N00158.AR.000049
NAS WILLOW GROVE
5090.3a

FINAL

INTERIM REPORT ON INVESTIGATIONS AT THE NAVY FUEL FARM, NAS WILLOW GROVE, NOVEMBER 1990 - JULY 1991

Contract No. N62472-86-C-1037

Prepared for:

United States Navy
Northern Division
Naval Facilities Engineering Command
Philadelphia, Pennsylvania 19142-5094

Prepared by:

EA Mid-Atlantic Regional Operations
EA Engineering, Science, and Technology, Inc.
15 Loveton Circle
Sparks, Maryland 21152

November 1991

EA Project 10388.06

FINAL

INTERIM REPORT ON INVESTIGATIONS AT THE NAVY FUEL FARM, NAS WILLOW GROVE, NOVEMBER 1990 - JULY 1991

Contract No. N62472-86-C-1037

Prepared for:

United States Navy
Northern Division
Naval Facilities Engineering Command
Philadelphia, Pennsylvania 19142-5094

Prepared by:

EA Mid-Atlantic Regional Operations
EA Engineering, Science, and Technology, Inc.
15 Loveton Circle
Sparks, Maryland 21152

November 1991

EA Project 10388.06

CONTENTS

	Page
LIST OF FIGURES	
LIST OF TABLES	
1. INTRODUCTION	1-1
1.1 Site History	1-1
1.2 Scope of Work	1-1
2. SITE GEOLOGY	2-1
2.1 Soil	2-1
2.2 Geology	2-1
2.3 Hydrology	2-2
3. PREVIOUS INVESTIGATIONS	3-1
4. PRESENT INVESTIGATION	4-1
4.1 Well Installation and Sampling	4-1
4.2 Analytical Results	4-1
4.2.1 Soil	4-1
4.2.2 Ground Water	4-2
4.3 Pumping Tests	4-3
4.3.1 Purpose and Scope	4-3
4.3.2 Methods	4-4
4.3.3 Results	4-5
5. Summary and Conclusions	5-1
5.1 Analytical Data	5-1
5.2 Pumping Test Data	5-1
6. Recommendations	6-1
REFERENCES	
APPENDIX A: BORING LOGS AND WELL COMPLETION DIAGRAMS	

LIST OF FIGURES

Number	Title
1-1	Navy Fuel Farm Site Map.
2-1	Cross-Section A-A′, Navy Fuel Farm.
4-1	Navy Fuel Farm site map with geohydrology and well additions.
4-2	Drawdown contours for Pumping Test No. 1, NFFW-2.
4-3	Drawdown contours for Pumping Test No. 2, NFFW-2R.
4-4	Drawdown contours for Pumping Test No. 3, NFFW-14.
4-5	Drawdown contours for Pumping Test No. 4, NFFW-16.
4-6	Drawdown contours for Pumping Test No. 5, NFFW-8.
4-7	Drawdown contours for Pumping Test No. 6, NFFW-12.
4-8	Theis curve match for production well NFFW-12.
4-9	Theis curve match for observation well NFFW-2R.
4-10	Cooper-Jacob line match for production well NFFW-12.
4-11	Cooper-Jacob line match for observation well NFFW-2R.
4-12	Neuman curve match for production well NFFW-12.
6-1	Proposed new well locations for 4-in. monitoring wells.

LIST OF TABLES

Number	Title
4-1	Analytical results for soil samples.
4-2	Analytical results for samples of ground water from additional wells at Navy Fuel Farm.
4-3	Summary drawdown tables.
4-4	Production well drawdown data for NFFW-12 pumping test no. 6.
4-5	Observation well drawdown data for pumping test no. 6.
4-6	Hand-gauged data for pumping test no. 6, production well NFFW-12.
4-7	Production well analytical results.
4-8	Aquifer parameter estimation methods.

1. INTRODUCTION

1.1 SITE HISTORY

The Navy Fuel Farm is located along the north side of Privet Road and immediately south of the Air National Guard Facility (Figure 1-1). From 1950 to 1991, two partially buried 210,000-gal fuel JP-4/JP-5 aviation fuel tanks were located at the site. Subsequent to an excavation of a utility trench onsite in 1989, nonaqueous phase liquid (NAPL) was observed on top of the ditch water in the excavation trench. The area where the NAPL was noticed was immediately adjacent to the dry well. The dry well accepted the effluent water which was periodically siphoned from the bottom of the fuel tanks. Areas of dead grass were also observed west of Tank 115. With this evidence of tank leakage, it was decided to empty and remove the two main fuel tanks. Removal of these tanks began in the Spring of 1991 and is scheduled to be completed by Fall 1991. New above ground fuel storage tanks will be installed by the end of 1991 in the area due east of the previous tank location. Building 157 has been removed.

A 500-gal underground waste oil storage tank, which was previously used as a fuel tank, was present at the site but was removed in 1990. Upon removal it was discovered that the tank was not intact and may have leaked product. An underground diesel fuel tank in the southwest corner of the site was also excavated and removed at this time.

1.2 SCOPE OF WORK

The scope of work of this phase of the Navy Fuel Farm investigation included the installation and sampling of nine wells and the completion of six pumping tests. Three of the new wells were 6-in. wells designed to be product recovery wells, if possible. The remaining six wells were located at appropriate sites to assess the migration of the contaminant plume beneath the Navy Fuel Farm. The pumping tests were conducted to assess the feasibility of using selected wells as product recovery wells and to obtain an estimate of aquifer characteristics such as hydraulic

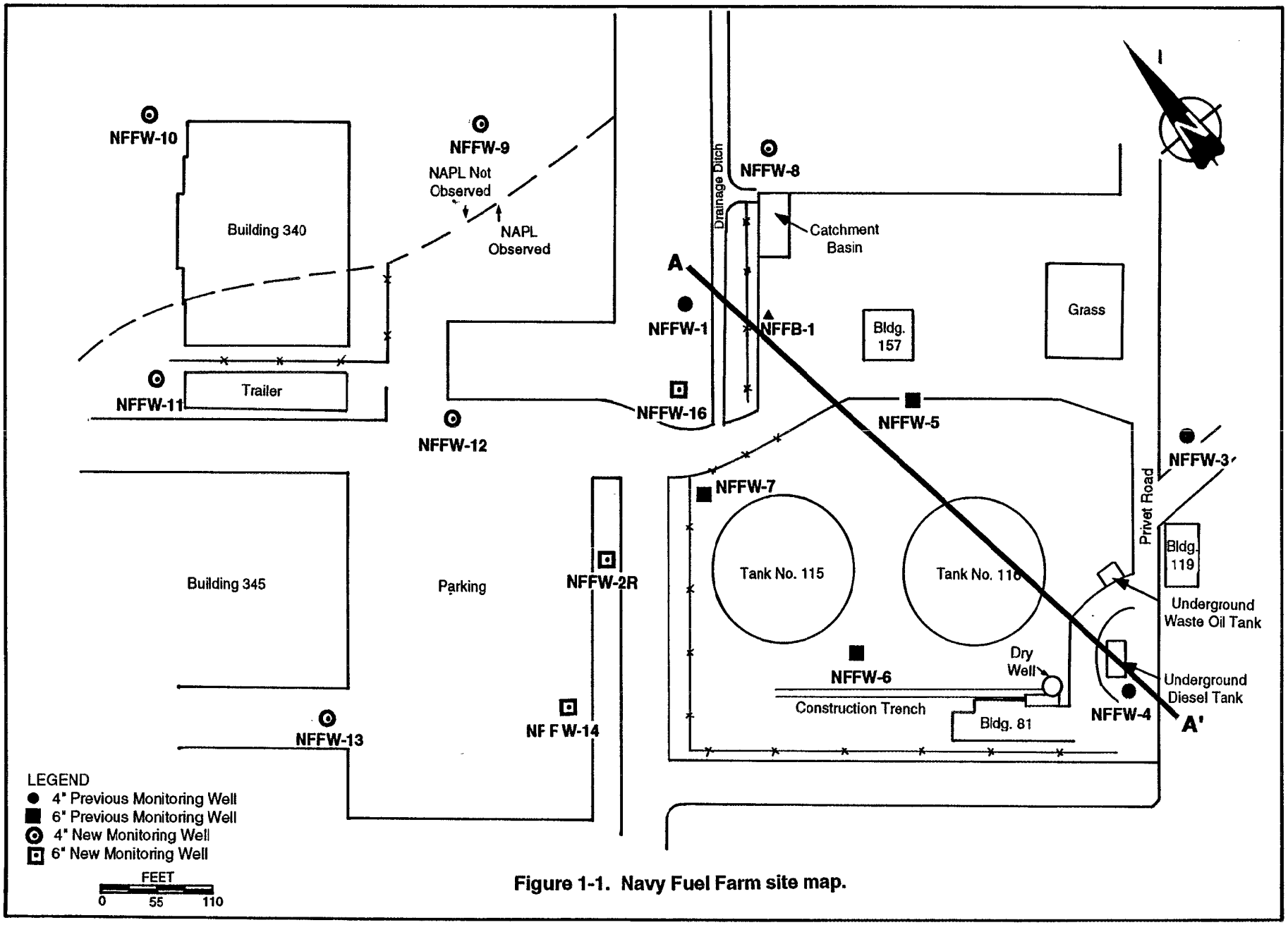


Figure 1-1. Navy Fuel Farm site map.

NOTE: The subsurface sections shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected.

conductivity and storativity. Based on the results of this work, further recommendations for plume delineation and site remediation are made in Chapter 4.

2. SITE GEOLOGY

2.1 SOIL

Soil cover varies in thickness over the site from 6 to 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 group "C" hydrologic soil. Typical permeability is in the range 0.04-0.2 in. per hour, while values for pH are reported in the range 4.5-6.5 (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.

2.2 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 to competent sandstone bedrock during site construction activities. Relict bedding structure is often present as a zone several ft thick and overlying shale or siltstone units. Regional dip ranges from 5 to 15 degrees to the north-northwest (Rima et al. 1962). Figure 2-1 illustrates the soil-bedrock contact, the distribution of shale and

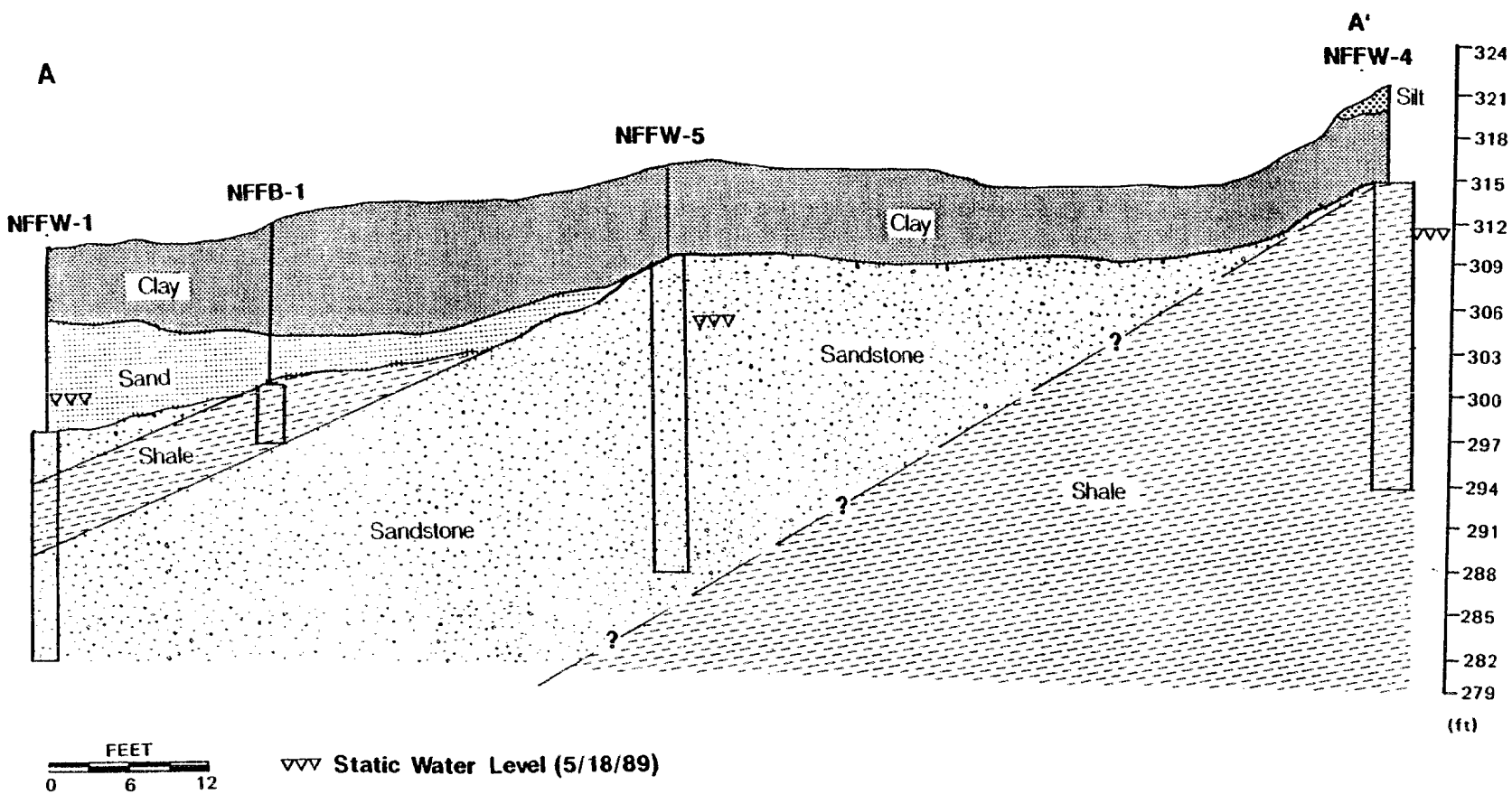


Figure 2-1. Cross-section A-A', Navy Fuel Farm.

NOTE: The subsurface sections shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected.

sandstone, and mean static water level as interpreted from the boring data. Beds vary laterally in thickness, often pinching out or grading into other facies. This makes prediction of lithologic occurrence difficult.

Regionally 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, trends northwest-southeast (Rima et al. 1962).

2.3 HYDROLOGY

The Middle Arkosic Member of the Stockton Formation is the most productive aquifer of the Stockton Formation. Reported yields range from 10 to 800 gpm with an average of 110 gpm. The average specific capacity is 3 gpm/ft of drawdown. Transmissivity values for this unit have been reported in the range 8,000-23,000 gpd/ft (Rima 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 presence of clay in the soil. The ground-water gradient under the site is in a northerly direction. However, because 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

brittle sandstone unit. Preferential movement through the arkosic sandstone units results in greater movement parallel rather than perpendicular to bedding, although local jointing and/or faulting may alter this trend. Static water levels not only reflect 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 show marked differences in nearby wells depending on the number and size of fractures intercepted by each well.

3. PREVIOUS INVESTIGATIONS

To assess the potential for soil and ground-water contamination, EA conducted a soil vapor survey of the site during November 1988 (EA 1989a). Based on these results, one test boring and additional monitoring wells were added to the original Site Inspection (SI) Plan of Action (EA 1988) to aid in interpretation of soil vapor anomalies and to detect possible sources of contamination both on and off the site. In March 1989, 18 borings were competed downgradient of the Navy Fuel Farm around Air National Guard 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 the water table using the air rotary drilling method. All boreholes were gauged with an interface probe to assess whether NAPL (i.e., floating product) was present. Soil samples were analyzed for total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene, and total xylenes (BTEX). Results indicated that a contaminant plume was migrating northwards from the Navy Fuel Farm toward the Air National Guard Facility. At that time the plume had advanced to the southwest corner of Building 340 (EA 1989b).

During the 1989 NAS Willow Grove SI field activities (EA 1990), a test boring (NFFB-1) was completed to the top of bedrock adjacent to the catchment basement northeast of Building 157. The water table was not encountered in this boring. A total of seven monitoring wells, four 4-in. wells and three 6-in. wells, were installed at the Navy Fuel Farm during this phase of work. Monitoring wells were screened 15 ft below and 5 ft above the water table.

One sample was selected from the test boring and each 6-in. well boring (NFFW-5, NFFW-6, NFFW-7) based on headspace screening with a photoionization detector (PID). The sample with the highest headspace reading was selected for analysis of volatile organic compounds (VOC), base/neutral extractable organic compounds (BN), total organic carbon (TOC), and TPH. All wells were gauged several times with an interface probe

to measure floating NAPL if present. Detection limits of the interface probe precluded measurement of NAPL less than 1/8 in. thick. NAPL was detected consistently in well NFFW-6 and irregularly in NFFW-7. A sheen was usually noted in well NFFW-1.

In June, September, and December 1989, the wells at the Navy Fuel Farm, which at the time of sampling did not contain floating NAPL, were sampled for laboratory analysis for VOC, TPH, and TOC. Well NFFW-6 was never sampled due to the presence of floating product.

Results from these sampling events showed that hydrocarbon contaminants were present in soil from NFFW-7. BTEX compounds were detected at levels exceeding applicable or relevant and appropriate requirements (ARARs) in wells NFFW-1, NFFW-2, and NFFW-7. Trichloroethene (TCE) and methyl ethyl ketone (MEK) were also detected, predominantly in wells NFFW-2 and NFFW-7 during one or more rounds of sampling. Only trace levels of benzene and unknown alkanes were present in well NFFW-5.

4. PRESENT INVESTIGATIONS

4.1 WELL INSTALLATION AND SAMPLING

Between 23 and 29 April 1991, EA installed three 6-in. and six 4-in. monitoring wells at the locations shown in Figure 4-1. One of the 6-in. wells, NFFW-2R, was a replacement for well NFFW-2. All 4-in. well boreholes were sampled continuously to bedrock. Soil samples with the highest headspace readings were submitted for analysis of BTEX compounds. The boring was continued into bedrock using a 10-in. or 8-in. diameter air hammer until a depth of 10 ft below static water level, nominally 25 ft, in the 4-in. wells was reached or a nominal depth of 38-40 ft in the case of 6-in. wells. The 6-in. wells were drilled to greater depths to facilitate their use as recovery wells if product was subsequently detected. Boring logs and well construction diagrams for these wells are provided in Appendix A.

On 16 May 1991 all new wells were sampled for TCL, VOCs, and BNs except for wells NFFW-8 and NFFW-14, which had floating product.

4.2 ANALYTICAL RESULTS

Results of soil and ground-water analyses are shown in Tables 4-1 and 4-2.

4.2.1 Soil

Two soil samples contained detectable hydrocarbons. Soil from NFFW-11 contained only trace amounts of BTEX compounds. Elevated levels of heavier fraction BTEX compounds were detected in the soil sample from NFFW-8. The sample was taken at a depth of 5 ft. The increase in concentration of the heavier fraction compounds suggest that the contamination is old and has been subjected to weathering. Organic vapor readings taken during drilling detected no organic vapors at shallow

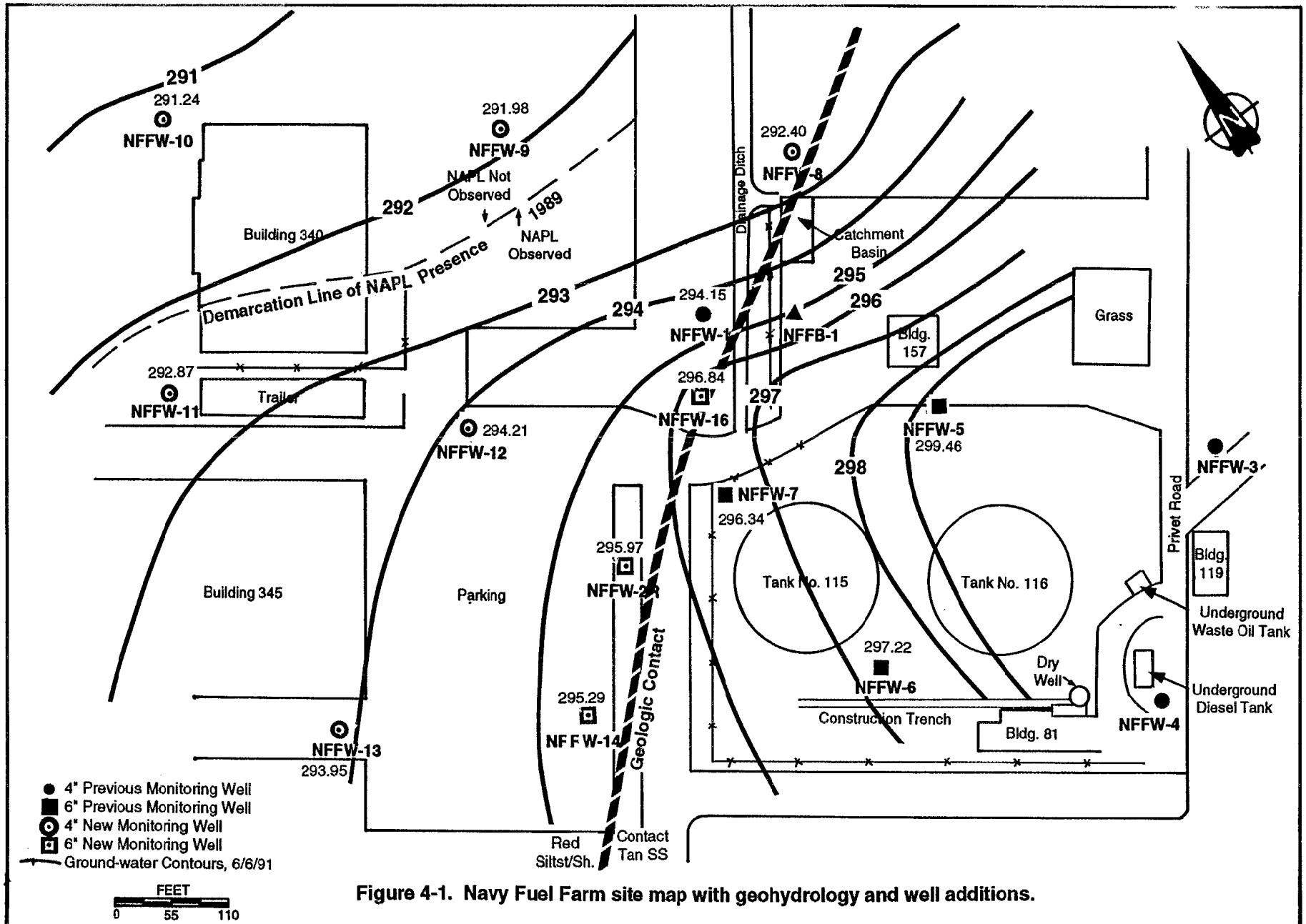


Figure 4-1. Navy Fuel Farm site map with geohydrology and well additions.

