BB' is a northwest to southeast trend of the area. The figure highlights the following:

- From the land surface to a depth of approximately 30-ft, the geologic materials consist of silt and clay with some sand and gravel.
- The geologic material consists of dry to damp clay and sand.
- Lenses or zones of sand and gravel are more evident in the northeast location of the pilot test plot.
- The potentiometric surface in the area of this test plot varies from 3-ft. bgs at RW-1 to 13-ft. bgs at the MTMW-4 location.

3.2.2 PW-6 Area

In September 1999, thirty-six split spoon soil samples were collected from three soil boring locations within this pilot test area. **FIGURE 8** shows the soil boring locations in the PW-6 pilot test area. The boring identifications were: MH-SB-1, MH-SB-3, and MH-SB-4, and the sample identifications were S-#s. Copies of the soil boring logs are also included as **APPENDIX C**.

FIGURE 9 shows one stratigraphic cross section for this area. This cross-section was developed using the 3 McLaren/Hart borings. This cross-section was developed to gain a conceptual understanding of the subsurface conditions in the pilot test plot and should not be considered representative of the site-wide geologic conclusions. Cross-section CC' is a northwest to southeast trend of the area. Based on the limited number of soil boring locations, the figure highlights the following:

- From the land surface to a depth of approximately 30-ft, the geologic materials consist of silt and clay with some sand and gravel.
- The geologic material consists of dry to damp clay and sand.
- In the area of MH-SB-4 there is a saprolite zone of weathered gabbro which is classified texturally as sand and gravel and occurs from grade to a depth of approximately 20-ft.
- The potentiometric surface in the area of the test plot is approximately 8-ft bgs.

3.3 GEOTECHNICAL TEST PROGRAM

To determine if PF could be applied to enhance the permeability of the soil formation at the site, samples were shipped to the research laboratory at the Center of Environmental Engineering and Science (CEES), located at NJIT in New Jersey, USA. These samples were reviewed by McLaren/Hart personnel and the NJIT PF technical team.

Five samples from zones identified for product recovery enhancement were analyzed for several geotechnical-engineering parameters. **TABLE 1** shows a summary of the geotechnical test program. It includes: boring ID, type of analysis, American Society for Testing and Materials (ASTM) methods, etc. These boring locations have been prioritized based on field screening of soil samples and the evidence of product in these boring locations. The main geotechnical parameters evaluated were: Atterberg Plastic and Liquid limits by ASTM D2217 and D4318; and Atterberg Shrinkage Limit by ASTM D427. These soils have been classified using the Unified Soil Classification System (ASTM D2487).

3.4. GEOTECHNICAL ANALYTICAL RESULTS

The results of the geotechnical analysis, performed on select soil samples by NJIT, are presented in **TABLEs 2, 3,** and **4**. A discussion of the results and a recommendation (based on the samples analyzed) for the PF strategy at the site are presented below.

Five soils from Roosevelt Roads were selected and tested for Atterberg limits [liquid limit (LL), plastic limit (PL), and shrinkage limit (SL)]. This selection was based on a review of the boring logs (*i.e.*, reference to potential product zones and logged PID readings) and odor from the samples. The results, including calculations of plasticity index (PI) and shrinkage index (SI), are presented in **TABLE 2**. Grain size data associated with the wash are shown in **TABLE 3**. The data suggest the following:

- The soils passing the No. 40 sieve are highly variable, ranging from silts to clays of both low and high plasticity. This is consistent with the saprolitic nature of the soil, where the residual clay mineralogy is expected to vary according to lithology and weathering conditions.

- The grain size data show that there is 10-50% medium to coarse sand, and gravel. Because the sand and gravel are completely coated with fines, it is expected that the fines will dominate the soil behavior.

An analysis of the potential expansivity of the soil passing the No. 40 sieve was also performed according to empirical relationships shown in Table 2.8 of Hall [Hall, H.A. 1995. "Investigation into Fracture Behavior and Longevity of Pneumatically Fractured Fine-Grained Formations,"

M.S. Thesis, New Jersey Institute of Technology, Newark, NJ]. Results are presented in **TABLE 4** and are summarized below:

- There is some potential for swelling to occur. Sample SB-6 12'-14' shows the greatest potential, with both a high PI (46.2) and a high SI (20.5). It is expected to contain the clay mineral montmorillonite. The sample SB-4 18'-18'10" appears to be of secondary concern.

- It will be difficult to predict swelling zones given the geologic history of the deposit. While lithology is one component which may be traced, clay mineral formation also depends on leaching history, pore water constituents, pH, and temperature. It is recommended that Atterberg limit testing be performed on samples at the screened interval, or, at the very least, that the samples be observed with a trained eye.

The degree of contamination was also monitored on the five samples tested for Atterberg limits. The samples were prioritized from most contaminated to least contaminated based on odor and oily sheen on the wash water as shown below:

SB-4 cuttings	▲	most contaminated
SB-8 18'-20'		
SB-4 18'-18'10"		
SB-6 12'-14'		
SB-6 24'-26'	▼	least contaminated

The two samples which appear to be most contaminated (SB-4 cuttings and SB-8 18'-20') do not exhibit a great degree of swelling behavior. The samples SB-4 18'-18'10" and SB-6 12-14' appeared to be contaminated to a lesser degree, but are both swelling soils. Sample SB-6 24'-26' seemed to be clean and exhibit relatively little swelling.

The results of this testing suggest that the soils must be monitored closely at the site, and that the consideration of proppant use is warranted. The fines are swelling and are expected to control soil behavior, contamination was found in the swelling soils, and the degree of potential swelling is believed to be great enough to influence fracture geometry and longevity.

3.5 PNEUMATIC FRACTURING MODEL EVALUATION

Originally when McLaren/Hart began evaluating the use of PF at the TWFF, two possible applications of PF to enhance product recovery were considered:

1) Using PF technology (which employs pressurized gases to create fractures) as a method to develop a network of interconnecting fractures that would vastly improve soil permeability and free product recovery.
2) Installing ERWs at strategic locations associated with product zones. This would be accomplished by using a variation of the PF technology to inject thin layers of ceramic beads (proppant) which would form highly

conductive lenses in and immediately within the vicinity of product zones. This would improve product recovery well performance by extending the well's radius of influence.

Initially, based upon field observations that the soil appeared to be dense and brittle, it was believed that the soil could be fractured without the need to maintain fracture apertures with proppants. However, as discussed above, when certain geotechnical tests were performed, some of the samples exhibited swelling behavior. Therefore, in a portion of this pilot test, ERWs will be installed to created thin conductive lenses adjacent to the product zones.

In association with technology applicability review, further evaluation of the application of PF and ERWs was performed using the windows-based PF Model. This program, developed at the CEES provided guidelines for optimum and safe field implementation of the technology (e.g., injections pressures, expected radius of influence and fracture aperture dimensions).

The model consists of three major components: site screening, system design, and calibration components. The site-screening component was used to determine a technology recommendation rating for permeability enhancement, dry media injection and liquid media injection. The system design component provided information on fracture aperture, radius of influence, maintenance pressures and the effect of various injection flow rates. The calibration component allowed data from site pilot tests to be inserted into the model so that the model could be calibrated to site-specific conditions.

The following conclusions were made using the PF Model in conjunction with geotechnical analyses:

1) The soils will benefit from a permeability enhancement program
2) Injection of a dry media (proppant) is recommended in select locations
3) Depending on treatment depth, injection pressures should be in the range of 250 to 600 psi
4) Maintenance pressures will vary between 81 to 87 psi
5) Injection flow rates will vary between 1000 – 3000 SCFM
6) Fracture apertures will vary from 0.02 –0.04 inches and
7) Radius of influence will vary between 10 – 16 ft.

3.6 PRODUCT EVALUATION

An evaluation of free product in the two pilot test areas was performed based on a review of soil geologic logs, evaluation of soil samples from a reconnaissance soil boring program and measurement of Light Non-Aqueous Phase Liquid (LNAPL) in pumping and monitoring (existing and M/H temporary) wells. The following summarizes the findings for each pilot test area.

3.6.1 RW-1 Area Soils

Six existing borings logs and soil samples from six McLaren/Hart soil borings were reviewed for this area. The existing soil boring logs are: RW-1, AW-1, AW-2, MTMW-1, MWMT-3, and MTMW-4. Except for RW-1, the logs were prepared by Mantech Environmental during their Chemical Oxidation Pilot test. The McLaren/Hart soil boring locations are: DP-31A, MH-SB-2, MH-SB-5, MH-SB-6, MH-SB-7 and MH-SB-8. All logs are included in **APPENDIX C**.

A review of the Mantech Environmental boring logs shows that product zones vary between a quarter of an inch and two feet. These thicknesses were observed at various elevations in the borings and were all above the water-saturated zone for that location. A two foot saturated product zone was observed at MTMW-4 at a depth of 18 to 20 ft. bgs. The deepest zone where product was identified was 29 to 29.5 ft. bgs at MTMW-1. There is no documented evidence of free product in the boring log of RW-1.

During the McLaren/Hart reconnaissance soil-boring program, samples from six soil borings were evaluated. Except for MH-SB-8 sample location (at a depth of 18 to 20 ft. bgs.) there was no clear evidence of product saturated zones in any of the remaining soil samples. At some sample depths, where no product was visible, but a strong odor was obvious, the locations were logged as damp.

During sampling at MH-SB-6, a damp sample, retrieved from a depth of 20 to 22 ft. bgs had a diesel odor. A measurement for product was made inside of the auger at this depth, and 22 inches of diesel fuel was measured. The first evidence of water was observed at 24 ft. bgs. This boring was completed to 29 ft. bgs, and no further evidence of product was observed in the soil samples. A check of the open borehole approximately 30 minutes after the final depth of 29 ft. was achieved show no evidence of free product. There was less than 4 inches of water in the well at the time of the measurement.

3.6.2 RW-1 Area LNAPL

A survey of existing wells and the new temporary monitoring wells installed by McLaren/Hart show that there is free product in some areas of the site. The results of several rounds of monitoring for free product and groundwater is summarized in **TABLE 5**. The distribution of free product is also shown on the geologic cross section A-A' and B-B' on **FIGURE 7**.

In the Mantech Environmental wells on 9/25/99, product thickness varied from 3.7 ft. at MTMW-4 to 5.0 ft. at MTMW-2. On the same day, 1.9 ft. of product was measured at the temporary McLaren/Hart monitoring well location MH-SB-6. There was no measurable product thickness in the RW-1 well on 9/25/99. Based on the groundwater data collected, the potentiometric level is approximately 16 to 18 ft. bgs (see **TABLE 5**).

This evidence from the soil and groundwater evaluation shows that there is a free product plume in the zone 15 to 25 ft. bgs. This plume is above a semi-confining layer which varies between 24 and 38 ft. bgs based on the soil boring logs for this area.

3.6.3 PW-6 Area Soils

No soil borings or well construction logs for existing wells were available for review. Evaluation of soils in this area was based on samples from three McLaren/Hart soil borings: MH-SB-1, MH-SB-3 and MH-SB-4. These logs are included in **APPENDIX C**.

During sampling at the MH-SB-1 location, evidence of product was observed in a moist zone 10 to 12 ft. bgs. There was also a petroleum odor at this zone. Samples collected above and below this zone were dry. At the MH-SB-3 location, a damp to moist zone was observed 16 to 18 ft. bgs on 9/20/99. Before continuing the boring on 9/21/99, one foot of product was measured in the borehole. Continued sampling at this location showed a moist zone of product at approximately 22.5 to 24 ft. bgs. There was no further evidence of product in samples collected from this location. At the MH-SB-4 location, product was observed at 16.5 to 17 ft. bgs on 9/21/99. Prior to sampling, on the following day (9/22/99), 2 ft. of product was measured in this borehole. During split spoon sampling, the 20 to 22 foot zone was observed to be saturated with product.

3.6.4 PW-6 Area LNAPL

A survey of existing wells and the temporary wells installed by McLaren/Hart show that there is some evidence of free product in this area. The results of several rounds of monitoring for free product and groundwater is summarized in **TABLE 5**. The distribution of free product is also shown on the geologic cross section C-C' on **FIGURE 9**.

In existing wells, product thickness varies from 0.3 to 0.2 ft. at PW-06 and PW-05 respectively. In the temporary McLaren/Hart monitoring wells product was observed in all wells, with product thickness varying from 1 to 10 ft. at MH-SB-3 and MH-SB-1 respectively. It should be noted that the thickness at MH-SB-1 might be an anomaly based on well construction technique. Based on the groundwater measurements, the potentiometric level is approximately 14 ft. bgs (see **TABLE 5**).

This evidence shows that there is a free product plume in the zone 10 to 25 ft. bgs. This plume is above a semi-confining layer

3.7 PERMIT ACQUISITION

Based on conversations with the U.S Naval Station Environmental Management team in Puerto Rico, no permits for the performance of a pilot test at the TWFF site is required. However, since the injection process involves the injection of an inert gas (e.g., industrial grade nitrogen) and an inert media (ceramic beads), this Workplan is to be submitted to Environmental Quality Board

(EQB) for review. Upon acceptance of the Workplan, the EQB will grant an approval letter for the term of the pilot test.

3.8 SITE HEALTH & SAFETY PLAN

APPENDIX D is an addendum to the site-specific Health and Safety (HASP) plan. This addendum provides supplemental information related to the proposed PF activities at the pilot test site. The following sections for the HASP have been updated for the pilot test:

Section 5.1.5 Site History and Description
Section 5.2.2 Site Health and Safety Officer
Section 5.5 Work Activities
Section 5.7 Potential Safety Hazards

The plan has been updated to ensure it addresses all issues related to the safe implementation of a PF pilot study. A signed copy of the HASP plan, together with all attachments, will be maintained on-site during all field activities. The HASP plan will include:.

- General site information
- Project information including a site description, purpose of work, scope of work, and project schedule
- Hazard analysis, non-chemical hazards, site Chemicals of Concern (COCs), and chemical hazards
- Requirements for Personal Protective Equipment (PPE), monitoring equipment, site zone delineation, and site communication protocol
- Site operating procedures
- Emergency response procedures
- Record keeping requirements
- Hospital route map

3.8.1 Health and Safety Meetings

Prior to the commencement of the pilot test, the health-safety officer will conduct a mandatory health and safety meeting for all personnel actively involved in the pilot test. Also, tailgate health and safety meetings will be conducted daily to remind personnel of hazards and the objectives for the day.

3.8.2 Personal Protection

To minimize exposure from the compressed gases, only authorized personnel will be involved in handling the gas supply sources and lines and in operating valves and/or equipment. During the injection periods, non-authorized personnel will be notified and kept clear of the compressed gas lines and general area. Hoses and fittings will be de-pressurized (through by-pass valves) before disconnection or handling of the PF equipment.

3.9 MATERIAL HANDLING AND OPERATIONAL PROCEDURES

The materials, which will be handled during this pilot test, are compressed nitrogen gas and extracted groundwater and product. MSDS data sheets for the compressed gas will be included in the site-specific Health and Safety Plan. The pumped fluid will be managed using the existing product recovery system at the site. This is described in Section 4.6 of this Work Plan.

3.9.1 On-Site Storage

Since the pilot test program will be performed at an U.S. Naval Station, all materials will be staged in an area designated by personnel representing the base.

3.9.2 Waste Disposal

Waste generated during the pilot test program will be managed in accordance with Section 3.0 of the approved TO # 9 Work Plan[3]. This waste includes soil cuttings from well installation activities, groundwater from well development and other pilot test activities, and other non-hazardous trash.

The drill cuttings generated during drilling activities will be stockpiled in designated areas near the pilot test plots (see **FIGURE 20**). Upon completion of drilling activities, the potentially contaminated soil stockpile will be sampled and analyzed for TPH and other required parameters for disposal. Soil with TPH levels less than 100 ppm will be considered non-contaminated and will be used on site to backfill excavations and complete grading and site restoration activities. Contaminated soil will be subsequently removed from the site for treatment and disposal by an approved subcontractor.

Groundwater generated during the pilot test program will be temporarily stored in 2,500 gallon holding tanks, passed through a treatment skid consisting of oil/water separator and carbon vessels before temporary storage in an effluent holding tank. Grab samples will then be collected and analyzed to comply with the on-site treatment system influent requirements. Based upon the analytical results obtained, the treated effluent will then be discharged into the on-site sewer system or will be routed back to the treatment system and retreated. Garbage and trash will be removed and properly disposed of by an approved subcontractor.

[3] 1. McLaren/Hart (Formerly PDG Environmental Services, Inc.), Work Plan D.O.# 0009, Free Product Recovery System for the Tow Way Fuel Facility, Project 945809, Contract No. N62470-93-D-3033, August 16, 1996.

4.0 PILOT TEST PROGRAM

4.1 INTRODUCTION

This section details McLaren/Hart's technical approach to the performance of the pilot test. This approach is based on McLaren/Hart's experience in performing pilot tests and is designed to accomplish the following goals in a timely and cost effective manner: 1) evaluation of the effectiveness of PF as an enhancement to an existing product recovery system, 2) evaluation of three PF enhancement options for product recovery, 3) evaluation of two product recovery methods, 4) conductance of the test in a logical manner, and 5) conductance of the pilot test with regards to safety considerations.

The following scope of work identifies the main tasks required to accomplish the goals stated above:

TASK	DESCRIPTION
Pre-Pilot Test Activities	Discussed in Section 3.0, these include: a soil sampling program; geotechnical analyses; free product evaluation; PF Model evaluation
RW-1 Area Pilot Program	Activities include: planning and mobilization; construction of the pilot test layout; baseline short-term product recovery tests at two to three locations (see Phase 1 Work Plan); PF at six locations within the target treatment zone; conversion of one fracture well into a product recovery well; heave monitoring; and post-fracturing short- and long-term product recovery testing.
PW-6 Area Pilot Program	Activities include: planning and mobilization; construction of the pilot test layout; baseline short-term product recovery tests at one location (see Phase 1 Work Plan); pneumatic fracturing at three locations within the target treatment zone; split spoon sampling at two well locations; PF and installation of proppant at selected product zones; conversion of SF boreholes into product recovery ERWs; heave monitoring; and post-fracturing short- and long-term product recovery testing.
Product Recovery Methods	This activity includes comparing two product recovery methods in the two treatment plots over a period of 90 to 120 days..
Performance Evaluation Criteria	These criteria will be discussed in Section 5.0.
Recovery Trench Installation	As discussed in Section 6.0, a recovery trench will be constructed and put into operation before the commencement of the PF pilot test activities. It will continue to operate during the Pilot Study Program. The trench will be equipped with a Single-Phase Discriminating Product Removal System.

4.2 PLANNING AND MOBILIZATION

This includes all planning and mobilization work required for the implementation of field activities. These include:

- Evaluating the existing single phase product recovery system and determination of how the baseline and post fracture product recovery tests will be integrated into the existing product recovery treatment system.
- Evaluating the logistics of shipping materials, and mobilization to the Site from New Jersey and Pennsylvania, USA.

Once mobilization has occurred, a site meeting of McLaren/Hart, U.S. Navy representatives and J.A. Jones (site management) personnel will be held to review site conditions and establish the pilot test locations.

4.3 RW-1 AREA PILOT TEST PROGRAM

The area containing product recovery well (RW-1) has historically shown evidence of product in the formation. In 1994, a well was installed to recover this product. More recently, a chemical oxidation pilot test was also performed. A recent soil reconnaissance boring program and evaluation of product in wells at this location has also confirmed the presence of product.

This evidence has led to the selection of this area, called RW-1 after the existing product recovery well, as one of the pilot test locations. This location is shown on **FIGURES 4** and **10**. The RW-1 pilot test area is approximately 850 ft^2 and is located north of the second pilot test area (PW-6) which is approximately 6 ft. above mean sea level. There are no structures or utilities in the RW-1 pilot test area.

FIGURE 4 shows the location of the RW-1 pilot test area while **FIGURE 10** shows a more detailed layout of the test area. **FIGURE 10** identifies the fracture wells (FWs) and their locations, the monitoring wells which will be equipped with instruments, and the yellow area denotes the anticipated treatment area that will be impacted by the PF Program. The figure also shows which locations will be used as radial fracture wells and directional fracture wells.

PF will be applied at 6 locations in the RW-1 area. The pilot test program is designed to stimulate product recovery for 3 test configurations: an existing product recovery well RW-1 which accesses product adjacent to the area; converting an existing monitoring well, MTMW-4, (which is located in an area where there is evidence of product) into a product recovery well and evaluating product recovery by fracturing around the well; and finally, installing a PF borehole, fracturing through the borehole, and then converting the borehole to a product recovery well. For the pilot test, several existing wells in the area will be converted to monitoring wells.

4.3.1 Layout and Construction of Pilot Test Plot

This task includes all work associated with laying out the test plot and installation of a network of wells. **FIGURE 10** shows the pilot test layout and **TABLE 6** provides a summary (i.e., well type, depth, screen interval and material of construction) of pre-fracture and post-fracture product recovery wells and monitoring wells for this pilot test plot.

The pilot test well network includes the following:

- Boring MH-SB-5 will be cement betonite grouted to eliminate the potential of short-circuiting during fracturing.
- One existing recovery well (RW-1) will be used to determine if PF can improve the performance of existing wells.
- Installation of six pneumatic fracture wells (FW). The wells will be installed as open boreholes and will receive the PF equipment. **FIGURE 11** shows a typical PF open borehole well and several construction notes.
- The area in the center of the Mantech Environmental wells AW-1, MTMW-1 & -3, and AW-2 will receive a standard 3.5 in. diameter open borehole (FW-6). The well will be used as both a PF and a product well. On completion of fracturing at FW-6, a 2½ in. inner diameter slotted screen will be placed inside the open borehole and the location will be evaluated as a product recovery well (see **FIGURE 12** with notes for details.)
- Seven wells (AW-1, AW-2, MTMW-1, MTMW-2, MTMW-3, MTMW-4 and RW-1) may be equipped with instruments to measure the radial effects of PF. The locations of these wells are shown on **FIGURE 10**.

4.3.1.1 Pilot Test Layout

FIGURE 10 shows a detail diagram of the pilot test layout. The figure identifies the fracture wells (FWs) and their locations, the existing monitoring well to be used as a product recovery well, boreholes which will be used as radial or directional fracture locations, and new monitoring wells which will be instrumented. The yellow area on the figure shows the anticipated PF treatment zone.

Located around the monitoring well MTMW-4 (converted to product recovery well MTMW-4) are three open borehole FWs. FW-1, FW-2 and FW-3 are located radially around MTMW-4 at distances of 5, 8, and 10 ft. respectively. FW-1 and FW-2 will be radially fractured and FW-3 will be directionally fractured. This layout is designed to enhance the performance of MTMW-4 as a product recovery well.

Located around the existing RW-1 product recovery well are three open borehole FWs. FW-3, FW-4, and FW-5 are located radially around RW-1 at distances of 10, 8, and 5 ft. respectively.

FW-4 and FW-5 will be directionally fractured and FW-3 will be radially fractured. This layout is designed to enhance the performance RW-1 as a product recovery well.

Located in the center of four Mantech Environmental wells (AW-1, AW-2, MTMW-1, and MTMW-2) is one open borehole FW (FW-6). FW-6 will be radially fractured and then converted to a recovery well. This layout is designed to determine if fracture wells can be converted to recovery wells.

4.3.1.2 Recovery and Fracture Well Construction Details

Recovery Well RW-1

Recovery Well RW-1, an existing well, is 30 ft. deep and is screened from 10 to 30 ft. bgs. It is a 4-in. diameter PVC well that was drilled and installed using 8¼-in. hollow stem augers. For the pilot test, the product recovery pump will be removed from the well and the well modified at the surface to accommodate a well cap and instrumentation. This may include pressure gauges, ball valves, and a discharge flexible hose. **TABLE 6** includes the materials for this modification.

Recovery Well (PF/RW-1)

> *[This well type and designation will not be installed as originally proposed in the Draft Work Plan. It will be replaced by adapting the monitoring well (MTMW-4) from the Mantech Environmental Corporation's Chemical Oxidation Pilot Test into a product recovery well.]*

Recovery Well (MTMW-4)

To provide an additional product recovery well in a location where product is known to be present, the 2 in. diameter Mantech Environmental monitoring well MTMW-4 will be used as a product recovery well.

A boring log and well construction details are included in **APPENDIX C.** The well is 36 ft. deep and is screened from 15 to 35 ft. bgs. Prior to commencement of the pilot test activities, the well will be developed to maximize hydraulic communication between the well and the geologic deposits. This is discussed in Section 3 of the Phase 1 Work Plan.

Open Borehole Fracture Wells (FWs)

The September 1999 soil-sampling program demonstrated that borings at the RW-1 test plot area will, because of the density and hardness of the soil, stay open to depths of 30 ft. or more. Open boreholes are the most efficient situation for PF application because direct contact with the soil is allowed. Thus, PF will be conducted in open boreholes constructed as shown on **FIGURE 11**.

In this test plot 6 boreholes (FW-1, FW-2, FW-3, FW-4, FW-5, and FW-6) will be constructed at various locations in the test plot. Each will be constructed with a 6 ft. long x 6 in. diameter steel casing. The casing will be installed to a depth of 5 ft. bgs to provide stability to the borehole. The remainder of the borehole will be drilled with 3½ in. solid stem augers to 35 ft. bgs. In order to preserve the integrity of the borehole prior to fracturing, a 2½-in. internal diameter Sch 40 PVC pipe will be placed in the borehole. **TABLE 6** provides a summary of construction materials for the well.

Pneumatic Fracture/Product Recovery Well (FW-1)

> *[This well type and designation will not be installed as originally proposed in the Draft Work Plan. The option is omitted to allow a more thorough evaluation of the ERWs and open borehole options.]*

4.3.2 Pre-Fracture Baseline Testing

A comprehensive baseline test program has been developed for the pilot test areas at the TWFF. This program has been submitted, under separate cover, as a Phase 1 Work Plan (dated 1/13/2000). Sections 3.0 and 3.1 of the Phase 1 Work Plan describe the baseline test design for the RW-1 area and Section 4.0 describes the details for the test program in the RW-1 area. An overview of this baseline program is presented below.

The short-term tests pn RW-1 are designed to determine:

1) pump placement elevation for optimum product recovery using only a pneumatic pump

2) difficulty of separating product and groundwater

3) estimates of the hydraulic parameters of the test plot

Prior to PF activities, a baseline-testing program will be performed in the RW-1 area using a total fluids controllerless pneumatic pump. In the test program, only existing wells RW-1 and MTMW-4 will be tested. The open borehole fracture well (FW-6) will not be installed until a few days before the commencement of PF activities and, therefore, will not be baseline tested. This approach is necessary to minimize any compromise to the integrity of the borehole prior to PF activities. The purpose of this program is to establish a product recovery baseline and a hydraulic properties (i.e., hydraulic permeability and transmissivity) baseline for the pilot test area. This data will be compiled with existing product recovery data for the test area and will be compared with post- fracturing data to determine the success of the PF program.

The program will consist of a product recovery evaluation and short-term pump tests at selected wells. **TABLE 7** provides a summary of the product recovery evaluation program which will be performed prior to the commencement of the PF activities. **TABLES 8** and **9** provide a summary of the short-term test schedule for the RW-1 and MTMW-4 product recovery wells, respectively. Data collected during the tests (*e.g.*, pump flow rates and groundwater recovery rates will be

used to evaluate several hydraulic parameters [*e.g.*, hydraulic permeability and transmissivity]. Drawdown data will be used to evaluate ROI.

On completion of the short term test, a longer-term product recovery and pump evaluation test will be performed using the same total fluids pump. This test will be conducted for 20 to 30 days, by which time product recovery and hydraulic equilibrium conditions are expected to have been reached.

4.3.3 Pneumatic Fracturing Program

The fracturing pattern for RW-1 area is shown on **FIGURE 10**. Six fracture wells will be used and the fracturing will be performed in open boreholes. The targeted fracture zone is between 16 and 30 ft.. Fracturing will be performed at two-foot intervals using an HQ injector. The PF program for this pilot test is summarized on **TABLE 10**. The following summarizes the rationale for fracture well location selection.

- FW-1 Well located 5 ft. from MTMW-4; directional fracturing oriented toward MTMW-4 to create a high fracture zone in the immediate vicinity of the recovery well.
- FW-2 Well located 8 ft. from MTMW-4; directional fracturing oriented toward MTMW-4 to create a high fracture zone in the immediate vicinity of the recovery well.
- FW-3 Well located approximately 10 ft. from RW-1 and MTMW-4; radial fracturing to impact the area between RW-1 and MTMW-4 and create an interconnected zone between these wells.
- FW-4 Well is located 8 ft. from RW-1; directional fracturing oriented toward RW-1 to create a high fracture zone in the immediate vicinity of the recovery well.
- FW-5 Well is located 5 ft. from RW-1; directional fracturing oriented toward RW-1 to create a high fracture zone in the immediate vicinity of RW-1
- FW-6 Well is located approximately 10 ft. from MTMW-2, MTMW-3, AW-1, and AW-2; radial fracturing in an area of know product distribution to achieve maximum distance of fracture propagation and aperture.

4.3.3.1 Equipment Set-Up

On completion of the construction of the pilot test area and the collection of baseline data, the PF program will commence. The key components of the program are:

- Pneumatic fracturing packers, HQ injector nozzle, delivery piping, and high pressure flexible hoses
- Compressed gas (*i.e.*, nitrogen tube trailer) supply and piping

- Instrumentation including pressure gauges, engineering optical levels, and graduated heave rods

The configuration of the injection system includes a direct connection of the compressed gas from the tanker to the movable packer assembly. A system of solenoid valves, check and ball valves, and a pneumatic control console will be used to control the pressurization of the formation and safely perform the PF injections.

Groundwater and product can potentially be forced out of some wells during fracturing. To minimize this occurrence and to limit impact to receptors, strategic wells will be instrumented (*e.g.,* with pressure gauges, liquid relief valves). (**FIGURE 10** shows well locations to be instrumented; **TABLE** 6 lists the wells in each test plot and the materials of constructions/notes.) Hoses can be attached to the top of the wells and any discharge routed to a drum. Fracture boreholes may be evacuated prior to fracture injections and/or sandbags may be placed on top of the boreholes to minimize any potential liquid discharge.

4.3.3.2 Fracturing

Based on the geologic data, fracturing will begin at the bottom of the uncased borehole and will then proceed upward. **FIGURE 13** shows a schematic of an HQ injection set in an open fracture borehole. The depths, injection parameters, and sequence of injections will be determined in the field. This approach will serve to ensure that the best possible fracturing networks are attained at each depth. It is estimated that seven to ten fracture events per fracture well will be performed.

Fracture injections will be accomplished at discrete 2-foot intervals using the HQ injector. The pneumatic injections will be relatively short, lasting approximately 20 seconds. Injection flow rates and pressures will be adjusted to site conditions, but are presently estimated to range between 1000 to 3000 SCFM and 250 to 600 psi, respectively. During injection, the flow rate and pressure from the compressed air supply will be measured. Influence at selected retrofitted monitoring wells may be recorded by gauges which will indicate the peak pressure at that well.

It is estimated that fracturing will require three days. There will be a one-day mobilization/set-up and a one-day demobilization.

4.3.3.3 Heave Monitoring

Practical experience has shown that fracturing causes slight deformation of the surface. The amount of deformation is determined by the depth at which the fracturing takes place. Information on surface heave is, therefore, critical when fracturing is done near active structures and utilities. One objective of the pilot test program is to measure heave during the fracture program and to gain understanding of the deformation behavior of the formation. This information will be critical to the safe implementation of a site-wide PF program in the future, particularly if fracturing has to be applied near structures (*i.e.,* tanks) and utilities and will also be used to calibrate the PF Model for existing site conditions.

During the PF activities of the pilot test program, surface heave will be monitored at select fracture and monitoring well locations in each test plot. Surface heave will be measured with optical engineering levels and graduated heave rods. Prior to fracturing, an operator will sight the levels on the graduated heave rods which will be either attached to wells or placed on the ground surface. The maximum surface heave will be recorded during the fracture event, and the residual heave will be recorded at the end of the pneumatic injection cycle. The information collected will also be used to make real time adjustments *(e.g.,* raise or lower injection pressures and flows) to the fracture program to improve its effectiveness (*i.e.,* increase fracture radius and apertures).

4.3.4 Post-Fracturing Short-Term Tests

Upon completion of the PF activities in the RW-1 pilot test area, a series of post-fracture tests and product recovery evaluations will be performed. These tests will be similar to the procedures discussed for the pre-fracture baseline tests described in the Phase I Work Plan. The tests will be performed to evaluate:

1) Optimum pump placement for product removal
2) Change in hydraulic parameters of the test plot as a result of fracturing

The significant differences between the Phase 1 activities and the post-fracture short term tests will be more wells. In the RW-1 test plot, these wells will be RW-1, MTMW-4, and FW-6.

As discussed previously, during fracturing, "real time" measurements will be obtained by placing pressure gauges on adjacent monitoring wells and measuring surface heave at varying distances from the fracture well. However, the most effective technique to evaluate the impacts of the fracturing is to duplicate the tests performed during the pre-fracture baseline test. These tests are a repeat of the baseline tests and are summarized in **TABLE 7**. These tests will be performed at one or all of the following wells: RW-1, MTMW-4 and FW-6. Following the short-term pumping tests, product accumulation rates will be measured for two to five days.

4.3.5 Post-Fracturing Long-Term Test

As a final step in the pilot test, a long-term (90 to 120 days) product recovery test will be performed. Initial testing criteria will be based on the results of the post-PF short-term test program. The term of the test will be based on the time it takes for removal rates to stabilize and be sustained at product removal rates greater than baseline conditions, or product removal rates become less than or equal to baseline conditions in the test plots. The controllerless pneumatic pumps used in the baseline program will again be used to evaluate the effectiveness of PF in improving the continuous product removal rate of the system. At each pilot test location, one to three product removal wells (RW-1; MTMW-4; FW-6) will be used to perform the test:

During the test, product thickness levels in adjacent wells will be measured, as will total product removal from the well. The evaluation procedure in each test plot is described in Section 4.5.

4.4 PW-6 AREA PILOT TEST PROGRAM

Based on reports, the area containing product recovery well PW-06 has historically shown evidence of product in the formation. In 1994 and 1995 Terra Vac performed a pilot test to enhance product recovery from this area. It is estimated that approximately 13,000 gallons of total product was removed from this area during the study. In September 1999, McLaren/Hart conducted a soil reconnaissance-boring program and evaluated free product at this location. This investigation confirmed the presence of product in an area south of PW-06, and southeast of the TerraVac pilot test area (*i.e.*, PW-03, and PW-05).

This evidence forms the basis for selecting this area as the second pilot test location, called PW-6 after the existing product recovery well, and shown on **FIGURE 4**. It has an area of approximately 1050 ft^2 and is located south-south-west of pilot test area RW-1.

One significant difference between the RW-1 and the PW-6 pilot tests is that in the PW-6 area extended radius wells (ERWs) will also be evaluated as a method to recover free product. Geotechnical analysis of soil samples from a portion of the PW-6 test plot indicate that there is potential for soil swelling to occur. In order to keep the soil from swelling the fractures shut, a proppant will be injected into the soil that will not only prop open the apertures but will also create a zone of enhanced permeability.

FIGURE 14 shows a more detailed diagram of the area. It identifies the fracture wells (FWs) and their locations, the ERWs and their locations, and the monitoring wells which will be equipped with instruments; the yellow area denotes the anticipated treatment area that will be impacted by the PF Program. The figure also shows which locations will be used as radial fracture wells and directional wells. Note in the figure that the ERWs will be installed in the southern portion of the test pilot. Also note that the identified treatment areas for the ERWs and the PF wells are separate from each other.

The pilot test program in PW-6 is somewhat similar to the RW-1 area in that PF will be applied in the northern component to determine if it can stimulate product recovery from an existing product recovery well (*e.g.*, PW-06). However, as mentioned above, two ERWs will also be installed in the PW-6 test area to evaluate this method. For the pilot test, several existing wells in the area will be converted to monitoring wells.

Structures close to the PW-6 test area include a building without a basement and an underground fiberglass tank (<25 ft. west of the PW-06 well). The injection pressures, flows, directional and radial fracturing techniques, and surface heave data obtained in the RW-1 pilot test plot will be used to manage the fracture program in the vicinity of these structures. The utilities in the PW-6 area have been identified and marked off in the field. Based on this information, the proposed fracture wells were sited to minimize potential impact to the utilities. Also, the depth of fracturing (≥15 ft) is well below the depth of the utilities.

4.4.1 Layout and Construction of Pilot Test Plot

This task includes all work associated with laying out the test plot and installation of well networks. **FIGURE 14** shows the pilot test layout, and **FIGURE 11** shows the construction details for the fracture boreholes. **FIGURES 15** and **16** show the construction details for the two ERWs before the injection of proppant. **TABLE 6** summarizes the fracture, ERW, and monitoring wells' construction details (i.e., well type, depth, screen interval and material of construction) for this pilot test plot.

The pilot test well network includes the following:

- Boring MH-SB-3 will be cement betonite grouted to eliminate the potential of short-circuiting during fracturing.
- One existing recovery well (PW-06) will be used to determine if PF can improve the performance of existing wells.
- Installation of three pneumatic fracture wells (FW). The wells will be installed as open boreholes and will receive the PF equipment. **FIGURE 11** shows a typical PF open borehole well and several construction notes.
- Three wells (PW-03, PW-05, and PW-06) will be equipped with instruments to measure the radial effects of PF. Figure 14 shows the locations of these wells.
- Two ERWs (ERW-1 and ERW-2) will be installed in the southern component of the test plot to test this method of product recovery.

4.4.1.1 Pilot Test Layout

FIGURE 14 shows a detail diagram of the pilot test layout. The figure identifies the fracture wells (FWs) and their locations, monitoring wells which will be instrumented, the boreholes which will be used as radial or directional fracture locations, and the locations of two ERWs. The yellow area on the figure shows the anticipated PF treatment zone.

Located in the southern portion of the test plot are two ERWs. They will be created using a dry media injection system in addition to the equipment used for PF. A borehole similar to the fracture wells will be split spoon sampled and drilled. During the sampling program, the product zones will be identified. These product zones will be the intervals that will receive proppant injection. After injection, one ERW will be finished as a 2 ½ in. diameter recovery well, and the other will be finished as a 4 in. diameter recovery well. Construction details well be discussed in following sections.

4.4.1.2 Recovery and Fracture Well Construction Details

Recovery Well PW-06

PW-06 is an existing recovery well and is constructed of 4-in. diameter PVC. Based on the depth of surrounding wells, it is estimated that it is 30 ft. deep and is screened from 10 to 30 ft. bgs. For the pilot test, the product recovery pump will be removed from the well and the well modified at the surface to accommodate a well cap and instrumentation. This may include pressure gauges, ball valves, and a discharge flexible hose. **TABLE 6** includes the materials for this modification.

Recovery Well (PF/RW-2)

> *[This well type and designation will not be installed as originally proposed in the Draft Work Plan. The option is omitted to allow a more thorough evaluation of the ERWs and open borehole options.]*

Open Borehole Fracture Wells

The construction of these boreholes are similar to those in the RW-1 pilot test area.

In this test plot, three boreholes (FW-7, FW-8, and FW-9) will be constructed at various locations in the test plot. Each will be constructed with a 6 in. diameter steel casing at the surface to provide stability of the borehole and will be drilled with 3½ in. solid stem augers to 35 ft. bgs (see **FIGURE 11**). In order to preserve the integrity of the borehole prior to fracturing, a 2½-in. internal diameter Sch 40 PVC pipe will be placed in the borehole. **TABLE 6** provides construction details for the wells.

Extended Radius Wells (ERWs)

During the pre-pilot test soil boring program, soil samples were obtained in portions of the PW-6 test plot (borings MH-SB-1, MH-SB-3, and MH-SB-4). As discussed in Section 3.2, a portion of these soil samples were shipped to the New Jersey Institute of Technology (NJIT) for geotechnical analysis to evaluate the soil characteristics with regard to the application of PF and fracture stability. The tests performed included grain size analysis, Atterberg liquid limit, plastic limit, and shrinkage limit. Of particular concern was whether the soil has the potential for swelling behavior which might lead to aperture closure. All of the samples except two showed a low potential for swelling. The two exceptions (SB-6 at 12 to 14 ft and SB-4 at 18 ft to 18 ft 10 in) showed a moderate to high potential. The SB-6 sample is above the target zone for PF, but the SB-4 sample is within our PF target zone and is also close to the product zone depth in that boring. Based upon this information , there is a need for a proppant to maintain the fractures at this location. Therefore, two ERWs are included in the southern part of the PW-6 test plot.

4.4.2 Pre-Fracture Baseline Testing

The baseline testing program is described in detail in the Phase 1 Work Plan (dated January 13, 2000).). Sections 3.0 and 3.1 of the Phase 1 Work Plan describe the baseline test design for the RW-1 area and Section 4.0 describes the details for the test program in the RW-1 area. An overview of this baseline program is presented below. The short-term tests on PW-06 are designed to determine:

1) pump placement elevation for optimum product recovery using only a pneumatic pump

2) optimum vacuum to maximize product recovery while pumping with a pneumatic pump

3) difficulty of separating product and groundwater

4) estimates of the hydraulic parameters of the test plot

Additionally, a long-term test (30 days) will be performed in PW-06 to determine product removal rates over an extended period. This will establish a product removal rate baseline that can be used to determine improvements associated with PF. The 30 day test will involve only pneumatic pumping for the first seven days. Following that period, for the duration of the test, a vacuum will also be applied to the well (see Section 4.4.2 of the Phase 1 Work Plan for details.)

4.4.3 Pneumatic Fracturing Program

The fracturing pattern is shown on **FIGURE 14**. Three fracture wells will be oriented around PW-06. The targeted fracture zone is between 16 and 30 ft. and fracturing will be performed in open boreholes at two-foot intervals using an HQ injector. The PF program for the PW-6 pilot test is summarized on **TABLE 13**. The following summarizes the rationale for fracture well location selection.

- FW-7 Directional fracturing to create a highly fractured zone in the immediate vicinity of PW-06
- FW-8 Radial fracturing to achieve a maximum distance of fracture propagation in the area south of PW-06 which has been shown to contain product zones.
- FW-9 Directional fracturing toward PW-06 and MH-SB-3 to enhance performance of PW-06 and induce migration of product in MH-SB-3 toward PW-06.

4.4.3.1 Equipment Set-Up

The PF equipment set-up is the same as for the RW-1 area (see Section 4.3.3.1 for details). In addition to the standard PF equipment that will be used for basic fracturing, the ERWs to be constructed in the PW-6 test plot will also require the use of the dry media injection system. This is a skid-mounted unit that is used to feed the proppant material into the air stream. It consists of two tanks to hold the media and various pneumatic-controlled valves to release proppant into the air stream at carious times in the fracturing process. The gas feed for the dry media system is the same gas source as for the basic fracturing. A separate control panel is used to operate the dry media system.

4.4.3.2 Fracturing

Based on the geologic data, fracturing in the FWs will begin at the bottom of the uncased or screened borehole and will then proceed upward. **FIGURE 13** shows a schematic of an HQ injection set in an open fracture borehole. The depths, injection parameters, and sequence of injections will be determined in the field. This approach will serve to ensure that the best possible fracturing networks are attained at each depth. It is estimated that ten fracture events per fracture well will be performed.

Fracture injections will be accomplished at discrete 2-foot intervals using the HQ injector. The pneumatic injections will be relatively short, lasting approximately 20 seconds. Injection flow rates and pressures will be adjusted to site conditions, but are presently estimated at 1000 to 3000 SCFM and 250 to 600 psi, respectively. Also, using experience gained from the RW-1 area, the injection parameters will be modified to optimize the fracturing program.

During injection, the flow rate and pressure from the compressed air supply will be measured. Influence at selected retrofitted monitoring wells will be recorded by gauges which will indicate the peak pressure at that well.

Creation of the proppant zones associated with the ERWs is a variation of the basic pneumatic fracturing technology. Rather than pressurize the standard two foot interval described above, the HQ injector is modified to compress the fracture pressure to a small interval that creates a single fracture immediately adjacent to the plate nozzle. Once this fracture has been created and the injection pressure has enlarged it to its maximum aperture, then the proppant is introduced into the gas stream. The proppant is transported by the carrier gas (nitrogen) into the fracture to form a conductive lens (normally, five to seven feet long). The gas is turned off and the formation relaxes, supported by the proppant. The entire process requires 45 to 75 seconds.

4.4.3.3 Heave Monitoring

The heave-monitoring program will follow the same procedure as discussed in Section 4.3.3.3 for the RW-1 pilot test area.

4.4.4 Post Fracturing Short Term Tests

The post-fracturing short term tests will be performed similar to the procedures discussed for the pre-fracture baseline tests described in the Phase I Work Plan. The tests will be performed to evaluate:

3) Optimum pump placement for product removal
4) Influence of vacuum on pump performance and product removal
5) Change in hydraulic parameters of the test plot as a result of fracturing

The significant differences between the Phase 1 activities and the post-fracture short term tests will be more wells. In the PW-6 test plot, these wells will be PW-06, ERW-1, and ERW-2.

4.4.5 Post-Fracture Long-Term Test

As a final step in the pilot test, a long-term (90 to 120 days) product recovery test will be performed. Initial testing criteria will be based on the results of the post-PF short-term test program. The term of the test will be based on the time it takes for removal rates to stabilize and be sustained at product removal rates greater than baseline conditions, or product removal rates become less than or equal to baseline conditions in the test plots. The controllerless pneumatic pumps used in the baseline program will again be used to evaluate the effectiveness of PF in improving the continuous product removal rate of the system. At each pilot test location, one to three product removal wells (PW-06; ERW-1; ERW-2) will be used to perform the test:

During the test, product thickness levels in adjacent wells will be measured, as will total product removal from the well. The evaluation procedure in each test plot is described in Section 4.5.

