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CLEANOX® PILOT TEST REPORT

Tow Way Fuel Farm
Naval Station Roosevelt Roads
Ceiba, Puerto Rico

PREPARED FOR:

Baker Environmental, Inc.
Airport Office Park, Building 3
420 Rouser Road
Coraopolis, Pennsylvania 15108

PREPARED BY:

ManTech Environmental Corporation
14290 Sullyfield Circle, Suite 100
Chantilly, VA 20151

ManTech Project No. 8207-000

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1.0 INTRODUCTION

This report documents the procedures, results and evaluation of the pilot test of the CleanOX® Process completed by ManTech Environmental Corporation (ManTech) at the Naval Station Roosevelt Roads (NSRR) Tow Way Fuel Farm (TWFF) in Ceiba, Puerto Rico (Figure 1). The pilot test was conducted under Subcontract No. 62470-277, Delivery Order No. 277-16000. Pilot test procedures were consistent with the Revised Pilot Scale Remediation Work Plan, dated December 10, 1998, and approved by the Puerto Rico Environmental Quality Board (EQB).

The purpose of the pilot test was to verify the applicability of the CleanOX® Process, an *in-situ* chemical oxidation remediation technology, to remediate groundwater containing free product, and to produce desired oxidation reactions in the uppermost saturated soil zone at the TWFF. The pilot test was also performed to refine the site-specific formulation of CleanOX® Process reagents to be used in any future applications of the process. The scope of work that was performed during the pilot test, ManTech's observations during pilot testing, a summary of the analytical results of pre- and post-treatment sampling, and ManTech's recommendations for full-scale application of the CleanOX® Process at the TWFF are presented in this report.

CleanOX® is an *in-situ* remediation process that involves the application of a proprietary formulation of chemical reagents to rapidly oxidize a wide range of organic compounds in saturated soil and groundwater, including the petroleum free product and dissolved constituents detected at the TWFF. The basis of the CleanOX® Process is related to Fenton's Reaction, wherein hydrogen peroxide reacts with ferrous ions in an acidified aqueous medium to produce hydroxyl free radical, an extremely powerful oxidizer, which degrades organic compounds through a series of oxidation reactions. During the process, the oxidation reactions proceed by degrading the petroleum constituents to progressively less complex, shorter chemical chains, ultimately yielding carbon dioxide and water.

A typical CleanOX® project is conducted in three phases. The first phase includes a bench test to develop site-specific chemical formulations to be applied in pilot-scale testing. Next, the results of the bench test are used to design a pilot test of the process that includes the application of CleanOX® reagents to application wells at the site. Saturated soil and groundwater samples are collected from borings and monitoring wells located in proximity to the pilot test treatment area before and after application of the CleanOX® Process reagents so that its effectiveness on a pilot-scale basis can be evaluated and engineering parameters for subsequent application can be determined. The results of the pilot test can then be used to develop a full-scale application of the process which typically includes two to three rounds of reagent application to a network of application wells installed within the full-scale treatment area.

This pilot test report is divided into five sections. The remainder of this section includes an overview of the CleanOX® Process, a review of the site background, and the objectives of the pilot test. Sections 2 and 3 discuss the pilot test field activities, results and interpretation of results. Section 4 presents conclusions and recommendations. Section 5 provides ManTech's conceptual approach and cost estimate for full-scale CleanOX® Process application at the TWFF.

1.1 Overview of the CleanOX® *In-Situ* Chemical Oxidation Process

CleanOX® is a patented *in-situ* process that involves the staged application of Fenton Reaction chemistry to create oxidation-reduction reactions leading to degradation of organic compounds present in groundwater. The CleanOX® process can remediate these organic compounds within a short period, is suitable for most urban and developed sites without disruption to site operations, and eliminates the long-term operation and maintenance (O&M) associated with conventional remediation technologies. Because the CleanOX® Process is an *in-situ* groundwater remediation technology, it produces no waste streams that require permitting, treatment, or disposal.

The basis of the CleanOX® Process is related to the well-known Fenton's Reaction wherein hydrogen peroxide reacts with ferrous ions to produce a hydroxyl radical in an acidified aqueous medium. The resultant hydroxyl free radical (•OH) is an extremely powerful oxidizer that progressively reacts with organic constituents through a series of oxidation reactions. The hydroxyl radicals do not selectively target specific organic constituents. It is a contact chemistry process, and the hydroxyl radicals will oxidize any organic compounds encountered. During the process, the oxidation reactions proceed by degrading the organic constituents to progressively less complex and shorter chemical chains, ultimately yielding carbon dioxide and water.

CleanOX® results in a reduction of the total organic compound mass in free product, dissolved, and sorbed phases. The Fenton Reaction and associated oxidation reactions are vigorous creating turbulent conditions and changing the chemical equilibrium conditions present within the saturated soil matrix. Therefore, application of the CleanOX® reagents results in not only oxidation of dissolved and adsorbed constituents, but also serves to liberate residual product and to desorb pockets of absorbed constituent mass which may be present in the capillary fringe or beneath the water table surface. This effect is often most pronounced during the initial round of reagent application where dissolved phase concentrations may be found to increase above the baseline concentrations. The constituent mass that has been desorbed and dissolved is more easily remediated by subsequent rounds of CleanOX® reagent application. A typical, full-scale CleanOX® remediation program involves the application of two to three rounds of reagents in order to reach the desired cleanup levels.

CleanOX® uses a proprietary, empirically-derived computer modeling program that has been developed from laboratory and field applications over the last several years. This Geo-Environmental Modeling Software (GEMS) is used to model and design each CleanOX® Process

application. Using the bench test and relevant site data (e.g., hydrogeology, water chemistry, and organic constituent types and concentrations), a customized, site-specific treatment design and dosage application is developed for each pilot-scale remediation project. This approach was used for the pilot test performed at the TWFF. For example, baseline laboratory data were incorporated into the GEMS model to estimate the volume of CleanOX® reagents for pilot testing at the site. Because the organic contaminants of concern and naturally-occurring Total Organic Carbon (TOC) will compete for the hydroxyl radicals, baseline concentrations for these parameters at the TWFF were used as input to the GEMS model.

Application of the CleanOX® Process at other sites has demonstrated significant mass reductions of a variety of organic compounds sorbed to saturated soils and dissolved in groundwater within a short time period following multiple rounds of reagent application. Based on bench, pilot, and full-scale applications, the CleanOX® Process has been determined to be applicable for the treatment of fuels, solvents, pesticides, and other organic constituents in groundwater.

The principal advantage of the CleanOX® Process over other *in-situ* treatments is the very rapid and complete degradation of organic constituents in the saturated soil and groundwater. More conventional technologies, such as groundwater pump-and-treat, oil skimmers, vapor extraction, air sparging, and bioventing, require years to produce concentration reductions of 50 to 90 percent, depending on soil type and the volatility or biodegradability of the organic compound. The CleanOX® Process is primarily directed toward remediation of dissolved-phase organics and also has been applied to address free-phase product. With respect to soil, the technology addresses organic degradation within the saturated matrix and the capillary fringe. The CleanOX® Process can be designed to target the specific layers of contaminant found in the subsurface for remediation.

1.2 Site Background

Our initial understanding of the site's history and hydrogeologic characteristics was based on information provided in the Revised Draft RCRA Facility Investigation (RFI) Report for Operable Unit 2 (SWMU 7/8) at NSRR dated June 1997 prepared by Baker Environmental, Inc. (Baker). During installation of the wells used as part of the CleanOX® Process, ManTech refined its conceptual model of the hydrogeologic conditions at the TWFF for pilot testing. Since remediation is on-going at the TWFF, the most recent McLaren/Hart data was used to evaluate free product levels for full-scale remediation.

NSRR is located in Ceiba, Puerto Rico and the TWFF area that comprises SWMU 7/8 ("the Site") has been operated by the U.S. Navy since the early 1940s. Based on the Site's elevations, the TWFF has been divided into an upper and lower TWFF where seven large fuel storage tanks have been partially buried. Reports reviewed by ManTech indicate that petroleum products, such as jet fuel (JP-5) and marine diesel fuel, were released at the site over a period of 30 years from piping and tank leaks, overfills, and past disposal practices. These past maintenance practices included the

common industry standard of disposing of accumulated sludge from the tanks in excavated pits adjacent to the tanks during tank cleaning operations.

Previous site investigations indicate that petroleum constituents have been detected in soil and groundwater. According to the Baker RFI, free product has also been identified at the site and a product recovery system has operated since 1994 recovering approximately 5% of the estimated 996,000 gallons of free product released. Previous studies have been conducted to define the extent of groundwater and soil contamination, to locate sludge burial pits, to characterize the site lithology and the underlying aquifer, and to identify risk-based contaminant concentrations for chemicals of concern. Although chemicals of concern and their respective risk-based cleanup goals have been proposed in the RFI, the final list of chemicals and cleanup goals have not been finalized.

According to the RFI report prepared by Baker, several feet of free product have been detected around the sloped area between the upper and lower tank farms, on the north side of Forrestal Drive, and identified as our pilot treatment area (Figure 2). The low permeability soils underlying the site and the difficulty in accessing the product plume (i.e., buildings, utilities, and other obstructions) are limiting factors in implementing remedial strategies at the site.

A review of site boring logs (Appendix A) from previous investigations indicates that the subsurface had been investigated to a depth of approximately 35 feet bgs in the pilot test area around UGW-3 and RW-1. There is heterogeneity reported in the boring logs, likely due in part to the clean fill material used to partially bury the fuel storage tanks. At UGW-3, the subsurface generally consists of the following vertical profile:

- Silty clay from ground surface to a depth of approximately 10 feet bgs; and
- Sand with layers of gravel from 10 to 35 feet.

At RW-1, located approximately 36 feet south of UGW-3, the subsurface generally consists of the following vertical profile:

- Silty clay from ground surface to a depth of approximately 13 feet bgs;
- Gravel from approximately 13 to 19 feet bgs;
- Rock, subangular cobbles of gabbro, from approximately 19 to 22 feet bgs;
- Silty clay from approximately 22 to 35 feet bgs.

In both wells, strong petroleum odors and gravel layers wet with petroleum product were reported. The gravel, rock, and sand sequences were believed to act as the surficial water-bearing zone. Groundwater was reportedly detected at an approximate depth of 25 feet bgs in the study area. However, water equilibrates to a depth of approximately 15 feet bgs within the monitoring wells, indicating semi-confined aquifer conditions. The surface topography suggests that groundwater in this aquifer flows to the southeast.

During ManTech's subsurface investigation, we refined our conceptual model of the hydrogeologic conditions at the TWFF. The same lithology was identified at various depths as indicated in the cross-sections (Figures 3, 4 and 5). The overlying clay layer results in a confined surficial aquifer. Gravel layers and lenses of gravel within silty clay wet with petroleum product were observed at each of ManTech's six drilling locations. It appears that the petroleum product is preferentially moving through these gravel layers and lenses approximately two feet above where the confined aquifer is encountered. Given these observations, ManTech screened the application and monitoring wells to intercept the petroleum product and thereby direct the CleanOX® Process at the petroleum product.

ManTech completed installation of four monitoring wells (MTMW-1, MTMW-2, MTMW-3 and MTMW-4) and two application wells (AW-1 and AW-2) (Figure 6) the week of December 14, 1998. Slug tests were conducted on the application wells in order to collect hydraulic conductivity (K) data. ManTech estimated a K of approximately 10^{-4} cm/sec.

Soil samples were collected from MTMW-4, AW-1 and AW-2 during the installation of the wells. Baseline groundwater samples of these wells and existing wells RW-1, UGW-3, UGW-14 and UGW-25 were collected the week of January 4, 1999. Analyses revealed that the primary contaminants of concern (benzene, toluene, ethylbenzene, xylenes (BTEX), total petroleum hydrocarbons (TPH) diesel, TPH gasoline, iron and lead) were present in most soil and groundwater samples.

- In soil, total BTEX concentrations of up to 3,956 ug/kg were detected, TPH gasoline concentrations of up to 5,600,000 ug/kg were detected and TPH diesel concentrations of up to 8,800 ug/kg were detected. It appears that the highest contaminant concentrations in soil are generally present slightly downgradient from the placement of the application wells in the gravel sequence, or approximately 20 feet bgs.

- In groundwater, concentrations were detected at up to 224 ug/l BTEX; 2,900 ug/l TPH gasoline; and 4.7 ug/l TPH diesel. Prior to the pilot test, free product was observed in monitoring wells UGW-3, RW-1, and MTMW-4.[1]

This information was important to the design and the objectives of the CleanOX® pilot study. As discussed above, ManTech screened the application wells in order to intercept the observed free product in the gravel layer approximately two feet above the confined aquifer. Further, given the observed free product, it was expected that application of the process would likely result in increased dissolved-phase petroleum constituent concentrations because the intensity of the Fenton

[1]Free product was observed in all of the borings and was expected in all of the wells. However, it may take many weeks for petroleum product to accumulate in a monitoring well, especially if the product is present in the unsaturated zone above the aquifer as is the case at TWFF.

Reaction chemistry would enhance dissolution of sorbed petroleum constituents. In such cases, there is potential that the effects of oxidation could be masked in laboratory analyses of saturated soil and groundwater samples collected after the pilot test application. Therefore, ManTech developed estimates of the contaminant mass present before and after the pilot test in order to gauge contaminant destruction potential at the site.

1.3 Purpose of the CleanOX® Pilot Test

The principal objectives of the pilot test were to verify that the CleanOX® Process reagents can be applied safely, in a controlled manner, and can induce desorption, dissolution, and desired oxidation reactions at the TWFF. The specific objectives for the pilot test are described below.

Assess the Infiltration Capacity of the Impacted Aquifer Material - This is accomplished by measuring the rate at which CleanOX® conditioning agents and oxidizer can be added to the aquifer through the application wells. Infiltration rates, which are related to *in-situ* permeability values, are important for evaluation of the effectiveness of the CleanOX® Process because they govern the field time required for application and are a factor in determining the lateral extent of aquifer material that can be treated from each application well.

Validate Bench Test Assumptions for Reagent Requirements - The quantities of conditioning reagents and oxidant to be applied at each application well are estimated for the pilot test by the GEMS model based on experience at similar sites, site-specific data, and the results of the bench test. The amount of conditioning agents and oxidizer needed during each application is verified during the pilot test. This is accomplished by periodic measurements of dissolved oxygen, oxidation-reduction potential (ORP), specific conductance, temperature, and pH during the pilot test and by laboratory analyses completed on groundwater samples before and after the pilot test.

Estimate Application Well Radius of Influence (ROI) - The radial influence of the CleanOX® Process from application wells is determined by field observations of bubbling and steam vapor in off-set groundwater monitoring wells; field measurements of free product levels, dissolved oxygen, ORP, specific conductance, temperature, and pH; and the laboratory measurements of dissolved concentrations in these same off-set wells.

Estimate Mass Removal Potential Per Application - This is determined primarily by the change in contaminant concentrations detected from analysis of soil and groundwater samples collected from borings and monitoring wells after application of the CleanOX® reagents as compared to the concentrations prior to the pilot-scale CleanOX® application. The change in contaminant concentrations is important because it helps in determining the extent of mass desorption that has occurred relative to the extent of oxidation that occurred during the pilot-scale application. These data are then used to refine the estimate of volume of CleanOX® reagents and number of applications that are needed to meet the project objective of contaminant mass removal.

1.4 Limitations of the CleanOX® Pilot Test

In preparing for the pilot test of the CleanOX® Process at the TWFF, ManTech relied upon the site characterization data ("Existing Site Information") provided to ManTech by Baker. This existing site information may have included, without limitation, data regarding site history and the identification, location, quantity, concentration and character of known or suspected soil and groundwater contamination. ManTech has assumed and relied upon the validity of this existing site information in designing and configuring the parameters of the specific pilot-scale CleanOX® application for the site. Baker acknowledges that the effectiveness of the CleanOX® pilot test depends, to a certain extent, upon the accuracy of the existing site information, and that if site conditions are found to differ from our proposal assumptions expected results could differ from originally proposed results in a positive or negative way.

2.0 FIELD ACTIVITIES

ManTech performed a two-well pilot test of the CleanOX® Process at the TWFF between January 11 through January 29, 1999. Field activities included application well and monitoring well installation, baseline soil and groundwater sampling, two rounds of CleanOX® reagent application, waste disposal, and post treatment soil and groundwater sampling.

Table 1 summarizes the sampling performed by ManTech as part of the pilot test. Soil and groundwater samples were analyzed by Severn Trent Laboratories (Severn) in University Park Illinois, an USEPA-approved CLP laboratory. Level IV QA/QC data review was completed by Heartland Environmental Services, Inc. (Heartland). Waste disposal analyses were performed by Transglobal Environmental Geochemistry (TEG), a laboratory located in Puerto Rico. The disposal facilities required these analyses to be performed by a local laboratory.

Pilot test laboratory analyses included BTEX, TPH gasoline, TPH diesel, iron, lead, sulfate and pH. Field parameters measured at the time of sample collection included water levels, product thickness, temperature, pH, ORP, specific conductance, and dissolved oxygen. Waste disposal analyses included reactivity, corrosivity, ignitability, TCLP benzene and metals, and TOX.

2.1 Well Installation and Sample Collection

This section describes the activities associated with installation of the application wells and monitoring wells at the TWFF and describes the soil and groundwater sampling and analyses completed in order to evaluate the effectiveness of the CleanOX® pilot-scale reagent application.

2.1.1 Application and Monitoring Well Installation

Well drilling was performed by Soil Tech, Inc.under contract to ManTech and was supervised by a ManTech geologist. Wells AW-1, AW-2, MTMW-1, MTMW-2, MTMW-3 and MTMW-4 were installed and baseline soil samples from AW-1, AW-2 and MTMW-4 were collected the week of December 14, 1998. Total well depths and the screened intervals were based on ManTech's field observations of petroleum product and groundwater elevations at each location. Complete boring logs and well completion records are provided in Appendix A. Construction details for the wells used as part of the pilot test are summarized in Table 2.

AW-1 and AW-2 were constructed of two-inch diameter, stainless-steel risers with 15 feet of 0.01-inch, slotted stainless-steel screens. AW-1 was drilled to a total depth of 35.5 feet below ground surface (bgs), and screened from a depth of 20.5 to 35.5 feet bgs. AW-2 was drilled to a total depth of 31 feet bgs and screened from a depth of 16 to 31 feet bgs. Four new monitoring wells (MTMW-1, MTMW-2, MTMW-3 and MTMW-4) were constructed of two-inch diameter, Schedule

40 PVC with 0.01-inch slotted screens. MTMW-1 was drilled to a total depth of 39.5 feet bgs, and screened from a depth of 19.5 to 39.5 feet bgs. MTMW-2 was drilled to a total depth of 38 feet bgs and screened from a depth of 18 to 38 feet bgs. MTMW-3 was drilled to a total depth of 35 feet bgs, and screened from a depth of 15 to 35 feet bgs. MTMW-4 was drilled to a total depth of 36 feet bgs and screened from a depth of 16 to 36 feet bgs.

The two application wells, AW-1 and AW-2, were spaced approximately 15 feet apart and are located approximately 11 feet south of UGW-3 and 10 feet north of RW-1, respectively. The four off-set monitoring wells (MTMW-1, MTMW-2, MTMW-3, and MTMW-4) were installed approximately 10 to 15-feet from the application wells. The application wells, the four newly installed wells, and four existing wells (RW-1, UGW-3, UGW-14, and UGW-25) were used to monitor pre- and post-treatment free product levels, and to measure site parameters during the application (Table 2).[2]

The boreholes were drilled with a hollow stem auger approximately eight inches in diameter and two-inch diameter risers and screens were installed. The borehole annulus was filled with a silica sand filter pack from the base of the borehole to approximately two feet above the screened interval. A minimum of two feet of hydrated bentonite pellets were installed above the filter pack, and a bentonite/cement grout was installed to complete each well. A flush-mounted, 8-inch diameter protective manhole was used at each location. At least four inches of riser section was exposed within the manhole. For the two application wells, the riser section was provided with a carbon-steel threaded coupling to allow connection of ManTech's CleanOX® well heads. The surface was completed with three foot by three foot concrete pads around each manhole. A generic CleanOX® application well construction diagram is provided as Figure 7.

Each application and monitoring well was developed by ManTech. Slug tests were performed on each application well to verify the hydraulic conductivity (K) around the application points. Based on the estimated K values of 10^{-4} cm/sec, application well radii of influence (ROI) of approximately 20 to 25 feet were estimated.

2.1.2 Baseline Soil and Groundwater Sampling

Soil and groundwater samples were collected prior to the CleanOX® reagent application in order to establish baseline concentrations of target organic constituents and select inorganic parameters within the treatment area and just outside the treatment area at the TWFF.

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[2]UGW-14 and UGW-25 are located outside the application wells ROI at distances of approximately 180 feet downgradient and 60 feet up/cross gradient, respectively, from the treatment area.

ManTech collected soil samples using split-spoon sampling methods during installation of the two application wells and one of the off-set monitoring wells (MTMW-4) during the week of December 14, 1998. Split-spoon soil samples were collected at the depth intervals having the greatest PID readings as follows: 30 to 34 feet bgs at AW-1, 24 to 28 feet bgs at AW-2, and at 18 to 20 feet bgs at MTMW-4.

ManTech also performed baseline free product measurements at the ten wells used for the pilot study the week of January 4, 1999. Corrected groundwater elevations were obtained using the apparent free product measurements collected in the field and using a petroleum product density compensation factor of 0.87 as follows:

$$\text{Corrected Groundwater Elevation} = \text{Measured Groundwater/Oil Interface Elevation} + \left\{ 0.87 * \text{Oil Thickness} \right\}$$

2.1.3 Post-Treatment Soil and Groundwater Sampling and Product Thickness Measurements

ManTech collected soil samples from three locations at two intervals (one-week and eight-week post treatment) and groundwater samples from the ten monitoring wells at three intervals (one-week, three-week, and eight-week post treatment) to evaluate the effectiveness of the CleanOX® Process at the site. Samples were collected during the weeks of February 8, February 22, and April 12, 1999, respectively.

Split-spoon soil samples were advanced adjacent to the two application wells and at the most downgradient application well, MTMW-4, to mimic the soil sampling locations in the baseline sampling event. Soil samples were collected from the same depth intervals as in the baseline sampling. Laboratory analyses completed on soil and groundwater samples are outlined in Table 1.[3]

2.2 CleanOX® Process Application

A site-specific formulation of CleanOX® Process reagents was applied to two application wells at the TWFF from January 11 through January 29, 1999. As described in the workplan, two rounds of reagent application were completed.

[3]Any discrepancies in sample collection and laboratory analyses from Table 1 are noted in the analytical summary tables, Figures 3 and 4.

The pilot test treatment area at the TWFF near existing RW-1 was selected due to its location near the upgradient portion of the free product plume and the general accessibility of the area. Well information specific to the application wells (AW-1 & AW-2) and off-set monitoring locations (MTMW-1, MTMW-2, MTMW-3, MTMW-4, RW-1, UGW-3) used for pilot testing is presented in Table 2.

CleanOX® reagents were added to AW-1 and AW-2 at the TWFF. The application wells are located near RW-1, within a topographic low nearest to the fuel farm's southern-most entrance from Forrestal Drive. The pilot test design estimated a ROI of the CleanOX® reagents of approximately 20 to 25 feet from the application well based on an estimated hydraulic conductivity of 10^{-4} cm/sec for the saturated, silty gravel matrix of the surficial, confined aquifer at the site.

ManTech's chemical delivery system consists of a well head assembly having a chemical feed string and a return line. The chemical feed string is generally placed at the depth of the application well's screen to add reagents to the vertical depth interval designated for treatment. At the TWFF, the strings were placed in AW-1 and AW-2 at the depths corresponding to the depth intervals of the product layers observed at during well installation.