NOTE: The subsurface contours shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected

TABLE 4-1 ANAYTICAL RESULTS FOR SOIL SAMPLES

Parameter (mg/kg)	NFFW-8	NFFW-9	NFFW-10	NFFW-11	NFFW-12
BTEX, total	335	U	U	23	ND
Benzene	U	U	U	U	ND
Toluene	6	U	U	13	ND
Ethylbenzene	39	U	U	6	ND
Meta- and Para-Xylene	160	U	U	2	ND
Ortho-Xylene	130	U	U	2	ND
Sample Depth	5.0 ft	5.0 ft	2.5 ft	10.0 ft	10.0 ft

Note:
(1) Trip blank had no detections.
(2) Rinsate blank had no detections.
(3) 6-in. wells were not sampled for BTEX in soil.

TABLE 4-2 ANALYTICAL RESULTS FOR SAMPLES OF GROUND WATER FROM ADDITIONAL WELLS AT NAVY FUEL FARM

Parameter	NFFW-9	NFFW-10	NFFW-11[2]	NFFW-12[2]	NFFW-13	NFFW-16[2]	Duplicate[2]
VOC							
Acetone	130[1]B	12B	1400B	1900B	825[1]	2300B	270JB
1,1 Dichloroethane	2J	--	--	--	2J	--	--
1,2 Dichloroethene (tot)	--	--	--	--	--	--	--
MEK	415[1]	--	2600	3200	2650[1]	3800	5600
TCE	--	--	--	--	10	--	--
Benzene	63	--	--	--	40	990	1100
Toluene	--	--	--	--	10	85J	250J
Ethylbenzene	10	--	200J	300J	285[1]	350	650
Xylene	--	--	--	--	420	510J	1100
1,2, Dichloroethane	--	--	130JB	110JB	--	--	--
4-Methyl, 1-2-pentanone	--	--	--	2000	--	--	--
BN							
Napthalene	1J	--	170	110	48	120	110
2-Methylnapthalene	--	--	220	94	96	140	170E
Fluorene	--	--	5J	1J	2J	2J	3J
Bis (2-Ethylhexyl phthalate)	3J	--	240	25	51	170E	150
Dibenzofuran	--	--	3J	1J	--	2J	3J
Di-n-octylphthalate	--	--	--	--	--	--	4J

Note: Wells NFFW-8 and 15 not sampled due to presence of NAPL.
1-Average value between normal and diluted runs.
2-Diluted run only for VOCs.
J-Estimated, below quantitation limit.
E-Estimated, above quantitation limit.
B-Compound detected in Method blank.

depths, but did detect organic vapors once the water table was encountered. This implies that the soil contamination detected in the 5-ft sample may be the remnant of product left adhered to soil at this depth during a period of elevated water table in the past.

4.2.2 Ground Water

Volatile Organic Compounds

The analytical data from the wells displayed evidence of hydrocarbon contamination except for well NFFW-10. The primary contaminants detected were acetone, benzene, ethylbenzene, xylene, and MEK. TCE was detected at 10 µg/L in one well, NFFW-13. Acetone was detected in the method blank at 14 µg/L, but levels were high enough in the samples to preclude lab contamination as the major source of the acetone detected. All of these compounds have been detected during various rounds of sampling in the previously installed Navy Fuel Farm wells, mostly in NFFW-1, NFFW-2, and NFFW-7. The BTEX compounds are indicative of a fuel contamination plume presumably emanating from the two main fuel tanks. MEK and TCE have only been detected in wells north of the boundary ditch located between the Navy and Air National Guard portions of the installation. This distribution suggests that the source for the compounds may be from spills channeled into the ditch or past storage of these compounds in the area where the north gate to the Navy Fuel Farm is currently located. Building 340 of the Air National Guard facility appears to be another possible source of these compounds.

Base/Neutral Extractable Organic Compounds

BNs were detected in all wells sampled except well NFFW-10. Only trace amounts of BNs were detected in well NFFW-9 but elevated levels of napthalene (48-170 µg/L) and 2-methyl napthalene (94-220 µg/L) were detected in the remaining wells NFFW-11, NFFW-12, NFFW-13, and NFFW-16. Comparison of these results with previous wells at the Navy Fuel Farm is not possible as the previous wells were never sampled for these

parameters. A soil sample from well NFFW-7's borehole contained 950 µg/kg of naphthalane.

The most recent round of data suggests that the contaminant plume has not migrated beyond Building 340 to the north, but the plume migration to the northwest and northeast has been further than previously suspected.

4.3 PUMPING TESTS

4.3.1 Purpose and Scope

The purpose of pumping tests at the Navy Fuel Farm during this phase of the investigation was two-fold. First, by pumping various wells and observing the amount of product recovered in the pumped well, an assessment of the potential for utilizing monitoring wells as recovery wells could be made. To accomplish this task, five 48-hour pumping tests were performed on wells 2, 2R, 14, 16, and 8 during which a product recovery system was placed in the pumped well to remove any accumulated product. Water levels in the closest monitoring wells were recorded with electronic water level recorders while those wells located further away were monitored by hand. Water level fluctuations in these wells provided an indication of fracture orientation and interconnectedness relative to the pumping, as well as an estimate of the pumped well's zone of influence. Pumping rate varied during these tests depending on product recovery. Summary drawdown tables for each of the pumping tests are presented in Table 4-3. Due to low yields, variable pumping rates, and recharge due to rain events, drawdown data from the 48-hour pump tests were (as anticipated) deemed not adequate to analyze for aquifer characteristics.

A 72-hour pumping test was performed on well NFFW-12 to assess aquifer characteristics of the underlying fractured bedrock aquifer. Pumping rates during this test were held constant. Detailed drawdown data tables for all wells monitored during the 72-hour pumping test are compiled in Tables 4-4, 4-5, and 4-6.

TABLE 4-3 SUMMARY DRAWDOWN DATA

Wells	TOC Elevation	Test #1 Static	Test #1 Total Drawdown	Test #2 Static	Test #2 Total Drawdown	Test #3 Static	Test #3 Total Drawdown	Test #4 Static	Test #4 Total Drawdown	Test #5 Static	Test #5 Total Drawdown	Test #6 Static	Test #6 Total Drawdown
1	309.84	17.48	-0.19	15.69	-0.19	16.20	-0.26	16.72	-1.08	10.49	+0.11	17.59	-0.15
2		22.90	-3.63										
2R	313.15	--	--	17.18	-6.27	19.40	-0.45	20.35	-0.15	20.61	-0.20	22.36	-1.25
5	315.54	19.03	-0.34	16.08	-0.40	(1)	(1)	17.96	+0.34	17.96	-0.19	19.11	-0.27
6	318.28	23.77	-0.29	21.06	-0.34	21.68	-0.32	22.49	+0.09	22.69	-0.06	23.85	-0.25
7	312.74	19.62	-0.38	16.40	-0.76	17.23	-0.25	18.39	-1.01	18.75	+0.03	19.73	-0.30
8	308.07	--	--	15.67	-0.18	16.15	-0.23	16.78	+0.15	16.95	-7.73	18.11	-0.22
9	298.61	--	--	6.63	-0.14	7.13	-0.29	7.72	+0.28	7.78	-4.73	8.88	-0.22
10	299.27	--	--	8.03	-0.33	8.84	-0.13	9.34	+0.30	9.30	-0.23	10.21	-0.35
11	301.76	--	--	8.89	-0.21	9.43	-0.27	10.08	+0.12	10.24	-0.09	10.83	-0.25
12	307.60	--	--	13.39	-0.34	13.12	+0.08	14.86	+0.02	15.06	-0.14	16.13	4.22
13	305.36	--	--	11.41	-0.97	12.84	-0.40	13.76	+0.11	13.92	-0.19	15.18	-0.34
14	311.64	--	--	16.35	-0.46	16.77	-0.32	18.18	-0.03	18.18	-0.09	19.46	-0.08
16	311.18	--	--	14.34	-0.06	16.31	+0.02	11.33	-6.63	9.64	+0.14	18.21	-0.27

(1) Not measured due to construction activities.
(2) Transducer cable destroyed by truck.

TABLE 4-4. PUMPING WELL DRAWDOWN DATA FOR NFFW-12 - PUMPING TEST NO. 6

Production Well	NFFW-12	
Time (min)	Water Level (ft)	Column Change (ft)
0.00	16.13	1.12
0.50	17.25	1.14
1.00	17.28	1.32
1.50	17.45	1.25
2.00	17.38	1.32
2.50	17.45	1.41
3.00	17.54	1.51
3.50	17.64	1.55
4.00	17.68	1.61
4.50	17.74	1.66
5.00	17.79	1.77
6.00	17.90	1.87
7.00	18.00	1.97
8.00	18.10	2.07
9.00	18.20	2.17
10.00	18.30	2.37
20.00	18.50	2.39
30.00	18.52	2.39
40.00	18.52	2.39
50.00	18.52	2.52
60.00	18.65	2.80
120.00	18.93	2.86
180.00	18.99	3.05
240.00	19.18	3.30
300.00	19.43	3.32
360.00	19.45	3.41
420.00	19.54	3.39
480.00	19.52	3.37
540.00	19.50	3.36
600.00	19.49	3.50
720.00	19.63	3.67
840.00	19.80	3.75
960.00	19.88	3.78
1080.00	19.91	3.80
1200.00	19.93	3.78
1320.00	19.91	3.80
1440.00	19.93	3.82
1560.00	19.95	3.86
1680.00	19.99	3.89
1800.00	20.02	3.90
1920.00	20.03	3.90
2040.00	20.03	3.90
2160.00	20.03	3.94
2280.00	20.07	3.97
2400.00	20.10	3.95
2520.00	20.08	3.95
2640.00	20.08	3.93
2760.00	20.06	3.91
2880.00	20.04	3.98
3000.00	20.11	4.15
3120.00	20.28	4.15
3240.00	20.28	4.37
3360.00	20.50	4.14
3480.00	20.27	4.14
3600.00	20.27	4.12
3720.00	20.25	4.17
3840.00	20.30	4.17
3960.00	20.30	4.22
4080.00	20.35	4.19
4200.00	20.32	4.20
4320.00	20.33	4.20

Table 4-5. OBSERVATION WELL DRAWDOWN DATA FOR PUMPING TEST NO. 6

Monitoring Wells	NFFW-7		NFFW-9		NFFW-16	
Time (min)	Water Level (ft)	Column Change (ft)	Water Level (ft)	Column Change (ft)	Water Level (ft)	Column Change (ft)
0.00	19.81	0.00	16.96	0.00	18.40	0.00
0.50	19.81	0.00	16.95	-0.01	18.40	0.00
1.00	19.81	0.00	16.95	-0.01	18.39	-0.01
1.50	19.82	0.01	16.96	0.00	18.39	-0.01
2.00	19.82	0.01	16.95	-0.01	18.37	-0.03
2.50	19.83	0.02	16.96	0.00	18.39	-0.01
3.00	19.81	0.00	16.96	0.00	18.40	0.00
3.50	19.84	0.03	16.96	0.00	18.39	-0.01
4.00	19.84	0.03	16.97	0.01	18.39	-0.01
4.50	19.83	0.02	16.96	0.00	18.42	0.02
5.00	19.82	0.01	16.96	0.00	18.40	0.00
6.00	19.82	0.01	16.97	0.01	18.39	-0.01
7.00	19.81	0.00	16.94	-0.02	18.39	-0.01
8.00	19.76	-0.05	16.95	-0.01	18.37	-0.03
9.00	19.76	-0.05	16.92	-0.04	18.39	-0.01
10.00	19.81	0.00	16.95	-0.01	18.39	-0.01
20.00	19.81	0.00	16.96	0.00	18.39	-0.01
30.00	19.82	0.01	16.97	0.01	18.42	0.02
40.00	19.82	0.01	16.97	0.01	18.40	0.00
50.00	19.80	-0.01	16.96	0.00	18.42	0.02
60.00	19.81	0.00	16.96	0.00	18.42	0.02
120.00	19.83	0.02	16.96	0.00	18.44	0.04
180.00	19.81	0.00	16.97	0.01	18.48	0.08
240.00	19.82	0.01	16.98	0.02	18.47	0.07
300.00	19.82	0.01	16.98	0.02	18.49	0.09
360.00	19.82	0.01	16.99	0.03	18.50	0.10
420.00	19.83	0.02	16.99	0.03	18.58	0.18
480.00	19.84	0.03	16.99	0.03	18.55	0.15
540.00	19.84	0.03	16.99	0.03	18.59	0.19
600.00	19.84	0.03	16.99	0.03	18.55	0.15
660.00	19.84	0.03	17.00	0.04	18.58	0.18
720.00	19.84	0.03	17.00	0.04	18.58	0.18
780.00	19.83	0.02	17.00	0.04	18.59	0.19
840.00	19.83	0.02	17.01	0.05	18.64	0.24
900.00	19.85	0.04	17.01	0.05	18.61	0.21
960.00	19.86	0.05	17.01	0.05	18.67	0.27
1000.00	19.86	0.05	17.01	0.05	18.64	0.24
1100.00	19.87	0.06	17.02	0.06	18.56	0.16
1200.00	19.89	0.08	17.02	0.06	18.59	0.19
1300.00	19.89	0.08	17.01	0.05	18.55	0.15
1400.00	19.87	0.06	17.01	0.05	18.51	0.11
1500.00	19.86	0.05	17.00	0.04	18.50	0.10
1600.00	19.88	0.07	17.01	0.05	18.55	0.15
1700.00	19.87	0.06	17.01	0.05	18.59	0.19
1800.00	19.90	0.09	17.02	0.06	18.59	0.19
1900.00	19.91	0.10	17.02	0.06	18.62	0.22
2000.00	19.93	0.12	17.02	0.06	18.61	0.21
2100.00	19.93	0.12	17.02	0.06	18.61	0.21
2200.00	19.93	0.12	17.03	0.07	18.64	0.24
2300.00	19.94	0.13	17.04	0.08	18.67	0.27
2400.00	19.97	0.16	17.04	0.08	18.69	0.29
2500.00	19.99	0.18	17.05	0.09	18.67	0.27
2600.00	20.01	0.20	17.05	0.09	18.70	0.30
2700.00	20.02	0.21	17.06	0.10	18.69	0.29
2800.00	20.04	0.23	17.06	0.10	18.67	0.27
2900.00	20.04	0.23	17.06	0.10	18.62	0.22
3000.00	20.05	0.24	17.06	0.10	18.64	0.24

Table 4-5. CONTINUED

Monitoring Wells	NFFW-7		NFFW-9		NFFW-16	
Time (min)	Water Level (ft)	Column Change (ft)	Water Level (ft)	Column Change (ft)	Water Level (ft)	Column Change (ft)
3100.00	20.04	0.23	17.07	0.11	18.69	0.29
3200.00	20.05	0.24	17.08	0.12	18.69	0.29
3300.00	20.07	0.26	17.08	0.12	18.78	0.38
3400.00	20.08	0.27	17.09	0.13	18.75	0.35
3500.00	20.09	0.28	17.09	0.13	18.83	0.43
3600.00	20.10	0.29	17.09	0.13	18.84	0.44
3700.00	20.11	0.30	17.10	0.14	18.86	0.46
3800.00	20.13	0.32	17.10	0.14	18.83	0.43
3900.00	20.16	0.35	17.11	0.15	18.86	0.46
4000.00	20.17	0.36	17.12	0.16	18.84	0.44
4100.00	20.16	0.35	17.13	0.17	18.80	0.40
4200.00	20.14	0.33	17.11	0.15	18.78	0.38
4300.00	20.16	0.35	17.12	0.16	18.75	0.35
4400.00	20.12	0.31	17.11	0.15	18.72	0.32
4500.00	20.16	0.35	17.13	0.17	18.75	0.35
4600.00	20.17	0.36	17.13	0.17	18.80	0.40
4700.00	20.19	0.38	17.14	0.18	18.86	0.46
4800.00	20.20	0.39	17.14	0.18	18.81	0.41
4900.00	20.22	0.41	17.14	0.18	18.80	0.40
5000.00	20.22	0.41	17.15	0.19	18.75	0.35
5100.00	20.21	0.40	17.15	0.19	18.73	0.33
5200.00	20.22	0.41	17.15	0.19	18.73	0.33
5300.00	20.21	0.40	17.10	0.14	18.67	0.27
5400.00	20.22	0.41			18.72	0.32
5500.00	20.22	0.41			18.69	0.29
5600.00	20.24	0.43			18.64	0.24
5700.00	20.27	0.46			18.59	0.19

Table 4-6. HAND-GAUGED DATA FOR PUMPING TEST NO. 6 PUMPING WELL NFFW-12

Time (min)	NFFW-01 Water Level (ft)	NFFW-01 Column Change (ft)	NFFW-01 Product Level (ft)	NFFW-01 Product Thickness (ft)	NFFW-02R Water Level (ft)	NFFW-02R Column Change (ft)	NFFW-02R Product Level (ft)	NFFW-02R Product Thickness (ft)	NFFW-05 Water Level (ft)	NFFW-05 Column Change (ft)	NFFW-05 Product Level (ft)	NFFW-05 Product Thickness (ft)
0.00	17.57	0.00		No product	22.81	0.00	21.31	1.50	19.11	0.00		No product
120.00	17.58	0.01		"	22.39	-0.42	21.64	0.75	19.13	0.02		"
240.00	17.59	0.02		"	22.45	-0.36	21.65	0.80	19.13	0.02		"
360.00	17.59	0.02		"	22.51	-0.30	21.66	0.85	19.13	0.02		"
480.00	17.60	0.03		"	22.57	-0.24	21.65	0.92	19.15	0.04		"
600.00	17.60	0.03		"	22.64	-0.17	21.65	0.99	19.17	0.05		"
720.00	17.60	0.03		"	22.69	-0.12	21.66	1.03	19.18	0.07		"
840.00	17.61	0.04		"	22.73	-0.08	21.65	1.08	19.20	0.09		"
960.00	17.61	0.04		"	22.79	-0.02	21.64	1.15	19.21	0.09		"
1080.00	17.62	0.04		"	22.81	0.00	21.62	1.19	19.19	0.08		"
1200.00	17.62	0.04		"	22.85	0.04	21.62	1.22	19.19	0.08		"
1320.00	17.62	0.05		"	22.87	0.06	21.61	1.27	19.19	0.08		"
1440.00	17.62	0.05		"	22.90	0.09	21.59	1.31	19.19	0.08		"
1560.00	17.62	0.05		"	22.93	0.12	21.59	1.34	19.18	0.07		"
1680.00	17.62	0.05		"	22.95	0.14	21.62	1.33	19.20	0.09		"
1800.00	17.63	0.06		"	23.01	0.20	21.64	1.37	19.19	0.08		"
1920.00	17.63	0.06		"	23.05	0.24	21.64	1.41	19.20	0.09		"
2040.00	17.64	0.07		"	23.08	0.27	21.65	1.43	19.20	0.09		"
2160.00	17.64	0.07		"	23.13	0.32	21.65	1.48	19.19	0.08		"
2280.00	17.65	0.08		"	23.15	0.34	21.65	1.50	19.20	0.09		"
2400.00	17.65	0.08		"	23.21	0.40	21.68	1.53	19.23	0.12		"
2520.00	17.66	0.09		"	23.24	0.43	21.71	1.54	19.26	0.15		"
2640.00	17.66	0.09		"	23.28	0.47	21.71	1.57	19.29	0.18		"
2760.00	17.68	0.11		"	23.29	0.48	21.70	1.59	19.27	0.16		"
2880.00	17.69	0.12		"	23.30	0.49	21.69	1.61	19.27	0.16		"
3000.00	17.68	0.11		"	23.33	0.52	21.71	1.62	19.27	0.16		"
3120.00	17.66	0.09		"	23.39	0.58	21.74	1.65	19.23	0.12		"
3240.00	17.65	0.07		"	23.44	0.63	21.75	1.69	19.21	0.10		"
3360.00	17.66	0.09		"	23.48	0.67	21.76	1.72	19.25	0.14		"
3480.00	17.69	0.11		"	23.52	0.71	21.78	1.74	19.28	0.16		"
3600.00	17.72	0.14		"	23.55	0.74	21.80	1.75	19.30	0.19		"
3720.00	17.74	0.16		"	23.58	0.77	21.81	1.77	19.33	0.21		"
3840.00	17.74	0.16		"	23.58	0.77	21.81	1.77	19.34	0.23		"
3960.00	17.74	0.17		"	23.59	0.78	21.82	1.77	19.36	0.25		"
4080.00	17.74	0.17		"	23.60	0.79	21.82	1.77	19.37	0.26		"
4200.00	17.74	0.16		"	23.61	0.80	21.83	1.78	19.38	0.27		"
4320.00	17.74	0.16		"	23.62	0.80	21.83	1.79	19.38	0.27		"

