INTERIM REPORT
SITE INSPECTION STUDIES
AT THE
NAVY FUEL FARM, NAS WILLOW GROVE
HORSHAM TOWNSHIP, PENNSYLVANIA
Contract No. N62472-86-C-1037

Prepared for:
United States Navy
Northern Division
Naval Facilities Engineering Command

Prepared by:
EA Mid-Atlantic Regional Operations
EA Engineering, Science, and Technology, Inc.

September 1989
EA Project 10388.05
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**LETTER OF TRANSMITTAL**

**DATE:** 18 September 1989  
**JOB NO.:** 10388.05

**ATTENTION:** Jim Shafer  
**REF.:** NAS Willow Grove  
**TRP Studies**

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**TO:** Commanding Officer  
**Naval Facilities Engineering Command**  
**Building 77, Code 1421/JS**  
**U.S. Naval Base Philadelphia, PA 19112-5004**

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**GENTLEMEN:**  
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☐ Under separate cover via  
☐ Plans  
☐ Samples  
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☐ Shop drawings  
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☐ Change order

☐ Copy of letter

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**REMARKS**

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**COPY TO:** P. Greco (4)  
**SIGNING:** C.W. Houliker, Jr., Ph.D., P.E.  
**Director, Geotechnical Services**

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If enclosures are not as noted, kindly notify us at once.
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1. INTRODUCTION

EA Engineering, Science, and Technology, Inc. has been contracted by Northern Division, Naval Facilities Engineering Command to perform Site Inspection (SI) studies at Naval Air Station (NAS) Willow Grove, Horsham Township, Pennsylvania. These SI studies are part of the Navy’s Installation Restoration (IR) Program, which is an ongoing effort established to investigate past hazardous materials handling and disposal practices at all Navy installations. The IR Program consists of four distinct phases:

- Preliminary Assessment (PA)
- Site Inspection (SI)
- Remedial Investigation/Feasibility Study (RI/FS)
- Remedial Action Plan (RA)

These phases are implemented sequentially with each phase determining whether the subsequent phase is necessary.

PA’s have been performed for 16 sites at NAS Willow Grove—seven sites at the Air Reserve Facility (ARF) in 1984 and nine sites at the NAS in 1986. Since then, an additional site, the Navy Fuel Farm, has been added to the program. The PA studies included record searches, interviews, air photo interpretations, and site reconnaissance to identify potential sites. No field investigations are performed in the PA phase. The SI phase includes field investigations designed to verify the presence of contamination at the suspected site or provide the basis for eliminating the site from the IR Program. The SI is not intended to evaluate the magnitude or extent of contamination. This more extensive evaluation is part of the RI/FS phase.

EA reviewed the PA studies, performed site reconnaissance, and prepared the Plan of Action (POA) for SI studies at NAS Willow Grove (EA, 1988a). The POA included electromagnetic terrain conductivity surveys (EM) and soil vapor contaminant assessments (SVCA) at selected sites to provide
remotely sensed data concerning potential contaminants. These data were utilized in finalizing plans for direct sampling methods (i.e., test borings and monitoring wells).

The final Field Sampling Plan for SI studies at NAS Willow Grove (EA, 1989a) presented the SVCA results for the Navy Fuel Farm. This information resulted in modification of the sampling plan for the Navy Fuel Farm to include three 6-in. monitoring wells, four 4-in. monitoring wells, and one test boring. One soil sample was selected from the test boring and each of the 6-in. monitoring well borings for laboratory analysis on the basis of field screening with a photoionization detector (PID). Samples were analyzed for volatile organic compounds (VOC), total petroleum hydrocarbons (TPH), total organic carbon (TOC), and EPA target compound list (TCL) base/neutral extractable organic compounds (BN). All sampling and analyses were performed in accordance with the Quality Assurance/Quality Control Project Plan for Installation Restoration Program Studies, NAS Willow Grove, Pennsylvania (EA 1988b).

In addition, pursuant to a contract amendment, EA completed 18 test borings in the vicinity of Building 340, which is located downgradient of the Navy Fuel Farm. One soil sample per boring was selected based on the highest field PID reading and submitted for analysis of TPH, and benzene, toluene, ethylbenzene, and xylene (BTEX). Results of that investigation were provided in April (EA, 1989b).

This report presents observations made during field work and the analytical laboratory results for samples of soil and ground water. The report has been prepared prior to completion of all SI studies so that the Navy can proceed with investigations and remedial action at the Navy Fuel Farm on a schedule which is accelerated with respect to the other SI sites.
2. SITE DESCRIPTION

2.1 LOCATION

The Navy Fuel Farm facility is an approximately 2 acre site located north of the intersection of Privet Road and the aircraft parking apron off Runway 15 (Figure 1). The site is due south of Air Reserve Facility (ARP) Building 345.

2.2 SITE FEATURES

Site features are illustrated on Figure 2. A catchment basin located north of Building 157 collects runoff from the site. Drums of aviation fuel are often stored within 50 ft of this basin. The catchment basin drains into a ditch which borders the north edge of the Navy Fuel Farm.

A gasoline filling station is present upgradient of the site (east of Building 119), but it has not been operated since spring, 1989.

In 1986 a spill occurred when Tank 115 was overfilled and fuel was released from the vent pipe onto the ground. The event was attributed to faulty gauges which registered less fuel than was actually present. During that same year a utility trench was dug along the west boundary of the site but work was discontinued when non-aqueous phase liquid (NAPL) was observed on standing water in the trench. Subsequent observations have confirmed the continued presence of at least a sheen of NAPL in the trench. In late March, 1989, jet fuel (JP-5) was detected emanating from two patches of dead grass of the west side of Tank 115. Heavy rain flushed this fuel into the ditch on the north edge of the site. Facility personnel responded with the placement of absorbent material in the ditch and adjacent to Tank 115.
2.3 GEOLOGY AND HYDROLOGY

In addition to field observations, information for this section was taken from the PA studies (Weston 1984; Rogers, Golden and Halpern 1986) and from published literature (Rima et al. 1962).

2.3.1 Topography

The Navy Fuel Farm is located on a graded site that is essentially flat-lying. There is a slight downgrade at the north end of the site which encourages runoff to flow northeast into the catchment basin or the adjacent ditch.

2.3.2 Surface Drainage

No natural drainage remains on the site. An earthen ditch bordering the north edge of the site receives most of the drainage from the site. An unfinished utility trench which runs due west of the two main fuel tanks often contains water. During heavy rain, the trench floods and usually discharges into the ditch to the north. A concrete stormwater sewer borders the south side of the site adjacent to Privet Road. The stormwater sewer diverts most of the runoff originating south of the site.

2.3.3 Soil

Soil cover varies in thickness over the site from 6-12 ft in depth. In general, soil depth increases from south to north, reflecting the dip of the underlying strata. The northeast edge of the site is underlain by soil types belonging to the Readington Silt Loam group which is classified as moderately well drained "C" hydrologic group soil. Typical permeability is in the range of 0.04-0.2 in. per hour while values for pH are reported in the range 4.5 to 6.5 (SCS, 1967). Soil over the rest of the site is fill material. The high proportion of clay observed in this fill material leads to reduced permeability and slow infiltration rates. During periods of high rainfall, this results in ponding of surface water and local flooding at the Navy Fuel Farm.
2.3.4 Geology

The site is underlain by the Middle Arkosic Member of the Late Triassic Stockton Formation. This member consists of interbedded red shale, siltstone, and grey-tan, medium grained, arkosic sandstone which was deposited as part of a coalescing fluvial channel system. Red shale and siltstone are predominant along the south edge of the site whereas grey, arkosic sandstone underlies most of the rest of the site.

Depth to competent rock may range from 20 ft in areas underlain by shale or siltstone to as shallow as 6 ft in areas where soil was previously removed down to competent sandstone bedrock during site construction activities. Relict bedding structure is often present as a zone several feet thick overlying shale or siltstone units. Regional dip ranges from 5-15 degrees to the north-northwest (Rime et al, 1962). Figure 3 illustrates the soil-bedrock contact, the distribution of shale and sandstone, and mean static water level as interpreted from boring data. Beds vary laterally in thickness, often pinching out or grading into other facies. This makes prediction of lithologic occurrence difficult without good local control.