CleanOX® reagents were transferred through the chemical feed string to the application well. The chemical feed string is equipped with a valve for manually controlling the volume and flow rate of reagents added to the application well. The application well return line allows visible observation by ManTech personnel of any vapor, foam, and/or fluid returning after oxidizer application to estimate the site-specific inhibit time of the reaction. The inhibit time is the time duration between starting the oxidizer application and the observation of fluid in the return line; it signifies the beginning of the hydroxyl radical formation and contaminant degradation reactions. At the TWFF, application well return lines and off-set well return lines were attached to 55-gallon drums designed to recover any liquid that may have refluxed through the return lines during the application.

The CleanOX® well head assemblies were secured to each application well by threading a metal well seal on the threaded riser of each well head, forming an air tight seal. CleanOX® reagents were then applied into the well on a controlled basis. Initially, acetic acid was applied to AW-1 and AW-2 to reduce the pH of the groundwater immediately surrounding the application wells to below 5 standard units. Next, an aqueous solution of ferrous sulfate was applied to each application well. Finally, hydrogen peroxide was added to each application well. The volumes and infiltration rates of reagents added to the application well were based on GEMS modeling but are often regulated by site conditions determined during pilot testing.

2.3 Derivative Waste

This section describes the liquid and solid wastes derived during the course of implementation of the CleanOX® Pilot Test at the TWFF. Descriptions of the wastes, the samples completed on the derived wastes, and the disposition of the wastes are described below.

Waste Generation Summary

Waste derived at the TWFF as part of the pilot test included soil cuttings from well installation activities, purge water from sampling and development of the wells, reflux fluid, groundwater saturated sand, and other non-hazardous trash. Soil cuttings were generated by well drilling activities during the week of December 14, 1998. During the same period, purge water was generated by well development. Purge water was also generated during groundwater sampling events the weeks of January 4, 1999; February 8, 1999; February 22, 1999; and April 15, 1999. Reflux fluid from application well return lines was collected during CleanOX® reagent application from January 11 through January 29, 1999. Groundwater-saturated sand that was produced when groundwater began emerging through the ground surface near IW-2. A sand and cinder block berm was constructed. Additional wastes generated during reagent application included empty and rinsed plastic reagent drums, plastic tarps, garden hoses, and PPE.

Waste Sampling and Results

Samples of potentially hazardous wastes were collected and sent to TEG for analysis. Soil cuttings were analyzed for TCLP benzene and purge and reflux water were analyzed for reactivity, corrosivity, ignitability, TCLP benzene and metals, and TOX.

A composite sample of soil cuttings was collected by ManTech and sent to TEG and analyzed on January 4, 1999. Analytical results of the composite sample show that BTEX constituents were below detectable limits; therefore, soil cuttings could be disposed as non-hazardous petroleum contaminated soil. Soil cuttings analytical results are presented in Appendix B.

Sand saturated with groundwater was considered to be similar to the soil cuttings and was, therefore, determined to be non-hazardous waste. It was not sampled nor analyzed.

Purge water samples that were collected during the three-week post-application groundwater sampling event were analyzed by TEG on February 24, 1999. Analytical results show BTEX levels to be below detection limits and pH to be 4.34 standard units. Based on these results, purge water could be disposed of as non-hazardous waste. It was determined unnecessary to analyze the purge water generated during the 60-day post-application sampling event. Purge water analytical results for the three-week sampling event are provided in Appendix C.

Reflux fluid was sampled on January 21, 1999, and a composite sample was sent to TEG for analysis. Laboratory analysis determined that the reflux fluid is negative in terms of reactivity, corrosivity, and ignitability. TCLP benzene and TOX were not detected, and TCLP metals concentrations are all below regulatory limits. Reflux liquid analytical results are presented in Appendix D.

Waste Disposal

Thirteen drums of non-hazardous soil cuttings were removed from the site by USA Waste, a licensed non-hazardous waste hauler, on January 25, 1999 and disposed of at Protecto Landfill Unit 14 in Penuelas, Puerto Rico; a Subtitle D landfill approved for disposal of non-hazardous waste. USA Waste removed four drums of non-hazardous sand saturated with groundwater, twenty empty plastic reagent drums, and three cubic yards of miscellaneous trash (cinder blocks, plastic tarps, and garden hoses) from the site on January 29, 1999, and disposed of at Protecto Landfill Unit 14. On March 16, 1999, two empty metal drums were removed from the site by USA Waste and disposed of at Protecto Landfill Unit 14. Ten drums of non-hazardous purge water were removed from the site by USA Waste and disposed of at Protecto Landfill Unit 14 on March 17, 1999. On April 21, 1999, USA Waste removed three drums of non-hazardous reflux fluid from the site and disposed of them at El Coqui Landfill in Humacao, Puerto Rico; a Subtitle D landfill approved for disposal of non-hazardous waste. El Coqui Landfill was used for this disposal due to the temporary closing of Protecto Landfill Unit 14. Acknowledgement of receipts documenting proper disposal are provided as Appendix E).

3.0 PILOT TEST RESULTS

This section presents the results of laboratory analyses of soil and groundwater samples collected from the soil borings and monitoring wells to evaluate the effectiveness of the CleanOX® pilot test. Specifically, ManTech examined the changes in organic constituent concentrations detected in the soil and groundwater samples collected before, and one week, three weeks, and eight weeks after the pilot test application at the TWFF. The results of the laboratory analyses of these soil and groundwater samples are provided in Appendix F and summarized in Tables 3 and 4, respectively. Heartland Environmental, Inc.performed a Quality Assurance (QA) review of the analytical data. The results of this QA review are provided in Appendix G.

Soil and groundwater samples were collected by ManTech at locations designed in the Work Plan:

- Soil samples were collected from three borings (AW-1, AW-2, and MTMW-4) positioned to coincide with the downgradient groundwater flow direction to determine the effects of the CleanOX® Process. During the drilling of each boring, soil samples were collected at the most contaminated interval based on field observations. Soil samples were collected from AW-1, AW-2, and MTMW-4 at the 30 to 32 foot depth interval (identified as the saturated zone); 24 to 28 foot depth interval (identified as the observed water table); and 18 to 20 foot depth interval (identified as the capillary fringe or smear zone), respectively. Soil sample collection took place before the CleanOX® application and one week, three weeks, and eight weeks after the application.

- Groundwater samples were collected from the two application wells (AW-1 and AW-2) and eight off-set monitoring wells (MTMW-1, MTMW-2, MTMW-3, MTMW-4, RW-1, UGW-3, UGW-14, and UGW-25). Groundwater sample collection and analyses took place before the CleanOX® application to establish baseline conditions, and one week, three weeks, and eight weeks after the CleanOX® application to evaluate post-treatment conditions.

ManTech has focussed the presentation and interpretation of the laboratory analyses to include the petroleum constituents of concern: BTEX, TPH gasoline, and TPH diesel. Summaries of the soil and groundwater laboratory data used by ManTech in our evaluation are provided as Tables 3 and 4, respectively. The results of our evaluation of the data are presented in the remainder of this section.

3.1 CleanOX® Process Application Observations

ManTech personnel recorded field observations and measurements during the pilot test. These parameters provide indications of how well the CleanOX® Process is proceeding in the field. They are also used to modify the CleanOX® Process design to yield maximum chemical efficiency better

suited to site-specific conditions for full-scale application at the TWFF. Static water level, temperature, conductivity, pH, dissolved oxygen, and ORP measurements were collected periodically during the application (Table 5). The effects of application to AW-1 and AW-2 were periodically monitored at six locations (MTMW-1, MTMW-2, MTMW-3, MTMW-4, RW-1, and UGW-3) throughout each day as well as at application wells AW-1 and AW-2 each morning. The following discussion relates to the parameters monitored during the field application.

Reagent Application

The field application consisted of two rounds of reagent application to AW-1 and AW-2. First, ManTech applied conditioning agents and the catalyst (i.e., acetic acid and ferrous sulfate) to the wells. Second, oxidizer (hydrogen peroxide) was added over two cycles in a two week period. Additional acid and ferrous sulfate were added periodically, as needed, to maintain the pH and catalyst in the proper ranges during the pilot test. In total, the following pounds of reagents were added to each application well:

	Acetic Acid (lb.)	Ferrous Sulfate (lb.)	Hydrogen Peroxide (lb.)
AW-1	915	80	945
AW-2	1050	180	1250

Field Observations

Exothermic reactions of the CleanOX® reagents began immediately after application of hydrogen peroxide, as evidenced by the presence of reflux through the return lines of both application wells. Based on these observations, ManTech determined that there is zero CleanOX® reaction inhibit time at the TWFF due to the presence of free product. Significant volumes of reflux were expected due to the historical levels of free product in the application area, and return lines were connected to 55 gallon drums for free product collection per ManTech's pilot test application design.

The reactivity of the aquifer in response to the addition of hydrogen peroxide was very strong. ManTech personnel observed minor volumes of fluids emerging to the surface near AW-1 and AW-2 during the initial phases of application. The rate of peroxide application was reduced, which temporarily eliminated the fluid return to the surface. Return line valves were manually operated to minimize the volume of reflux and the volume of oxidizer in the reflux fluid.

After approximately 125 lb. of peroxide at 8% dilution, fluid began emerging to the surface near AW-1 at greater volumes. This may be due to auger refusal during the application well installation; a pathway for short-circuiting resulted. ManTech personnel attempted to contain the fluid by constructing a sand and cinder block berm around the pilot test treatment area and continued with

application to both AW-1 and AW-2. Generally, this method of containment is temporarily used when strong reactions are observed. Due to the nature of the soil matrix at this site and the extreme reactivity observed, application to AW-1 was terminated before the pilot test design volume of oxidizer could be applied.

ManTech personnel continued to have difficulty in achieving an adequate flow of peroxide because of the intensity of the reactions and subsequent pressurization of the application wells resulting in fluid surfacing at the application wells. As a result, only about 20 % of the design volume of oxidizer was added to the application wells. This is significant because the effectiveness of the process generally relies of two phenomena: dissolution of adsorbed mass followed by oxidation of the dissolved organic mass. Although the formation and consumption of the hydroxyl radical results in both dissolution and oxidation of organic contaminants, the rate of dissolution is more pronounced during the initial phases of application while the rate of oxidation is more pronounced in the latter phases of application.

Throughout the pilot test, ManTech personnel observed reactions in downgradient wells RW-1 and MTMW-4 (bubbling at RW-1 and bubbling and visible liquid vapor within casing at MTMW-4) located approximately 10 feet southwest and 11 feet southeast of AW-1, respectively. These field observations indicate that the CleanOX® Process produced effects in the aquifer at locations at least 11 feet away from the application well and that reactions were somewhat stronger downgradient from the application wells.

In summary, the infiltration rate of CleanOX® reagents at the TWFF was limited during the pilot test for the following reasons: 1) the semi-confined aquifer conditions and the predominantly silty clay matrix; 2) very exothermic reaction created due to the presence of free product, and 3) the high water vapor generation from the CleanOX® Process due to the free product.

Static Water Level Measurements

Static water level measurements were collected periodically during the application, and minor water level fluctuations were observed during the treatment. Temporary drops and rises in the water level ranging from approximately 0.30 to 0.35 feet and 0.10 to 2.37 feet, respectively, were observed in the application wells and surrounding monitoring wells within a radius of 14 feet from AW-1 and AW-2. Likewise, fluctuations of free product thickness were observed in both application wells and off-set observation wells ranging from decreases of 0.92 feet to increases of 2.59 feet.

Pressure

CleanOX® well head assemblies used to apply CleanOX® reagents to AW-1 and AW-2 are equipped with gauges to measure pressure and temperature at the return line valve. These measurements give ManTech personnel indications of application well conditions and help to gauge and regulate the

rate of application. Pressures observed at AW-1 during the application of oxidizer remained at 10 pounds per square inch gauge (psig) or less and ranged from 10 to 50 psig at AW-2. Pressures at both wells were kept low by manual operation of the return valves by ManTech personnel in order to minimize fluid surfacing and to regulate collection of reflux liquid.

Temperature

Temperature observations at the CleanOX® well head assembly, which measure vapor temperature within the return line, were monitored at both application wells during reagent application and ranged from 32 to 98 ^{0}C. Groundwater temperature measurements were also monitored during the pilot test in both application and monitoring wells. As expected, the greatest rises in temperature occurred at the application wells. A 9.58 ^{0}C rise in temperature from 29.05^{0}C (baseline) to 38.63^{0}C (mid-application) was observed at AW-1, and a 14.61 ^{0}C rise in temperature from 29.03^{0}C (baseline) to 43.64 ^{0}C (post-application) was observed at AW-2. These temperature increases are within the range of temperature changes expected and demonstrate that exothermic reactions are taking place.

Temperature monitoring in the off-set wells during the CleanOX® application are indicative of the large heat capacity of the treatment area aquifer. Off-set well temperature changes ranged from 0.04^{0}C at UGW-3 to 0.34^{0}C at RW-1.

Specific Conductivity

Specific conductivity is an indication that the ferrous ion concentration is within the expected range for a field application and that the catalyst is dispersed in the aquifer as needed for hydroxyl radical formation. During the pilot testing, off-set well RW-1 showed the greatest increase in specific conductivity of 13,039 µS/cm, from 2,570 µS/cm (baseline) to 15,609 µS/cm. This increase indicates possible preferential flow to RW-1 from AW-2. An increase of 5,782 µS/cm was observed at application well AW-1, from 7,491 µS/cm (baseline) to 13,273 µS/cm (post-application); and 4,693 µS/cm at AW-2, from 3,411 µS/cm to 8,104 µS/cm. Specific conductivity increases ranging from 157 µS/cm (MTMW-1) to 13,039 µS/cm (RW-1) and decreases from 28 µS/cm(MTMW-2) to 389 µS/cm (MTMW-4) were measured in the observation wells within 14 feet of AW-1 and AW-2. The greatest decreases were observed at MTMW-3 and MTMW-4 which are located hydraulically downgradient from AW-1 and cross-gradient to AW-2.

Increases in specific conductivity in off-set wells is not a critical parameter but rather is used to evaluate continuity between the application well and the monitoring locations.

pH

Measurements of pH indicate whether the proper acidified aqueous medium is present for hydrogen peroxide to react with ferrous ions to produce hydroxyl radicals. The optimum pH range is from

3 to 5 s.u. for Fenton Reaction chemistry. Since the Fenton Reaction production of hydroxyl radical occurs near the application well, reduction of pH to below 5 s.u. is only critical for the application well. Reduction of pH in off-set monitoring wells, similar to specific conductivity, is not critical and is used to evaluate application well/monitoring well continuity.

Both application well and off-set well pH measurements were collected periodically throughout the application process. At AW-1, decreases in pH from 7.06 s.u. (baseline) to 2.12 s.u. (post acidifier application) and 4.72 s.u. (post-application) were measured. Decreases in pH from 7.04 s.u. (baseline) to 2.02 s.u. (post-acidifier application) and 4.29 s.u. (post-application) were measured at AW-2. These measurements indicate that satisfactory acidified conditions were present in the vicinity of the application wells to initiate and maintain hydroxyl radical production.

In the off-set monitoring wells, pH reduction was most pronounced in RW-1 (3.69 s.u.), which is a very significant change for a monitoring point 10 feet from an application point. RW-1 also showed the greatest change in specific conductivity. Other monitoring wells generally showed a decrease in pH from 0.14 s.u. at UGW-3 to 0.50 s.u. at MTMW-3 which are more typical for monitoring wells about 10 feet from application wells, which indicates that a general reduction in pH occurred radially from the application wells.

Dissolved Oxygen

Dissolved oxygen is an indicator of the oxidation process. Increases in dissolved oxygen were measured at all six of the monitoring locations, from 16.21 ppm to 65.53 ppm. These observations indicate that the Fenton reaction was occurring throughout the pilot study area.

ORP

ORP readings are used in the pilot test to gauge the oxidative and reductive conditions produced by the CleanOX® Process. ORP is also a good indicator for judging whether the reactions are completed and to approximate the radial extent of the process during field applications.

A +494.5 mV increase in ORP from –31.8 mV (baseline) to +462.7 mV during the application was observed at AW-1. AW-2 showed an increase in ORP of +512.7 mV, from -65.0 mV (baseline) to +447.7 mV (mid-application). Monitoring well MTMW-1 became more reductive indicated by decreases in ORP measurements of up to -220.3 mV from -28.2 mV (baseline) to -248.5 mV (mid-application). The other five monitoring wells all displayed increases in ORP ranging from +17.7 to +350.1 mV. These increases in ORP demonstrate that the application of CleanOX® reagents to the application well had caused the aquifer surrounding them to become more highly oxidative, indicative of Fenton Reaction chemistry.

Air Quality Monitoring

Air quality within the application area was monitored on a regular basis for volatile organic compounds (VOCs), lower explosive limit (LEL), and hydrogen sulfate (H_2S). Monitoring for VOCs using a photo ionization detector (PID) ranged from 0.00 to 3.6 ppm above background levels. LEL levels were generally 0%; a maximum concentration of 5% was recorded. There was no detection of H_2S.

3.2 Soil Sample Analytical Results

One week and 60 days after the pilot test, ManTech collected soil samples from well locations AW-1, AW-2 and MTMW-4 using split-spoon sampling methods over two-foot intervals. During each sampling event, the samples were collected immediately adjacent to the specified wells to monitor the post-treatment progress of the CleanOX® Process. The laboratory analytical results for soil samples collected are provided as Table 3 and are discussed below:

AW-1. Soil samples were collected from well AW-1, as follows.

A grab soil sample was collected from 30 to 32 foot bgs as a baseline during installation of AW-1. Total BTEX concentrations of 21 ug/kg, TPH Gasoline concentrations of 32,000 ug/kg, and TPH Diesel concentrations of 19 mg/kg in soil were detected in laboratory analyses.

The one-week post-treatment grab soil sample was collected from a boring drilled within 5 feet of AW-1 and at the same depth of 30 to 32 feet bgs. Analytical results show decreased concentrations to below method detection limit of 6 ug/kg, 390 ug/kg, and to below method detection limit for total BTEX, TPH Gasoline, and TPH Diesel concentrations, respectively. These results indicate substantial concentration and mass reduction occurred in the vicinity of the application well and demonstrate the destruction efficacy of the CleanOX® Process.

The eight-week post-treatment grab soil sample was collected from a boring drilled within 5 feet of AW-1 and at the same depth of 30 to 32 feet bgs. Analytical results show concentrations to below method detection limit, 290,000 ug/kg, and 790 mg/kg for total BTEX, TPH Gasoline, and TPH Diesel concentrations, respectively. These increases after 60 days suggest reinfiltration of contaminants into this heavily contaminated area.

AW-2. AW-2 is located approximately 30 feet southwest of AW-1. Soil samples were collected as follows.

A grab soil sample was collected from 24 to 28 feet bgs as a baseline during installation of AW-2. Total BTEX concentrations of 564 ug/kg, TPH Gasoline concentrations of 350,000 ug/kg, and TPH Diesel concentrations of 580 mg/kg were detected.

The one-week post-treatment grab soil sample was collected from a soil boring drilled within 5 feet of AW-2 and at the same depth of 24 to 28 feet bgs. Analytical results show decreased concentrations to 125 ug/kg, 61,000 ug/kg, and 140 mg/kg for total BTEX, TPH Gasoline, and TPH Diesel concentrations, respectively.

The eight-week post-treatment soil sample was collected from a boring drilled within 5 feet of AW-2 and at the same depth of 24 to 28 feet bgs. Analytical results show decreased concentrations to below method detection limits for total BTEX, TPH Gasoline, and TPH Diesel concentrations. These results indicate that substantial concentration and mass reduction occurred and were maintained during the 60 day period under evaluation.

MTMW-4. MTMW-4 is located approximately 12 feet southeast of AW-2. Soil samples were collected as follows.

A grab soil sample was collected from 18 to 20 feet bgs as a baseline during installation of MTMW-4. Total BTEX concentrations of 3,956 ug/kg, TPH Gasoline concentrations of 5,600,000 ug/kg, and TPH Diesel concentrations of 8,800 mg/kg were detected.

The one-week post-treatment grab soil sample was collected from a boring drilled within 5 feet of MTMW-4 and at the same depth of 18 to 20 feet bgs. Analytical results show increased total BTEX concentrations to 10,700 ug/kg, while decreased concentrations to 5,100,000 ug/kg and 3,400 mg/kg were detected for TPH Gasoline and TPH Diesel concentrations, respectively.

The eight-week post-treatment grab soil sample was collected from a boring drilled within 5 feet of MTMW-4 and at the same depth of 18 to 20 feet bgs. Analytical results show decreased concentrations of 410 ug/kg, 320,000 ug/kg, and 2,000 mg/kg for total BTEX, TPH Gasoline, and TPH Diesel concentrations, respectively. Similar to the AW-2 results, these results demonstrate that substantial concentration and mass reduction occurred but was evidenced primarily during the period between one and eight weeks following reagent application.

Isoconcentration maps for BTEX, TPH Diesel and TPH Gasoline results for sampling points AW-1, AW-2 and MTMW-4 for baseline, one-week post-treatment sampling, and eight-week post-treatment sampling are found in Figures 8, 9 and 10, respectively.

3.3 Groundwater Sample Analytical Results

ManTech collected groundwater samples, from well locations AW-1, AW-2, MTMW-1, MTMW-2, MTMW-3, MTMW-4, RW-1, UGW-3, UGW-14, and UGW-25. The laboratory analytical results for groundwater samples collected are provided as Table 4 and are discussed below:

AW-1. At application well AW-1, a baseline total BTEX concentration of 10 ug/L was increased to 508 ug/L during the one-week sampling event, reduced to 343 ug/L during the three-week sampling event, then increased to 552 ug/L during the eight-week sampling event. A baseline TPH Gasoline concentration of 640 ug/L was increased to 36,000 ug/L during the one-week sampling event, reduced to 22,000 ug/L during the three-week sampling event, then increased to 160,000 ug/L during the eight-week sampling event. A baseline TPH Diesel concentration of 0.96 mg/L was increased to 6,500 mg/L during the one-week sampling event, then reduced to 1,600 mg/L and 1,500 mg/L during the three-week sampling event and eight-week sampling event, respectively.

The increases in dissolved petroleum constituent concentrations were expected. Substantial concentration and mass reduction were achieved in saturated soil. The increases in dissolved concentrations likely resulted from desorption and dissolution of petroleum constituent mass from the vigorous reaction created in the saturated zone by the Fenton Reaction.

It is also important to note that baseline measurements of free product were not observed in the well immediately following its installation although it was very likely present at that time. During the drilling, a saturated layer of petroleum product was observed approximately 2 feet above the water table. The screened interval of AW-1 intercepts this saturated layer; however, it takes a significant amount of time for product to accumulate within a well.

AW-2. AW-2 is located approximately 30 feet southwest and hydraulically downgradient of AW-1. At application well AW-2, a baseline total BTEX concentration of 95 ug/L was increased to 159 ug/L, 182 ug/L, and 325 ug/L during the one-week, three-week, and eight-week sampling events, respectively. A baseline TPH Gasoline concentration of 1,700 ug/L was increased to 6,300 ug/L during the one-week sampling event, reduced to 5,700 ug/L during the three-week sampling event, then increased to 77,000 ug/L during the eight-week sampling event. A baseline TPH Diesel concentration of 3.6 mg/L was increased to 190 and 1,000 mg/L during the one-week and three-week sampling events, respectively. It was then reduced to 420 mg/L during the eight-week sampling event. As discussed above, increases in dissolved concentrations were expected.