Table 4-6. CONTINUED

Time (min)	NFFW-06 Water Level (ft)	NFFW-06 Column Change (ft)	NFFW-06 Product Level (ft)	NFFW-06 Product Thickness (ft)	NFFW-07 Water Level (ft)	NFFW-07 Column Change (ft)	NFFW-07 Product Level (ft)	NFFW-07 Product Thickness (ft)	NFFW-08 Water Level (ft)	NFFW-08 Column Change (ft)	NFFW-08 Product Level (ft)	NFFW-08 Product Thickness (ft)
0.00	23.77	0.00	23.43	0.34	19.86	0.00	19.87	SHEEN	18.11	0.00	18.04	0.07
120.00	23.86	0.09	23.50	0.36	19.73	-0.13	19.72	SHEEN	18.12	0.01	18.05	0.07
240.00	23.86	0.09	23.50	0.36	19.73	-0.13	19.72	SHEEN	18.13	0.02	18.06	0.07
360.00	23.86	0.09	23.50	0.36	19.74	-0.12	19.73	SHEEN	18.15	0.04	18.08	0.07
480.00	23.87	0.10	23.51	0.36	19.74	-0.12	19.73	SHEEN	18.16	0.05	18.08	0.08
600.00	23.87	0.10	23.51	0.36	19.74	-0.12	19.73	SHEEN	18.16	0.05	18.09	0.07
720.00	23.88	0.11	23.52	0.36	19.74	-0.12	19.73	SHEEN	18.17	0.06	18.10	0.07
840.00	23.88	0.11	23.53	0.36	19.74	-0.12	19.74	SHEEN	18.18	0.07	18.11	0.07
960.00	23.89	0.12	23.54	0.35	19.76	-0.10	19.75	SHEEN	18.18	0.07	18.11	0.07
1080.00	23.90	0.13	23.54	0.36	19.76	-0.10	19.75	SHEEN	18.21	0.09	18.11	0.09
1200.00	23.90	0.13	23.54	0.36	19.77	-0.09	19.76	SHEEN	18.21	0.09	18.13	0.07
1320.00	23.91	0.14	23.55	0.36	19.77	-0.09	19.76	SHEEN	18.18	0.07	18.11	0.07
1440.00	23.91	0.14	23.54	0.37	19.76	-0.10	19.75	SHEEN	18.17	0.06	18.11	0.06
1560.00	23.90	0.13	23.54	0.36	19.76	-0.10	19.75	SHEEN	18.18	0.07	18.11	0.07
1680.00	23.90	0.13	23.54	0.36	19.78	-0.08	19.78	SHEEN	18.19	0.08	18.12	0.07
1800.00	23.90	0.13	23.55	0.35	19.80	-0.06	19.79	SHEEN	18.21	0.10	18.14	0.07
1920.00	23.91	0.14	23.55	0.36	19.81	-0.05	19.80	SHEEN	18.22	0.11	18.15	0.07
2040.00	23.93	0.16	23.57	0.36	19.82	-0.04	19.81	SHEEN	18.23	0.12	18.15	0.08
2160.00	23.94	0.16	23.58	0.36	19.83	-0.03	19.82	SHEEN	18.24	0.13	18.17	0.07
2280.00	23.95	0.18	23.58	0.37	19.84	-0.02	19.83	SHEEN	18.25	0.14	18.17	0.08
2400.00	23.95	0.18	23.59	0.36	19.85	-0.01	19.84	SHEEN	18.26	0.15	18.18	0.08
2520.00	23.97	0.20	23.60	0.37	19.88	0.02	19.86	SHEEN	18.26	0.15	18.18	0.08
2640.00	23.97	0.20	23.61	0.36	19.89	0.03	19.88	SHEEN	18.26	0.15	18.18	0.08
2760.00	23.97	0.20	23.61	0.36	19.90	0.04	19.89	SHEEN	18.26	0.14	18.18	0.08
2880.00	23.97	0.20	23.61	0.36	19.90	0.04	19.89	SHEEN	18.26	0.14	18.18	0.08
3000.00	23.98	0.21	23.62	0.36	19.92	0.06	19.91	SHEEN	18.26	0.15	18.18	0.08
3120.00	23.99	0.22	23.64	0.35	19.93	0.07	19.91	SHEEN	18.29	0.18	18.21	0.08
3240.00	24.02	0.25	23.65	0.37	19.94	0.07	19.93	SHEEN	18.31	0.20	18.23	0.08
3360.00	24.04	0.27	23.67	0.37	19.98	0.12	19.94	SHEEN	18.31	0.20	18.23	0.08
3480.00	24.05	0.28	23.68	0.37	19.99	0.13	19.97	SHEEN	18.32	0.21	18.24	0.08
3600.00	24.07	0.30	23.70	0.37	20.00	0.14	19.97	SHEEN	18.33	0.22	18.24	0.09
3720.00	24.08	0.31	23.71	0.37	20.02	0.16	19.99	SHEEN	18.34	0.23	18.24	0.10
3840.00	24.09	0.32	23.72	0.37	20.02	0.16	19.99	SHEEN	18.33	0.22	18.24	0.09
3960.00	24.09	0.32	23.72	0.37	20.03	0.16	20.00	SHEEN	18.33	0.22	18.24	0.09
4080.00	24.10	0.32	23.73	0.36	20.03	0.16	20.00	SHEEN	18.33	0.22	18.24	0.09
4200.00	24.10	0.32	23.73	0.36	20.03	0.17	20.00	SHEEN	18.33	0.22	18.24	0.09
4320.00	24.10	0.32	23.73	0.36	20.03	0.17	20.00	SHEEN	18.33	0.22	18.24	0.09

Table 4-6. CONTINUED

Time (min)	NFFW-09 Water Level (ft)	NFFW-09 Column Change (ft)	NFFW-09 Product Level (ft)	NFFW-09 Product Thickness (ft)	NFFW-10 Water Level (ft)	NFFW-10 Column Change (ft)	NFFW-10 Product Level (ft)	NFFW-10 Product Thickness (ft)	NFFW-11 Water Level (ft)	NFFW-11 Column Change (ft)	NFFW-11 Product Level (ft)	NFFW-11 Product Thickness (ft)
0.00	8.86	0.00		No product	10.24	0.00		No product	10.83	0.00		No product
120.00	8.89	0.03		"	10.22	-0.02		"	10.85	0.02		"
240.00	8.90	0.04		"	10.25	0.01		"	10.85	0.02		"
360.00	8.90	0.04		"	10.29	0.05		"	10.86	0.03		"
480.00	8.91	0.05		"	10.29	0.05		"	10.91	0.08		"
600.00	8.92	0.06		"	10.30	0.06		"	10.91	0.08		"
720.00	8.92	0.06		"	10.31	0.07		"	10.90	0.07		"
840.00	8.93	0.07		"	10.32	0.08		"	10.90	0.06		"
960.00	8.93	0.07		"	10.33	0.09		"	10.90	0.07		"
1080.00	8.93	0.07		"	10.33	0.09		"	10.90	0.07		"
1200.00	8.93	0.07		"	10.33	0.09		"	10.91	0.08		"
1320.00	8.94	0.08		"	10.30	0.05		"	10.93	0.10		"
1440.00	8.94	0.08		"	10.29	0.05		"	10.93	0.10		"
1560.00	8.95	0.09		"	10.32	0.08		"	10.93	0.10		"
1680.00	8.96	0.10		"	10.34	0.10		"	10.96	0.13		"
1800.00	8.97	0.11		"	10.37	0.13		"	10.97	0.14		"
1920.00	8.98	0.12		"	10.40	0.15		"	10.99	0.16		"
2040.00	8.98	0.12		"	10.43	0.19		"	11.00	0.17		"
2160.00	8.99	0.13		"	10.47	0.22		"	11.01	0.18		"
2280.00	8.99	0.13		"	10.49	0.25		"	11.03	0.20		"
2400.00	9.00	0.14		"	10.62	0.38		"	11.03	0.20		"
2520.00	9.00	0.14		"	10.62	0.38		"	11.04	0.21		"
2640.00	9.00	0.14		"	10.57	0.33		"	11.04	0.21		"
2760.00	9.01	0.15		"	10.53	0.29		"	11.04	0.21		"
2880.00	9.02	0.16		"	10.52	0.28		"	11.05	0.22		"
3000.00	9.02	0.16		"	10.52	0.28		"	11.05	0.22		"
3120.00	9.03	0.17		"	10.55	0.30		"	11.06	0.23		"
3240.00	9.05	0.19		"	10.57	0.33		"	11.06	0.23		"
3360.00	9.05	0.19		"	10.58	0.34		"	11.06	0.23		"
3480.00	9.06	0.20		"	10.59	0.35		"	11.07	0.24		"
3600.00	9.06	0.20		"	10.60	0.36		"	11.07	0.24		"
3720.00	9.07	0.21		"	10.60	0.36		"	11.07	0.24		"
3840.00	9.08	0.22		"	10.60	0.36		"	11.07	0.24		"
3960.00	9.09	0.23		"	10.60	0.36		"	11.07	0.24		"
4080.00	9.09	0.23		"	10.60	0.36		"	11.07	0.24		"
4200.00	9.09	0.23		"	10.60	0.36		"	11.07	0.24		"
4320.00	9.10	0.24		"	10.56	0.32		"	11.08	0.25		"

Table 4-6. CONTINUED

Time (min)	NFFW-13 Water Level (ft)	NFFW-13 Column Change (ft)	NFFW-13 Product Level (ft)	NFFW-13 Product Thickness (ft)	NFFW-14 Water Level (ft)	NFFW-14 Column Change (ft)	NFFW-14 Product Level (ft)	NFFW-14 Product Thickness (ft)	NFFW-16 Water Level (ft)	NFFW-16 Column Change (ft)	NFFW-16 Product Level (ft)	NFFW-16 Product Thickness (ft)
0.00	15.24	0.00		No product	19.46	0.00	19.39	0.07	18.40	0.00		No product
120.00	15.19	0.00		"	19.30	0.00	19.22	0.08	18.22	0.00		"
240.00	15.23	0.04		"	19.34	0.04	19.25	0.09	18.23	0.01		"
360.00	15.25	0.06		"	19.35	0.05	19.26	0.09	18.25	0.03		"
480.00	15.26	0.07		"	19.35	0.05	19.27	0.08	18.26	0.04		"
600.00	15.26	0.07		"	19.36	0.06	19.28	0.08	18.27	0.05		"
720.00	15.27	0.08		"	19.36	0.06	19.28	0.08	18.27	0.05		"
840.00	15.28	0.09		"	19.36	0.06	19.28	0.08	18.28	0.05		"
960.00	15.27	0.08		"	19.34	0.04	19.28	0.06	18.29	0.07		"
1080.00	15.27	0.08		"	19.35	0.05	19.28	0.07	18.28	0.06		"
1200.00	15.27	0.08		"	19.34	0.04	19.27	0.07	18.28	0.06		"
1320.00	15.26	0.07		"	19.36	0.06	19.27	0.09	18.27	0.05		"
1440.00	15.26	0.07		"	19.35	0.05	19.27	0.08	18.26	0.04		"
1560.00	15.27	0.08		"	19.36	0.06	19.29	0.07	18.27	0.05		"
1680.00	15.30	0.11		"	19.38	0.08	19.30	0.08	18.28	0.06		"
1800.00	15.34	0.15		"	19.40	0.10	19.31	0.09	18.28	0.06		"
1920.00	15.35	0.16		"	19.42	0.11	19.32	0.10	18.30	0.08		"
2040.00	15.37	0.18		"	19.42	0.12	19.33	0.09	18.32	0.10		"
2160.00	15.38	0.19		"	19.43	0.13	19.34	0.09	18.33	0.11		"
2280.00	15.40	0.21		"	19.43	0.13	19.35	0.08	18.35	0.13		"
2400.00	15.44	0.25		"	19.46	0.15	19.38	0.08	18.36	0.14		"
2520.00	15.45	0.26		"	19.46	0.16	19.38	0.08	18.38	0.16		"
2640.00	15.45	0.26		"	19.47	0.16	19.38	0.09	18.39	0.17		"
2760.00	15.44	0.25		"	19.46	0.16	19.38	0.08	18.39	0.17		"
2880.00	15.43	0.24		"	19.47	0.16	19.39	0.08	18.39	0.17		"
3000.00	15.44	0.25		"	19.50	0.20	19.39	0.11	18.37	0.15		"
3120.00	15.48	0.29		"	19.51	0.20	19.41	0.09	18.40	0.18		"
3240.00	15.51	0.32		"	19.51	0.21	19.43	0.09	18.42	0.20		"
3360.00	15.51	0.32		"	19.52	0.22	19.43	0.09	18.43	0.21		"
3480.00	15.52	0.33		"	19.54	0.24	19.44	0.10	18.46	0.23		"
3600.00	15.53	0.34		"	19.55	0.25	19.45	0.10	18.48	0.26		"
3720.00	15.53	0.34		"	19.56	0.26	19.46	0.10	18.50	0.28		"
3840.00	15.53	0.34		"	19.56	0.26	19.46	0.10	18.50	0.28		"
3960.00	15.53	0.34		"	19.56	0.26	19.47	0.09	18.50	0.28		"
4080.00	15.53	0.34		"	19.56	0.26	19.47	0.09	18.50	0.28		"
4200.00	15.53	0.34		"	19.55	0.25	19.46	0.09	18.49	0.27		"
4320.00	15.52	0.33		"	19.54	0.24	19.46	0.08	18.48	0.26		"

4.3.2 Methods

The methodology adopted for the first five pumping tests was to pump one well for a period of 48 hours while monitoring the drawdown and product accumulation in all other wells in the immediate vicinity. EA utilized a product recovery system which allowed for simultaneous recovery of product while a water table depression pump operated to enhance product migration to the well. Due to pump configuration, this system could not be used for the first pump test because the 4-in. diameter of the well did not provide enough space. During the first pump test a submersible pump was lowered into the well and manually manipulated to bring product and water up together into an oil/water separator tank where the product was then siphoned off.

Prior to initiation of each pumping test, static water levels were recorded for each well. Data loggers were then set in the close proximity wells and the proper reference, scale, and offset factors were entered. Each transducer was protected with a PVC sleeve to prevent damage to the transducer cable by NAPL. The product-recovery/water pump was lowered into the designated pumping well. When the pump was started, an initial indicator reading was taken to record the pumping rate and total gallons pumped throughout the entirety of the test. The pumping rate was directly controlled by a gate valve leading from the water pump.

An initial water sample was taken at the beginning and at 24-hour intervals of the last five tests and analyzed for BTEX and TPH. All samples were shipped by Federal Express under chain-of-custody procedure to EA Laboratories in Sparks, Maryland. Sampling was not appropriate during the first test of NFFW-2 due to the thorough mixing of water and product during pumping. The replacement well NFFW-2R was sampled during the second pumping test when it served as the production well.

Wells not monitored by data logger onsite were hand gauged with an interface probe which accurately (to 0.1 in.) detects floating product

and water levels. These records were detailed in a field book. All other details that could have affected the test were also included such as rainfall, equipment changes, etc.

The purge water taken from the wells was filtered through a sediment trap and four 500-lb Carbitrol Carbon Canisters, then discharged into a storm drain or drainage ditch. Any product that accumulated on top of the static water column in the well casing of the production well was pumped up through the product recovery system directly into a drum, which was labeled and stored onsite for proper disposal. Product accumulation records were detailed in the field book.

4.3.3 Results

4.3.3.1 Pumping Test No.1

The first of five 48-hour pumping tests was performed from 6 to 8 November 1990. At this time, NFFW-2 was the pumping well and wells NFFW-1, NFFW-3, NFFW-4, NFFW-6, and NFFW-7 were monitored. Pumping rates varied from 0.5 to 1 gpm with a total of 1,402 gal of water removed during the test.

The drawdown relationships during this test are somewhat anomalous in that greater drawdown was observed further away (NFFW-3 and NFFW-4) from the pumping well than adjacent to it (Figure 4-2).

One possible explanation is that fractures connect well NFFW-2 with NFFW-3 and NFFW-4 which are not intercepted by wells NFFW-5, NFFW-6, and NFFW-7. Another possibility is that the water level drops observed in NFFW-3 and NFFW-4 were unrelated to the pumping test, possibly the result of withdrawals from the production well NW-2 or other local conditions.

Product recovery results from NFFW-2 were encouraging enough that it was decided to replace the original 4-in. well with a deeper 6-in. well to

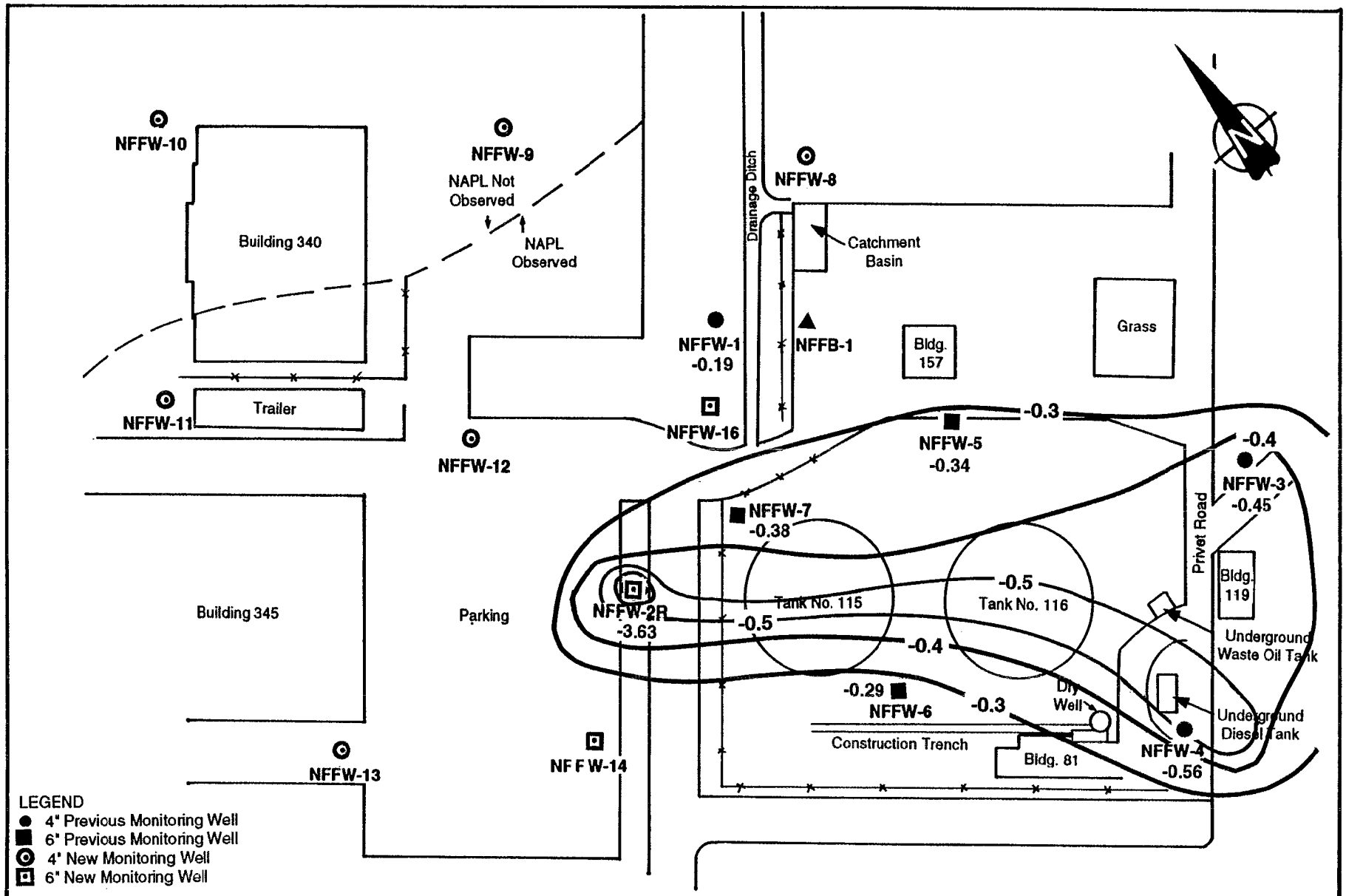


Figure 4-2. Drawdown contours for Pumping Test No. 1, NFFW-2.