Small displacement normal faults trending northeast-southwest are present throughout the unit. Two sets of vertical joints, roughly parallel and perpendicular to strike direction are well developed. A third set of joints, less well expressed, is present trending northwest southeast (Rime et al, 1962).

2.3.5 Hydrology

The Middle Arkosic Member of the Stockton Formation is the most productive aquifer of the Stockton Formation. Reported yields range from 10-800 gpm with 110 gpm being average. The average specific capacity is 3 gpm/ft of drawdown. Transmissivity values for this unit have been reported in the range 8000-23,000 gpd/ft (Rime et al, 1962). NAS Willow Grove directly overlies the area of recharge to this important regional aquifer.
The static water table (April 1989) under the Navy Fuel Farm lies 9-12 ft beneath grade. In most cases, this places the water table within bedrock fractures or within the upper weathered zone immediately overlying competent rock. Shallower water level depths detected during or immediately after rain events are probably the result of retarded infiltration rates due to the presence of clay in the soil. The ground-water gradient under the site is in a northerly direction (Figure 2). However, since flow is primarily through fractures within the bedrock or within the zone of weathered rock with relict bedding features, flow direction may be more related to fracture orientation rather than gradient. Ground-water movement through the arkosic sandstone is more rapid than through the shale/siltstone units as evidenced by more rapid recharge rates observed during installation and development of wells in the arkosic sandstone facies. This is probably due to greater size and density of the fractures present in the more brittle sandstone unit. Preferential movement through the arkosic sandstone units results in greater movement parallel rather than perpendicular to bedding, although local faulting may alter this trend. Static water levels reflect not only the regional potentiometric surface but also the composite head resulting from the different water-yielding zones penetrated during drilling. For this reason water levels may differ markedly in nearby wells depending on the number and size of fractures intercepted by the well.
3. SITE CONTAMINATION ASSESSMENT

3.1 FIELD METHODS

To assess the potential for soil and ground-water contamination, EA first conducted a soil vapor survey of the site during fall of 1988. Based on these results, one test boring and additional monitoring wells were added to the original Plan of Action (EA, 1989a) to aid in interpretation of soil vapor anomalies and to detect possible sources of contamination both on and off the site. In March, 1989, eighteen borings were completed, downgradient of the Navy Fuel Farm around Buildings 330, 340 and 345 to assess potential contamination in that area. Soil samples were obtained from test borings until bedrock refusal occurred, and then the borings were advanced to water table using the air rotary drilling method. All boreholes were then gauged with an interface probe to assess whether NAPL (e.g. floating product) was present.

Figure 2 shows the location of test borings and monitoring wells installed at the Navy Fuel Farm and near Buildings 330, 340, and 345. The Navy Fuel Farm test boring (NFFB 1) was completed at the top of bedrock; the water table was not encountered. A total of seven monitoring wells, four 4-in. wells and three 6-in. wells, were installed at the Navy Fuel Farm. Monitoring wells were screened 15 feet below and five feet above the water table and constructed with Schedule 40 PVC with a screen slot size of 0.02 in. A summary of well construction data is presented in Table 1. Refer to well construction diagrams in Appendix A for complete details. Boring logs for all wells and the test boring at the Navy Fuel Farm are included in Appendix A.

At the Navy Fuel Farm, one sample was selected from the test boring and each 6-in. well based on headspace screening with a photoionization detector (PID). The sample with the highest headspace reading was selected for analysis of the following parameters: EPA target compound list (TCL), volatile organic compounds (VOC), and base/neutral extractable organic compounds (BN), total organic carbon (TOC), and total petroleum hydrocarbons (TPH). Soil samples from the environmental test
borings around Buildings 330, 340, and 345 at the Air National Guard facility were analyzed for TPH and benzene, toluene, ethylbenzene, and total xylenes (BTEX). All borings which encountered the water table and all wells were gauged several times with an interface probe to measure floating NAPL if present. Detection limits of the interface probe preclude measurement of NAPL less than 1/8 in. thick.

In June, 1989, five wells at the Navy Fuel Farm were sampled for laboratory analysis for VOC, TPH, and TOC. Wells NFFW-2 and NFFW-6 were not sampled because NAPL was present in these wells on the sampling date. Before sampling, five well volumes were purged from each well using a submersible pump. Pumps were steam cleaned between wells to prevent cross contamination. Due to suspected contamination in the aqueous phase in wells NFFW-1, NFFW-5, and NFFW-7, the pump effluent from these wells was treated by carbon filtration before being discharged. Dedicated, laboratory-cleaned bailers were used to obtain samples which were placed in laboratory cleaned bottles with proper preservatives when appropriate. Samples were hand carried to the laboratory on the date obtained.

3.2 FIELD OBSERVATIONS

3.2.1 PID Headspace Readings

Table 2 summarizes the headspace readings of soil samples taken during test borings or monitoring well installation at the Navy Fuel Farm. Samples from NFFW-1, 3, and 4 showed no detectable contamination. Samples from NFFW-2 showed only minor amounts of ionizable compounds. NFFW-7 samples showed the highest and most widespread contamination with peaks in samples obtained directly above the current water table and immediately overlying bedrock. Readings were high in surficial soil samples at this location as well. Samples from NFFW-5 and NFFB-1 show the highest readings in the 2-4 ft interval. NFFW-6 samples were clean at the surface with a gradual increase in readings reaching a maximum in samples obtained directly overlying the water table. Samples from NFFB-1 also shows an elevated reading just above the water table.
3.2.2 Interface Probe Readings

Interface probe gaugings detected NAPL on several occasions at monitoring wells NFFW-2 and NFFW-6. NFFW-6 showed the greatest thickness of product with up to 2.5 in. of NAPL being detected on one occasion. NFFW-2 never showed more than 1/8 in. NAPL. The amounts of NAPL detected in these wells varied unpredictably over time. NAPL was not detected with the interface probe in any other wells. However, during development and purging, water from NFFW-1 showed a persistent sheen which indicates that NAPL is often present in this well as a thin layer less than 1/8 in. thick. Headspace readings of drilling fluid and development water collected in glass jars during well installation indicate dissolved contamination is present in wells NFFW-5 and NFFW-7.

None of the test borings at Buildings 330, 340, 345 showed measurable product with an interface probe, however, high PID readings from the borehole and detectable sheen and odor on the interface probe indicated that NAPL was present in seven of the borings. In most cases the failure to detect NAPL was probably due to insufficient thickness of NAPL for the instrument to detect (1/8 of an inch). In one case, NFFB-18, running mud in the hole caused by infiltrating surficial runoff prevented an accurate reading despite the obvious presence of NAPL indicated by the strong odor of fuel. Those borings which showed NAPL present are noted on Figure 2.
4. ANALYTICAL RESULTS

All samples were processed using EPA Contract Laboratory Program (CLP) methods with Navy Level C data quality objectives as per the Plan of Action. Dry weights were used in calculating total petroleum hydrocarbons and total organic carbon concentrations in soil to maintain consistency with CLP procedures for other analytical parameters. The large number of unknowns reported is due in part to the fact that many of the hydrocarbons expected from jet fuel degradation are not targeted compounds and therefore, are not standardized for quantification by the methods utilized. For this reason, the lack of TCL listed volatile or semi-volatile organic compounds in soil or ground-water samples from the Navy Fuel Farm should not necessarily be interpreted as an indication that no contamination exists.

4.1 SOIL

Each soil sample was analyzed for base/neutral extractable, organic compounds, volatile organic compounds, total petroleum hydrocarbons, and total organic carbon. The results of soil sampling analyses are summarized in Table 3 and discussed in detail below.