MTMW-1. MTMW-1 is located within the pilot test's estimated ROI approximately 12 feet northwest and hydraulically upgradient of AW-1. A baseline BTEX concentration of 59 ug/L was increased to 89 ug/L, 170 ug/L, and 181 ug/L during the one-week, three-week, and eight-week sampling events, respectively. A baseline TPH Gasoline concentration of 1,400 ug/L was increased to 5,000 ug/L and 12,000 ug/L during the baseline one-week and three-week sampling events, respectively; it was then reduced to 11,000 ug/L during the eight-week sampling event. A baseline TPH Diesel concentration of 2 mg/L was increased to 19 mg/L, 270 mg/L, and 6,200 mg/L during the one-week, three-week, and eight-week sampling events, respectively. Again, increases in dissolved concentrations were expected.

MTMW-2. MTMW-2 is located within the pilot test's estimated ROI approximately 15 feet southeast and hydraulically downgradient of AW-1. A baseline BTEX concentration of 157 ug/L was increased to 196 ug/L and 343 ug/L one-week and three-week sampling events, respectively. It was then reduced to 85 ug/L during the eight-week sampling event. A baseline TPH Gasoline concentration of 1,900 ug/L was increased to 15,000 ug/L during the one-week sampling event, then reduced to 9,600 ug/L and 4,600 ug/L during the three-week and eight-week sampling event, respectively. A baseline TPH Diesel concentration of 3.1 mg/L was increased to 290 mg/L, 450 mg/L, and 8,800 mg/L during the one-week, three-week, and eight-week sampling events, respectively. Interpretation of these results is consistent with that of the application wells. Substantial reductions in the saturated soil indicate desorption and dissolution processes were on-going and result in higher dissolved concentrations.

MTMW-3. MTMW-3 is located within the pilot test's estimated ROI approximately 12 feet northwest and hydraulically upgradient of AW-2. A baseline BTEX concentration of 8 ug/L was increased to 258 ug/L, 396 ug/L, and 415 ug/L during the one-week, three-week, eight-week sampling events, respectively. A baseline TPH Gasoline concentration of 760 ug/L was increased to 24,000 ug/L during the one-week sampling event, reduced to 18,000 ug/L during the three-week sampling event, then increased to 200,000 ug/L during the eight-week sampling event. A baseline TPH Diesel concentration of 2.3 mg/L was increased to 1,300 mg/L and 3,200 mg/L during one-week and three-week sampling events, respectively; it was then reduced to 300 mg/L during the eight-week sampling event. These increases in dissolved concentrations were expected. Note the increase in free product suggests that elevated levels of adsorbed and absorbed phase petroleum constituents are present at this location. The turbulence of the Fenton Reaction results in desorption and dissolution of these petroleum constituents.

MTMW-4. MTMW-4 is located within the pilot test's estimated ROI approximately 12 feet southeast and hydraulically downgradient of AW-2. Baseline concentrations of BTEX of 224 ug/L were increased to 376 ug/L during the one-week sampling event, then reduced to 363 ug/L and 230 ug/L in the three-week and eight-week sampling events, respectively. TPH Gasoline increased from baseline concentrations of 2,600 ug/L to 6,800 and 42,000 ug/L during the one-week and three-week sampling events. It was then reduced back to 2,600 ug/L during the eight-week sampling event. TPH Diesel baseline concentrations of 3.7 mg/L increased to 500 mg/L, 1,300 mg/L, and 18,000 mg/L during the one-week, three-week, and eight-week sampling events, respectively. These fluctuations in dissolved concentrations are not unusual when the CleanOX® Process is applied at a site with free product, such as the TWFF. Significant decreases in free product thickness as MTMW-4 from 2.22 feet to not detectable for six weeks were observed. The slight increase to 0.22 feet likely results from on-going desorption and dissolution, and to a less extent, from reinfiltration of contaminants.

RW-1. RW-1 is located within the pilot test's estimated ROI approximately 10 feet southeast and hydraulically downgradient of AW-2. A baseline BTEX concentration of 20 ug/L was increased

to 370 ug/L in the one-week sampling event, reduced to 102 ug/L during the three-week sampling event, then increased to 310 ug/L in the eight-week sampling event. A baseline concentration of TPH Gasoline of 2,900 ug/L increased to 240,000 ug/L during the one-week sampling event, reduced to 3,400 ug/L during the three-week sampling event, then increased to 35,000 ug/L during the eight-week sampling event. A baseline concentration of TPH Diesel of 4.7 mg/L increased to 1,300 mg/L during the one-week sampling event, reduced to 250 mg/L during the three-week sampling event, then increased to 520 mg/L during the eight-week sampling event. Again, these fluctuations and general increases in dissolved concentrations are typical and demonstrate that desorption and dissolution reactions are on-going.

UGW-3. UGW-3 is located within the pilot test's estimated ROI approximately 12 feet northeast and hydraulically upgradient of AW-1. A baseline concentration of total BTEX of 36 ug/L increased to 100 ug/L during the one-week sampling event, reduced to 11 ug/L during the three-week sampling event, then increased to 39 ug/L during the eight-week sampling event. Baseline TPH Gasoline concentrations of 550 ug/L increased to 19,000 ug/L during the one-week sampling event, then reduced to 4,300 ug/L and 1,300 ug/L during the three-week and eight-week sampling events, respectively. Baseline TPH Diesel concentrations of 3.8 mg/L increased to 170 mg/L during the one-week sampling event, then reduced to 33 mg/L and 28 mg/L during the three-week and eight-week sampling events, respectively. While increases in dissolved concentrations were observed, the free product thicknesses steadily decreased from 0.35' to 0.15' then to not detectable at the 1-week, 3-week, and eight-week sampling events. These results indicate a significant reduction in petroleum constituent mass at this location.

UGW-14. UGW-14 is located approximately 100 feet south and hydraulically downgradient of AW-2. This is not within the pilot test's estimated ROI. No significant change in total BTEX concentration was detected in laboratory analysis . Baseline concentrations of TPH Gasoline of 1,300 ug/L increased to 24,000 ug/L during the one-week sampling event, then reduced to 5,400 ug/L and 870 ug/L during the three-week and eight-week sampling events, respectively. Baseline concentrations of TPH Diesel of 5.8 mg/L increased to 98 mg/L during the one-week sampling event, then reduced to 34 mg/L and 5 mg/L during the three-week and eight-week sampling events, respectively.

UGW-25. UGW-25 is located approximately 110 feet northwest and hydraulically upgradient of AW-1. This is not within the pilot test's estimated ROI. Baseline concentrations of total BTEX of 76 ug/L were reduced to 61 ug/L and 31 ug/L during the one-week and three-week sampling events, respectively; it was then increased to 41 ug/L during the eight-week sampling event. Baseline concentrations of TPH Gasoline of 220,000 ug/L decreased to 4,000 ug/L during the one-week sampling event, then increased to 5,100 ug/L and 30,000 ug/L during the three-week and eight-week sampling events, respectively. Baseline concentrations of TPH Diesel of 360 mg/L decreased to 280 mg/L during the one-week sampling event, then increased to 740 mg/L and 7,400 mg/L during the three-week and eight-week sampling events, respectively.

The rather substantial variation in BTEX and TPH concentrations in this area is likely due to normal sampling variations in locations that are likely to contain free product an extensive sorbed phase.

Isoconcentration maps for BTEX, TPH Diesel and TPH Gasoline results for sampling points AW-1, AW-2, MTMW-1, MTMW-2, MTMW-3, MTMW-4, RW-1 and UGW-3 for baseline, one-week, three-week, and eight-week post-treatment sampling are found in Figures 11, 12 and 13, respectively. These maps illustrate the significant reductions in sorbed concentrations achieved by the CleanOX® Process and the increases in dissolved concentrations temporarily resulting from reduction of free product levels.

3.4 Mass Destruction Estimates

ManTech used a simplified method to determine a rough estimate of the mass of petroleum constituents that were destroyed within the pilot test treatment area through application of the CleanOX® Process reagents after one-week and after 60 days. We believe the development and presentation of this data is important in the evaluation of the CleanOX® Process at the site because the presence of elevated concentrations of petroleum constituents in free product, residual product, sorbed, and dissolved phases makes the mass removal element of any remedial approach a significant factor in the effectiveness evaluation process. Described below is the simplified calculation method used by ManTech to estimate the TPH Diesel and TPH Gasoline mass removed within the treatment area at the site through application of the CleanOX® Process reagents after one-week and after 60 days.

The one-week and eight-week sampling events were used for our calculations because both soil and groundwater analytical data were collected. The mass of TPH Diesel and TPH Gasoline present as free product and in saturated soils and groundwater is based on the baseline and the eight-week post-treatment soil and groundwater sampling data. It is important to note the inherent limitations in soil sampling for estimation of the petroleum constituent mass in soil. Further, the limitations inherent in any sampling event (i.e., heterogeneity of the subsurface, repeatability of sampling procedures, variability of handling and shipping conditions, etc.)are incorporated into our calculations. Finally, the mass removal calculations are based on averages. Note that the application well area is an average of two sampling locations, while the monitoring well area is based on the one soil sampling location of MTMW-4. Depending on how representative these results are, the calculations may either overestimate or underestimate of the efficiency of the CleanOX® Process at the TWFF.

For purposes of simplifying the mass reduction calculations, ManTech assumed the following:

- The analytical data from the application wells, AW-1 and AW-2, are considered representative of the soil and groundwater to a distance of 7.5 feet from each application well. The resulting volume consists of a cylinder with a radius of 7.5 feet and a height of 15 feet (the application well screen lengths);

- The analytical data from the monitoring wells located approximately 12 feet from the application wells (MTMW-1, MTMW-2, MTMW-3, MTMW-4, UGW-3, and RW-1) are considered representative of the soil and groundwater 7.5 to 22.5 feet from the application well. The resulting volume consists of a hollow cylinder with a radius of 7.5 to 22.5 feet and a height of 15 feet; and

- The saturated soil is assumed to have a porosity of 30%.

Table 6 presents the estimated mass destruction calculations in these two areas after one week and after 60 days. ManTech calculated the total mass of soil in the two areas within the estimated ROI of the application well. As shown in Table 6, the calculations resulted in an estimated total of 8,215 kg (or 2,259 gallons) of petroleum constituent destruction after one week and 12,889 kg (or 3,544 gallons) of petroleum constituent destruction after 60 days. ManTech believes that this degree of destruction for a two-cycle round of chemical application to two application wells demonstrates the effectiveness of the process for source-area mass reduction at the TWFF.

4.0 CONCLUSIONS

ManTech has drawn the following conclusions from the results of the CleanOX® field application at the site:

- Technical Feasibility of the CleanOX® Process at the TWFF. The CleanOX® Process is the only remediation technology capable of treating the free product found in the gravel layers and lenses above the confined aquifer at the TWFF. The existing product recovery system is designed to remove product that is within the saturated zone/capillary fringe or has accumulated within the wells, while our investigation results indicate that a significant portion of the free product is present within the unsaturated zone.

- Mass Reduction. Significant mass reductions of greater than 12,800 kg of petroleum constituents were produced by applying the CleanOX® Process to two application wells. Field observations verified that substantial oxidation of constituent mass occurred. The hydrocarbon mass represented by the free product and soil concentration reductions is substantial.

- Safe and Efficient Process. The pilot test procedure was performed in a safe, controlled manner at the TWFF. Because of significant reactivity of the aquifer in response to the addition of the reagents, only about 20% of the design volume of oxidizer could be added during the two-cycle pilot study. The resulting application rate was less than desired and planned, but did result in significant mass reduction. Since the process relies on dissolution followed by oxidation of the dissolved mass, ManTech believes that our inability to apply the pilot scale design's volume of oxidizer likely resulted in a substantial dissolution effect. Future applications would require the use of more dilute oxidizer to be applied over a longer period of time. In the same way, the use of a more dilute oxidizer would reduce the short-circuiting of CleanOX® reagent reflux to ground surface. This factor was incorporated into the full-scale conceptual approach discussed in Section 5.

- Reagent Infiltration. The pilot test demonstrated sufficient permeability at the TWFF to infiltrate CleanOX® reagents to the surficial, semi-confined aquifer. Field observations and measurements demonstrated that the reagents were distributed to a ROI of approximately 15 feet. As stated above, reactivity of the aquifer due to high organic concentrations limited the reagent application rate.

- Aquifer Response. Field observations and measurements demonstrated the ability of the CleanOX® reagents to adjust the pH and specific conductivity to within optimum ranges for the Fenton Reaction chemistry to take place. Further, observed bubbling, dissolved oxygen,

and ORP readings demonstrated oxidation occurred within an estimated 25 foot radius of the application wells.

The pilot test yielded important site-specific data enabling ManTech to refine the site-specific formulation of CleanOX® Process reagents to be used if additional applications of the process are implemented. In summary, the application of the CleanOX® Process at the site demonstrated that the reagents could be added in a safe, controlled manner and that, based on post-treatment sampling data, field observations and monitoring, a large mass of organic constituents was oxidized. If the overall remedial strategy for the TWFF continues to include a source removal element, ManTech believes the CleanOX® Process should be included as an alternative for further consideration.

5.0 FULL-SCALE CLEANOX® PROCESS APPLICATION ESTIMATE

5.1 Conceptual Approach

ManTech is providing this full-scale free-product remediation project cost estimate for the TWFF site based upon the results of the pilot test conducted in the area by ManTech in January 1999 and free product recovery system monitoring data (April 1999) provided by Baker (Figure 14). Pilot test results were used to determine CleanOX® application well radial influence, number of wells to be installed, personnel needed, reagent quantity and concentrations, application procedures, the duration of each application round, and the number of rounds of application needed for each zone.

In preparing this estimate, ManTech has divided the free-product plume into five zones based upon product thickness and geographical location. Each CleanOX® application well will receive similar volumes and concentrations of reagents per each cycle. However, based upon the varying apparent free-product thickness in each area, the number of cycles required varies from zone to zone. A stabilization period of one to two weeks will be required between each cycle for a specific zone. If more than one zone is to be treated, field crews can work within other zones during these stabilization periods. Zones are designated as Zones A, B, C, D, and E (Figure 15) and discussed in detail below:

Zone A:

Zone A is located approximately 550 feet north northwest of the intersection of Forrestal Drive and Palau Street in the general vicinity of the pilot test performed by ManTech near monitoring well UGW-3. The area of this zone is approximately 14,400 square feet with current free-product thicknesses ranging from 0.10 to 1.00 foot. Based upon CleanOX® application well radial influence demonstrated during the pilot test, Zone A will require fourteen (14) CleanOX® application wells to be installed. Based upon reagent volume and infiltration rates determined to sufficiently oxidize free product during the pilot test, the full-scale application in Zone A will require two application cycles which are estimated to take three weeks per cycle.

Zone B:

Zone B is situated north northwest from the intersection of Forrestal Drive and Palau Street, in the area near monitoring well UGW-4 and just beyond the pump station. This zone is approximately 21,600 square feet in size and the current free-product in the area is less than 0.10 feet in thickness. CleanOX® application well radial influence demonstrated during the pilot test indicates that Zone B will require twenty-two (22) CleanOX® application wells. Based upon free product reductions during the pilot test and the current apparent product thickness, it is estimated that two cycles would

be required to sufficiently reduce the free product in this area. It is estimated that each cycle will take approximately four weeks.

Zone C:

Zone C is at the northern border of Forrestal Drive where it meets Palau Street just to the east of the pump station in the vicinity of monitoring well UGW-5. The area of this zone is comprised of approximately 27,000 square feet and Baker reports that current free-product thickness is generally between 0.01 and 4.00 feet. Based upon pilot test results and current apparent product thickness, twenty-seven (27) CleanOX® application wells will need to be installed in this area and three cycles with a duration of five weeks per cycle will be performed in order to sufficiently oxidize the free product in this area.

Zone D:

Zone D lies along the northeast border of Forrestal Drive, approximately 240 feet to the southeast of the intersection of Forrestal Drive and Palau Street in the general vicinity monitoring well UGW-13. The area of this zone is approximately 11,880 square feet with current free-product thicknesses of 4.00 feet and greater. Zone D will require twelve (12) CleanOX® application wells be installed based upon CleanOX® application well radial influence demonstrated during the pilot test. The application in this zone will require approximately three weeks to complete each cycle with a total of four cycles to sufficiently reduce the free product in this area based upon free product reductions during the pilot test and the current apparent product thickness in the area.

Zone E:

Zone E lies along the northeastern border of Forrestal Drive just to the southeast of Zone D and approximately 550 feet from the intersection of Forrestal Drive and Palau Street near monitoring well UGW-19. Zone E consists of approximately 8,640 square feet and currently shows between 0.10 and 4.00 feet of free-product thickness. Radial influence determined during ManTech's pilot test indicates that nine (9) CleanOX® application wells will need to be installed in this area. Based upon pilot test results and current apparent free product thickness in this zone, four cycles with a duration of three weeks per cycle will be applied to this area in order to effectively oxidize the free product in this area.

All Zones:

In order to perform a full-scale remediation application in all areas with reported free-product, ManTech will install 84 CleanOX® application wells throughout the 83,520 square foot area within the TWFF and points along the northeast border of Forrestal Drive to the southeast of the compound. The application procedure will incorporate all of the above mentioned number of cycles

per Zone over the course of fifty (50) weeks. The first cycle which will be applied to the entire area delineated in Figure 15 will require approximately eighteen (18) weeks to complete. The second cycle will encompass the same area and time frame as the first cycle of eighteen (18) weeks. However, the third cycle will only be required for Zones C, D, and E and will therefore require only eleven (11) weeks to complete. The fourth and final cycle will be applied to Zone D alone and require approximately a three (3) week duration to complete.

5.2 Cost Estimate

This CleanOX® full-scale application cost has been conservatively estimated using parameters determined during ManTech's pilot test at the TWFF. Parameters including reagent volume, concentration, infiltration rates, radial influence, and free product reduction values from the pilot test area were used to determine well spacing, reagent specifications, and application durations for all other zones. ManTech expects that the application parameters will be slightly different from area to area and has added a twenty percent contingency amount to the total conservative estimates in anticipation of this. The following table provides an overview of the full-scale estimate; however, details of estimated costs per cycle are provided in Table 7 and details of total estimated costs are shown in Table 8.

CleanOX® Full-Scale Application Estimated Cost Summary

Zone	Square Feet	No. Wells	No. Cycles	Total Cost
A	14,400	14	2	$ 517,500
B	21,600	22	2	$ 708,300
C	27,000	27	3	$ 1,250,000
D	11,880	12	4	$ 745,100
E	8,640	9	3	$ 483,800
ALL ZONES	83,520	84	2-4	$ 3,704,400

5.3 Assumptions

Key assumptions that were used in the development of this scope of work and cost estimate include:

- Utilities are available at the site including a potable water bib and supply and electrical service (120 V, 60 Hz, 15 amp electrical outlet) within 100 feet of the work areas;
- Adequate facilities are available at the site for the unloading and storage of CleanOX® reagents in or near the proposed treatment area;
- We assume that there are no other sources of contamination in the immediate vicinity of the treatment area since their presence would mask the effectiveness of the CleanOX® Process. Work elements necessary to verify the absence of other sources have not been included in this proposal;
- Weather conditions will permit execution of the pilot test without work delays. Pilot test work can be completed under Occupational Safety Health Administration (OSHA) guidelines using Level D personnel protective equipment (PPE);
- ManTech and the Navy will be responsible for locating underground utilities, and/or other subsurface features that would delay the pilot test activities;
- ManTech will provide information and coordinate with Baker to obtain regulatory approval to perform the CleanOX® application;
- ManTech will mobilize all equipment and personnel required to apply the CleanOX® Process at the property. ManTech will be responsible for arranging the delivery of chemical reagents required to conduct the full-scale program, applying the CleanOX® reagents using the newly installed application wells, and monitoring on-site conditions to ensure that the process is being applied appropriately. During the application of the CleanOX® reagents, parameters such pH, dissolved oxygen, ORP, temperature, and groundwater elevation will be measured periodically in the application and off-set observation wells by ManTech; and
- Characterization, transportation, and disposal of derivative wastes, if any, are not included in ManTech's scope of work. Empty chemical reagent containers will be rinsed and recycled after the full-scale program. Waste materials that may be generated include decontamination water from well sampling and drilling activities, drill cuttings from installing monitoring wells, and PPE.

Table 1
Tow Way Fuel Farm
Pilot Test Sampling Summary

Sampling Event	Groundwater Analysis									Soil Analysis						Misc.		Totals
	8260 (BTEX only)	TPH by 8015M (DRO & GRO)	Iron by 236.2/ 6010	Lead by 239.2/ 7421	Hardness by 130.2	Alkalinity by 310.1	Sulfates by 9056	Nitrates/ Nitrites by 9056	TDS by 160.1	pH by 9040/ 9045	TPH by 8015M (DRO/ GRO)	BTEX by 8260	Iron by 6010	Lead by 7421	Sulfates by 9035/9036	Drilling Cuttings*	Purge Water*	
Task 2 - Baseline Soil	1									3	3	3	3	3	3			19
Task 3 - Baseline GW	12	10	10	10	10	10	10	10	10									92
Task 5 - Waste Disposal																1	1	2
Task 6 - 1 week sampling	12	10	10	10	10	10	10	10	10	3	3	3	3	3	3		1	111
Task 7 - 3 week sampling	12	10	10	10	10	10	10	10	10									92
Task 8 - 60 day sampling	12	10	10	10	10	10	10	10	10	3	3	3	3	3	3			110
Task 9 - 120 day sampling	12	10	10	10	10	10	10	10	10	3	3	3	3	3	3			110

*Drill cuttings analyzed for TCLP benzene only. Purge water analyzed for reactivity, corrosivity, ignitability, TCLP benzene & metals, and TOX.

Table 2
Wells Used As Part of the CleanOX® Process Pilot Test
Naval Station Roosevelt Roads Tow Way Fuel Farm

Well ID	Well Diameter (in.)	Well Construction Material	Static Water Level (ft. bgs)	Measured Depth of Well (ft. bgs)	Screened Interval (ft. bgs)	Location Relative to Application Well
AW-1	2	SS	14.15	34.5	20.5-35.5	15ft. NE AW-2
AW-2	2	SS	15.65	30.2	16-31	15ft. SW AW-1
MTMW-1	2	PVC	15.25	37.5	19.5-39.5	11ft. NW AW-1
MTMW-2	2	PVC	15.46	36.6	18-38	13ft. SE AW-1
MTMW-3	2	PVC	14.09	35.1	15-35	14ft. NW AW-2
MTMW-4	2	PVC	15.99	33.9	15.5-36	11ft. SE AW-2
RW-1*	6	PVC	13.49	30.2	10-30	10ft. SW AW-2
UGW-3*	2	PVC	15.01	33.5	25.44-35.44	11ft. NE AW-1

* Installed by others.