NOTE: The subsurface contours shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected

promote product recovery and allow for greater drawdown. The primary effect this had was to improve connections with well NFFW-7 which seems to contradict the above concept of fracture communication with NFFW-3 and NFFW-4.

Analytical Results

No samples were taken during the first test for the reasons stated above.

4.3.3.2 Pumping Test No. 2

The second pumping test was conducted 6 June 1991. During the previous April, nine additional wells had been installed as detailed in Section 4.1. Well NFFW-2R, the replacement well for NFFW-2, was the pumped well for pumping test No. 2. The pumping rate varied from 0 to 2 gpm and a total of 3,818 gal of water were removed. Only 2 gal of product were recovered.

The drawdown contours as shown in Figure 4-3 suggest an orthogonal bimodal pumping zone of influence trending north-south and east-west. The east-west trending zone of influence may simply reflect bedding and related parting and/or fractures, whereas the north-south trending zone is probably related to fractures which cut across bedding and/or lithologies. These results conform to regional structural features as observed by the description of the area geology by Rima et al. (1962). They also show that the bedrock aquifer underlying the site has pronounced anisotropy due to differential transmissivity between matrix and fractures in the underlying bedrock. Anisotropy is enhanced by the subcrop transition from tan arkosic sandstone in the southern half of the site to interbedded shale and siltstone in the northern half of the site (Figure 4-1). The contact runs east-west just north of the drainage ditch which bisects the site.

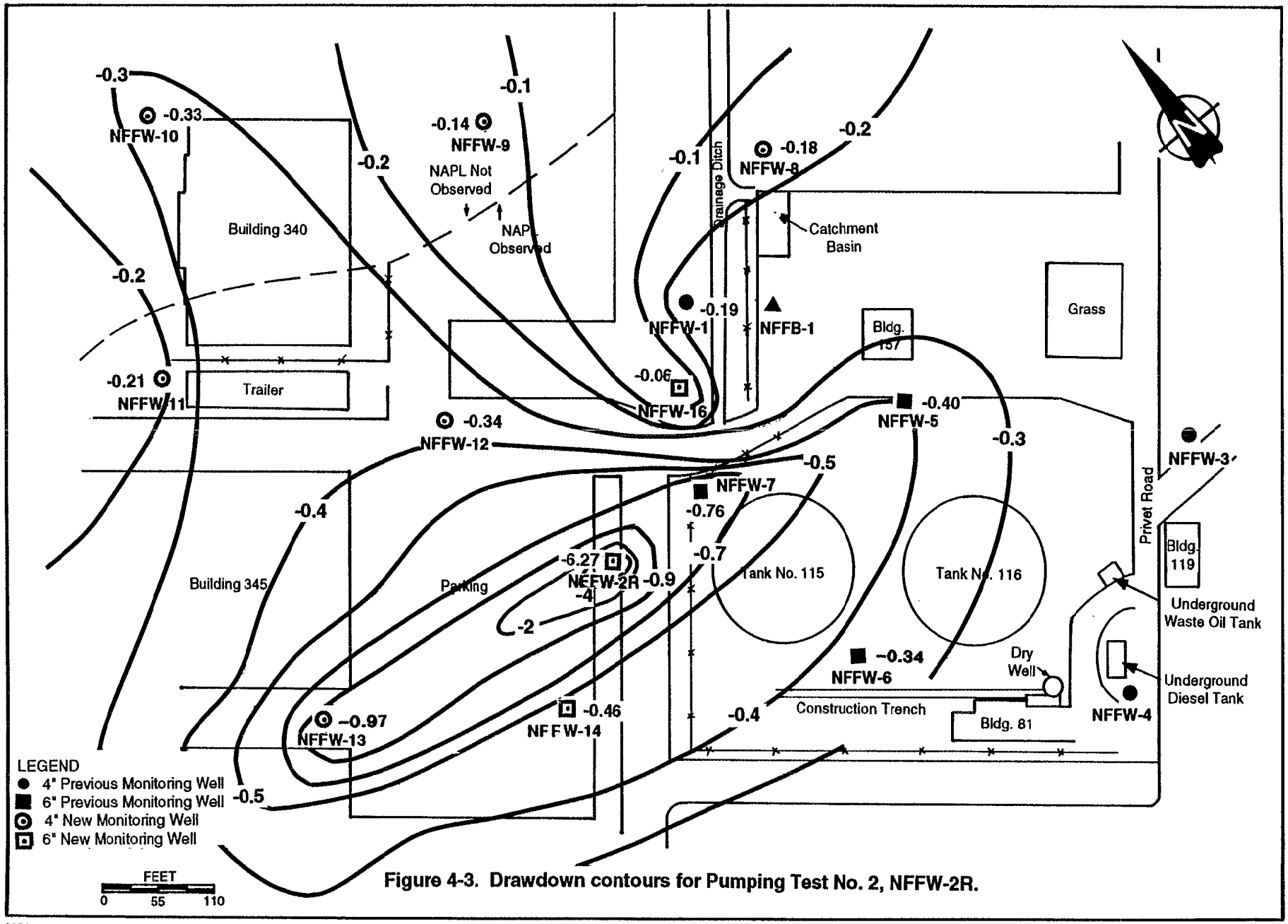


Figure 4-3. Drawdown contours for Pumping Test No. 2, NFFW-2R.

NOTE: The subsurface contours shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected

The lack of product recovery from NFFW-2R during the second pumping test was disappointing. The difference from Pumping Test No. 1 may be related to higher water table conditions during the second pump test, which prevented interception of the product yielding fractures with the pumping zone of influence or the possibility that the first pump test removed the bulk of the product contained in fractures intercepted by this well. Results from subsequent pump tests suggest that the former explanation may be the case. This will be further discussed below (Pumping Test No. 6).

Analytical Results

Analytical results of BTEX compounds in the effluent from pumping well NFFW-2R are summarized in Table 4-7. Benzene ranged from 300 to 410 µg/L, toluene from 17 to 24 µg/L, ethylbenzene from 470 to 550 µg/L, and total xylenes from 1,120 to 1,440 µg/L. TPH values ranged from 1.8 to 3.5 mg/L. No consistent trend in total BTEX or TPH compound concentrations was present through time.

4.3.3.3 Pumping Test No. 3

Pumping Test No. 3 began 13 June 1991 and finished on 15 June. NFFW-14 was the pumped well. Pumping rate averaged 0-1 gpm and a total of 1,337 gal of water was removed. One gallon of product was recovered from NFFW-14.

Drawdown relationships during this test were obscured by a rain event near the end of the test which caused a net rise in water levels in wells NFFW-16 and NFFW-12. This is shown as a depression in the drawdown contours in Figure 4-4. NFFW-16 is located in a mowed grass area with direct recharge, and NFFW-12 is located directly downgradient from this recharge area. Drawdown in wells NFFW-7, NFFW-1, and NFFW-6 may also have been decreased due to direct recharge, from ground infiltration. All other wells are under or near asphalt or compacted ground (NFFW-8). Despite the rain, the east-west zone of influence, probably related to

TABLE 4-7. PUMPING WELL ANALYTICAL RESULTS

NFFW-2R	Test 2	Hour 0	24	48
	Benzene	300	410	390
	Toluene	17	24	24
	Ethylbenzene	470	550	520
	Meta+Para Xylene	1,000	1,200	1,200
	Ortho Xylene	120	240	150
	Total BTEX	1,907	2,424	2,284
	TPH (1)	1.8	3.5	2.3

NFFW-14	Test 3	Hour 0	24	48
	Benzene	270	330	280
	Toluene	110	72	36
	Ethylbenzene	590	370	370
	Meta+Para Xylene	1,500	830	820
	Ortho Xylene	115	62	60
	Total BTEX	2,585	1,664	1,566
	TPH	24.4	10.5	2.6

NFFW-16	Test 4	Hour 0	24	48
	Benzene	480	620	540
	Toluene	100	130	99
	Ethylbenzene	320	360	320
	Meta+Para Xylene	470	470	410
	Ortho Xylene	28	33	30
	Total BTEX	1,398	1,613	1,399
	TPH	2.6	3.1	1.4

NFFW-08	Test 5	Hour 0	24	48
	Benzene	1	2	3
	Toluene	1	1	1
	Ethylbenzene	16	8	20
	Meta+Para Xylene	6	4	6
	Ortho Xylene	1	1	1
	Total BTEX	25	16	31
	TPH	3.6	0.73	0.73

(1) All values are expressed in µg/L except TPH, which is expressed as mg/L.
(2) Not Detected (i.e., <0.33 mg/L).

TABLE 4-7 (Cont.)

NFFW-12	Test 6	Hour 0	24	48	72
	Benzene	230	330	310	290
	Toluene	3	3	2	2
	Ethylbenzene	140	190	190	160
	Meta+Para Xylene	21	75	81	78
	Ortho Xylene	2	2	4	3
	Total BTEX	396	600	587	533
	TPH	12.6	1.9	0.72	ND(2)

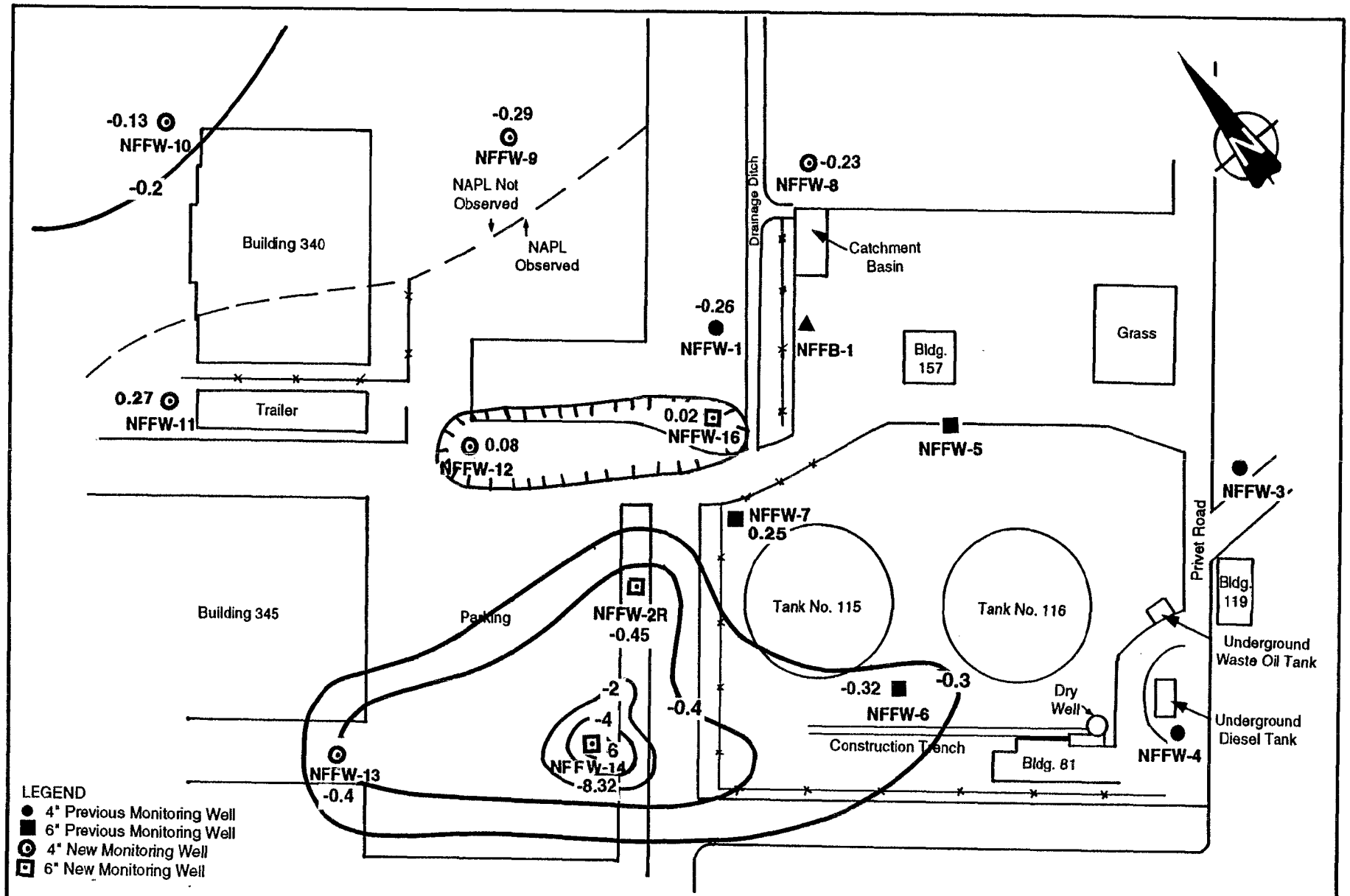


Figure 4-4. Drawdown contours for Pumping Test No. 3, NFFW-14.

NOTE: The subsurface contours shown represent our evaluation of the most probable conditions based upon *interpretation of presently available data. Some variations* from these conditions must be expected

bedding, may still be observed. Nevertheless, the zone of influence associated with NFFW-14 appears to be less than for NFFW-2R. The lower yield and resulting decrease in total gallons removed during this pumping test suggest that well NFFW-14 intercepts less fractures than well NFFW-2, thereby decreasing yield and reducing interconnectedness with other wells.

Product recovery from NFFW-14 was minor. The product that was recovered was dark brown in color with a gelatinous consistency unlike the product recovered in NFFW-2R, which was clear. The difference is probably attributable to weathering and may be an indication that well NFFW-14 is connected to an older product source in a different fracture system than intercepted by well NFFW-2R. Product levels in other wells which showed product at the beginning of the test (NFFW-2R, NFFW-16, NFFW-8, NFFW-6) stayed essentially constant during pumping.

Analytical Results

Analytical results of BTEX compounds in the effluent from the pumping well NFFW-14 are summarized in Table 4-7. Benzene ranged from 270 to 330 µg/L, toluene from 36 to 110 µg/L, ethylbenzene from 370 to 590 µg/L, and total xylenes from 880 to 1615 µg/L. Total BTEX and TPH values declined from an initial value of 2,585 µg/L and 24.4 mg/L, respectively to 1,566 µg/L and 2.6 mg/L after 48 hours.

4.3.3.4 Pumping Test No. 4

Pumping Test No. 4 began on 18 June and finished on 20 June 1991. Well NFFW-16 was the pumped well. The pumping rate ranged from 0 to 1 gpm with an average rate of 0.35 gpm. A total of 1,133 gal of water was removed. Less than 1/2 gal of clear to greenish product was recovered. Product recovery may have been inhibited by the thinness of the NAPL layer which could not be efficiently scavenged with the product recovery pump. Almost 2 in. of rain fell during this test, resulting in a net recharge to most of the wells except those in the immediate vicinity of

the pumping well, namely NFFW-1 and NFFW-7. Drawdown patterns shown in Figure 4-5 are consistent with alternate fluid movement parallel to bedding and perpendicular to strike via fractures. As noted for the previous test, product levels noted in other wells at the beginning of the test did not change appreciably during the test.

Analytical Results

Analytical results of BTEX compounds in the effluent from the pumping well NFFW-16 are summarized in Table 4-7. Benzene ranged in value from 480 to 620 µg/L, toluene from 99 to 130 µg/L, ethylbenzene from 320 to 360 µg/L, and total xylenes from 440 to 503 µg/L. TPH values ranged from 1.4 to 3.1 mg/L. No discernible trend in total BTEX concentrations was noted through time.

4.3.3.5 Pumping Test No. 5

Pumping Test No. 5 began on 25 June and ended on 27 June 1991. Well NFFW-8 was the pumped well. Pumping rates ranged from 0 to 1 gpm with an average rate of 0.4 gpm. Total volume of water removed was 1,507 gal. No product was recovered during pumping, although a sheen was detected in water removed from the well.

Drawdown relationships suggest that this well is only directly connected to well NFFW-9, in which substantial drawdown was observed (Figure 4-6). Minor drawdown effects may also have been present in wells NFFW-10 and NFFW-5. These effects are consistent with fluid migration via fractures perpendicular to bedding strike. The remaining wells were largely unaffected, and wells in vegetated areas (NFFW-1, NFFW-16, and NFFW-7) continued to show a net increase in water level related to continued recharge from the heavy precipitation event during the previous pumping test. Product levels remained unchanged in other wells during the test.

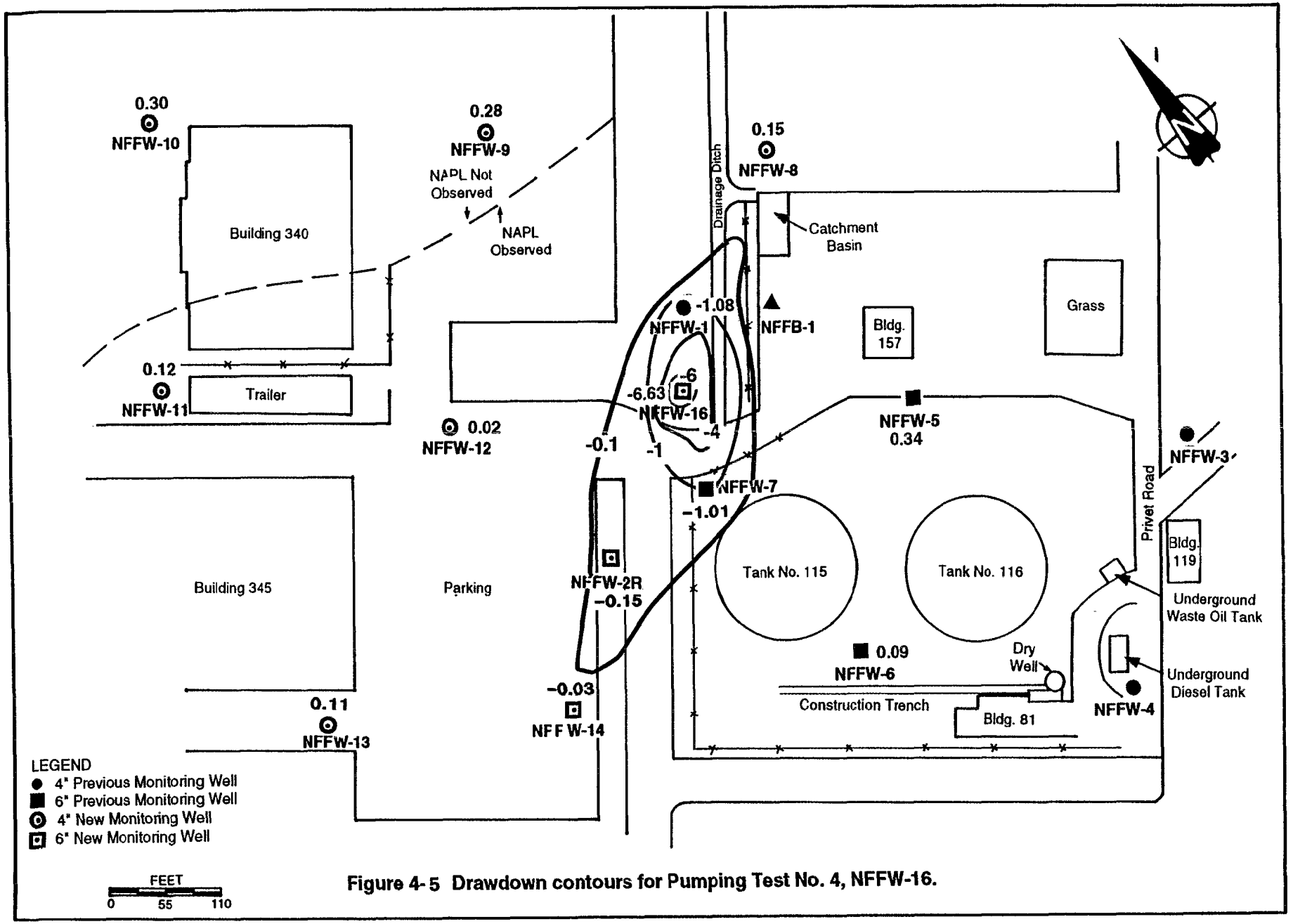


Figure 4-5 Drawdown contours for Pumping Test No. 4, NFFW-16.