After completion of the post-fracture short-term tests, the PW-6 test plot will be allowed to stabilize for one to two days. Once water levels in observation wells have returned to near static conditions, the post-fracturing long-term product removal test will begin. This test will last 90 to 120 days and will consist of product removal pumping from PW-06, ERW-1, and ERW-2 using a pneumatic pump in association with VER. Measurements of product removal and liquid removal rates will be performed during this period.

4.5 PRODUCT RECOVERY METHODS

There are two phases to the pilot tests. One is to evaluate the effectiveness of PF to increase permeability and subsequently total fluids and product recovery, and the other is to evaluate the two methods of product recovery. The first method evaluated will be pneumatic pumping only (before and after PF) in the RW-1 area. The second method will involve evaluation (before and after PF) of pneumatic pumping in association with Ver in the PW-6 area.

4.5.1 Pumping System Evaluation Strategy

Recovery due to the effects of PF can be differentiated from that due to the use of a total fluids recovery system by conducting the designed baseline testing (See Phase 1 Work Plan) of hydraulic properties and product recovery rates in the test plots. After the formation is fractured, these parameters will be re-evaluated, and any changes in performance of the wells and hydraulic parameters in the treatment area will be attributable to the PF enhancement program. While PF can enhance subsurface conditions to allow greater access to the product, selection of the most cost-effective pumping system is critical to the long-term success of the product removal system.

The fluid recovered from wells in the test areas will be routed to an on-site temporary treatment system to remove free and dissolved product and to discharge these, in accordance with the operating discharge permit, to the sanitary sewer for the site. The treatment system components are discussed in Section 4.6. A schematic of a typical product recovery treatment skid is shown on **FIGURE 19**, and the site plan showing the layout of the treatment system's components is shown on **FIGURE 20**.

4.5.2 RW-1 Area Pump Evaluation

Based on the design of the test plot and the construction of the new product recovery wells, McLaren/Hart recommends that the evaluation of the pneumatic submersible pump be conducted in the RW-1 pilot test location. In this location, the pumps will be installed in RW-1, MTMW-4, and FW-6.

The pumping will be performed, as described in the Phase 1 Work Plan, by conducting baseline tests, including short term pumping tests and long term baseline pumping tests. The optimum locations and depths in wells will be used to perform the long term test for the wells after PF for the post-fracture evaluation program.

4.5.3 PW-6 Area Pump Evaluation

The evaluation of the pneumatic submersible pump at the PW-06 well in the PW-6 area will be performed in Phase 1 by conducting a baseline test and short-term tests to determine the optimum location of the pump and short term tests to determine the optimum level of vacuum required to enhance product recovery at the site. Based on the results of Phase 1, the VER tests will be performed on three wells: PW-06, ERW-1, and ERW-2 after PF.

4.6 TREATMENT SYSTEM DESCRIPTION

The groundwater and product recovery pilot tests after PF at RW-1 area will be performed on one 4 - in. (RW-1), one 2-in. (MTMW-4) and one 2½-in. (FW-6) recovery wells. The recovery test in the PW-6 area will be performed on two 4-in. (PW-06 and ERW-1) and one 2½ -in. (ERW-1) recovery wells. FW-6, ERW-1, and ERW-2 are the fracture wells converted into recovery wells.

During testing , each well in the RW-1 area will consist of a pneumatic recovery pump, a holding tank, and a transfer pump. PW-6 well testing will consist of the same components as in RW-1 except that a vacuum pump will be added to apply negative pressure to the well. A groundwater/product treatment system will be installed to treat the influent from both areas. Each recovery well will contain a pneumatically-operated total fluid recovery pump to remove groundwater/product. The flow from each of the wells will be directed through a flow gauge then into a dedicated 55-gallon drum to determine each well's extraction rate and quantity of product recovered. The groundwater and product that is collected during this test will be processed through a treatment system consisting of an product/water separator, intermediate holding tanks, and liquid phase carbon. The treatment system can be operated as a batch or continuous flow process. The product recovery and treatment schematic is shown on **FIGURE 19**.

4.6.1 Treatment System Setup

- Install product oil/water separator and connect the discharge lines from the transfer pump to the influent of the separator. The flow rate to the separator will be controlled by a globe valve.
- Install pump and piping to pump separated free product from the separator to the temporary product storage tank.
- Install the surge tank and accessories and connect the separator effluent pipe to the surge tank.
- Install the liquid phase carbon units and piping to direct the flow from the surge tank through the carbon units. Carbon units will be piped so that they can operate in series or parallel.
- Install the treated water holding tanks and connect the effluent form the carbon units to the tanks.
- Install discharge pump to pump the treated water from the holding tanks into the site sanitary sewer. Install the piping and valves so that the discharge from the holding tank can be re-routed back through the treatment system if the chemical analysis shows that treatment was not adequate.

4.6.2 Equipment at the Wellhead

- Install the total fluid recovery pump in the well with discharge hose, air supply hose and exhaust vent.
- Connect the discharge hose and air supply hose to the bottom of the well cap.
- Connect the discharge hose and air supply hose form the top of the well cap to continue the piping.
- Install the vacuum pump with liquid knockout tank and connect the vacuum line to the well head (for PW-6 area only).

- Install coalescing filter on the pressure side of the vacuum pump (for PW-6 area only).
- Install pump to evacuate liquids from the liquid knock out tank (for PW-6 area only).
- Install 55-gallon tanks at each wellhead and connect the pump discharge to them. The 55-gallon tanks will gravity drain into the holding tank(s).
- Install water holding tanks and piping to gravity drain from the 55-gallon tank.
- Install transfer pumps and piping to pump from the water holding tanks to the treatment system skid.
- Interconnect the piping to incorporate the vacuum extraction system, compressed air supply, and product recovery system to the wellhead.

4.6.3 Recovery Pumps

Pneumatic submersible pumps will be utilized to recover the product and groundwater from the pilot test recovery wells. The pumps will be operated using an on-site compressed air source. The pumps are controllerless, top loading submersible pumps that are designed to operate continuously, provided the liquid in the well is sufficient to fill the pump body. The total fluid stream recovered will be directed to 55-gallon drums to accurately gauge the pumping rate and the quantity of product recovered from each well.

4.6.4 Vacuum Pumps & Air Treatment

A high vacuum extraction pump will be utilized to induce a vacuum at the recovery well head to enhance the total fluid recovery of the collection system in the PW-6 area. The high vacuum system will be capable of providing 140 scfm flow with a vacuum of 20–25 inches of mercury. This high vacuum system will consist of a condensate/vapor knockout tank, a vacuum pump, and a vapor phase carbon system for the treatment of the vacuum pump air effluent. The knockout tank will remove the condensate/vapor that may be carried over from the recovery well into the vacuum system. The knockout tank will be equipped with a pumping system and liquid levels controls to process the collected condensate through the liquid treatment system.

4.6.5 Groundwater Treatment

The product and groundwater collected in the 55-gallon tanks from RW-1 area and PW-6 area will be drained by gravity to the 2,500-gallon and 5,000-gallon holding tanks respectively. The product and groundwater from the holding tanks will be pumped, utilizing a progressive cavity pump, to a product/water separator for separation and removal of the free product. The product collected in the 55-gallon tanks, holding tanks and separator will be pumped to the existing product storage tank for proper disposal (*i.e.*, as currently practiced at the site). The water from the product separator will be pumped to a surge tank and then processed through liquid phase carbon units for the removal of any dissolved contaminants. The treated water from the carbon units will be collected in one of the two 500-gallon water holding tanks

The effluent will then be tested to ensure it meets the stipulated discharge standards prior to release to the sanitary sewer and on-site treatment facility. If the final effluent does not meet the discharge requirements, it will then be re-directed through the treatment system again for additional processing.

An ERW is created by injecting proppant media into the subsurface at specific zones immediately above and below the product zones and, thereby, creating a conductive lens that radiates outward from the well. Since these conductive lenses have a permeability which is significantly greater than the native soil, the recovery of liquids and vapors is increased. The typical radii of injection for proppants are five to seven ft.. At this test plot, the proppant will be injected using a specially-designed variation of the HQ injector – a device used for pneumatic fracturing in open boreholes.

Thus, an important component of building an ERW is identification of the product zones. A method has been included in this approach that allows for this product zone identification during drilling. The following steps will be undertaken to construct the ERWs:

1) Drill and install 5 ft long surface casing
2) Drill borehole to 12 ft. with 3½ in. solid stem augers
3) Obtain continuous split spoon samples from the borehole to locate product zone(s)
4) Drill out borehole to 35 ft. bgs with 3½ in. solid stem augers
5) Identify product zones in the borehole and select the proppant injection zones
6) Install proppant injection nozzle in the borehole and inject the proppant at the identified zone.

In this test plot, there will be two open boreholes with proppant injected at the appropriate zones. Both boreholes will be converted to product recovery wells ERW-1 and ERW-2 using the following techniques so that recovery rates from different casing diameters can be evaluated.

ERW-1 **(FIGURE 17)** will be constructed using a 2½ in. PVC casing and screen. This diameter was selected so that the casing could easily slide in the borehole. The well annulus will be filled with well gravel (if possible) to a depth of approximately 5 ft. bgs. Next 6" of bentonite chips will be placed on top of the well gravel and hydrated in 3" lifts. The well will be completed with cement bentonite grout as shown on the figure.

ERW-2 **(FIGURE 18)** will be constructed using a 4 in. diameter PVC casing and screen. To accommodate this diameter screen, the 3½ in. borehole will be drilled out by 4½ in. hollow stem augers to create an eight in. diameter borehole. The well will be built up with filter pack around the screen and sealed at the surface by grouting between the well and surface casings.

5.0 PERFORMANCE EVALUATION CRITERIA

It is important to establish agreement with regards to performance evaluation criteria in order to have a common understanding of how the pilot test will be judged. From an overall perspective, the preeminent criteria will be the effectiveness of PF technology to enhance the removal of petroleum product from the formation at select locations in TWFF. Factors to be measured include the enhancement of the test plot site's product removal systems and, to a lesser extent, various well construction techniques, product removal pumps and engineering design parameters.

5.1 INCREASED PRODUCT REMOVAL

The overall objective of this entire pilot test is to determine if PF technology can be used as a product recovery enhancement technique at the site. The strategy for this evaluation is to conduct a 90 to 120 day long-term product removal program in each test plot and compare these results to the historical product removal data for the area.

Compared to the present pilot test, the historical data covers a much longer time frame. To logically evaluate the increase in product recovery, therefore, comparable time frames must be devised. Historically, the operating system has performed less efficiently as time has passed. To make an objective comparison, any increase in the quantity of product removed must be measured against recent historical values rather than an average value for the existing PW-06 and RW-1 wells. Therefore, the data will be evaluated on a monthly basis and compared to historical data from that of the last quarter. The quantity of product removed from each pilot test area after fracturing will be measured at 2-3 of the new and/or existing product recovery wells. The results of this evaluation will be reported as a Volume 2 Pilot Test Report.

5.2 MEASUREMENT OF PERFORMANCE IMPROVEMENT AT EXISTING PRODUCT RECOVERY WELLS

A recent survey of recovery wells in the pilot test area showed that very little product is in these wells. To evaluate if PF technology can be integrated into the existing recovery system and if it will improve the performance of poorly producing wells, fracturing will be performed around existing product recovery wells. Four criteria will be used to make this evaluation:

1) Increased product removal after fracturing
2) Increased radius of influence during short term pump tests.
3) Improved hydraulic parameters as determined by the short term pump tests.
4) Evaluation of the performance of various product recovery well types.

1) ***Increased product removal after fracturing***
At some locations it is possible that the amount of product recovered will increase significantly immediately after fracturing. This behavior is not uncommon in subsurface fracturing projects and is known as "flush production". This production may be sustained for several days, or may begin to decline after a few days due to a depletion of product in the immediate vicinity of the well. To measure any increase, a combination of product baildown tests and/or short-term pump tests will be performed, focusing on the RW-1 and PW-06 wells. The results from these tests will be compared with the baseline data as a measure of any improvement.

2) ***Increased radius of influence during short term pump tests.***
Another determining factor for the measurement of product recovery improvement is radius of influence per recovery well. The radius measured depends upon the configuration of fracture locations and the monitoring well network, and will be determined using field indicator parameters (pressure, groundwater mounding). Also, the difference in drawdown at fixed pumping rates during the pre- and post-pilot short-term pumping tests will be used in evaluating the radius of influence.

3) ***Improved hydraulic parameters as determined by the short term pump tests.***
In well locations RW-1 and PW06, where there is little evidence of product, an enhancement may not be possible. However, a change in hydraulic parameters in the treatment area would suggest that product recovery rates would have increased if product were present. The results of the short term pump tests will be used to determine several hydraulic parameters, including hydraulic conductivity and transmissivity. This information will be used to evaluate the overall effectiveness of the PF program.

4) ***Evaluate the performance of various product recovery well types.***
The effect of employing various well constructions will also be studied during the pilot test to determine the most cost- and performance-effective design. The well construction techniques will be evaluated with regards to:

- Ease of installation
- Drilling method required
- Amount of cuttings and purge water generated
- Impact of the fracturing on the structural integrity of the well
- Ability to accommodate pumps and other recovery equipment

Also, the evaluation will include determination (based primarily on measurement of the quantity of product removed after fracturing) of whether:

- Fracturing is effective for enhancing existing wells

- Fracturing through screened wells and using them as product recovery wells is viable
- Conversion of open fracture boreholes to product recovery wells is viable
- Installation of ERW is an effective product recovery well design

5.3 PRODUCT RECOVERY METHODS EVALUATION

An evaluation will be performed on two types of product recovery methods. These systems will also be compared with the existing product only system. For the product only, the evaluation will be based on historical performance data. The performance of these two methods will be evaluated based on the following:

- Ease of installation
- Ease of accommodation by the well construction
- Ability to control operation
- Simplicity of operation
- Durability
- Ability to minimize water pumping and maximize product recovery

5.4 PILOT TEST REPORTS

5.4.1 Preparation of Draft Pilot Test Report

Following the completion of the pilot testing activities, McLaren/Hart will prepare a pilot test report which will be completed in two volumes. The Volume 1 report will contain the results of the pilot test, and the Volume 2 report will supplement the findings of Volume 1 by including the results of the long-term product evaluation program. A draft of both documents will be submitted to the Navy for review.

The Volume 1 report will describe the test procedures for the two pilot test areas, the construction of the recovery trench, discuss the results from each pilot test, evaluate the effectiveness of PF to enhance the performance of the existing system, evaluate various well types, and evaluate the performance of the two total fluids product recovery methods to improve the removal of product from the formation. The Volume 2 report will summarize the results from the long-term product removal test, evaluate the overall performance of the pilot test and the product recovery trench, and propose recommendations for a full scale design.

5.4.2 Preparation of Final Pilot Test Report

Upon receiving one set of consolidated comments, for the Volume 1 and Volume 2 Report, from the Navy, McLaren/Hart will revise the Draft Report and submit the Final Report.

6.0 RECOVERY TRENCH

Concurrent with the PF and pump performance pilot studies, the effectiveness of a product recovery trench will be evaluated. Well monitoring results indicate the free product plume has migrated eastward between Forrestal Drive and the natural slope. It is concluded that the product migration is confined to a narrow path near the utility corridor bounded by the bedrock surface to the North and the dense soil beneath Forrestal Drive. Flow of the product may be aided by the more porous granular soils comprising the utility trenches adjacent to Forrestal Drive.

The recovery trench will be constructed to tie into the utility trenches and will extend from Forrestal Drive on the South to the toe of the rock slope on the North. The trench is designed to intercept and collect free-phase product occurring in the near surface strata. The trench will be located near recovery well RW-8, which is located along the utility corridor (near the leading edge of the measured free product plume) adjacent to Forrestal Drive. The trench is intended to control migration of free product toward the East.

6.1 SPECIFICATIONS

Specifications for installation of a recovery trench were included in the approved Work Plan "Product Recovery System at the Tow Way Fuel Facility" which was submitted in August 1996. These specifications provide details of construction materials and procedures and will serve as a guideline for construction activities. The recovery trench will be installed as shown on **FIGURES 21** (Recovery Trench Plan) and **22** (Recovery Trench Sections) and to the specifications presented in the approved Work Plan. Site temporary facilities and staging areas are illustrated on **FIGURE 20**.

The recovery trench will be approximately 6 ft. wide, 20 ft. long and 12 ft. deep. The final dimensions will depend upon actual subsurface conditions and the location of existing utilities in the area. The width of the trench (perpendicular to Forrestal Drive) will be maximized to intercept as much of the product flow path as practical. The width will be limited by maintaining support of Forrestal Drive the South and the competent bedrock to the North. The trench will extend a minimum of two feet below the recorded seasonal low groundwater surface to allow for seasonal fluctuation of groundwater levels.

A sump will be installed at the eastern (down gradient) end of the trench to house product recovery equipment. The sump will consist of a six-inch diameter slotted (0.02-in. opening) PVC standpipe with capped end. The sump will extend an additional two feet below the bottom of the trench to allow room for the pumping equipment below the groundwater surface. A 2-in. diameter PVC piezometer will also be installed at the western (up gradient) end of the trench to monitor groundwater and product levels during operation.

The sump will be fitted with a discriminating skimmer type recovery pump previously used at the site. The pumps are pneumatically driven pumps fitted with a specific gravity float mechanism to skim floating product. The trench will be incorporated into the existing product

recovery system utilizing existing pneumatic equipment, conveyance lines and product storage. Pump controls and wellhead plumping will be housed in a flush-mounted steel vault box. The vault box will be constructed with a water resistant, lockable hinged lid with hydraulic assist designed to withstand AASHTO H20 highway loads. Discharge from the skimmer pumps will be conveyed in product resistant hose to the existing product storage tank for recycling/disposal. The compressed air and product lines will be run between the vaults in secondary containment pipes. The pipes will be approximately 24 inches below the ground surface to prevent damage by surface loads.

The trench will be backfilled with of clean, pea size gravel to approximately 2 ft. below the ground surface, followed by compacted soil placed to the ground surface to minimize infiltration of surface water into the trench. A geotextile filter fabric will be installed between the soil and gravel interface to provide separation. Geotextile is susceptible to clogging not specified on the sides of the trench. It is anticipated that free floating product intercepted by the trench will readily flow through the pea gravel into the sump and draw down of the groundwater will not be necessary to enhance product recovery at this location. An impermeable lining on the down gradient end of the trench was considered. However, the effectiveness of the barrier would be limited due the he configuration of the trench. Due to physical constraints at the site, the trench will be only 4 to 6 ft. wide. Flow distances around the impermeable barrier wold be relatively short thus minimizing the effect of the barrier.

6.2 SUBSURFACE CONDITIONS

Evaluation of soils and product in this area was based on well installation logs for two recovery wells in the area, RW-7 and RW-8. These logs are included in **APPENDIX C**.

During installation of these wells, evidence of product was observed in the drill cuttings below a depth of five ft. below the surface. Based on review of well gauging data from UGW-21 and RW-8, groundwater levels range from 3 to 10 ft. bgs. Free product has historically been measured floating on the groundwater surface ranging from 0.1 to over 2 ft. thick in these wells.

The near surface soils in this area consist of asphalt pavement and granular base to a depth of 1 foot. This is followed by a well-graded granular fill to a depth of 4 ft. bgs. This layer is likely the utility trench for the buried waterline that runs adjacent to Forrestal Drive as indicated on **FIGURE 21**. From a depth of 4 to 18 ft. bgs the soil is classified as a mixture of gravel, sand and silt. At a depth of 18 ft., weather rock is encountered consisting of gray-green weathered Olivine Gabro. The rock surface is believed to be encountered at less depth closer to the toe of slope. Excavation of the trench is anticipated to be limited by the location of the competent bedrock.

6.3 PRE-CONSTRUCTION ACTIVITIES

Prior to the start of intrusive activities the McLaren/Hart will conduct an Environmental Conditions Survey to document pre-existing condition of existing structures and surfaces. The Environmental Conditions Survey will include taking photographs of existing structures such as pavement, buildings and sidewalks within the work areas, and discussing and noting existing conditions. This report will be submitted to the Resident Officer in Charge of Construction (ROICC) and reviewed prior to site restoration activities.

An important consideration is the constructability of the trench given the depth at which the product layer is encountered and the proximity of existing utilities. Both buried and overhead utilities are present in the area between Forrestal Drive and the toe of the slope. Known utilities include an 8-in. PVC waterline approximately 3 ft. bgs adjacent the road, a fiber optic line approximately 2.5 ft. bgs and a copper communications line at an unknown depth. In addition, an overhead electric line is located approximately 15 ft. from the road.

Prior to mobilization of excavation equipment, a Level B utilities survey will be conducted by the Naval Station Mechanical Utilities Depart Engineer and McLaren/Hart's representative. The horizontal location of buried utilities will be determined by non-destructive locating methods such as electromagnetic, sonic, and other energy fields. Known utilities will be marked in the proposed trench excavation area with color-coded flags and paint. A meeting will then be held with the Naval Station Communications department to discuss the handling and protection of the communication lines near the trench.

Mobilization of equipment and setup of temporary facilities, including an office trailer, equipment storage and material stockpile areas, and water treatment system, will be coordinated with the RIOCC and Naval Station Fuels Department. The temporary facilities and staging areas will be located north of Palua Drive in the Tow Way Fuel Facility near recovery well RW-2 as shown on **FIGURE 20**. Any changes to the facilities will be coordinated with the ROICC. Site controls such as construction barricades, security fencing and sediment control features will be installed during this phase.

The proposed location of the recovery trench and temporary facilities will be marked in the field and discussed with the ROICC.

6.4 EXCAVATION

Exploratory borings will be installed to locate and confirm all field-marked utilities. Trench excavation and construction operations will be supervised by McLaren/Hart personnel, and care will be taken to locate all utilities. For example, prior to excavation, known utilities in the vicinity of the trench will be located and exposed using hand excavation methods and power operated equipment. All power operated equipment will be maintained at least two feet away

from known utilities. Each utility exploration hole will be advanced by hand and then opened further with power utility line excavating equipment.

The joints of the water line within the trench excavation will be laterally supported. Each joint will be exposed using hand excavation methods prior to extending the trench excavation below the level of the waterline. The waterline will be supported using a combination of jacks, struts and/or tie-back cables.

Once the communication lines are exposed, the Naval Station Communications Department will be consulted to determine the final course of action. The lines may be temporarily or permanently relocated beyond the anticipated limits of the trench excavation. Temporarily relocation would involve uncovering the lines within the lines of the trench excavation, and placing the lines adjacent to the trench encased in a split-case PVC pipe for protection during trench construction. Once, construction of trench is completed, the fiber optic and communications lines would be reinstalled in accordance with Naval Station Communications Department specifications.

Once the existing utilities are secured, trench excavation will begin. The trench will be excavated with a hydraulic excavator guided by a spotter during operation. Care will be taken to maintain the required 10 ft. safe operating distance from the overhead 13 KVA power lines. It will not be necessary for personnel to enter the excavation below the level of the existing utilities (less than 4 ft. deep) to complete the recovery trench. Use of a trench box is not anticipated.

Based on well gauging data and the presence of free product in the area, soil from the recovery trench below a depth of approximately five feet may be contaminated with POL. Each bucket of soil removed from the trench will be visually observed and screened for TPH using either a PID or an OVA. Screening will be used to determine if the soils are to be placed in the clean or the potentially contaminated soil stockpile (*i.e.*, readings above background will be used as the criteria for segregating soils into a "potentially contaminated" soil stockpile.

Soil removed from the trench will either be loaded directly into a truck for transportation to the soil stockpile areas in the Tow Way Fuel Facility (see **FIGURE 20**) or temporarily staged adjacent to the trench in a prepared soil containment stockpile located west of the trench excavation. In order to segregate the potentially contaminated soil from the clean soil, the trench will be excavated in lifts equal to the entire width of the trench until the level of soil contamination is reached. Once soil contamination is encountered in any portion of the trench excavation, all soil removed from the trench from that point on is considered potentially contaminated. The temporary stockpile adjacent to the trench will be used for staging potentially contaminated soil from the trench.

Each bucket of soil removed from the trench will be allowed to drain prior to dumping to minimize handling of potentially contaminated water. Saturated soil will be allowed to drain in the temporary soil stockpile adjacent to the trench prior to transporting to the stockpiles in the staging area. Drainage from the stockpiles will be placed either into the temporary treatment system of the product/water storage tank. Soil stockpiles will be covered during non-working

hours to divert rainfall and minimize non-project personnel exposure. They will also be cordoned off and the appropriate traffic controls will be implemented (details will be provided in an Excavation Plan).

Once the trench excavation is complete, recovery sump and piezometer will be installed. The trench will be backfilled with pea size clean gravel to approximately two feet below the surface, followed by compacted soil placed to the ground surface. A geotextile filter fabric will be installed between the soil and gravel interface to provide separation. A vault box will be installed to house product recovery pumps, and associated controls and piping. Conveyance piping will be connected to the RW-7 vault and tied into the existing air supply and product return lines.

6.5 OPERATION

Existing single-phase discriminating product recovery pumps will be used to evacuate the recovery trench. Controller-less pneumatic driven diaphragm "Genie" pumps manufactured by Clean Environment Equipment Company are currently used at the site. These pumps are fitted with specific gravity product intake floats that are capable of handling 42 inches of water level fluctuation. The intake skimmer is calibrated to float on the oil/water interface and allow free-floating product to be drawn into the pump chamber. Once the chamber completely opens, the pneumatic pressure is used to forced the product from the chamber towards the equipment compound and the product storage tank. Since other portions of the product recovery system will be temporarily shut down during pilot studies, product recovery from the trench can be monitored by measuring the levels in the product tank directly.

6.6 WASTE MANAGEMENT

Wastes will be handled in accordance with the Waste Stream Management Plan specified in Section 3.0 of the Approved Work Plan. Based on assessment data for the site, the work is expected to involve materials contaminated only with petroleum constituents at non-hazardous levels. It is anticipated that the proposed activities will generate the following four waste streams:

- Contaminated Water – Water removed from areas of know contamination or suspected contamination based on field observations. To include water generated by well development and pumping, decontamination operations, excavation de-watering and runoff from contaminated soil stockpiles.
- Contaminated Soil – Soil removed from areas of known contamination or suspected contamination based on field observations. To include excess soils generated from trench installation and well installation.
- General Demolition Debris – Non-metallic debris generated from demolition of existing structures including pavement or other materials of construction.

6.6.1 Contaminated Water

Contaminated water generated from the pilot tests and trench installation will be processed in the temporary on-site treatment system. The system consists of a product/water separator, intermediate holding tanks, and liquid phase carbon. The treatment system is described in detail Section 5.0 of the Phase 1 Work Plan.

The final effluent will be collected in two 500-gallon holding tanks and tested to ensure it meets the requirements of the discharge standards prior to release to the sanitary sewer for final treatment by the Naval Station sanitary treatment plant (STP). If the final effluent does not meet the discharge requirements, it will be re-directed to the head of the treatment system for additional processing. The STP authorities will be notified prior to discharge. In addition, a letter identifying the anticipated discharge rates from the pilot studies will be submitted to the STP so that the US EPA can be notified for a potential temporary NPDES permit modification.

Groundwater samples from two wells in the vicinity of the proposed test plots were obtained and analyzed for a full scan surface water parameter list. Results indicate that the groundwater would meet the base STP influent criteria without pretreatment. The concentration of hydrocarbons in the groundwater will likely increase due to pumping activities. We anticipate sufficient clarification and hydrocarbon separation will be accomplished with the sizable (5,000 and 2,500 gallon tank) surge tanks and oil/water separator to meet treatment influent criteria.

6.6.2 Contaminated Soil

Clean and potentially contaminated soil stockpile areas will be located in the Tow Way Fuel Facility as shown on **FIGURE 20**. In order to determine handling and transportation and disposal requirements, soil samples will be collected from both the clean and potentially POL contaminated soil removed from the trench and analyzed for TPH and disposal parameters required by the disposal facility as discussed in Section 2.0 of the Approved Work Plan. Based on analytical results of the soil samples, excavated soil will be direct loaded for transportation and disposal or stockpiled for later transportation and disposal or potential reuse if clean. Soil with less than 50 ppm TPH shall be considered clean (non-regulated) and spread in areas in the Tow Way Fuel Facility where POL soil contaminated has been identified. Non-contaminated soil stockpiles, which will not be returned to the excavation by the end of the shift, will be covered with a single layer of 10 mil poly liner to minimize moisture content increases due to rainfall events. Concrete and asphalt pavement will be disposed as construction debris at the designated area on base.

In the event rainfall occurs during excavation activities, standing water will be removed from the excavation by pumping prior to placing materials or backfilling. Any POL evident will be skimmed off and disposed into the product storage tank. Water from uncontaminated areas will be filtered and discharged into existing surface water facilities.

6.6.3 General Construction Debris

Construction debris will be disposed at the designated on-site construction debris disposal site.

6.6.4 Recovered Free Product

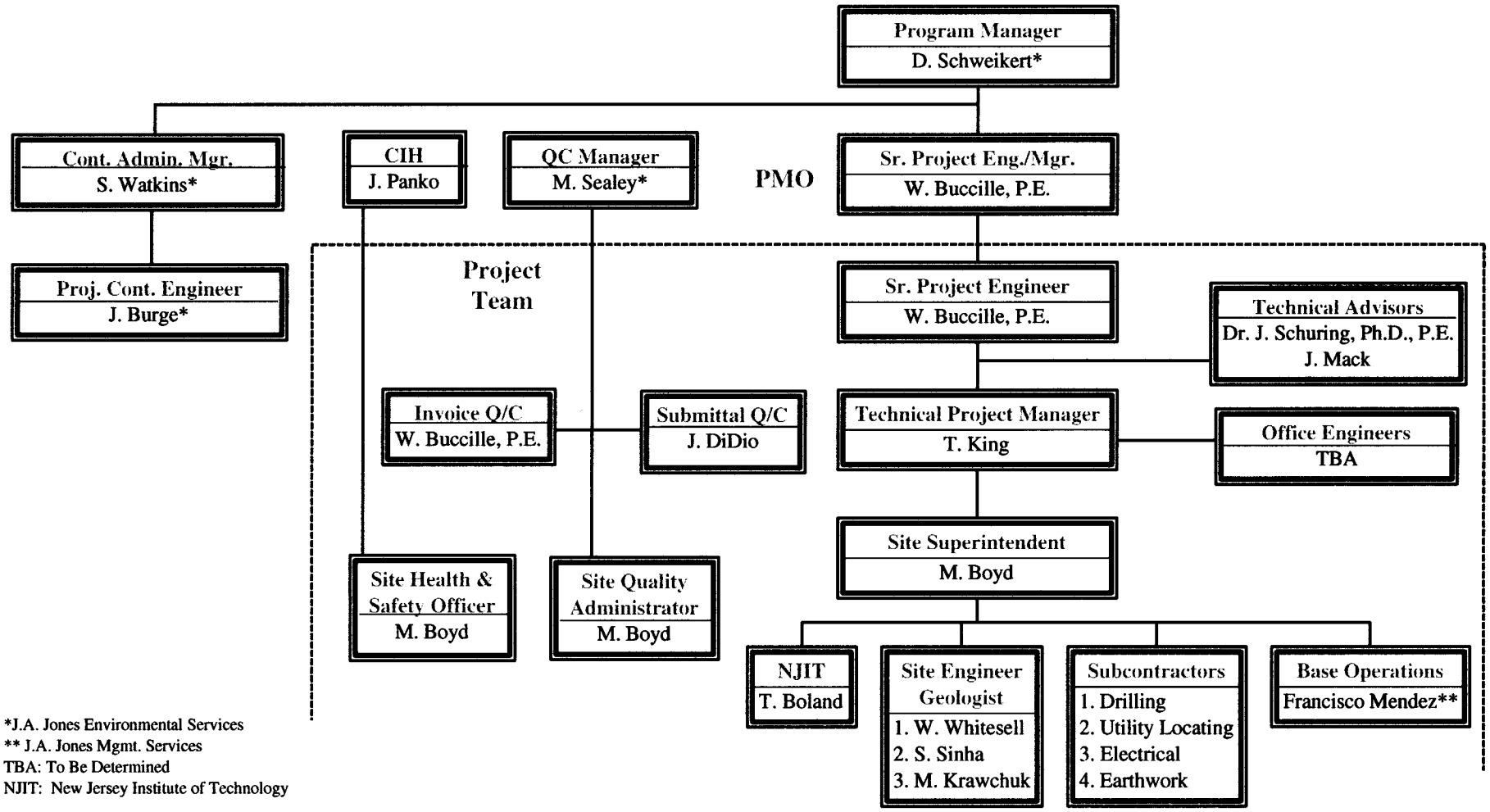
Recovered free product will be temporarily stored in the existing on-site 500 gallon product storage tank pending analysis and final disposition.

7.0 PROJECT ORGANIZATION

The project team is structured to provide the Roosevelt Roads U.S. Naval Management team with a strong, streamlined group of technical experts who collectively will implement and evaluate the pilot study. This team of engineers, geologists, and scientists will be selected from McLaren/Hart, Inc. and New Jersey Institute of Technology's staff. A project organization chart is attached.

PROJECT ORGANIZATION CHART

Pilot Studies to Evaluate Enhancement of Product Recovery
Tow Way Fuel Facility
Naval Station, Roosevelt Roads
Ceiba, Puerto Rico



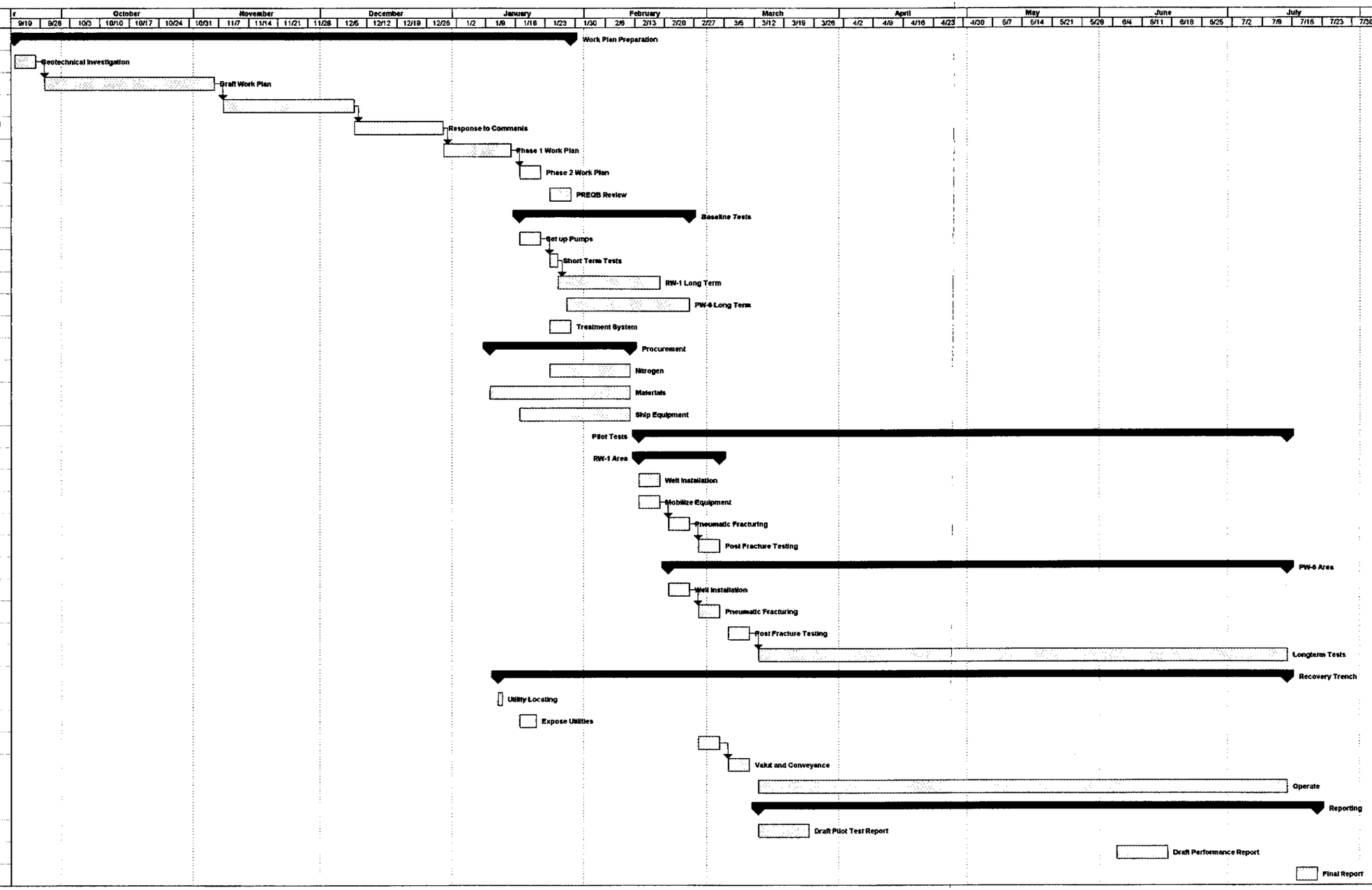
*J.A. Jones Environmental Services
** J.A. Jones Mgmt. Services
TBA: To Be Determined
NJIT: New Jersey Institute of Technology

G:\Clients\Gov't\Navy\RoRds\Phase2\OrgChart

8.0 PROJECT SCHEDULE

The Project Schedule is attached.

ID	Task Name	Duration	Start	Finish
1	**Work Plan Preparation**	**95d**	**Mon 9/20/99**	**Fri 1/28/00**
2	Geotechnical Investigation	5d	Mon 9/20/99	Fri 9/24/99
3	Draft Work Plan	30d	Mon 9/27/99	Fri 11/5/99
4	Navy Review	23d	Mon 11/8/99	Wed 12/8/99
5	Response to Comments	15d	Thu 12/9/99	Wed 12/29/99
6	Phase 1 Work Plan	12d	Thu 12/30/99	Fri 1/14/00
7	Phase 2 Work Plan	5d	Mon 1/17/00	Fri 1/21/00
8	PREQB Review	5d	Mon 1/24/00	Fri 1/28/00
9	**Baseline Tests**	**30d**	**Mon 1/17/00**	**Fri 2/25/00**
10	Set up Pumps	5d	Mon 1/17/00	Fri 1/21/00
11	Short Term Tests	2d	Mon 1/24/00	Tue 1/25/00
12	RW-1 Long Term	18d	Wed 1/26/00	Fri 2/18/00
13	PW-6 Long Term	21d	Fri 1/28/00	Fri 2/25/00
14	Treatment System	5d	Mon 1/24/00	Fri 1/28/00
15	**Procurement**	**25d**	**Mon 1/10/00**	**Fri 2/11/00**
16	Nitrogen	15d	Mon 1/24/00	Fri 2/11/00
17	Materials	25d	Mon 1/10/00	Fri 2/11/00
18	Ship Equipment	20d	Mon 1/17/00	Fri 2/11/00
19	**Pilot Tests**	**110d**	**Mon 2/14/00**	**Fri 7/14/00**
20	**RW-1 Area**	**15d**	**Mon 2/14/00**	**Fri 3/3/00**
21	Well Installation	5d	Mon 2/14/00	Fri 2/18/00
22	Mobilize Equipment	5d	Mon 2/14/00	Fri 2/18/00
23	Pneumatic Fracturing	5d	Mon 2/21/00	Fri 2/25/00
24	Post Fracture Testing	5d	Mon 2/28/00	Fri 3/3/00
25	**PW-6 Area**	**105d**	**Mon 2/21/00**	**Fri 7/14/00**
26	Well Installation	5d	Mon 2/21/00	Fri 2/25/00
27	Pneumatic Fracturing	5d	Mon 2/28/00	Fri 3/3/00
28	Post Fracture Testing	5d	Mon 3/6/00	Fri 3/10/00
29	Lonterm Tests	90d	Mon 3/13/00	Fri 7/14/00
30	**Recovery Trench**	**133d**	**Wed 1/12/00**	**Fri 7/14/00**
31	Utility Locating	1d	Wed 1/12/00	Wed 1/12/00
32	Expose Utilities	4d	Mon 1/17/00	Thu 1/20/00
33	Construct Trench	5d	Mon 2/28/00	Fri 3/3/00
34	Vault and Conveyance	5d	Mon 3/6/00	Fri 3/10/00
35	Operate	90d	Mon 3/13/00	Fri 7/14/00
36	**Reporting**	**95d**	**Mon 3/13/00**	**Fri 7/21/00**
37	Draft Pilot Test Report	10d	Mon 3/13/00	Fri 3/24/00
38	Draft Performance Report	10d	Mon 6/5/00	Fri 6/16/00
39	Final Report	5d	Mon 7/17/00	Fri 7/21/00



Project: Pilot Study 2b.mpp
Date: Mon 1/24/00

Task | Progress | Milestone | Summary

Table 1. Summary of Geotechnical Test Program
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Pilot Test Location	Sample Media	Boring ID	Laboratory Analysis	ASTM Designation	Number of Samples	Field Sample Collection
RW-1	Soil	• MH-SB-6 • MH-SB-8	• USCS Classification • Grain Size • Liquid Limit • Plastic Limit • Shrinkage Limit	• D2487-93 • D422-63 • D2217-85 • D4318-84 • D427	3 3 3 3 3	• Auger/ Drill Rig • Split spoon
PW-6	Soil	• MH-SB-4	• USCS Classification • Grain Size • Liquid Limit • Plastic Limit • Shrinkage Limit	• D2487-93 • D422-63 • D2217-85 • D4318-84 • D427	2 2 2 2 2	• Auger/ Drill Rig • Split spoon

RW- Recovery well location
PW- Pumping well location
USCS- Unified Soil Classification System
MH-SB-#- McLaren/Hart - soil boring- number

Table 2. **Atterberg Limit Test Results**
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Sample ID	Sample Depth	Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	Plasticity Index (%)	Shrinkage Index (%)	Classification**
MH-SB-8	18' - 20'	36.9 37.4	20.8 20.8	16.8	16.4	4	CL
MH-SB-4	18' - 18'10"	59.9	38.6	21.7	21.7	21.2	MH
MH-SB-4 cuttings*		40.6	21.4	19.2	19.2	8.3	CL
MH-SB-6	24' - 26'	45.8	29.4	17.9	16.4	11.5	ML
MH-SB-6	12' - 14'	80.9	34.7	14.2	46.2	20.5	CH

* Soil cuttings collected from a depth of 21' below grade surface using augers.

Represents plasticity chart classification for soil passing the No. 40 sieve, **not total soil sample.

MH-SB-# - McLaren/Hart soil boring number
CL - Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays
MH - Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
ML - Inorganic silts, very fine sands, rock flour, silty or clayey fine sands
CH - Inorganic clays of high plasticity, fat clays

Table 3. **Grain Size Data**
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Sample ID	Sample Depth	>No. 40 Sieve (%)	<No. 40 Sieve (%)
MH-SB-8	18' - 20'	23.8	76.2
MH-SB-4	18' - 18'10"	50.1	49.9
MH-SB-4 cuttings*		36.3	63.7
MH-SB-6	24' - 26'	53.1	46.9
MH-SB-6	12' - 14'	10.5	89.5

* Soil cuttings collected from a depth of 21' below grade surface using augers.

MH-SB-# - McLaren/Hart soil boring number

Table 4. **Volume Change Potential**
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Investigator*	MH-SB-8 18'-20'	MH-SB-4 18'-18'10"	MH-SB-4 cuttings**	MH-SB-6 24'-26'	MH-SB-6 12'-14'
Chen (1988)	M	M	M	M	H
Ranganatham and Satyanarayana (1965)	L	M	L	L-M	M
Raman (1967)	L-M	M	L-M	L-M	M-VH
Altmeyer (1955)	L	L	L	L	L
Holtz and Gibbs (1956)	L	L-M	M	L-M	M-VH
Chen (1965)	M	VH	H	H	VH
Snethen et al. (1977)	L	L-H	L	L	H

* Hall, H.A. "Investigation into fracture behavior and longevity of pneumatically fractured fine-grained formations", Master's Thesis, NJIT, Table 2.8, pg. 44, October 1995.
** Soil cuttings collected from a depth of 21' below grade surface using augers.