Table 3
CleanOX® Pilot Test Project
Naval Station Roosevelt Roads Tow Way Fuel Farm
Soil Analytical Results

Well	AW-1 (30 to 32 feet bgs)			AW-2 (24 to 26 feet bgs)			MTMW-4 (18 to 20 bgs)		
Date	12/16/98	2/8/99	4/27/99	12/16/98	2/8/99	4/15/99	12/16/98	2/8/99	4/15/99
Distance from application well (ft)	0	0	0	0	0	0	12	12	12
8260 BTEX									
Benzene (ug/kg)	6	ND(<6)	ND(<130)	32	ND(<33)	ND(<6)	36	ND(<120)	ND(<59)
Toluene (ug/kg)	6	ND(<6)	ND(<130)	32	ND(<33)	ND(<6)	120	ND(<120)	ND(<59)
Ethylbenzene (ug/kg)	4	ND(<6)	ND(<130)	280	64	ND(<6)	1,600	4,200	160
Xylene (Total) (ug/kg)	5	ND(<6)	ND(<130)	220	61	ND(<6)	2,200	6,500	250
Total BTEX (ug/kg)	21	ND(<24)	ND(<520)	564	125	ND(<24)	3,956	10,700	410
8015M Gasoline Range Organics (ug/kg)	32,000	390	290,000	350,000	61,000	ND(<55)	5,600,000	5,100,000	320,000 Y
8015M Diesel Range Organics (mg/kg)	19	ND(<7)	790 Y	580	140	ND(<6.8)	8,800	3,400	2,000 Y
Iron, Total (mg/kg)	31,000	32,800	29,000	24,400	41,500	36,100	47,900	42,600	34,500
Lead, Total (mg/kg)	0.56	0.7	ND(<0.45)	0.51	0.7	1.8	1.8	3.1	2.2
Sulfate (mg/kg)	16.4	35.2	*	10.6	47.9	*	8.8	55.0	*
pH (s.u.)	8.2	4.4	7.4	9.3	5.4	8.5	8.9	7.5	8.1

Y=The chromatographic response resembles a typical fuel pattern.

NA= Not analyzed

* Data should arrive from STL late next week (6.4.99) or early the following week.

Table 4
CleanOX® Pilot Test Project
Naval Station Roosevelt Roads Tow Way Fuel Farm
Groundwater Analytical Results

Well	AW-1				AW-2				MTMW-1				MTMW-2			
Sample Collection Date	1/7/99	2/8/99	2/22/99	4/15/99	1/7/99	2/8/99	2/22/99	4/15/99	1/7/99	2/8/99	2/22/99	4/15/99	1/7/99	2/8/99	2/22/99	4/15/99
Distance from application well (ft	0	0	0	0	0	0	0	0	12	12	12	12	15	15	15	15
8260 BTEX																
Benzene (ug/L)	2	50	37	62	9	ND(<25)	29	37	3	11	14	22	40	30	22	13
Toluene (ug/L)	1	28	16	ND(<50)	4	ND(<25)	ND(<25)	18	2	3	ND(<12)	8	10	6	11	3
Ethylbenzene (ug/L)	1	180	120	160	37	68	59	120	20	33	68	59	57	92	160	3
Xylene (Total) (ug/L)	6	250	170	230	45	91	94	170	34	42	88	92	50	68	150	66
Total BTEX (ug/L)	10	508	343	552	95	159	182	325	59	89	170	181	157	196	343	85
8015M Gasoline Range Organics	640	36,000	22,000	160,000 Y	1,700	6,300	5,700	77,000 Y	1,400	5,000	12,000	11,000 Y	1,900	15,000	9,600	4,600 Y
8015M Diesel Range Organics (m	0.96	6,500	1,600	1,500 Y	3.6	190	1,000	420 Y	2.0	19	270	6,200 Y	3.1	290	450	8,800 Y
Iron, Total (ug/L)	5,030	59,600	577,000	377,000	23,900	416,000	550,000	473,000	7,140	23,900	80,900	10,200	12,700	56,900	208,000	5,250
Lead, Total (ug/L)	ND(<1.3)	16.1	10.3	ND(<20)	2.9	13.5	13.8	ND(<20)	ND(<1.3)	ND(<1.3)	1.3	ND(<1.7)	ND(<1.3)	2.3	5.8	ND(<5)
Alkalinity (mg/L)	783	10	10	ND(<10)	609	10	10	ND(<10)	767	839	764	911	700	795	863	458
Hardness by EDTA (mg/L)	1,590	6,620	4,700	1,020	342	6,470	7,000	7,450	1,920	4,880	2,000	1,800	1,820	2,090	1,350	877
Nitrate, as N (mg/L)	3.3	2.6	0.16	0.18	0.1	5.3	2.7	ND(<0.01)	6.5	0.37	1.4	1	0.1	0.1	0.1	ND(<0.01)
Sulfate (mg/L)	238	2,220	3,060	1,130	43	1,860	2,440	1,730	320	187	105	181	152	14.5	145	52
Total Dissolved Solids (mg/L)	4,800	16,000	15,000	17,000	1,600	11,000	15,000	17,000	5,600	5,400	5,800	5,500	5,300	3,500	3,400	3,600
Field Parameters																
Depth to water (ft)	14.15	14.42	14.8	16.16	13.87	15.29	15.62	16.54	15.12	15.26	15.66	17.87	15.01	16.07	16.77	18.45
Product Thickness (ft)	ND(<0.01)	ND(<0.01)	ND(<0.01)	0.05	ND(<0.01)	0.09	0.01	0.16	ND(<0.01)	0.01	ND(<0.01)	ND(<0.01)	ND(<0.01)	0.01	ND(<0.01)	0.14
pH (s.u.)	7.06	6.41	6.3	4.39	7.04	6.56	5.87	5.2	7.08	6.71	6.74	6.6	6.77	6.86	6.67	7.19
Temperature (oC)	29.05	28.8	26.1	29.5	29.03	31.2	28.1	33.8	29.04	27.3	27.2	30.2	29.12	30	27.5	31.4
Dissolved Oxygen (ppm)	3.73	23.2*	3.37	3.54	5.41	51.2*	3.2	2.75	1.35	2.5*	0.46	1.17	1.85	8.2*	0.01	0.54
ORP (mV)	-31.8	222.7	205.3	197.5	-65	233.7	205.8	168.7	-28.2	-70.2	4.2	18.1	-105.8	53.8	21.7	34.9
Specific Conductance (us/cm)	7,491	D(>20,00	D(>20,00	1,070	3,411	157,600	18,340	21,000	7,990	17,680	17,280	19,130	10,482	17,920	13,880	12,170

Y=The chromatographic response resembles a typical fuel pattern

ND(<X)=Value not detected below X

ND(>X)=Value not detected above X

*=Measured in percent

Table 4
CleanOX® Pilot Test Project
Naval Station Roosevelt Roads Tow Way Fuel Farm
Groundwater Analytical Results

Well	MTMW-3				MTMW-4				RW-1			
Sample Collection Date	1/7/99	2/8/99	2/22/99	4/15/99	1/7/99	2/8/99	2/22/99	4/15/99	1/7/99	2/8/99	2/22/99	4/15/99
Distance from application well (ft	12	12	12	12	12	12	12	12	10	10	10	10
8260 BTEX												
Benzene (ug/L)	1	30	32	23	44	42	19	42	2	ND(<50)	10	ND(<50)
Toluene (ug/L)	1	12	14	12	16	24	14	17	2	ND(<50)	4	ND(<50)
Ethylbenzene (ug/L)	1	76	120	140	69	110	120	71	7	130	36	80
Xylene (Total) (ug/L)	5	140	230	240	95	200	210	100	9	240	52	130
Total BTEX (ug/L)	8	258	396	415	224	376	363	230	20	370	102	310
8015M Gasoline Range Organics	760	24,000	18,000	200,000 Y	2,600	6,800	42,000	2,600 Y	2,900	240,000	3,400	35,000 Y
8015M Diesel Range Organics (m	2.3	1,300	3,200	300 Y	3.7	500	1,300	18,000 Y	4.7	1,300	250	520 Y
Iron, Total (ug/L)	90,000	32,400	91,300	79,100	8,140	61,100	82,000	11,900	1,910	499,000	371,000	293,000
Lead, Total (ug/L)	7.1	9.2	2.4	2.6	1.4	7.4	2.2	ND(<6)	ND(<1.3)	34.3	18.0	ND(<6)
Alkalinity (mg/L)	716	765	751	872	767	839	809	793	674	1,280	10	513
Hardness by EDTA (mg/L)	1,650	2,340	1,500	1,640	1,430	1,990	1,370	898	384	6,470	5,050	1,640
Nitrate, as N (mg/L)	12.2	7.9	5.9	8.4	0.10	0.10	0.10	0.48	0.10	0.10	0.10	0.11
Sulfate (mg/L)	287	281	317	276	77.2	24.6	69.4	32.4	21.5	1,600	1,520	933
Total Dissolved Solids (mg/L)	4,200	4,900	4,100	5,100	4,300	4,300	4,100	4,800	1,500	12,000	13,000	9,800
Field Parameters												
Depth to water (ft)	14	13.56	13.85	15.67	16.12	15.28	16.1	17.9	13.49	14.8	14.46	16.7
Product Thickness (ft)	ND(<0.01)	0.01	0.01	0.16	2.22	0.01	ND(<0.01)	0.22	ND(<0.01)	0.20	ND(<0.01)	ND(<0.01)
pH (s.u.)	7.11	7.64	6.28	5.15	7.02	6.78	6.14	6.02	7.41	5.26	5.51	4.3
Temperature (oC)	28.97	30	27	33.7	28.92	28.2	26.4	30.4	28.7	29	28.3	28.8
Dissolved Oxygen (ppm)	0.72	24.5*	1.67	1.54	1.08	20.5*	1.53	1.18	0.39	8.2*	0.25	0.17
ORP (mV)	-70.7	99.3	93.4	84	-116.5	-3.1	18	26.1	-230	134.7	133.5	117.4
Specific Conductance (us/cm)	7,027	13,400	13,250	15,340	8,266	14,470	12,790	16,020	2,570	D(>20,00	D(>20,00	16,360

Y=The chromatographic response resembles a typical fuel pattern

ND(<X)=Value not detected below X

ND(>X)=Value not detected above X

*=Measured in percent

Table 4
CleanOX® Pilot Test Project
Naval Station Roosevelt Roads Tow Way Fuel Farm
Groundwater Analytical Results

Well	UGW-3				UGW-14				UGW-25			
Sample Collection Date	1/7/99	2/8/99	2/22/99	4/15/99	1/7/99	2/8/99	2/22/99	4/15/99	1/7/99	2/8/99	2/22/99	4/15/99
Distance from application well (ft)	12	12	12	12	100	100	100	100	110	110	110	110
8260 BTEX												
Benzene (ug/L)	7	ND(<12)	ND(<2)	7	ND(<2)	ND(<2)	ND(<2)	ND(<2)	10	14	7	8
Toluene (ug/L)	ND(<2)	ND(<12)	ND(<2)	ND(<2)	ND(<2)	ND(<2)	ND(<2)	ND(<2)	ND(<2)	1	0.6	ND(<2)
Ethylbenzene (ug/L)	17	42	11	14	ND(<2)	9	5	5	10	7	3	3
Xylene (Total) (ug/L)	12	58	ND(<2)	18	ND(<2)	ND(<2)	ND(<2)	7	56	39	20	28
Total BTEX (ug/L)	36	100	11	39	ND(<8)	9	5	16	76	61	30.6	41
8015M Gasoline Range Organics (	550	19,000	4,300	1,300 Y	1,300	24,000	5,400	870 Y	220,000	4,000	5,100	30,000 Y
8015M Diesel Range Organics (m	3.8	170	33	28 Y	5.8	98	34	5.0 Y	360	280	740	7,400 Y
Iron, Total (ug/L)	12,900	14,900	86,700	3,180	37,100	90,700	28,200	2,180	2,320	3,780	3,150	4,030
Lead, Total (ug/L)	ND(<1.3)	ND(<1.3)	2.2	ND(<2)	4.8	6.7	1.3	ND(<1.7)	1.5	1.3	1.3	ND(<1.7)
Alkalinity (mg/L)	783	842	805	909	990	1,030	1,060	1,050	998	992	943	1,060
Hardness by EDTA (mg/L)	1,870	2,240	1,800	1,600	1,270	2,490	1,250	1,230	310	1,590	320	271
Nitrate, as N (mg/L)	0.95	0.35	0.34	ND(<0.01)	0.14	0.10	0.10	ND(<0.01)	0.1	0.1	0.1	ND(<0.01)
Sulfate (mg/L)	275	180	239	69.6	23.2	25.1	37.6	19.6	54	9.6	73.8	15.7
Total Dissolved Solids (mg/L)	5,600	5,700	5,100	5,200	3,900	3,600	4,300	4,100	2,200	1,800	2,000	2,500
Field Parameters												
Depth to water (ft)	15.02	17.33	17.6	17	12.09	13.71	14.3	14.2	45.4	47.2	47.64	47.55
Product Thickness (ft)	0.35	0.15	ND(<0.01)	ND(<0.01)	ND(<0.01)	ND(<0.01)	ND(<0.01)	ND(<0.01)	1.34	1.34	1.39	ND(<0.01)
pH (s.u.)	6.98	7.08	6.49	5.45	7.3	6.95	6.67	5.75	7.2	7.28	6.79	5.1
Temperature (oC)	29	27.6	27.9	29.3	27.8	27.4	26.3	28.2	28.3	27.7	26.8	27.9
Dissolved Oxygen (ppm)	1.78	1.8*	0.5	0.67	NM	0*	0.54	0.45	NM	21.4*	2.08	1.77
ORP (mV)	-163.5	-122.3	2.3	-54.2	NM	-159.9	16.9	-29.4	NM	55.3	16.6	66.9
Specific Conductance (us/cm)	8,365	18,320	17,880	4,140	13,200	13,450	12,630	13,130	13,100	6,980	7,160	6,120

Y=The chromatographic response resembles a typical fuel pattern

ND(<X)=Value not detected below X

ND(>X)=Value not detected above X

*=Measured in percent

Table 5
CleanOX® Pilot Test Project
Naval Station Roosevelt Roads Tow Way Fuel Farm
Pilot Test Field Measurements

Well	AW-1			AW-2			MTMW-1			MTMW-2		
Condition	Baseline	Max/End	Change	Baseline	Max/End	Change	Baseline	Max/End	Change	Baseline	Max/End	Change
Parameter												
Temperature (°C)	29.05	38.63	9.58	29.03	43.64	14.61	29.04	29.19	0.15	29.12	29.20	0.08
Sp. Cond (uS/cm)	7,491	13,273	5,782	3,411	8,104	4,693	7,990	8,147	157	10,482	10,454	-28
pH	7.06	2.12	-4.94	7.04	2.02	-5.02	7.08	6.80	-0.28	6.77	6.81	0.04
DO (ppm)	3.73	19.66	15.93	5.41	48.85	43.44	1.35	66.88	65.53	1.85	51.05	49.20
ORP (mV)	-31.8	462.7	494.5	-65.0	447.7	512.7	-28.2	-41.2	-13.0	-105.8	-72.0	33.8
Depth to product (ft.bgs)	14.15*	ND(<0.01)	0.00	15.64	ND(<0.01)	0.00	15.20	15.38	0.18	15.20	16.12	0.92
Depth to water (ft. bgs)	14.15	13.85	-0.30	15.65	15.30	-0.35	15.25	15.53	0.28	15.48	16.34	0.86
Product thickness (ft.)	0.00	0.00	0.00	0.01	0.00	-0.01	0.05	0.15	0.10	0.28	0.22	-0.06

Well	MTMW-3			MTMW-4			RW-1			UGW-3		
Condition	Baseline	Max/End	Change	Baseline	Max/End	Change	Baseline	Max/End	Change	Baseline	Max/End	Change
Parameter												
Temperature (°C)	28.97	29.30	0.33	28.92	29.14	0.22	28.70	29.04	0.34	29.00	29.04	0.04
Sp. Cond (uS/cm)	7,027	6,765	-262	8,366	7,977	-389	2,570	15,609	13,039	8,365	8,672	307
pH	7.11	6.61	-0.50	7.02	6.69	-0.33	7.41	3.72	-3.69	6.98	6.84	-0.14
DO (ppm)	0.72	16.93	16.21	1.08	55.83	54.75	0.39	58.39	58.00	1.78	56.50	54.72
ORP (mV)	-70.7	73.3	144.0	-116.5	-40.8	75.7	-230.0	120.1	350.1	-163.5	-145.8	17.7
Depth to product (ft.bgs)	14.04	13.82	-0.22	13.90	15.18	1.28	13.49*	14.57	1.08	14.67	14.92	0.25
Depth to water (ft. bgs)	14.09	16.46	2.37	16.18	16.40	0.22	13.49	14.58	1.09	15.04	15.14	0.10
Product thickness (ft.)	0.05	2.64	2.59	2.28	1.22	-1.06	0.00	0.01	0.01	0.37	0.22	-0.15

ND(<0.01)=Free product not detected less than 0.01 s.u.
*=Depth to water value used for Depth of Product baseline value.
Max/End data = data collected during pilot test.

Table 6
Mass Removal Calculations

Mass Removal Calculations (2/8/99)

	Application Well Area	Monitoring Well Area	Total
Volume of Soil Treated (cu.ft.)	5,301.45	18,555.08	23,856.53
Mass of Soil Treated (kg)	267,750.00	937,125.00	1,204,875.00
Soil Porosity	0.30	0.30	0.60
Volume of Groundwater Treated (gal)	11,896.45	41,637.59	53,534.04
Soil DRO Concentration Change (mg/kg)	-226	-5,400	-5,626.00
Soil GRO Concentration Change (mg/kg)	-160	-500	-660.31
Groundwater DRO Conc. Increase (mg/L)	3,343	111	3,453.40
Groundwater GRO Conc. Increase (mg/L)	20	50	70.41
PSH Thickness Change (ft)	0.0	-0.36	-0.32
Mass of PSH Change (kg)	101	-2,861	-2,759.60
Mass of DRO/GRO Change in Soil (kg)	-103	-5,529	-5,632.47
Mass of DRO/GRO Desorbed (kg)	152	25	177.04
Total Mass of DRO/GRO/PSH Change (kg)	150	-8,365	-8,215.03

Mass Removal Calculations (4/15/99)

	Application Well Area	Monitoring Well Area	Total
Volume of Soil Treated (cu.ft.)	5,301.45	18,555.08	23,856.53
Mass of Soil Treated (kg)	267,750.00	937,125.00	1,204,875.00
Soil Porosity	0.30	0.30	0.60
Volume of Groundwater Treated (gal)	11,896.45	41,637.59	53,534.04
Soil DRO Concentration Change (mg/kg)	99	-6,800	-6,701.10
Soil GRO Concentration Change (mg/kg)	-46	-5,280	-5,325.97
Groundwater DRO Conc. Increase (mg/L)	958	5,156	6,113.24
Groundwater GRO Conc. Increase (mg/L)	117	41	158.54
PSH Thickness Change (ft)	0.1	-0.34	-0.24
Mass of PSH Change (kg)	236	-2,688	-2,451.10
Mass of DRO/GRO Change in Soil (kg)	14	-11,320	-11,306.30
Mass of DRO/GRO Desorbed (kg)	48	820	868.55
Total Mass of DRO/GRO/PSH Change (kg)	299	-13,188	-12,888.85

Table 7
CleanOX® Process Full-Scale Application Cost Estimate per Cycle

	ZONE A	ZONE B	ZONE C	ZONE D	ZONE E	ALL ZONES
Well Installation						
Zone sq. ft.	14,400	21,600	27,000	11,880	8,640	83,520
No. Wells	14	22	27	12	9	84
Cost	$64,800	$97,200	$121,500	$53,500	$38,900	$375,900
Application						
Labor Cost	$143,500	$191,300	$239,100	$111,600	$95,700	$781,000
Reagent Costs	$19,000	$28,400	$35,500	$15,700	$11,400	$109,800
ODC	$20,000	$25,000	$30,000	$15,000	$15,000	$105,000
Waste disposal	$2,200	$3,300	$4,100	$1,800	$1,300	$12,600
Total Cost	**$249,500**	**$345,200**	**$430,200**	**$197,600**	**$162,300**	**$1,384,300**

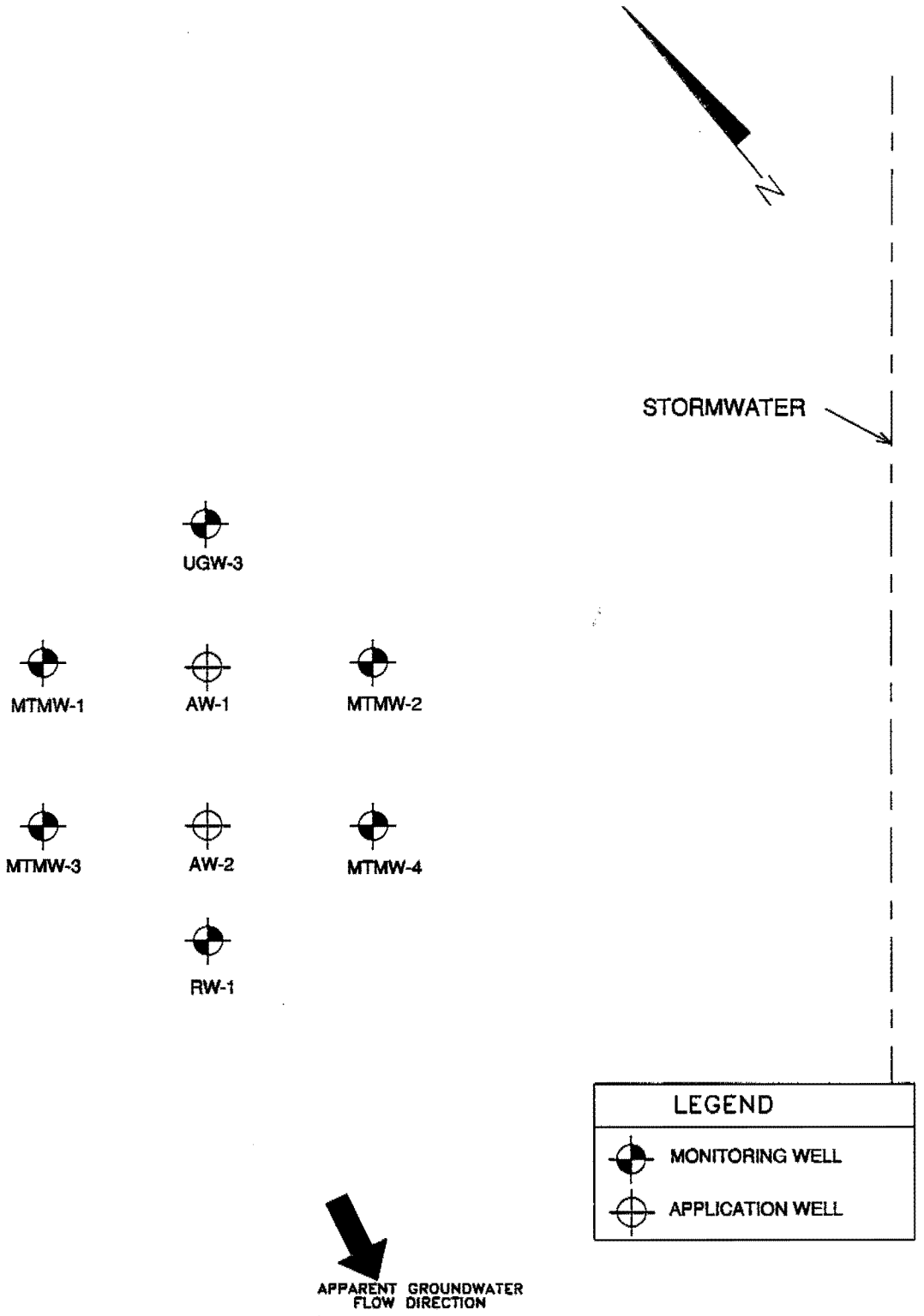
*Cost/Man/day includes labor plus per diem.