NOTE: The subsurface contours shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected

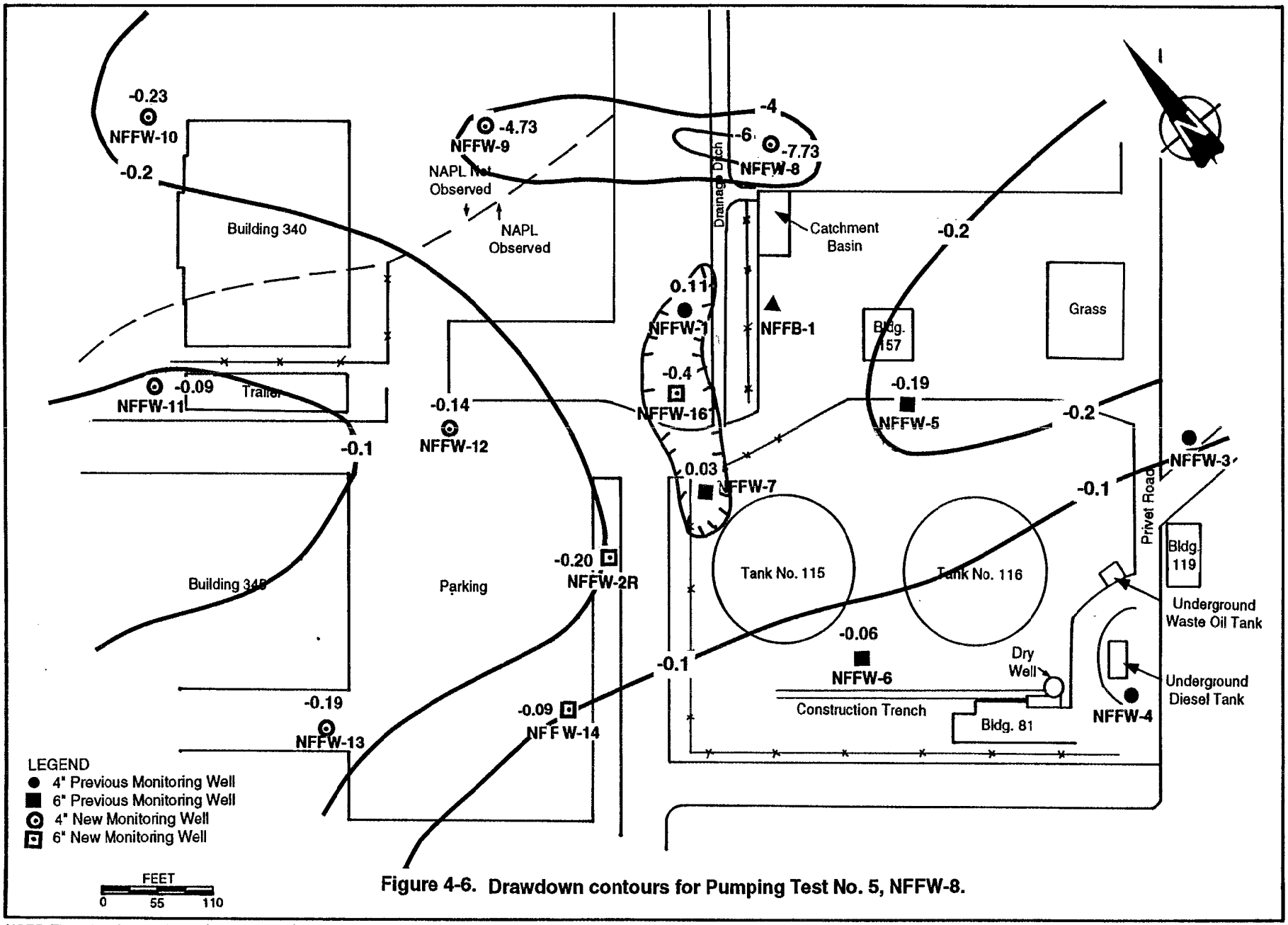


Figure 4-6. Drawdown contours for Pumping Test No. 5, NFFW-8.

NOTE: The subsurface contours shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected

Analytical Results

Analytical results of BTEX compounds in the effluent from the pumping well NFFW-8 are summarized in Table 4-7. Benzene ranged in value from 1 to 3 µg/L, toluene remained constant at 1 µg/L, ethylbenzene ranged from 8 to 20 µg/L, and total xylenes ranged from 5 to 7 µg/L. No discernible trend in total BTEX values was noted through time. Relative to all other wells tested, NFFW-8 showed much lower BTEX levels and the overall composition was dominated by heavier fraction compounds similarly to well NFFW-2/2R. TPH values declined to a constant level of 0.73 mg/L after 24 hours.

4.3.3.6 Pumping Test No. 6

Pumping Test No. 6 began on 9 July and finished 12 July 1991. This test differed from the previous tests in that it lasted for 72 hours and an effort was made to maintain a constant pumping rate by disconnecting the automatic cut-off on the product pump. The primary purpose of this test was to obtain data suitable for analysis of aquifer characteristics, primarily transmissivity and storativity. Well NFFW-12 was selected for the pumping well based on a high expected water yield and its central location. A constant pumping rate of 0.25 gpm was maintained and a total of 8,843 gal of water was removed. Drawdown patterns were similar to Pumping Tests 1 and 2 (Figure 4-7) except in this case symmetrical drawdown was observed along both the north-south and east-west trends.

Although an odor and sheen were detected in water removed from the well, no product was recovered from NFFW-12 during the pump test. A significant change in product thickness occurred in well NFFW-2R, which showed an increase in product thickness of 1.14 ft. Other product thicknesses in wells 6, 7, 8, and 14 remained constant throughout the test.

APPENDIX A

BORING LOGS AND WELL COMPLETION DIAGRAMS

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-2R

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 10" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: NA

Start Date: 4-29-91 Completion Date: 4-29-91

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS / SOIL DESCRIPTION
						200/0			BREATHING ZONE AT 25 PPM
							5		
						200/0			BREATHING ZONE AT >50 PPM.
							10		HARD DRILLING, SANDSTONE UNIT READINGS LEVELING OFF BETWEEN 1 AND 20 PPM.
									READINGS FALLING TO <5 PPM IN BREATHING ZONE REMOVE RESPIRATORS
							15		
									TERMINATE DRILLING AT 37 FT.
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-2R

Coordinates:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 10" AIR HAMMER, MOBILE B-80 DRILL RIG
Sampling Method: NA

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Start Date: 4-29-91 Completion Date: 4-29-91

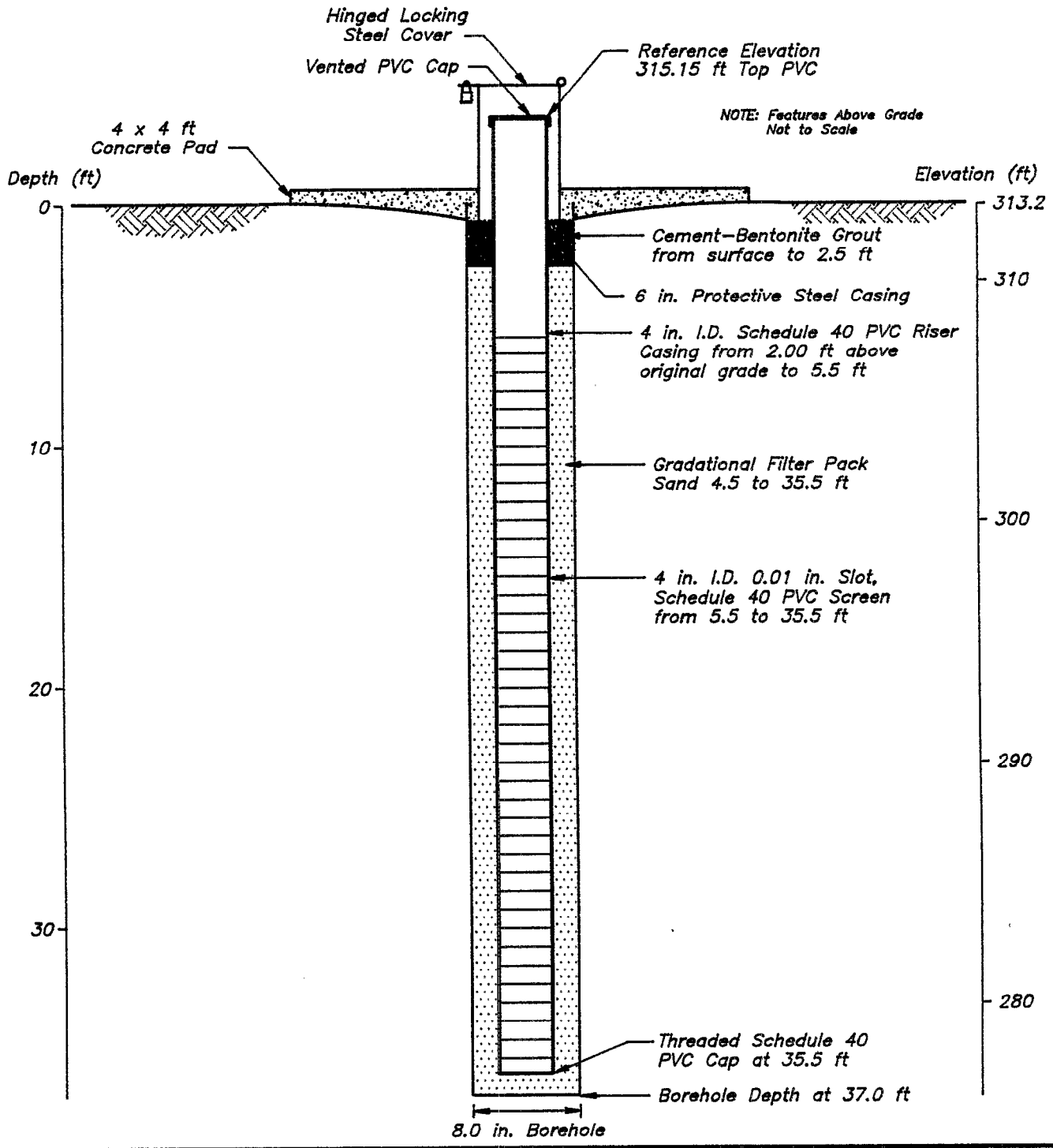
SURFACE CONDITIONS: FLAT GRASSY, LOCATED AT NFFW-2

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
									PULL PROTECTIVE CASING ON NFFW-2, CASING BROKE AT 10 FT. DRILL OUT THE REMAINING CASING.
							5		
									SAND PACK, MUD SLURRY UNABLE TO DISTINGUISH LITHOLOGY.
							10		
						20/0			
							15		
						150/0			BREATHING ZONE MONITORING SHOWED > 15 PPM DONNING RESPIRATORS FOR THE REMAINDER OF THE DRILLING.
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-2R
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.	Client: U.S. Navy Job No. 10388.06	Location: Willow Grove NAS Coordinates X: 2726736 Y: 328669

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-8

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

Start Date: 4-26-91 Completion Date: 4-26-91

SURFACE CONDITIONS: FLAT, GRASSY LOCATED NW OF FUEL TANKS ADJACENT TO SPILLWAY, AND SURFACE DRAINAGE DITCH

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
SS	24	20	1	2.5	3-11-9-12	0/0	X	ML	MOTTLED BROWN AND YELLOWISH BROWN, SLIGHTLY MOIST, CLAYEY SILT, ML, HARD SANDSTONE FRAGMENTS.
							5		
SS	24	20	2	5	3-8-11-9	0/0	X	ML	REDDISH BROWN, MOIST, SILT W/ SOME SAND, ML, SOME LITHIC FRAGMENTS, AND HYDROCARBON SMELL.
SS	24	16	3	7.5	6-7-11-31	0/0	X	ML	BROWN, MOIST, CLAYEY SILT W/ SAND, ML, MANY LITHIC FRAGMENTS, SOME RELIC TEXTURE.
					35-51/3"		10		SPLIT SPOON REFUSAL AT 8.5 FT. SWITCH TO AIR HAMMER.
									CUTTINGS LOG:
								SS	BROWN, MICACEOUS SS/SILTSTONE
							15		
						10/0		SHALE	REDDISH BROWN SHALE, EASIER DRILLING
									WATER DETECTED AT 17 FT.
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-8

Coordinates:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

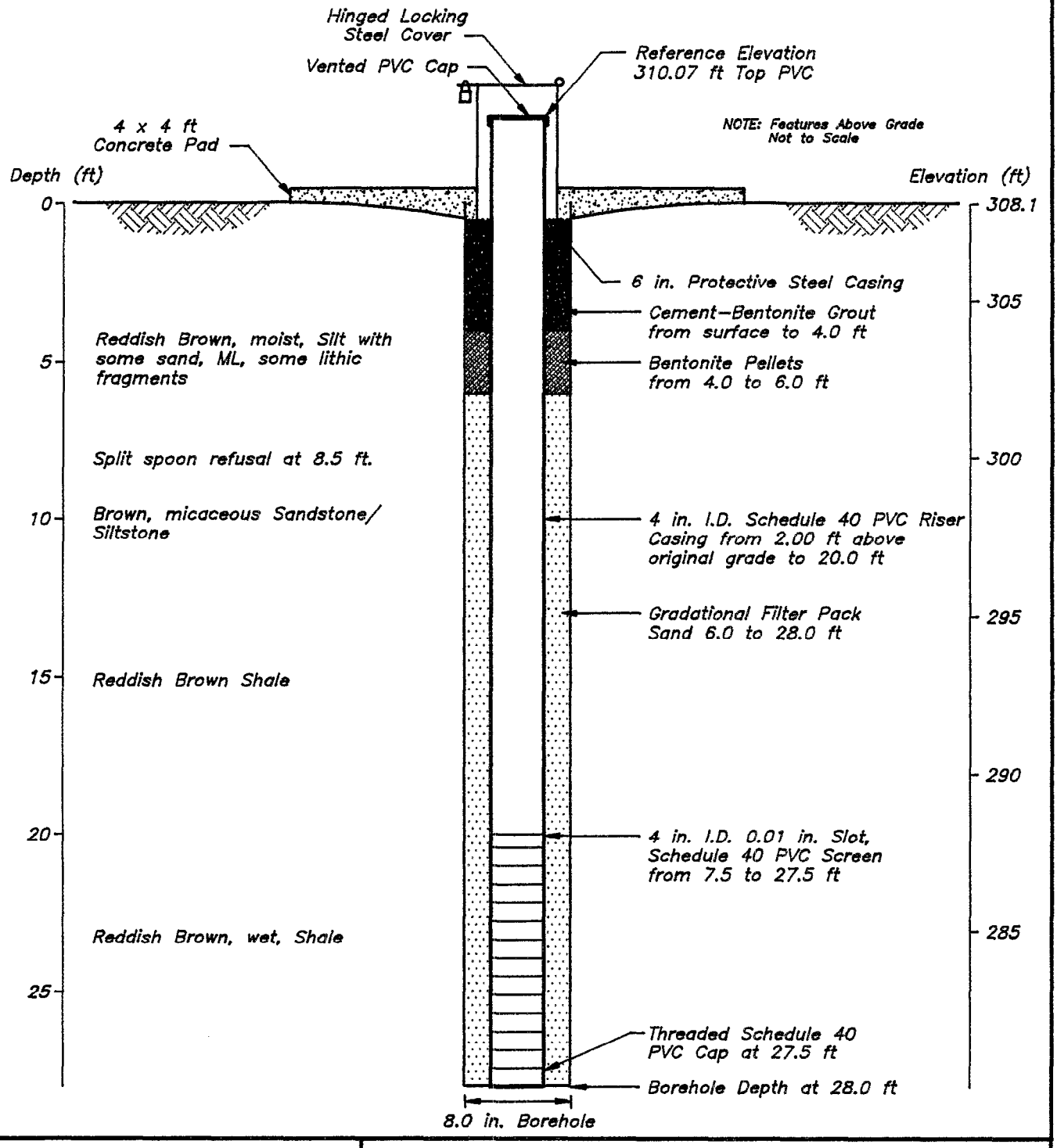
Start Date: 4-26-91 Completion Date: 4-26-91

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS / SOIL DESCRIPTION
							20		
						50/0	25	SHALE	REDDISH BROWN, WET SHALE, STRONG HYDROCARBON SMELL
						200/0			TERMINATE BORING AT 28 FT.
							30		
							35		
							40		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-8
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.	Client: U.S. Navy	Location: Willow Grove NAS
	Job No. 10388.06	Coordinates X: 2727073 Y: 328847

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-9

Coordinates:

Surface Elevation:

Casing Above Surface:

Reference Elevation:

Reference Description:

Location: NAS WILLOW GROVE

Job No. 10388.07

Client: NAVY

Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

Start Date: 4-23-91 Completion Date: 4-23-91

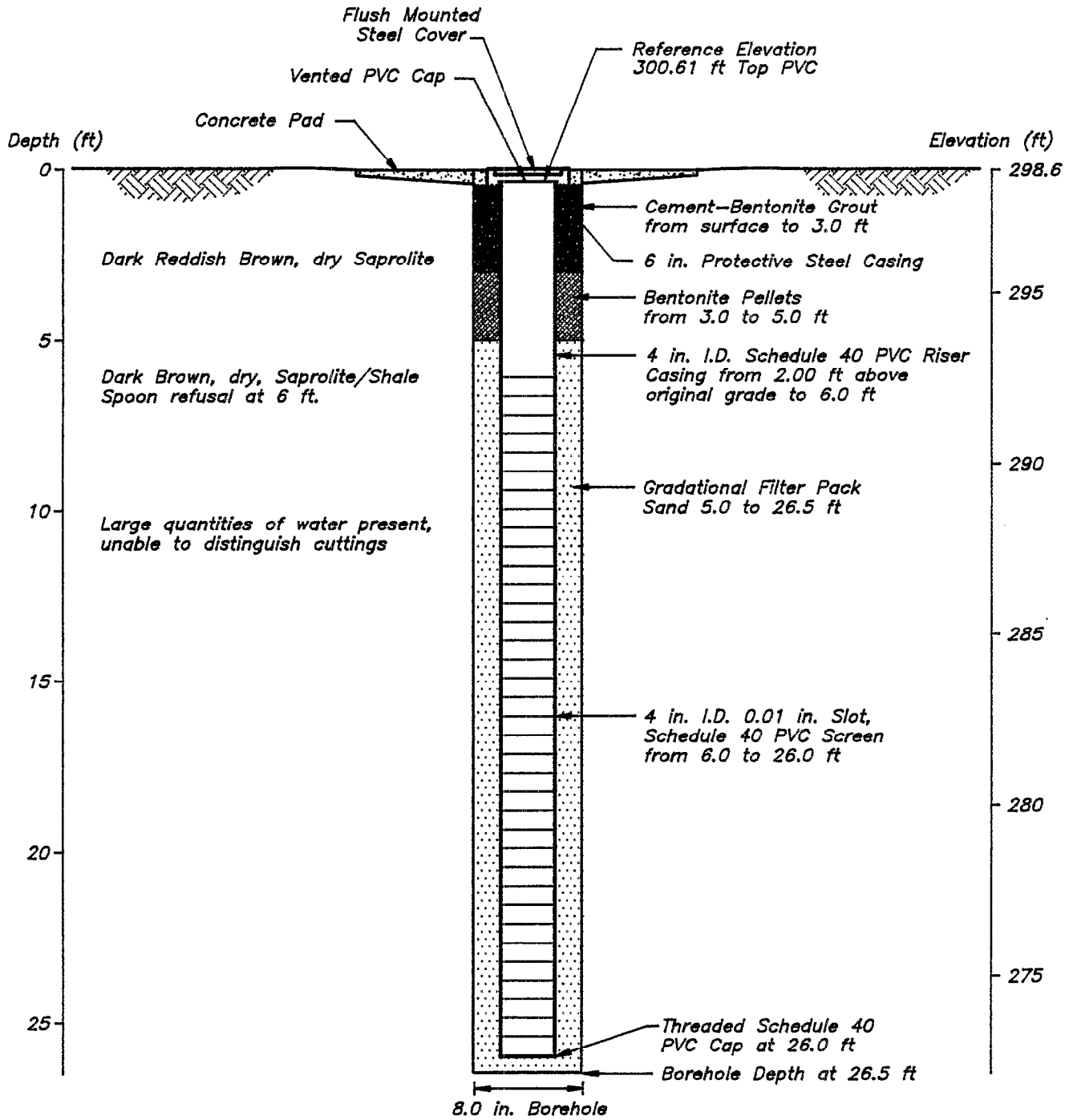
SURFACE CONDITIONS: FLAT, PAVED. LOCATED IN SUPPLIES AREA BEHIND BUILDING 340.