MH-SB-# - McLaren/Hart soil boring number
L- Low
M- Moderate
H- High
V- Very

Table 5. **Groundwater and Product Recovery Data**
September 1999
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well ID	Depth of well*	9/22/1999			9/23/1999			9/25/1999			9/30/1999		
		Depth to Product*	Depth to Water*	Apparent Product Thickness	Depth to Product*	Depth to Water*	Apparent Product Thickness	Depth to Product*	Depth to Water*	Apparent Product Thickness	Depth to Product*	Depth to Water*	Apparent Product Thickness
	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
MH-SB-1	18	NA	NA	NA	NA	NA	NA	7.70-18.00	0.00	10.40	7.70	18.05	10.35
MH-SB-3S	25	14.90	15.60	0.70	NA	NA	NA	11.50	12.50	1.00	5.20	8.00	2.80
MH-SB-3D	30	0.00	13.30	0.00	NA	NA	NA	0.00	11.60	0.00	10.90	11.05	0.15
MH-SB-3 Hole	25	NA	NA	NA	NA	NA	NA	10.90	14.10	3.20	NA	NA	NA
MH-SB-4	21.5	NA	NA	NA	6.63	12.03	5.40	9.43	15.63	6.20	9.44	15.36	5.92
MH-SB-4 Hole	21.5	NA	NA	NA	12.60	15.70	3.10	9.50	13.30	3.80	7.20	13.00	5.80
PW-06	NA	11.37	11.52	0.15	NA	NA	NA	11.40	11.52	0.03	NA	NA	NA
PW-05	26.9	9.15	9.30	0.15	NA	NA	NA	9.20	9.40	0.20	NA	NA	NA
PW-03	26.3	NA	NA	NA	NA	NA	NA	9.83	9.98	0.15	NA	NA	NA
UGW-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-4	27.7	NA	NA	NA	NA	NA	NA	3.87	3.97	0.10	NA	NA	NA
MW-3	22.2	NA	NA	NA	NA	NA	NA	10.27	10.35	0.08	NA	NA	NA
RW-1	35	0.00	16.25	0.00	0.00	16.59	0.08	0.00	16.50	0.00	NA	NA	NA
UGW-3	NA	17.57	18.2	0.63	17.55	18.17	0.62	0.00	17.62	0.00	NA	NA	NA
AW-1	36	16.95	21.1	4.15	16.95	21.20	4.25	16.95	21.15	4.20	NA	NA	NA
AW-2	31	16.14	19.81	3.67	16.26	19.69	3.43	16.24	19.64	3.40	NA	NA	NA
MTMW-1	40	17.83	21.68	3.85	17.91	21.65	3.74	17.93	21.68	3.75	NA	NA	NA
MTMW-2	NA	19.08	21.98	2.90	17.1	22.03	4.93	17.13	22.13	5.00	NA	NA	NA
MTMW-3	35	16.89	20.59	3.70	16.86	20.59	3.73	16.34	20.38	4.04	NA	NA	NA
MTMW-4	36	18.29	21.09	2.80	16.35	21.13	3.78	16.89	20.59	3.70	NA	NA	NA
DP-31A	18	NA	NA	NA	NA	NA	NA	0.00	13.00	0.00	NA	NA	NA
MH-SB-2	30	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-5	29	NA	NA	NA	NA	NA	NA	0.00	15.68	0.00	0.00	15.25	0.00
MH-SB-5 Hole	29	NA	NA	NA	0.00	19.80	0.00	0.00	16.70	0.00	NA	NA	NA
MH-SB-6 S	19	NA	NA	NA	NA	NA	NA	15.70	15.90	0.20	13.60	15.50	1.90
MH-SB-6 D	29	NA	NA	NA	NA	NA	NA	0.00	15.50	0.00	0.00	16.25	0.00
MH-SB-6 Hole	19	NA	NA	NA	16.01	16.31	0.30	14.91	15.91	1.00	12.51	14.21	1.70
MH-SB-7	13.5	NA	NA	NA	NA	NA	NA	0.00	0.00	0.00	NA	NA	NA
MH-SB-8	26	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

*- Level measured from grade
MH-SB-#, S,D- McLaren/Hart soil boring number, shallow well or deep well.
MH-SB-#, Hole- McLaren/Hart soil boring number, borehole common with shallow well.
PW- Pumping well
RW- Product recovery well
DP- Direct push monitoring well
MW- Monitoring well
AW- Mantech chemical oxidation pilot test delivery well
MTMW- Mantech chemical oxidation pilot test monitoring well
NA - Not available

Table 5. (cont.)

Groundwater and Product Recovery Data
October 1999
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well ID	Depth of well*	10/6/1999			10/13/1999			10/27/1999		
		Depth to Product*	Depth to Water*	Apparent Product Thickness	Depth to Product*	Depth to Water*	Apparent Product Thickness	Depth to Product*	Depth to Water*	Apparent Product Thickness
	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
MH-SB-1	18	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-3S	25	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-3D	30	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-3 Hole	25	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-4	21.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-4 Hole	21.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
PW-06	NA	15.02	15.52	0.50	10.87	11.62	0.75	9.12	9.92	0.80
PW-05	26.9	8.80	8.95	0.15	7.45	7.52	0.07	7.22	7.3	0.08
PW-03	26.3	9.38	9.48	0.10	7.83	7.93	0.10	4.03	4.13	0.10
UGW-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW-3	22.2	9.82	9.92	0.10	9.17	9.22	0.05	11.80	11.83	0.03
RW-1	35	14.86	14.88	0.02	14.16	14.17	0.01	13.45	13.68	0.23
UGW-3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
AW-1	36	NA	NA	NA	NA	NA	NA	NA	NA	NA
AW-2	31	NA	NA	NA	NA	NA	NA	NA	NA	NA
MTMW-1	40	NA	NA	NA	NA	NA	NA	NA	NA	NA
MTMW-2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MTMW-3	35	NA	NA	NA	NA	NA	NA	NA	NA	NA
MTMW-4	36	NA	NA	NA	NA	NA	NA	NA	NA	NA
DP-31A	18	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-2	30	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-5	29	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-5 Hole	29	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-6 S	19	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-6 D	29	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-6 Hole	19	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-7	13.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-8	26	NA	NA	NA	NA	NA	NA	NA	NA	NA

*- Level measured from grade
MH-SB-#, S,D- McLaren/Hart soil boring number, shallow well or deep well.
MH-SB-#, Hole- McLaren/Hart soil boring number, borehole common with shallow well.
PW- Pumping well
RW- Product recovery well
DP- Direct push monitoring well
MW- Monitoring well
AW- Mantech chemical oxidation pilot test delivery well
MTMW- Mantech chemical oxidation pilot test monitoring well
NA - Not available

Table 5. (cont.) **Groundwater and Product Recovery Data**
November 1999
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well ID	Depth of well*	11/3/1999			11/10/1999			12/1/1999		
		Depth to Product*	Depth to Water*	Apparent Product Thickness	Depth to Product*	Depth to Water*	Apparent Product Thickness	Depth to Product*	Depth to Water*	Apparent Product Thickness
	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)
MH-SB-1	18	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-3S	25	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-3D	30	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-3 Hole	25	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-4	21.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-4 Hole	21.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
PW-06	NA	9.32	10.12	0.80	9.42	10.22	0.80	4.92	4.92	Sheen
PW-05	26.9	7.20	7.31	0.11	7.13	7.25	0.12	4.10	4.15	0.05
PW-03	26.3	7.37	7.37	0.00	7.46	7.46	0.00	3.43	3.43	0.00
UGW-1	NA	NA	NA	NA	NA	NA	NA	6.10	6.20	0.10
MW-4	NA	NA	NA	NA	NA	NA	NA	0.52	0.77	0.25
MW-3	22.2	8.27	8.27	0.00	8.45	8.45	0.00	2.97	2.97	0.00
RW-1	35	12.45	12.63	0.18	12.15	12.4	0.25	6.35	6.50	0.15
UGW-3	NA	NA	NA	NA	15.32	15.97	0.65	12.12	12.77	0.65
AW-1	36	NA	NA	NA	14.70	18.55	3.85	NA	NA	NA
AW-2	31	NA	NA	NA	12.69	14.59	1.9	NA	NA	NA
MTMW-1	40	NA	NA	NA	15.73	18.93	3.2	NA	NA	NA
MTMW-2	NA	NA	NA	NA	13.38	21.48	8.1	NA	NA	NA
MTMW-3	35	NA	NA	NA	17.39	17.84	0.45	NA	NA	NA
MTMW-4	36	NA	NA	NA	12.59	20.64	8.05	NA	NA	NA
DP-31A	18	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-2	30	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-5	29	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-5 Hole	29	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-6 S	19	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-6 D	29	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-6 Hole	19	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-7	13.5	NA	NA	NA	NA	NA	NA	NA	NA	NA
MH-SB-8	26	NA	NA	NA	NA	NA	NA	NA	NA	NA

*- Level measured from grade
MH-SB-#, S,D- McLaren/Hart soil boring number, shallow well or deep well.
MH-SB-#, Hole- McLaren/Hart soil boring number, borehole common with shallow well.
PW- Pumping well
RW- Product recovery well
DP- Direct push monitoring well
MW- Monitoring well
AW- Mantech chemical oxidation pilot test delivery well
MTMW- Mantech chemical oxidation pilot test monitoring well
NA - Not available

Table 6. **Summary of Construction Materials for Pneumatic Fracturing/Product Recovery and Monitoring Wells**
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well Type and ID	Depth bgs (ft)	Screen Interval bgs (ft)	Material of Construction/Construction Notes	Design Reference
Product Recovery Well			• 1-2" diameter, 2-4" diameter threaded Sch. 40 PVC well caps (M) w/ barbed fitting	NA
New:			• 1-4" diameter, 6" long Sch. 40 PVC pipe (one end M)	
• MTMW-4	36	16 to 36	• 1-4" diameter PVC well cap w/ three fittings (CEE*)	
Existing:			• 1-2' x 2" diameter Sch. 40 PVC pipe (one end F) riser	
• RW-1	30	10 to 30	• 2-2' x 4" diameter Sch. 40 PVC pipe (one end F) riser	
• PW-06	NA	NA	• 1-4" x 4" x 2"; 2-2" x 2" x 1/2"; 6-1" x 1" x 1/2"; 3-1/2" x 1/2" x 1/2" Sch. 40 PVC tees	
			• 13-1/2" BV; 3-1" BV; 1-1" CV; 1-1" strainer	
			• 1-2" and 2-4" flexible sleeve pipe coupling	
Fracture Well			• 8-36' x 21/2" diameter Sch. 40 PVC pipe (to keep boreholes open)	Figure 11
• FW-1,2,3,4,5,7,8,9	35	14 to 34	• 2-20' x 21/2" diameter Sch. 40 PVC screen	Figure 12
• FW-6	≤ 35	14 to 34	• 1-20' x 4" diameter Sch. 40 PVC screen	Figure 15
• ERW-1	≤ 35	14 to 34	• 2-16' x 21/2" diameter Sch. 40 PVC riser	Figure 16
• ERW-2	35	14 to 34	• 1-16' x 4" diameter Sch. 40 PVC riser	
			• 2-21/2" diameter Sch. 40 PVC well cap (M) with barbed fittings	
			• 2-21/2" diameter Sch. 40 PVC well cap w/ three fittings	
			• 1-21/2" x 21/2" x 2"; 6-2" x 2" x 1/2"; 1-4" x 4" x 2"; 3-1" x 1" x 1/2"; 3-1/2" x 1/2" x 1/2" tees	
			• 13-1/2" BV; 3-1" BV; 3-2" BV; 3-1" CV; 3-1" strainer	
			• 2-21/2" and 1-4" flexible sleeve piping	
Monitoring Well				
PW-6 Area:				NA
• PW-03	23	NA	• 3-4" diameter threaded PVC well cap (M)	
• PW-05	23	NA	• 3-4" diameter Sch. 40 PVC coupling	
• MW-03	22	NA	• 3-4" diameter Sch. 40 PVC Male adapter (NPTx Socket)	
			• 3-2' x 4" diameter Sch. 40 PVC riser (F x F)	

Table 6 (cont.). **Summary of Construction Details for Pneumatic Fracturing/Product Recovery and Monitoring Wells**
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well Type and ID	Depth bgs (ft)	Screen Interval bgs (ft)	Material of Construction/Construction Notes	Design Reference
RW-1 Area:				NA
• AW-1	35.5	20.5-35.5	• 5-2" diameter Sch. 40 PVC coupling	
• AW-2	31	16-31	• 5-2" x 2' Sch. 40 PVC pipe	
• MTMW-2	38	18-38	• 5-2" diameter Sch. 40 PVC Male adapter (NPTx Socket)	
• MTMW-1	39.5	19.5-39.5	• 5-2" diameter threaded PVC well cap (M)	
• MTMW-3	35	15-35		

*Can be obtained from Clean Environmental Equipment.

RW- Recovery Well
PW- Pumping Well
MTMW- Mantech chemical oxidation pilot test monitoring well
AW- Mantech chemical oxidation pilot test delivery well
FW- Pneumatic fracture well
ERW- Extended radius well
BV- Ball valve
CV- Check valve
bgs- Below ground surface
NA- Not available

Table 7. Summary of Pre-Fracture and Post-Fracture Product Recovery Evaluation Program
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Pilot Test Location	Test Well ID	Projected Duration for Test	Parameters Measured	Frequency of Measurement	Field Equipment
RW-1					• Oil/water interface probe
• Pre	• FW-6 • MTMW-4 • RW-1	• 30 days	• Total fluids removed • Total product removed	• Daily, weekly, or as conditions allow	• M-scope • Pneumatic pump • Bailers
• Post	• FW-6 • MTMW-4 • RW-1	• 90-120 days	• Total fluids removed • Total product removed	• Daily, weekly, or as conditions allow	
PW-6					• Oil/water interface probe
• Pre	• PW-06 • ERW-1 • ERW-2	• 30 days • Not installed • Not installed	• Total fluids removed • Total product removed	• Daily, weekly, or as conditions allow	• M-scope • Pneumatic and vacuum pump • Bailers
• Post	• PW-06 • ERW-1 • ERW-2	• 90-120 days	• Total fluids removed • Total product removed	• Daily, weekly, or as conditions allow	

FW- Pneumatic Fracture Well
PW- Pumping Well
RW- Recovery Well
ERW- Extended Radius Well
MTMW- Mantech Chemical Oxidation Pilot Test Monitoring Well

Table 8. RW-1 Short Term Test Schedule
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well I.D.	Well Use	Depth (ft)	Screen Interval (ft)	SWL, 9/25/99 (ft)	Short Term Tests (1,2&3) Pump Intake (ft)	Duration (Hrs)	Pumping Rate (gpm)	Transducer Depth (ft)	Water Level Measurements Frequency (Hr)	Method
RW-1	PW	30	10-30	16.5	[1] 19	4	TBD	29	1	Data Logger/M-Scope
					[2] 22	4	TBD			
					[3] 27	4	TBD			
AW-2	OW	31	16-31	19.64	NA	4	TBD	30	1	Data Logger/M-Scope
UGW-3	OW	35.4	25.4-35.4	17.62	NA	4	TBD	NA	1	M-Scope
MTMW-1	OW	39.5	19.5-39.5	21.68	NA	4	TBD	NA	1	M-Scope
MTMW-2	OW	38	18-38	22.13	NA	4	TBD	NA	1	M-Scope
MTMW-3	OW	35	15-35	20.38	NA	4	TBD	NA	1	M-Scope
AW-1	OW	35.5	20-35.5	21.15	NA	4	TBD	NA	1	M-Scope
MTMW-4	OW	36	15-35	20.59	NA	4	TBD	NA	1	M-Scope

NA- Not Applicable
SWL- Static Water Level
TBD- To be Determined
PW- Pumping Well
OW- Observation/Monitoring Well
AW- Mantech chemical oxidation pilot test delivery well
MTMW- Mantech chemical oxidation pilot test monitoring well

Table 9. **MTMW-4 Short Term Test Schedule**
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well I.D.	Well Use	Depth (ft)	Screen Interval (ft)	SWL, 9/25/99 (ft)	Short Term Tests (1,2&3)			Transducer Depth (ft)	Water Level Measurements	
					Pump Intake (ft)	Duration (Hrs)	Pumping Rate (gpm)		Frequency (Hr)	Method
MTMW-4	PW	36	15-35	20.59	[1] 22	4	TBD	34	1	Data Logger/M-Scope
					[2] 27	4	TBD			
					[3] 32	4	TBD			
AW-2	OW	31	16-31	19.64	NA	4	TBD	30	1	Data Logger/M-Scope
UGW-3	OW	35.4	23.4-35.4	17.62	NA	4	TBD	NA	1	M-Scope
MTMW-1	OW	39.5	19.5-39.5	21.68	NA	4	TBD	NA	1	M-Scope
MTMW-2	OW	38	18-38	22.13	NA	4	TBD	NA	1	M-Scope
MTMW-3	OW	35	15-35	20.38	NA	4	TBD	NA	1	M-Scope
AW-1	OW	35.5	20-35.5	21.15	NA	4	TBD	NA	1	M-Scope
RW-1	OW	30	10-30	16.5	NA	4	TBD	NA	1	M-Scope

NA- Not Applicable
SWL- Static Water Level
TBD- To be Determined
OW- Observation/Monitoring Well
AW- Mantech chemical oxidation pilot test delivery well
MTMW- Mantech chemical oxidation pilot test monitoring well

Table 10. Summary of Pneumatic Fracturing Program in RW-1 Pilot Test Area
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

PF Well ID	Depth of PF Well (ft)	Proposed Treatment Zone (bgs)	Number of PF Injections	Comments
FW-1	35	16 to 30	7	• Directional fracturing towards MTMW-4, • Instrument wells AW-2, MTMW-2, MTMW-4, and RW-1, • See Figure 10.
FW-2	35	16 to 30	7	• Directional fracturing towards MTMW-4, • Instrument wells AW-2, MTMW-2, MTMW-4, and RW-1, • See Figure 10.
FW-3	35	16 to 30	7	• Radial fracturing towards RW-1 and MTMW-4, • Instrument wells AW-2, MTMW-4, and RW-1, • See Figure 10.
FW-4	35	16 to 30	7	• Grout MH-SB-5, • Directional fracturing towards RW-1, • Instrument wells AW-2, MTMW-4, and RW-1, • See Figure 10.
FW-5	35	16 to 30	7	• Directional fracturing towards RW-1, • Instrument wells AW-2, MTMW-4, and RW-1, • See Figure 10.
FW-6	35	16 to 30	7	• Radial fracturing between AW-1, AW-2, MTMW-2, and MTMW-4, • Instrument wells AW-1, AW-2, MTMW-1, and MTMW-3, • See Figure 10.

FW- Pneumatic fracture well
PF- Pneumatic fracture
MTMW- Mantech chemical oxidation pilot test monitoring well
AW- Mantech chemical oxidation pilot test delivery well
RW- Prodect recovery well
bgs- Below ground surface
Borehole Construction- 3 1/2 Solid stem augers or approved drilling method.
- Open borehole to depth specified by client representative.
- Install 2 1/2" I.D. PVC pipe to keep borehole open.

Table 11. PW-06 Short Term Test Schedule
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

Well I.D.	Well Use	Depth (ft)	Screen Interval (ft)	SWL, 9/25/99 (ft)	Short Term Tests (1,2&3)			Transducer Depth (ft)	Water Level Measurements	
					Pump Intake (ft)	Duration (Hrs)	Pumping Rate (gpm)		Frequency (Hr)	Method
PW-06	PW	Not Available	Not Available	11.52	[1] 19-22	4	TBD	1' above bottom of well	1	Data Logger/M-Scope
					[2] 25	4	TBD			
					[3] 30	4	TBD			
PW-04	OW	Not Available	Not Available	Not Available	NA	4	TBD	1' above bottom of well	1	Data Logger/M-Scope
UGW-1	OW	Not Available	Not Available	Not Available	NA	4	TBD	NA	1	M-Scope
PW-05	OW	Not Available	Not Available	9.4	NA	4	TBD	NA	1	M-Scope
PW-03	OW	Not Available	Not Available	9.98	NA	4	TBD	NA	1	M-Scope
MW-03	OW	Not Available	Not Available	Not Available	NA	4	TBD	NA	1	M-Scope

NA- Not Applicable
SWL- Static Water Level
TBD- To be Determined
PW- Pumping Well
OW- Observation/Monitoring Well

Table 12. PW-06 Short VER Test Schedule
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

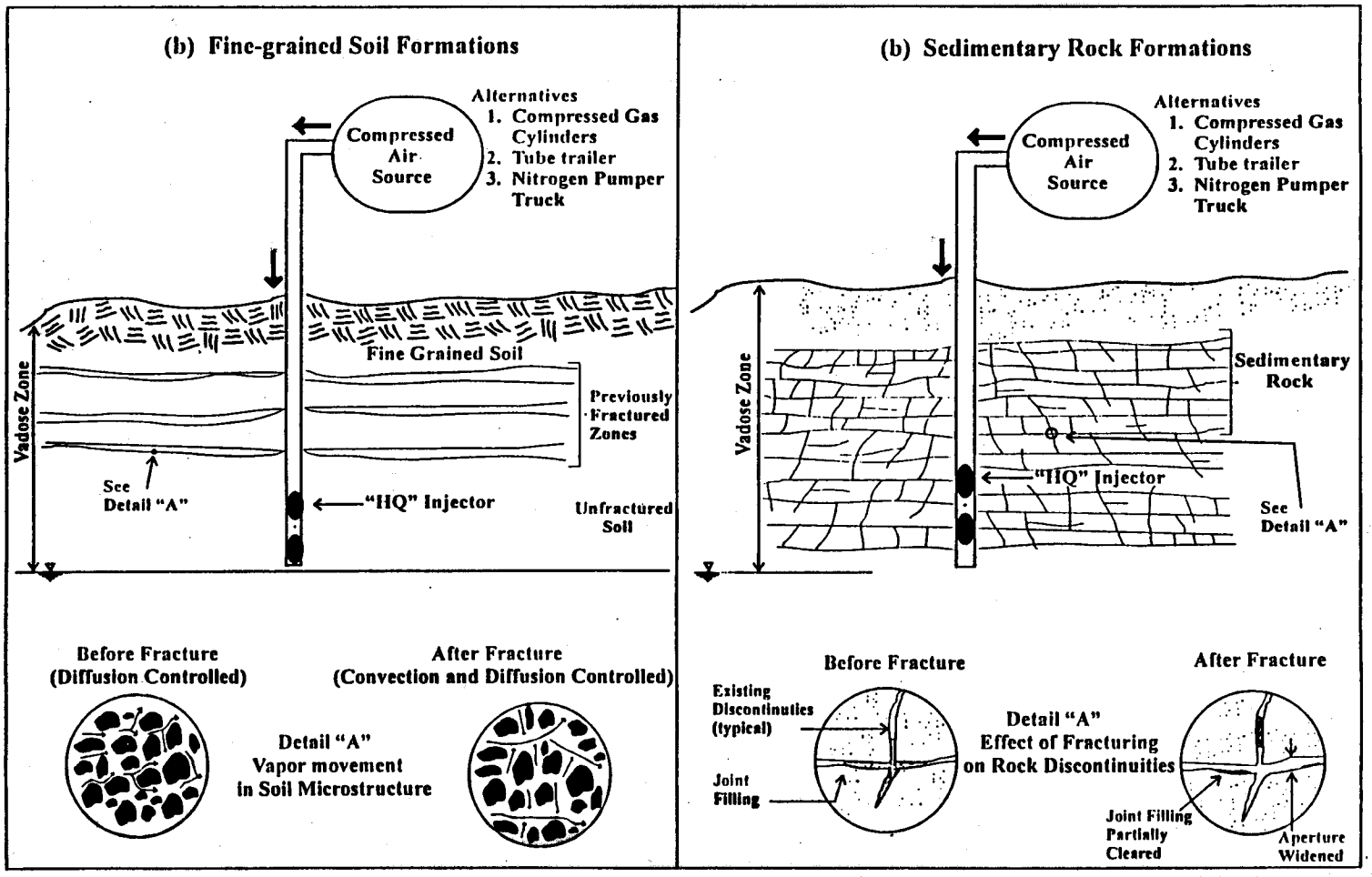
Well I.D.	Well Use	Depth (ft)	Screen Interval (ft)	SWL, 9/25/99 (ft)	Short VER Tests (1,2&3)			Transducer Depth (ft)	Water Level Measurements	
					Pump Intake (inches of mercury)	Duration (Hrs)	Pumping Rate (gpm)		Frequency (Hr)	Method
PW-06	PW	Not Available	Not Available	11.52	[1] 15	4	TBD	1' above bottom of well	1	Data Logger/M-Scope
					[2] 20	4	TBD			
					[3] 25	4	TBD			
PW-04	OW	Not Available	Not Available	Not Available	NA	4	TBD	1' above bottom of well	1	Data Logger/M-Scope
UGW-1	OW	Not Available	Not Available	Not Available	NA	4	TBD	NA	1	M-Scope
PW-05	OW	Not Available	Not Available	9.4	NA	4	TBD	NA	1	M-Scope
PW-03	OW	Not Available	Not Available	9.98	NA	4	TBD	NA	1	M-Scope
MW-03	OW	Not Available	Not Available	Not Available	NA	4	TBD	NA	1	M-Scope

NA- Not Applicable
SWL- Static Water Level
TBD- To be Determined
PW- Pumping Well
OW- Observation/Monitoring Well

Table 13. Summary of Pneumatic Fracturing Program in PW-6 Pilot Test Area
Tow Way Fuel Facility, Roosevelt Roads, Puerto Rico

PF Well ID	Depth of PF Well (ft)	Proposed PF Treatment Zone (bgs)	Number of PF Injections	Comments
FW-7	35	16 to 30	7	• Grout MH-SB-3 • Directional fracture towards PW-06 • Instrument PW-03, PW-05, and PW-06 • See Figure 14
FW-8	35	16 to 30	7	• Radial fracture towards PW-06 • Instrument wells PW-06 and PW-05 • See Figure 14
FW-9	35	16 to 30	7	• Directional fracture towards PW-06 • Instrument PW-03, PW-05 and PW-06 • See Figure 14
ERW-1	< 35*	16 to 30	7	• Radial fracture • Instrument well PW-05 • See Figure 14
ERW-2	< 35*	16 to 30	7	• Radial fracture • Instrument well PW-05 • See Figure 14

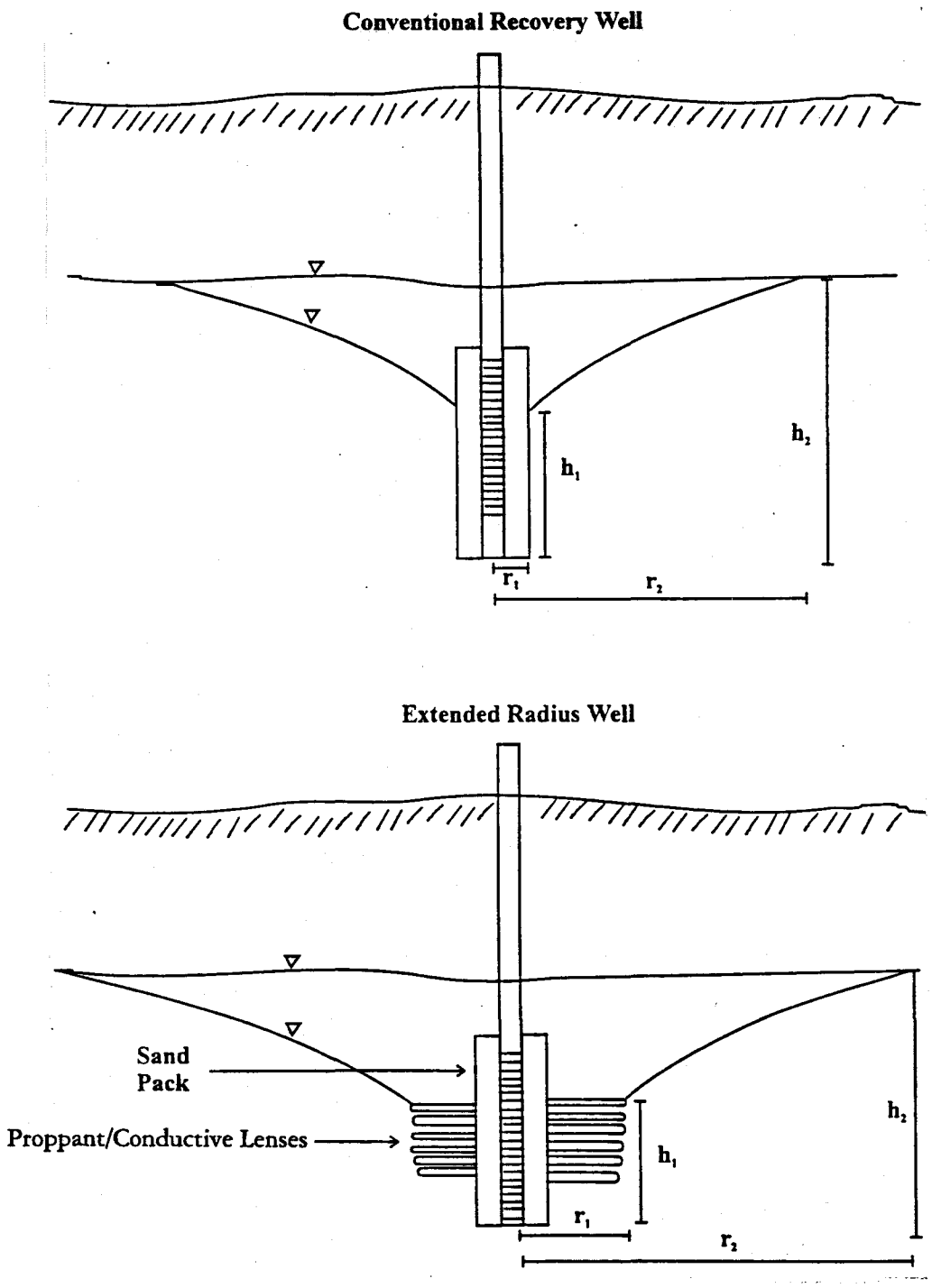
MH-SB-# - McLaren/Hart soil boring number
ERW- Extended radius well
FW- Fracture well
PW- Pumping well
bgs- Below ground surface
Borehole
Construction- 3 1/2 Solid stem augers or approved drilling method.
- Open borehole to depth specified by client representative.
- Install 2 1/2" I.D. PVC pipe to keep borehole open.
*- Final depth depends on product zone seen in split spoon samples at this location.



SOURCE: SCHURING AND CHAN, 1992

FIGURE 1	
PNEUMATIC FRACTURING CONCEPT	
ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO	
McLaren Hart INC.	
DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 10/27/99

DWG: 45800902 10/27/99



SOURCE: GALBRAITH, 1999.

FIGURE 2

CONCEPT OF CONVENTIONAL WELL VERSUS EXTENDED WELL

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 10/27/99

DWG: 45800903 10/27/99

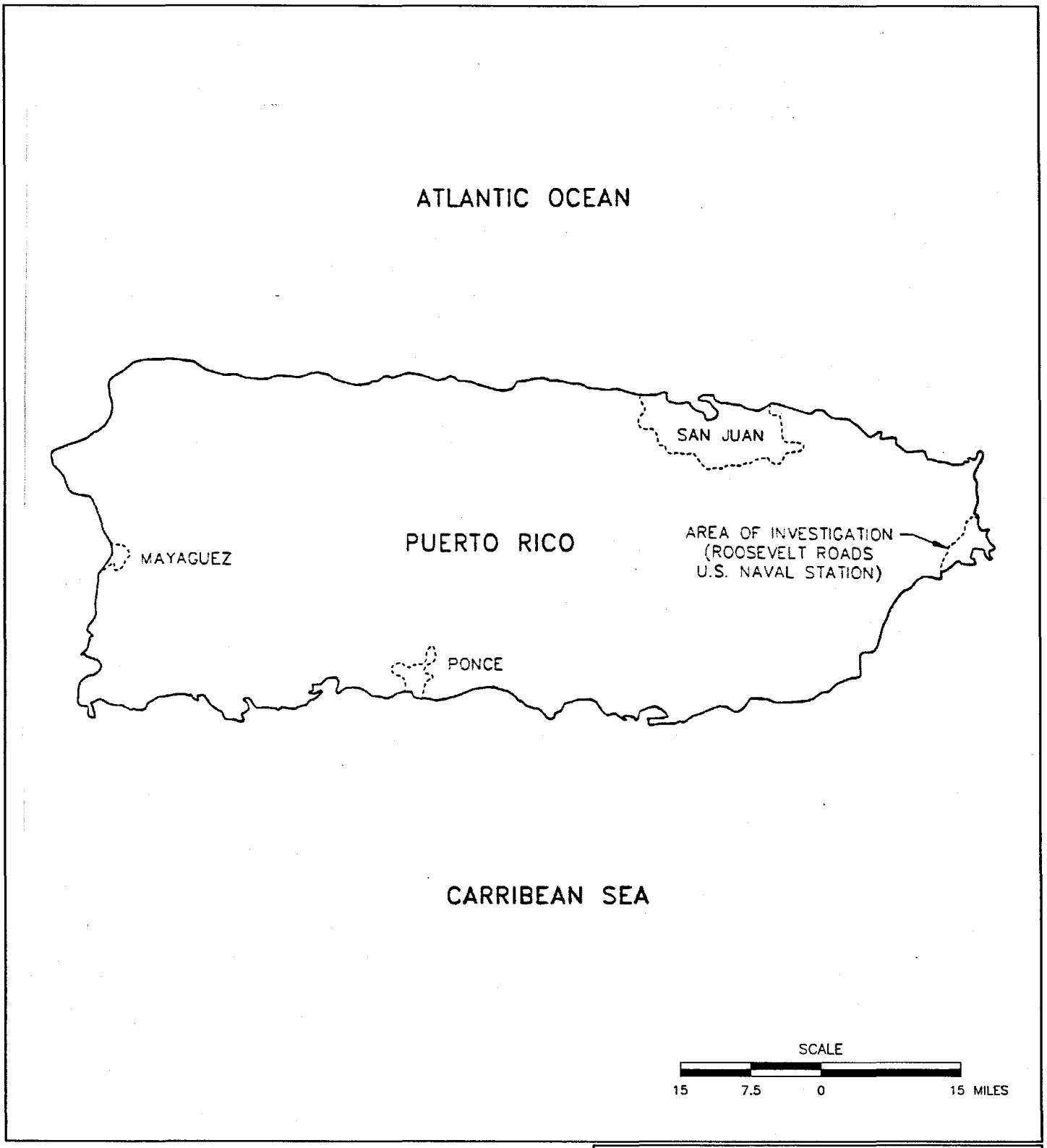


FIGURE 3

SITE LOCATION MAP

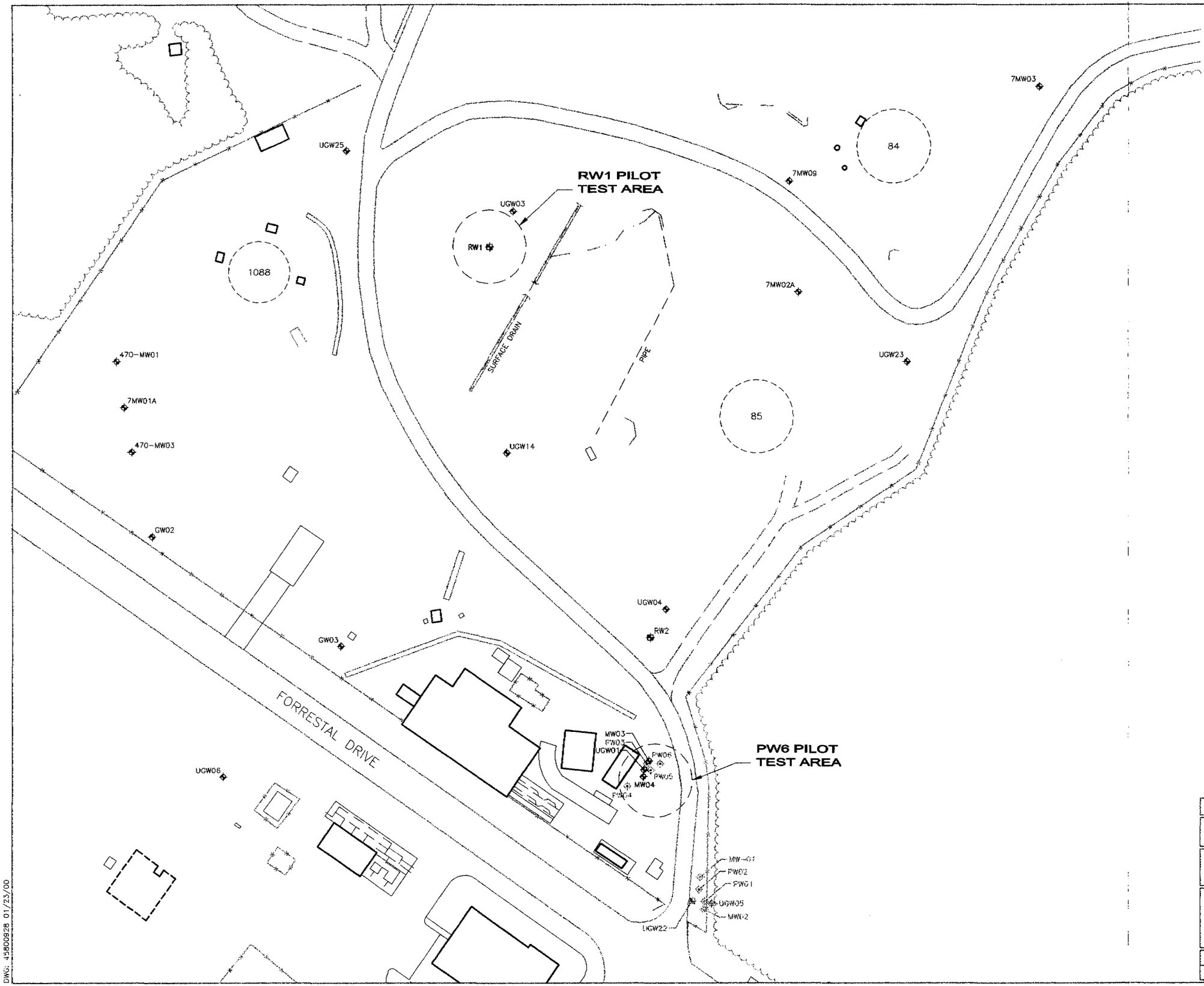
ROOSEVELT ROADS U.S. NAVAL STATION –
TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 10/27/99

QUADRANGLE LOCATION

DWG: 45800901 10/27/99



N
W E
S

LEGEND

- FENCE
- VEGETATION
- EXISTING MONITORING WELL LOCATION
- McLAREN/HART PRODUCT RECOVERY WELL LOCATION
- TERRAVAC PRODUCT RECOVERY WELL LOCATION
- APPROXIMATE LOCATION OF PILOT TEST AREAS

SCALE

80 40 0 80 FEET

FIGURE 4

SITE PLAN SHOWING PROPOSED LOCATION OF PILOT TEST AREAS

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800928 01/23/00

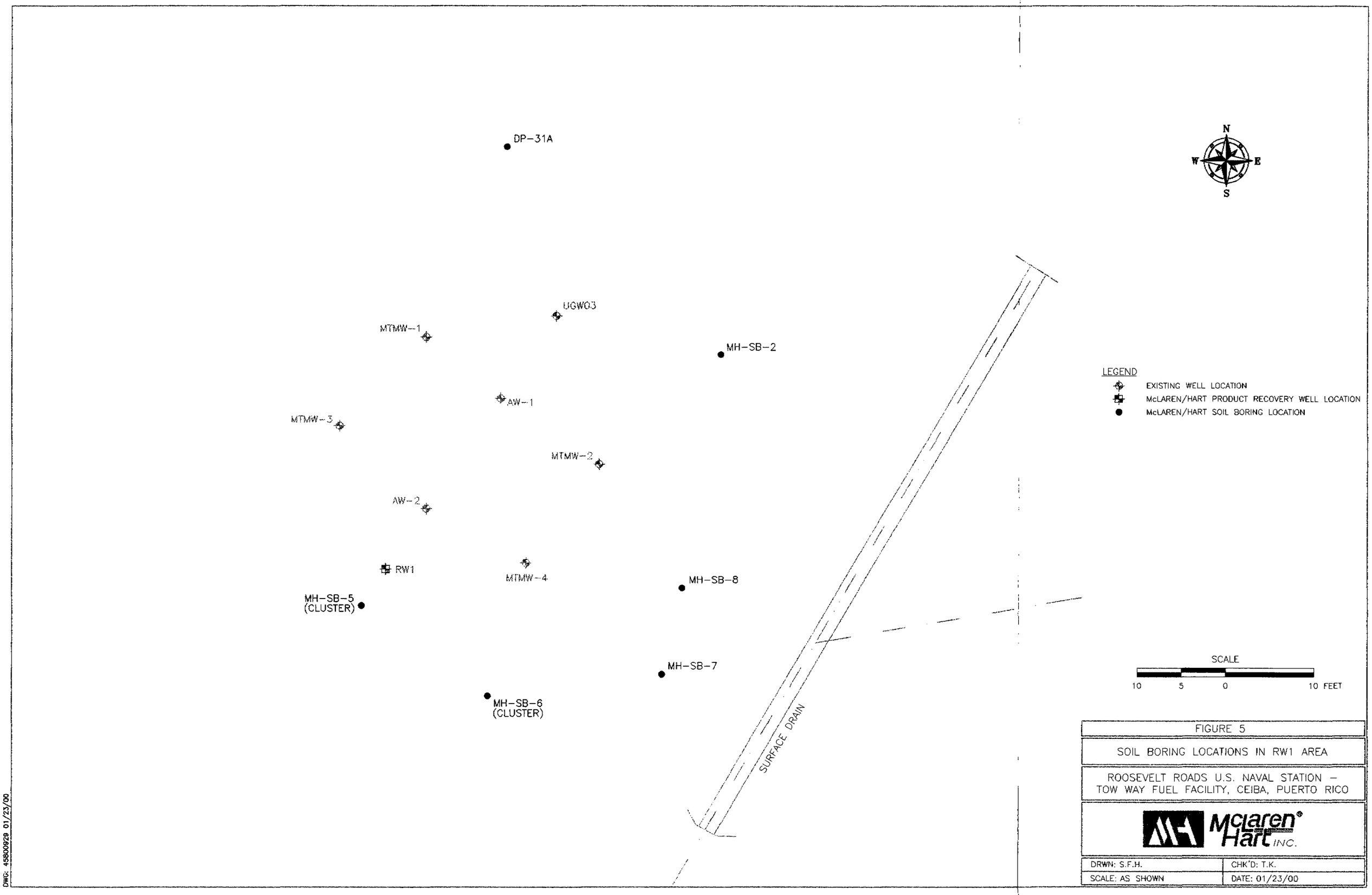


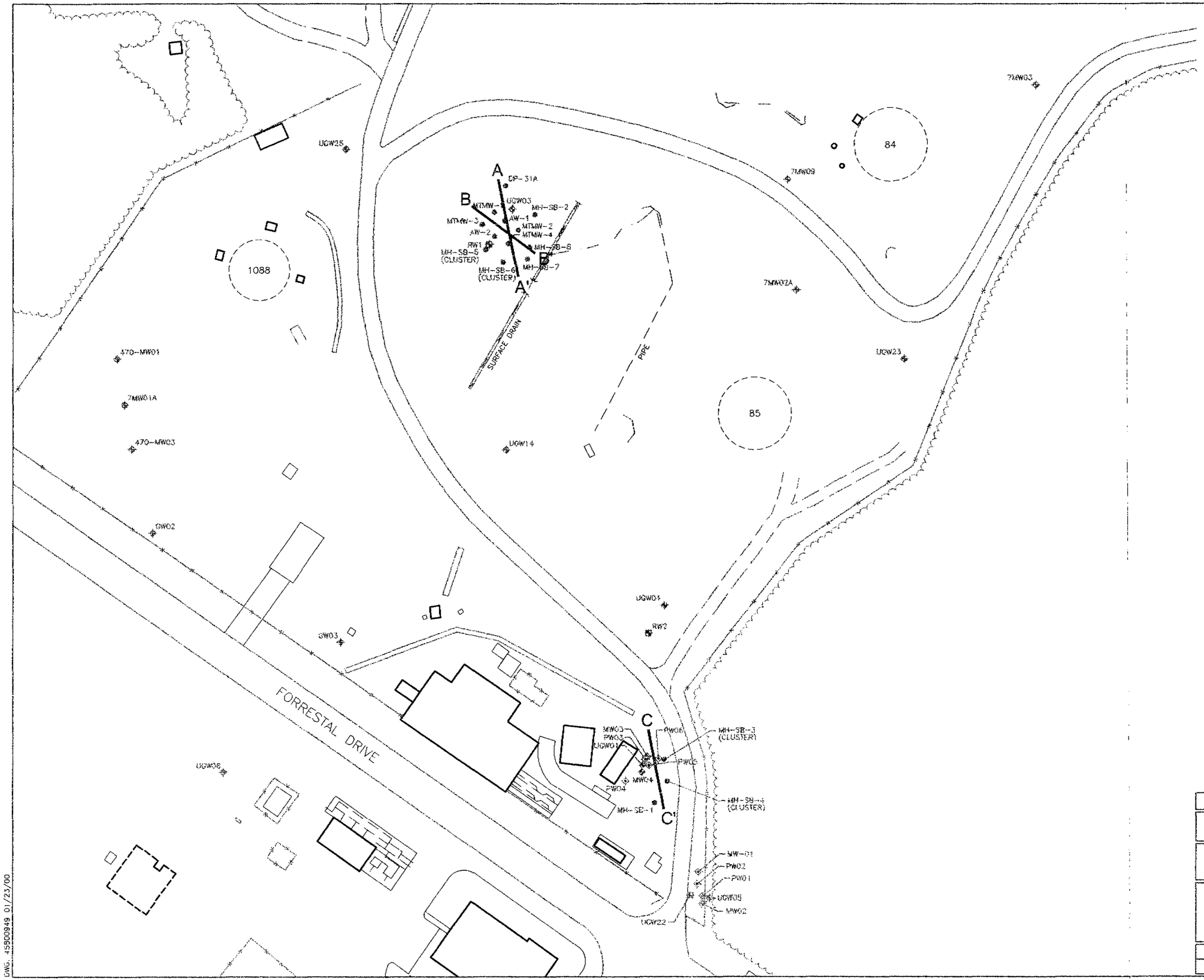
FIGURE 5

SOIL BORING LOCATIONS IN RW1 AREA

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45600929 01/23/00



LEGEND

- FENCE
- VEGETATION
- EXISTING MONITORING WELL LOCATION
- McLAREN/HART PRODUCT RECOVERY WELL LOCATION
- TERRAVAC PRODUCT RECOVERY WELL LOCATION
- McLAREN/HART SOIL BORING LOCATION
- CROSS-SECTION LOCATION