MANTECH ENVIRONMENTAL CORPORATION

NAVAL STATION ROOSEVELT ROADS

SITE LOCATION MAP
TOW WAY FUEL FARM
CEIBA, PUERTO RICO

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/5/99	FIGURE1.DWG	CT	CC	1

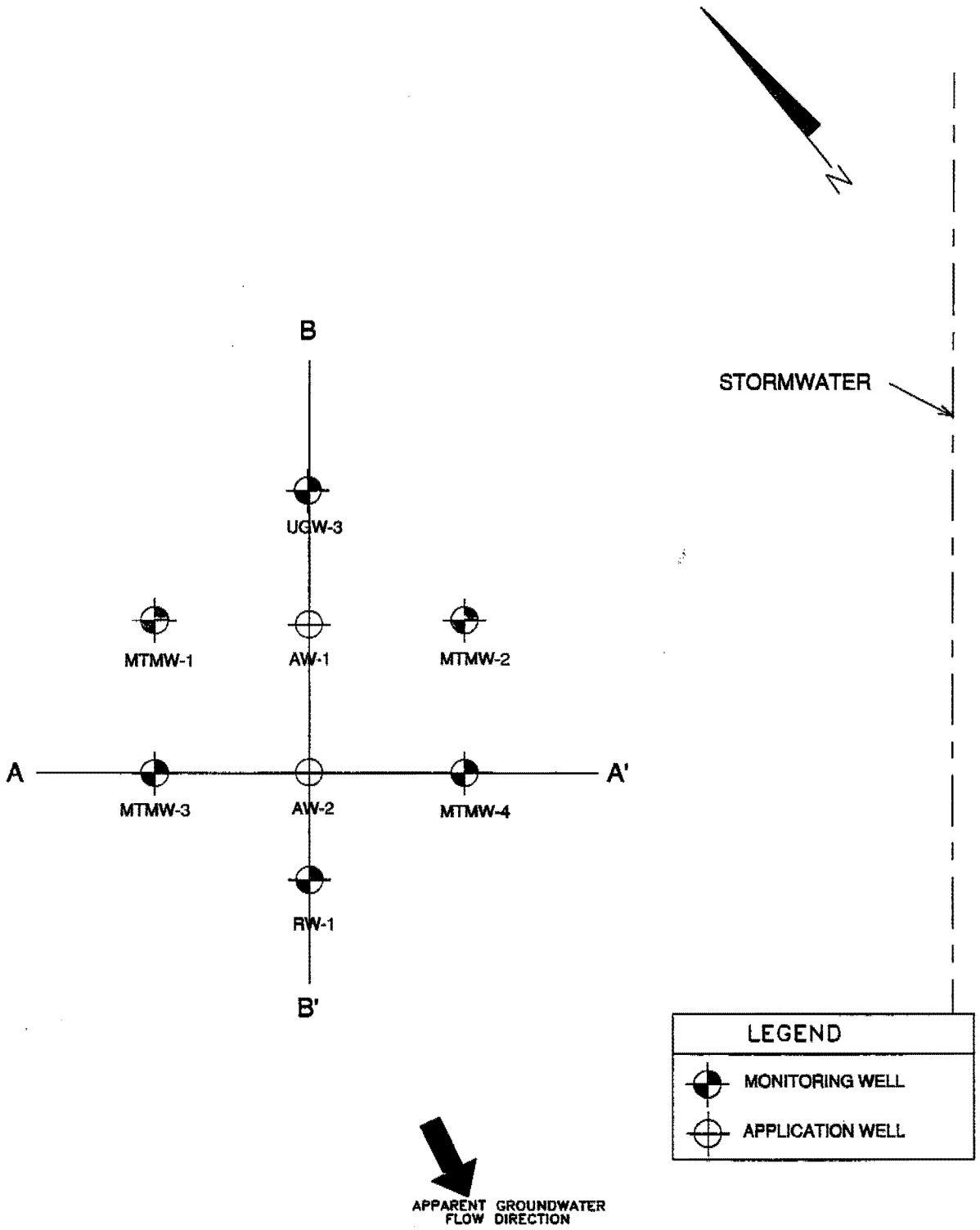


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

SITE MAP
TOW WAY FUEL FARM
CEIBA, PUERTO RICO

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	12/16/99	FIGURE2.DWG	CT	CC	2

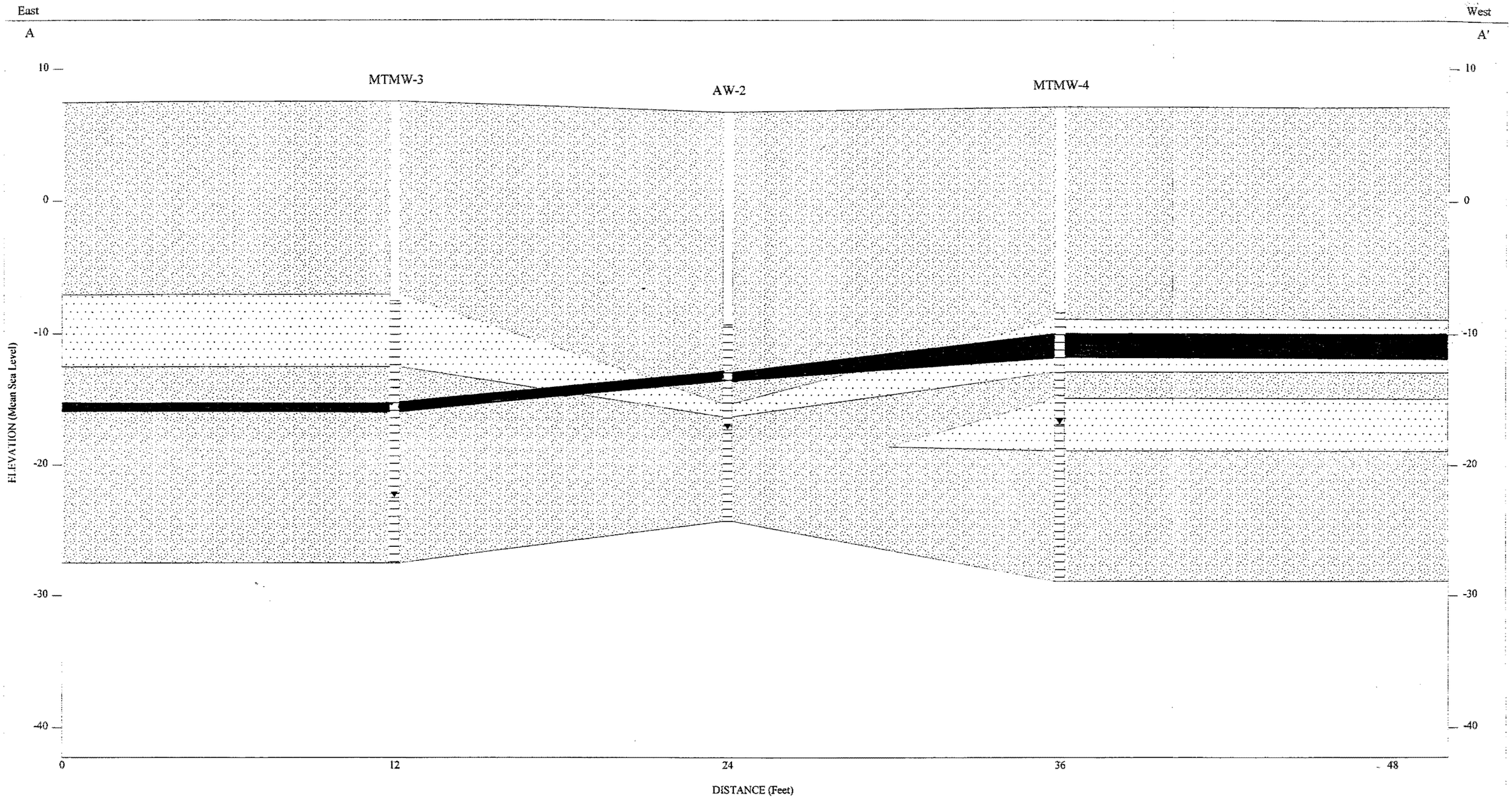


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

CROSS SECTION REFERENCE
TOW WAY FUEL FARM
CEIBA, PUERTO RICO

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	12/16/99	FIGURE3.DWG	CT	CC	3



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

MANTECH ENVIRONMENTAL
14290 Sullyfield Circle, Suite 100
Chantilly, Virginia 20151

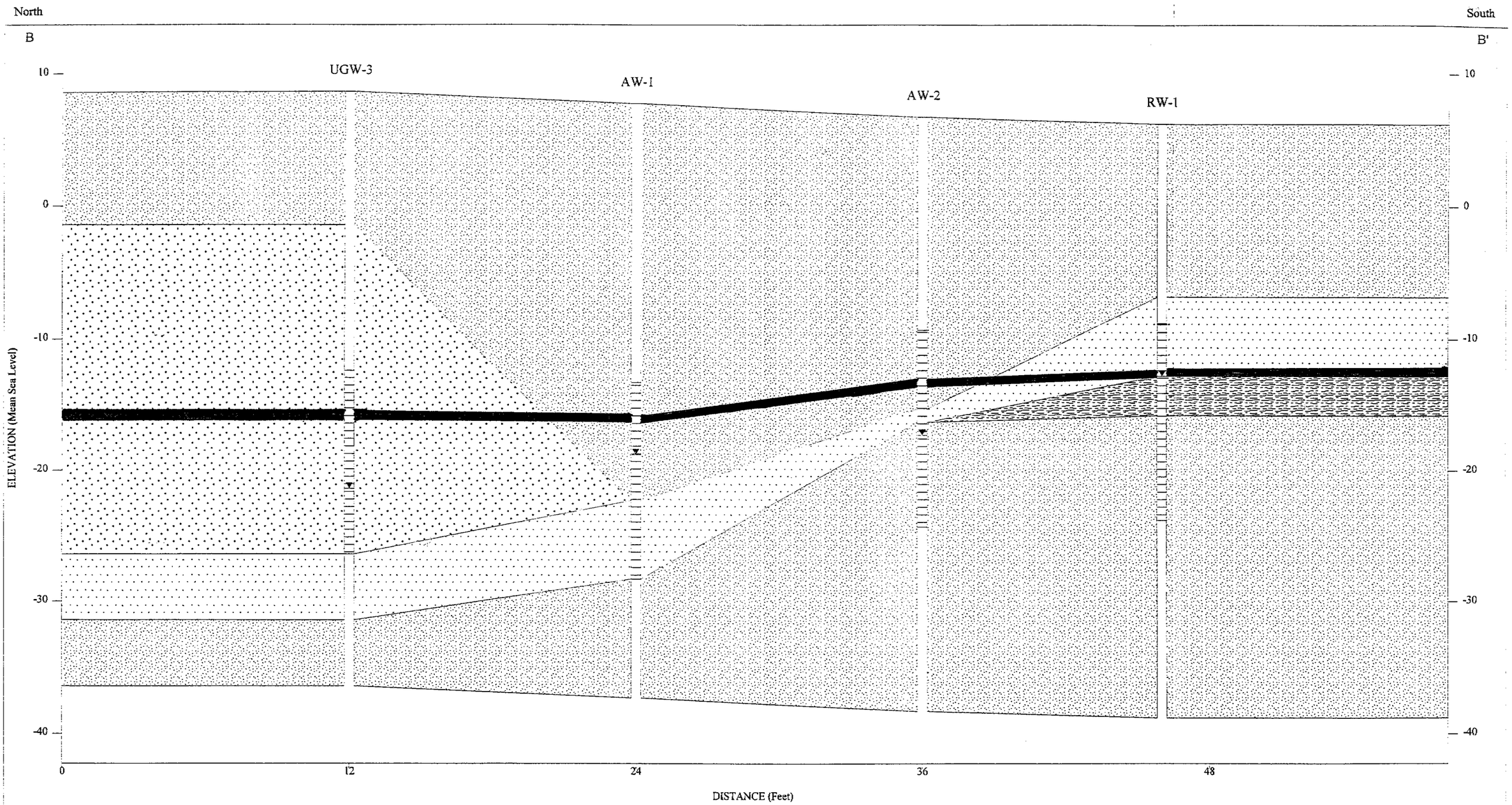
Figure 4

GEOLOGIC CROSS SECTION
Section A-A'
East-West
Scale 1 inch = Approximately 3.5 Feet

LEGEND

- Silty clay with angular gabbro lenses.
- Gravel, angular gabbro cobbles.
- Wet With Petroleum Product.

06-02-1999 L:\Projects\8207\Borlog\simcros.cro



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

MANTECH ENVIRONMENTAL
14290 Sullyfield Circle, Suite 100
Chantilly, Virginia 20151

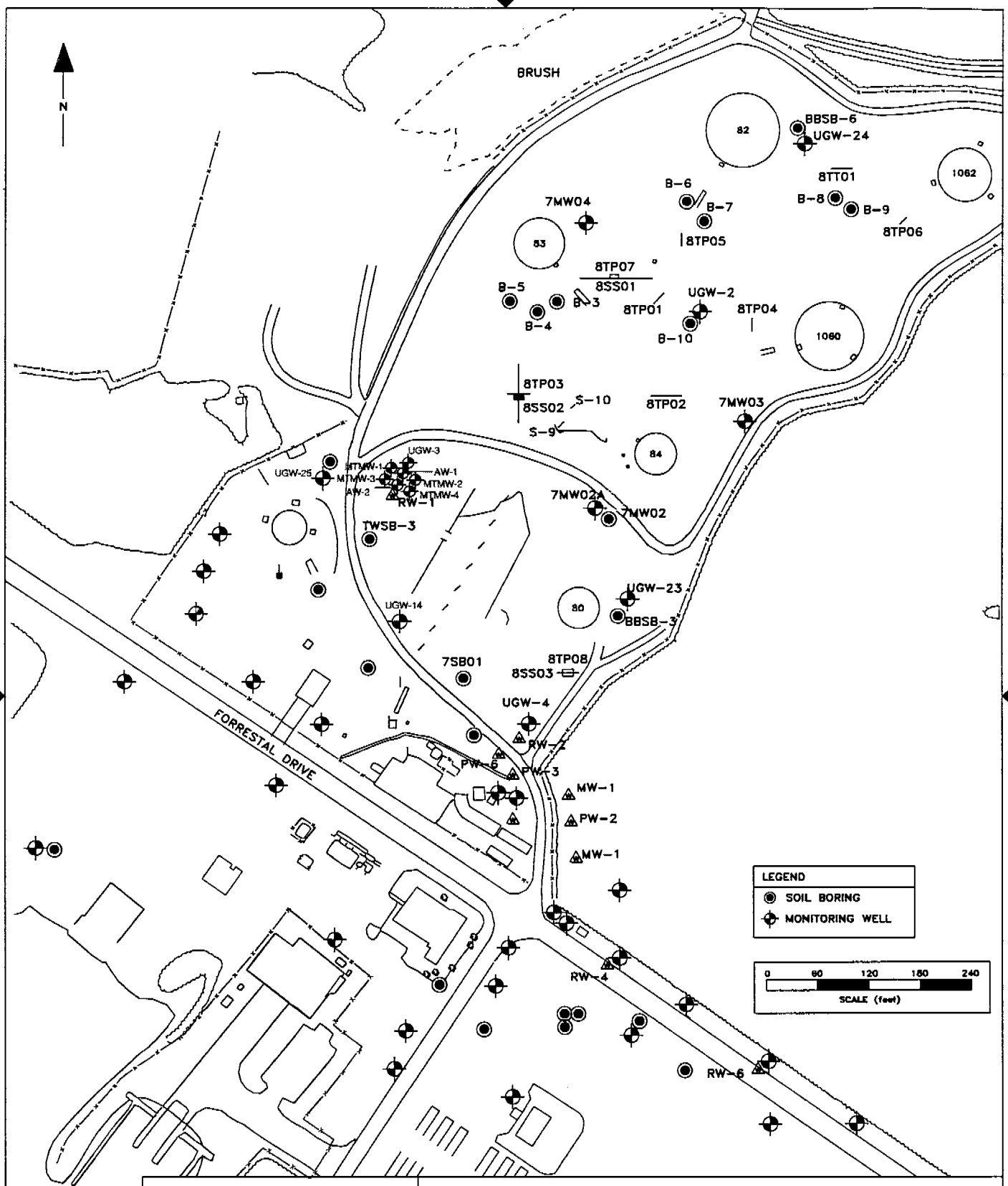
Figure 5

GEOLOGIC CROSS SECTION
Section B-B'
North-South
Scale 1 inch = Approximately 3.5 Feet

LEGEND

- Silty clay with angular gabbro lenses. Wet With Petroleum Product
- Fine to coarse dense brown sand, well sorted.
- Gravel, angular gabbro cobbles.
- Rock fragments, subangular, grey to green gabbro.

06-02-1999 L:\Projects\8207\Borlog\bsimcros.cro

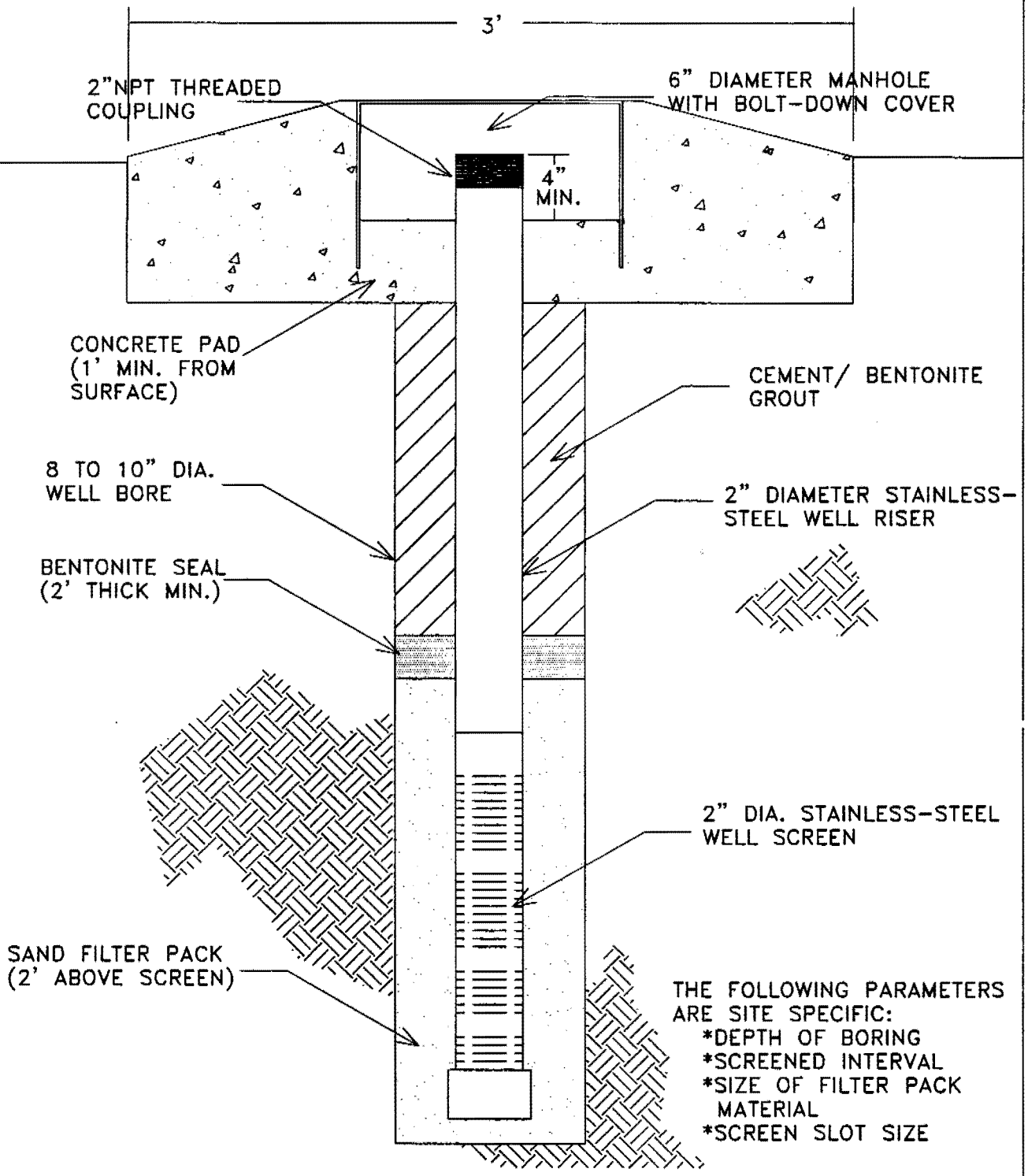


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

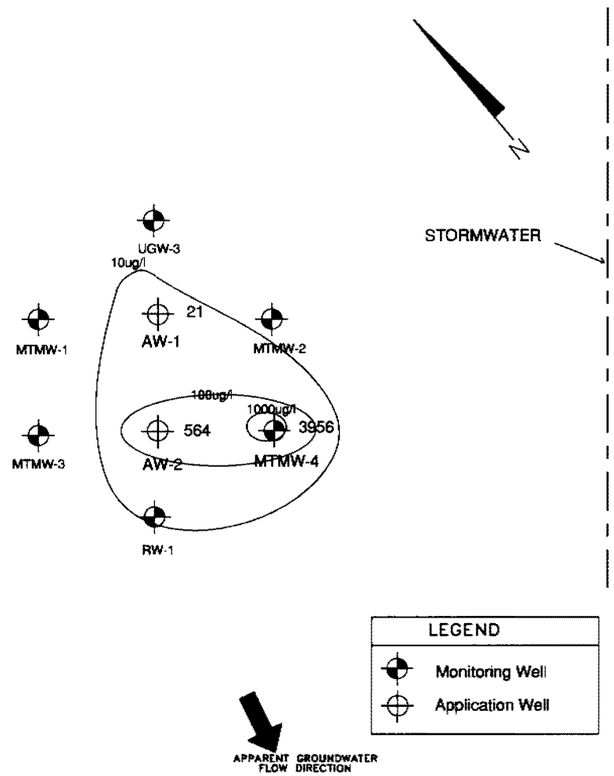
MONITORING AND APPLICATION
WELL LOCATION
TOW WAY FUEL FARM
CEIBA, PUERTO RICO

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/12/99	FIGURE6.DWG	CT	CC	6



DRAWING NOT TO SCALE

MANTECH ENVIRONMENTAL CORPORATION 14290 SULLYFIELD CIRCLE, SUITE 100 CHANTILLY, VIRGINIA 20151	CleanOX® APPLICATION WELL (TYPICAL) CONSTRUCTION DIAGRAM MANTECH ENVIRONMENTAL CORPORATION				
CLIENT: BAKER ENVIRONMENTAL, INC.	DATE: 4/14/99	DWG. FILE: PLTFIG7.DWG	DRWN BY: CT	REV'D BY: CC	FIG. NO.: 7

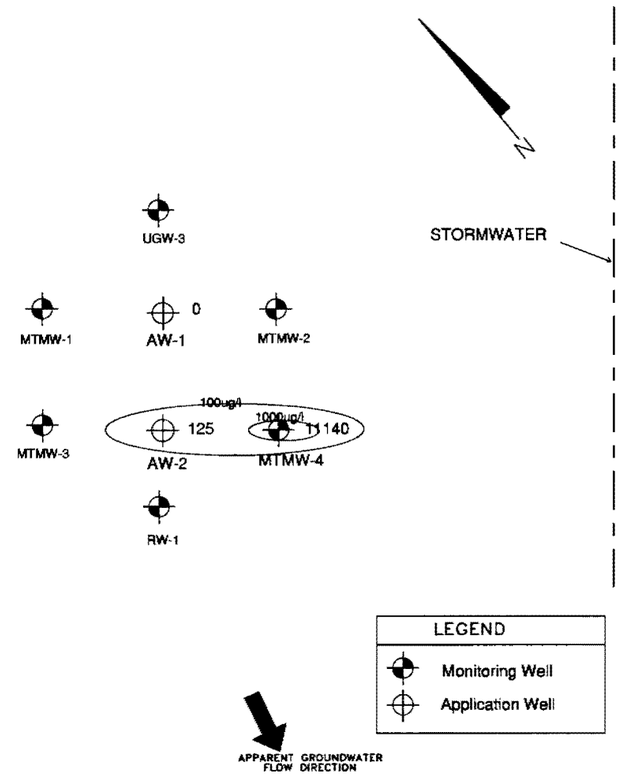


MANTECH ENVIRONMENTAL CORPORATION
14500 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