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
SS	24	18	1	2.5	6-6-7-21	0/0	X	SAP	DARK REDDISH BROWN, DRY SAPROLITE, STIFF
SS	15	14	2	5	22-44-51/3"	0/0	5	SAP	REDDISH BROWN , DRY, SAPROLITE/SHALE, HARD RELIC STRUCTURE PRESENT. SPOOON REFUSAL AT 6 FT., SWITCH TO AIR HAMMER.
									LARGE QUANTITIES OF WATER PRESENT, UNABLE TO DISTINGUISH CUTTINGS.
									HNU READINGS ON MUD PAN BETWEEN 5 AND 20 PPM.
							10		SET WELL AT 26 FT.
							15		
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-9
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.	Client: U.S. Navy	Location: Willow Grove NAS
	Job No. 10388.06	Coordinates X: 2726905 Y: 328896

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-10

Coordinates:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

Start Date: 4-24-91 Completion Date: 4-24-91

SURFACE CONDITIONS: FLAT, PAVED. LOCATED NW OF BUILDING 340.

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
SS	24	18	1	2.5	14-20-26-45	0/0	X	SAP	MOTTLED YELLOWISH BROWN, TO BLUEISH GREY, DRY, SAPROLITE W/ SHALE FRAGMENTS, RELIC TEXTURE, SOFT, NO ODOR.
					50/5"	0/0	5		SPOON REFUSAL AT 4.5 FT., SWITCH TO AIR HAMMER.
									CUTTINGS:
									REDDISH BROWN, S. MOIST, SHALE, NO ODOR.
							10		
						0/0			REDDISH BROWN, S. MOIST, SHALE, NO ODOR.
							15		
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-10

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

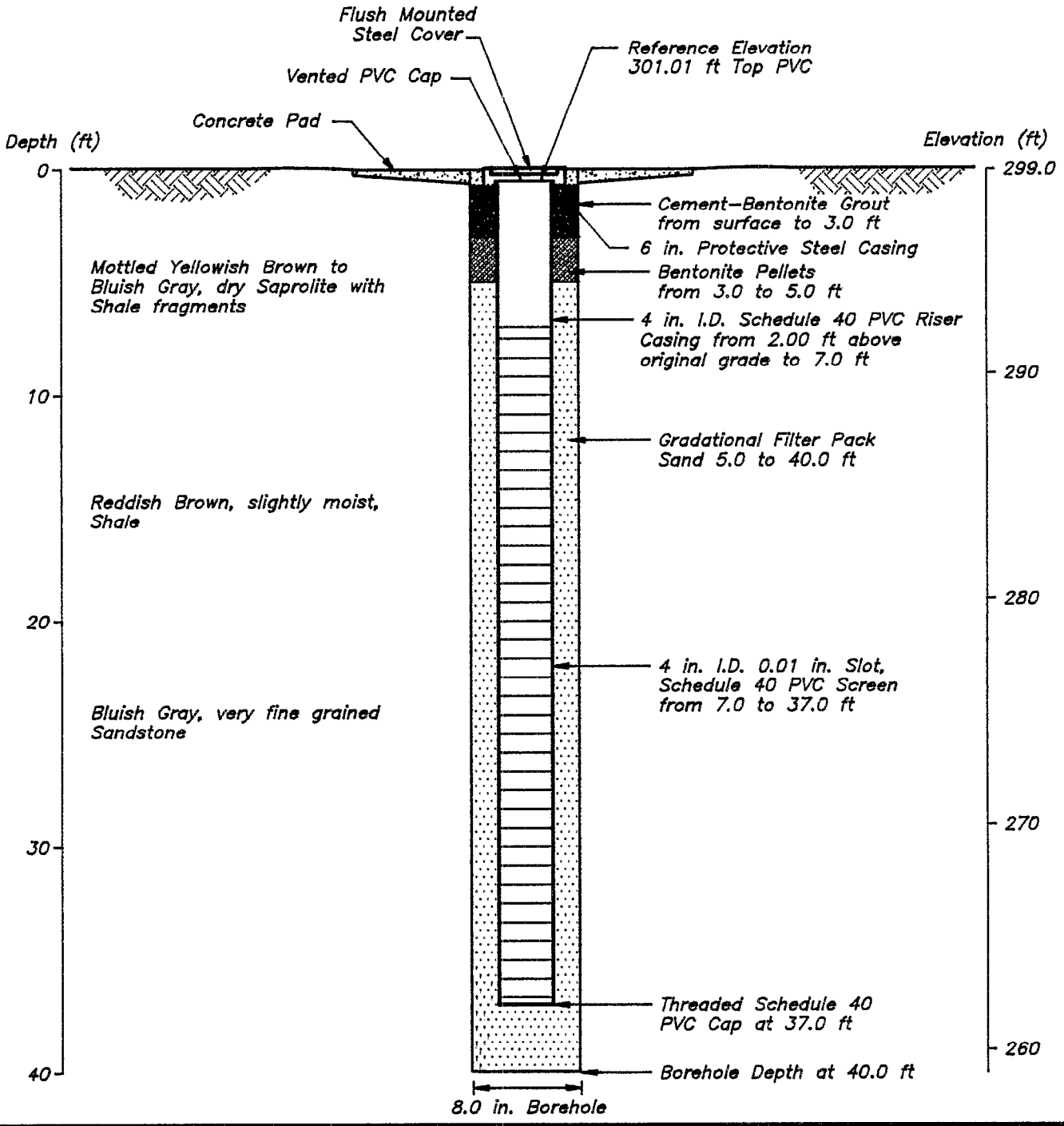
Start Date: 4-24-91 Completion Date: 4-24-91

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS / SOIL DESCRIPTION
						0/0			BLUEISH/GREY VERY FINE GRAINED SANDSTONE, HARD.
							25		
						0/0			BLUEISH/GREY VERY FINE GRAINED SANDSTONE, HARD.
							30		DRILLING RATE INCREASED, REDDISH BROWN SHALE, SOFT
						5/0	35		WATER AT 35 FT.
							40		TERMINATE DRILLING AT 40 FT.

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-10
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.

Client: U.S. Navy

Location: Willow Grove NAS

Job No. 10388.06

Coordinates X: 2726790
Y: 329112

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-11

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

Start Date: 4-24-91 Completion Date: 4-25-91

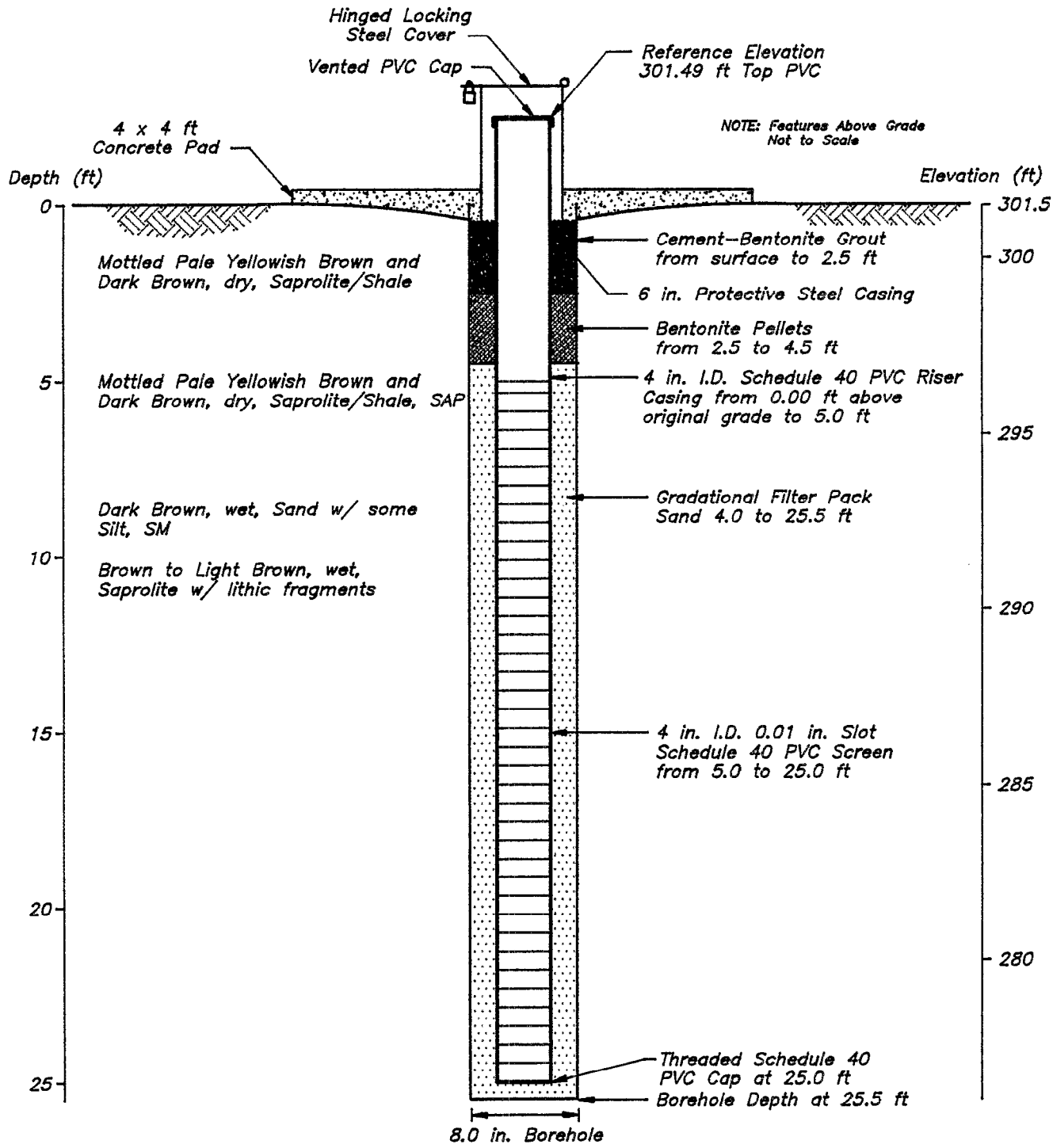
SURFACE CONDITIONS: FLAT, GRASSY. LOCATED 25 FT. WEST OF TRAILER, BETWEEN BUILDINGS 340 AND 345.

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
SS	24	20	1	2.5	16-21-18-21	0/0	X	SAP	MOTTLED PALE YELLOWISH BROWN, AND DARK BROWN, DRY S. MOIST, SAPROLITE SHALE, RELIC STRUCTURE, SOFT
							5		
SS	24	16	2	5	8-18-22-30	0/0	X	SAP	MOTTLED PALE YELLOWISH BROWN, AND DARK BROWN, DRY S. MOIST, SAPROLITE SHALE, RELIC STRUCTURE, SOFT
SS	24	22	3	7.5	8-11-8-15		X	SM	DARK BROWN, WET, SAND W/ SOME SILT, SM, SOME LITHIC FRAGMENTS. WATER DETECTED AT 8 FT.
SS	24	14	4	9.5	18-48-38-51/3"	20/0	10	SAP	BROWN TO LIGTHT BROWN, WET, SAPROLITE, MANY LITHIC FRAGMENTS, HYDROCARBON SMELL. SPOON REFUSAL AT 10 FT, SWITCH TO AIR HAMMER.
									DRILLING SHUTDOWN FOR THUNDERSTORM RESUME DRILLING ON 4-25-91, DRILL TO 25.5 FT. SET WELL AT 25.5 FT.
							15		
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-11
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.	Client: U.S. Navy	Location: Willow Grove NAS
	Job No. 10388.06	Coordinates X: 2726624 Y: 328988

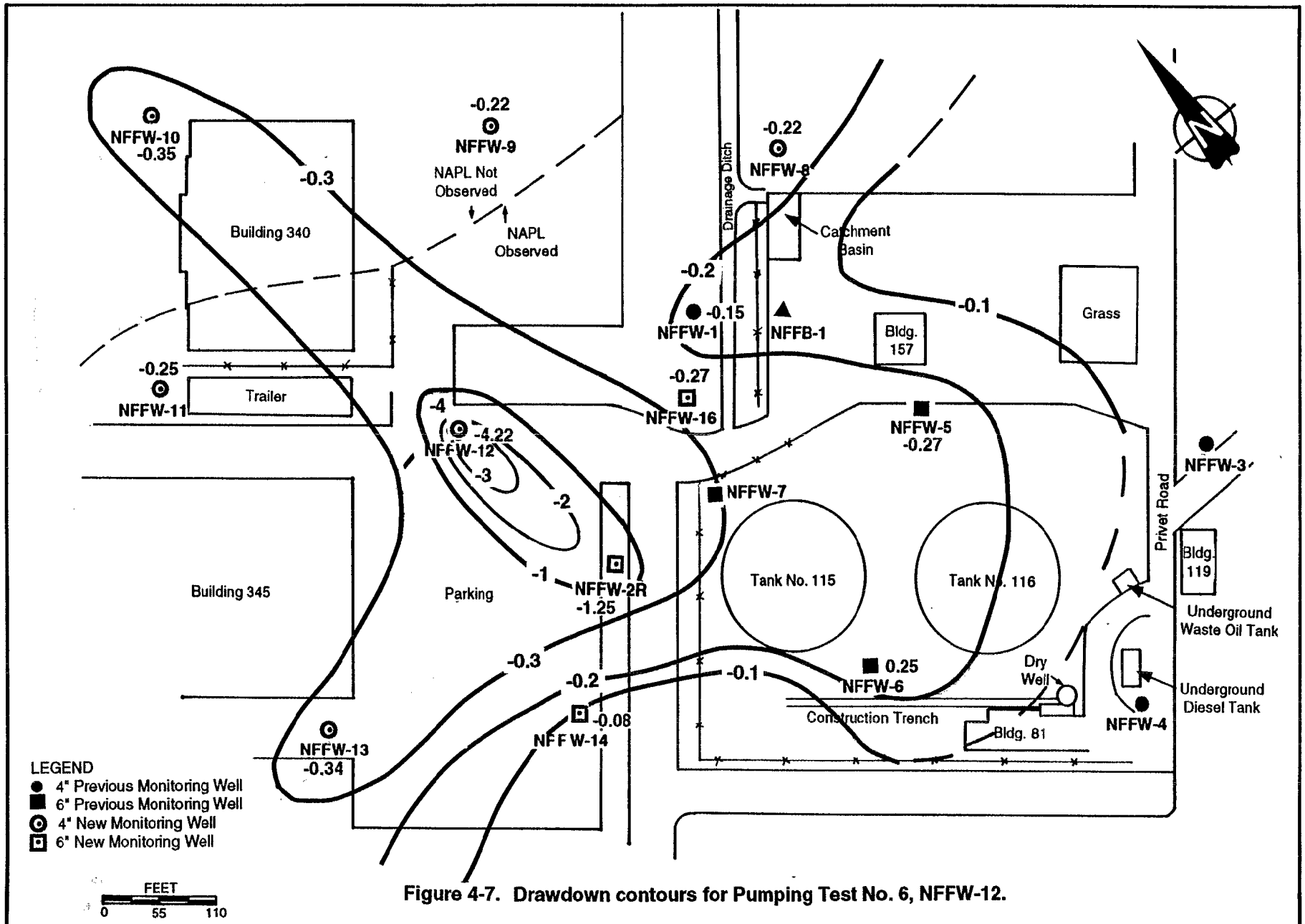


Figure 4-7. Drawdown contours for Pumping Test No. 6, NFFW-12.

NOTE: The subsurface contours shown represent our evaluation of the most probable conditions based upon interpretation of presently available data. Some variations from these conditions must be expected

Aquifer Characteristics

The aquifer characteristics of transmissivity (T), and storativity (S), were calculated by type-curve fitting of graphed drawdown versus time data obtained from the pumping well, NFFW-12, and the observation well, NFFW-2R, which showed the most effect from pumping. Basic physical parameters used in the various models simulating aquifer behavior included a distance of 198 ft between the two wells, effective radius for pumping and observation well of 8-in. and 10-in. respectively, and an aquifer thickness of 50 ft. Drawdown versus time data for Pumping Test 6 are shown in Table 4-4, 4-5, and 4-6.

Three analytical methods were applied to the data in order to compare results for a variety of assumptions. The different results are compared in Table 4-8. An average gradient of 0.029 was determined by measurements taken from ground-water contours as measured at the initiation of pumping tests in June 1991.

The Theis type curve method was first applied to the time versus drawdown data. Theis (1935) developed a log-log plot to determine T and S by the use of a type curve, which is the function of $W(\mu)$ versus $1/\mu$ on log-log paper. Time drawdown data h_o-h versus t are plotted on log-log paper and matched to the appropriate type curve. An arbitrary "match point" is selected and values for $W(\mu)$, $1/\mu$, h_o-h, and t are determined by using those values, pumping rate (Q) and the radial distance (r), from pumping to observation well. T is calculated by the following equation:

$$T = \frac{114.6Q\ W(\mu)}{s} \quad \text{and} \quad \mu = \frac{1.87r^2s}{Tt}$$

TABLE 4-8 AQUIFER PARAMETER ESTIMATION METHODS

	Unit	Theis	Cooper-Jacob	Neuman
Transmissivity (T)	ft^2/min			
NFFW-12		7.47×10^{-3}	7.47×10^{-3}	3.99×10^{-3}
NFFW-2R		3.42×10^{-3}	6.53×10^{-3}	---
Hydraulic Conductivity (K)	ft/min			
NFFW-12		1.49×10^{-4}	1.49×10^{-4}	7.98×10^{-5}
NFFW-2R		6.84×10^{-5}	1.31×10^{-4}	---
Average		1.09×10^{-4}	1.4×10^{-4}	---
Storativity (S)				
NFFW-2R	None	1.94×10^{-4}	1.04×10^{-4}	---
Thickness of aquifer	ft	50	50	50
Darcian pore factor (dpf)	None	0.8	0.8	0.8
Effective porosity (Ne)	None	0.07	0.07	0.07
Gradient (I)	None	0.029	0.029	0.029
Average Ground -Water velocity (Vav)	ft/year	30	38	22

[2] Percent

where

T = transmissivity

Q = pumping rate

$W(\mu)$ = well function of μ

s = drawdown

r = distance from pumped well to observation well

t = time since pumping began

Storativity (S) is then calculated by the equation

$$S = \frac{\mu T t}{1.87 r^2}$$

where

S = storativity (valid for observation well data only)

T = transmissivity

t = time since pumping began

r = distance from pumped well to observation well

The assumptions underlying this method for unsteady-state flow include

- The aquifer is confined.
- The aquifer has a seemingly infinite areal extent.
- The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by the test.
- Prior to pumping, the piezometric surface is flat (nearly horizontal) over the area that will be influenced by the test.
- The aquifer is pumped at a constant discharge rate.
- The well penetrates the entire thickness of the aquifer and thus receives water by horizontal flow.

- The water removed from storage is discharged instantaneously with decline of head.

- The diameter of the well is small, i.e. the storage in the well can be neglected (Kruseman and deRidder 1990).

Results are shown in Figures 4-8 and 4-9. Although the aquifer underlying the site is in bedrock, anistotropic, and unconfined, results from the Theis method provide an approximation of aquifer coefficients. The results give a hydraulic conductivity of 1.09×10^{-4} ft/min which is within the normal range for sandstone as compiled by Freeze and Cherry (1979). Storativity values were calculated from the observation well data. The low value obtained is reasonable considering the low primary porosity of the lithologies involved and low yield of the pumping well.