SCALE

80 40 0 80 FEET

FIGURE 6

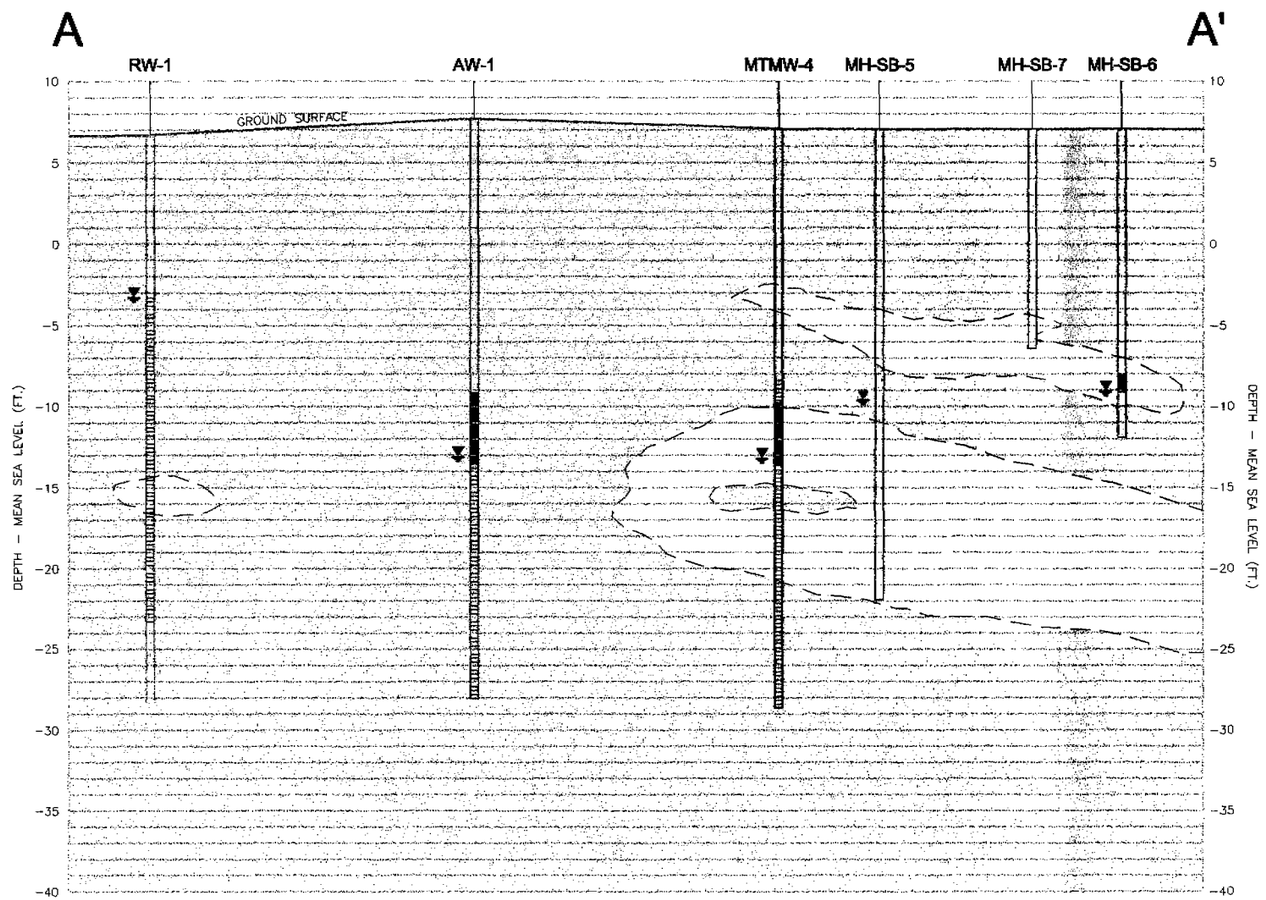
GEOLOGIC CROSS-SECTION LOCATION MAP

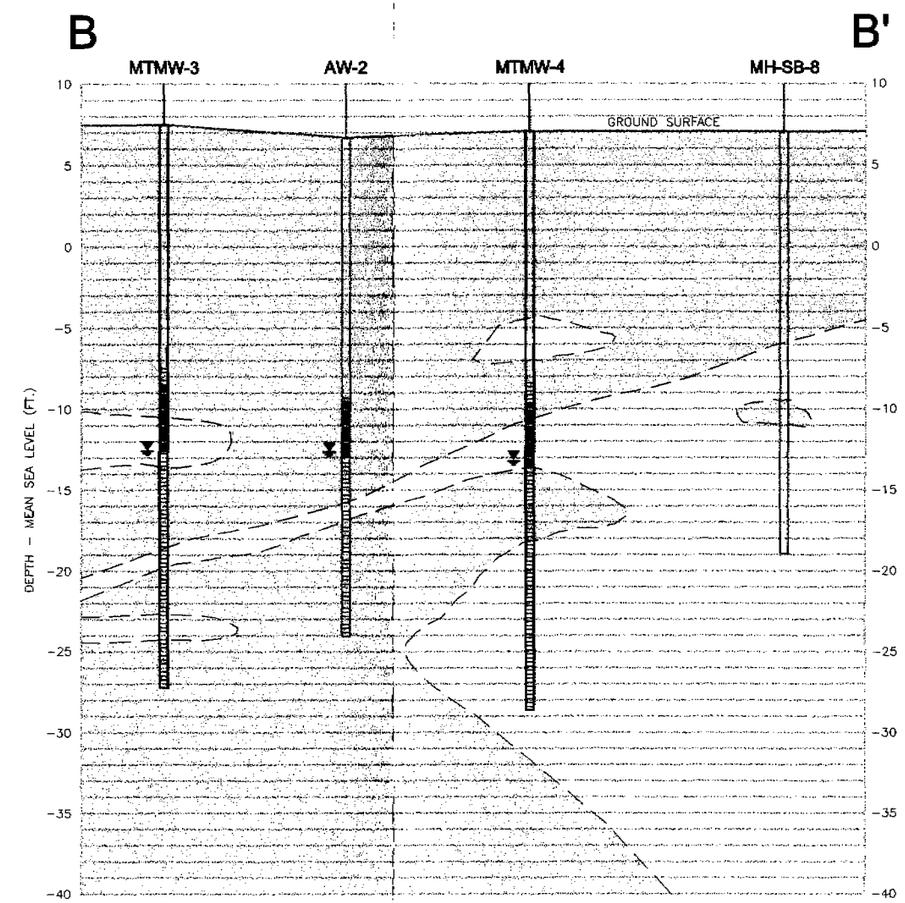
ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG. 45800949 01/23/00





LEGEND

- SCREENED INTERVAL
- PETROLEUM PRODUCT ZONE
- WATER TABLE
- SAND & GRAVEL
- CLAY & SILT

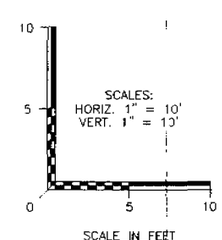


FIGURE 7

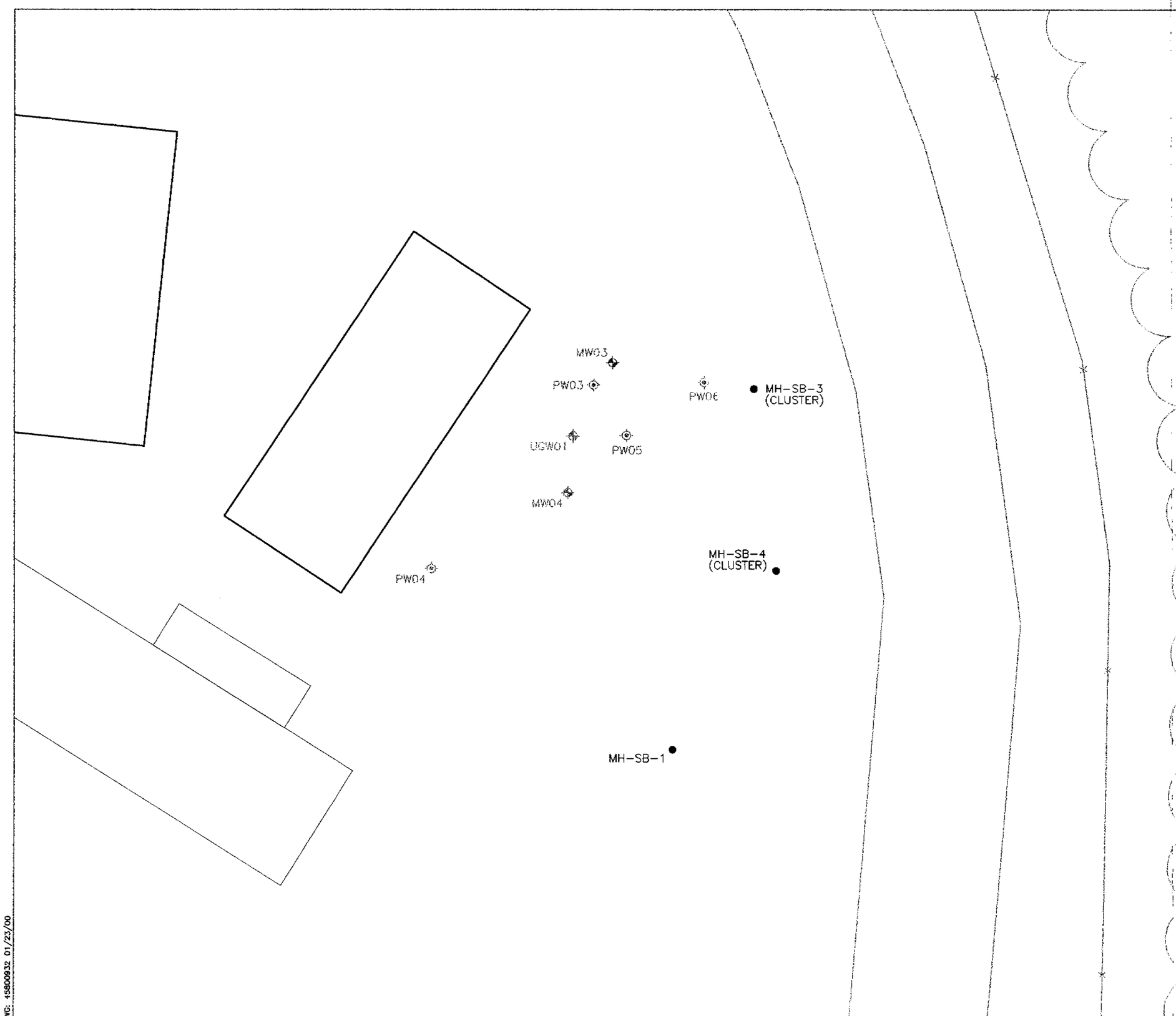
GEOLOGIC CROSS–SECTIONS
A–A' AND B–B' FOR RW1 AREA

ROOSEVELT ROADS U.S. NAVAL STATION –
TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800931 01/23/00



LEGEND

- FENCE
- VEGETATION
- EXISTING WELL LOCATION
- TERRAVAC PRODUCT RECOVERY WELL LOCATION
- McLAREN/HART SOIL BORING LOCATION

SCALE

10 5 0 10 FEET

FIGURE 8

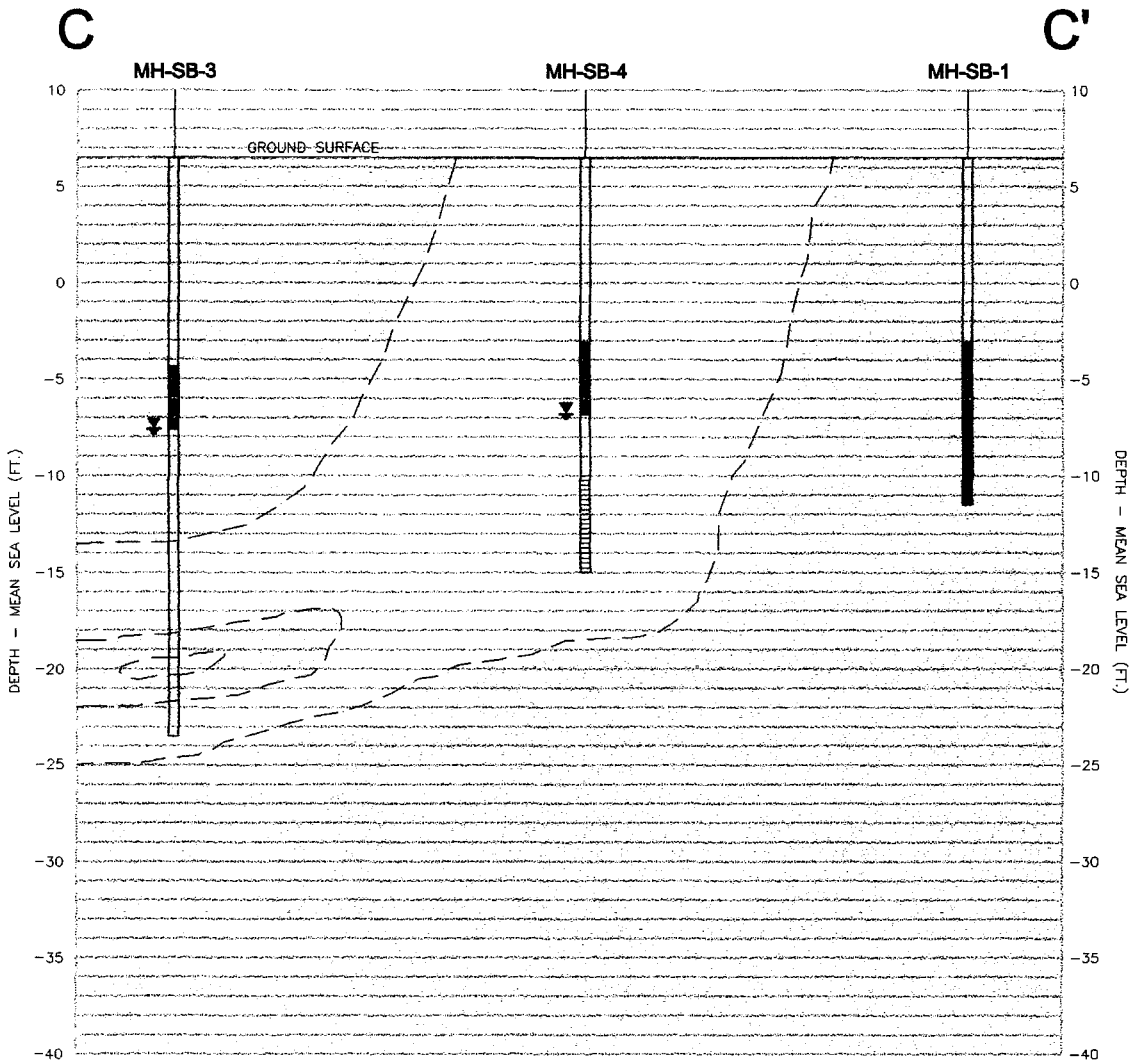
SOIL BORING LOCATIONS IN PW6 AREA

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

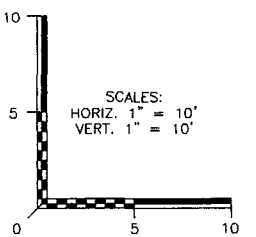
DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800932 01/23/00



LEGEND

- SCREENED INTERVAL
- PETROLEUM PRODUCT ZONE
- WATER TABLE
- SAND & GRAVEL
- CLAY & SILT



SCALE IN FEET

FIGURE 9

GEOLOGIC CROSS-SECTION
C-C' FOR PW6 AREA

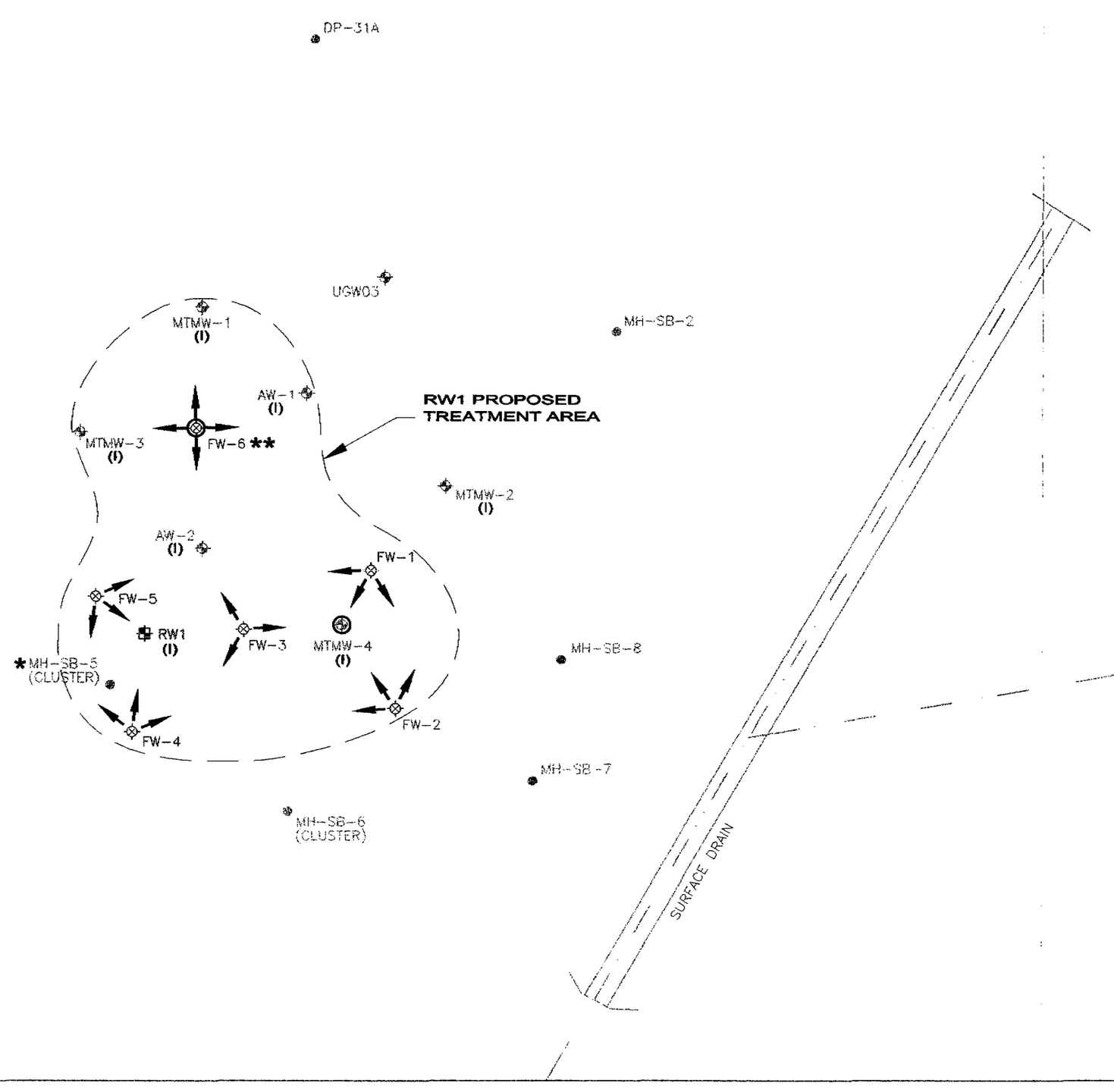
ROOSEVELT ROADS U.S. NAVAL STATION –
TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

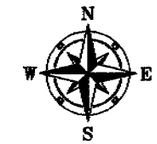
McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800933 01/23/00

WELLS		DISTANCE (FT)
TO	FROM	
RW-1	FW-1	19
UGW-03	FW-1	24
RW-1	FW-2	21
UGW-03	FW-2	35
RW-1	FW-3	8
UGW-03	FW-3	31
RW-1	FW-4	8
UGW-03	FW-4	42
RW-1	FW-5	5
UGW-03	FW-5	35
RW-1	FW-6	17
UGW-03	FW-6	20





LEGEND

- EXISTING WELL LOCATION
- McLAREN/HART PRODUCT RECOVERY WELL LOCATION
- MTMW-4 USED AS A PRODUCT RECOVERY WELL
- McLAREN/HART SOIL BORING LOCATION
- RADIAL PNEUMATIC FRACTURE LOCATION
- DIRECTIONAL PNEUMATIC FRACTURE LOCATION
- (I) WELLS INSTRUMENTED DURING FRACTURING
- * SOIL BORING LOCATION TO BE GROUTED IN PLACE
- ** LOCATION CONVERTED TO PRODUCT RECOVERY WELL AFTER FRACTURING (SEE FIGURE 12 AND NOTE 6)
- ESTIMATED TREATMENT AREA = 850 ft^2

SCALE

10 5 0 10 FEET

FIGURE 10

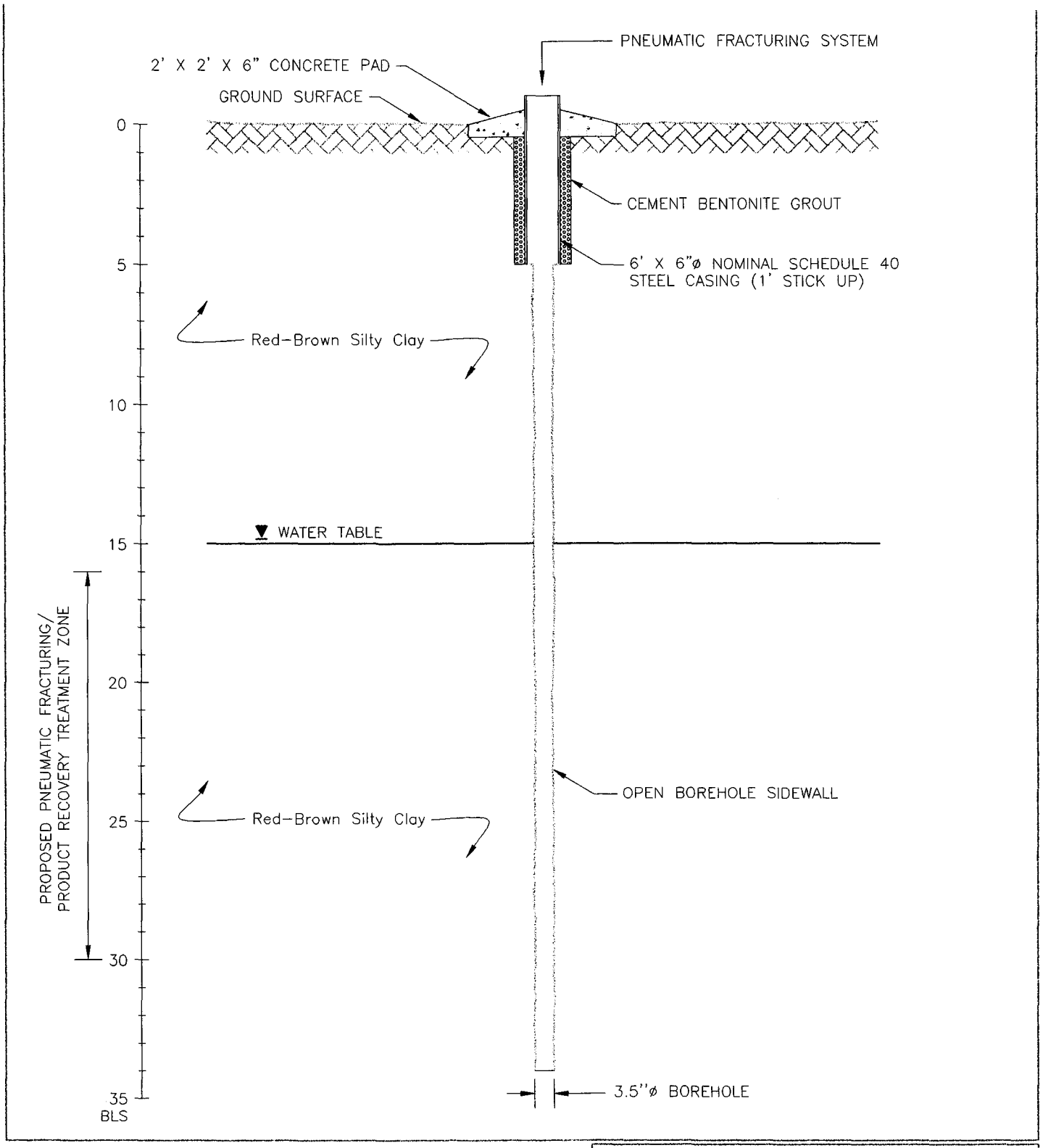
LAYOUT OF PRODUCT RECOVERY AND MONITORING WELLS IN RW1 AREA

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800936 01/23/00



NOTES

1) ALL FINAL DEPTHS WILL BE DETERMINED AT TIME OF INSTALLATION BY CLIENT REPRESENTATIVE.
2) LOCATE BOTTOM OF FILL ZONE USING GEOPROBE (OPTIONAL).
3) DRILL/AUGER A 10"ø BOREHOLE TO 5' BELOW GRADE.
4) PLACE 6' X 6"ø STEEL CASING IN BOREHOLE. COMPLETE SETTING OF CASING AS SHOWN ON FIGURE.
5) 24 HOURS LATER DRILL/CORE A 3.5"ø BOREHOLE 4' PASS THE BOTTOM OF THE PROPOSED TREATMENT ZONE.
6) PLACE A 36' X 2 1/2" I.D. SCHEDULE 40 PVE PIPE IN BOREHOLE TO KEEP IT OPEN.
7) INSTALL SURFACE COMPLETION AS DIRECTED BY CLIENT REPRESENTATIVE.

FIGURE 11

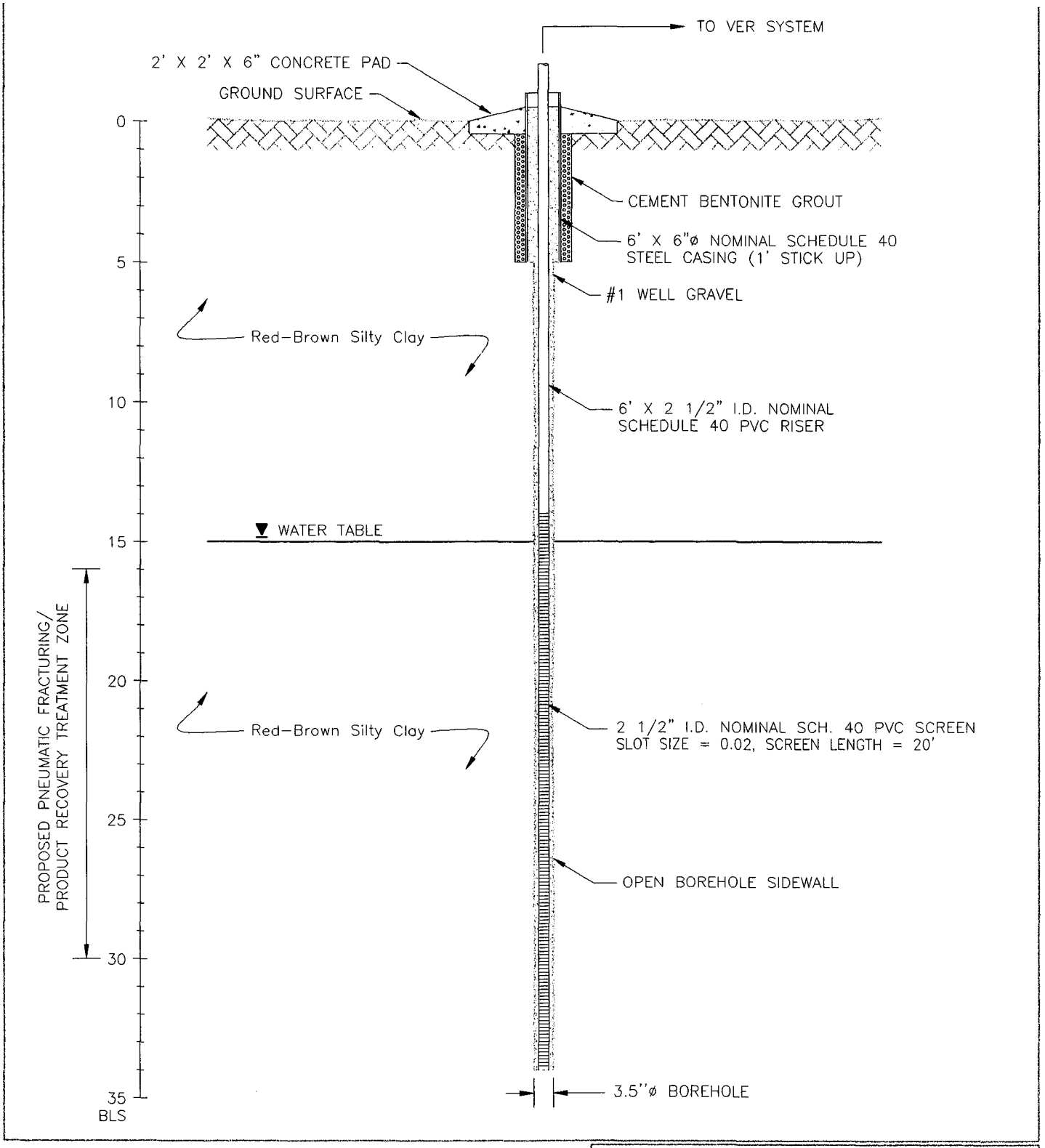
DETAILS FOR TYPICAL PNEUMATIC FRACTURE OPEN BOREHOLE WELL (FW-#)

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45600946 01/23/00



NOTES

1) AFTER PNEUMATIC FRACTURING CONVERT TO A PRODUCT RECOVERY WELL BY PLACING A 20' X 2 1/2 I.D. NOMINAL SCH. 40 PVC SCREEN (20 SLOT), WITH 16' PVC RISER IN OPEN BOREHOLE.
2) FILL ANNULUS WITH #! WELL GRAVEL.
3) COMPLETE WELL AS SHOWN ON FIGURE.

FIGURE 12

CONSTRUCTION DETAILS FOR COMPLETING FW-6 AS A PRODUCT RECOVERY WELL

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45600948 01/23/00

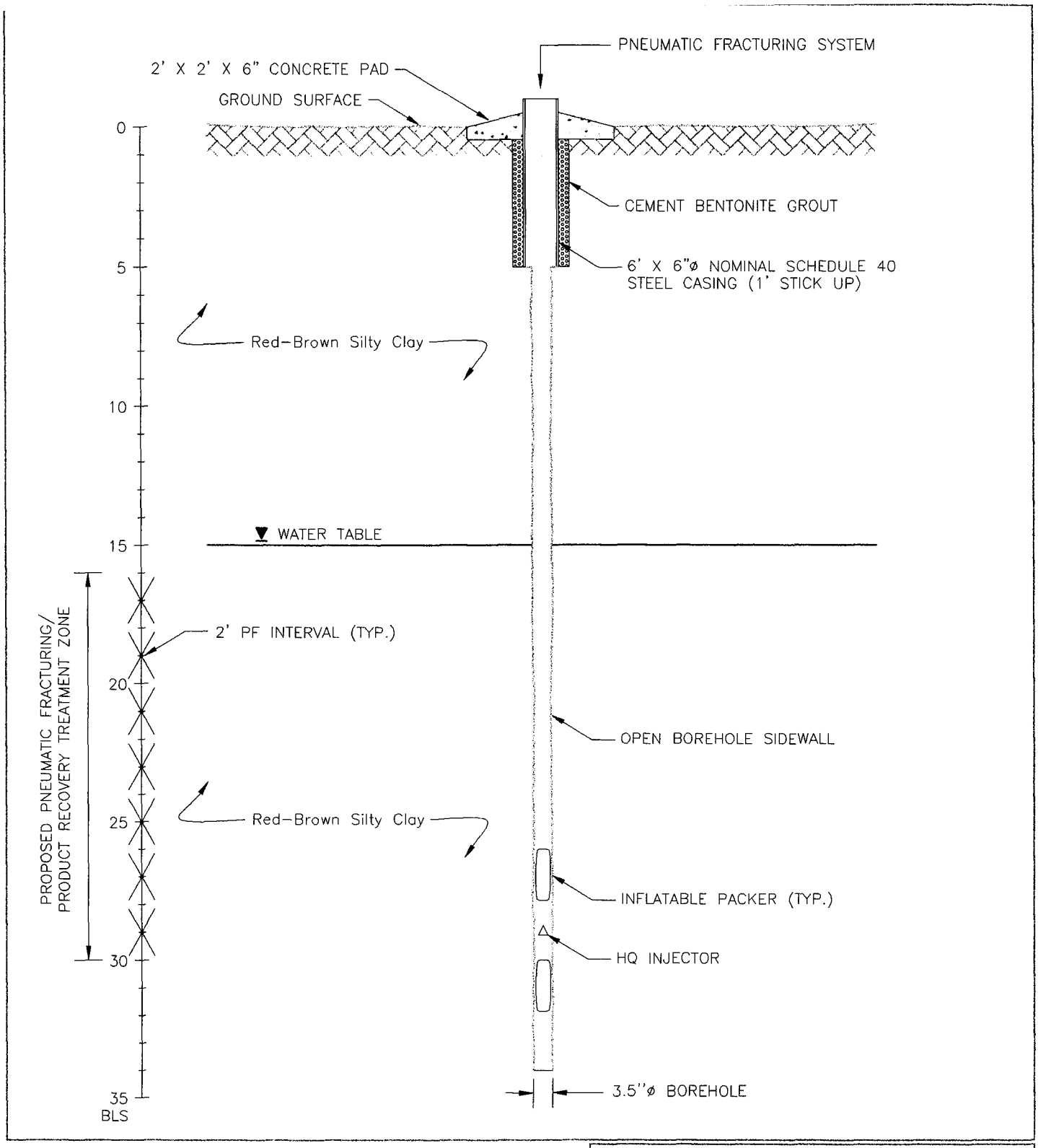


FIGURE 13

SCHEMATIC OF HQ INJECTOR
SET IN FRACTURE OPEN BOREHOLE

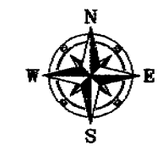
ROOSEVELT ROADS U.S. NAVAL STATION –
TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren® Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800940 01/23/00

WELLS		DISTANCE (FT)
TO	FROM	
PW-04	FW-7	29
PW-05	FW-7	7
PW-04	FW-8	32
PW-05	FW-8	12
PW-04	FW-9	40
PW-05	FW-9	17
PW-04	ERW-1	17
PW-05	ERW-1	16
PW-04	ERW-2	39
PW-05	ERW-2	30



LEGEND

- FENCE
- VEGETATION
- EXISTING MONITORING WELL LOCATION
- TERRAVAC PRODUCT RECOVERY WELL LOCATION
- McLAREN/HART SOIL BORING LOCATION
- RADIAL PNEUMATIC FRACTURE LOCATION
- DIRECTIONAL PNEUMATIC FRACTURE LOCATION
- (I) WELLS INSTRUMENTED DURING FRACTURING
- * SOIL BORING LOCATION TO BE GROUTED IN PLACE
- ** PROPPANT WILL BE PNEUMATICALLY INJECTED INTO WELLS
  - FOR ERW-1 SEE FIGURES 15 AND 17
  - FOR ERW-2 SEE FIGURES 16 AND 18
- ESTIMATED TREATMENT AREAS = 1,050 ft²

SCALE

10 5 0 10 FEET

FIGURE 14

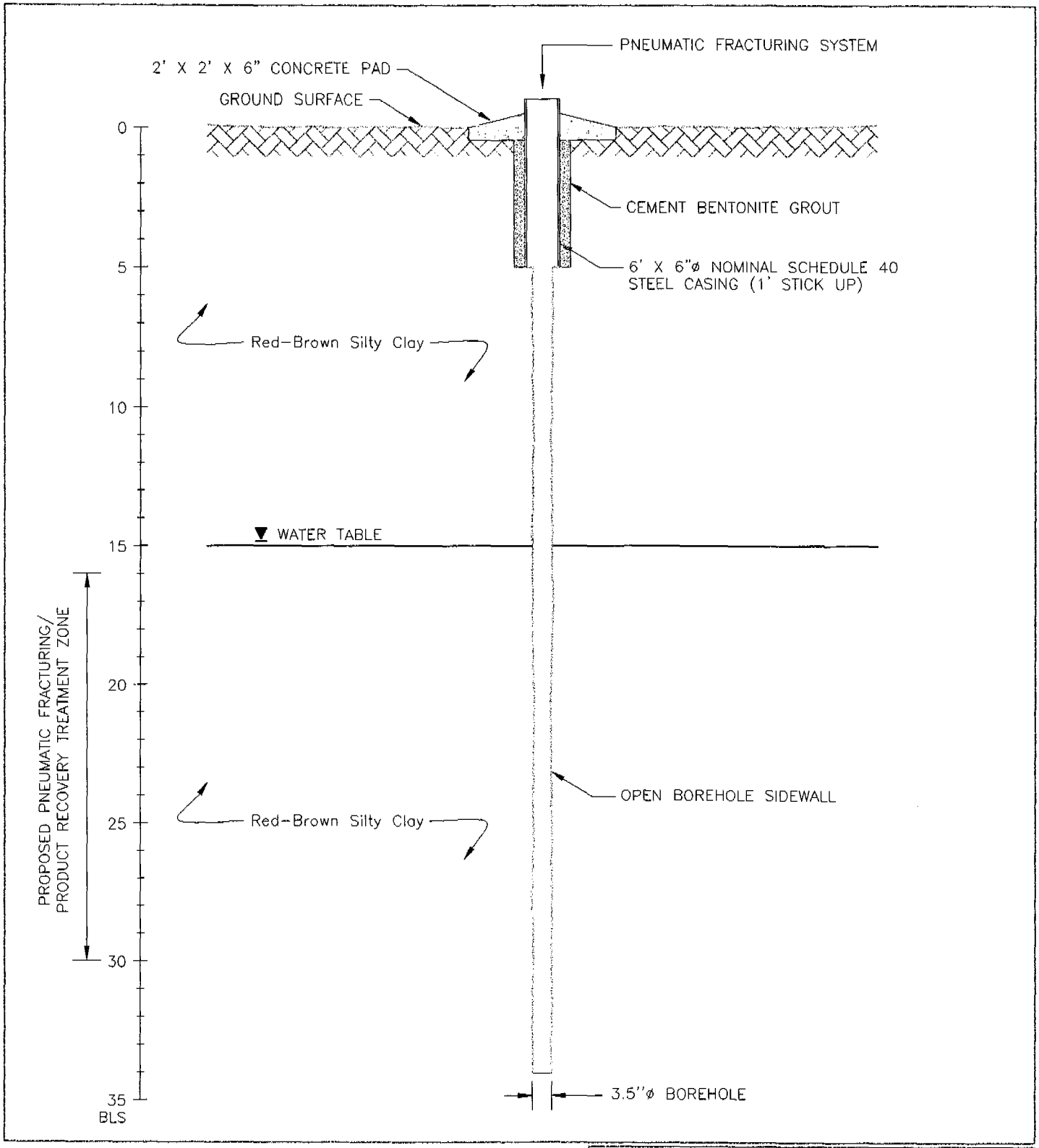
LAYOUT OF PRODUCT RECOVERY AND MONITORING WELLS IN PW6 AREA

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800937 01/23/00



NOTES

1) ALL FINAL DEPTHS WILL BE DETERMINED AT TIME OF INSTALLATION BY CLIENT REPRESENTATIVE.
2) LOCATE BOTTOM OF FILL ZONE USING GEOPROBE (OPTIONAL).
3) DRILL/AUGER A 10"ø BOREHOLE TO 5' BELOW GRADE.
4) PLACE 6' X 6"ø STEEL CASING IN BOREHOLE. COMPLETE SETTING OF CASING AS SHOWN ON FIGURE.
5) 24 HOURS LATER DRILL/CORE A 3.5"ø BOREHOLE 4' PASS THE BOTTOM OF THE PROPOSED TREATMENT ZONE.
6) PLACE A 36' X 2 1/2" I.D. SCHEDULE 40 PVE PIPE IN BOREHOLE TO KEEP IT OPEN.
7) INSTALL SURFACE COMPLETION AS DIRECTED BY CLIENT REPRESENTATIVE.

FIGURE 15

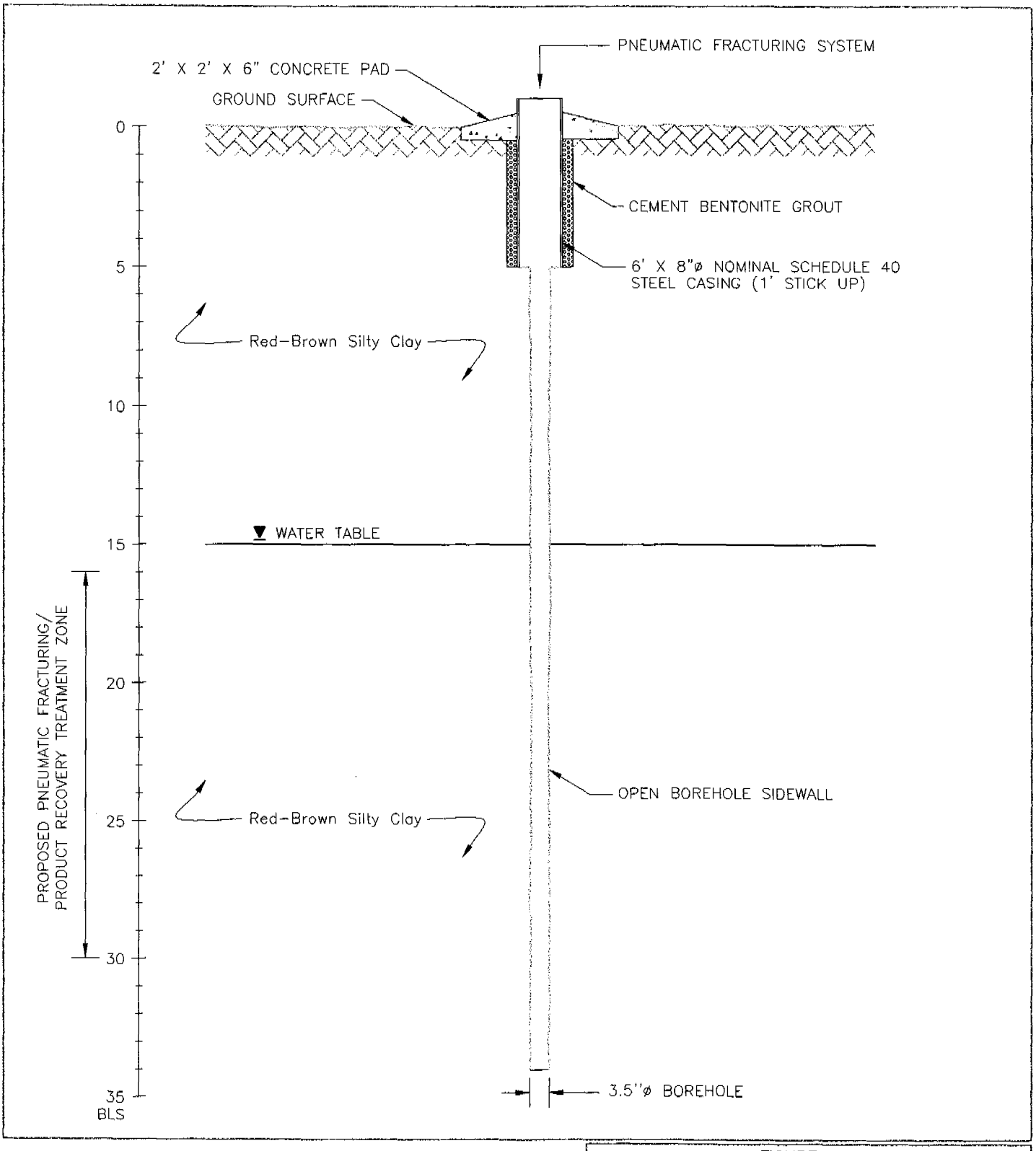
CONSTRUCTION DETAILS FOR ERW-1
BEFORE INSTALLATION OF PROPPANT

ROOSEVELT ROADS U.S. NAVAL STATION –
TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800938 01/23/00



NOTES

1) ALL FINAL DEPTHS WILL BE DETERMINED AT TIME OF INSTALLATION BY CLIENT REPRESENTATIVE.
2) LOCATE BOTTOM OF FILL ZONE USING GEOPROBE (OPTIONAL).
3) DRILL/AUGER A 12"ø BOREHOLE TO 5' BELOW GRADE.
4) PLACE 6' X 8"ø STEEL CASING IN BOREHOLE. COMPLETE SETTING OF CASING AS SHOWN ON FIGURE.
5) 24 HOURS LATER DRILL/CORE A 3.5"ø BOREHOLE 4' PASS THE BOTTOM OF THE PROPOSED TREATMENT ZONE.
6) PLACE A 36' X 2 1/2" I.D. SCHEDULE 40 PVE PIPE IN BOREHOLE TO KEEP IT OPEN.
7) INSTALL SURFACE COMPLETION AS DIRECTED BY CLIENT REPRESENTATIVE.