BTEX CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
BASELINE 12/16/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE8.DWG	CT	CC	8a

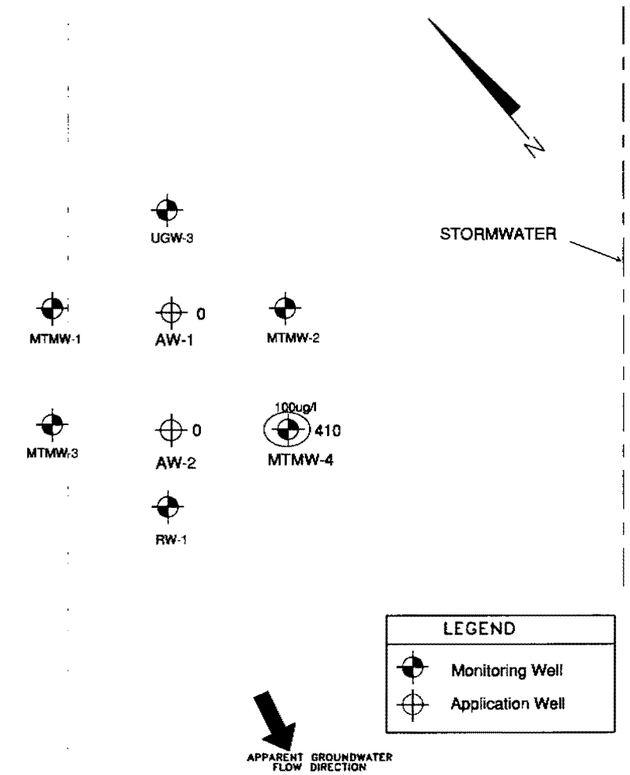


MANTECH ENVIRONMENTAL CORPORATION
14500 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

BTEX CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
1 WEEK POST TREATMENT 2/8/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE8.DWG	CT	CC	8b

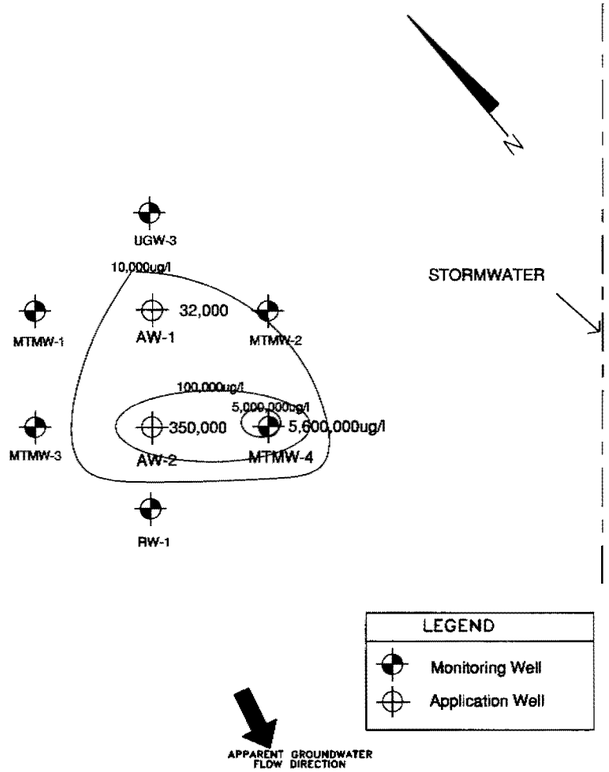


MANTECH ENVIRONMENTAL CORPORATION
14500 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

BTEX CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
8-WEEK POST TREATMENT 4/15/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE8.DWG	CT	CC	8c

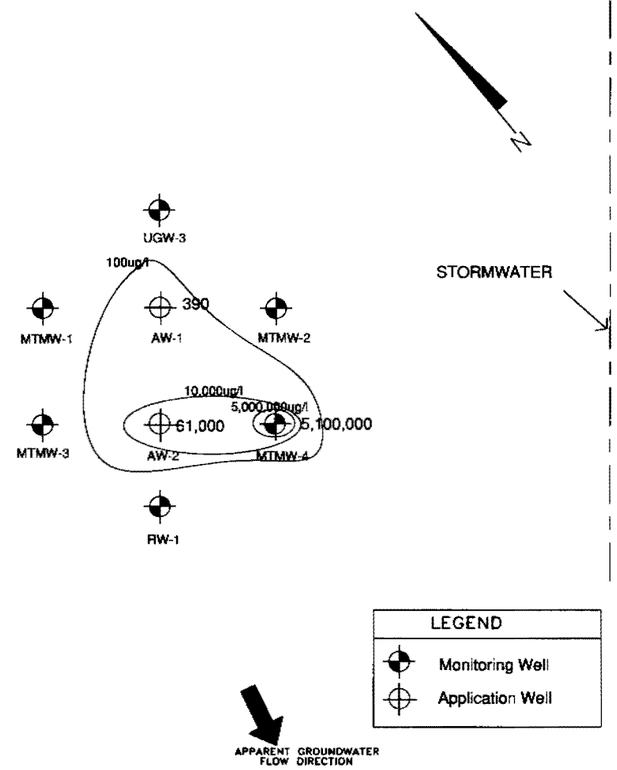


MANTECH ENVIRONMENTAL CORPORATION

NAVAL STATION ROOSEVELT ROADS

GRO CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
BASELINE 12/16/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE9.DWG	CT	CC	9a

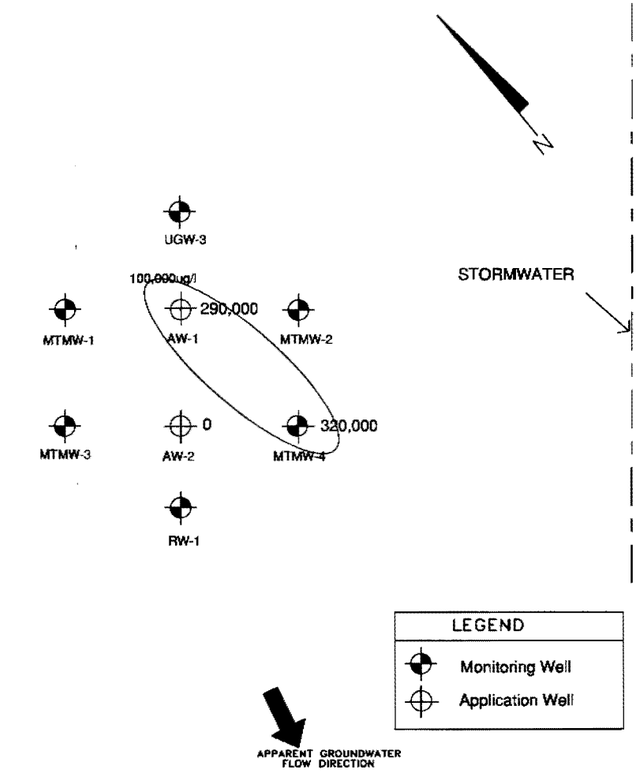


MANTECH ENVIRONMENTAL CORPORATION

NAVAL STATION ROOSEVELT ROADS

GRO CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
1 WEEK POST TREATMENT 2/8/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE9.DWG	CT	CC	9b

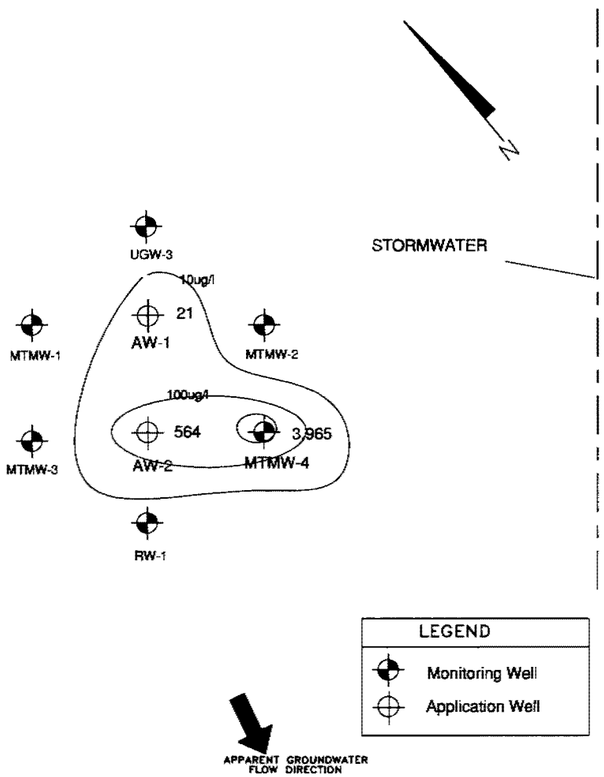


MANTECH ENVIRONMENTAL CORPORATION

NAVAL STATION ROOSEVELT ROADS

GRO CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
8-WEEK POST TREATMENT 4/15/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE9.DWG	CT	CC	9c

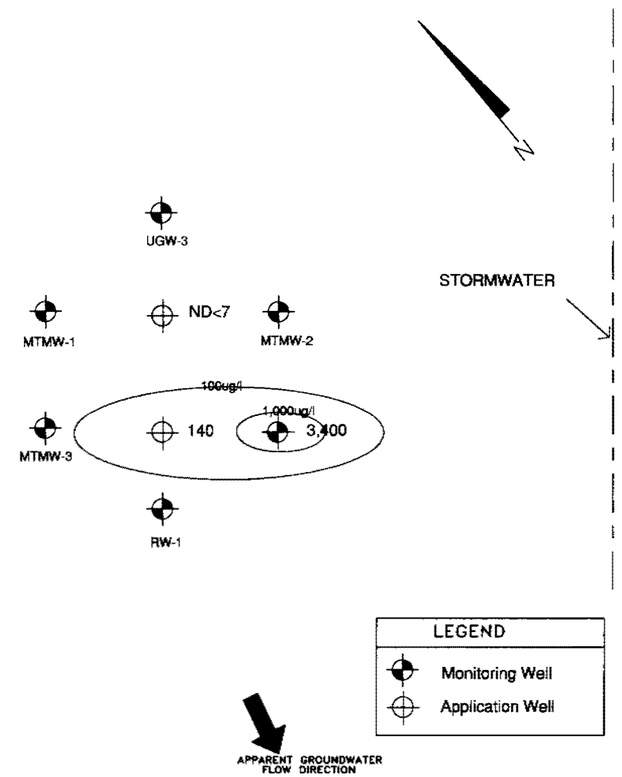


MANTECH ENVIRONMENTAL CORPORATION

NAVAL STATION ROOSEVELT ROADS

DRO CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
BASELINE 12/16/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE10.DWG	CT	CC	10a

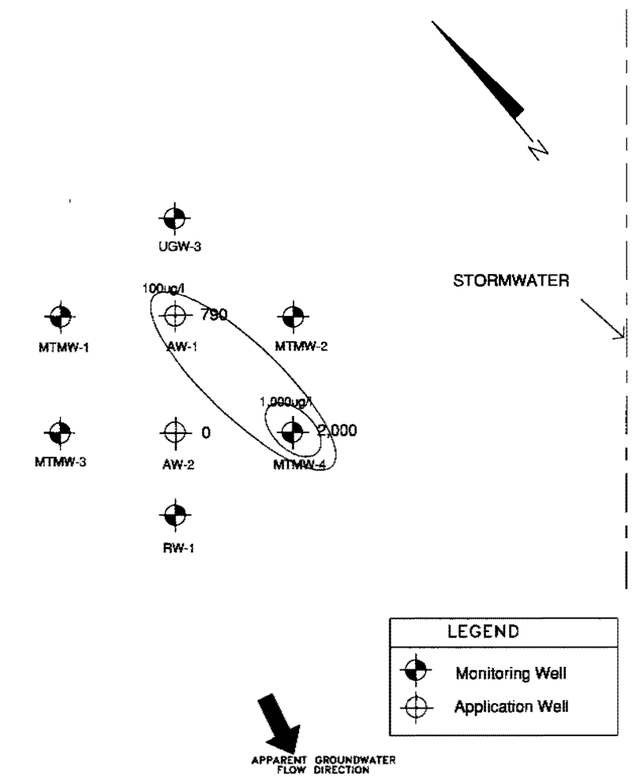


MANTECH ENVIRONMENTAL CORPORATION

NAVAL STATION ROOSEVELT ROADS

DRO CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
1 WEEK POST TREATMENT 2/8/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE10.DWG	CT	CC	10b

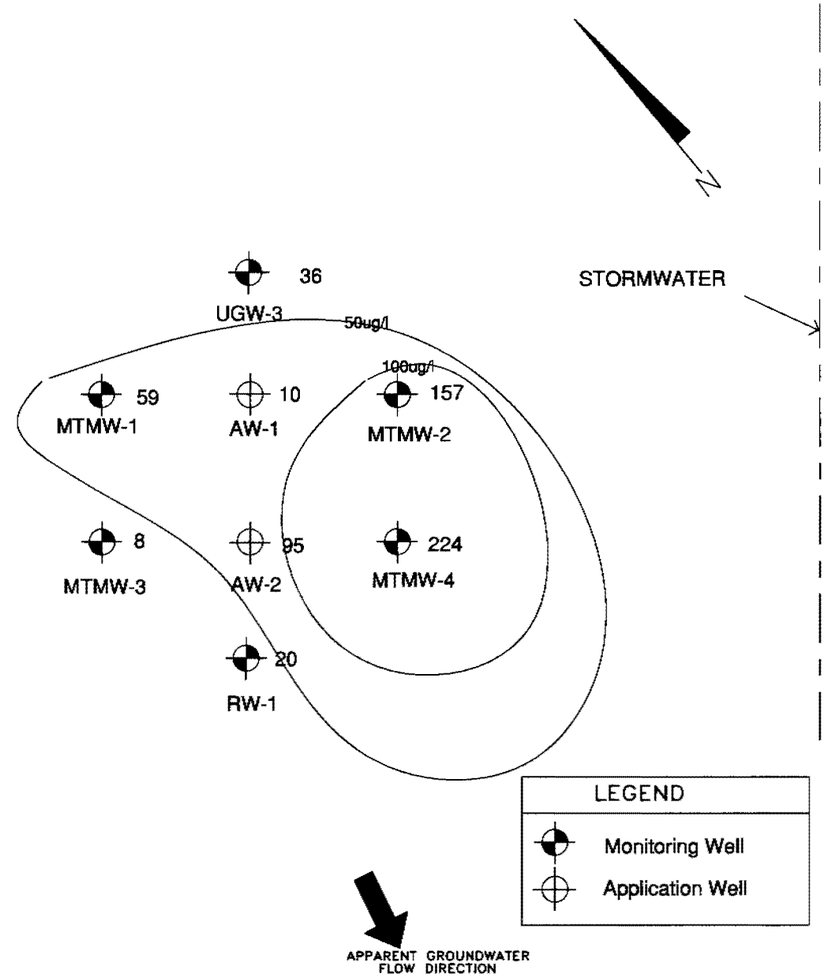


MANTECH ENVIRONMENTAL CORPORATION

NAVAL STATION ROOSEVELT ROADS

DRO CONCENTRATIONS IN SOIL (DEPTH)
TOW WAY FUEL FARM
8-WEEK POST TREATMENT 4/15/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE9.DWG	CT	CC	10c

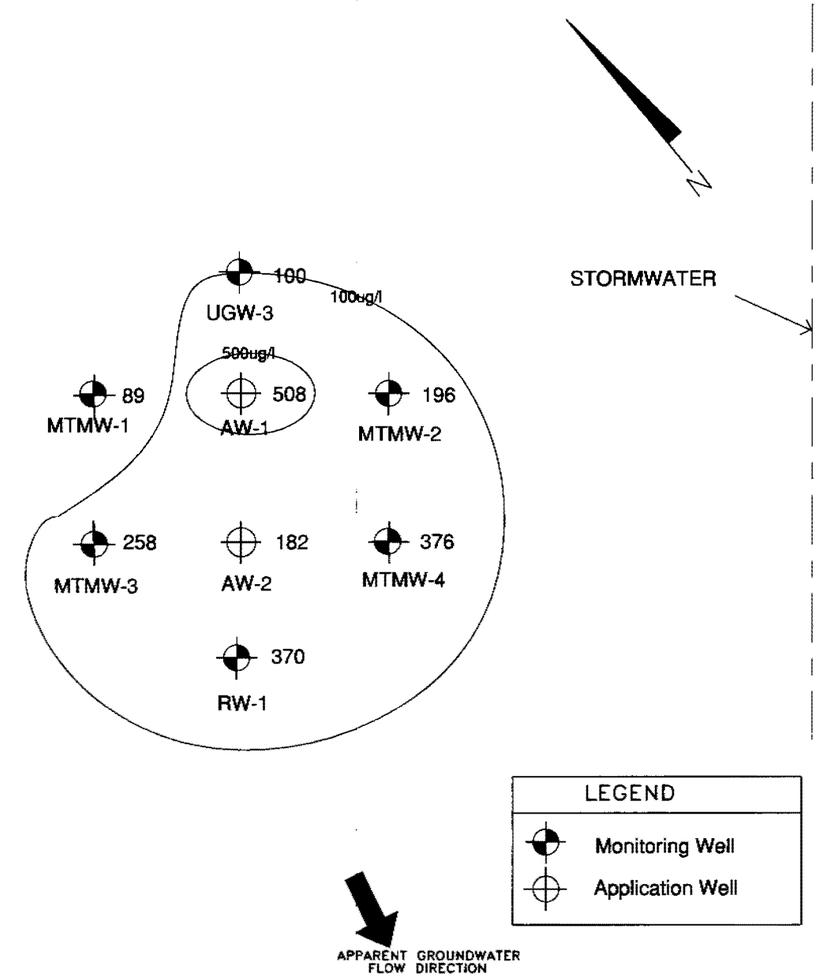


MANTECH ENVIRONMENTAL CORPORATION
14150 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

BTEX CONCENTATIONS IN GROUNDWATER
TOW WAY FUEL FARM
BASELINE 1/7/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE11.DWG	CT	CC	11a

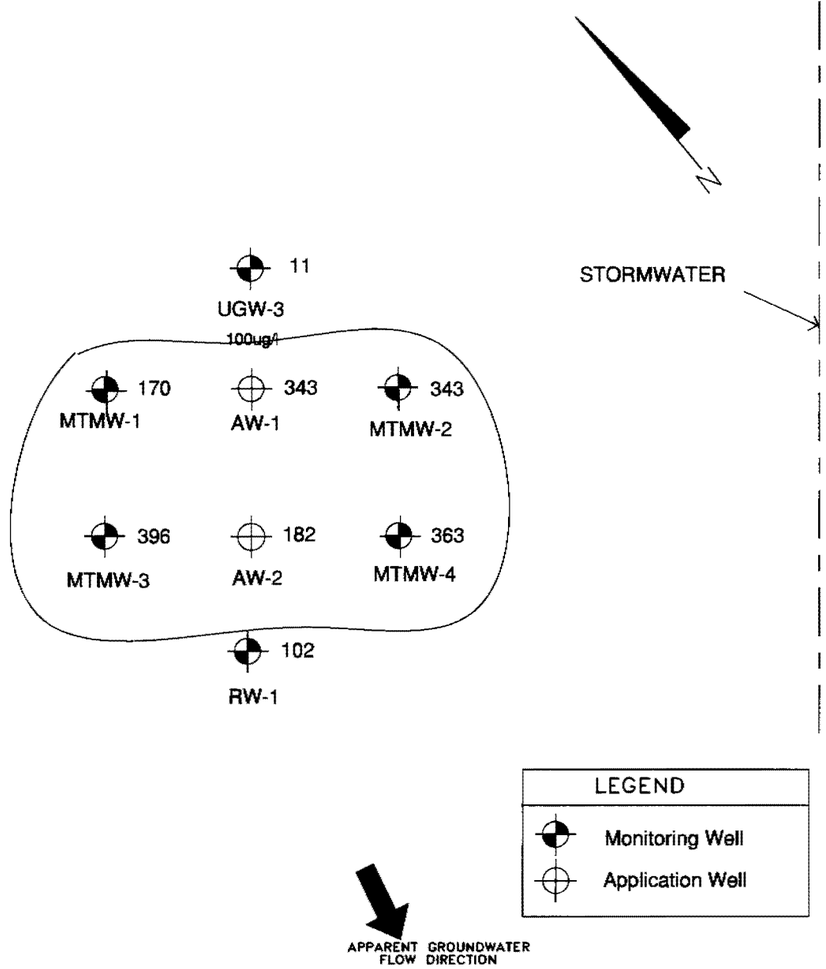


MANTECH ENVIRONMENTAL CORPORATION
14150 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

BTEX CONCENTATIONS IN GROUNDWATER
TOW WAY FUEL FARM
1 WEEK POST TREATMENT 2/8/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE11.DWG	CT	CC	11b

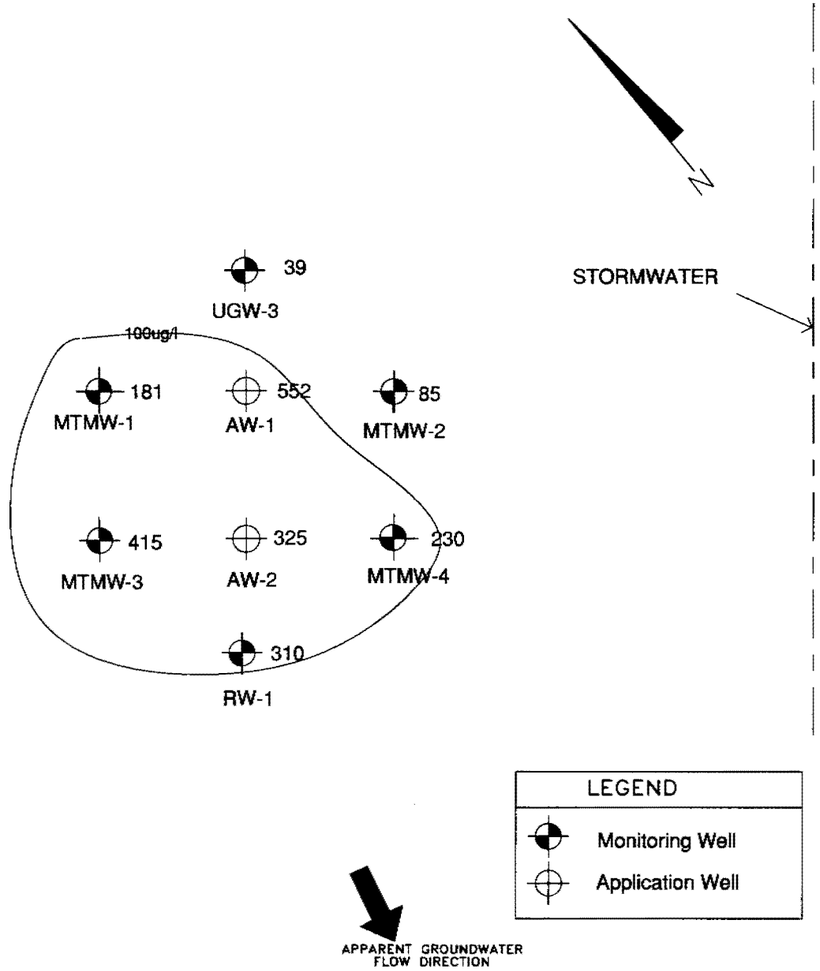


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

BTEX CONCENTATIONS IN GROUNDWATER
TOW WAY FUEL FARM
3 WEEK POST TREATMENT 2/22/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE11.DWG	CT	CC	11c