4.1.1 Base/Neutral Extractable Organic Compounds (BN)

No TCL BN compounds except for a trace of naphthalene in NFFW-7 and a trace of Bis(2-ethylhexyl)phthalate in NFFW-5 were detected in the soil samples. The phthalate compound is probably lab contamination. All samples contained unknown organic compounds at estimated concentrations. Concentrations of unknowns have been summed to provide a rough measure of the amount of unknown BNs present relative to the total amount of BNs detected. Spectral patterns of unknown organic compounds in the soil sample from NFFW-7 are indicative of degraded jet fuel.
4.1.2 Volatile Organic Compounds (VOC)

Seven TCL volatile components were detected in soil samples from the fuel farm. Acetone and methylene chloride were detected in several samples, but in this instance, are probably due to lab contamination. Most of the remaining compounds were found in soil from NFFW-7. Nontargeted compounds were present in all samples. Unknown compounds are presented in Table 3 as combined concentrations to allow an estimate of the relative proportion of unknown volatile compounds to the total VOC detected.

4.1.3 Total Petroleum Hydrocarbons (TPH)

Soil samples from NFFB-1, NFFW-5, and NFFW-6 contained less than 100 mg/kg TPH. The sample from NFFW-7 contained 352 mg/kg. Soil samples from test borings adjacent to Building 330, 340, and 345 contained TPH in the range 120-590 mg/kg (EA 1989b).

4.1.4 Total Organic Carbon (TOC)

TOC values were within the range of normal soil values (0.1 - 2%), but the lack of background samples for comparison leaves the significance of these results uncertain. The higher value in NFFW-6 as compared to other samples may be attributable to previous NAPL releases which have left residual product on soil directly above the water table.

4.2 GROUND WATER

Each ground-water sample was analyzed for volatile organic compounds, total organic carbon, and total petroleum hydrocarbons. The results of analysis of samples of ground water obtained in June 1989 are summarized in Table 4 and discussed in detail below.
4.2.1 Volatile Organic Compounds (VOC)

Benzene, ethylbenzene, and xylenes were detected in Wells NFFW-1 and NFFW-7. A number of unknown alkanes and hydrocarbons were also detected. The sample from NFFW-5 contained a trace of benzene and a number of unknown alkanes. The samples from Wells NFFW-3 and NFFW-4 showed no VOCs indicative of contamination by petroleum sources. Trace levels of chlorinated hydrocarbons were detected in the NFFW-3 sample. Neither of the two compounds involved was detected in the sample of source water used in drilling these wells (Table 5). However, these compounds have been detected in samples from the source water supply wells (Earth Data 1985).

4.2.2 Total Petroleum Hydrocarbons (TPH)

TPH were not detectable in samples from Wells NFFW-3 and NFFW-4 confirming the absence of petroleum products in the ground water at these locations. Trace levels of TPH were found in the NFFW-5 sample and low but clearly present levels of TPH were found in the NFFW-1 sample. The sample from NFFW-7 contained 110 mg/L TPH.

4.2.3 Total Organic Carbon (TOC)

The low values of TOC in wells NFFW-3 and NFFW-4 may be considered representative of background levels in the area. Using this as a guide, the other wells show an increase in TOC concentrations which mirror an increase in concentration levels of petroleum hydrocarbons. By this criteria, NFFW-5 levels are five times above background, NFFW-1 levels are at 15 times background, and NFFW-7 levels are 30 times above background.
5. CONCLUSIONS

5.1 SOIL

The analytical results show that the underlying soil at the sampled locations may not require treatment or special handling if disturbed for construction purposes except for the area in the vicinity of NFFW-7. The fuel spill of 1986 impacted this area which probably accounts for the high TPH, trace naphthalene, and spectral pattern of tentatively identified and unknown compounds obtained from the soil sample at NFFW-7. The clay-rich nature of the fill at this site may have enhanced adsorption of the fuel as it soaked into the ground during this event. The potential need for treatment of soil at the Navy Fuel Farm for purposes of alleviating a source of contamination to ground water will be evaluated in the RI/FS.

Soil samples from around Buildings 330, 340, and 345 contained TPH in the range 120-590 mg/kg. The lack of positive BTEX results and BN data makes the significance of the TPH values uncertain without background data for comparison.

High PID readings in the 2-4 ft interval of both NFFB-1 and NFFW-5 locations indicate contamination from a surficial source is likely. All the soil at NFFW-5 is fill material. This well is adjacent to or within the backfill of a utility trench. PID readings indicate that soil above the water table in NFFB-1, NFFW-6, and NFFW-7 has been contaminated, probably by exposure to floating NAPL or contaminated ground water.

5.2 GROUND WATER

Floating NAPL has been detected in three wells (NFFW-1,2,6) at the Navy Fuel Farm site and in seven of the eighteen borings surrounding Buildings 340 and 345. The amount of NAPL present varies unpredictably with fluctuations in the water table through time. Detected amounts have ranged from a sheen up to 2.5 in. Occurrence of floating NAPL appears to be
controlled by secondary fracture porosity in the bedrock and overlying saprolite which retains remnant bedrock structure. Due to the irregular distribution of these fractures and their varying degree of hydraulic interconnection, the intercepted area in wells may not be representative of the average fracture frequency or NAPL occurrence in areas surrounding the well. Present wells may not intercept fractures which contain floating NAPL in connection with the NAPL reservoir or may be incapable of capturing such floating NAPL if hydraulic drawdowns are induced. Conversely, gauged wells may not exhibit NAPL but become recharged with NAPL at hydrostatic conditions once a cone of depression is induced by pumping. Further development of these wells is necessary to more accurately evaluate their communication with the NAPL reservoir.

Based the presence of floating NAPL and the results of ground-water sampling and analysis, aqueous-phase contamination is present in all wells downgradient of the two main fuel tanks. The two upgradient wells appear to be free of hydrocarbon contamination.

A contamination plume underlies the main fuel tanks at the Navy Fuel Farm. Both NAPL and aqueous-phase contamination is present. The plume appears to be moving offsite north-northwest in the direction of the ground-water gradient towards Buildings 340 and 345.
6. RECOMMENDATIONS

6.1 CHARACTERIZATION

At present, the existing well network does not define the extent of either the NAPL or aqueous-phase plume emanating from the Navy Fuel Farm. Additional downgradient monitoring wells will be needed. The recommended locations for six 4-in. monitoring wells and one recovery well are shown on Figure 2. The additional recovery well has been located in the area of the most recently observed spill. The diameter and depth of this well will be determined subsequent to pump testing the existing wells (Section 6.2.1). The 4-in. monitoring wells will further assess contaminant distribution, however, it is likely that one or more additional well installation programs will be necessary to complete site characterization.

No further action is warranted at this time to treat soil at the Navy Fuel Farm although limited excavation around NFFW-7 or soil venting may be necessary in the future. Additional borings or hand auger sampling may be necessary to determine the extent of the contaminated soil.

The TPH data for shallow soil samples around Buildings 330, 340 and 345, suggest the possibility of a local source of contamination in that area. Analysis of soil samples from the above recommended well borings will assist in assessing whether soil contamination may be related to local sources or the Fuel Farm plume.

Existing utility trenches located downgradient of the site may already be serving as conduits of contaminant migration, particularly if trench backfill is relatively permeable and the water table is elevated. To further assess the potential for contaminant migration via utility trenches it will be necessary to obtain, collate, and interpret all existing data on utility trench location, depth to bedrock, and depth to the water table for the area of interest. It will be necessary for the facility to make available all plans, specifications, and drawings for underground construction in the area of interest during a site visit by an EA geologist or engineer. In the event that this analysis reveals
locations of likely interception of NAPL by utility trenches, EA would recommend locations for test pit exploration to evaluate this potential.

6.2 REMEDIATION

6.2.1 Well Recovery Pilot Program

The initial phase of remediation should be an interim pumping program designed to evaluate the interconnectedness of the recovery wells with the NAPL reservoir and the aqueous plume to determine the feasibility of product recovery by pump and treat methods. Two steps are proposed.

First, further development of all wells with aqueous or floating product is necessary to improve recharge rates in these wells. Previous development was minimized due to the need to containerize all development water. Future development water will be treated with an oil/water separator and carbon filtration before being discharged to surface water. Well performance during development will be evaluated to estimate a sustainable yield for each well.