FIGURE 16

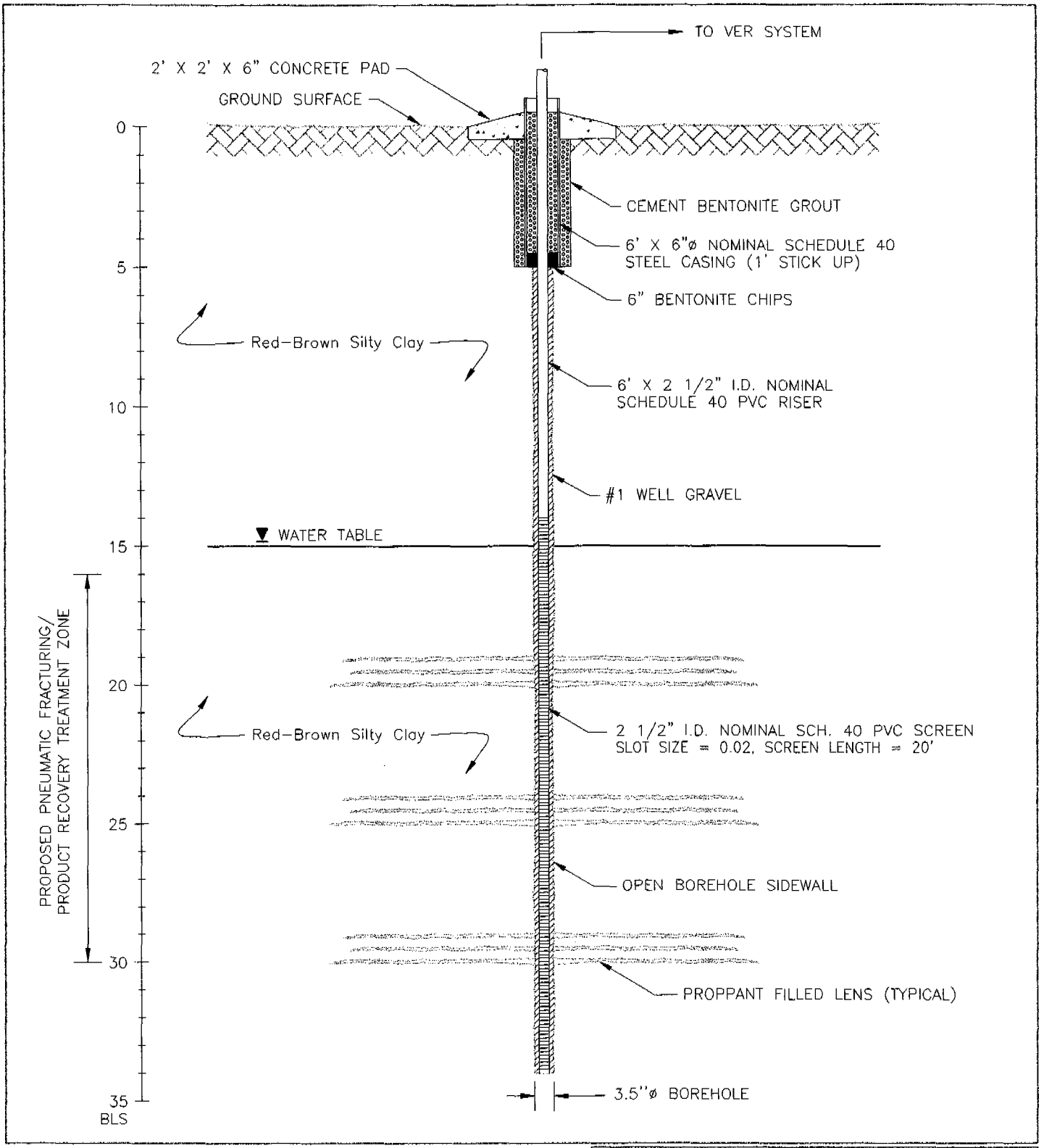
CONSTRUCTION DETAILS FOR ERW-2
BEFORE INSTALLATION OF PROPPANT

ROOSEVELT ROADS U.S. NAVAL STATION –
TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren® Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45600939 01/23/00



NOTES

1) AFTER PNEUMATIC FRACTURING AND INSTALLATION OF PROPPANT AT ERW-2 LOCATION, CONVERT TO A PRODUCT RECOVERY WELL BY PLACING A 20' X 2 1/2 I.D. NOMINAL SCH. 40 PVC SCREEN (20 SLOT), WITH 16' PVC RISER IN OPEN BOREHOLE.
2) COMPLETE WELL AS SHOWN ON FIGURE.
3) HYDRATE BENTONITE CHIPS IN 3" LIFTS.

FIGURE 17

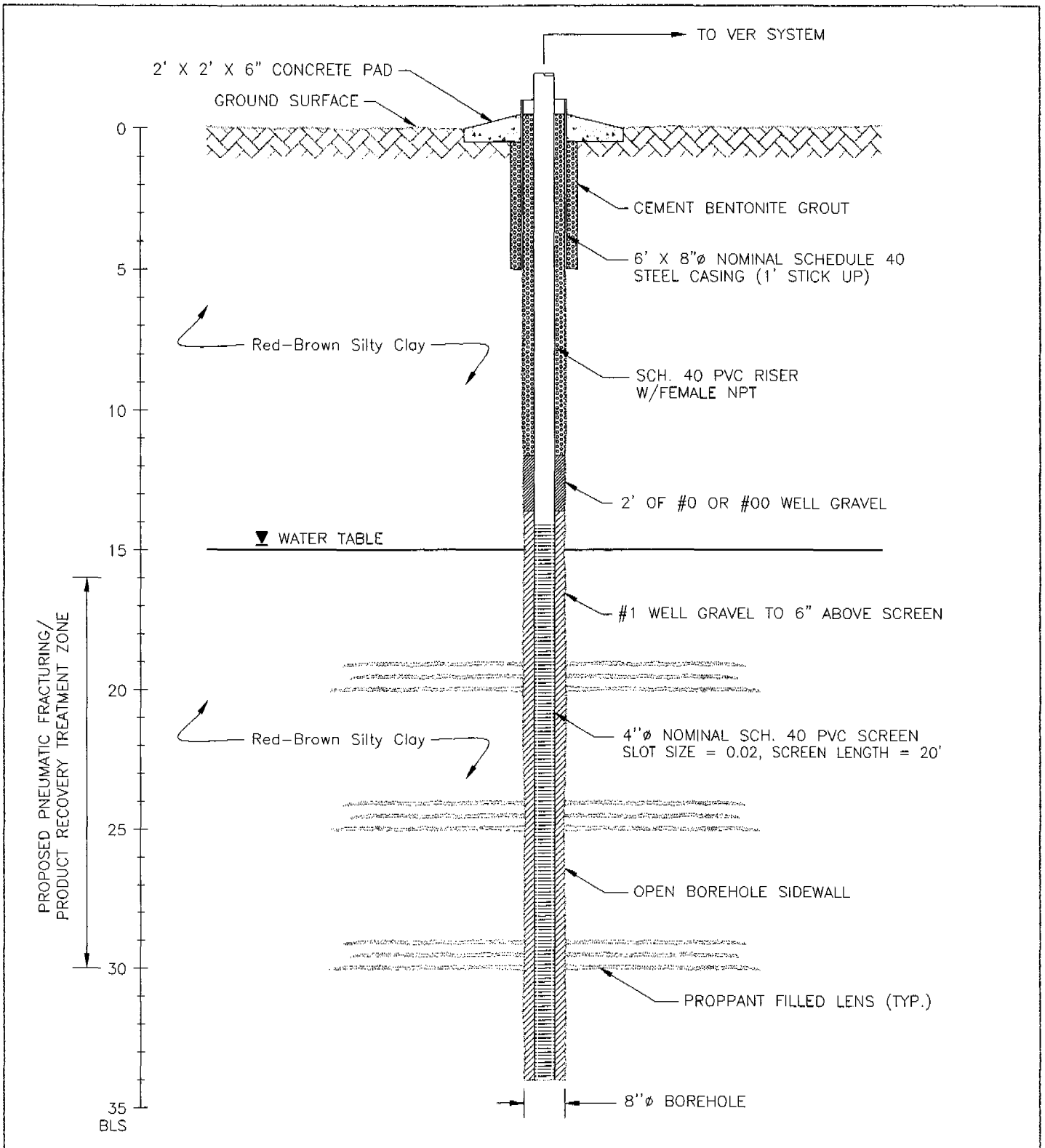
CONSTRUCTION DETAILS FOR CONVERTING ERW-1 TO AN ENHANCED PRODUCT RECOVERY WELL

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren® Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45600941 01/23/00



NOTES

1) AFTER PNEUMATIC FRACTURING AND INSTALLATION OF PROPPANT AT ERW-1 LOCATION, CONVERT TO A PRODUCT RECOVERY WELL AS SHOWN ON FIGURE.
2) DRILL A 8"ø BOREHOLE USING 4 1/2"ø HOLLOW STEM AUGERS.
3) INSTALL 4"ø PVC WELL AS SHOWN ON FIGURE.
4) DEVELOP WELL USING SURGE BLOCK.

FIGURE 18

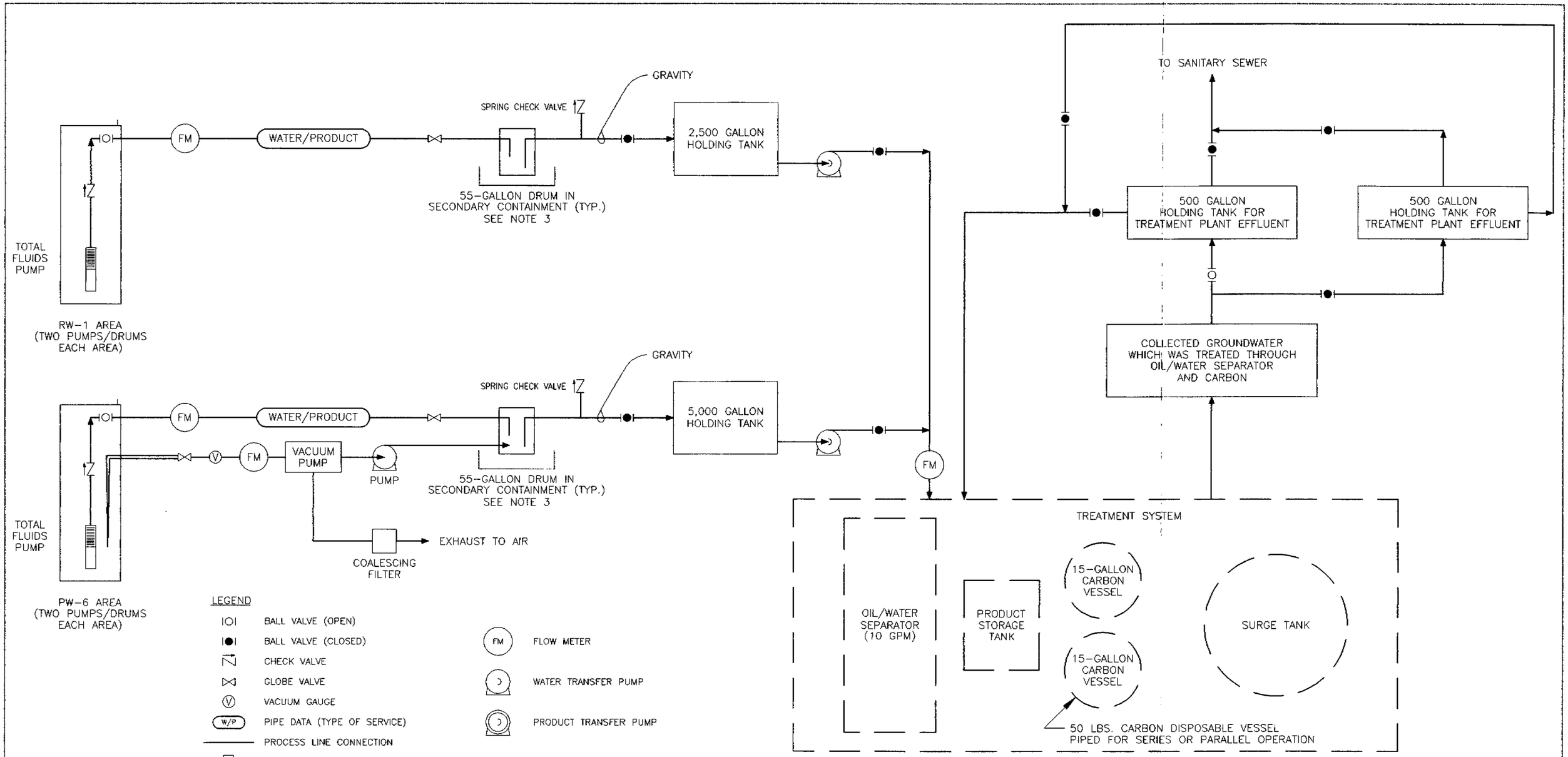
CONSTRUCTION DETAILS FOR CONVERTING ERW-2 TO AN ENHANCED PRODUCT RECOVERY WELL

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800942 01/23/00



LEGEND

- BALL VALVE (OPEN)
- BALL VALVE (CLOSED)
- CHECK VALVE
- GLOBE VALVE
- VACUUM GAUGE
- W/P — PIPE DATA (TYPE OF SERVICE)
- PROCESS LINE CONNECTION
- PNEUMATIC TOTAL FLUID RECOVERY PUMP
- FM — FLOW METER
- WATER TRANSFER PUMP
- PRODUCT TRANSFER PUMP

NOTES:

1. ALL PRODUCT SHALL BE REMOVED FROM HOLDING TANKS PRIOR TO TREATMENT OF COLLECTED GROUNDWATER.
2. COLLECTED GROUNDWATER WILL BE TREATED UTILIZING AN OIL/WATER SEPARATOR. THE EFFLUENT WILL BE ANALYZED BEFORE DISCHARGE TO ON-SITE SANITARY SEWER FOR FINAL TREATMENT, BY ON-SITE WASTEWATER TREATMENT PLANT.
3. GAUGE PRODUCT AND WATER IN 55-GALLON DRUM BEFORE TRANSFER TO HOLDING TANK.
4. PRODUCT ACCUMULATED IN THE 55-GALLON DRUM AND 5,000/2,500-GALLON HOLDING TANKS WILL BE PUMPED OUT MANUALLY AND TRANSPORTED TO THE EXISTING PRODUCT STORAGE TANK.

FIGURE 19

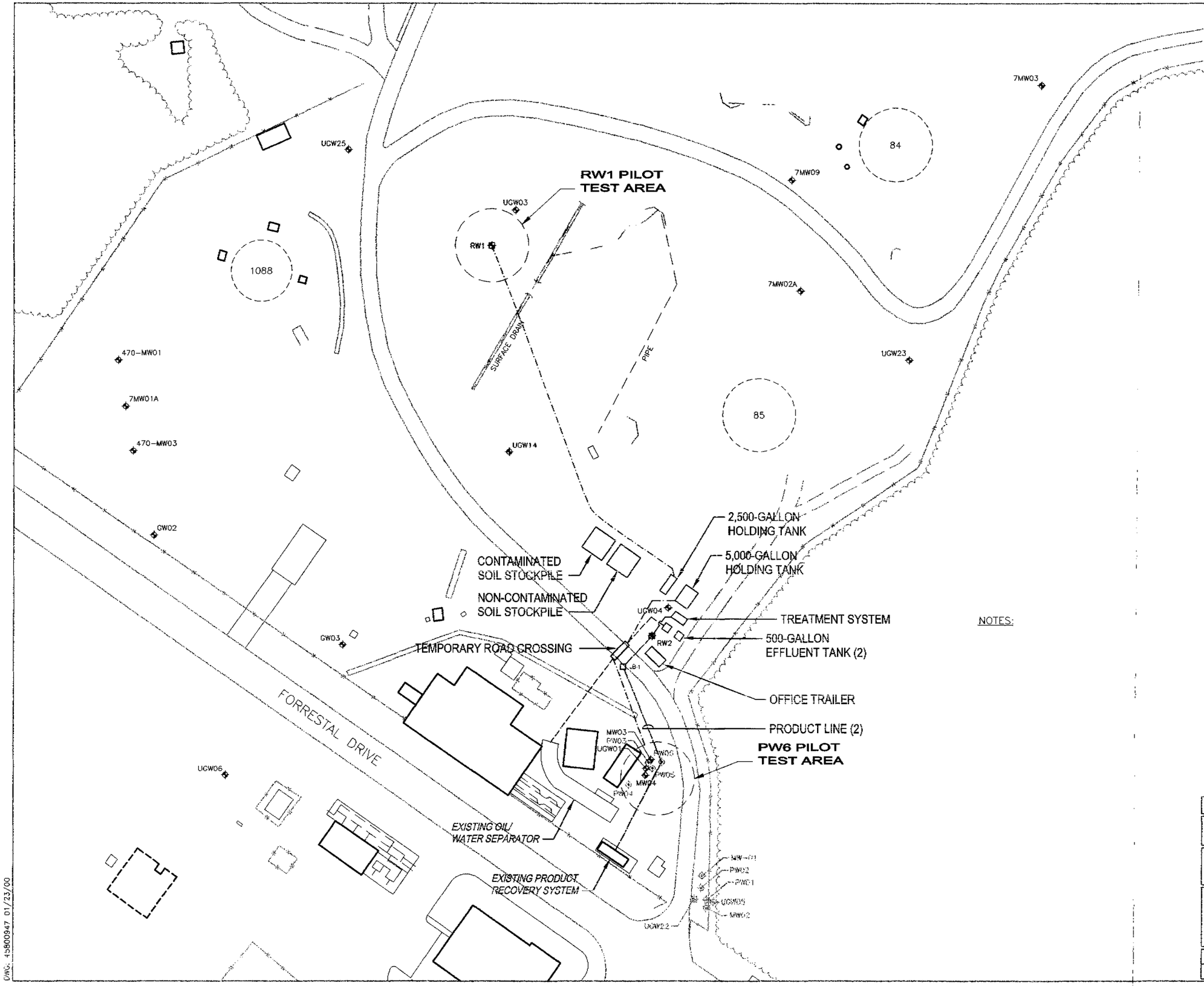
SCHEMATIC OF PRODUCT RECOVERY SYSTEM

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800943 01/23/00



NOTES:

LEGEND

- FENCE
- VEGETATION
- ABOVEGROUND GROUNDWATER LINE
- ABOVEGROUND TREATED WATER DISCHARGE LINE
- UNDERGROUND PRODUCT LINE (1)
- EXISTING MONITORING WELL LOCATION
- McLAREN/HART PRODUCT RECOVERY WELL LOCATION
- TERRAVAC PRODUCT RECOVERY WELL LOCATION
- APPROXIMATE LOCATION OF PILOT TEST

NOTES

1. THE TREATMENT SYSTEM, PRODUCT STORAGE, AND PRODUCT LINES FROM THE TREATMENT SYSTEM SHALL BE SECONDARY CONTAINED. EXISTING BELOW GRADE CONVEYANCE LINES TO BE USED TO THE EXTENT PRACTICAL.
2. REFER TO FIGURE 16 FOR DETAILS OF THE TREATMENT SYSTEM.

SCALE

80 40 0 80 FEET

FIGURE 20

SITE PLAN SHOWING TEMPORARY FACILITIES

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: T.K.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800947 01/23/00

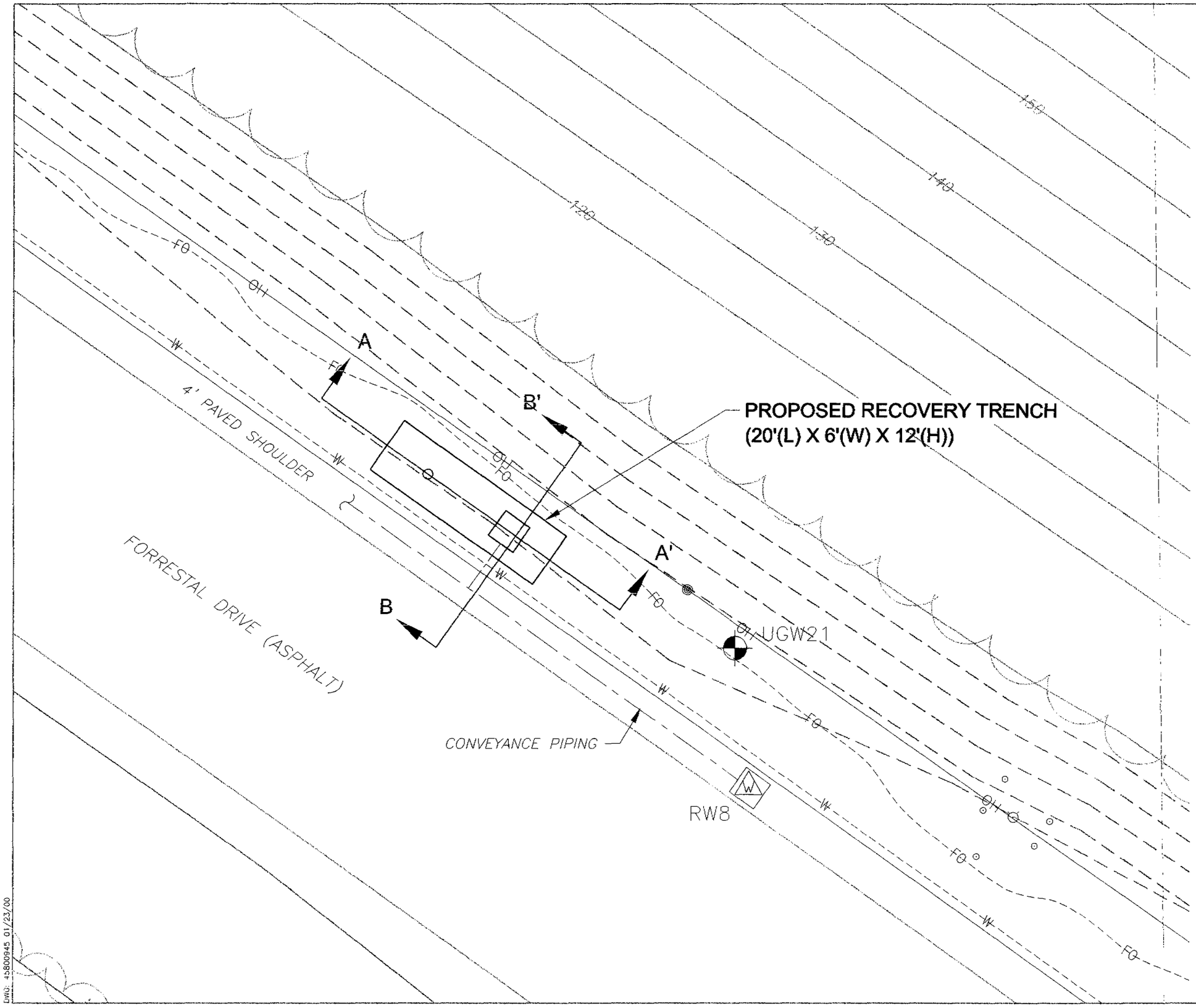


FIGURE 21

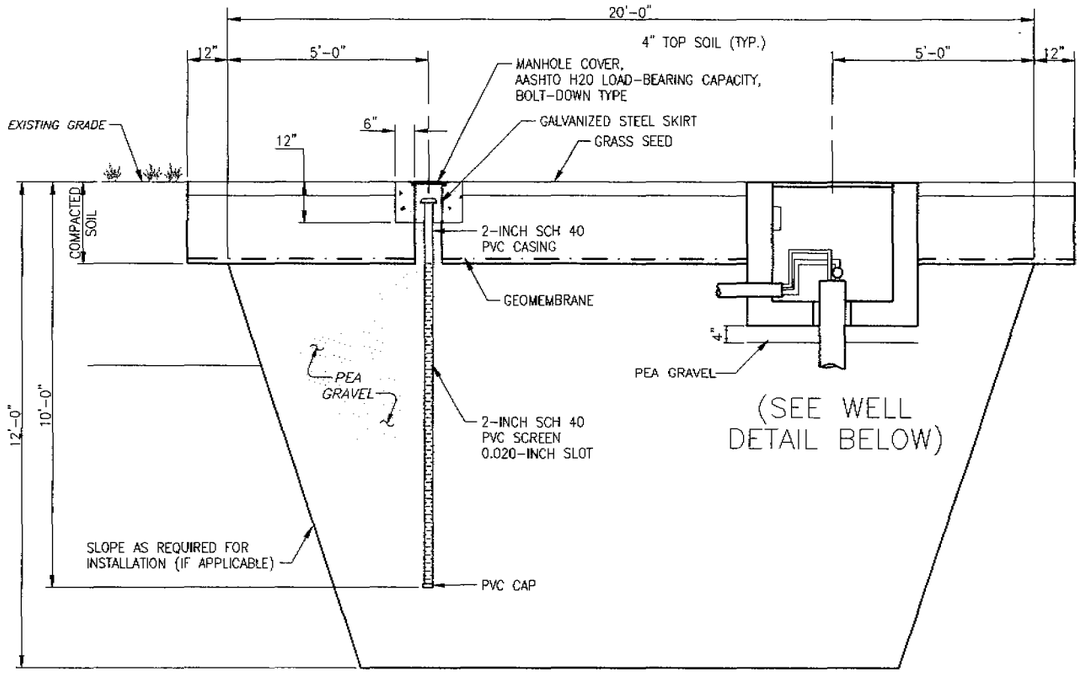
RECOVERY TRENCH PLAN

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

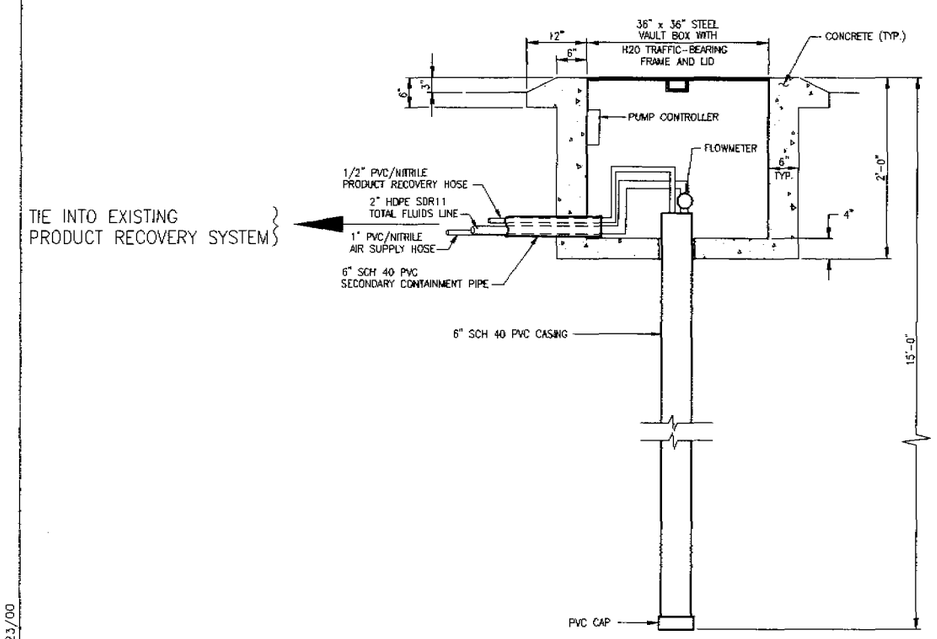
McLaren Hart INC.

DRWN: S.F.H.	CHK'D: B.B.
SCALE: AS SHOWN	DATE: 01/23/00

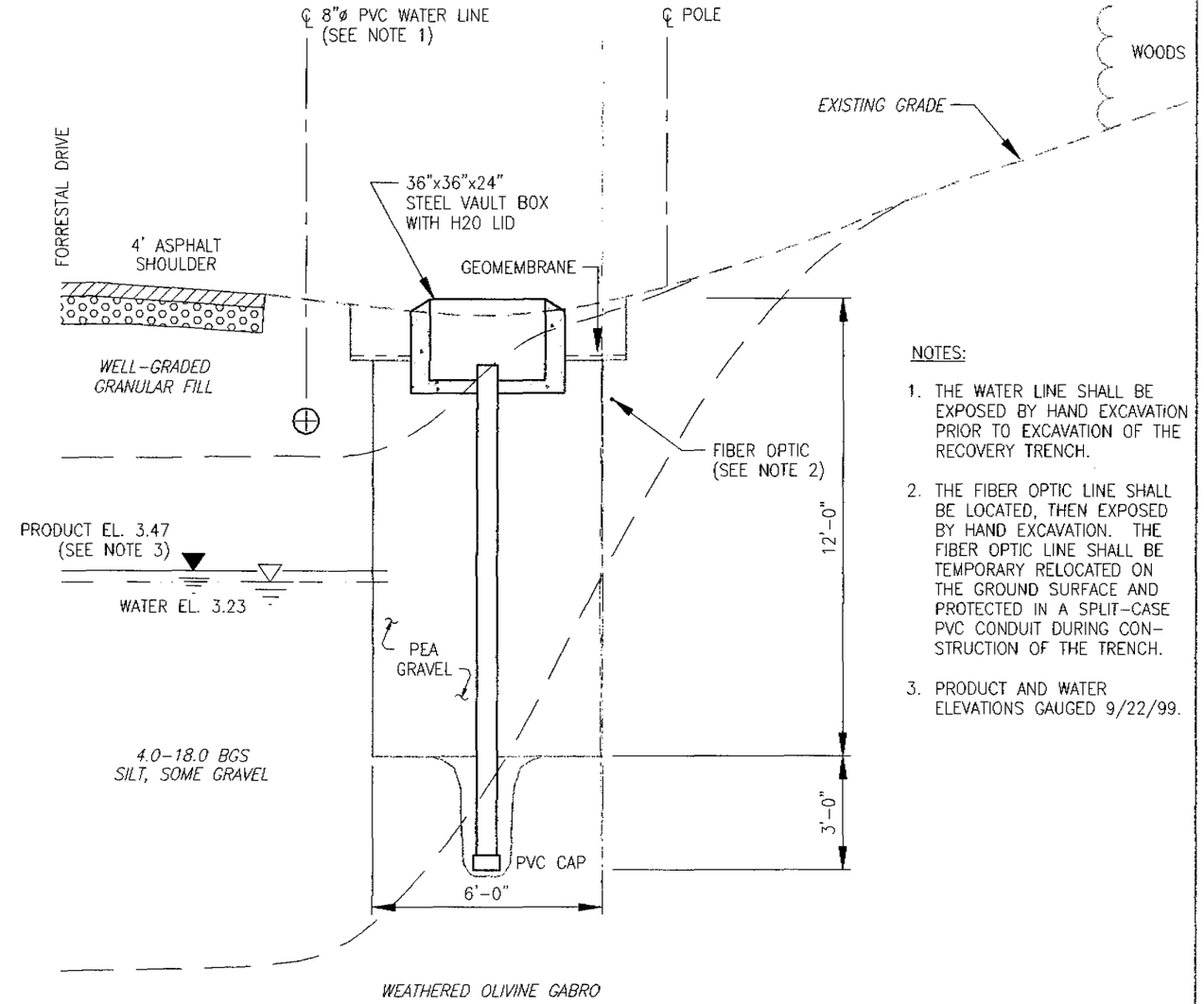
DWG: 45800945 01/23/00



SECTION A-A '



WELL DETAIL



SECTION B-B '

NOTES:

1. THE WATER LINE SHALL BE EXPOSED BY HAND EXCAVATION PRIOR TO EXCAVATION OF THE RECOVERY TRENCH.
2. THE FIBER OPTIC LINE SHALL BE LOCATED, THEN EXPOSED BY HAND EXCAVATION. THE FIBER OPTIC LINE SHALL BE TEMPORARY RELOCATED ON THE GROUND SURFACE AND PROTECTED IN A SPLIT-CASE PVC CONDUIT DURING CONSTRUCTION OF THE TRENCH.
3. PRODUCT AND WATER ELEVATIONS GAUGED 9/22/99.

FIGURE 22

RECOVERY TRENCH SECTIONS

ROOSEVELT ROADS U.S. NAVAL STATION – TOW WAY FUEL FACILITY, CEIBA, PUERTO RICO

McLaren Hart INC.

DRWN: S.F.H.	CHK'D: B.B.
SCALE: AS SHOWN	DATE: 01/23/00

DWG: 45800944 01/23/00

APPENDIX A

RESPONSE TO COMMENTS ON DRAFT WORK PLAN

Response to Comments
Draft Work Plan
Pilot Test to Evaluate Enhancement of Product Recovery

Tow Way Fuel Facility
U.S. Naval Station Roosevelt Roads
Ceiba, Puerto Rico

December 29, 1999

Contract No. N62470-93-3033
POLRAC Task Order No. 0009

Project No. 945809

Prepared By:

McLaren/Hart, Inc.
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Pittsburgh, Pa 15212-1410

Response to Comments Submitted by
Mark Kimes, Baker Environmental
Via E-mail, December 3, 1999

1. pg ES-2 line 4

   What does lbs mean?

   Should read "bls" (below land surface).

2. pg 1-2 line 3 and 4

   What characteristics are significantly different between the two pumps to warrant testing these two pumps? (Jet pumps are used for deep well applications and pneumatic is used for wells up to 30 feet deep or cavitation)

   Two pumping systems for performance evaluation were previously identified: 1. Pneumatic total fluids and, 2. Jet pumps. The characteristics of each of these systems plus a vacuum pump (liquid ring type) system are presented below.

   Jet Pump System

   Jet pumps utilize water (Q1) and a venturi/ejector system contained in the well to remove groundwater from water bearing formation (Q2). Q1 is supplied from an initial storage of water to start the operation of the jet pumps system. Upon starting of the system, Q1+Q2 are introduced to the system discharge tank for re-use for Q1 and re-circulation into the jet pump system. The excess water collected, Q2, in this case, will be directed to an on-site treatment facility to process the collected groundwater and the free phase product.

   A disadvantage to a jet pump system in this application is the re-circulation of contaminated groundwater and free phase product for the supply to the jet pump system Q1. This may cause emulsification of the free phase product causing problems with separation of this product during the treatment of the contaminated groundwater.

   An advantage of a jet pump system is the unit cost per jet pump is significantly less than a deep well system with individual pumping units. Jet pumps systems consist of relatively inexpensive pumping equipment for each recovery wells with one (1) common pumping station to operate the jet pump system. Also, jet pump systems may be used in deep applications for the collection of groundwater and free phase product.

   Pneumatic Total Fluids Systems

   A pneumatic pumping system utilizes compressed air for the driving force to remove groundwater from recovery wells. Pneumatic pumping system must have a clean dry source of compressed air to operate the individual pumping equipment in each recovery well.

Disadvantages to a pneumatic pumping system is the cost for the installation a compressed air source (typically an air compressor) and a compressed air delivery system to each recovery point. Also, pneumatic pumps require frequent maintenance when there is a high concentration of dissolved metals (iron, manganese) in the groundwater.

Advantages to a pneumatic pumping system is that is a reliable method of total fluids collection in groundwater recovery systems. Most pneumatic pumps do not cause emulsification of collected free phase product thus, not complicating the separation process of free phase product and groundwater in treatment systems. Furthermore, similar to jet pump systems, pneumatic collection systems may be used in deep applications for the collection of groundwater and free phase product.

Vacuum Pump System

This system uses a central located vacuum pump system to remove floating product, water and vapors from the well. The system is comprised of a suction pipe network, an air/water separator vacuum pump, and a discharge pump. The vacuum pump is an oil-free liquid ring pump capable of operating at a wide range of vacuum conditions (5 – 25" Hg). Fluid removal is assisted by a drop tube, which extends into the well. Groundwater draw down and removal is controlled by adjusting the vacuum and position of the drop tube in the well.

The primary advantage of the vacuum system is that a vacuum is applied to the well to enhance the mobility of product toward the well. The system can also be operated to remove vapors from the soil surrounding the well.

Disadvantages of the vacuum system are the relatively high capital cost for full-scale implementation and potential emulsification of free phase product.

Due to site restrictions, time and monetary constraints, we are limited to evaluating two types of pumping systems with respect to the pneumatic fracture technology. McLaren\Hart recommends evaluating the Pneumatic total fluids pump system and a vacuum (liquid ring pump) system. While the Jet pumps system may be selected for full-scale implementation at the site, it's operational characteristics fall between the pneumatic total fluids pump and the vacuum pump systems. The vacuum pump system offers a wider range of operating pressure (vacuum) than the Jet pump system. The operational characteristics of the jet pumps system can be duplicated operating by the high vacuum system at lower vacuum pressures. In addition, the existing discriminating skimmer pump system will be further evaluated with the proposed recovery trench.

3. pg 1-2 line 16

   Recovery rates are extremely low, which means a "longer" pump test to get adequate results. Why do a short duration pump test?

   The short duration pump test was proposed as a mechanism to compare hydraulic parameters with existing information and to compare this data before and after fracturing.

They were originally intended to be used to obtain test plot-specific hydraulic parameters. Data available indicates that hydraulic conductivity is low and, therefore, it was felt that a short-duration test would stabilize quickly, thus allowing calculation of hydraulic parameters. Based on the data collected after fracturing, these pumps would be utilized in longer-term pumping/evaluation testing. (i.e. see Section 4.6.2 and 4.6.3 of the workplan for details).

The suggestion of a longer baseline will be more conclusive in terms of product recovery. It will, however, add to the cost of the pilot test. The proposed duration of the pump tests is intended to serve as a basis for the evaluation program. During the testing program the task leader will make the field calls and decisions with regards to achieving the respective task objectives. A more detailed baseline workplan is being developed which will provide additional information on "longer" pump tests.

4. pg 2-2 line 21

   Have we measured permeability at this location? If not, we should do this prior to PF to get a baseline.

   The hydrogeologic information was reported from the Quarterly Summary Progress Report Number 8, dated February 26, 1999. Hydraulic information collected from the pumping tests (pre and post-fracture) will be used to calculate the hydraulic conductivity of the formation.

5. pg 2-3 line 21

   Why not do a total fluids recovery performance test before PF? This is much more cost effective and should recover more product than existing single phase. You shouldn't have to PF yet.

   Total fluid recovery tests are planned as part of the pilot test. They will be performed before and after pneumatic fracturing as a basis to evaluate the effectiveness of fracturing in enhancing product recovery.

6. pg 2-3 line 24

   Where are the engineering design calculations and assumptions used in the PF Model? I believe we should see these before proceeding forward to double check assumptions.

   Refer to Section 3.4 of the Workplan for the basis of the PF Model Evaluation. Additionally, an abstract and overview of the model is included as Attachment 1 to these Responses; they will also be incorporated as an Appendix to the Workplan. The model is based upon a mathematical description of the pneumatic fracturing process. Input data primarily consists of soil type and depth. At this point, geotechnical analysis of site-specific soil samples is being conducted to further refine the model.

7. pg 2-3 line 27

   What data? What parameters? We have no information on the model or data ranges that go into the model. No reference is made to the scientific validity of the model.

   Site-specific engineering design data is not model specific. The design data referred to in this objective include hydraulic data, effective radius of influences, drawdown, optimum pumping rates, etc.

8. pg 2-3 line 29

   How long do we need to have system down to reach equilibrium?

   McLaren/Hart recommends that potentiometric levels be monitored for 24 hrs. to establish a baseline trend for the pilot test area.

9. pg 3-3 line 9

   What is meant by piezometric surface? Is this the same as potentiometric? Or oil/ water interface?

   Piezometric surface and potentiometric are the same.

10. pg 3-5 line 6 thru 9

    How long should these pressures and scfms be maintained? Do you plan to truly pressurize the formation and hold it for a given time while adjusting flow rate or do you plan to "jet in" the fractures with a blast of pressurized air?

    The actual process of fracturing involves several steps. The first involves pressurizing an isolated section of a borehole. Once the formation ruptures, high velocity gas is used to propagate the fractures radially outward from the borehole. The final component of the fracturing process involves achieving a condition where the rate of injected gas is equal to the rate of fracture "leak-off". At that point, fractures will not propagate any further and the fracturing process stops.

    Pressures and flows during the fracturing process will be maintained for approximately 10 to 30 seconds. The duration of the fracture cycle is a function of depth and the type of geologic media and will be regulated and optimized by the fracture technician, based on experience and by utilizing knowledge gained at the site. Included as Attachment 2 is a detailed description of the Methodology of Pneumatic Fracturing.

11. pg 3-8 line 9

    It is unclear why an inert media is not being used to hold the "fractures" open. After sufficient pressure is applied to the formation, a fracture is created. Once the pressure is

released, the formation will attempt to return to its pre-fracture state. You identify "maintenance pressure" to keep the fractures open. How will you keep the fractures from closing when pressure is released to place recovery equipment down hole?

The use of an inert media (proppant) is a proven technology in the petroleum industry for the enhancement of product recovery from a formation. The primary difference between the petroleum industry application and our application is the depth of treatment and the type of fracture propagation fluid (i.e., liquid compared to gas in the PF applications). In the petroleum industry the in situ stresses at the depth (i.e., >1000 ft) of treatment are significantly greater and fractures tend to close more readily because of the depth of the overburden. In shallower applications, fracture closure is less dependent on the depth of treatment and more dependent on the swelling capacity of the soils (i.e., expansive or non-expansive clays) being treated.

Based on our preliminary evaluation of the soils, it is our opinion that the soils would not benefit significantly by the addition of an inert media to propagate the fractures. This opinion is being confirmed by geotechnical analysis (i.e. Atterburg limits, mineralogical testing) of soils collected from the site.

At the time of writing this response, the preliminary results of the geotechnical analysis show evidence of expansive clays. The need for an inert media is being evaluated and a recommendation to the Roosevelt Roads Technical Team will be made.

12. pg 3-11 line 6

Will the sump include a total fluid pump or product only? Why aren't you pilot testing different recovery scenarios (i.e. total fluid pump vs. skimmer pump)?

The recovery trench sump will be fitted with a discriminating skimmer type pump previously used at the site. The proposed recovery trench is located along the utility corridor adjacent to Forestall Drive. Based on free product measurements and geologic conditions, it is concluded that product migration is confined to a narrow path near the utilities bounded by the bedrock surface and dense soil beneath Forestall Drive. The trench will be constructed to intercept the utility trenches and will extend from the Forestall Drive on the South to the toe of the rock slope on the North. It is anticipated that free phase product intercepted by the trench will flow readily into the sump and draw down of the water surfacewill not be necessary to enhance product recovery at this location.

13. pg 3-11 line 21

Figure?

Should read "Figure 17"

14. pg 3-14 line 14 thru 23

Since recovery of free product has been relatively low, has there been any consideration to determine the volume of free product necessary to fill "new" recovery piping before it reaches the recovery area?

Yes. The internal diameters of the various piping sections will be known and volume determinations will be made as necessary. Other options for product accounting may include: pumping into a container (i.e., 55-gallon drum in the vicinity of the well and then transferring the fluid to the recovery system. The field project team will make the necessary field decisions to account for various performance scenarios.

15. pg 4-1 after line 13

Again. short duration pump test may not be justified since the recovery rate is extremely slow. Are there contingencies to deal with the anticipated low flow rate and subsequent slow recovery?

Short duration pump tests were proposed to confirm existing hydraulic information and to establish a basis for pre- and post-fracture performance evaluations.

16. pg 4-2 line 28

What is meant by no proppant needed? Previously you identify the need for a "maintenance pressure" to keep apertures open.

The term "maintenance pressure" is used to refer to a specific component of the fracturing process. As mentioned previously, a typical pneumatic fracturing event contains several steps. Maintenance pressure refers to the period after the initial rupture of the formation, when high flows of gas are used to maintain and migrate the fracture radially from the well. This time period can be fairly short (i.e.. 10 to 30 seconds). Once the fracturing process is complete, the aperture of the fracture is maintained by the self-propping nature of fractured soil.

17. pg 4-3 line 28 thru 33

Does this mean RW-1 is 24 feet below mean sea level?

Lines 31 and 32 of page 4-3 should read "The difference in elevation between the two areas is approximately 6 feet, with the RW-1 area approximately 6 feet higher than the PW-6 area. PW-6 is approximately 16 feet"

18. pg 4-4 line 7 thru 13

If you have to maintain pressure after PF. then how much of the aperture will close when pressure on the formation is released to install recovery pumps and piping?

Pressure is not used to "maintain" the fracture after an actual fracturing event. Experience at over 30 sites throughout the US and Canada has show that, after the fracture event (10 to 30 seconds), there is a slight reduction in fracture apertures, but they do not close. Extensive research has shown that the self-propping aspect of the soil maintains a fracture aperture.

19. pg 4-7

Are you putting the formation under pressure, as measured at the well head or within packer, or are you "jetting' with high pressure through a nozzle?

See the answer to Question 11. A high pressure "jetting" nozzle is not used.

20. pg 4-7 line 22 thru 31

What is the well screen tension rating? I am concerned about collapsing the screen with unknown hydraulic force applied to drill stem. How do you prevent this from happening? You also do not leave enough space to cement annulus near surface, however you show this in your diagrams. Which is correct? If you plan to leave enough room to cement, then why not overdrill the hole to fit drill stem and then backfill with sand then cement about PF zone?

This paragraph refers to the installation procedure for the Pneumatic Fracture/Product Recovery Well (FW-1). See Figure 13 of the Workplan for well construction details and installation notes.

The proposed well is of steel construction and will not collapse from installation or operational procedures. Because of the need for flexibility in performance of the well, the design allows for raising the screen and riser so that unfractured zones of the formation can be fractured if required. The flexibility of moving the screen and riser negates the need for a cement grout annulus.

21. pg 4-8 line 13

How short is short? How many hours do you plan to run the pump test with extremely low, anticipated flow rates?

In the baseline testing program described in Section 4.3.2 of the Workplan, the program recommend conducting a step test in each of the product recovery wells (existing and new), in each test plot. Next a pump test would be conducted at each well for approximately 4 hours. The purpose of this program is to evaluate the change in hydraulic properties due to the Pneumatic Fracturing enhancement program. (See Table 5 of the Workplan for a summary of the pumping test procedures.)

A second component of the evaluation was to monitor product rates/recovery from the wells using bailing techniques, before and after fracturing. This would then be complemented by the pumping test total fluids evaluation. This program is designed to evaluate Pneumatic

Fracturing before and after fracturing. See Table 4 of the Workplan for a summary of the proposed product recovery evaluation.

Based upon additional comments, the baseline-testing program has been expanded to 30 days in order to test two types of pumps and to allow longer times to obtain product recovery information.

22. pg 4-9 line 29 thru 30

Do you plan to pressurize the formation, as measured at the wellhead or within packer, or are you "jetting" in the fractures with a high pressure nozzle?

See the answer to question 11.