Secondly, the Cooper-Jacob straight line method was used. This method is a result of the Theis curve developed by altering the Theis solution to a semi-log method by the equation

$$h_o - h = \frac{Q}{4\pi T}\left(-0.5772 - \ln \mu + \mu - \frac{\mu^2}{2.2!} + \frac{\mu^3}{3.3!} + \ldots\right)$$

By noticing that for small μ the sum of the series beyond $\ln \mu$ becomes negligible, and further manipulating the equations it becomes clear that h_o-h versus log t should plot as a straight line.

Therefore, if time-drawdown data are plotted on a semilog graph, and Δh is the drawdown for one log cycle of time and t_o is the time intercept where the drawdown line intercepts the zero drawdown axis, the values of transmissivity and storativity are found by the following equation:

$$T = \frac{264Q}{\Delta s}$$

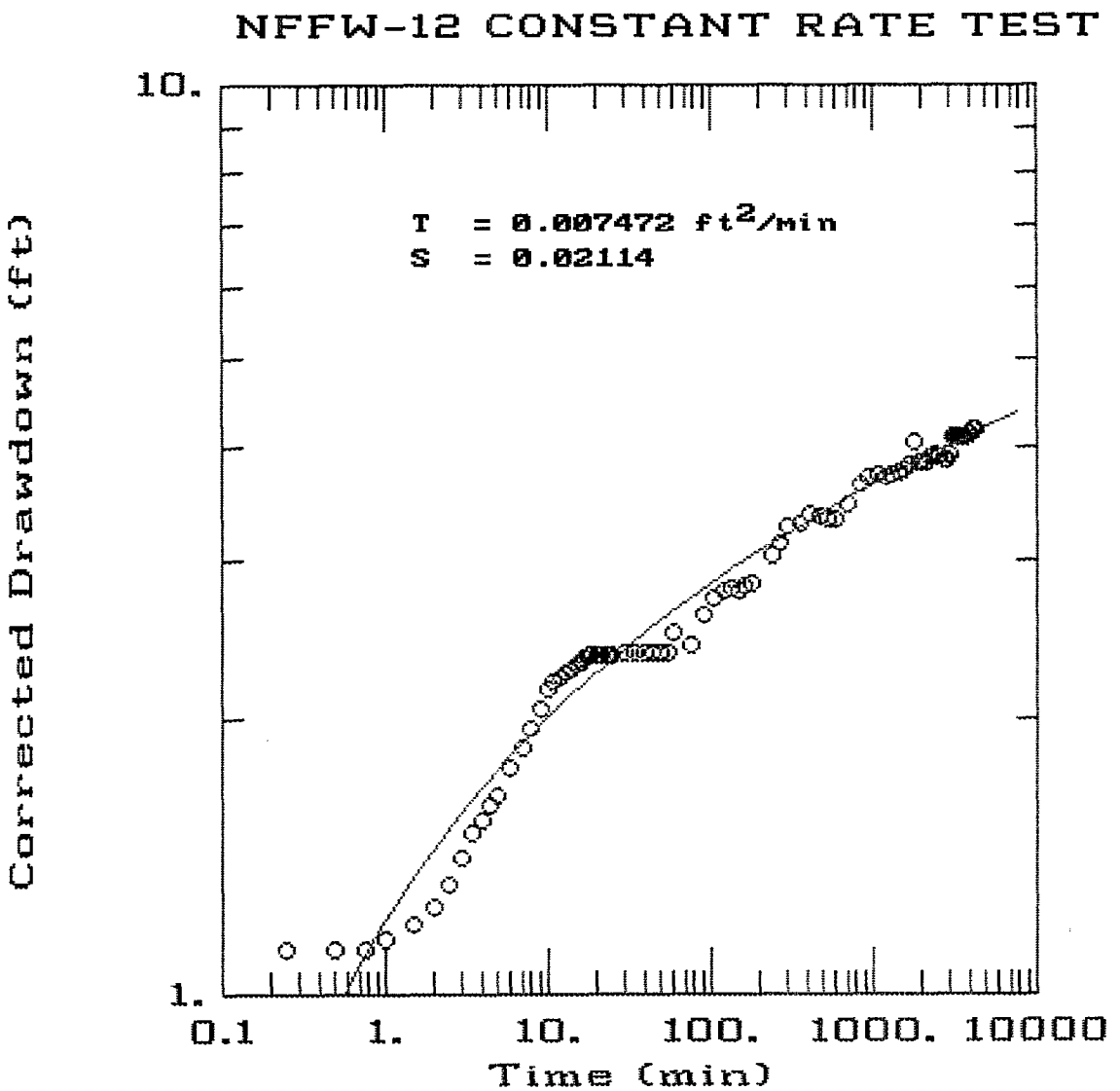


Figure 4-8. Theis curve match for pumping well NFFW-12.

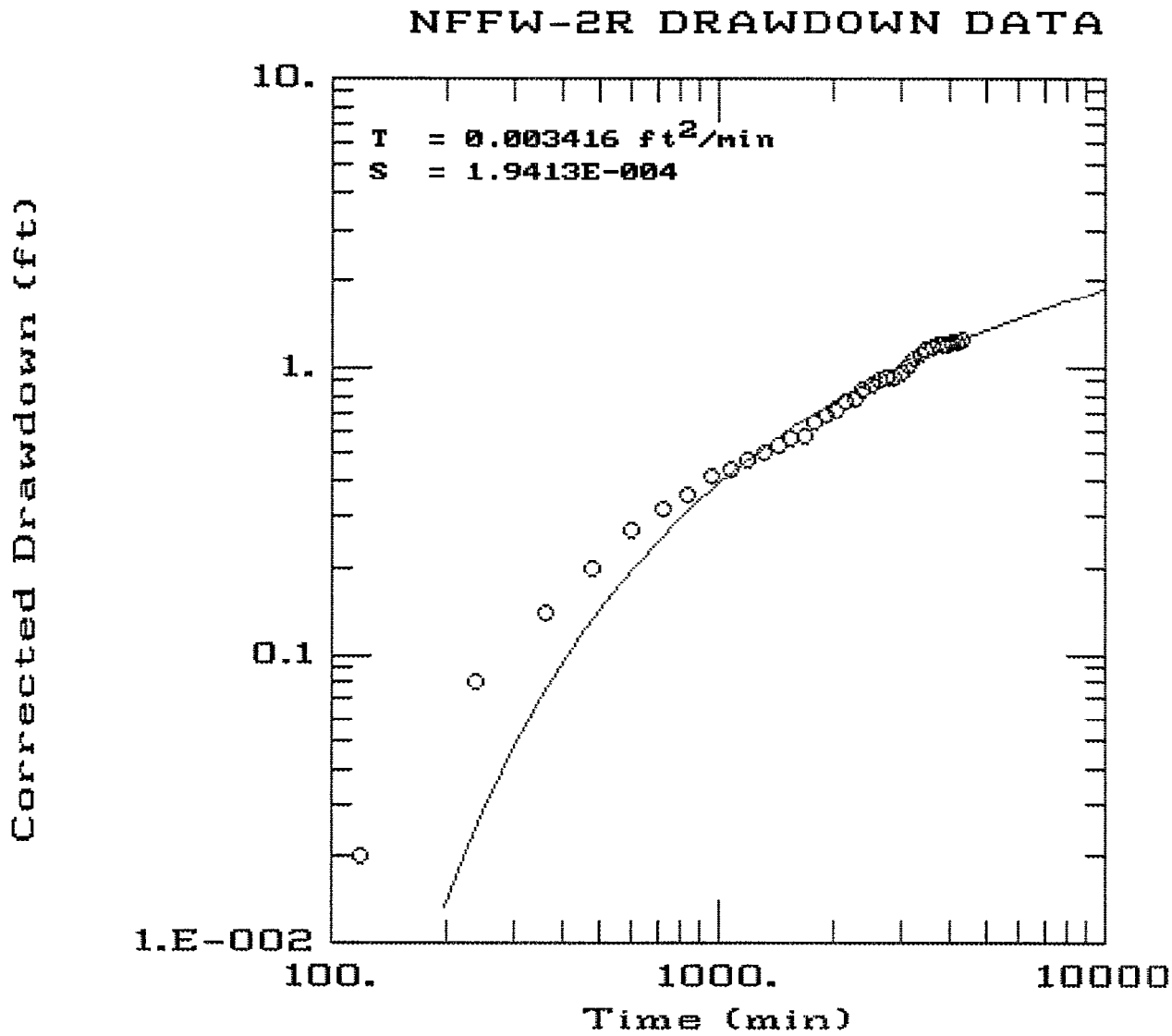


Figure 4-9. Theis curve match for observation well NFFW-2R.

where

T = transmissivity

Q = pumping rate

s = change in drawdown across a log cycle

$$S = \frac{0.3Tt_o}{r^2}$$

where

S = storativity

T = transmissivity

t_o = intercept of the straight line at time zero

r = distance from pumped well to observation well

The assumptions underlying this method are the same as for the Theis method.

The results of this method give an average hydraulic conductivity of 1.4×10^{-4} ft/min, which shows a good agreement to the calculated Theis values. The storativity value from NFFW-2R also shows a close match to the Theis value. The line plots are shown in Figures 4-10 and 4-11.

Thirdly, the Neuman curve fitting method was used. This method is based on the theory of delayed water table response to pumping (in an unconfined aquifer). Time-drawdown data h_o-h versus t are plotted on log-log paper and the resulting data plot is used in type curve matching. A type curve match is used to derive certain values or coordinates on the graph used in the calculation of both a vertical and horizontal hydraulic conductivity. These values multiplied with the saturated thickness of the aquifer will yield the transmissivity value. Specific yield and storativity are also determined using this method.

Two type curves are utilized, a type A curve to match against early time-drawdown data and a type B curve to match against late time-drawdown data. The log-log plot of observed time versus drawdown data was matched

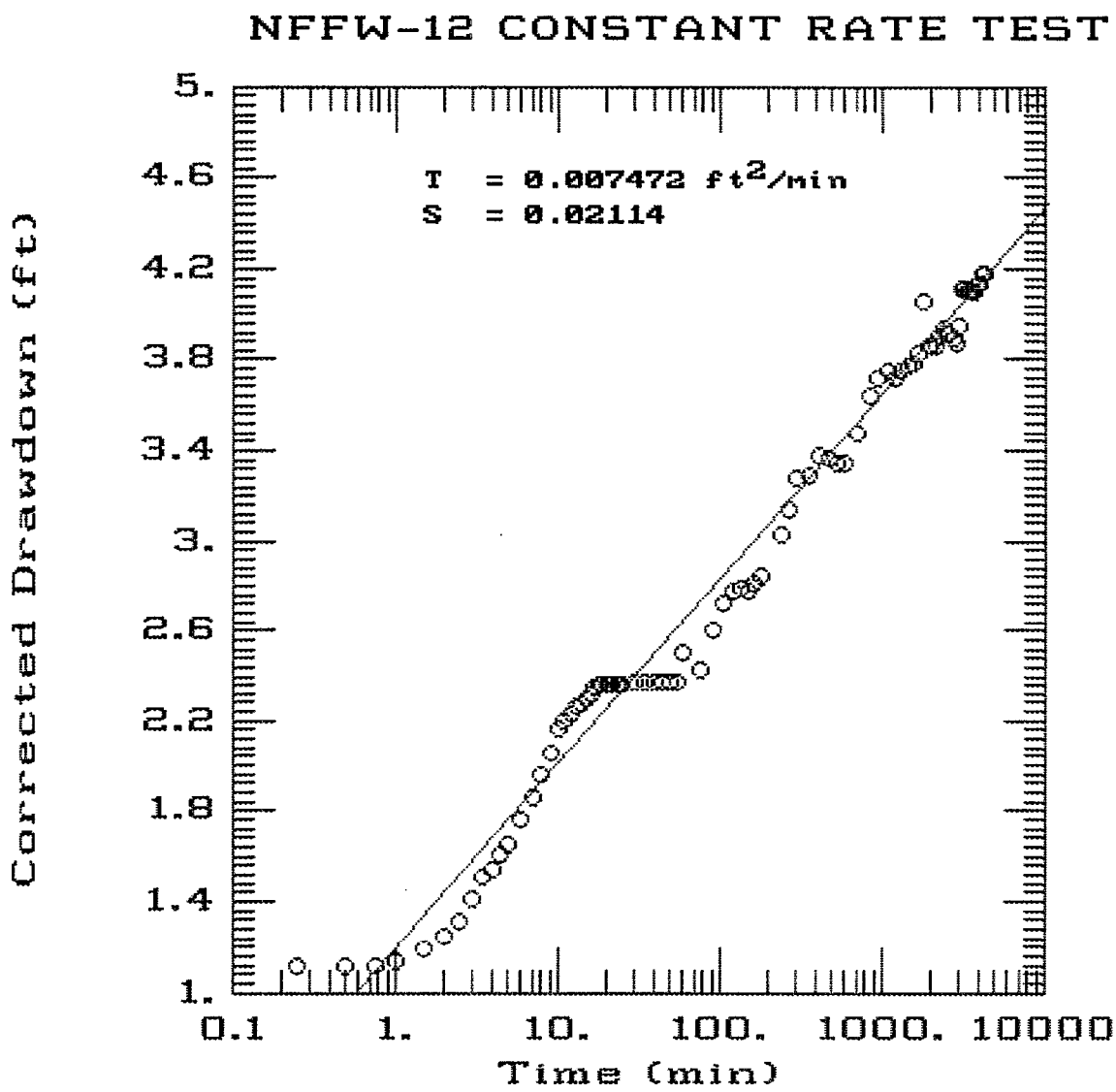


Figure 4-10. Cooper-Jacob line match for pumping well NFFW-12.

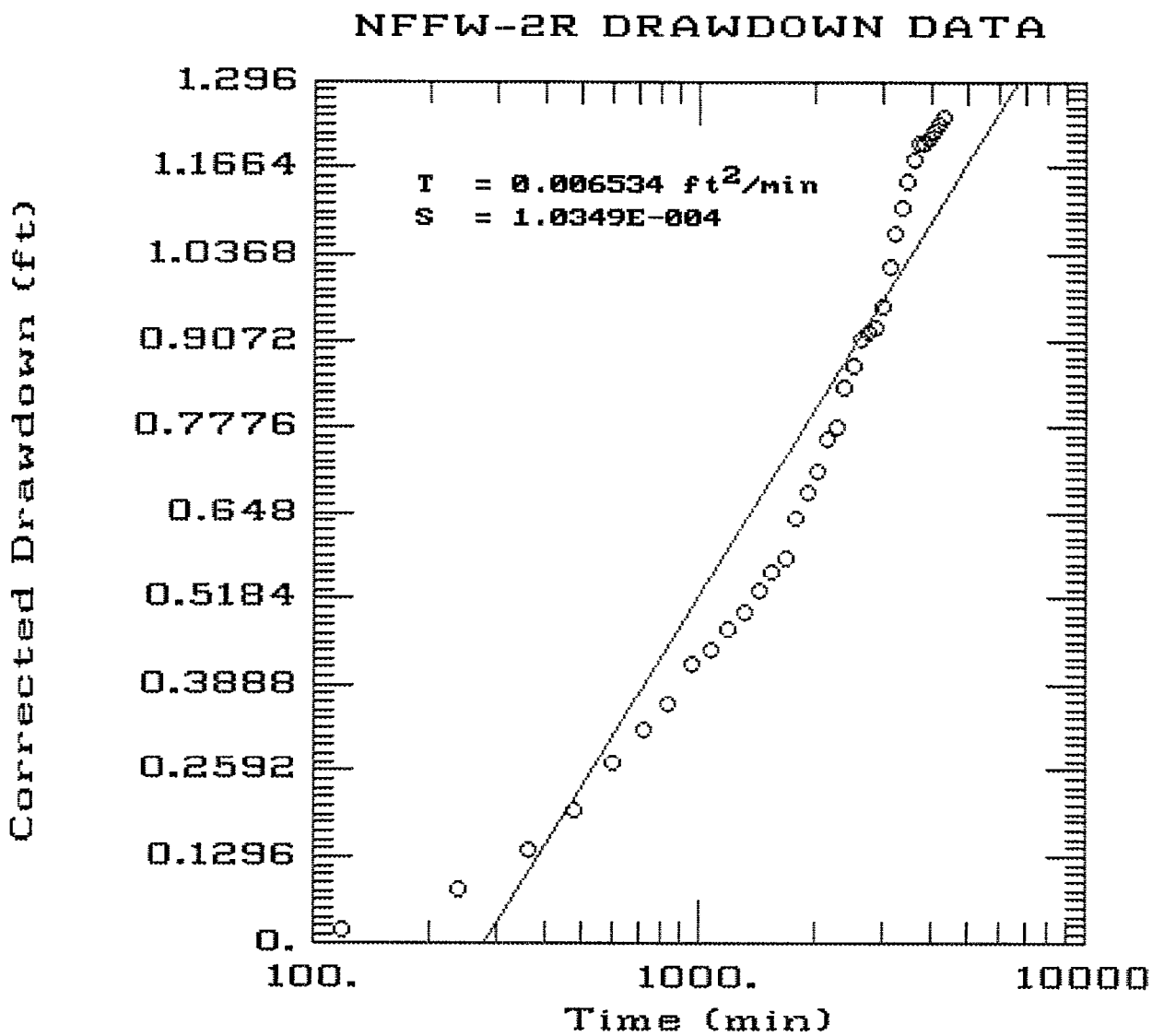


Figure 4-11. Cooper-Jacob line match for observation well NFFW-2R.

against a type A curve to determine hydraulic conductivity (K) and storativity (S). Late time-drawdown was matched to determine K and specific yield (otherwise known as unconfined storativity).

The following assumptions apply to the Neuman curve fitting method.

- The aquifer is unconfined, isotropic or anisotropic.
- The aquifer has a seemingly infinite areal extent, is homogeneous, and is of a uniform thickness.
- The water table is nearly horizontal prior to the test.
- The aquifer is pumped at a constant discharge rate.
- The well penetrates the entire aquifer and receives water from the total saturated thickness.
- The flow to the well is in an unsteady state.
- The influence of the saturated zone is negligible upon drawdown.
- Observation wells penetrate the entire aquifer thickness.
- Storage in pumped and observation wells can be neglected (Kruseman and deRidder 1990).

The results of the Neuman type curve match show a hydraulic conductivity of 7.98×10^{-5} ft/min. Given the water table type aquifer in which the monitoring wells were placed, this value would provide a better approximation of aquifer coefficients. The data plot showed a slight double curve which is indicative of delayed water table response. The data plots and curves are shown in Figure 4-12.

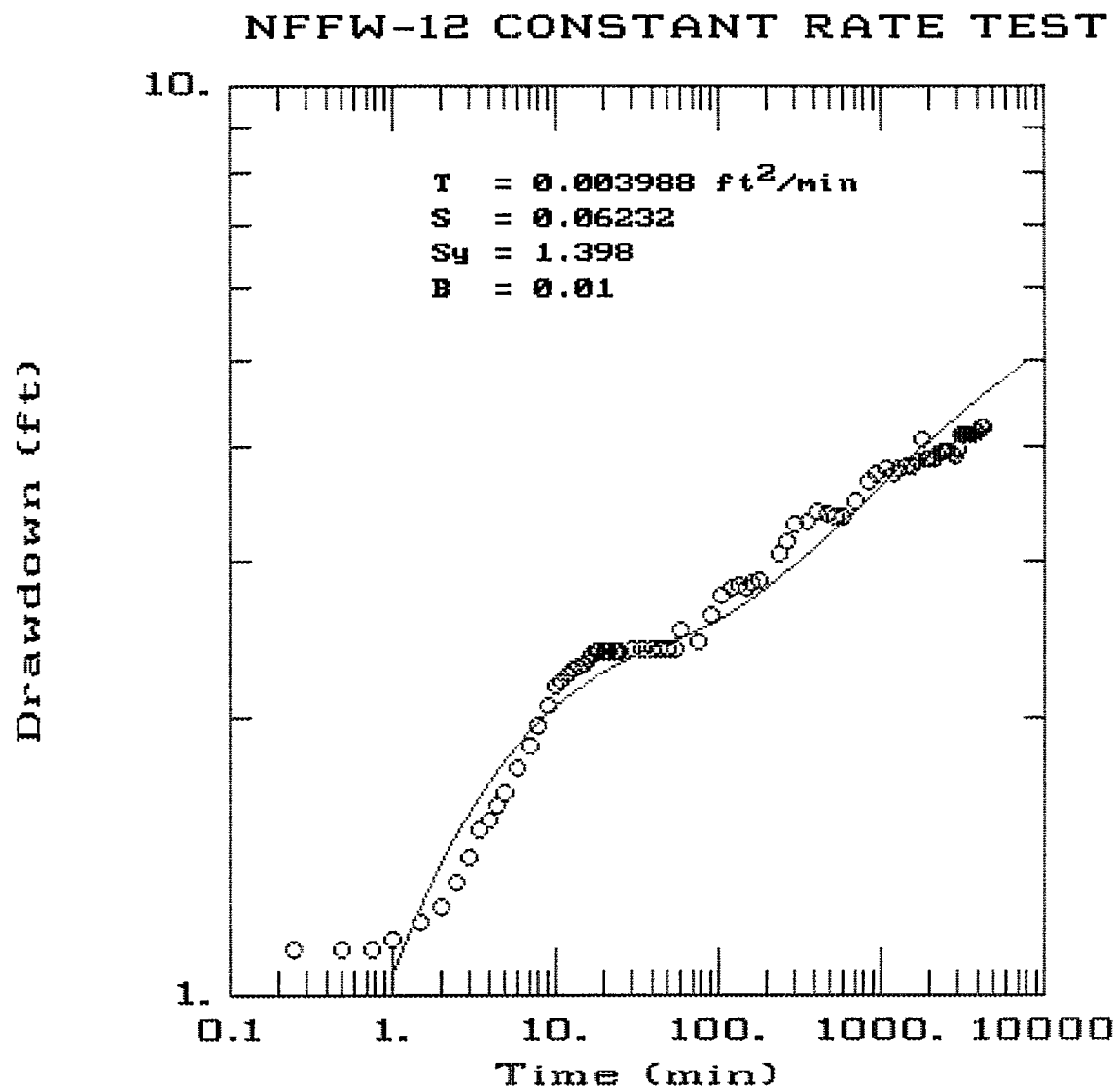


Figure 4-12. Neuman type curve match for pumping well NFFW-12.