The second step will be pump testing. Each downgradient well will be subjected to 72 hours of continuous pumping. For each pump test hermit automatic data loggers will be utilized to record elapsed time versus drawdown in selected wells. Every 4 hours all wells involved in the test will be gauged for floating product to monitor changes in NAPL distribution with progressive drawdown. Pump effluent will be treated with an oil/water separator and a carbon filtration unit before discharge. Every 24 hours a sample of the pump effluent will be taken before carbon filtration and submitted for analysis of TPH and BTEX. Recovery will be monitored for 24 hours subsequent to pumping. Water levels will be allowed to recover to near static level prior to initiating the next test. The results of the pump tests will allow calculation of aquifer characteristics as well as an estimate of the optimum pumping rate for product recovery. Zones of influence around the pumping wells will be evaluated and potential NAPL recovery rates estimated.
If the trial pumping program is successful in demonstrating that one or more of the existing wells can serve as a recovery well with sufficient hydraulic capture, the trial pumping system may be retained onsite as an interim remedial pumping system. A more permanent system can be added at a later date. If trial pumping demonstrates the inadequacy of the existing well system for recovery, either additional wells may be required in known NAPL zones or another remediation approach may be warranted.

6.2.2 Trenching

If wells prove to be inadequate for effective NAPL recovery, remediation may be accomplished by installing one or more recovery trenches perpendicular to the ground-water gradient. Trenches may have a higher probability than wells of intercepting product-bearing fractures due to the greater surface area intercepted at the interface between the water table and the overlying NAPL layer.

Logistical and practical considerations such as existing utility trenches and the need to trench into the bedrock must be evaluated pursuant to initiation of this form of remediation. Trenches should be deep enough to penetrate the water table (9-11 ft) several ft for adequate drawdown and be filled with porous gravel surrounding a ground water/NAPL withdrawal system. Trench feasibility and configuration may be evaluated further following aquifer character assessment.

6.3 RECOMMENDED APPROACH

These recommendations have two objectives. First, the feasibility of NAPL recovery at its known extent should be evaluated and recovery actions implemented. Second, the downgradient extent of both the NAPL and dissolved plumes should be characterized in order to develop the long-term, overall remedial action plan for the site.

The first step in achieving these objectives is the Well Recovery Pilot Program. Assuming the pilot study leads to implementation of an interim (possibly long-term) pumping system, attention would then be directed to
the second objective. In the event the pilot study reveals less than desirable performance of the existing wells, the next step would be the evaluation of the feasibility of a trench recovery system.

Concurrent with the Well Recovery Pilot Program, the existing data for underground utilities would be evaluated and recommendations for test pit locations made if appropriate.

Upon completion of the pilot program and utility data evaluation, plans for the additional recovery and monitoring wells, and test pits, if appropriate, can be finalized. These actions, intended to further characterize the extent of contamination, could be initiated concurrent with either the implementation of the existing well recovery system or the evaluation of trench recovery feasibility.
REFERENCES


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<tr>
<td>NFFW-4</td>
<td>4</td>
<td>26</td>
<td>26-6</td>
<td>0.02</td>
<td>323.86</td>
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<td>NFFW-5</td>
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<td>316.88</td>
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<td>29</td>
<td>26-6</td>
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<td>319.62</td>
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<tr>
<td>NFFW-7</td>
<td>6</td>
<td>27</td>
<td>26-6</td>
<td>0.02</td>
<td>314.08</td>
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</table>

Note: All wells were completed with 2 ft of screen pack above the screened interval, 2 ft of bentonite pellets above the screen pack, and the remainder of the hole filled with cement grout. Protective steel casings are in place around the PVC riser stick-up of all wells.
<table>
<thead>
<tr>
<th>Sample Interval (ft)</th>
<th>NFFB</th>
<th>NFFW-1</th>
<th>NFFW-2</th>
<th>NFFW-3</th>
<th>NFFW-4</th>
<th>NFFW 5</th>
<th>NFFW-6</th>
<th>NFFW-7</th>
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<tbody>
<tr>
<td>1-2</td>
<td>70</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
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<td>0</td>
<td>96</td>
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<tr>
<td>2-4</td>
<td>120</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>55</td>
<td>4</td>
<td>64</td>
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<td>4-6</td>
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<td>6-8</td>
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<td>1</td>
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<td>8-10</td>
<td>60</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>24</td>
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<td>10-12</td>
<td>14</td>
<td>--</td>
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<td>--</td>
<td>0</td>
<td>--</td>
<td>--</td>
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<td>14-16</td>
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<td>--</td>
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<td>18-20</td>
<td>--</td>
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<td>--</td>
<td>--</td>
<td>0</td>
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</table>

(a) Total ionizable compounds detected in sample jar headspace by photoionization detector.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>NFPB-1</th>
<th>NFFW-5</th>
<th>NFFW-6</th>
<th>NFFW-7</th>
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</thead>
<tbody>
<tr>
<td>Total Petroleum Hydrocarbon</td>
<td>mg/kg</td>
<td>49</td>
<td>96</td>
<td>90</td>
<td>352</td>
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<tr>
<td>Total Organic Carbon</td>
<td>mg/kg</td>
<td>9,300</td>
<td>2,600</td>
<td>16,600</td>
<td>730</td>
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<tr>
<td>VOLATILE ORGANIC COMPOUNDS</td>
<td>µg/kg</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Methylene chloride</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2,300E</td>
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<tr>
<td>Acetone</td>
<td>42</td>
<td>120</td>
<td></td>
<td></td>
<td>190</td>
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<tr>
<td>4-methyl-2-pentanone</td>
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<td></td>
<td>29</td>
<td></td>
<td>88</td>
</tr>
<tr>
<td>2-butane</td>
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<td></td>
<td></td>
<td>83</td>
<td>83</td>
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<tr>
<td>Toluene</td>
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<td>160</td>
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<td>Ethylbenzene</td>
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<td></td>
<td></td>
<td></td>
<td>1,500</td>
</tr>
<tr>
<td>Xylene (total)</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>TENTATIVELY IDENTIFIED VOLATILE</td>
<td>µg/kg</td>
<td>(1) 10J</td>
<td>(1)700J</td>
<td></td>
<td>(1)40J</td>
</tr>
<tr>
<td>ORGANIC COMPOUNDS</td>
<td></td>
<td>(3)320J</td>
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<td></td>
<td>(1)300J</td>
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<tr>
<td>2-propanone</td>
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<td></td>
<td></td>
<td>(1)200J</td>
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<tr>
<td>Octane, 2,5,6-trimethyl</td>
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<td></td>
<td></td>
<td>(1)300J</td>
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<tr>
<td>Hexane</td>
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<td></td>
<td></td>
<td></td>
<td>(1)500J</td>
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<tr>
<td>2-hexene, 2,3-dimethyl</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2-cyclopentan-1-one 3-amino</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Cyclohexane, 1-ethyl-4-methyl</td>
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<tr>
<td>Tricyclo [3.3.1.13.7] decane</td>
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<tr>
<td>Bycyclo [2.2.1]heptane, 2.2.3</td>
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<td>(2) 47</td>
<td>(8) 134</td>
<td>(2) 15</td>
<td>(7)4,170J</td>
</tr>
<tr>
<td>Unknown</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BASE/NEUTRAL EXTRACTABLE</td>
<td>µg/kg</td>
<td>(2) 47</td>
<td>(8) 134</td>
<td>(2) 15</td>
<td>(7)4,170J</td>
</tr>
<tr>
<td>ORGANIC COMPOUNDS</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naphthalene</td>
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<td></td>
<td></td>
<td></td>
<td>950J</td>
</tr>
<tr>
<td>Bis(2-ethylhexyl)phthalate</td>
<td></td>
<td></td>
<td></td>
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</table>