23. pg 4-18 line 14 thru 20

The outcome of the comparison between current product only system and a total fluids system (post PF) will be obvious. How do you plan to differentiate recovery data to determine effects from PF as opposed to PF combined with total fluid recovery?

The pilot test is designed such that the effects of Pneumatic Fracturing can be differentiated from a total fluids recovery system. This will be achieved by conducting baseline testing of hydraulic properties and product recovery rates in the test plots. After the formation is fractured, these parameters will be re-evaluated. Any change in performance of the wells, and hydraulic properties in the treatment area will be attributed to the Pneumatic Fracturing enhancement program.

24. pg 4-18 line 28

What significant differences exist between these two pumps would warrant a test between them?

A pilot test for these two types of pumping systems would be warranted to determine the level of emulsification of free product that occurs during the recovery process. This test will determine if product separation will be possible after free phase product is collected/processed (possibly several times) through the jet pump system. Typically, with diaphragm pumping systems typically utilized in pneumatic pumping systems, emulsification of the free phase product is not a problem.

25. pg 5-2 line 22

How are you going to overcome the collapse of the apertures during retrofitting of pumps?

As described in the response to questions 10 and 11, there is no need to respond to a "collapse of the apertures", because once a fracture is created in the geologic formation and

a product recovery pumping system is implemented (i.e., <1 week), the movement of the fluid through the fractures will cause development of the fractures. However, if the soils at the site have a high percentage of expansive minerals, the longevity of the fractures can diminish with time, and from a lack of fluid moving through them. The pilot test is designed to answer these questions.

26. Figure 7

Should the depths on the "Y-axis" be referenced as below mean sea level instead of below ground surface?

Yes.

Response to Comments and Recommendations
Submitted by Booz-Allen & Hamilton, Inc.
December 6, 1999

Section 3.9 Recovery Trench

1. Soils removed from trench excavation will be wet. The screening and loading area for this soil should be contained to prevent any contaminated groundwater or product contained in the soils from infiltrating into the ground or reaching surface water drainage areas.

   Wet soils removed from the trench will be staged adjacent to Forestall Drive near the trench. The soil stockpile will be constructed in accordance with the details provided in the approved Work Plan (August 16, 1996) for construction of the existing product recovery system. The stockpile will be lined and covered during off hours. Excess water from the soil stockpile will be collected and treated in the temporary on-site treatment system

2. The Draft Work Plan does not specify what type of instrument is to be used to screen the soils, what the instrument screening level will be, and how it will be determined and correlated to a TPH value in soil. These items should be defined. It is anticipated that the instrument used would be either a Flame Ionization Detector (FID) or Photo Ionization Detector (PID). A concern is that portable instruments generally do not provide the accuracy of laboratory analysis. Thus the readings obtained from these instruments may not accurately reflect the true level of petroleum hydrocarbon content. Additionally, field PIDs and FIDs are generally only capable of detecting volatile components. If the petroleum at the site is less volatile in nature, such as diesel fuel, the instrument may not detect the presence of petroleum hydrocarbons in soil. Therefore, use of these instruments for final determination of clean versus contaminated soil may not be appropriate without some method of correlating the instrument readings to laboratory measured values.

   Either a Flame ionization Detector (FID) or Photo Ionization Detector (PID) will be used along with visual observations to screen soils removed from the trench. This screening will be used to determine if the soil is to be placed in the clean soil stockpile or the potentially contaminated soil stockpile. Any observed PID or FID reading above background will be reason to place the soil in the potentially contaminated stockpile. The trench will be excavated in relatively horizontal lifts. Once contaminated soil is encountered in any portion of the trench excavation, all soil removed from the trench from that point on will be considered potentially contaminated. Upon completion of the trench, composite soil samples of each stockpile will be collected and characterized for final disposition.

3. The Draft Work Plan indicates that soil removed from the trench area will be segregated based on field screening and that soil contaminated with less than 100 ppm TPH will be used as backfill. The Draft Work Plan indicates that only the soil stockpile with field

screening results exceeding 100 ppm will be sampled and laboratory analyzed. It is suggested that both soil piles (clean and dirty) be laboratory analyzed to verify sensitivity and accuracy of the field screening instrument as well as the levels of petroleum contamination and other constituents prior to disposal or use as backfill.

See previous response

4. The Draft Work Plan calls for the interceptor trench to be constructed under or adjacent to utility conduits along the roadway. Hydraulic connection between the recovery trench and the utility conduits should be avoided, and as much distance as possible placed between them.

   Alternatively, the downgradient side of the trench could be lined with an impermeable barrier. If the recovery trench is hydraulically connected to the utility trench, the utility trench could act as a conduit for further migration of the LNAPL. These measures will help prevent the possible migration of LNAPL into and through the utility trench.

   Selection of the recovery trench location was based on intercepting free product migrating along the utility corridor. Migration of free product is likely aided by the more permeable material comprising the utility trenches. Avoiding a hydraulic connection between the utility trench and the recovery trench would defeat the purpose of the recovery trench installed at this location.

   Installation of an impermeable lining on the down gradient side of the trench will be considered. However, the effectiveness of the barrier will be limited due to the configuration of the recovery trench. Due to physical constraints the site, the trench will only be from 4 to 6 feet wide. Flow distances around the impermeable barrier would be relatively short thus minimizing the effect of the barrier.

5. If the migration of dissolved phase hydrocarbons is a concern for the site, the recovery trench should include active groundwater pumping for gradient control.

   Migration of dissolved phase Hydrocarbons is not addressed with the Recovery Trench. In addition, it is difficult to excavate the trench below the groundwater level, thus limiting the amount of draw down available.

6. The Draft Work Plan calls for Level B utility location to be performed prior to excavation of the recovery trench. This term should be defined.

   A level B utility location survey will be used to determine the approximate horizontal location of existing buried utilities. Plan review and nonintrusive field locating methods are employed such as electromagnetic, conductivity, etc. The utility survey will be further described in the Revised Work Plan

Section 4.0 Pilot Test Program

1. The Draft Work Plan states that the existing recovery system will be turned off prior to pilot testing to allow the subsurface to equilibrate prior to the test. However, the amount of time of equilibration and the rationale for it is not presented. Therefore, it is not possible to evaluate whether adequate time has been allowed for the aquifer to equilibrate. Allowing the aquifer to equilibrate before the test will ensure, to the extent possible, that aquifer changes observed during the test are the result of pumping influences and not recharge influences.

   We agree with the comment. Based on a review of the hydrogeologic information available and results from the pumping test conducted at recovery well PW-06, the specific yield of the formation is very low. To evaluate the benefit of the Pneumatic Fracturing program, several criteria will be used. They include changes in hydraulic properties, changes in product recovery rates/bailing and short duration pump tests, long term pump/product recovery evaluations. The difference in trends between pre- and post-testing evaluations will be used as Pneumatic Fracturing enhancement performance criteria.

2. The use of a proppant is a widely accepted practice in the petroleum industry and has been shown to improve the long-term stability of fractures and consequently the long-term performance of the recovery systems in general. Given the number of different recovery well configuration techniques that have been chosen for testing, it is unclear why it has been decided not to test the construction of a recovery well with a proppant. Using a proppant increases the costs for the technology and may not be warranted based on the geologic conditions. However, without a well constructed with a proppant for comparison, the assumption that use of a proppant is not necessary, or provides no benefit, is difficult to prove. Since the Draft Work Plan proposes to convert two existing monitoring wells to recovery wells with identical construction (PF/RW-1, PF/RW-2), perhaps one of these could be fractured and proppant installed to evaluate this technique.

   See answer to question #11 in previous section. McLaren/Hart agrees that it is difficult to negate the benefits of a proppant without testing this option. In developing the program and the various test scenarios to be evaluated (i.e., total fluid system, types of total fluid pumps, Pneumatic Fracturing well types, etc.) and based on the geologic information available at the time of workplan preparation, McLaren/Hart believes that enhancement of the formation could be achieved, with or without the use of a proppant, if the formation is pneumatically fractured. The longevity of the fracture system will be determined by the long term test program since longevity is a function of the mineralogy of the soil type (i.e., expansive soils "heal" quicker compared to granular soils) and the aggressiveness of the recovery system.

3. Section 4.3.1 references Table 2 as containing the construction details for the recovery and monitoring wells. It appears that the reference should be changed to Table 3, which contains the well construction details.

   That is correct.

4. It is suggested that the well reference PF/RW-1 be changed (renamed) to avoid any future confusion with the existing recovery well RW-1. Proposed well PF/RW-2 should be similarly renamed for consistency.

   PF/RW-1 and PF/RW-2 will be renamed to PF/RW-9 and PF/RW-10 respectively.

5. In general, the methodology for the pre-and post-fracture product recovery and short term pump testing appears to be sufficient, but the procedures and duration of the tests are unclear as presented in the text. Section 4.3.2 states that the pre-fracturing product recovery evaluation will be performed for 5 days prior to the fracturing program, while Table 4 indicates the testing will take place over 7 to 14 days. This section also states that following the short-term pilot test, a longer term pilot test will be performed until equilibrium conditions are achieved. However, this test and the purpose for it is not described. It is assumed that adequate time will be taken between tests to allow the aquifer to stabilize in order to prevent recharge affects from one test impacting data collected during the next test.

   Section 4.3.2 provides an outline of the proposed Baseline Test program. Tables 4 and 5 of the Workplan are presented to support the proposed program.

   As proposed in Table 4, the pre- and post-fracture product recovery evaluation includes shutting down recovery wells RW-1 and PW-06 and monitoring product recovery rates from strategic wells in both test plots to determine product removal and product recovery rates. The objective will be to conduct this test for 7 to 14 days before and after fracturing depending on the performance of the system and the timelines of the pilot test program.

   This test would also be complemented with the short duration pump test. The duration of this test is summarized in Table 5. The primary objective of this program is to determine the change in hydraulic properties before and after fracturing in the test plots. First, a step test will be performed in each test well and the data used to design a 4-hour pump test. It is anticipated that each well will require 1 day of testing. To complete each test plot, including set-up time 5 days estimated are estimated.

6. Contingency plans should be made to contain any groundwater and/or product that may be expelled from the monitoring wells during the test to prevent such spills from impacting any receptors. Given the shallow depth to groundwater, it is conceivable that the fracture injections could force water and product out of nearby wells if they are not very tightly secured. This occurrence has been observed during similar PF tests at other locations.

   McLaren/Hart agrees that groundwater and product can potentially be forced out of some wells during fracturing. To minimize this occurrence and to limit impact to receptors, strategic wells will be instrumented. See Figures 10 and 15 of the Workplan for well locations to be instrumented, and Table 3 lists the wells in each test plot and the materials of construction/notes.

McLaren/Hart will have the ability to attach hoses to the top of wells, such that discharge is routed to a drum. For fracture boreholes, McLaren/Hart proposes to evacuate these boreholes prior to fracture injections and/or to place sandbags on top of the boreholes, if necessary. McLaren/Hart is experienced in this type of response and will be prepared with a redundancy program as described above.

7. The pilot testing in Area PW-6 will occur very close to existing structures, so the impact of the fracturing on these structures should be monitored. The Draft Work Plan does specifically cite the risks to nearby structures and utilities when performing PF activities, thus the fracturing closest to the structures will be directed away from them. However, the Draft Work Plan does not specifically mention what precautions have been taken to ensure protection of the nearby structures, or if any utilities have been identified in the pilot test areas. It is recommended that full utility surveys be performed (if they have not been performed already), and that adequate precautions are taken to ensure the stability of any utilities identified. Additionally, any basements in the structures near PW-6 should be monitored for the presence of organic vapors. During the fracturing it is possible that organic vapors could be forced into these spaces given the close proximity of the structures.

   McLaren/Hart agrees that care should always be exercised when working near structures. To manage the fracture program in the vicinity of the fiberglass tank, McLaren/Hart will use the experience gained (i.e., injection pressures, flows, directional and radial fracturing techniques, and surface heave data) in the RW-1 pilot test plot and utilize it during the fracture program in the PW-6 pilot test plot. See Section 4.4.3.3 of the Workplan.

   As part of the McLaren/Hart Site Health and Safety Plan, a utility identification and clearance program will be performed. Based on preliminary information by site personnel, there are no utilities in the RW-1 pilot test area. In the PW-6 area, the utilities have been identified and marked off in the field. The locations of the proposed fracture wells were based on this information, and wells have been sited to minimize potential impact to the utility. The depth of fracturing, (i.e., $\geq$ 15 feet) is also well below the depth of the utilities.

8. Well construction and completion details presented in the text are confusing. It is not clear if any of the other open bore-hole PF borings are to be converted to monitoring wells, aside from F-1 and F-11, or if will they remain open bore holes. Furthermore, it is not clear whether these borings are to be completed with flush mount manholes, or if will they remain after the test is completed. This issue should be clarified.

   The Workplan is intended to be a working document for the pilot testing execution team and sections are intentionally written to be read in association with the referenced Tables and Figures. Please refer to Sections 4.3.1 for construction details for each test plot. With regards to F-1 and F-11, they are being converted to product recovery wells. They will be initially drilled in the same manner as the other pneumatic fracturing boreholes and retrofitted as product recovery wells. The other pneumatic fracturing boreholes will remain as open boreholes. Completion of these borings will be determined by the performance of the pilot test.

9. It appears from the Draft Work Plan that one reason for testing alternate pumps is because the well diameters of the fracture wells are too small to accommodate a standard size pump. This is discussed in Section 4.6.2, but the discussion is unclear on this point. If this is the case, it is suggested that a larger diameter borehole be used for the fracture wells to permit installation of a standard size 4-inch well following the fracturing. Installing 4-inch wells would permit the installation of standard size total fluids recovery pumps and eliminate the need to find and test an alternate pump that will fit in the 3.5-inch wells, such as the Jet Pumps. If larger diameter holes cannot be used, there are other pumps currently available on the market specifically designed for total-fluids product recovery that will fit in the 3.5-inch wells. Additionally, there are dual pump systems available for small diameter wells that may offer more precise control of the volume of water removed and would eliminate the need for an oil water separator.

   Comment noted. Pneumatic fracturing for this pilot test is limited to a maximum borehole diameter of 4 inches. Thus, retrofitting F-1 and F-11 is limited to casings that will fit within a 4-inch diameter borehole. A 3.5-inch diameter was chosen because it will give a "snug" fit between the borehole and casing.

10. The use of Jet Pumps for product recovery presents several concerns. Typically, the inlet of these pumps remains submerged to prevent the introduction of air into the recovered water stream. If these are to be used to recover product, the inlet of the pumps will likely be exposed to air as the water level in the well is drawn down in the well. This may cause two problems:

    - It may cause excessive surging and turbulence due to the suctioning of air, which may in turn cause product to become emulsified in the water stream, making it difficult to separate
    - It may cause the oxidation of dissolved minerals, such as iron and calcium if they are present, which will promote biological and chemical precipitation fouling of the piping and equipment.

    The only way to prevent this suctioning of air is to keep the pump inlet venturi submerged. One way to keep the venturi submerged and still recover product would be to add some type of liquid level controls, and to modify the pump inlet to a J-tube configuration.

    Comment noted. The baseline product recovery and post-product recovery tests are being modified to include high vacuum removal instead of a jet pump.

11. It is unclear from the Draft Work Plan whether the water generated during the pilot test will be treated before being discharged to the sanitary sewer system. It is also unclear whether any samples of this water will be collected and analyzed for treatment design parameters. If this water is to be discharged directly to the sewer system, it is assumed that all the appropriate authorities will be notified and permission obtained to perform this action. It is

recommended that periodic samples of the water be collected and analyzed for design parameters to confirm the actual discharge concentration and mass loading.

Comment noted. The water generated from the product recovery operation will pass through a treatment process before being discharged to a 2,500 gallon holding tank. The tank will be sampled before discharge to the sanitary sewer system. Base authorities will be notified and proper permits obtained before discharge.

Response to Comments Submitted by
John Tomik, CH_2M Hill, Inc.
Via E-mail
December 8, 1999

1. p. 4-4.

   What instruments will be used to measure radial effects of PF wells?

   The primary criteria for the measurement of ROI will be drawdown during pumping tests (i.e., short- and long-duration testing).

2. p.4-4

   How do you differentiate the radius of influence of a single PF well from the radius of influence of the multiple PF wells installed in the same area?

   Several wells will be instrumented during fracturing. McLaren/Hart recognizes that pressures or flows at wells are gross indicators of direction preference for fractures during a fracture program (i.e., directional or radial fractures). This information in addition to drawdown data from wells during pump testing, will be used to interpolate between wells and to make conclusions.

   McLaren/Hart recommends that a treatment strategy be implemented to enhance and optimize a treatment zone (i.e., use of directional and radial fractures) rather than focus on specific fractures.

3. p. 4-6

   Why are we removing well MTMW-4T? Can't this well be used as a monitoring well in the pilot test?

   MTMW-4 will be removed and replaced with a four-inch diameter recovery well. The reason that a new product recovery well will be installed is that this well shows evidence of product in the test area and it is located near existing wells (Mantec). Also, it is in an area where evidence of product was confirmed during the recent preliminary soil-boring program.

   Several of the wells around MTMW-4 will be instrumented and used as monitoring wells (see Figure 10 and Table 3 of the Workplan). Converting this well also allows a new well to be strategically located and fractured for enhancement of the proposed treatment area as shown in Figure 10.

4. p. 4-8 Table 5

   Why is the pre-fracturing test only run for 4 hours and the post-fracturing test is run for 90 – 120 days? If we are going to compare the before and after fracturing, shouldn't the tests be

run for the same duration? How will you demonstrate that any increase in product recovery rates are from the pneumatic fracturing and not the use of the jet pump or pneumatic pump?

The baseline-testing program is being expanded to address these issues. It will consist of a 30-day period where two types of product recovery pumps will be evaluated. This will provide adequate time to develop the pre-fracturing performance information that can be used to evaluate post-fracturing product recovery performance.

5. p 4-9

You stated on p 3-5 that all the free product zones are above the water saturation zone and the fractures will be predominantly horizontal. If this is the case, how does the fracturing increase the mobility of the free product?

The free product zones, as observed during the reconnaissance soil boring program and zones identified in former boring logs (i.e., Mantec logs for RW-1 area), show that the first evidence of moisture or water saturation occurs below the product zone for borings established to approximately 30 feet bgs. Refer to Appendix B of the workplan to review boring logs. However, the potentiometric surface of the groundwater or product/water interface is above the product and first water zones identified during the boring/drilling program. Refer to Sections 3.2.1 and 3.2.2 and Figures 7 and 9.

By fracturing the proposed treatment zone 15 – 30 feet bgs (includes unconsolidated and a few feet below first water/saturated zone), fractures from nearby fracture boreholes will overlap and intersect the product zones at the various elevations within the treatment depth. By increasing the effective permeability of the targeted treatment zone and applying a hydraulic stress to the formation, by the pumping action of the total fluids/pumping system, the mobility of the free product would be increased.

6. p. 4-9

Why is directional fracturing conducted? Wouldn't you maximize product recovery with radial fractures?

To optimize the fracture programs within a test plot, McLaren/Hart recommends a combination of directional and radial fractures. Based upon experience, if the fracture objective is to maximize fracture propagation in a specific direction, use of a special nozzle which is designed to focus the energy in that direction will create a longer fracture network which is predominant in that direction. The resultant fracture geometry is more elliptical than radial. For enhancement of existing wells and to limit the impact to buildings and utilities, this option will be integral to the success of the program.

7. p. 4-20

Should reference to Figure 18 be changed to Figure 16? What are the specifications of the treatment system: size of O/W separator, size and type of air stripping/carbon treatment

systems? It appears that a temporary discharge permit is required prior to conducting the test. How will you demonstrate that the discharge requirements (flow and water quality) will be met prior to the test? You indicate that treatment with air stripping and carbon will be provided "if necessary". How and when do you determine if this treatment is required?

Yes, Figure 18 should be changed to Figure 16.

Based on past testing performed at the site, the treatment system should be sized for a minimum of 5 GPM due to the low yields from recovery wells. Therefore, based on this minimum flow, all treatment equipment should be sized to treat this flow rate to discharge permit limits. This would result in a 5 GPM O/W separator; two 55-gallon drums of carbon, and a minimum of one 500-gallon storage/discharge tank.

The base sanitary treatment plant discharge permit provides up to 999 gallons per DAY (GPD) of additional flow. It is assumed that a temporary discharge permit will not be necessary to conduct this test due to the fact that the treated water from this test will be discharged to a sanitary sewer in the area, and the total discharge from the treatment system will be limited less than 999 GPD. A permit will be necessary should average discharge rates exceed 999 CPD. Another option will be to transport excess treated water to an off-site wastewater treatment facility or disposal facility.

Prior to commencing the test, mass balance calculations will be performed to determine if the treatment equipment selected for this test will be sufficient to address the levels of anticipated contamination in the groundwater. The level of contamination in groundwater that will be assumed in these calculations will be based on previous groundwater sampling as well as prior pump testing perfumed at the site.

Regarding whether carbon/air stripper will be provided "if necessary". This determination will be based on the results of previous groundwater sampling as well as prior pump testing performed at the site.

8. p. 4-20

You state that based on experience, on-site air stripping or carbon will not be required. Need to explain how this will be resolved.

Groundwater samples from two wells in the vicinity of the proposed test plots were obtained and analyzed for a full scan wastewater parameter list. Results indicted that the groundwater would meet the base Sanitary Treatment Plant influent criteria without pretreatment. We anticipate sufficient clarification and hydrocarbon separation will be accomplished with the sizable (2,500 gallon tank) surge tank and oil/water separator to meet treatment plant influent criteria. Carbon vessels will be provided in the treatment string as a contingency.

9. Will the increase in permeability cause product from PW-6 area to migrate towards the road or off-site faster?

   There is a possibility that this condition can occur. McLaren/Hart recognizes that the product recovery system needs to be implemented within 5 days of the treatment program. The location of the proposed recovery wells and the fracture direction program has been conceptualized to minimize migration outside of the proposed treatment area.

10. What effects will nitrogen have on buried utilities and buildings?

    Since nitrogen is an inert material, McLaren/Hart does not believe it will have any affect on buildings or utilities in the proposed treatment area.

ATTACHMENT 1

Development of a Computer Model and Expert System for Pneumatic Fracturing of Geologic Formations

CONFIDENTIAL

DEVELOPMENT OF A COMPUTER MODEL AND EXPERT SYSTEM FOR PNEUMATIC FRACTURING OF GEOLOGIC FORMATIONS

by
Brian Michael Sielski

A Dissertation
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Doctor of Philosophy

Department of Civil and Environmental Engineering

May 1999

CONFIDENTIAL

ABSTRACT

DEVELOPMENT OF A COMPUTER MODEL AND EXPERT SYSTEM FOR PNEUMATIC FRACTURING OF GEOLOGIC FORMATIONS

by
Brian Michael Sielski

The objective of this study was the development of a new computer program called PF-Model to analyze pneumatic fracturing of geologic formations. Pneumatic fracturing is an *in situ* remediation process that involves injecting high pressure gas into soil or rock matrices to enhance permeability, as well as to introduce liquid and solid amendments. PF-Model has two principal components: (1) Site Screening, which heuristically evaluates sites with regard to process applicability; and (2) System Design, which uses the numerical solution of a coupled algorithm to generate preliminary design parameters.

Designed as an expert system, the Site Screening component is a high performance computer program capable of simulating human expertise within a narrow domain. The reasoning process is controlled by the inference engine, which uses subjective probability theory (based on Bayes' theorem) to handle uncertainty. The expert system also contains an extensive knowledge base of geotechnical data related to field performance of pneumatic fracturing. The hierarchical order of importance established for the geotechnical properties was formation type, depth, consistency/relative density, plasticity, fracture frequency, weathering, and depth of water table.

The expert system was validated by a panel of five experts who rated selected sites on the applicability of the three main variants of pneumatic fracturing. Overall, PF-Model demonstrated better than an 80% agreement with the expert panel.

The System Design component was programmed with structured algorithms to accomplish two main functions: (1) to estimate fracture aperture and radius (Fracture Prediction Mode); and (2) to calibrate post-fracture Young's modulus and pneumatic conductivity (Calibration Mode). The Fracture Prediction Mode uses numerical analysis to converge on a solution by considering the three coupled physical processes that affect fracture propagation: pressure distribution, leakoff, and deflection. The Calibration Mode regresses modulus using a modified deflection equation, and then converges on the conductivity in a method similar to the Fracture Prediction Mode.

The System Design component was validated and calibrated for each of the 14 different geologic formation types supported by the program. Validation was done by comparing the results of PF-Model to the original mathematical model. For the calibration process, default values for flow rate, density, Poisson's ratio, modulus, and pneumatic conductivity were established by regression until the model simulated, in general, actual site behavior.

PF-Model was programmed in Visual Basic 5.0 and features a menu driven GUI. Three extensive default libraries are provided: probabilistic knowledge base, flownet shape factors, and geotechnical defaults. Users can conveniently access and modify the default libraries to reflect evolving trends and knowledge.

Recommendations for future study are included in the work.

ABOUT PF-MODEL

PF-MODEL is computer program designed to analyze pneumatic fracturing of geologic formations. Pneumatic fracturing is an *in situ* remediation process that involves injecting high-pressure gas into soil or rock matrices to enhance permeability, as well as to introduce liquid and solid amendments. PF-Model has two principal components: (1) Site Screening, which heuristically evaluates sites with regard to process applicability; and (2) System Design, which uses the numerical solution of a coupled algorithm to generate preliminary design parameters.

PF-Model was programmed in Visual Basic 5.0 and features a menu driven GUI. The program can also be command driven if desired. Three extensive default libraries are provided: probabilistic knowledge base, flownet shape factors, and geotechnical defaults. Users can conveniently access and modify the default libraries to reflect evolving trends and knowledge.

Site Screening Component

Designed as an expert system, the Site Screening component is a high performance computer program capable of simulating human expertise within a narrow domain. The reasoning process is controlled by the inference engine, which uses subjective probability theory (based on Bayes' theorem) to handle uncertainty. The expert system also contains an extensive knowledge base of geotechnical data related to field performance of pneumatic fracturing. The hierarchical order of importance established for the geotechnical properties was formation type, depth, consistency/relative density, plasticity, fracture frequency, weathering, and depth of water table.

The expert system was validated by a panel of five experts who rated selected sites on the applicability of the three main variants of pneumatic fracturing. Overall, PF-Model demonstrated better than an 80% agreement with the expert panel.

Site Screening Component

The System Design component was programmed with structured algorithms to accomplish two main functions: (1) to estimate fracture aperture and radius (Fracture Prediction Mode); and (2) to calibrate post-fracture Young's modulus and pneumatic conductivity (Calibration Mode). The Fracture Prediction Mode uses numerical analysis to converge on a solution by considering the three coupled physical processes that affect fracture propagation: pressure distribution, leakoff, and deflection. The Calibration Mode regresses modulus using a modified deflection equation, and then converges on the conductivity in a method similar to the Fracture Prediction Mode.

The System Design component was validated and calibrated for each of the 14 different geologic formation types supported by the program. Validation was done by comparing the results of PF-Model to the original mathematical model. For the calibration process, default values for flow rate, density, Poisson's ratio, modulus, and pneumatic conductivity were established by regression until the model simulated, in general, actual site behavior.

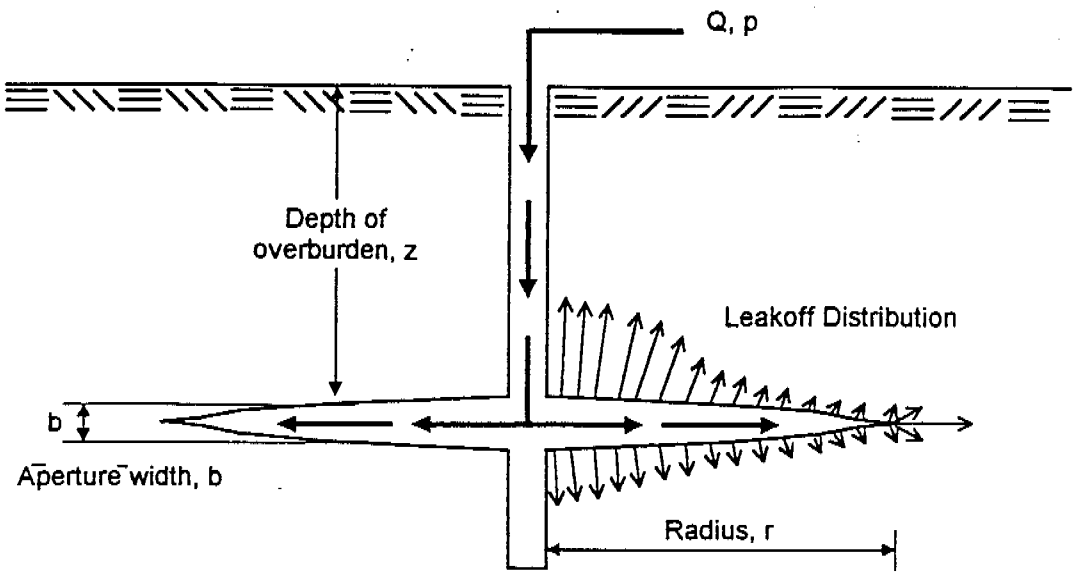
For More Information:

PF-model makes extensive use of research on the pneumatic fracturing process performed at the Center for Environmental Engineering and Science (CEES) at New Jersey Institute of Technology (NJIT). To obtain more information on PF-Model, contact Dr. John Schuring at the Department of Civil and Environmental Engineering at 973-596-5849. For documentation on model engines, deflection solvers, solution methods, and expert system design, the following references are helpful:

Sielski, B., *Development of a Computer Model and Expert System for Pneumatic Fracturing of Geologic Formations*, Ph.D. Dissertation, Department of Civil and Environmental Engineering, New Jersey Institute of Technology, Newark, NJ, May 1999.

Puppala, S., *Fracture Propagation and Particulate Transport in Pneumatically Fractured Geologic Formations*, Ph.D. Dissertation, Department of Civil and Environmental Engineering, New Jersey Institute of Technology, Newark, NJ, August 1998.

Pneumatic Fracturing Process



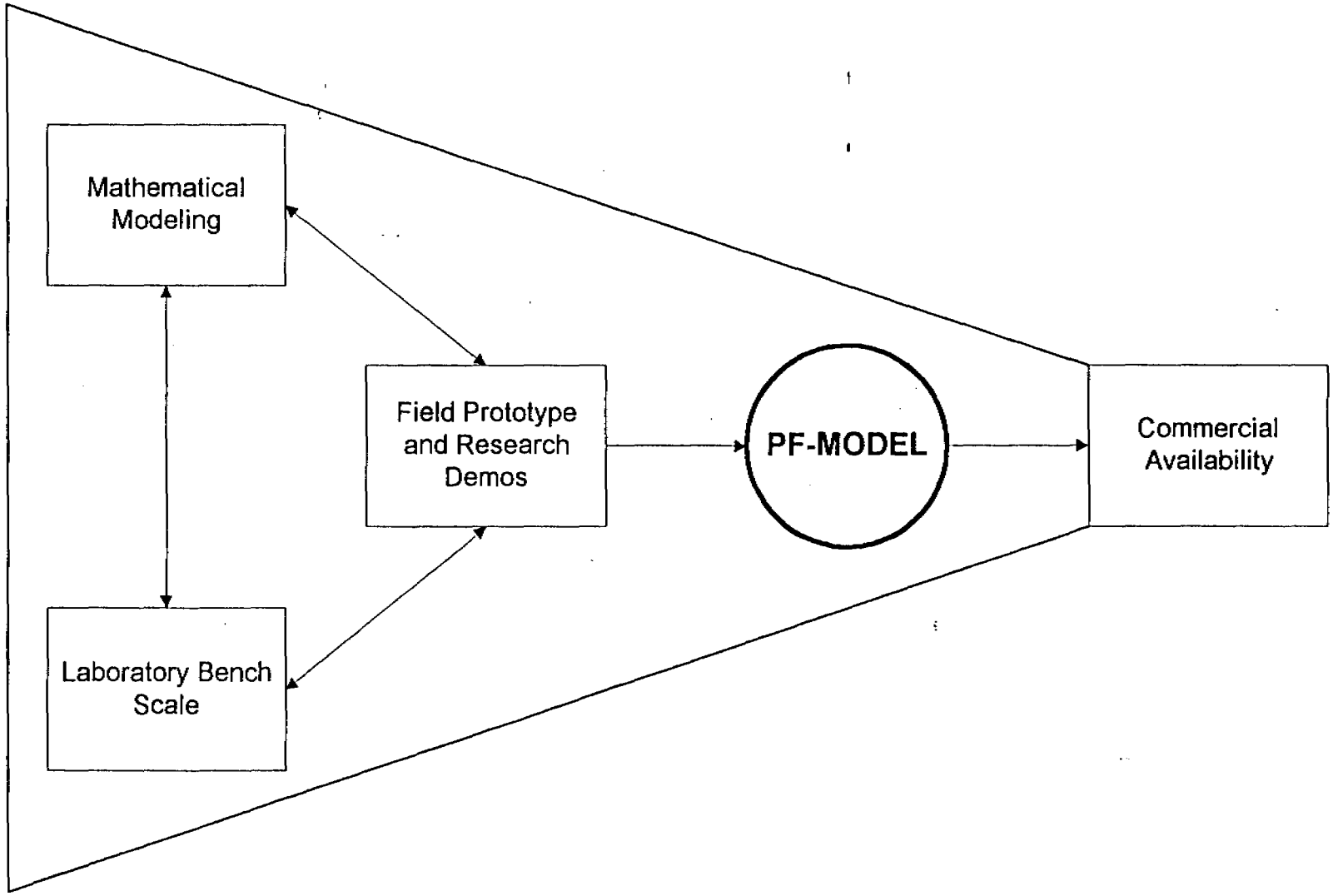
Pneumatic fracturing is an *in situ* enhancement technique that can:

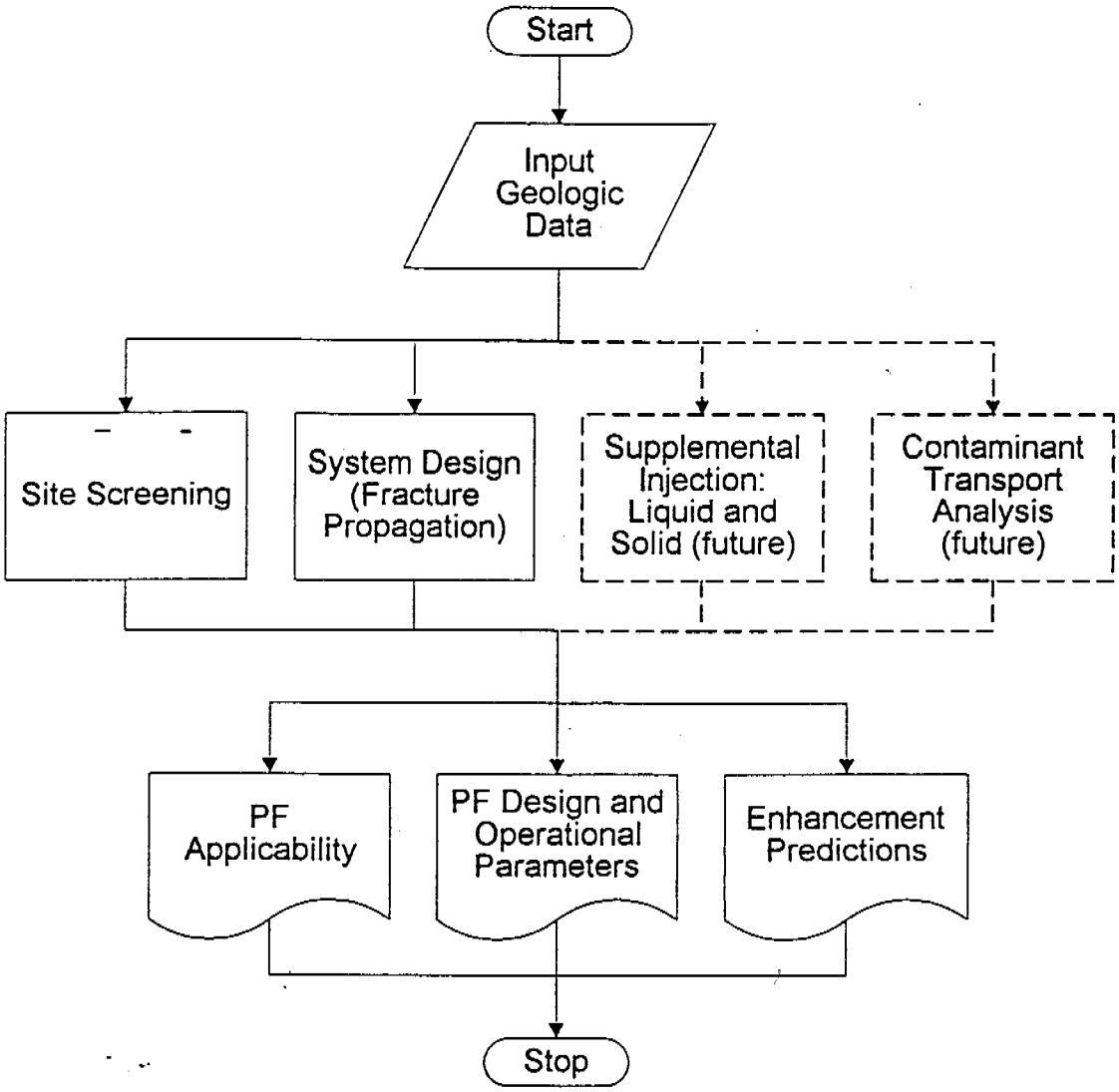
- Increase pneumatic/hydraulic conductivity
- Shorten diffusive distances
- Improve homogeneity
- Allow better gradient control
- Deliver liquid or granular supplements into the formation including:
  - nutrients and buffers
  - inocula
  - chemically reactive media
  - conductive media
  - proppants

Outline

- Overview and Objectives
- Site Screening Component
- System Design Component
- Validation and Calibration
- Default Libraries
- *PROGRAM DEMONSTRATION*

PF-MODEL


Mathematical Modeling
Field Prototype and Research Demos
PF-MODEL
Commercial Availability
Laboratory Bench Scale


Start
Input Geologic Data
Site Screening
System Design (Fracture Propagation)
Supplemental Injection: Liquid and Solid (future)
Contaminant Transport Analysis (future)
PF Applicability
PF Design and Operational Parameters
Enhancement Predictions
Stop

Why an Expert System?

- Pneumatic fracturing is a narrow domain
- Knowledge is known by only a few individuals
- Real solutions tend to be approximate and use "rules of thumb"

Geotechnical Qualifiers

Formation Type

Clay
Clayey Sand
Clayey Silt
Silty Clay

Silt
Silty Sand
Sand
Sand & Gravel
Gravel

Shale/Siltstone
Sandstone
Limestone/Dolomite
Granite/Gneiss/Schist
Basalt

Depth for Rocks

< 4 ft
4 - 8 ft
> 8 ft

Depth for Soils

< 6 ft
6 - 12 ft
> 12 ft

Consistency

Soft
Medium
Stiff

Relative Density

Loose
Medium dense
Dense

Plasticity

$w < PL$
$PL < w < LL$
$w > LL$

Fracture Frequency

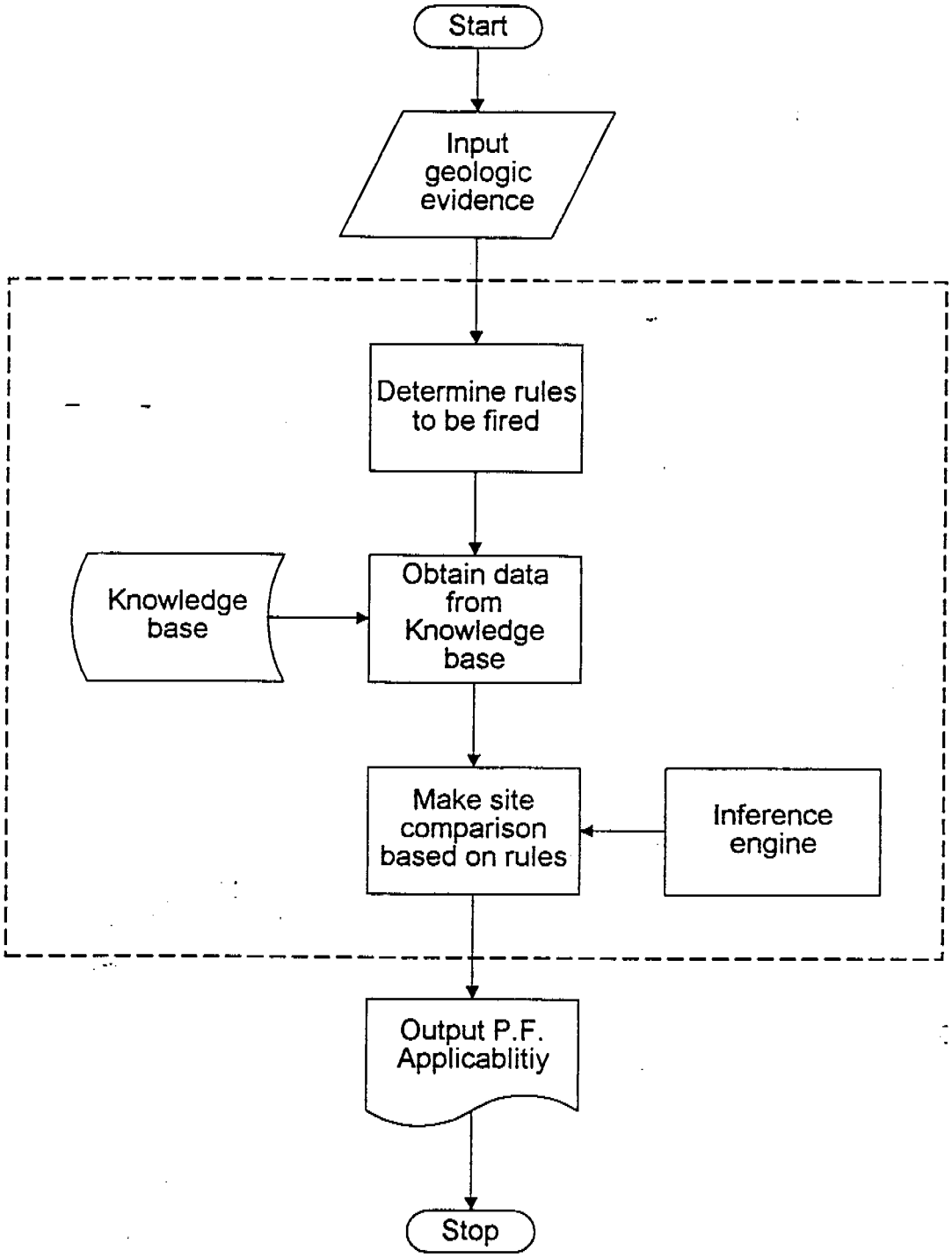
Widely jointed
Medium jointed
Closely jointed

Weathering

Slightly weathered
Moderately weathered
Heavily weathered

Water Table

Fracturing is above
Fracturing is below


Start
Input geologic evidence
Determine rules to be fired
Knowledge base
Obtain data from Knowledge base
Make site comparison based on rules
Inference engine
Output P.F. Applicablitiy
Stop

Handling Uncertainty

A mathematical extension of Bayes' Rule modified for expert systems was used.