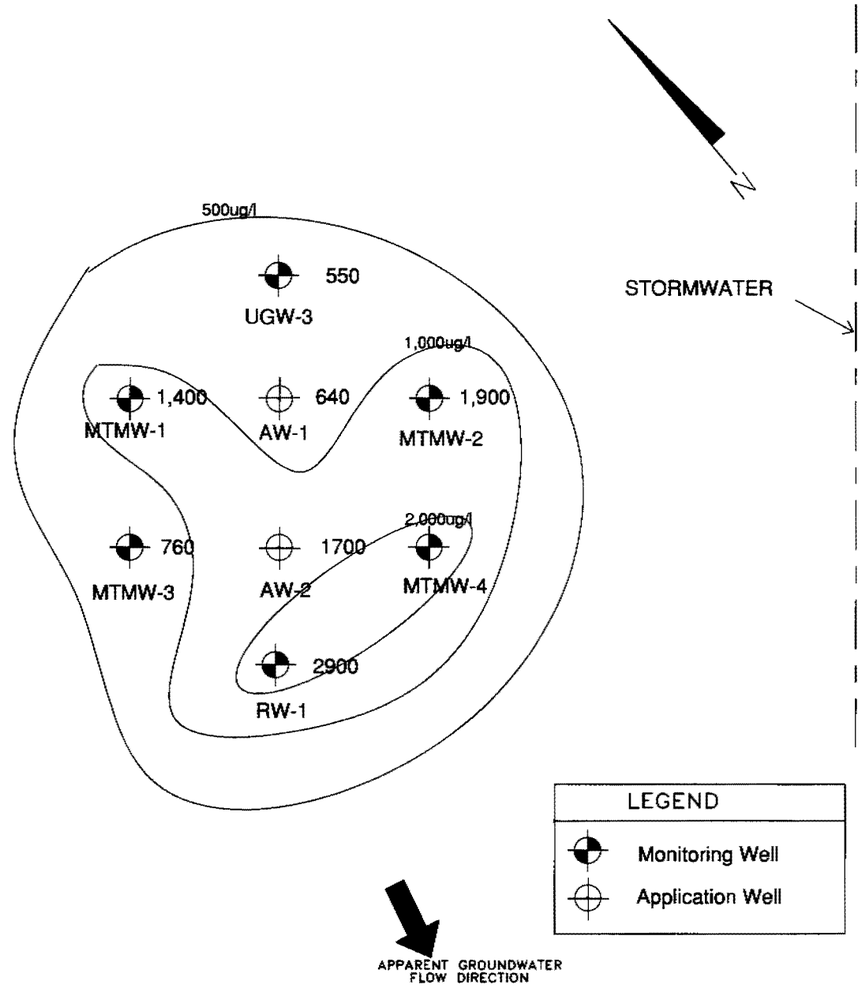


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

BTEX CONCENTATIONS IN GROUNDWATER
TOW WAY FUEL FARM
8-WEEK POST TREATMENT 4/15/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE11.DWG	CT	CC	11d

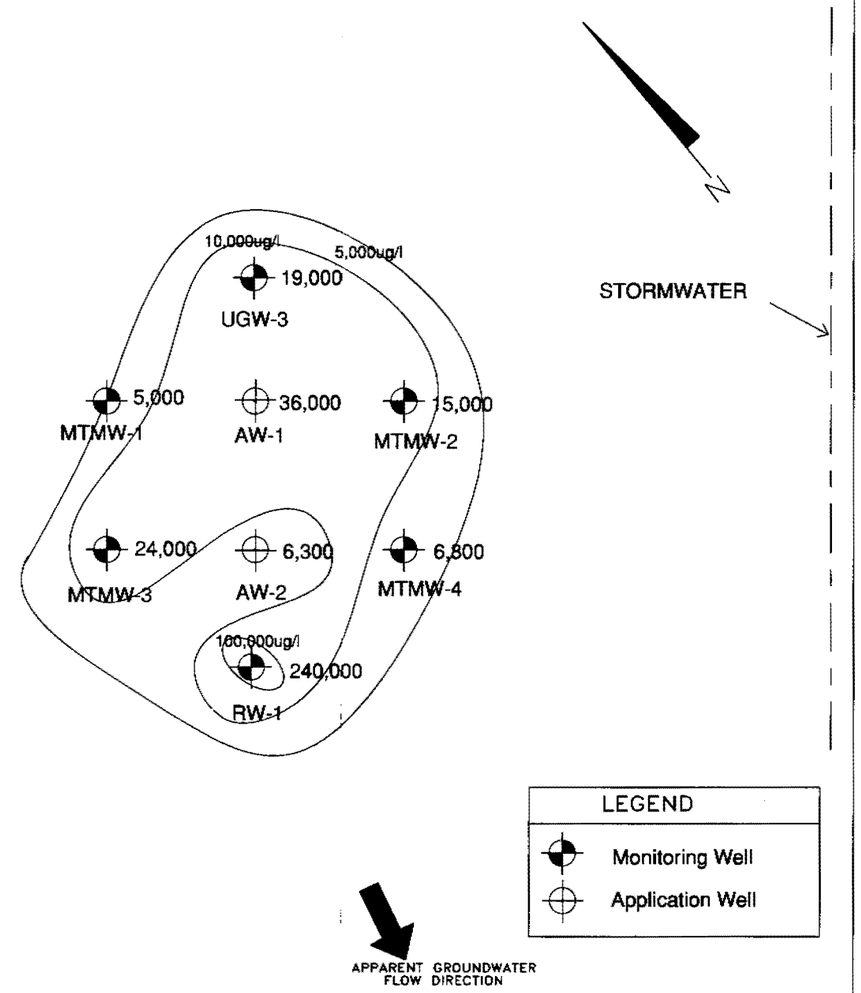


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

GRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
BASELINE 1/7/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE12.DWG	CT	CC	12a

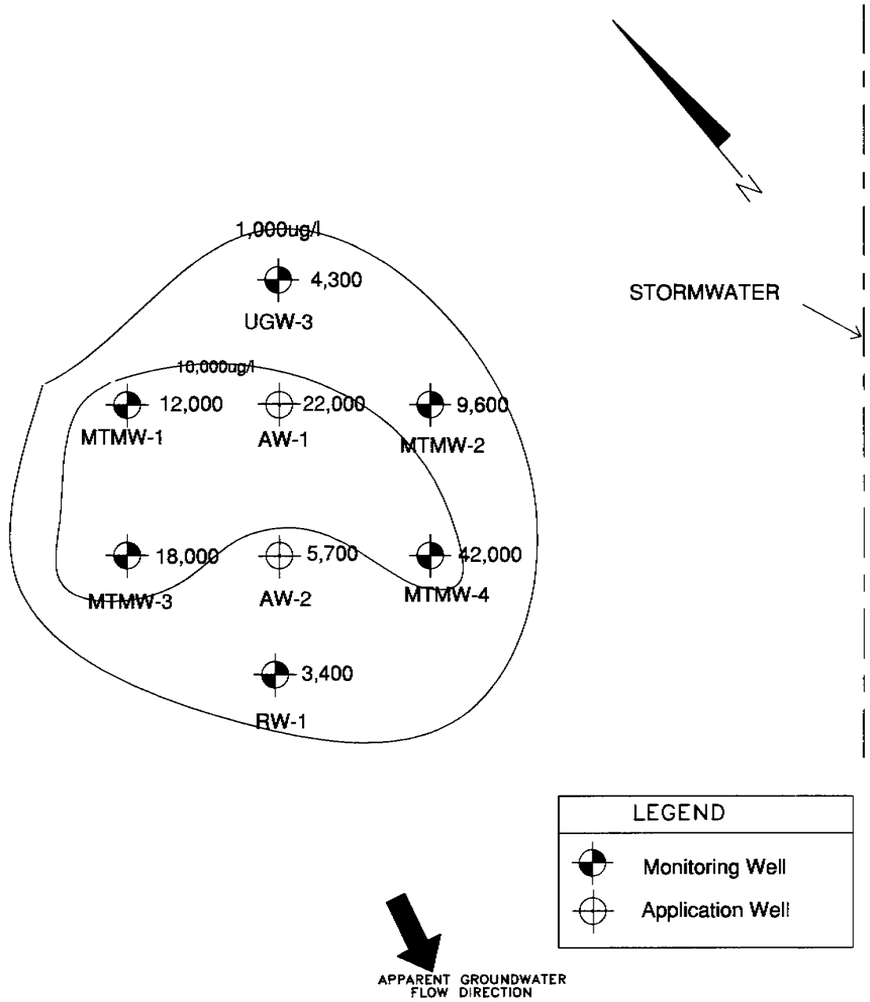


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

GRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
1 WEEK POST TREATMENT 2/8/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE12.DWG	CT	CC	12b

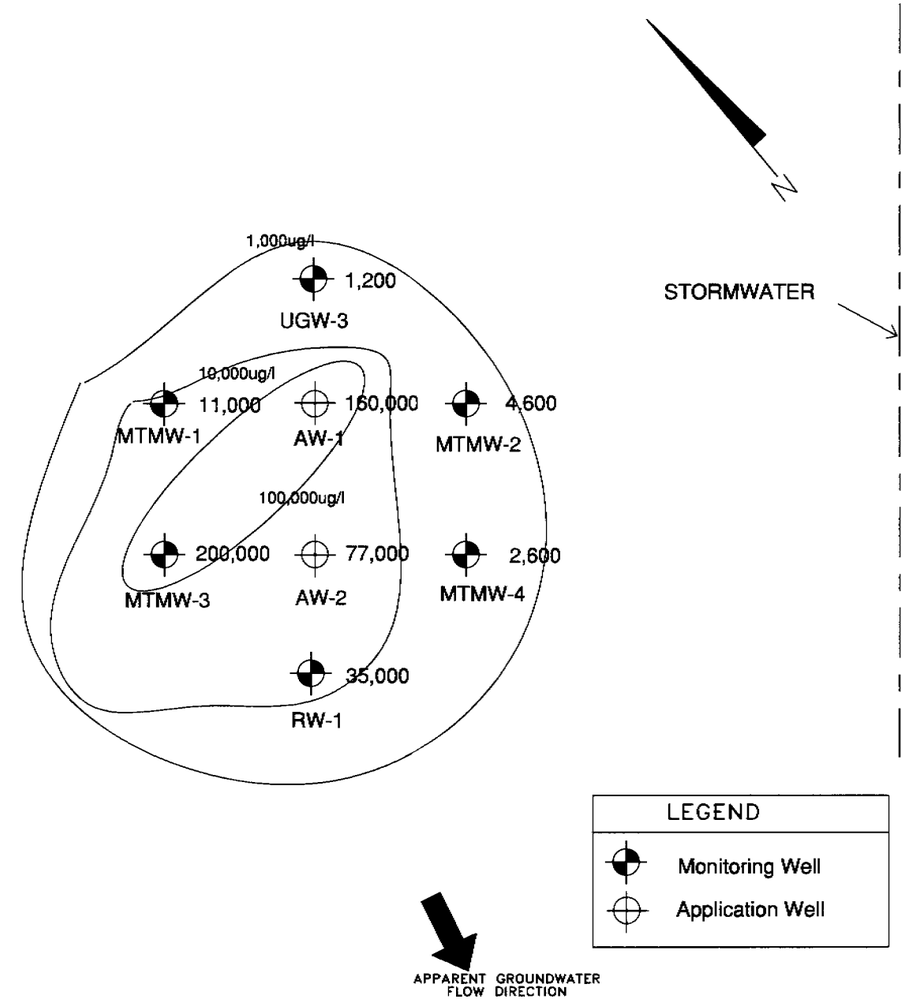


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

GRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
3 WEEK POST TREATMENT 2/22/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE12.DWG	CT	CC	12c

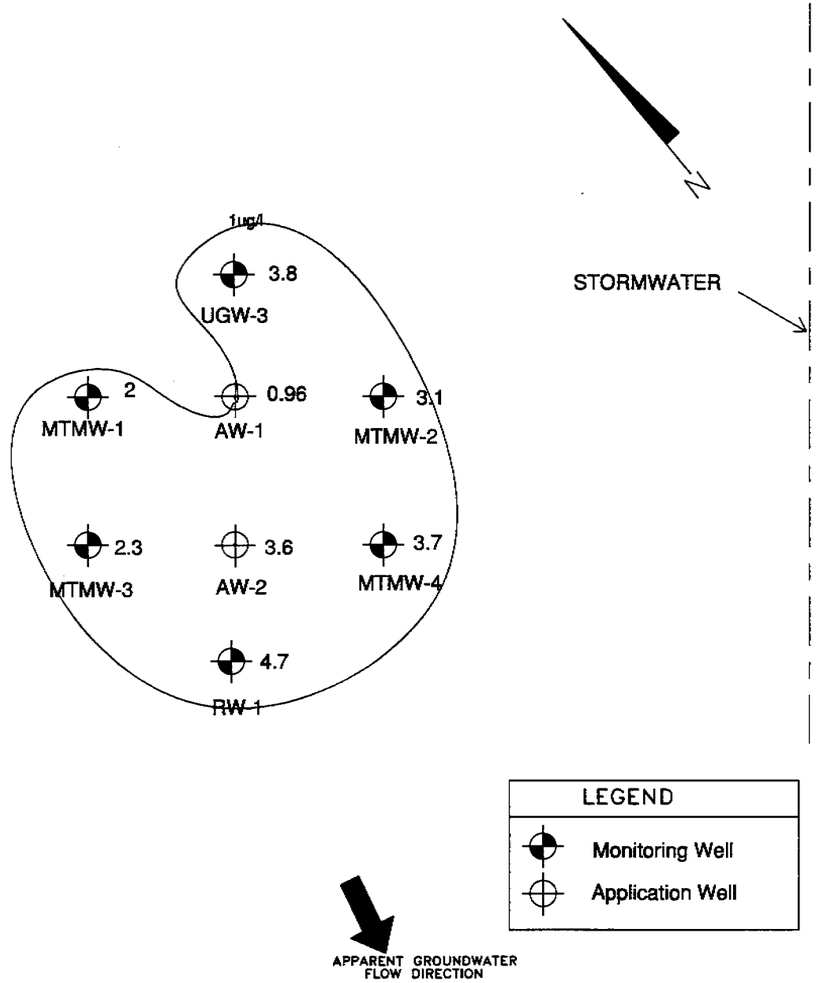


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

GRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
8-WEEK POST TREATMENT 4/15/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE12.DWG	CT	CC	12d

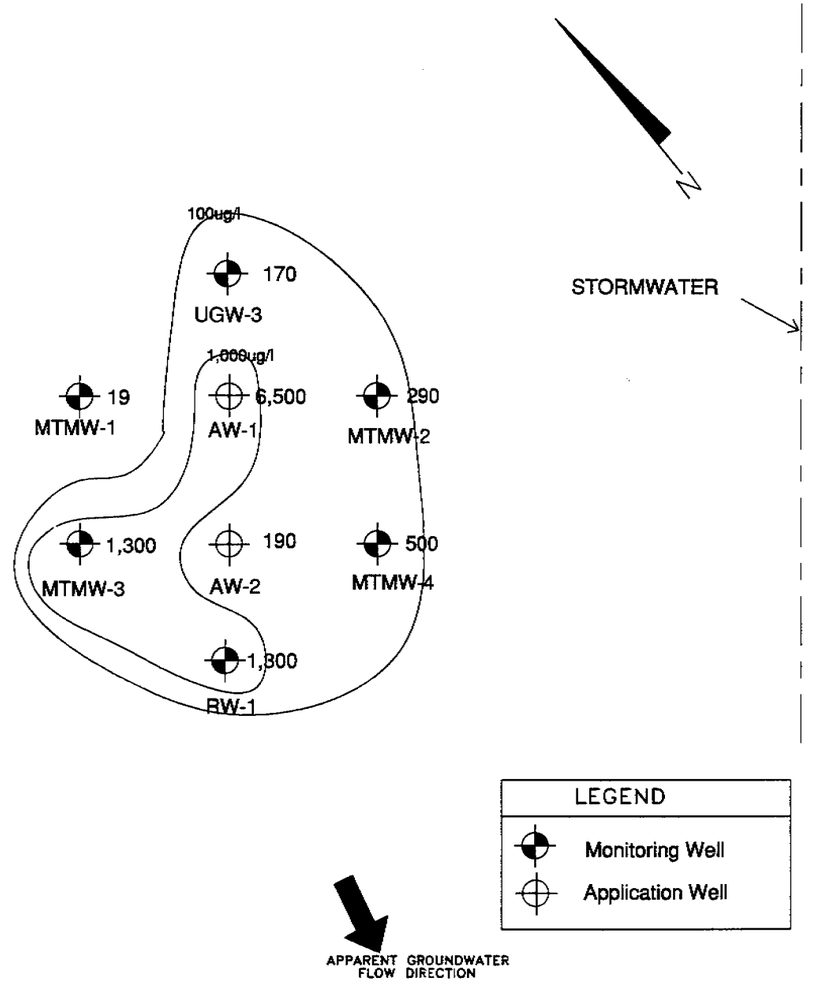


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

DRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
BASELINE 1/7/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE13.DWG	CT	CC	13a



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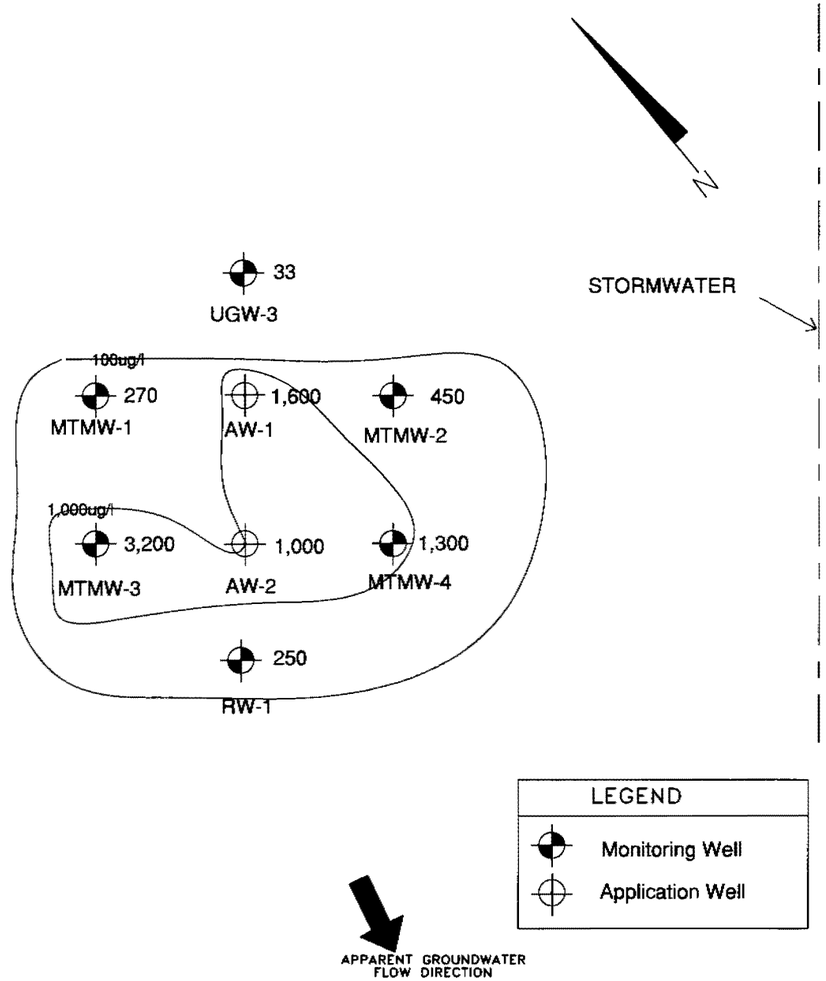
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

DRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
1 WEEK POST TREATMENT

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE13.DWG	CT	CC	13b

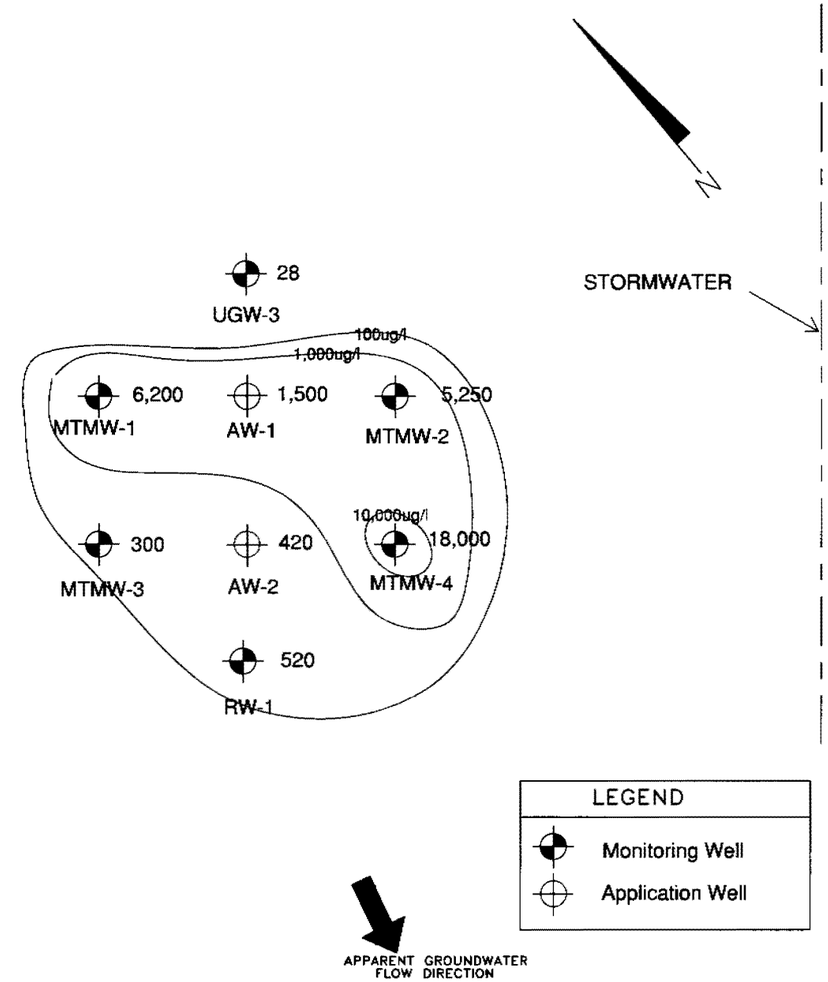


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

DRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
3 WEEK POST TREATMENT 2/22/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE13.DWG	CT	CC	13c