E = estimated concentration, above quantitation limit.
J = estimated concentration, below quantitation limits for TCL compounds or tentatively identified
( ) = numbers in parenthesis indicate numbers of compounds detected.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>NFFB-1</th>
<th>NFFW-5</th>
<th>NFFW-6</th>
<th>NFFW-7</th>
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</thead>
<tbody>
<tr>
<td><strong>TENTATIVELY IDENTIFIED BASE/NEUTRAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EXTRACTABLE ORGANIC COMPOUNDS</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cyclohexane, pentyl</td>
<td></td>
<td></td>
<td></td>
<td>(1) 990J</td>
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<tr>
<td>Dodecane</td>
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<td></td>
<td></td>
<td>(1) 5,400J</td>
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<tr>
<td>Undecane</td>
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<td>(1) 7,900J</td>
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<tr>
<td>Undecane, 2-methyl</td>
<td></td>
<td></td>
<td></td>
<td>(1) 990J</td>
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<tr>
<td>Undecane, 3,6-dimethyl</td>
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<td></td>
<td></td>
<td>(1) 2,300J</td>
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<tr>
<td>Pentane, 2,3,4-trimethyl</td>
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<td>(1) 3,100J</td>
<td>(1) 810J</td>
<td>(1) 1,000J</td>
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<tr>
<td>Propanoic acid, 2-methyl</td>
<td>(1) 850J</td>
<td>(1) 640J</td>
<td></td>
<td>(7) 21,670J</td>
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<tr>
<td>Hexadecanoic acid</td>
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<td></td>
<td>(1) 4,700J</td>
<td></td>
</tr>
<tr>
<td>Sulfur, mol.</td>
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<td></td>
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<td>(1) 1,000J</td>
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<td>Unknown cyclohexane</td>
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<td>(7) 21,670J</td>
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<tr>
<td>Unknown alkane</td>
<td>(3) 4,240J</td>
<td>(10) 32,180J</td>
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<td>(4) 5,080J</td>
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<td></td>
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<tr>
<td>Parameter</td>
<td>Units</td>
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<td>NFW-3</td>
<td>NFW-4</td>
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<tr>
<td>----------------------------------</td>
<td>-----------</td>
<td>-------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>Total Petroleum Hydrocarbon</td>
<td>mg/L</td>
<td>2.10</td>
<td>3.70</td>
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<tr>
<td>Total Organic Carbon</td>
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<td>VOLATILE ORGANIC COMPOUNDS</td>
<td>µg/L</td>
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<tr>
<td>Methylene Chloride</td>
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<td>5 UJ</td>
<td>1 UJ</td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td></td>
<td>11 UJ</td>
<td>13 UJ</td>
<td>10 UJ</td>
</tr>
<tr>
<td>1,1-Dichloroethane</td>
<td></td>
<td>3 J</td>
<td>1 J</td>
<td></td>
</tr>
<tr>
<td>1,1,1-Trichloroethane</td>
<td></td>
<td></td>
<td>4 J</td>
<td></td>
</tr>
<tr>
<td>Benzene</td>
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<td>3 J</td>
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<td>61 E</td>
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<td>220 E</td>
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<tr>
<td>TENTIATIVELY IDENTIFIED VOLATILE</td>
<td>µg/L</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORGANIC COMPOUNDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkane</td>
<td></td>
<td>(8) 960 J</td>
<td>(6) 968 J</td>
<td>(8) 1140 J</td>
</tr>
<tr>
<td>Cyclic</td>
<td></td>
<td>(1) 20 J</td>
<td>(2) 30 J</td>
<td>(1) 80 J</td>
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<tr>
<td>Hydrocarbon</td>
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</tr>
<tr>
<td>Unknown</td>
<td></td>
<td>(1) 20 J</td>
<td>(2) 17 J</td>
<td>(2) 11 J</td>
</tr>
</tbody>
</table>

U = undetected, sample data negated due to laboratory blank contamination.
B = detected in blank
J = estimated concentration, below quantitation limit for TCL compounds or tentatively identified
E = estimated concentration, above quantitation limit
() = number indicates number of compounds detected
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>NFFW-1</th>
<th>NFFW-2</th>
<th>NFFW-3&amp;4</th>
<th>NFFW-5</th>
<th>NFFW-6</th>
<th>NFFW-7</th>
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<tbody>
<tr>
<td>VOLATILE ORGANIC COMPOUNDS</td>
<td>ug/L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Chloroform</td>
<td></td>
<td></td>
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<td>3 J</td>
<td></td>
<td></td>
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<tr>
<td>Bromodichloromethane</td>
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<td></td>
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<td></td>
<td>4 J</td>
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<td>Dibromochloromethane</td>
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<td>5 J</td>
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<td></td>
<td>4 J</td>
</tr>
<tr>
<td>Bromoform</td>
<td></td>
<td>11</td>
<td>12</td>
<td></td>
<td>9</td>
<td>4 J</td>
<td>6</td>
</tr>
<tr>
<td>Tetrachloroethene</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1 J</td>
<td></td>
</tr>
</tbody>
</table>

J = estimated concentration, below quantitation limit or tentatively identified
Figure 2. Navy Fuel Farm well locations, depth to water and groundwater contours (2ft intervals).
Figure 3. Cross-section A - A', Navy Fuel Farm.
APPENDIX A

TEST BORING LOGS AND WELL COMPLETION DIAGRAMS
## LOG OF SOIL BORING

### IS LOVETON CIRCLE SPARKS, MARYLAND 21152

**Date:** 4/4/09  
**Completion Date:** 4/4/09

**Location:** NAS, Willow Grove  
**Job Number:** 10300.03  
**Client:** Northern Division, NAVFAC

**Drilling Method:** Mayhew 500, Air Rotary, 5 1/8 - 10 inch bit  
**Sampling Method:** Split Spoon, 300 lb hammer, 30 inch drop, variable spoon size, continuous sampling

### SURFACE CONDITIONS

<table>
<thead>
<tr>
<th>SOIL DESCRIPTION</th>
<th>Asbestos, level grade</th>
</tr>
</thead>
</table>

### SURFACE CONDITIONS

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>TIME</th>
<th>DEPTH</th>
<th>BLMNS/&quot;</th>
<th>PFFM</th>
<th>FEET</th>
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<tbody>
<tr>
<td>SS</td>
<td>24</td>
<td>9</td>
<td>1.5</td>
<td>20/13/12/25</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>20</td>
<td>2</td>
<td>12/6/8/9</td>
<td>120</td>
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<tr>
<td></td>
<td>24</td>
<td>18</td>
<td>3</td>
<td>5/3/7/7</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>24</td>
<td>4</td>
<td>3/5/6/7</td>
<td>35</td>
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<td></td>
<td>24</td>
<td>4</td>
<td>5 19.6</td>
<td>9/8/6/7</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>6</td>
<td>11</td>
<td>5/8/17/33</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>7</td>
<td>13</td>
<td>17/45/80</td>
<td>8</td>
</tr>
<tr>
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<td>14</td>
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<td></td>
<td>14</td>
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<td></td>
<td>15</td>
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<td>15</td>
</tr>
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<td></td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
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**TOTAL BORING DEPTH:** 13.5 feet

---

**GROUND-WATER DEPTH BELOW GRADE**

<table>
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<tr>
<th>AT COMPLETION</th>
<th>AFTER 6 HRS.</th>
<th>AFTER 24 HRS.</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT.</td>
<td>FT.</td>
<td>FT.</td>
</tr>
</tbody>
</table>

**SAMPLER TYPE**

- SS-DRIVEN SPLIT SPOON
- SH-PRESSED SHELBY TUBE
- SST-TURBO PISTON SAMPLER
- DEN-HONJIN CORE BARREL SAMPLER
- SPT-STANDARD PENETRATION TEST (ASTM D (356-84))
**LOG OF SOIL BORING**

**BORING NO. NFFW-1**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DRIVNRCV'D NO.</th>
<th>IDPTH</th>
<th>BLOWS/6&quot;</th>
<th>PID</th>
<th>DEPTH</th>
<th>LOG</th>
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<tr>
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<td>24</td>
<td>22</td>
<td>1</td>
<td>1</td>
<td>4/4/4/9</td>
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<tr>
<td>SS</td>
<td>24</td>
<td>24</td>
<td>2</td>
<td>3</td>
<td>7/9/11/13</td>
<td>0</td>
</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>12</td>
<td>3</td>
<td>5.5</td>
<td>11/17/25/31</td>
<td>0</td>
</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>2</td>
<td>4</td>
<td>17.8</td>
<td>21/17/29/41</td>
<td>0</td>
</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>12</td>
<td>5</td>
<td>9.5</td>
<td>12/17/23/64</td>
<td>0</td>
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</tbody>
</table>