For multiple evidence and multiple hypotheses:

$$p(H_i|E_1E_2...E_n) = \frac{p(E_1E_2...E_n|H_i) \times p(H_i)}{\sum_{k=1}^{m} p(E_1E_2...E_n|H_k) \times p(H_k)}$$

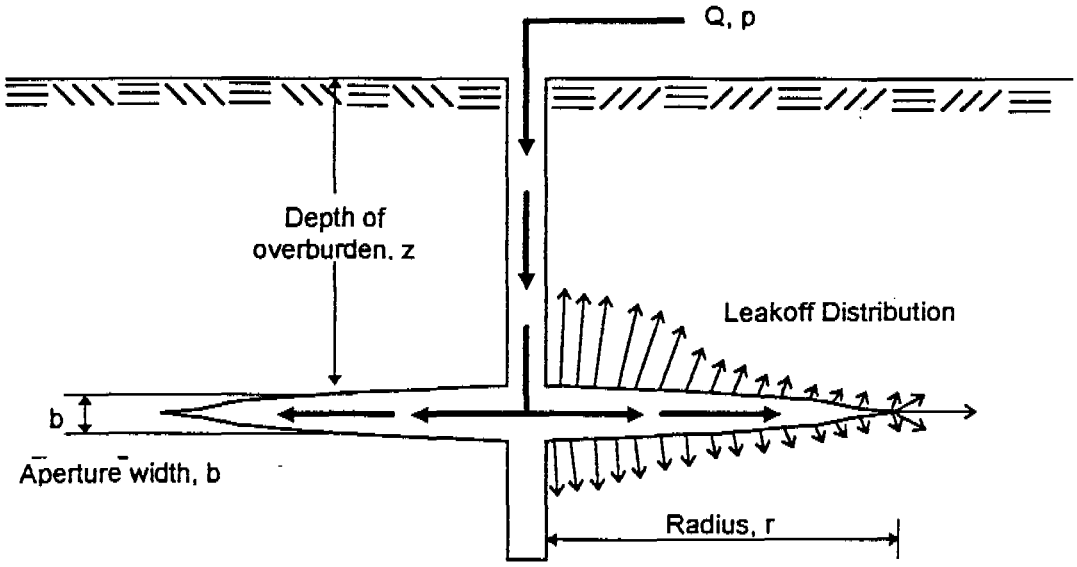
Given conditional independence:

$$p(H_i|E_1E_2...E_n) =$$

$$\frac{p(E_1|H_i) \times p(E_2|H_i) \times ... \times p(E_n|H_i) \times p(H_i)}{\sum_{k=1}^{m} p(E_1|H_k) \times p(E_2|H_k) \times ... \times p(E_n|H_k) \times p(H_k)}$$

Hierarchical Order of Geotechnical Properties

- Formation type
- Depth
- Plasticity (soils)
- Relative Density/Consistency (soils)
- Fracture frequency (rocks)
- Weathering (rocks)
- Water table



Three physical processes controlling fracture propagation:

- **<u>Pressure loss</u> due to fluid friction**
- **<u>Leakoff</u> into the surrounding formation**
- **<u>Deflection</u> of the overburden**

Coupling the Physical Processes

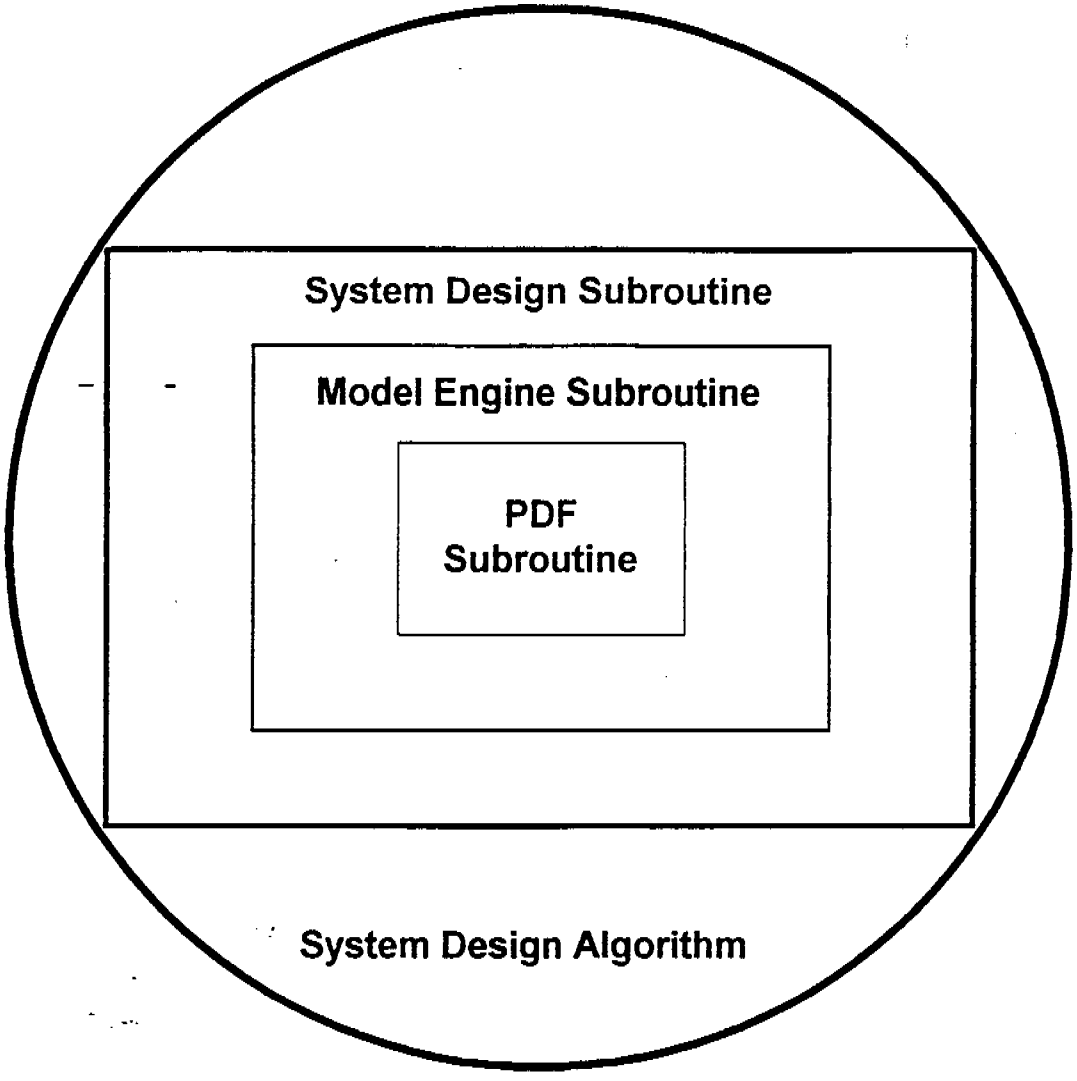
Mathematical coupling of these physical processes determines aperture and radius of a pneumatic fracture:

$$p_r = f\left(Q_{res}, m_{gas}, r_{gas}, r, b, p_w\right)$$

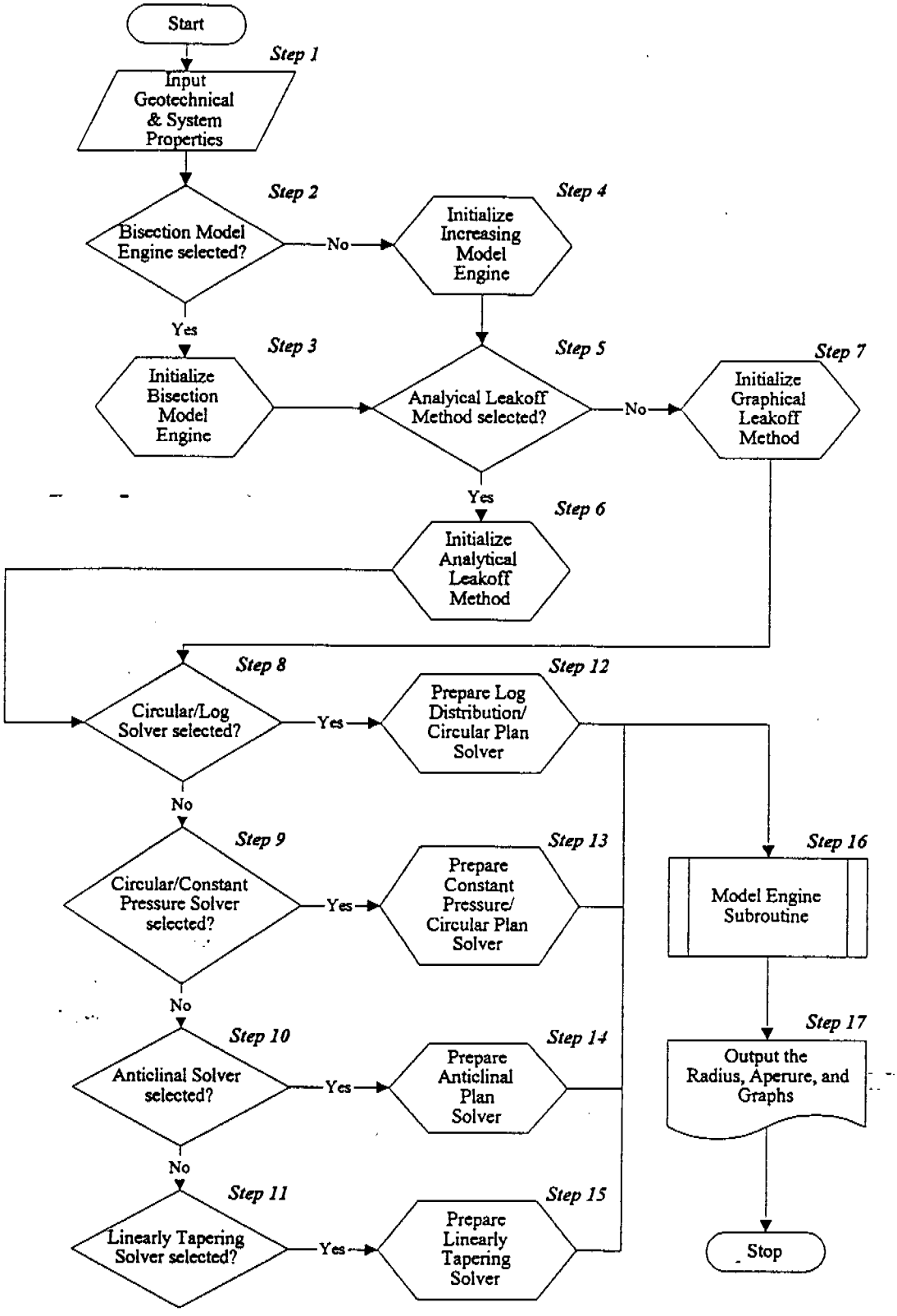
$$Q_{leak} = f\left(R, p_r, K_{h-gas}, K_{v-gas}, z, {}^{N_f}\!/_{N_d}, t\right)$$

$$b = f\left(R, E, u, p_r, z, t\right)$$

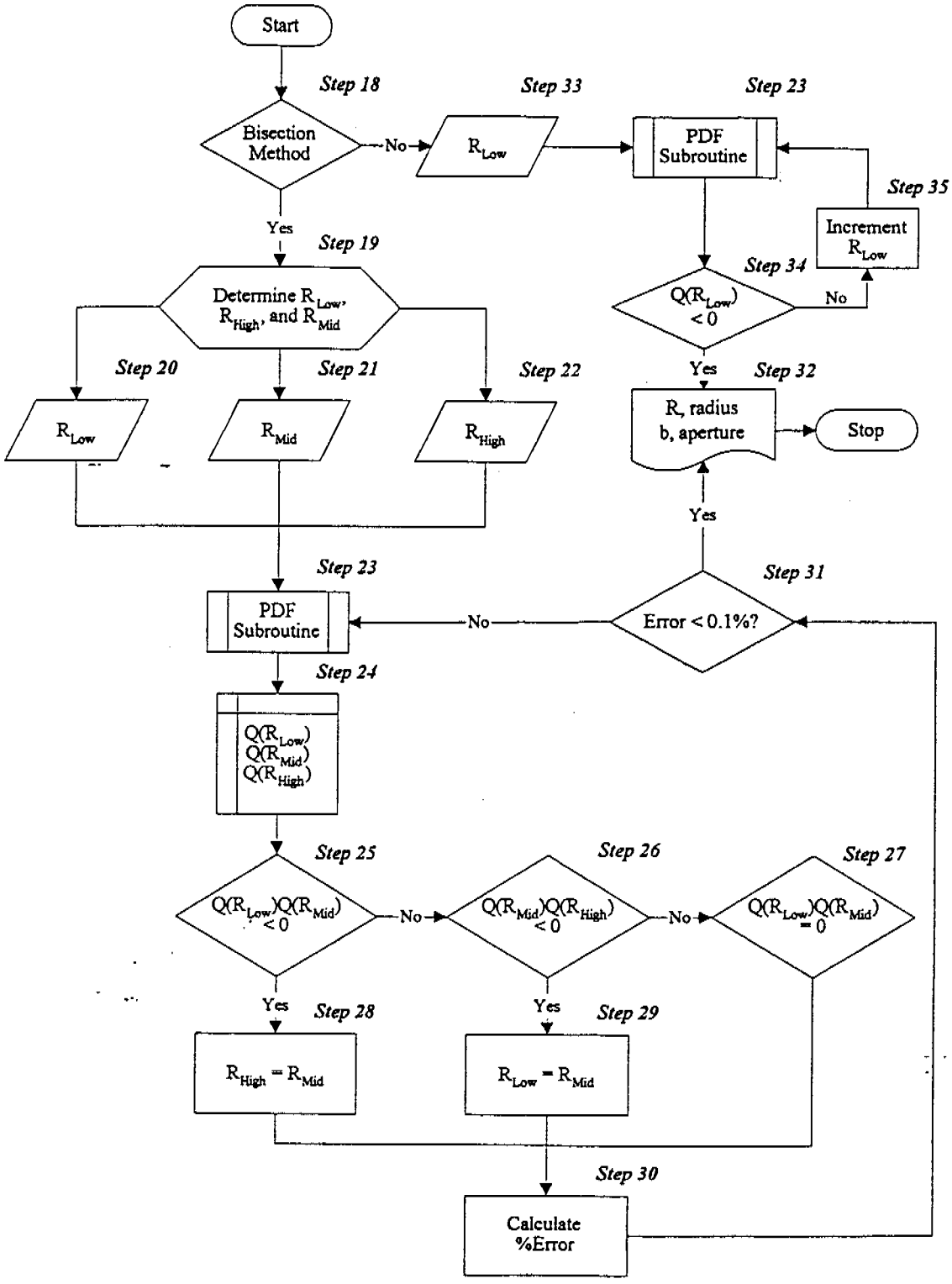
System Design Algorithm



System Design Subroutine



Model Engine Subroutine



System Validation and Calibration

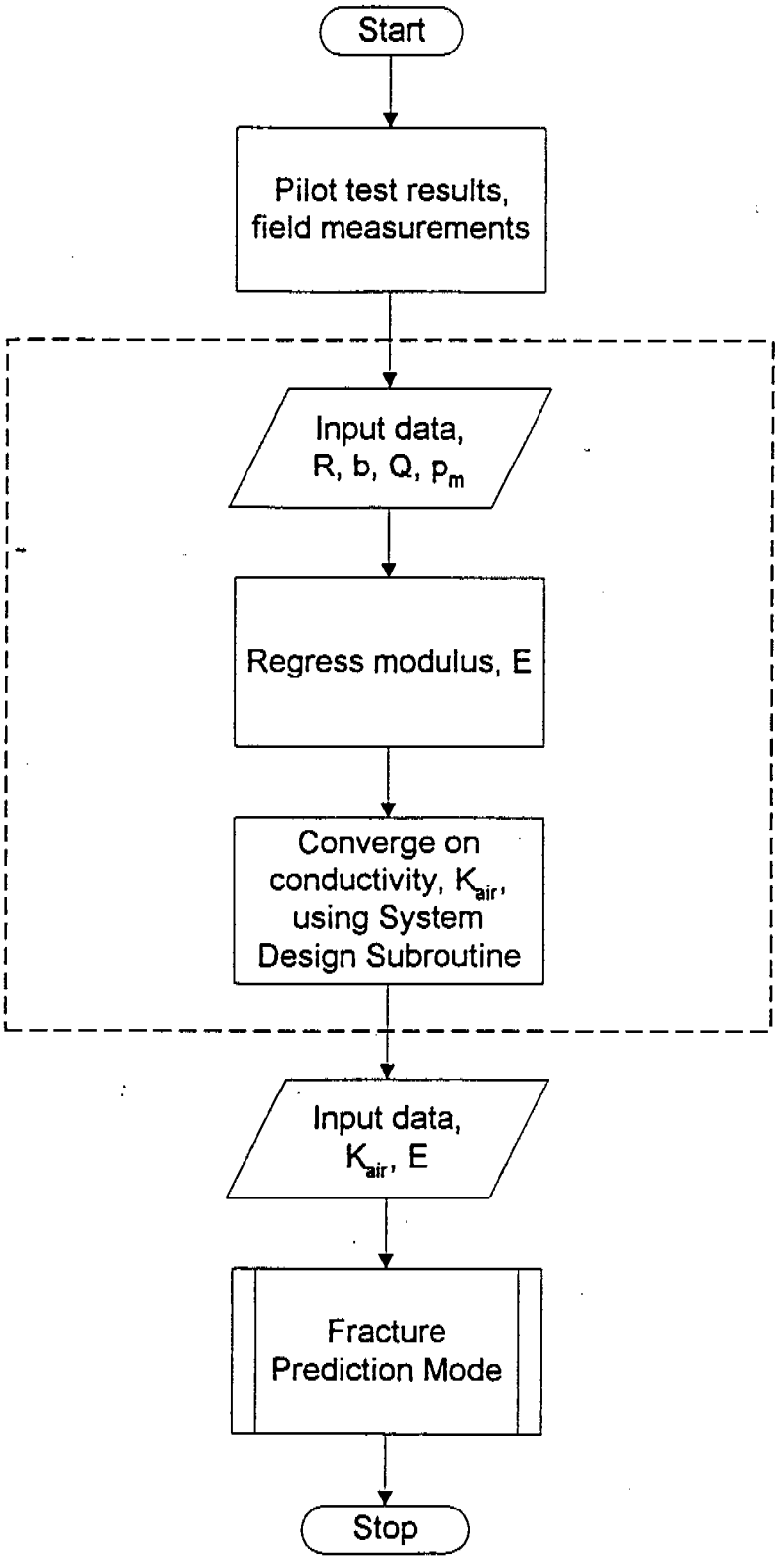
Site Screening:

- Test criterion
- Test cases
- Panel of expert evaluators
- Demonstrated better than 80% agreement

System Design:

- Calibrated to existing sites
- Default values regressed for geotechnical and system properties
- Approximated actual site behavior

Calibration Mode



Default Libraries

Knowledge base (Probabilistic default library):

- allows for updates as technology evolves and increases

Geotechnical and system default library:

- allows input of proprietary information

Flownet default library:

- allows for future expansion of array

ATTACHMENT 2

Mechanism of Pneumatic Fracturing

MECHANISM OF PNEUMATIC FRACTURING

by
Trevor Compton King

A Thesis
Summitted to the Faculty of
New Jersey Institute of Technology in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Environmental Engineering

Department of Civil and Environmental Engineering

May 1993

2.2 Methodology of Pneumatic Fracturing

Figure 2 shows the prototype pneumatic fracturing system. The first step in applying the pneumatic fracturing technology, consists of drilling boreholes to predetermined depths in a selected area. The location and depths of these boreholes is determined by the hydrogeology of the site, as well as the distribution of the contaminant.

Next, a pneumatic device known as an "HQ injector" is inserted into the borehole to a predetermined elevation. The nozzle can be positioned at any elevation within the hole depending on the desired number of fractures, and degree of aeration required. The seals of the HQ injector are inflated using nitrogen gas which isolates an approximate two foot borehole section for the injection.

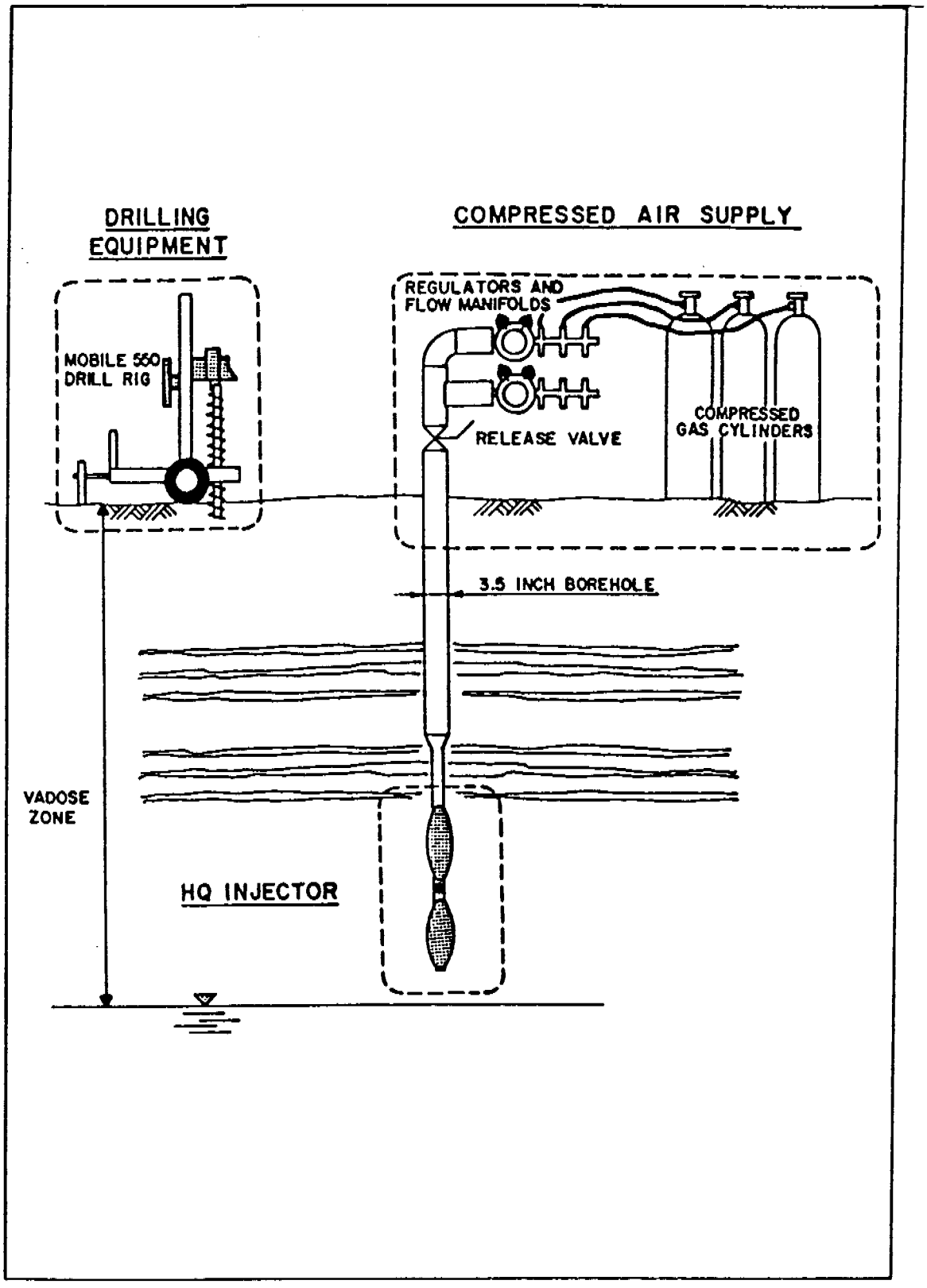


Figure 2 Prototype Pneumatic Fracturing System.

The inflation pressure of the packers is important from a fracturing efficiency and safety perspective. It has been found that during pressurization of the interval, there is a tendency for the pressure to force the packers away from the interval. This movement is counteracted both by the frictional forces that exist between the seals and the borehole, as well as the attaching rod between the two seals.

A packer friction test is conducted prior to any fracture operation to determine the proper inflation pressure of the packer for the particular formation. For most formations the packer is inflated to at least twice the anticipated injection pressure.

The fracturing process involves the injection of high-pressured air or other gas through the HQ injector and into the geologic formation for a specific time period. The pressurized air required to initiate pneumatic fractures is controlled by a pressure manifold system. This system consists of regulators, valves, pressure gauges and a compressed air source.

The injection pressures and flow rates are selected so that they exceed material in-situ stresses and the permeability of the formations. The fracture initiation pressures have been found to be relatively modest and to range below 100 psi for the soils tested and below 200 psi for rock formations tested. To date, fracturing has been conducted at depths ranging from 3 to 21 ft.

The response of geologic formations to pneumatic fracturing and the potential benefits which may be derived, depend on the nature of the deposit. In fine-grained soils, which naturally have low permeability values, pneumatic injections create conductive channels which increase the permeability and exposed surface area of the formation. Application of pneumatic fracturing to fine-grained soils is shown conceptually in Figure 3.

For coarse-grained soils e.g. sand and gravel, whose natural permeability is already high, the ability to create new fractures is limited. However, the process provides a means for rapidly aerating the formation under aerobic and anaerobic conditions. As

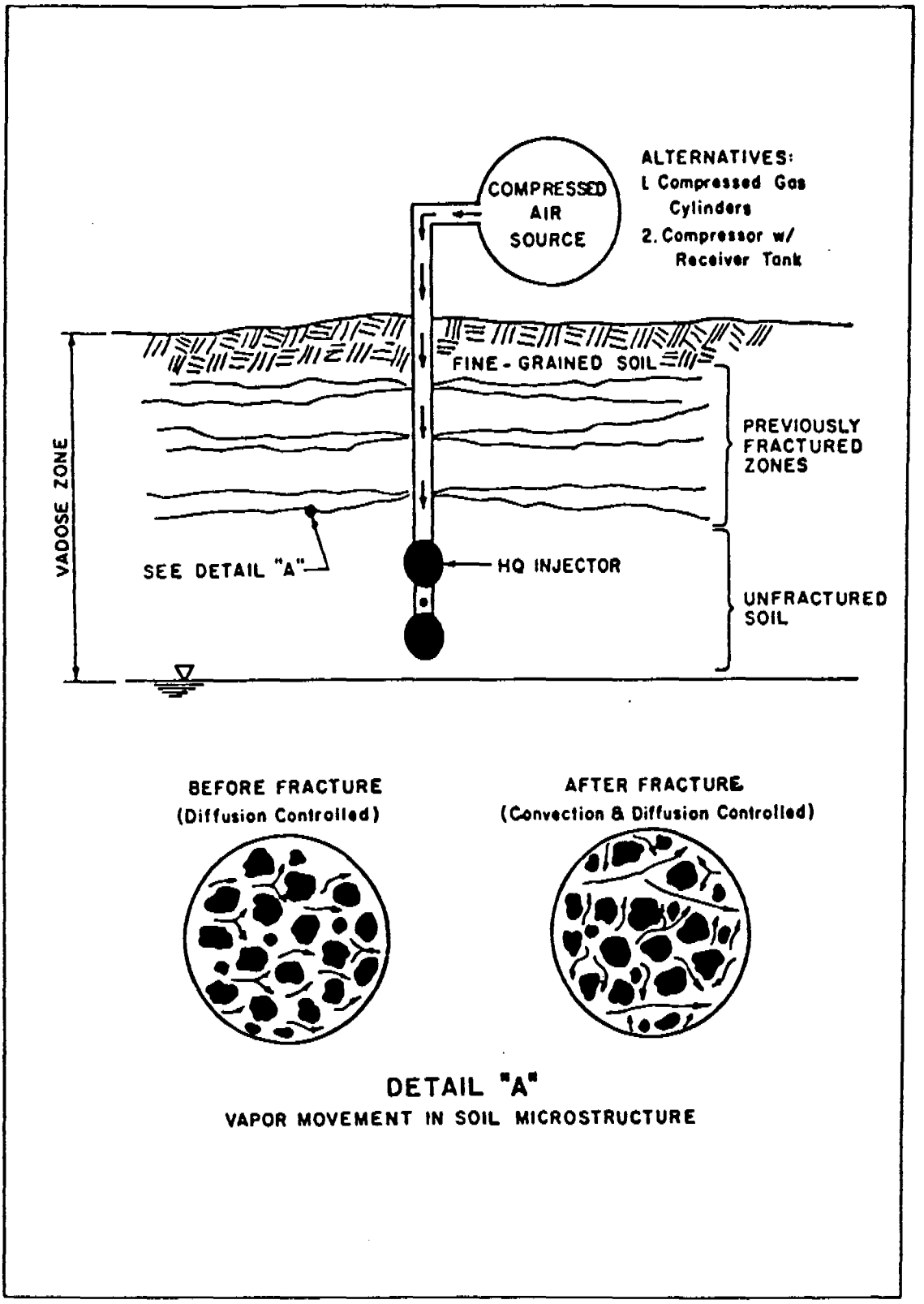


Figure 3 Pneumatic Fracturing Concept for Fine-Grained Soils.

indicated in Figure 4, an injection of two minutes in duration can affect a radius of up to 18 feet from the borehole.

For sedimentary rocks, such as shale and sandstone, pneumatic fracturing can enhance formation permeability by widening the apertures of existing discontinuities and/or clearing soil fillings from primary joints. It may also create a minor amount of new fractures. The application of pneumatic fracturing to sedimentary rock is depicted in Figure 5.

Although the response of different geologic conditions to pneumatic fracturing will vary, the net effect remains the same, i.e. acceleration of the rate at which pore gases and liquids can move through the formation. This will result in reduction of in-situ remediation times and also extension of current technologies to more difficult geologic conditions.

CHAPTER 4

4.1 General Approach

This section describes an original approach to predict fracture initiation pressures for pneumatic fracturing. Consideration has been given to hydraulic fracturing theory, with appropriate modifications to account for the uniqueness of air as an injection fluid. The first section will begin with a qualitative assessment of fracture measurements which is used to describe the mechanism of pneumatic fracturing. Next, an analytical model for predicting fracture initiation pressure will be presented, followed by a regressive analysis to establish coefficients for the proposed model.

4.2 Pneumatic Fracturing Initiation

In the development of an analytical model for pneumatic fracturing, it is first necessary to analyze pressure-time histories of the injection process. Useful background information was obtained from previous work done in hydraulic fracturing, since it was observed that pressure-time histories in pneumatic fracturing are similar. After reviewing the pressure-time histories generated during numerous pneumatic fracturing injections, it was observed that the fracturing event can be divided into several distinct stages:

- Breakdown of the formation.
- Fracture extension.
- Fracture maintenance.
- Fracture residual.
- Fracture reopening.

These stages are illustrated in Figure 17, and they apply to an idealized geologic formation. It is noted that the shape of the pressure-time history curve depends on a number of factors including in-situ stress fields and geologic characteristics of the medium.

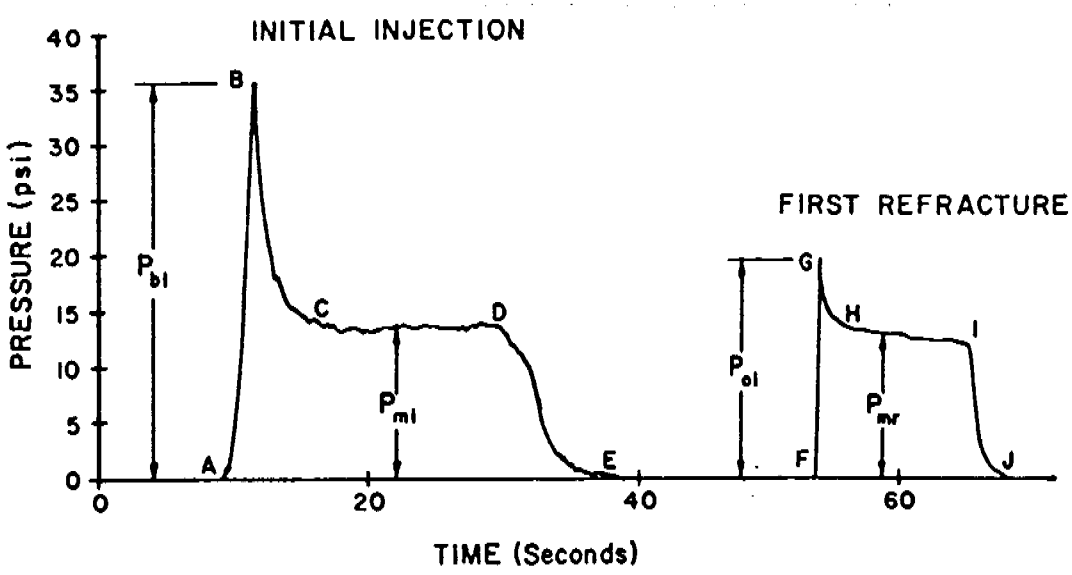


Figure 17 Schematic of an Idealized Pressure-Time history for an Initial Fracture and a Refracture

The following section describes each stage as it relates to the pneumatic fracturing mechanism shown in Figure 17.

During the first stage known as "breakdown", the pressure rapidly builds up as air is injected into the sealed portion of the borehole. This stage is indicated by curve segment A-B. It is possible to develop these elevated pressures because the formation is not yet fractured and still has a low permeability. This stage is relatively short and typically lasts 2 to 3 seconds.

Once the pressure exceeds the in-situ stress conditions and media strength prevailing around the pressurized borehole, breakdown of the formation occurs. The pressure at this instant is known as the breakdown pressure, P_b, which is the minimum pressure that can initiate fractures at a particular depth for a given geologic formation. At the depths and for the soil types tested, pneumatic fracture initiation pressures were found to range between 20 to 50 psi, and for the rock formations, they ranged from 100 to 160 psi. The higher values for rock can be attributed to higher tensile strengths and densities in the formations.

Following breakdown, the pressure decreases rapidly in the borehole and eventually stabilizes at a pressure "plateau" as injection continues. During this time period, air rushes out of the pressurized interval and fractures propagate radially into the formation. This accounts for the rapid decline in the borehole pressure as represented by the curve segment B-C. Based on observations of ground surface heave during injection, fracture extension is quite rapid and typically continues for 3 to 6 seconds only.

The pressure "plateau" C-D represents a period of fracture maintenance which is nearly constant for the remainder of the injection period. This is designated as the initial maintenance pressure, P_{mi}. This pressure indicates that an equilibrium state has been attained for that particular injection flow rate. During this equilibrium state, crack propagation ceases and the affected overburden area can be visualized as "floating" on a cushion of air. During this period, the flow rate into the fractured formation exactly

equals the leak-off into the formation from the fracture surfaces and tips. This contrasts with the earlier stages of fracture formation, i.e. breakdown, and propagation, during which the flow rate into the fractured formation is greater than that leakoff.

As the injection pressure is terminated, the maintenance pressure declines rapidly from D to E. This decline is due to the natural tendency of the formation to return to its original state and also the continuing leak-off of the air into the formation. This process continues until a state is reached where no further closures take place. The residual fractures are then supported by a combination of asperities and block shifting along the fracture network. This phenomenon is known as "self-propping", and the pressure at which this occurs is represented by the change in slope at E.

During the refracture of a formation, the trends of the pressure-time histories are similar as indicated by curves F-J in Figure 17. There are however differences in the magnitude of the pressures which are summarized as:

- The pressure , P_o, at which reopening occurs is less than the breakdown pressure, P_b.
- The reopening pressure, P_o, is greater than the maintenance pressure, P_m.
- Subsequent maintenance pressures, P_{mr}, decline progressively compared with previous maintenance pressures.

The difference between P_b and P_o is attributed to the initial cohesion and/or tensile strength that originally exists in a formation. During subsequent injections these initial strengths have already been overcome, thereby resulting in lower reopening pressures P_o. It is probable, however, that some residual cohesion and/or tensile strength may still have to be overcome in subsequent refracture injections.

It is significant to note that a pressure spike was obtained during reinjection, to reopen the fracture, designated as curve segment F-G-H. This spike was consistently observed during all field tests, and indicates that when reopening a previously fractured formation, it is not sufficient to just overcome the overburden stress, i.e. inject at the

maintenance pressure, P_m. It is believed that the spike is caused by one or more of the following factors. First, even a fractured formation can exhibit a residual cohesion and/or tensile strength. Possible sources of this residual value could be rehealing of the solid fractured surface or surface tension effects due to moisture. A second factor which may also contribute to the pressure spike is gas compressibility. During the first one to two seconds of injection, the gas in the packed off interval becomes highly compressed. During this period , the compressed gas is behaving elastically and is storing any work done as strain energy. As the formation reopens, the strain energy is released and the maintenance pressure is attained.

Another factor which may contribute to a pressure spike is formation inertia. Since the pneumatic injection is very rapid, the mass of the overburden will initially resist dilation of the existing fracture network. Upon reopening, the inertia is overcome and the pressure then reduces to maintenance levels. Of notable interest in the data, is the successive decrease in maintenance pressure with each injection. This is attributed to the progressive weakening of the formation each time it is refractured and disturbed. Progressive extension and cleaning (removal of loose deposits)of fractures may also contribute to this phenomena. The observed reduction in surface heave during reinjection compared with initial injections supports the above hypothesis.

The actual pressure-time histories for the geologic formations studied are given in Appendix C_1 to C_{20}. A review of these curves have led to the following general conclusions:

- Fracture breakdown pressure, P_b, is proportional to the overburden pressure (formation depth and density).
- Fractures become fully established within the first 5 to 10 seconds of injection. Continued injection after this period at the same flow rate, does not significantly increase fracture growth, but may instead contribute to cleaning of the fractures.
- Less pressure is required to refracture the formation.

- Tensile or cohesive strengths of the geologic formation are most significant during initial fractures.
- Maintenance pressures decrease slightly with each successive injection.

The general conclusions drawn from the pressure-time histories were useful in formulating the model described later in this chapter.

APPENDIX B

NAVAL BASE ACCESS REQUIREMENTS

Date_ 16

From: Public Works Department
To: Officer in Charge, Security Detachment

Subj: REQUEST FOR GENERAL PURPOSE PASS

1. It is requested that a General Purpose Pass be issued to:

Last Name First Name M.I. Classification/Rate/Rank (State if Supervisor)

Address

SSN Company Name (If applicable)

Contract Number:
Contract Title:_____

2. It is understood that this application is submitted to enable the bearer to be admitted through the Naval Station gates without escort to conduct business within the time limits stipulated on the pass.

3. It is also understood that passholders are required to turn in their General Purpose Pass to the gate sentry or Pass and ID Office upon expiration. If the pass is issued without a picture, the passholder must present a valid pictured ID with the pass.

4. Pass Information:

Required period of access (i.e. 30 NOV91-03DEC91) _____
Required days of access (i.e. Mon-Wed) _____
Required times of access (i.e. 0800-1600) __
Birth Date _____ Height _____ Weight _____
Color Hair _____ Color Eyes _____ Admit with vehicle Y

Sponsor Signature | ENV ENG DIR/ Classification/Rate/Rank | SSN

PUBLIC WORKS DEPARTMENT (809) 865-4429
Command Work Phone

FIRST ENDORSEMENT

From: Officer in Charge, Security Detachment
To: General Purpose Pass Applicant

Subj: REQUEST FOR GENERAL PURPOSE PASS

1. Returned, Approved/Disapproved.
2. Security Record:

Category of pass _____ Authorized Access Code _____ Guest Authorized YES/NO
Good Conduct Certificate filed YES/NO Issued Date _____
Good Conduct Receipt on file YES/NO Pass Number _____

OIC, SECDEP or Designated Representative

Date:

From: **PUBLIC WORKS DEPARTMENT, ENVIRONMENTAL ENGINEERING DIVISION**
To: Officer in Charge, Security Department

Subj: **REQUEST FOR TEMPORARY BASE ACCESS**

1. It is requested that a TEMPORARY BASE ACCESS be issued to the following individual(s):

Contract Title:

Purpose of Visit:

LAST NAME	FIRST NAME	MI	SS#	COMPANY's NAME

2. It is understood that this application is submitted to enable the bearer to be admitted through the Naval Station gates without escort to conduct business with the time limits stipulated on this request.

Required period of access (i.e. 30NOV95-05DEC95)
Required days of access (i.e. Mon-Wed)
Required times of access (i.e. 0800-1600)

S. CASTILLO — EED DIRECTOR GS-13 (Rate/Rank) — SSN

PWD (Command) — 865-4429 (Work Phone)

FIRST ENDORSEMENT

From: Officer in Charge, Security Detachment
To: General Purpose Pass Applicant

Subj: REQUEST FOR TEMPORARY BASE ACCESS

1. Returned: Approved_____ Disapproved_____

2. Issue Date:_____

_____
OIC, SECDET or Designated Representative

APPENDIX C

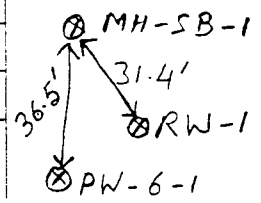
SOIL BORING LOGS:

1 - McLaren/Hart
2 – Mantech Environmental
3 – RW-1

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**MH-SB-1**
Client:	U.S. Naval Station
Boring Location:	MH-SB-1
Northing:	18.23204716
Easting:	-65.61994268
Start - Finish Date:	9/17/99 - 9/17/99
Drilling Contractor:	STC
Driller:	Robert Marrero Mojica
Logged By:	Will Whitesell/Pittsburgh
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	BK-51
Total Depth (ft):	18.0
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch

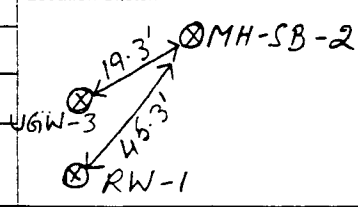


Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
		1.63/2	SILT, clayey, stiff, light brown, tan; with fill. Dry.			S-1
2		1.25/2	SILT, clayey, stiff, reddish brown and light gray; with some silty sand. Dry.		0	S-2
4		0.83/2	SILT and GRAVEL, very stiff, gray red; with some pebbles and cobbles.		1	S-3
6		0.75/2	SILT, very soft, light brownish tan; with some orange stained fresh and weathered gabbro. Dry.			S-4
			SILT, medium stiff brown; with light gray and orange severly weathered and fresh gabbro.			
8		1.17/2				S-5
10		1/1	SILT, clayey, very stiff, light brown; with some reddish orange silt, moist petroleum, heavy odor. Moist.			S-6
			SILT, very soft, light brown; with some gray highly weathered gabbro, heavy odor. Dry.			
12		0.38/0				S-7
			SILT, very soft, light brown; with some gray highly weathered gabbro, heavy odor.			
14		0.67/0				S-8
			No recovery.			
16		0/0				S-9
		0/1				S-10
18			End of boring at 18' bgs.			

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**MH-SB-2**
Client:	U.S. Naval Station
Boring Location:	MH-SB-2
Northing:	18.2338933
Easting:	-65.62022733
Start - Finish Date:	9/18/99 - 9/19/99
Drilling Contractor:	STC
Driller:	Robert Marrero Mojica
Logged By:	Trevor King/Warren
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	BK-51
Total Depth (ft):	30.3
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch



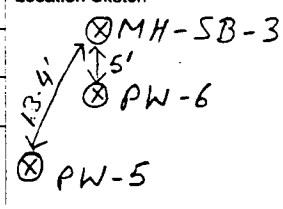
Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
		1.08/2	SILT, sandy, very soft, brown with fill. Dry.			S-1
2		1.29/2	CLAY, sandy, very stiff, light brown and reddish with fresh gabbro cobbles and pebbles. Moist.			S-2
4		0.83/2	CLAY, sandy, very stiff, light brown and reddish with some fresh gabriel or fill pebbles, cobbles. Moist.			S-3
6		0.21/2	CLAY, stiff reddish brown, with some granular sand and moderatly weathered pebble gabbro. Moist.			S-4
8		1.33/2	CLAY, stiff reddish brown with trace light gray coloring. Moist.			S-5
10		1.79/2	CLAY, stiff reddish brown with trace light gray coloring. Moist.			S-6
12		1.75/2	CLAY, stiff reddish brown with trace light gray coloring. Moist.			S-7
			SILT, sandy, very stiff, light brown; with light gray and light tan fine to coarse weathered gabbro, heavy odor. Slightly moist.			
14		1.96/2	SILT, sandy, very stiff, brown; with some highly weathered gabbro, granular pebbles with reddish orange coloring. Slightly moist.			S-8
			CLAY, sandy, stiff, gray; with highly weathered gabbro and staining. Large pebbles, gabbro or fill between 15 to 15.5', heavy odor. Moist.			
16		0.92/2	SILT, clayey, hard, greenish gray; with dark gray highly weathered gabbro and staining. Dry.			S-9
18		0.13/1	ROCK, slightly weathered gabbro; with some clayey silt, odor. Dry.			S-10
20		1.92/2	ROCK, very stiff, dark gray, slightly weathered gabbro; with some sandy silt, possible staining, odor. Dry.			S-11
			ROCK, and debries, fresh gabbro.			
22		2/2	CLAY, sandy, hard olive gray and dark gray; with trace highly weathered rock or gabbro, odor. Moist.			S-12
		0.46/1	SILT, soft, light brown to tan; with highly weathered gabbro. Refusal: 23.5-24', slight odor.			S-13
24		0.42/1	CLAY, silty, very stiff, olive gray and reddish orange; with fine grained highly weathered gabbro. Refusal: 24.5-25', slight odor. Dry.			S-14
		0.86/2	SILT, sandy, stiff, dark gray; with some white fine to medium stiff debries. Moist.			S-15
26		0.83/1	SILT, sandy, soft, olive gray reddish brown, top 1" saturated. Moist.			S-16
		0.58/1	SILT, sandy, soft, olive gray reddish brown, with semi moderate to highly weathered gabbro. Wet.			S-17
28		1.33/2	SILT, sandy, stiff, reddish orange; with some weathered gabbro, dark gray, dark staining. Fresh to slightly weathered gabbro towards to bottom, Wet and saturated sample. Wet.			S-18
30		0.25/0	End of boring at 30.25' bgs.			S-19
32						

BASIC GEOPROBE LOG FUELFARM.GPJ MH_WAF.GDT 10/18/99

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**MH-SB-3**
Client:	U.S. Naval Station
Boring Location:	MH-SB-3
Northing:	18.23215581
Easting:	-65.61992843
Start - Finish Date:	9/20/99 - 9/21/99
Drilling Contractor:	STC
Driller:	Robert Marrero Mojica
Logged By:	Will Whitesell/Pittsburgh
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	BK-51
Total Depth (ft):	30.0
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch

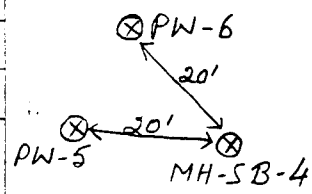


Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
		0.7/2	CLAY, sandy, very stiff, dark gray; with rock fill. Slightly moist.			S-1
2		1.4/2	CLAY, sandy, very soft, yellowish red; with some grayish pebbles and coarse sand, highly weathered, heavy odor. Moist.			S-2
4		1.25/2	SILT, sandy, soft, light brown; with trace clay, heavy odor. Moist.			S-3
			CLAY, sandy, very stiff, greenish and olive gray; with some moderate to highly weathered gabbro, slight odor. Dry.			
6		1/2	CLAY, sandy, very stiff, greenish and olive gray; with highly weathered large pebble gabbro. Slightly moist.			S-4
8		1.4/2	CLAY, sandy, very stiff, greenish and olive gray, dark gray to blackish staining; with highly weathered large pebble gabbro, heavy odor.			S-5
10		1.3/2	SILT, sandy, stiff, dark gray; with reddish and black trace clay, staining, some highly weathered gabbro. Moist.		8-12	S-6
12		1.3/2	SILT, sandy, stiff, dark gray; with reddish and black trace clay, dark staining, some fresh to moderatly weathered gabbro with trace sandy silt. Dry.		10-19	S-7
14		1.25/2	SILT, sandy, stiff, dark gray; with reddish and black trace clay, dark staining, some fresh to moderatly weathered gabbro with trace sandy silt. Dry.		25-43	S-8
16		1.7/2	CLAY, silty, very stiff, dark gray; with mostly highly weathered gabbro \ rock, trace reddish color, dark staining. Moist.		37-50	S-9
18		0.5/1	SILT, clayey, stiff, dark brown to dark olive gray; with trace of some moderatly weathered gabbro.		30-40	S-10
		0.8/1	GRAVEL, very dense, gray-rust-brown; some medium to coarse sand, little silty clay. Slightly moist.		30-40	S-11
20		1.5/2	GRAVEL, sandy, very dense, rust brown, gray mottling and some silty clay.		50-100	S-12
22		1.7/2	0-6": GRAVEL, sandy, very dense, rust brown, gray mottling and some silty clay. 6-8": SAND, medium to coarse, red-gray-white. 8-20": GRAVEL, sandy dark gray , red, little silty clay. Slightly moist.		250	S-13
24		1.7/2	0-3": SAND, medium to coarse, medium dense, light gray (rock, some gravel). 3-6": SILT, clayey, very stiff, light gray-rust-brown, trace gravel. Slightly moist.		35	S-14
26		1.8/2	0-7": SILT, clayey, very stiff, light gray brown. 7-22": Silt, clayey, hard rust brown, light gray.		20	S-15
28		1.3/2	0-6": Sand, gravely, very dense, light gray-rust brown; some clayey silt. 6-16": SAND, silty, very dense, rust brown/light gray; trace gravel, trace clay. Slightly moist.		20-70 15-40	S-16
30			End of boring at 30' bgs.			
32						

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**MH-SB-4**
Client:	U.S. Naval Station
Boring Location:	MH-SB-4
Northing:	18.23209721
Easting:	-65.61990645
Start - Finish Date:	9/21/99 - 9/22/99
Drilling Contractor:	STC
Driller:	Luciano Rodriguez Velez
Logged By:	T. King/Warren & W. Whitesell/Pittsburg
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	BK-51
Total Depth (ft):	21.5
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch

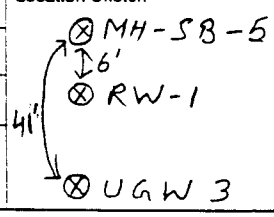


Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
		1.7/2	GRAVEL, sandy, medium to very dense light gray and rust-brown highly weathered, some clayey silt. Dry.			S-1
2		1.4/2	GRAVEL, sandy, very dense light gray highly weathered (saprolitic), little clayey silt. Dry.			S-2
4		1.5/2	SAND, gravelly, very dense light gray (saprolitic), trace fine sand. Dry.		21	S-3
6		1.25/2	SAND, gravelly, very dense light gray, brown; trace fine sand. Dry.		20-50	S-4
8		1.6/2			8-10	S-5
10		1.4/2	SAND, gravelly, very dense light gray, brown; trace fine sand, trace clayey silt. Dry.			S-6
12		1.4/2				S-7
			SAND, gravelly, very dense reddish-gray (saprolitic); trace clayey silt. Dry.			
14		1.3/2	SAND, gravelly, very dense light gray (saprolitic); trace clayey silt, refusal at 15.5'. Dry.		5.5-10	S-8
			Auger advanced to 16'. No recovery.			
16		1.3/2	SAND, gravelly, very dense reddish-gray (saprolitic); trace clayey silt. Moist.			S-9
			SAND, dark brown fine to medium grained, moist to wet with product from 16.5-17'. Dry with odor from 17-18'. 2 feet of diesel in auger (16-18').			
18		0.7/1	SAND, gravelly, very dense rust-brown and gray highly weathered (saprolitic). Refusal at 18.8'. Moist.			S-10
			Auger to 19.5', difficult drilling. No recovery. Auger to 20'.			
20		0.8/1	SAND, gravelly, very dense rust-brown and gray highly weathered (saprolitic). Refusal at 20.9'. wet.			S-11
		0.5/1	1' SAND. Difficulty drilling; refusal at 21.5'. Auger cuttings like slop with diesel.			S-12
22			End of boring at 21.5' bgs.			