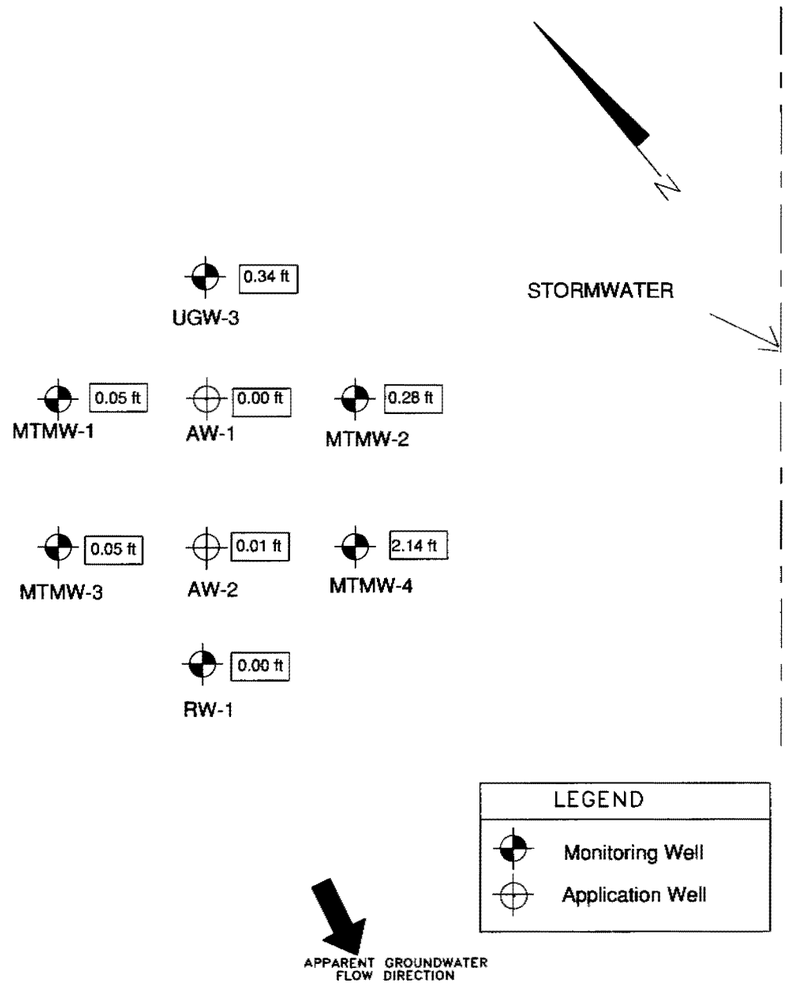


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

DRO CONCENTRATIONS IN GROUNDWATER
TOW WAY FUEL FARM
8-WEEK POST TREATMENT 4/15/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE13.DWG	CT	CC	13d

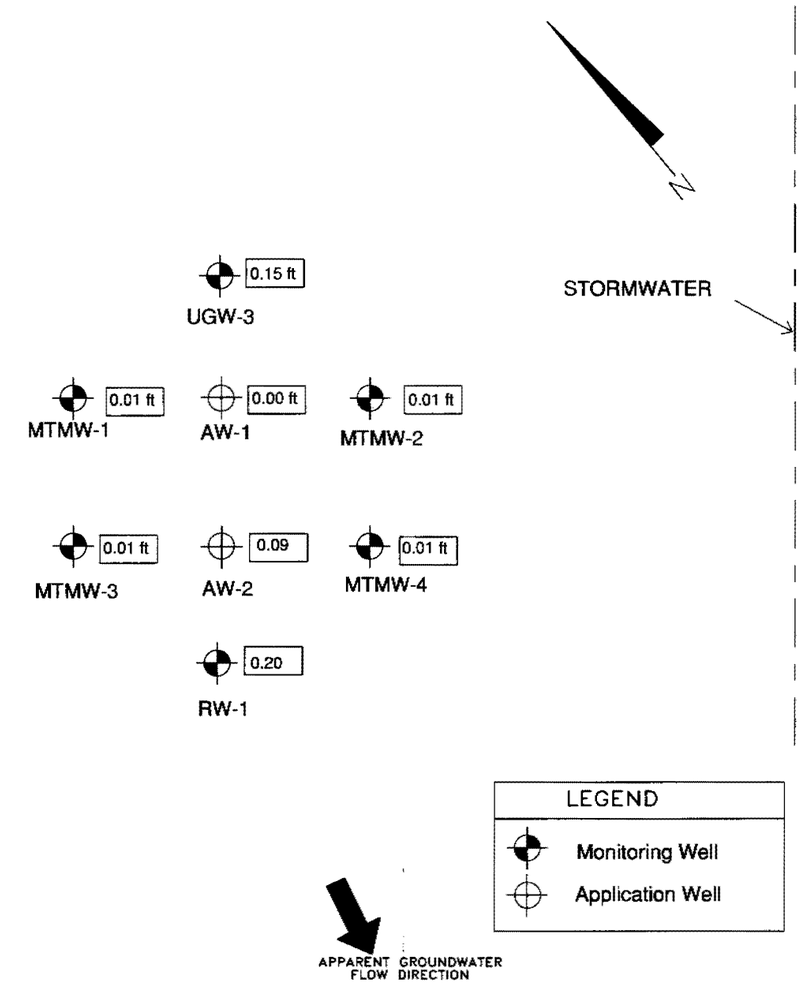


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

FREE PRODUCT MEASUREMENTS
TOW WAY FUEL FARM
BASELINE 1/7/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE14.DWG	CT	CC	14a

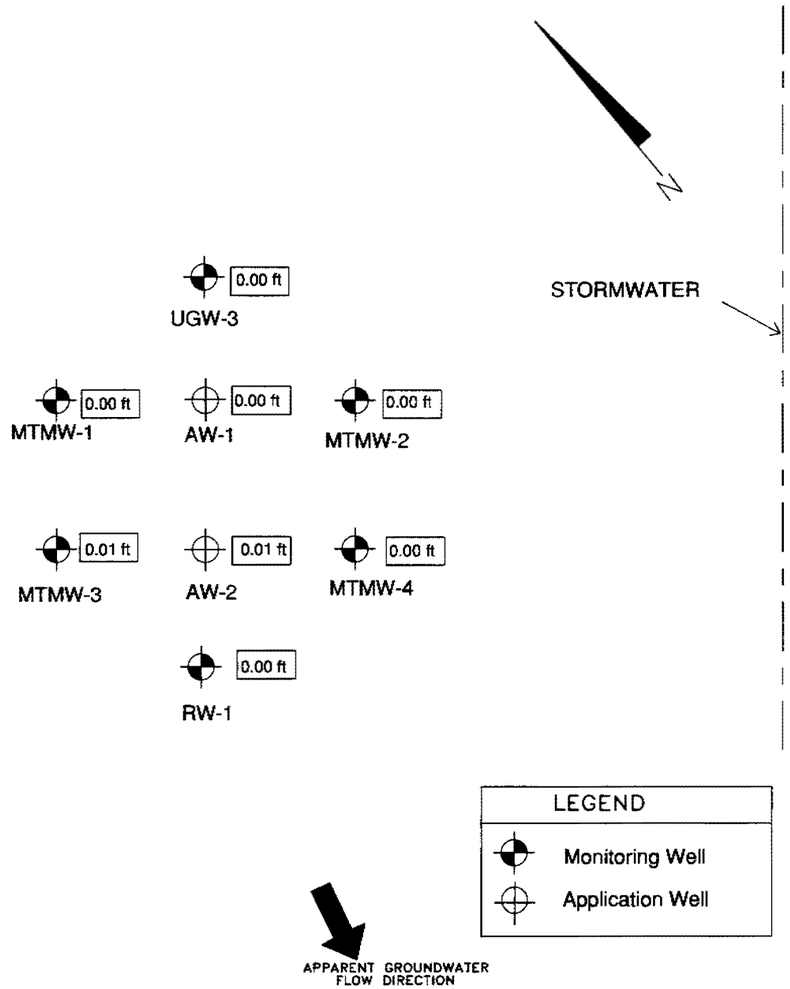


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

FREE PRODUCT MEASUREMENTS
TOW WAY FUEL FARM
1 WEEK POST TREATMENT

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE14.DWG	CT	CC	14b

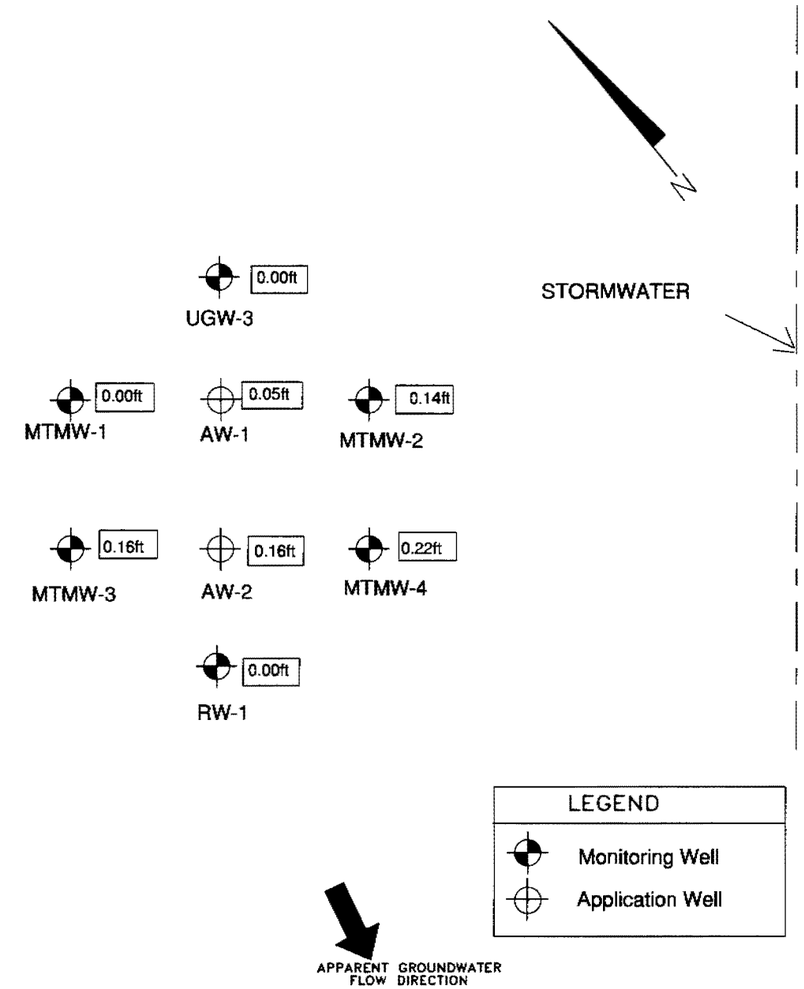


MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

FREE PRODUCT MEASUREMENTS
TOW WAY FUEL FARM
3 WEEK POST TREATMENT

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE14.DWG	CT	CC	14c



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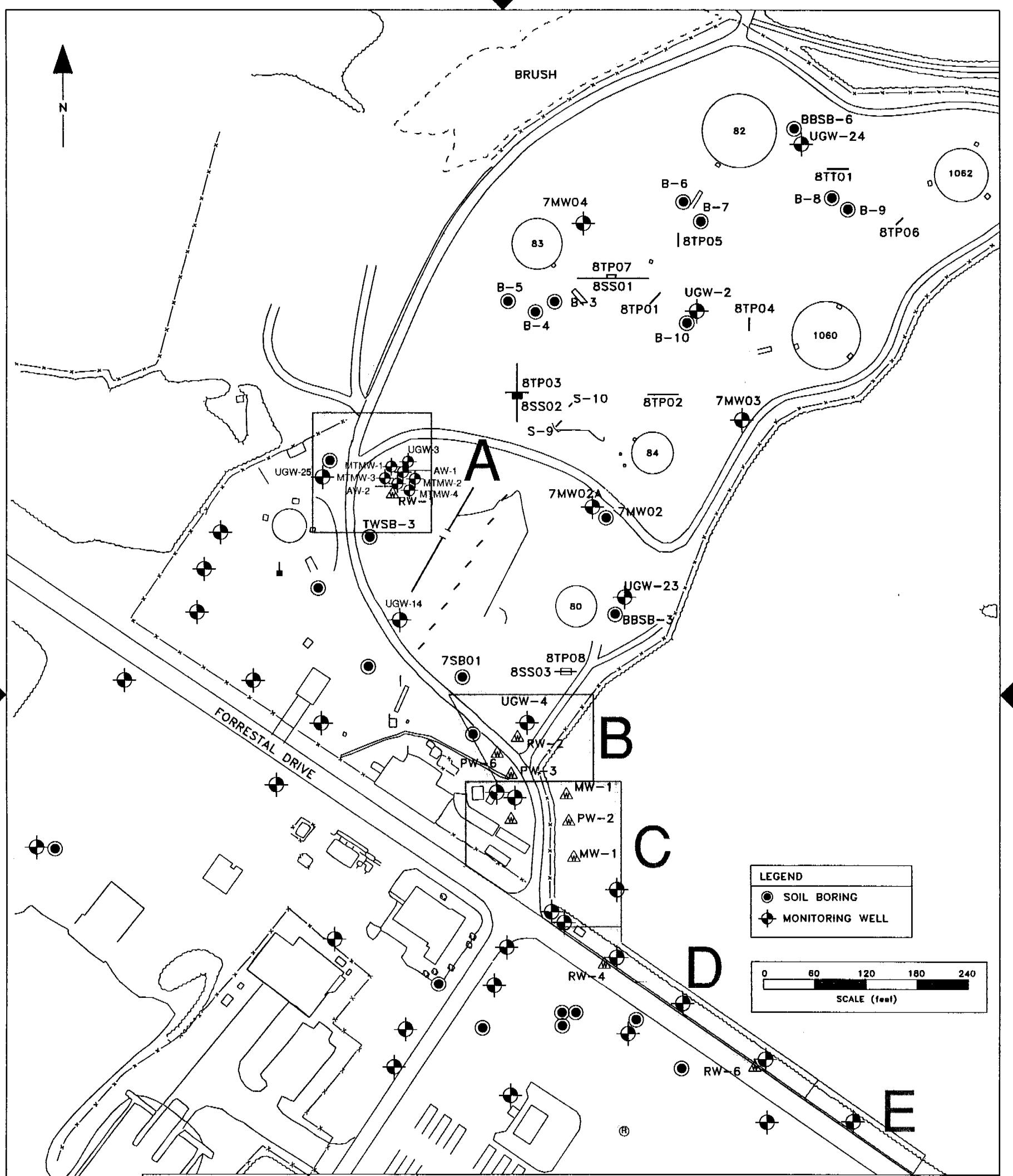
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

FREE PRODUCT MEASUREMENTS
TOW WAY FUEL FARM
8-WEEK POST TREATMENT 4/15/99

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/13/99	FIGURE14.DWG	CT	CC	14d



MANTECH ENVIRONMENTAL CORPORATION
14290 SULLYFIELD CIRCLE SUITE 100
CHANTILLY, VIRGINIA 20151

NAVAL STATION ROOSEVELT ROADS

CLEANOX® REMEDIATION ZONES
TOW WAY FUEL FARM
CEIBA, PUERTO RICO

CLIENT:	DATE:	DWG. FILE:	DRWN BY:	REV'D BY:	FIG. NO.:
BAKER ENVIRONMENTAL, INC.	4/12/99	FIGURE15.DWG	CT	CC	15

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APPENDIX A

SITE BORING LOGS

MANTECH ENVIRONMENTAL
14290 Sullyfield Circle, Suite 100
Chantilly, Virginia 20151

LOG OF BORING AW-1

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

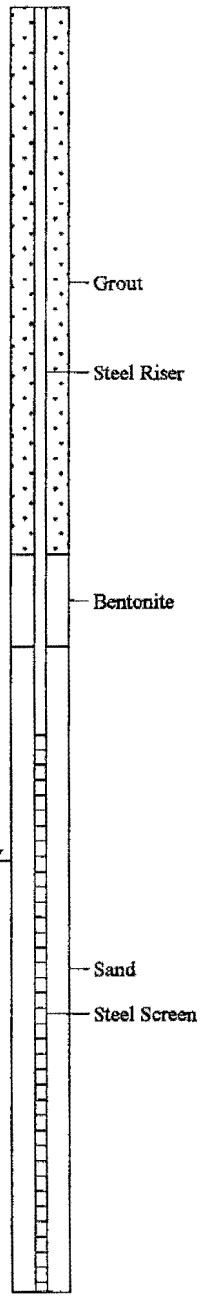
Drilling Method	: Hollow Stem Auger	Static Water Level	: 24 feet bgs
Driller	: Soil Tech	Stick Up	: 0
ManTech Rep.	: Carol Callaghan	Well Inner Diameter	: 2 inch
Sample Type	: Split Spoon, Grab	Well Construction	: PVC Screen/Riser
Hole Diameter	: 8 inches	Well Depth	: 36 Feet

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, slight petroleum odor, Dry	CH
24	Dense red-brown clay slight 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
36		

Samples

Blow Count



MANTECH ENVIRONMENTAL
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Chantilly, Virginia 20151

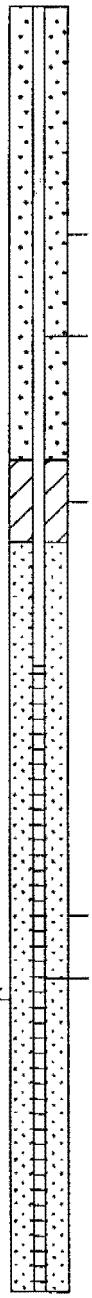
LOG OF BORING AW-2

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 inches
Sample Type	: Split Spoon, Grab	Well Construction	: Steel Screen/Riser
Hole Diameter	: 8 Inches	Well Depth	: 31

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

Depth in feet	DESCRIPTION	USCS
0–8	Cuttings brown silty clay, then light brown - red clay	CH
8–9	Red brown silty clay, Dry	CH
9–10	Brown and grey mottled clay, Dry	CH
10–12	Dense brown clay, Dry	CH
12–16	Dense brown clay with cobbles, Dry	CH
16–20	Grey silty clay with cobbles, petroleum odor, Dry	CH
20–21	Dense grey clay with cobbles WET WITH PETROLEUM PRODUCT	PD
21–22	Dense grey clay with cobbles, Dry	CH
22–23	Angular cobbles of gabbro petroleum stained, Wet	GW
23–24	Red Clay, Dry	CH
24–31	Silty clay with cobbles, petroleum stained, Wet	CH



MANTECH ENVIRONMENTAL
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Chantilly, Virginia 20151

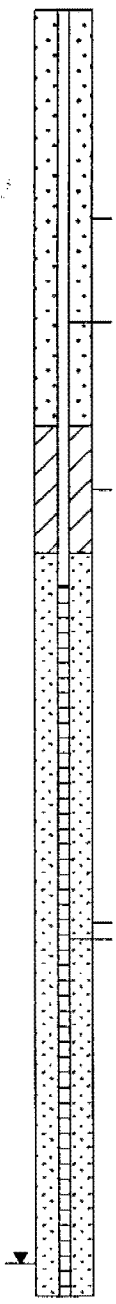
LOG OF BORING MTMW-1

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 sity clay, Petroleum saturated soil at 29 feet bgs. Water at 39 feet bgs.	CH		0		
2				2		
4				4		
6				6		
8				8		
10				10		
12				12		
14				14		
16				16		
18				18		
20				20		
22				22		
24				24		
26				26		
28				28		
30				30		
32				32		
34				34		
36				36		
38				38		
40				40		

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



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MANTECH ENVIRONMENTAL
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Chantilly, Virginia 20151

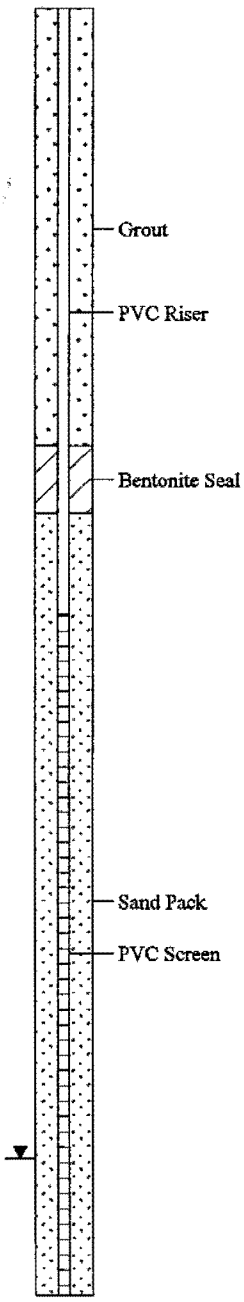
LOG OF BORING MTMW-2

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

Drilling Method	: Hollow Stem Auger	Static Water Level	: 34 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	: 38

Well1: MTMW-2
Elev.: 8.0 Feet Above Mean Sea Level

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



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Chantilly, Virginia 20151

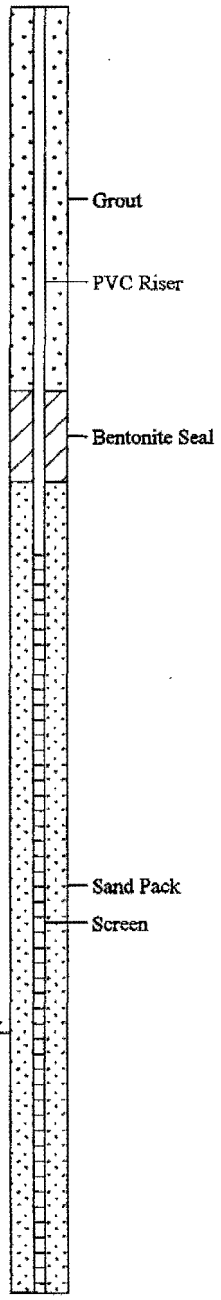
LOG OF BORING MTMW-3

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	Samples	Blow Count
0–10	Silty clay	CH			
10–14	Dense red brown to olive silty clay with cobbles, Dry	CH			
14–15	Dense red and grey mottled clay, Dry	CH			
15–18	Gravel and cobbles, Dry	GW			
18–20	Dense greyish gabbro saprolite, strong petroleum odor, dry	GW			
20–22	Dense petroleum stained brown silty clay with cobbles, dry	CH			
22–24	Dense petroleum stained grey silty clay with cobbles, Dry	CH			
24–25	Dense petroleum stained grey silty clay with cobbles, WET WITH PETROLEUM PRODUCT	PD, CH			
25–26	Silty sand with cobbles, Dry	CH			
26–27	Red brown silty clay with cobbles				
27–30	Silty sand with cobbles, Wet at 30 Feet	CH			
30–35	Silty clay	CH			



MANTECH ENVIRONMENTAL
14290 Sullyfield Circle, Suite 100
Chantilly, Virginia 20151

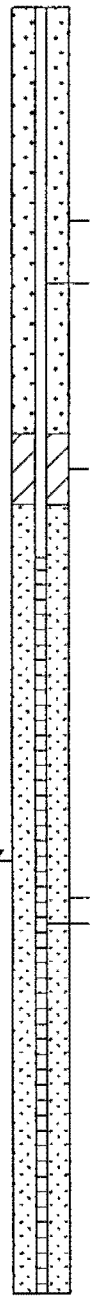
LOG OF BORING MTMW-4

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

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

Depth in Feet	DESCRIPTION	USCS
0–7	Brown silty clay	CH
8–9	Dense brown and grey mottled clay, dry	CH
9–10	Gravel, dry	GW
10–12	Red clay, dry	CH
12–13	Grey clay, strong petroleum odor, dry	CH
13–14	Grey clay some angular gravel, strong petroleum odor, dry	CH
14–16	Green silty clay with angular gabbro gravel, petroleum odor,dry	CH
16–18	Angular gabbro gravel, dry	GW
18–20	Angular gabbro gravel, WET WITH PETROLEUM PRODUCT	PD
20–22	Silty clay with gravel, strong petroleum odor, dry	CH
22–26	Gabbro gravel, wet	GW
26–36	Olive silty clay, wet	CH



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APPENDIX B

SOIL CUTTINGS ANALYTICAL RESULTS

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APPENDIX C

PURGE WATER ANALYTICAL RESULTS

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APPENDIX D

REFLUX LIQUID ANALYTICAL RESULTS

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APPENDIX E

SOIL AND GROUNDWATER ANALYTICAL RESULTS