**SOIL DESCRIPTION**

- **CL**: Mottled grayish-brown, moist, sandy clay, with a little gravel, CL, medium stiff
- **CL**: Dark brown, moist, silty clay, SC, stiff
- **CL**: Orange-brown, dry, silty clay, with fragments of red ss, CL, very stiff
- **SC**: Reddish-brown, dry, clayey, mg sand with some silt, SC, very dense sandstone/shale saponite
- **SP**: Tan-cream, dry mg sand with fragments of cream ss, SP, dense
- **SS**: Tan-cream fg-mg sandstone, very hard
- **Water first noted at 12 feet**
- **Stable water level at 11.75 feet below ground, 1530, 4/4/89**

**SAMPLER TYPE**

- SS-DRIVEN SPLIT SPOON
- SH-PRESSED SHELBY TUBE
- OST-OSTENBURG PISTON SAMPLER
- DEN-DENISON CORE BARREL SAMPLER
- SPT-STANDARD PENETRATION TEST (ASTM D 1586-84)

**GROUND-WATER DEPTH BELOW GRADE**

- AT COMPLETION: FT.
- AFTER 24 HRS: FT.
NFFW-1
WELL COMPLETION DIAGRAM

Reference Elevation
311.18 ft

Concrete Pad

Cement Grout Surface - 3 ft.

Bentonite Pellets 3-5 ft.

4-in. Sch. 40 PVC Casing, Surface to 7 ft.

Sand Pack (No. 2 Sand) from 5-27 ft.

Sch. 40 PVC Screen, 4-in. I.D.: 0.02 in. Slot 7-27 ft.

Sch. 40 PVC Cap (Threaded) at 27 ft.

8-in. Borehole
# LOG OF SOIL BORING

**IS LOVETON CIRCLE**

**SPARKS, MARYLAND 21152**

**TELE: 301-771-4950**

**RUNNING NO.** NFFW-2

**Coordinates:**

**Surface Elevation:** 312.60

**Casing Above Surface:** 315.48

**Reference Elevation:** 315.04

**Reference Description:** Top of PVC

**Start Date:** 4/04/89

**Completion Date:** 4/04/89

**Location:** NAS, WILLOW GROVE

**Job No.** 10338.03

**Client:** NORTHERN COMMAND, NAIFAC

**Drilling Method:** MATHEN 500 AIR ROTARY, 5 1/8, 8 IN. BIT

**Sampling Method:** SS, 300 LBS., 30" DROP

## SOIL DESCRIPTION

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Depth (Feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample 1</td>
<td>0</td>
<td>WET GRAVEL FILL AT TOP</td>
</tr>
<tr>
<td>Sample 2</td>
<td>1</td>
<td>MOTTLED OR. BRN. BANDY CLAY, MOIST, FRAG. OF RED SS, VERY STIFF, LOW PLAS.</td>
</tr>
<tr>
<td>Sample 3</td>
<td>2</td>
<td>MED. OR. BRN. SILITY CLAY, MOIST, VERY STIFF, MED. PLAS.</td>
</tr>
<tr>
<td>Sample 4</td>
<td>3</td>
<td>MED. RED CLAYEY SILT, DRY, VERY STIFF, SLIGHTLY PLAS.</td>
</tr>
<tr>
<td>Sample 5</td>
<td>4</td>
<td>DK. RED SILTY SAND WITH A LITTLE CLAY, DRY, WEATHERED SS/SILTST. SAPROLITE, MED. DENSE</td>
</tr>
<tr>
<td>Sample 6</td>
<td>5</td>
<td>DK. RED SILTY VFG-VG SAND, DRY, MED. DENSE</td>
</tr>
<tr>
<td>Sample 7</td>
<td>6</td>
<td>DK. RED-PURPLE MICACEOUS CG SAND, WEATHERED SS SAPROLITE, DRY, SOME CLAY AT BASE, MED. DENSE</td>
</tr>
<tr>
<td>Sample 8</td>
<td>7</td>
<td>LARGE FRAGS. OF RED SS, DENSE</td>
</tr>
<tr>
<td>Sample 9</td>
<td>8</td>
<td>DK. RED SILSTONE, UNWEATHERED</td>
</tr>
</tbody>
</table>

**OIL/FUEL ON BIT, PROBABLY NAIFL, STOPPED DRILLING**

## GROUND-WATER DEPTH BELOW GRADE

**At Completion:** 250 FT.

**After 24 HRS.:** 20 FT.
NFFW-2
WELL COMPLETION DIAGRAM

Reference Elevation 315.04 ft

Depth (ft)

-0
-3
-6
-9
-12
-15
-18
-21
-24
-27

6-in. Steel Casing Locking Cap
Concrete Pad
Cement Grout Surface - 3 ft.
Bentonite Pellets 3-5 ft.
4-in. Sch. 40 PVC Casing, Surface to 7 ft.

Sand Pack (No. 2 Sand) from 5-27 ft.

Sch. 40 PVC Screen, 4-in. I.D.: 0.02 in. Slot 7-27 ft.

Sch. 40 PVC Cap (Threaded) at 27 ft.

8-in. Borehole

Silty Sand

Siltstone

SS Saprolite SP

Clayey Silt ML

Silty Clay CL

Sandy Clay CL

Water Level V V

Depth (ft)

-0
-3
-6
-9
-12
-15
-18
-21
-24
-27

6-in. Steel Casing Locking Cap
Concrete Pad
Cement Grout Surface - 3 ft.
Bentonite Pellets 3-5 ft.
4-in. Sch. 40 PVC Casing, Surface to 7 ft.

Sand Pack (No. 2 Sand) from 5-27 ft.

Sch. 40 PVC Screen, 4-in. I.D.: 0.02 in. Slot 7-27 ft.

Sch. 40 PVC Cap (Threaded) at 27 ft.

8-in. Borehole

Silty Sand

Siltstone

SS Saprolite SP

Clayey Silt ML

Silty Clay CL

Sandy Clay CL

Reference Elevation 315.04 ft

Depth (ft)
# Log of Soil Boring

**15 Loveton Circle**  
**Sparks, Maryland 21152**  
**Tele: 301-771-4950**

**Boring No.: NFFW-3**  
**Location:** NAS, Willow Grove  
**Job No.: 10388.03**  
**Client:** Northern Division, NAVFAC  
**Drilling Method:** MARIO 500 Air & Water Rotary  
**Sampling Method:** SS, 300 lb hammer, 30° Drop