McLaren Hart INC.

Site: Tow Way Fuel Farm, Roosevelt Roads	Location: Roosevelt Roads , Puerto Rico	Boring ID: **MH-SB-5**
Client: U.S. Naval Station	Boring Location: MH-SB-5	Northing: 18.23330955 Easting: -65.62034561	Start - Finish Date: 9/22/99 - 9/22/99
Drilling Contractor: STC	Driller: Robert Marrero Mojica	Logged By: Trevor King/Warren	Boring Permit: N/A
Drilling Method: Hollow-stem auger	Drilling Equipment: BK-51		
Total Depth (ft): 29.0	Ground Elevation (ft): NA	Vertical Datum:	Horiz Coor Sys: Lat/Long 1983
Sampling Method: 2" Split spoon	Borehole Diameter (in): 6		
Memo:			

Location Sketch

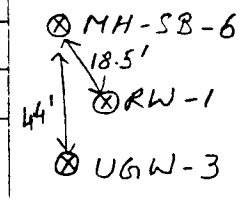


Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
		0.8/2	0-5": SILT, clayey, medium stiff, dark brown; trace fine sand and gravel, grass roots. 5-8": SAND, medium to coarse grained, soft to medium hard, brown and gray. 8-10": same as 0-5".. Moist.			S-1
2		1.08/2	CLAY, silty, stiff rust-brown, mottling gray; trace gravel and fine sand. Moist.		0	S-2
4		1.08/2	CLAY, silty, stiff rust-brown mottling gray; trace fine sand. Moist.			S-3
6		1.17/2	CLAY, silty. 0-9": very stiff to hard, rust-brown mottling gray, trace fine sand. 9-14": hard, rust-brown, mottling of gray and black color; some fine to coarse sand.		0	S-4
8		0/2	No recovery. Augered soil same as between 6-8"..		0	S-5
10		1.75/2	0-5": CLAY, silty, very stiff, rust-brown mottling gray. 5-2" : GRAVEL, sandy, medium dense to dense; trace clayey silt.. Slightly moist.		0	S-6
12		0.92/2	GRAVEL, fine and sand, dense, light and dark gray, rust brown; trace coarse gravel, trace clayey silt. Slightly moist.		0	S-7
14		1.58/2	SILT, clayey, hard, rust-brown and gray; some fine to coarse sand. 15-18": fine to coarse sand - dry.		20-50	S-8
16		1.17/2	SAND, fine to coarse grained, very stiff to hard, dark gray and rust brown; some clayey silt, trace gravel. Slightly moist.		10-30	S-9
18		1.33/2	SAND,fine to coarse, very dense, rust-brown and gray; trace gravel, trace clayey silt. Slightly moist.		100-200	S-10
20		1.42/2	0-8", 14-17": SAND,fine to coarse, very dense, rust-brown and gray; trace gravel, trace clayey silt. 8-14": same but less clay and sand. Dry.		90-110	S-11
22		0/1	SAND,fine to coarse, very dense, rust-brown and gray; trace gravel, trace clayey silt. Refusal at 22', auger to 23'. Moist.		100-120	S-12
		0/1				S-13
		0/1				S-14
24		0/1				S-15
		0/1				S-16
		0/1				S-17
26		0/1				S-18
		0/1				S-19
		1.83/2	0-14": SAND, very dense, rust-brown and dark gray mottlings; some gravel and fine sand, little to some clayey silt. 14-22": SAND, clayey, hard, light gray, white, rust-brown mottled, trace coarse sand (saprolitic appearance). Slightly moist.			
28		0.67/1	CLAY, mottled, hard, light gray, white, rust-brown; some fine to coarse sand, trace gravel. Refusal at 28'7". ~~End of boring at 29' bgs.~~ Auger to 29'.		3-10	S-20
30						S-21

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**MH-SB-6**
Client:	U.S. Naval Station
Boring Location:	MH-SB-6
Northing:	18.23328684
Easting:	-65.62029761
Start - Finish Date:	9/22/99 - 9/22/99
Drilling Contractor:	STC
Driller:	Robert Marrero Mojica
Logged By:	Trevor King/Warren
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	BK-51
Total Depth (ft):	29.0
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch

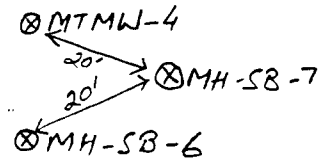


Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
2, 4, 6, 8			Auger advanced to 10' below ground surface (b.g.s.). Moist.			
10	X	1.7/2	CLAY, silty. 0-9": hard rust- brown/gray, trace sand. 9-20": dense, light and dark gray; with some rust-brown fine gravel and sand. Moist.		120 210	S-1 S-2
12	X	1.6/2	CLAY, sandy, hard olive gray/rust-brown and white mottling(saprolitic appearance), trace gravel. Moist.		150	S-3
14	X	1.6/2	CLAY, sandy, very stiff to hard olive gray/rust-brown and white mottling(saprolitic appearance), trace gravel. 9-14": fine to coarse sand, trace gravel. Dry.		200 60	S-4
16	X	1.75/2	CLAY, sandy, hard olive gray/rust-brown and white mottling(saprolitic appearance), trace gravel. Moist.		120 30	S-5
18	X	1.7/2	CLAY, sandy, hard olive gray/rust-brown and white mottling(saprolitic appearance), friable and crumbling; trace gravel. Slightly moist.		120 70	S-6
20	X	1.4/2	CLAY, sandy, hard olive gray/rust-brown and white mottling(saprolitic appearance), friable and crumbling; trace gravel. 10-12": dry sand and gravel. Moist.		160	S-7
22	X	1.7/2	SAND, 0-9": very dense, rust-brown and gray, gravelly fine to coarse grained; little clay. 9-20": very dense, rust-brown with some gray white mottling clayey sand, trace gravel. Wet.		100	S-8
24	X	1.4/2	SAND, very light gray brown, fine to medium grained, trace coarse sand. 5-7": gray sand and gravel. 7-17": sandy clay, very stiff to hard olive gray/rust brown and white mottling (saprolitic appearance), trace gravel. Wet and saturated towards the bottom. Wet.			S-9
26	X	1.5/2	SAND, 0-6": clayey, very dense rust-brown and white mottling (saprolitic appearance). 6-18": fine to medium grained, very dense, rust-brown with white/gray crystals, trace gravel, trace clay.			S-10
28			Auger to 29'.			S-11
30			End of boring at 29' bgs.			

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**MH-SB-7**
Client:	U.S. Naval Station
Boring Location:	MH-SB-7
Northing:	18.23329614
Easting:	-65.62023884
Start - Finish Date:	9/24/99 - 9/24/99
Drilling Contractor:	STC
Driller:	Robert Marrero Mojica
Logged By:	Trevor King/Warren
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	BK-51
Total Depth (ft):	13.4
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch

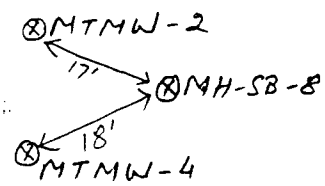


Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
2, 4			CLAY, silty, soft to medium stiff, olive gray and brown; trace fine to medium sand. Moist.			S-1
6, 8			CLAY, silty, soft to medium stiff, olive gray and light brown; trace fine to medium sand. Moist.			S-2
10		1.08/2	0-5": CLAY, silty, soft rust-brown gray; trace fine to medium sand. 5-19": SAND and gravel, light gray; little silty clay. Moist.			S-3
12		1.58/2	0-7": CLAY, silty, very stiff rust-brown gray; trace fine to medium sand. 7-16": SAND and gravel, very dense light gray; trace silty clay. 16-19": SAND and gravel, very dense rust-brown; trace silty clay. Slightly moist.			S-4
			End of boring at 13.42' bgs.			
14						

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**MH-SB-8**
Client:	U.S. Naval Station
Boring Location:	MH-SB-8
Northing:	18.23333816
Easting:	-65.62023577
Start - Finish Date:	9/24/99 - 9/24/99
Drilling Contractor:	STC
Driller:	Robert Marrero Mojica
Logged By:	Trevor King/Warren
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	BK-51
Total Depth (ft):	26.0
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch

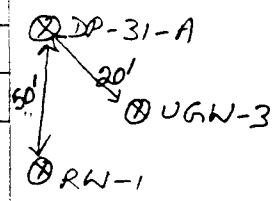


Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
2, 4		NA	CLAY, silty, soft to medium stiff, yellowish orange; trace fine to medium sand. Moist.			S-1
6, 8		NA	CLAY, silty, soft to medium stiff, yellowish orange; trace fine to medium sand. Moist.			S-2
10		1.83/2	0-5": CLAY, silty, stiff rust-brown; trace sand. 5-13": CLAY, sandy, hard rust-brown, gray and white crystals (saprolitic appearance); trace gravel. 13-22": GRAVEL and sand, dense rust-brown gray and white crystals (saprolitic appearance); little silty cl. Slightly moist.			S-3
12		1.5/2	SAND, clayey, dense to very dense rust-brown (saprolitic appearance), gray and white crystals; little gravel. Moist.			S-4
14		1.33/2	SAND, fine to medium grained, medium dense to dense, yellowish orange, light gray; trace gravel, little clay (saprolitic and crumbling). Moist.			S-5
16		1.5/2	0-9": CLAY, silty, hard rust-brown light gray and white crystals; trace sand. 9-18": SAND, fine to coarse, very dense, light gray; trace gravel, trace clayey silt (smell of diesel in cuttings). Wet.			S-6
18		1.33/2	SAND, fine to coarse, very dense, light and olive gray and white crystals, trace gravel (smell of diesel, core not well defined). Slightly moist.			S-7
20		1.67/2	SAND, fine to medium grained, very dense, light gray and brown; trace coarse sand, trace clayey silt. Moist.			S-8
22		1.75/2	SAND, fine to medium grained, very dense, light gray and brown; trace coarse sand, trace clayey silt (6-10": crumbled), several horizontal breaks.			S-9
24		1.42/2	0-9": SAND,very dense rust-brown. 9-17": SAND, and gravel, very dense light brown; trace clay. Dry.			S-10
26			End of boring at 26' bgs.			
28						

McLaren Hart INC.

Site:	Tow Way Fuel Farm, Roosevelt Roads
Location:	Roosevelt Roads , Puerto Rico
Boring ID:	**DP-31A**
Client:	U.S. Naval Station
Boring Location:	DP-31A
Northing:	
Easting:	
Start - Finish Date:	9/15/99 - 9/15/99
Drilling Contractor:	STC
Driller:	Robert Marrero Mojica
Logged By:	T. King/Warren & W. Whitesell/Pittsburg
Boring Permit:	N/A
Drilling Method:	Hollow-stem auger
Drilling Equipment:	SIMCO 2400 SK-1
Total Depth (ft):	18.0
Ground Elevation (ft):	NA
Vertical Datum:	
Horiz Coor Sys:	Lat/Long 1983
Sampling Method:	2" Split spoon
Borehole Diameter (in):	6
Memo:	

Location Sketch



Depth (ft)	Geoprobe Sample	Recovery (ft)	Soil Description	Lithology	PID/FID (ppm)	Sample ID
		0.33/2	FILL, very soft, clay and conglomerate fill. Very moist.			S-1
2		1.17/2	CLAY, very stiff, brown; with some fine gravel fill.			S-2
4		0.79/2	CLAY, very stiff, brown; with some fine gravel fill.			S-3
6		1.08/2	FILL, blueish-gray, coarse sand; trace clay. Moist.			S-4
			GABBRO, fresh dark gray jointed. 8.0': refusal. Jointing due to pneumatic system (not geological).			
8		1.58/2	GABBRO, highly weathered reddish brown and gray olive. Dry.			S-5
10		1.5/2	GABBRO, weathered blue gray; some coarse sand and red staining. Moist.			S-6
12		1.75/2	GABBRO, (coarse sand) highly weathered brown and gray; red staining, trace clay. Moist.			S-7
14		2/2	GABBRO, (fine gravel) highly weathered light gray, strong organic odor. Dry.			S-8
16		1.91/2	CLAY, silty, stiff, tan white orange; some fine sand, less weathered towards the bottom, slight odor. Moist.			S-9
18			End of boring at 18' bgs.			

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LOG OF BORING AW-1

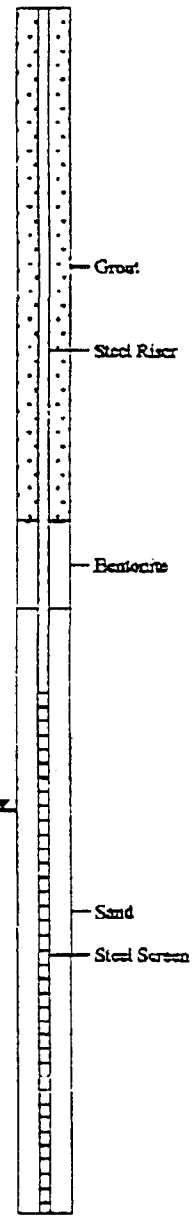
(Page 1 of 1)

Naval Station Roosevelt Roads
Tow Way Fuel Farm
Ceiba, PR
Project # 8207.000

Drilling Method	: Hollow Stem Auger	Static Water Level	: 24 feet bgs
Driller	: Soil Tech	Stick Up	: 0
ManTech Rep.	: Carol Callaghan	Well Inner Diameter	: 2 inch
Sample Type	: Split Spoon, Grab	Well Construction	: PVC Screen/Riser
Hole Diameter	: 8 inches	Well Depth	: 36 Feet

Well1: AW-1
Elev.: 7.7 Feet Above Mean Sea Level

Depth in Feet	DESCRIPTION	USCS
0	Brown silty clay	CH
16	Dense grey clay with gravel and cobbles. Petroleum odor. Dry	CH
18	Dense brown clay with angular cobbles and boulders, sligh petroleum odor. Dry	CH
24	Dense red-brown clay sligh petroleum odor. Dry	CH
26	Rock-angular cobbles and boulders, WET WITH PETROLEUM PRODUCT	PD
28	Brown clay with gravel, Wet	CH
30	Brown silty gravel, Wet	GW



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LOG OF BORING AW-2

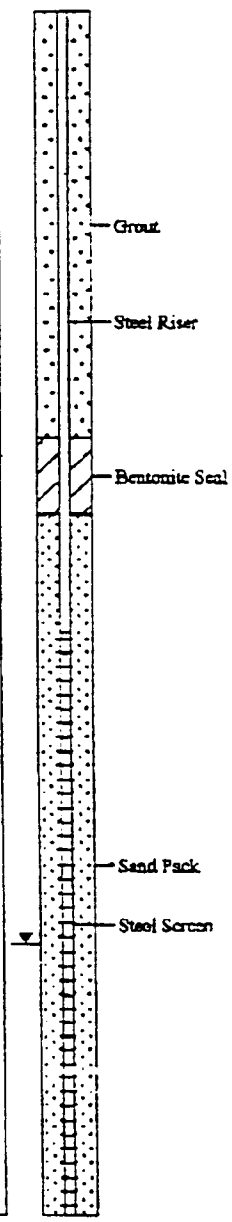
(Page 1 of 1)

Naval Station Roosevelt Roads
Tow Way Fuel Farm
Ceiba, PR
Project # S207.000

Drilling Method	: Hollow Stem Auger	Static Water Level	: 24 Feet bgs
Driller	: Soil Tech	Stick Up	: 0
ManTech Rep.	: Carol Callagian	Well Inner Diameter	: 2 inches
Sample Type	: Split Spoon, Grab	Well Construction	: Steel Screen/Riser
Hole Diameter	: 8 Inches	Well Depth	: 31

Depth in feet	DESCRIPTION	USCS	GRAPHIC	Depth in feet	Blow Count
0	Cuttings brown silty clay, then light brown - red clay			0	
1				1	
2				2	
3				3	
4		CH		4	
5				5	
6				6	
7				7	
8	Red brown silty clay, Dry			8	
9		CH		9	
10	Brown and grey mottled clay, Dry	CH		10	
11	Dense brown clay, Dry	CH		11	
12	Dense brown clay with cobbles, Dry			12	
13				13	
14		CH		14	
15				15	
16	Grey silty clay with cobbles, petroleum odor, Dry			16	
17				17	
18		CH		18	
19				19	
20	Dense grey clay with cobbles WET WITH PETROLEUM PRODUCT	CH		20	
21				21	
22	Dense grey clay with cobbles, Dry			22	
23	Angular cobbles of gabbro petroleum stained, Wet	GW		23	
24	Red Clay, Dry	CH		24	
25	Silty clay with cobbles, petroleum stained, Wet			25	
26				26	
27				27	
28		CH		28	
29				29	
30				30	
31				31	

Well1: AW-2
Elev.: 6.7 Feet Above Mean Sea Level



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LOG OF BORING MTMW-1

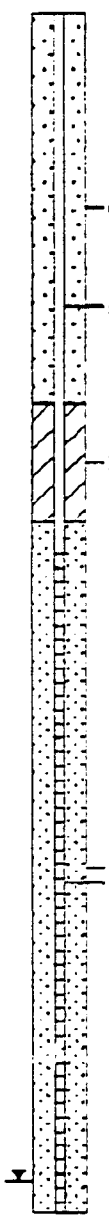
(Page 1 of 1)

Naval Station Roosevelt Roads
Tow Way Fuel Farm
Ceiba, PR
Project # 8207.000

Drilling Method	: Hollow Stem Auger	Static Water Level	: 39 Feet bgs
Driller	: Soil Tech	Stick Up	: 0
ManTech Rep.	: Carol Callaghan	Well Inner Diameter	: 2 inches
Sample Type	: Split Spoon, Grab	Well Construction	: PVC Screen/Riser
Hole Diameter	: 8 Inches	Well Depth	: 40

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Depth in Feet	Samples	Blow Count
0	Brown silty clay, Dry.			0		
2				2		
4				4		
6				6		
8				8		
10				10		
12				12		
14		CH		14		
16				16		
18				18		
20				20		
22				22		
24				24		
26				26		
28				28		
30	WET WITH PETROLEUM PRODUCT.	PD		30		
	Brown silty clay, Wet at 39 feet bgs.					
32				32		
34		CH		34		
36				36		
38				38		
40				40		

Well1: MTMW-1
Elev.: 8.6 Feet Above Mean Sea Level



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LOG OF BORING MTMW-2

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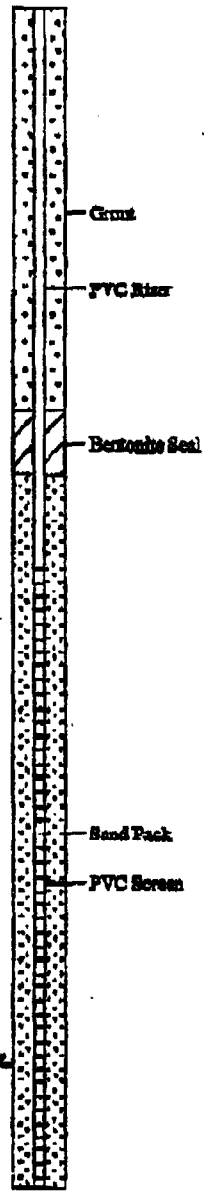
Naval Station Roosevelt Roads
Tow Way Fuel Farm
Ceiba, PR
Project # 8207.000

Drilling Method	: Hollow Stem Auger	Static Water Level	: 24 Feet bgs
Driller	: Sell Tech	Stick Up	: 0
MantTech Rep.	: Carol Gallagher	Well Inner Diameter	: 2 inches
Sample Type	: Split Spoon, Grab	Well Construction	: PVC Schedule 40
Hole Diameter	: 8 Inches	Well Depth	: 38

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Depth in Feet	Samples	Blow Count
0	Grey clay and gravel with petroleum odor. Water at 24 feet bgs.			0		
2				2		
4				4		
6				6		
8				8		
10				10		
12				12		
14				14		
16				16		
18				18		
20		CH		20		
22				22		
24				24		
26				26		
28				28		
30				30		
32				32		
34				34		
36				36		
38				38		

Well: MTMW-2
Elev.: 8.0 Feet Above Mean Sea Level



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LOG OF BORING MTMW-3

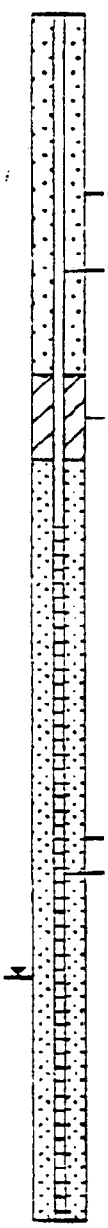
(Page 1 of 1)

Naval Station Roosevelt Roads
Tow Way Fuel Farm
Ceiba, PR
Project # 8207.000

Drilling Method	: Hollow Stem Auger	Static Water Level	: 28 feet bgs
Driller	: Soil Tech	Stick Up	: 0
ManTech Rep.	: Carol Callaghan	Well Inner Diameter	: 2 inch
Sample Type	: Split Spoon, Grab	Well Construction	: PVC Screen/Riser
Hole Diameter	: 8 inches	Well Depth	: 35 Feet

Well1: MTMW-3
Elev.: 7.5 Feet Above Mean Sea Level

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Depth in Feet	Samples	Blow Count
0	Silty clay	CH		0		
10	Dense red brown to olive silty clay with cobbles, Dry	CH		10		
15	Dense red and grey mottled clay, Dry	CH		15		
16	Gravel and cobbles, Dry	GW		16		
18	Dense greyish gabbro saprolite, strong petroleum odor, dry	GW		18		
20	Dense petroleum stained brown silty clay with cobbles, dry	CH		20		
22	Dense petroleum stained grey silty clay with cobbles, Dry	CH		22		
24	Dense petroleum stained grey silty clay with cobbles, WET WITH PETROLEUM PRODUCT	PD		24		
25		CH		25		
26	Silty sand with cobbles, Dry	CH		26		
27	Red brown silty clay with cobbles			27		
28	Silty sand with cobbles, Wet at 30 Feet	CH		28		
30	Silty clay	CH		30		
35				35		



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LOG OF BORING MTMW-4

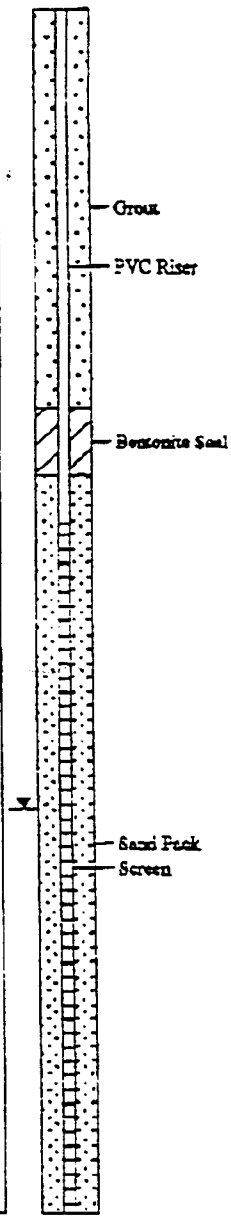
(Page 1 of 1)

Naval Station Roosevelt Roads
Tow Way Fuel Farm
Ceiba, PR
Project # 8207.000

Drilling Method	: Hollow Stem Auger	Static Water Level	: 22
Driller	: Soil Tech	Stick Up	: 0
ManTech Rep.	: Carol Callaghan	Well Inner Diameter	: 2 inch
Sample Type	: Split Spoon, Grab	Well Construction	: PVC Screen/Riser
Hole Diameter	: 8 in.	Well Depth	: 36 Feet

Depth in Feet	DESCRIPTION	USCS	GRAPHIC	Depth in Feet	Samples	Blow Count
0–8	Brown silty clay	CH		0–8		
8–9	Dense brown and grey mottled clay, dry	CH		8–9		
9–10	Gravel, dry	GW		9–10		
10–12	Red clay, dry	CH		10–12		
12–13	Grey clay, strong petroleum odor, dry	CH		12–13		
13–14	Grey clay some angular gravel, strong petroleum odor, dry	CH		13–14		
14–16	Green silty clay with angular gabbro gravel, petroleum odor, dry	CH		14–16		
16–18	Angular gabbro gravel, dry	GW		16–18		
18–20	Angular gabbro gravel, WET WITH PETROLEUM PRODUCT	PD		18–20		
20–22	Silty clay with gravel, strong petroleum odor, dry	CH		20–22		
22–26	Gabbro gravel, wet	GW		22–26		
26–36	Olive silty clay, wet	CH		26–36		

Well1: MTMW-4
Elev.: 7.1 Feet Above Mean Sea Level



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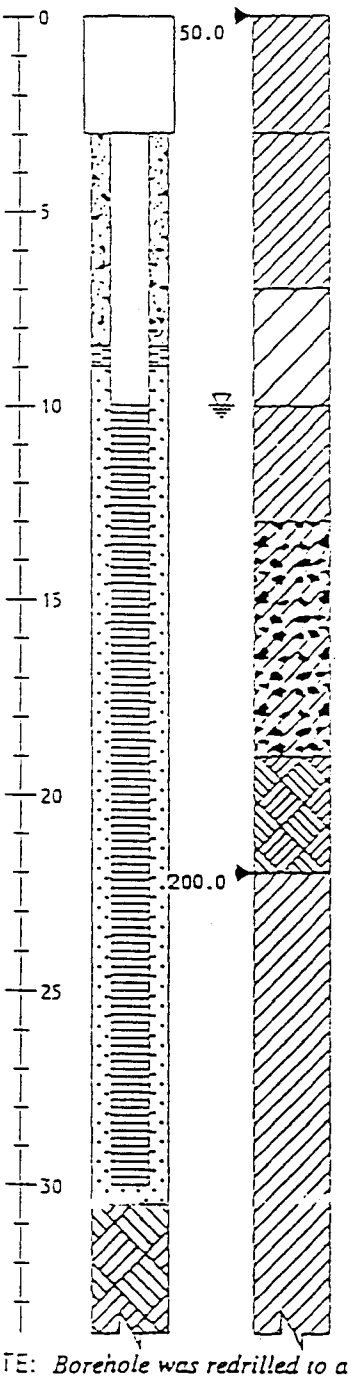
BORING / WELL LOG

BORING NO.: RW-1

PROJECT: Free Product Recovery
PROJECT NO.: 945809
CLIENT/OWNER: U.S. Navy
BORING LOCATION: Upper Tow-Way Fuel Facility
DRILLING CO.: Soil Tech
DRILLER: Jorge Diaz
DRILLING METHOD: 8 1/4" HSA
DRILL RIG: Mobile B-90

DATE DRILLED: 10/17/96
TOC ELEVATION:
GS ELEVATION:
DTW AT COMPLETION: 10'9"
DTW AFTER 24 HOURS:
LOGGED BY: D. Drozd



ELEVATION/ DEPTH (feet)	WELL DETAIL	PID READINGS, SOIL SYMBOLS, SAMPLERS, AND TEST DATA	USCS	DESCRIPTION	SAMPLE No.	SAMPLE Rec.	STANDARD PENETRATION TEST DEPTH	STANDARD PENETRATION TEST N	CURVE 10 30 50
0		50.0	cl	SILT and CLAY, little gravel, brown, moist, fill					
3.0			cl	CLAY, some silt, some gravel, gray-green, strong odor, moist, compacted					
7.0			ch	CLAY, light brown, strong odor, moist, compacted					
10.0			cl	CLAY, some silt, little gravel, angular to subangular, light brown, slight odor, compacted					
13.0			gc	GRAVEL, little clay, light brown, medium odor, moist, uncompacted					
19.0			rock	ROCK, subangular, gray-green, hard, little clay, medium brown, wet, medium odor					
22.0		200.0	cl	CLAY, little sand, medium to coarse grained, trace gravel, wet, strong odor, compacted					

NOTE: *Borehole was redrilled to a depth of 35 feet because well originally collapsed and to allow room for installation of the well if the borehole collapsed.*

CHECKED BY:

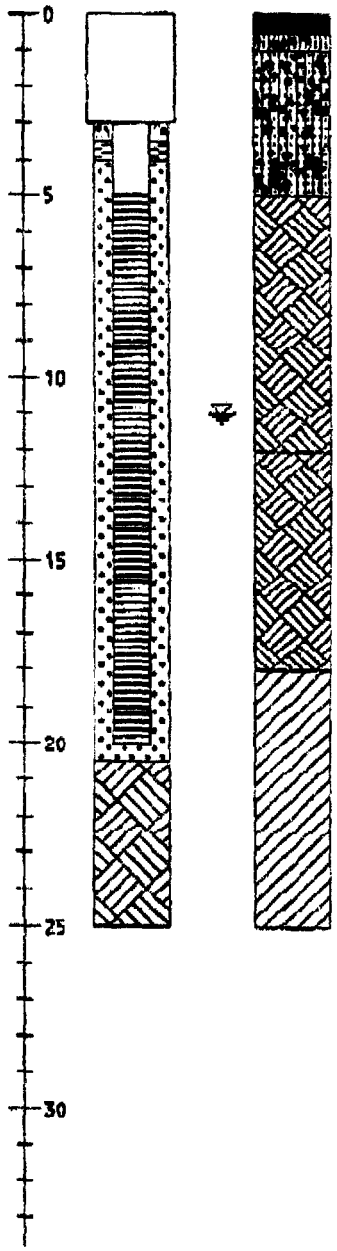
This information pertains only to this boring and should not be interpreted as being indicitive of the site.

BORING / WELL LOG

BORING NO.: RW-7

PROJECT: Free Product Recovery
PROJECT NO.: 945809
CLIENT/OWNER: U.S. Navy
BORING LOCATION: Forrestal Road
DRILLING CO.: Soil Tech
DRILLER: Jorge Diez
DRILLING METHOD: 8 1/4" HSA
DRILL RIG: Mobile B-90

DATE DRILLED: 10/18/96
TOC ELEVATION:
GS ELEVATION:
DTW AT COMPLETION: 11'3"
DTW AFTER 24 HOURS:
LOGGED BY: D. Drozd



ELEVATION/ DEPTH (feet)	WELL DETAIL	PID READINGS, SOIL SYMBOLS, SAMPLERS, AND TEST DATA	USCS	DESCRIPTION	SAMPLE No.	SAMPLE Rec.	STANDARD PENETRATION TEST DEPTH	STANDARD PENETRATION TEST N	CURVE 10 30 50
			0.5	ASPHALT					
			vg 1.0	BEDDING					
			GP-GM	GRAVEL, some silt, trace sand, brown, dry, uncompacted, fill					
			5.0 rock	ROCK, grey-green, hard, subangular to angular, little silt, brown, dry, medium odor, uncompacted					
			12.0 rock	ROCK, grey-green, hard, slight to medium odor, dry, uncompacted					
			18.0 cl	CLAY, trace gravel, trace sand, light to medium brown, medium odor, wet, compacted					
			25.0	Bottom of Boring					

NOTE: *Borehole was drilled to a depth of approximately 25 feet to allow room for installation of well if borehole collapsed.*

CHECKED BY:

This information pertains only to this boring and should not be interpreted as being indicitive of the site.

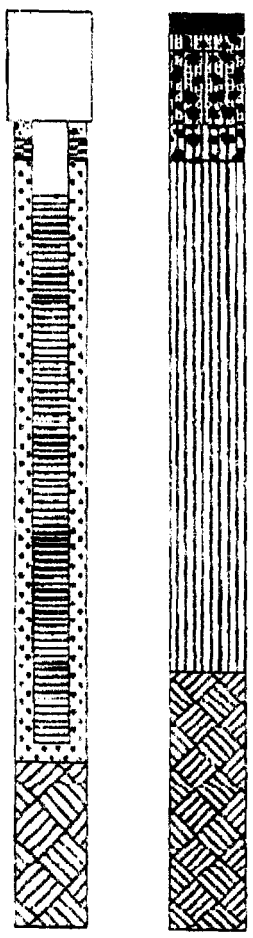
ICHOR Services, Inc.

BORING / WELL LOG

BORING NO.: RW-8

PROJECT: Free Product Recovery
PROJECT NO.: 945809
CLIENT/OWNER: U.S. Navy
BORING LOCATION: Forrestal Road
DRILLING CO.: Soil Tech
DRILLER: Jorge Diaz
DRILLING METHOD: 8 1/4" HSA
DRILL RIG: Mobile B-90

DATE DRILLED: 10/21/96
TOC ELEVATION:
GS ELEVATION:
DTW AT COMPLETION:
DTW AFTER 24 HOURS:
LOGGED BY: D. Drozd

ELEVATION/ DEPTH (feet)	WELL DETAIL	PID READINGS, SOIL SYMBOLS, SAMPLERS, AND TEST DATA	USCS	DESCRIPTION	SAMPLE No.	SAMPLE Rec.	STANDARD PENETRATION TEST DEPTH	STANDARD PENETRATION TEST N	CURVE (10 30 50)
0			0.5	ASPHALT					
			vg 1.0	BEDDING					
			SM-GM 3.0	GRAVEL and SAND, some silt, trace clay, medium brown, dry, uncompacted, fill					
			gm 4.0	GRAVEL and SILT, some sand, medium brown, dry, uncompacted, fill					
			ml	SILT, some gravel, some sand, dry, light to medium brown, uncompacted					
			18.0						
			rock	ROCK, dark grey, light brown, hard, angular, wet					
			25.0						
				Bottom of Boring					

NOTE: *Borehole was drilled to a depth of approximately 25 feet to allow room for installation of well if borehole collapsed.*

CHECKED B

This information pertains only to this boring and should not be interpreted as being indicitive of the site.

ICHOR Services, Inc.

APPENDIX D

ADDENDUM TO SITE HEALTH & SAFETY PLAN

APPENDIX D

HEALTH AND SAFETY PLAN ADDENDUM

This addendum to the Health and Safety Plan (HASP) contained in Section 5.0 of the approved Work Plan[1], provides supplemental information related to the proposed pneumatic fracturing (PF) activities at the project site in Naval Station Roosevelt Roads. The following sections of the HASP are affected:

Section 5.1.5 Site History and Description

The scope of the Task Order has been expanded to include pilot studies to evaluate enhancement of product recovery using pneumatic fracturing techniques. The process uses pressurized gas at controlled pressures and flow rates to initiate and propagate a network of fractures in low permeability soil and rock formations. In addition, short- and long-term pump performance tests will be conducted to evaluate various product removal pump systems.

Section 5.2.2 Site Health and Safety Officer

Mr. Mark Body, McLaren/Hart's Project Superintendent, will be the acting SHSO. He possesses remedial action experience and a working knowledge of the commonwealth and federal occupational safety and health regulations. Mr. Boyd served as the SHSO on three other POL RAC projects at MCAS Cherry Point, North Carolina in the past two years. He has completed the required 40-hour health and safety training in accordance with 29 CFR 1910.120 and the 8-hour supervisory training. In addition, Mr. Boyd and one additional McLaren\Hart employee will be trained in standard first aid and CPR. The SHSO will be on site during major on site activities.

Section 5.5 Work Activities

Work activities also include:

- Pneumatic Fracturing Pilot Tests

Section 5.7 Potential Safety Hazards

Section 5.7.11 is added to the HASP to cover potential physical hazards associated with pneumatic fracturing.

Section 5.7.11 Pneumatic Fracturing

Non-chemical hazards associated with pneumatic fracturing include:

1. Slip/trip/fall associated with any operations at the site or within the general area. For precaution, steel toe boots will be worn at all times.

2. Heat stress associated with any activities on-site. Operations will strictly adhere to McLaren/Hart health & safety policy (HS-28) for heat stress. Water will be provided.

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[1] McLaren/Hart Environmental Engineering, Inc. (Formerly PDG Environmental Services, Inc.), Work Plan, Free Product Recovery System for the Tow Way Fuel Facility, Naval Station Roosevelt Roads, Ceiba, Puerto Rico, Department of the Navy, Atlantic Division, Contract No. N62470-D-93-3033 POL RAC Task Order # 9, Prepared for J. A. Jones Environmental Services, Charlotte, NC, August 16, 1996.

3. On-site utilities: Utility clearance will be performed in accordance with McLaren/Hart's Utility Clearance policy (HS-34). This includes a utility mark out in the pilot test areas prior to the implementation of site work. Confirmation of utility mark outs will be performed by a review of facility drawings and site clearance by the U.S. Naval site management team.

4. Noise: A noise hazard is likely when working close to drill rigs and bleed off of compressed air hose. Hearing protection will be supplied for all personnel on-site during activities.

5. Machinery: Drill rig, support trucks, compressed nitrogen trailers

6. High Pressure:

   1) Pilot test activities require the use of high gas pressures for the pneumatic injections. During the test program, the compressed nitrogen will be regulated to <700 psi. Precautions to be taken during the testing program include: no unauthorized personnel in the test area; check the integrity of the hoses and fittings prior to injections; and stand clear of pressure hoses and the well cluster network during injections.

PRODUCT NAME: NITROGEN

1. Chemical Product and Company Identification

BOC Gases,
Division of
The BOC Group, Inc.
575 Mountain Avenue
Murray Hill, NJ 07974

TELEPHONE NUMBER: (908) 464-8100
24-HOUR EMERGENCY TELEPHONE NUMBER:
CHEMTREC (800) 424-9300

BOC Gases
Division of
BOC Canada Limited
5975 Falbourne Street, Unit 2
Mississauga, Ontario L5R 3W6

TELEPHONE NUMBER: (905) 501-1700
24-HOUR EMERGENCY TELEPHONE NUMBER:
(905) 501-0802
EMERGENCY RESPONSE PLAN NO: 20101

PRODUCT NAME: NITROGEN
CHEMICAL NAME: Nitrogen
COMMON NAMES/SYNONYMS: Nitrogen, compressed; Nitrogen gas
TDG (Canada) CLASSIFICATION: 2.2
WHMIS CLASSIFICATION: A

PREPARED BY: Loss Control (908)464-8100/(905)501-1700
PREPARATION DATE: 6/1/95
REVIEW DATES: 6/7/96

2. Composition, Information on Ingredients

INGREDIENT	% VOLUME	PEL-OSHA[1]	TLV-ACGIH[2]	LD_{50} or LC_{50} Route/Species
Nitrogen FORMULA: N_2 CAS: 7727-37-9 RTECS #: QW9700000	99.995 to 99.999	Simple Asphyxiant	Simple Asphyxiant	Not Available

[1] As stated in 29 CFR 1910, Subpart Z (revised July 1, 1993)
[2] As stated in the ACGIH 1994-95 Threshold Limit Values for Chemical Substances and Physical Agents

3. Hazards Identification

EMERGENCY OVERVIEW

Simple Asphyxiant - This product does not contain oxygen and may cause asphyxia if released in a confined area. Maintain oxygen levels above 19.5%. Nonflammable.

SKIN:
Remove contaminated clothing and flush affected areas with lukewarm water. If irritation persists, seek medical attention.

INGESTION:
Ingestion is unlikely as product as a gas at room temperature.

INHALATION:
PROMPT MEDICAL ATTENTION IS MANDATORY IN ALL CASES OF OVEREXPOSURE. RESCUE PERSONNEL SHOULD BE EQUIPPED WITH SELF-CONTAINED BREATHING APPARATUS. Victims should be assisted to an uncontaminated area and inhale fresh air. Quick removal from the contaminated area is most important. Unconscious persons should be moved to an uncontaminated area, and if breathing has stopped, administer artificial resuscitation and supplemental oxygen. Further treatment should be symptomatic and supportive.

5. Fire Fighting Measures

Conditions of Flammability: Nonflammable		
Flash point: None	Method: Not Applicable	Autoignition Temperature: None
LEL(%): None	UEL(%): None	
Hazardous combustion products: None		
Sensitivity to mechanical shock: None		
Sensitivity to static discharge: None		

FIRE AND EXPLOSION HAZARDS:
None. Nonflammable.

EXTINGUISHING MEDIA:
None required. Use as appropriate for surrounding materials.

6. Accidental Release Measures

Evacuate all personnel from affected area. Use appropriate protective equipment. If leak is in container or container valve, contact the appropriate emergency telephone number listed in Section 1 or call your closest BOC location.

7. Handling and Storage

Electrical classification:
Non-hazardous.

This gas mixture is noncorrosive and may be used with all common structural materials.

Use only in well-ventilated areas. Valve protection caps must remain in place unless container is secured with valve protection outlet piped to use point. Do not drag, slide or roll cylinders. Use a suitable hand truck for cylinder movement. Use a pressure reducing regulator when connecting cylinder to lower pressure (<3000 psig) piping or systems. Do not heat cylinder by any means to increase the discharge rate of product from the cylinder. Use a check valve or trap in the discharge line to prevent hazardous back flow into the cylinder.

9. Physical and Chemical Properties

PARAMETER	VALUE	UNITS
Physical state (gas, liquid, solid)	: Gas	
Vapor pressure	: Not Available	
Vapor density (Air = 1)	: 0.97	
Evaporation point	: Not Available	
Boiling point	: -320.4	°F
	: -195.8	°C
Freezing point	: -345.9	°F
	: -209.9	°C
pH	: Not Applicable	
Specific gravity	: Not Available	
Oil/water partition coefficient	: Not Available	
Solubility (H20)	: Very slightly soluble	
Odor threshold	: Not Applicable	
Odor and appearance	: Colorless, odorless gas	

10. Stability and Reactivity

STABILITY:
Stable

INCOMPATIBLE MATERIALS:
None

HAZARDOUS POLYMERIZATION:
Does not occur.

11. Toxicological Information

Oxygen deficiency during pregnancy has produced developmental abnormalities in humans and experimental animals.

No data given in the Registry of Toxic Effects of Chemical Substances (RTECS) or Sax, Dangerous Properties of Industrial Materials, 7th ed.

12. Ecological Information

No data given.

13. Disposal Considerations

Do not attempt to dispose of residual waste or unused quantities. Return in the shipping container PROPERLY LABELED, WITH ANY VALVE OUTLET PLUGS OR CAPS SECURED AND VALVE PROTECTION CAP IN PLACE to BOC Gases or authorized distributor for proper disposal.