**Start Date:** 4/10/89  
**Completion Date:** 4/10/89

<table>
<thead>
<tr>
<th>Sample</th>
<th>Blow/6&quot;</th>
<th>Ppm</th>
<th>Depth</th>
<th>Log</th>
<th>Surface Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS 24</td>
<td>1 4-6-5-5</td>
<td>0</td>
<td>CL</td>
<td>TAN SILTY CLAY, MOIST, ASPHALT FILL NOTED IN UPPER HALF (DK. GRN, SILTY CLAY, ROOTED) TOP SOIL MD. STIFF, MED. PLAS.</td>
<td></td>
</tr>
<tr>
<td>SS 24</td>
<td>2 3 5-5-8-10</td>
<td>0</td>
<td>CL</td>
<td>MOTTLED OR. GR. GRAY WITH IRON STAINED ZONES (4&quot; AT TOP) SILTY CLAY, MOIST, SAND IN IRON STAINED PORTION, MED. PLAS.</td>
<td></td>
</tr>
<tr>
<td>SS 24</td>
<td>3 5 7-9-8-9</td>
<td>0 5</td>
<td>CL</td>
<td>DK. RED SANDY CLAY, DRY, WEATHERED SS/SILTST., MICACEOUS, SMALL SS FRAG. V. STIFF, LOW PLAS.</td>
<td></td>
</tr>
<tr>
<td>SS 24</td>
<td>4 7 6-9-9-9</td>
<td>0</td>
<td>CL</td>
<td>DK. RED SILTY CLAY, MOIST, WEATHERED SILTST./SHALE MICACEOUS, VERY STIFF, LOW PLAS.</td>
<td></td>
</tr>
<tr>
<td>SS 24</td>
<td>5 9 4-5-8-15</td>
<td>0</td>
<td>CL</td>
<td>DK. RED SANDY CLAY, DRY, V. STIFF, WEATHERED SS/SILTST., MED. PLAS.</td>
<td></td>
</tr>
<tr>
<td>SS 24</td>
<td>6 11 5-6-14-29</td>
<td>10</td>
<td>CL</td>
<td>WEATHERED RED SHALE/SILTST., DRY</td>
<td></td>
</tr>
<tr>
<td>SS 24</td>
<td>7 13 10-19-46-42</td>
<td>15</td>
<td>CL</td>
<td>FRESH RED SHALE/SILTSTONE, WATER AT BOTTOM OF SPOON</td>
<td></td>
</tr>
<tr>
<td><strong>20</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>DRILLING RATE SLOWS, PROBABLY TAN SS</td>
</tr>
</tbody>
</table>

**Sampler Type:** SS-Driven Split Spoon  
**Ground-Water Depth Below Grade:** At Completion: 0 ft.  
**Sample After 24 Hrs.:** 0 ft.
NFFW-3
WELL COMPLETION DIAGRAM

Reference Elevation
322.58 ft
1.58 ft

6-in. Steel Casing Locking Cap
Concrete Pad
Cement Grout
Surface - 3 ft.
Bentonite Pellets 3-5 ft.
4-in. Sch. 40 PVC Casing,
Surface to 6 ft.

Depth (ft)
0
-3
-6
-9
-12
-15
-18
-21
-24
-27

-0.02 in. Slot 6-26 ft.

Sand Pack (No. 2 Sand)
from 5-26 ft.

Water Level
Shale/Siltstone
Sandy Clay CL
Sandy Clay CL
Silty Clay, CL
Silty Clay CL

Sandstone

Sch. 40 PVC Screen, 4-in. I.D.:
8-in. Borehole

Sch. 40 PVC Cap
(Threaded) at 26 ft.
### EA ENGINEERING, SCIENCE, AND TECHNOLOGY

**LOG OF SOIL BORING**

15 LOVETON CIRCLE  
SPARKS, MARYLAND 21152  
**TELE:** 301-771-4950

**PORTING N.** MFFW-4

<table>
<thead>
<tr>
<th>Coordinates:</th>
<th>Location: NAS, WILLOW GROVE</th>
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</thead>
<tbody>
<tr>
<td>Surface Elevation: 321.61</td>
<td>Job No. 10386.03</td>
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<tr>
<td>Casing Above Surface: 324.14</td>
<td>Client: NORTHERN DIVISION, NAVFAC</td>
</tr>
<tr>
<td>Reference Elevation: 323.86</td>
<td>Drilling Method: MAYHEW 500 AIR &amp; WATER ROTARY, 5 1/8, 8 IN. BIT</td>
</tr>
<tr>
<td>Reference Description: TOP OF PVC</td>
<td>Sampling Method: SS, 300 LB HAMMER, 30° DROP</td>
</tr>
</tbody>
</table>

**Start Date:** 4/11/89  
**Completion Date:** 4/12/89

<table>
<thead>
<tr>
<th>SAMPLE IN (IN ISAMPSAMPLE)</th>
<th>BLDG/ft²</th>
<th>PID</th>
<th>DEPTH</th>
<th>ISAMPS</th>
<th>SURFACE CONDITIONS</th>
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</thead>
<tbody>
<tr>
<td>SS 24 24 1 1</td>
<td>17-5-6-7</td>
<td>0</td>
<td>ML</td>
<td>DK, BRN, CLAYEY SILT WITH ACQVALT SILT, MOIST GRADING INTO MED. OR SANDY CLAY, STIFF</td>
<td></td>
</tr>
<tr>
<td>SS 24 20 2 3</td>
<td>13-3-3-3</td>
<td>0</td>
<td>CL</td>
<td>MED. OR SANDY CLAY, MOIST, SOME WATER ON SURFACE MED. STIFF, MED. PLAS.</td>
<td></td>
</tr>
<tr>
<td>SS 24 24 3 5</td>
<td>3-3-3-3</td>
<td>0</td>
<td>SC</td>
<td>OR-TAN CLAYEY CB SAND AT TOP GRADING INTO GRAY-GRN, SANDY CLAY WITH GRAY SHALE FRAGS AT BASE, DRY, STIFF, MED. PLAS.</td>
<td></td>
</tr>
<tr>
<td>SS 24 16 4 7</td>
<td>12-15-12-17</td>
<td>0</td>
<td>CL</td>
<td>WEATHERED RED SHALE AND SILTSTONE, MICACEOUS, DRY, POORLY PRESERVED LAMINAE</td>
<td></td>
</tr>
<tr>
<td>SS 24 14 5 9</td>
<td>11-7-11-17</td>
<td>0</td>
<td></td>
<td>WEATHERED RED SHALE AND SILTSTONE, MICACEOUS, DRY</td>
<td></td>
</tr>
<tr>
<td>SS 24 22 6 11</td>
<td>19-11-9-13</td>
<td>0</td>
<td>10</td>
<td>WEATHERED TO A CLAYEY SILT, DRY, CRUMBLY</td>
<td></td>
</tr>
<tr>
<td>SS 24 22 7 13</td>
<td>18-10-12-17</td>
<td>0</td>
<td></td>
<td>RED WEATHERED FB SS, WEATHERS TO A SILTY SAND WITH A LITTLE CLAY, DRY, CRUMBLY</td>
<td></td>
</tr>
<tr>
<td>SS 24 12 8 15</td>
<td>13-17-13-14</td>
<td>0</td>
<td>15</td>
<td>WEATHERED RED SHALE/SILTSTONE, WEATHERS TO A CLAYEY SILT, DRY, MICACEOUS</td>
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<tr>
<td>SS 24 6 9 17</td>
<td>15-16-24-29</td>
<td>0</td>
<td></td>
<td>WEATHERED RED SHALE AND SILTSTONE, WET WEATHERS TO A CLAYEY SILT, MICACEOUS, SPOON GOT STUCK ON LAST SAMPLE DUE TO WATER SUCTION</td>
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</tr>
<tr>
<td>SS 24 10 19 19-24-26</td>
<td>0</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**SAMPLER TYPE**

- SS-DRIVEN SPLIT SPOON
- SH-PRESSED SHELBY TUBE
- OST-OSTENBURG PISTON SAMPLER
- DEN-DENTSON CORE BARREL SAMPLER
- SPT-STANDARD PENETRATION TEST (ASTM D 1586-64)

**GROUND-WATER DEPTH BELOW GRADE**

- AT COMPLETION: FT.
- AFTER 24 HRS.: FT.
Reference Elevation - 323.86 ft.

Concrete Pad

Cement Grout
Surface - 3 ft.

Bentonite Pellets 3-5 ft.

4-in. Sch. 40 PVC Casing,
Surface to 6 ft.

Sand Pack (No. 2 Sand)
from 5-26 ft.

Sch. 40 PVC Screen, 4-in. L.D.:
0.02 in. Slot 6-26 ft.

Sch. 40 PVC Cap
(Threaded) at 26 ft.

8-in. Borehole
# LOG OF SOIL BORING

**15 LOVETON CIRCLE**

SPARKS, MARYLAND 21152

**TELE:** 301-771-4950

**BORING NO.** MFFW-5

**Location:** NAS, WILLOW GROVE

**Job No.** 10399.03

**Client:** NORTHERN DIVISION, NAVFAC

**Drilling Method:** MARVIN 500 AIR & WATER ROTARY, 5 1/6, 8, 10 IN. BIT

**Sampling Method:** SS, 300 LB HAMMER, 30° DROP

**Start Date:** 4/12/89

**Completion Date:** 4/12/89

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>IN</th>
<th>IN</th>
<th>SAMPLE</th>
<th>BLOWS/6&quot;</th>
<th>PPI</th>
<th>DEPTH</th>
<th>LOG</th>
<th>SURFACE CONDITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>24</td>
<td>20</td>
<td>1</td>
<td>17-13-5-7</td>
<td>5</td>
<td></td>
<td>X</td>
<td>LT. OR CG SAND WITH GRAVEL &amp; ASPHALT FILL (UPPER 6&quot;), DRY, MEDIUM DENSE</td>
</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>20</td>
<td>2</td>
<td>1:3-5-7</td>
<td>55</td>
<td></td>
<td>X</td>
<td>MED. OR. BRN. SILTY CLAY, MOIST, MED. STIFF, MED. PLAS.</td>
</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>8</td>
<td>3</td>
<td>15-6-7/750</td>
<td>40</td>
<td></td>
<td>X</td>
<td>MOTTLED OR. TAN SANDY CLAY, MOIST, CRUMBLY, STIFF, LOW PLAS.</td>
</tr>
</tbody>
</table>

**SOIL DESCRIPTION**

- BRN. SS, HARD

---

**SPRINGER TYPE**

- SS-DRIVEN SPLIT SPOON
- SH-PRESSED SHELBY TUBE
- UDST-OSTENBURG FISTON SAMPLER
- DEN-DEVISON CORE HAMMER SAMPLER
- SPT-STANDARD PENETRATION TEST (ASTM D 1586-84)

**GROUND-WATER DEPTH BELOW GRADE**

- AT COMPLETION
- AFTER HRS.
- AFTER 24 HRS.
- FT.
NFFW-5
WELL COMPLETION DIAGRAM

Reference Elevation 316.88 ft.

8 in. Steel Casing Locking Cap
Concrete Pad
Silty Clay CL
Sandy Clay CL
Sandstone

Cement Grout Surface - 3 ft.
Rentonite Pellets 3-5 ft.
6-in. Sch. 40 PVC Casing,
Surface to 6 ft.

Water Level \( \n\)

Sand Pack (No. 2 Sand)
from 5-26 ft.

Sch. 40 PVC Screen, 6-in. I.D.:
0.02 in. Slot 6-26 ft.

Sch. 40 PVC Cap
(Threaded) at 26 ft.

Cavings

10-in. Borehole

Depth (ft)
0
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30

1.77 ft
**LOG OF SOIL BORING**

- **BORING NO.:** NFWW-6
- **Coordinates:**
- **Surface Elevation:** 317.62
- **Casing Above Surface:** 320.08
- **Reference Elevation:** 319.62
- **Reference Description:** TOP OF PVC
- **Start Date:** 4/14/89
- **Location:** NAS, WILLOW GROVE
- **Job No.:** 10388.03
- **Client:** NORTHERN DIVISION, NAVFAC
- **Drilling Method:** MAYHEW 500 AIR ROTARY, 5" DIAMETER, 10" BIT
- **Sampling Method:** SS, 300 LB HAMMER, 30" DROP, SPOON SIZE VARIABLE, CONTINUOUS SAMPLING
- **Completion Date:** 4/14/89

<table>
<thead>
<tr>
<th>Sample</th>
<th>In</th>
<th>ft.</th>
<th>Sample</th>
<th>In</th>
<th>ft.</th>
<th>BLM2/ft.</th>
<th>PID</th>
<th>Depth</th>
<th>Graph</th>
<th>Surface Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>24</td>
<td>22</td>
<td>1</td>
<td>1</td>
<td>2-2-5-5</td>
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<td>X</td>
<td>4/2</td>
<td>MEDIUM ORANGE-BROWN, MOIST SILTY CLAY, MEDIUM STIFF MEDIUM PLASTICITY</td>
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</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>9-9-11</td>
<td>5/5</td>
<td>X</td>
<td>7/4</td>
<td>LIGHT ORANGE, DRY GRAVELLY SAND WITH FRAGMENTS OF TAN SS, MEDIUM DENSE</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>8</td>
<td>4</td>
<td>7.5</td>
<td>15-23-17</td>
<td>10/4</td>
<td>X</td>
<td>SP</td>
<td>LIGHT YELLOW-BROWN GRAVELLY SAND WITH LARGE (1&quot;) FRAGMENTS OF TAN SS, SAPPILITE, DENSE</td>
<td></td>
</tr>
<tr>
<td>SS</td>
<td>24</td>
<td>8</td>
<td>5</td>
<td>19-19-72/3&quot;</td>
<td>22</td>
<td>10</td>
<td>X</td>
<td>SP</td>
<td>MEDIUM REDISH-ORANGE, DRY CLAYFY SAND, DIRT, SAPPILITE, MED. DENSE</td>
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<td>LIGHT YELLOW GRAVELLY CSL SAND WITH FRAGMENTS OF LT. YELLOW SS, SAPPILITE, HARD ROCK</td>
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</tbody>
</table>

**SAMPLER TYPE**
- SS-DRIVEN SPLIT SPOON
- SH-FLUSHED SHELBY TUBE
- OST-OSTENBURG PISTON SAMPLER
- DEN-DEWISON CRETE BARREL SAMPLER
- SPT-STANDARD PENETRATION TEST (ASTM D 1586-64)

**GROUND WATER DEPTH BELOW GRADE**
- AT COMPLETION: 25 FT.

**PID 21', 25 PPM IN ROUGHFILL, 0-1 IN R7, 1442**
**DRILLED TO DEPTH OF 22', 0.22 FT OF NAPL AT 16.65', 1632**
NFFW-6
WELL COMPLETION DIAGRAM

Reference Elevation 319.62 ft.

8-in. Steel Casing Locking Cap
Concrete Pad
Cement Grout Surface - 3 ft.
Bentonite Pellets 3-5 ft.
6-in. Sch. 40 PVC Casing, Surface to 6 ft.

Silty Clay CL
Gravelly Sand SP
Clayey Sand SC
Sandstone

Water Level △ △

Sch. 40 PVC Screen, 6-in. I.D.: 0.02 in. Slot 6-26 ft.

Sch. 40 PVC Cap (Threaded) at 26 ft.
Cavings

10-in. Borehole

Depth (ft)

0
-3
-6
-9
-12
-15
-18
-21
-24
-27
-30
## Soil Conditions

### Surface Conditions
- Clay, moist
- Dark brown clay, moist
- Clays and claysols, moist, stiff
- Gray clay, stiff
- Clay, fine, stiff
- Clay, stiff

### Soil Description
- Clay, silty, trace to little gravel, soft
- Clay, silty, trace to little gravel, soft
- Clay, silty, trace to little gravel, soft
- Clay, silty, trace to little gravel, soft
- Clay, silty, trace to little gravel, soft
- Clay, silty, trace to little gravel, soft

### Calibrated PID 72 FPM/100 RPM at 0 Span

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**Sampler Type**
- SS-driven split spoon
- SH-pressed Shelby tube
- OST-DENVER Piston sampler
- DEN-KENTON core barrel sampler
- SPT-standard penetration test (ASTM D 1586-84)

**Ground-Water Depth Below Grade**
- After completion
- After 24 hrs.
NFFW-7
WELL COMPLETION DIAGRAM

Reference Elevation
314.08 ft.

8-in. Steel Casing Locking Cap
Concrete Pad
Cement Grout Surface - 3 ft.
Bentonite Pellets 3-5 ft.
6-in. Sch. 40 PVC Casing, Surface to 6 ft.

Water Level

Sandy Silt SM
Clayey Silt ML

Sandy Silt SM
Clayey Silt ML
Sandstone

Sand Pack (No. 2 Sand) from 5-26 ft.

Sch. 40 PVC Screen, 6-in. I.D.: 0.02 in. Slot 6-26 ft.

Sch. 40 PVC Cap (Threaded) at 26 ft.

10-in. Borehole

Depth (ft)
-30
-27
-24
-21
-18
-15
-12
-9
-6
-3
0