The average ground-water-flow velocity at the site can be estimated by substituting the hydraulic conductivity values into the equation

$$V_{av} = \frac{KI}{N_e dpf}$$

where:

V_{av} = average ground-water velocity
K = hydraulic conductivity
I = hydraulic gradient
N_e = effective porosity
dpf = Darcian pore factor

An effective porosity of 7 percent was chosen based on literature values for the sandstone and shale unit present the Navy Fuel Farm (Satterthwaite and Associates, Inc. 1984). The Darcian pore factor (dpf) was graphically determined using data published in Fetter (1988, p. 127).

If an effective porosity of 7 percent and maximum gradient of 0.029 is used with the K value of 8×10^{-5} ft/min obtained using the Neuman method, an average ground-water-flow velocity of 22 ft/year is calculated. The distance between Navy Fuel Farm Tank 115 and monitoring well NFFW-11 is approximately 600 ft. Chemical data suggest that the contaminant plume from the Navy Fuel Farm has reached this well. At this flow rate and known migration distance, it may be inferred that the first spill would have occurred or the first leak would have begun approximately 27 years ago. This estimate would have to be modified in consideration of natural retardation of contaminant migration by the conducting matrix, dispersion, increased flow gradients due to mounding at the spill/leak site, and flow rates within fracture zones.

Modeling, at best, is only approximation of actual parameters. Uncertainties over effective porosity, gradients, and mathematical approximation techniques will cause parameter values to be estimates. Further,

none of the methods used are designed to address the fractured bedrock nature of the aquifer. Ground-water-flow rates within fracture zones may be substantially higher than those estimated.

Analytical Results

Analytical results for BTEX compounds in effluent from pumping well NFFW-12 are summarized in Table 4-7. Benzene concentrations ranged from 230 to 330 µg/L, toluene from 2 to 3 µg/L, ethylbenzene from 140 to 190 µg/L, and total xylenes from 23 to 85 µg/L. Total BTEX concentration peaked at 24 hours and then gradually tapered off with time. The range in values was 396-600 µg/L. TPH values declined from an initial 12.6 mg/L to not detected at 72 hours, showing a continuous decrease through time. The largest decrease in TPH values corresponded to an increase in BTEX values.

5. SUMMARY AND CONCLUSIONS

5.1 ANALYTICAL DATA

The contaminant plume underlying the Navy Fuel Farm continues to move in a northerly direction. Floating product seems to extend no further north than the southwest corner of Building 340 at present. Migration may be inhibited by the bedding plane contact between the grey sandstone in the south half of the site and the less permeable red siltstone and shale to the north. The compounds MEK and TCE were detected in wells located north of the drainage ditch and around Buildings 345 and 340. They may indicate a separate source rather than the Navy Fuel Farm, possibly in the vicinity of the drainage ditch and/or buildings of the Air National Guard facility. BTEX contamination detected in soil from the borehole of NFFW-8 most probably represents residual fuel left adsorbed to the soil during periods of elevated water table.

BTEX analyses taken of water removed from pumping wells during the pumping tests revealed BTEX compounds in concentrations above ARARs in all production wells except NFFW-8. The samples from this well were low in volatile fraction BTEX compounds supporting an interpretation of an older weathered product source for NFFW-8. In all samples, toluene appeared to be depleted relative to other BTEX compounds. TPH values in general showed trends similar to those of BTEX concentrations.

5.2 PUMPING TEST DATA

Analyses of pumping test data were hindered by low yields in the production well, small observed effects in observation wells, and recharge during several of the pump tests. Due to these factors and the variable pumping rate necessitated by the product recovery system, the 48-hour pumping test drawdown data were not used for aquifer analysis.

The 72-hour pumping test differed from the 48-hour tests in that the aquifer had 10 days to recover from the previous pumping test instead of the nominal 3 days. The pumping rate was also held constant by disconnecting the product pump and monitoring product levels by hand. Data gathered from the pumping well NFFW-12 and the observation well NFFW-2R showed trends amenable to analysis.

Three analytical methods were used to interpret the data, the Theis method, the Cooper-Jacob straight line approximation, and the Neuman Curve Matching method. The Neuman (unconfined aquifer) method resulted in an estimated hydraulic conductivity (8×10^{-5} ft/min) approximately one-half order of magnitude lower than the confined aquifer methods. Fracture zone values may be considerably higher.

Product recovery results from pumping tests 1 and 6 suggest that well NFFW-2R may serve as a product recovery well. The only other well with consistently measurable product was well NFFW-14; however, the volume and weathered nature of the product and the well's limited zone of influence make well NFFW-14 less attractive as a potential recovery well than NFFW-2R.

6. RECOMMENDATIONS

Based on the conclusions derived from the data collected from well installation and sampling as well as pumping tests, the following recommendations for further work at the Navy Fuel Farm are proposed.

1. Install six additional 4-in. wells at the locations shown in Figure 6-1. Wells NFFW-15, NFFW-17, NFFW-18, NFFW-20, and NFFW-21 will be used to assess the northwest and northeast extent of plume migration from the Navy Fuel Farm. Well NFFW-19 would be installed immediately downgradient of the recently removed underground waste oil storage tank in order to assess the potential for a plume migrating downgradient from the tank site. Well depth nominally would be 15 ft below static water level with a 20-ft screened interval extending 5 ft above the water table.

2. Install a pilot product recovery system on well NFFW-2R and initiate product recovery by pumping NFFW-2R and/or NFFW-12.

3. Install a product skimmer pump or automated bailer on well NFFW-6 and assess its potential to continuously yield product without water table depression.

4. During operation of 2 and 3, all other wells at the site would be gauged for product, initially once per day. Depending on the results of daily gauging for about 2 weeks, the gauging scheduled may be extended to weekly or larger time intervals. During the well gauging, wells showing product accumulation would have the product removed by hand bailing. If any of these wells show consistent product accumulation, they may become candidates for an additional product recovery

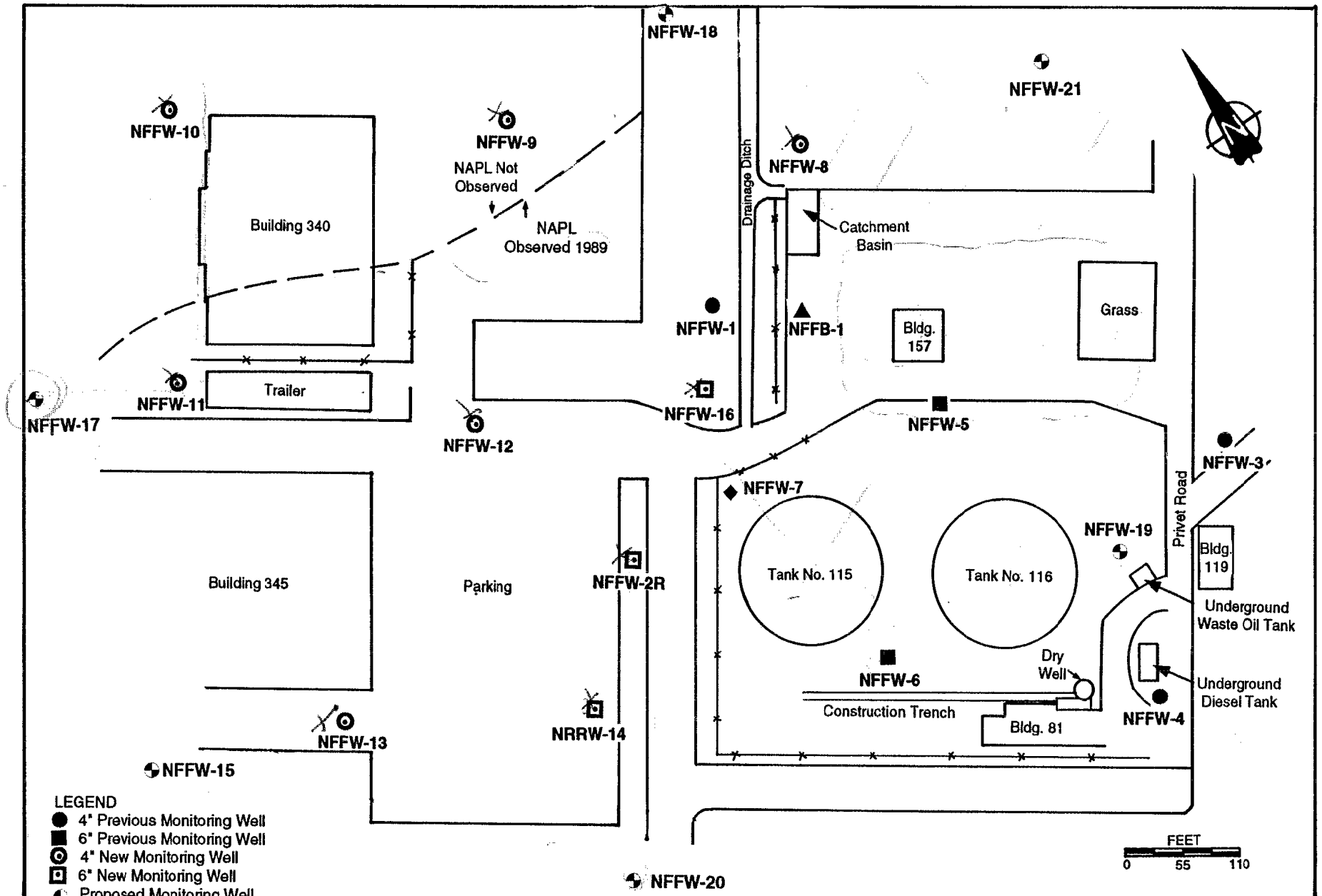


Figure 6-1. Proposed new well locations for 4-in. monitoring wells.

well using either a water table depression product recover system or an autoskimmer pump depending on water levels in the wells.

5. Prepare a CAD map of the site utilizing recent aerial photography. This will greatly improve the accuracy of the site map and allow a more accurate determination of ground-water flow directions and gradients.

All recommendations except number five would be contingent on construction activities being completed at the Navy Fuel Farm. Any product recovered will be properly drummed, labeled, and turned over to base personnel for recycling and/or disposal.

REFERENCES

Cooper, H.H. and C.E. Jacob. 1946. A generalized graphical method for evaluating formation constants and summarizing well field history. Am. Geophys. Union Trans., Vol. 27, pp. 526-534.

EA Engineering, Science, and Technology, Inc. 1988. Plan of Action for Site Inspection NAS Willow Grove, Pennsylvania. Prepared for U.S. Navy, Naval Facilities Engineering Command, Philadelphia, PA.

EA Engineering, Science, and Technology, Inc. 1989a. Electromagnetic Survey, Soil Vapor Contaminant Assessment, and Revised Field Sampling Plan for Site Inspection Studies at NAS Willow Grove. Interim Report Prepared for U.S. Navy, Naval Facilities Engineering Command, Philadelphia, PA.

EA Engineering, Science, and Technology, Inc. 1989b. Environmental Test Boring Investigation at the Air National Guard Facility. Final Report Prepared for U.S. Naval Air Station Willow Grove, Horsham Township, Pennsylvania. U.S. Navy, Naval Facilities Engineering Command, Philadelphia, PA.

EA Engineering, Science, and Technology, Inc. 1990. Site Inspection Studies at NAS Willow Grove. Horsham Township, Pennsylvania. Final Report.

Fetter, C.W. 1988. Applied Hydrogeology C.E. Merrill Publishing Co., Columbus, OH. 592 pp.

Freeze, R., and J. Cherry. 1979. Groundwater. Prentice-Hall Inc. Englewood Cliffs, New Jersey. 604pp.

Kruseman, G.P., and N.A. deRidder. 1990. Analysis and Evaluation of Pumping Test Data. Pub. 47 Inter. Inst. Land Reclamation and Improvement. Wageningen, The Netherlands.

Neuman, S.P. 1975. Analysis of pumping data from anisotropic unconfined aquifers considering delayed gravity response. Water Resources Res., Vol. 11, pp. 329-342.

Rima, D.R., H. Meisler, and S. Longwill. 1962. Geology and Hydrology of the Stockton Formation in Southeastern Pennsylvania. Bulletin W-14, Pennsylvania Topographic and Geologic Survey 111 pp.

Satterthwaite and Associates, Inc. 1984. Final Report on the Ground Water Monitoring and Hydrogeologic Investigation. U.S. Navy, Naval Air Development Center, Warminster, PA.

Theis, C.V. 1935. The relations between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground water storage. Trans. Amer. Geophys. Union 16:519-524.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-12

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

Start Date: 4-25-91 Completion Date: 4-25-91

SURFACE CONDITIONS: FLAT PAVED, LOCATED AT CROSSROADS BETWEEN BUILDINGS 340 AND 345.

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
SS	24	12	1	2.5	2-4-8-10	0/0	X	ML	WATER AT SURFACE(PERCHED) BROWN, WET, CLAYEY SILT W/ TRACE VERY FINE SAND, ML MICACEOUS
SS	24	20	2	5	7-9-11-13	8/0	X 5	ML	REDDISH BROWN , S. MOIST, CLAYEY SILT, W/ TRACE VERY FINE SAND, MICACEOUS. HYDROCARBON ODOR.
SS	24	20	3	7.5	2-11-13-14	7/0	X	ML	DARK REDDISH BROWN, S. MOIST, CLAYEY SILT W/ TRACE VERY FINE SAND, MICACEOUS.
SS	24	20	4	10	7-7-7-10	10/0	X 10	ML	DARK REDDISH BROWN, S. MOIST, CLAYEY SILT W/ TRACE VERY FINE SAND, MICACEOUS, HYDROCARBON STAIN.
SS	24	6			7-13-13-26	12/0		SM	POOR RECOVERY, NO SAMPLE TAKEN DARK REDDISH BROWN, S. MOIST, SILTY SAND, SM.
SS	24	6			5-50/5"				SPOON REFUSAL AT 13.5 FT. SWITCH TO AIR HAMMER.
							15		REDDISH BROWN, MOIST, SHALE, MICACEOUS, FISSEL
						20/0			STRONG HYDROCARBON SMELL. WATER AT 17 FT.
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-12

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

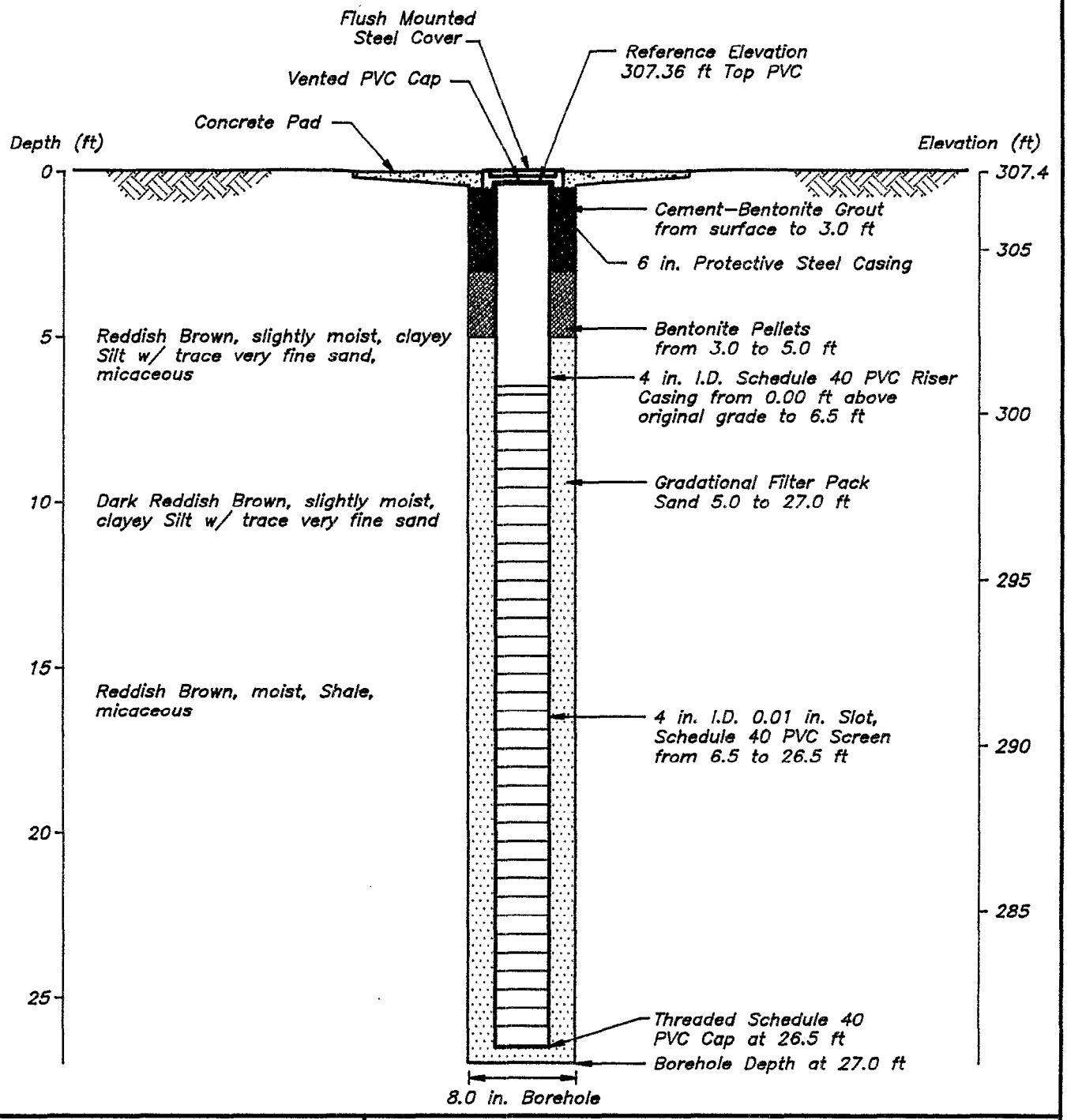
Start Date: 4-25-91 Completion Date: 4-25-91

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS / SOIL DESCRIPTION
							20		
						50/0			BREATHING ZONE READINGS BETWEEN 1 AND 20 PPM.
							25		
									TERMINATE DRILLING AT 28 FT.
							30		
							35		
							40		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-12
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.	Client: U.S. Navy	Location: Willow Grove NAS
	Job No. 10388.06	Coordinates X: 2726751 Y: 328781

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-13

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

Start Date: 4-23-91 Completion Date: 4-23-91

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS: FLAT, PARKING LOT. 10 FT. SW OF BUILDING 345. SOIL DESCRIPTION
									FILL MATERIAL- CLAYEY SILT, GRAVEL
SS	9	8	1	2.5	50-50/3"	0/0	X	FILL	SPLIT SPOON REFUSAL, SWITCH TO AIR HAMMER
								SS	LIGHT BROWN TO WHITE, FINE TO MED GRAIN SANDSTONE W/ IRON STAINING, HARD
							5		CUTTINGS:
						0/0			REDDISH BROWN SHALE/SILTSTONE
							10		
						0/0			REDDISH BROWN SHALE SILTSTONE, SLIGHTLY MICACEOUS
							15		
						0/0			BLUEISH GREY, FINE GRAIN SANDTONE/SILTSTONE
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-13

Coordinates:

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 8" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: SPLIT SPOON, 140 IB. HAMMER, 30" DROP.

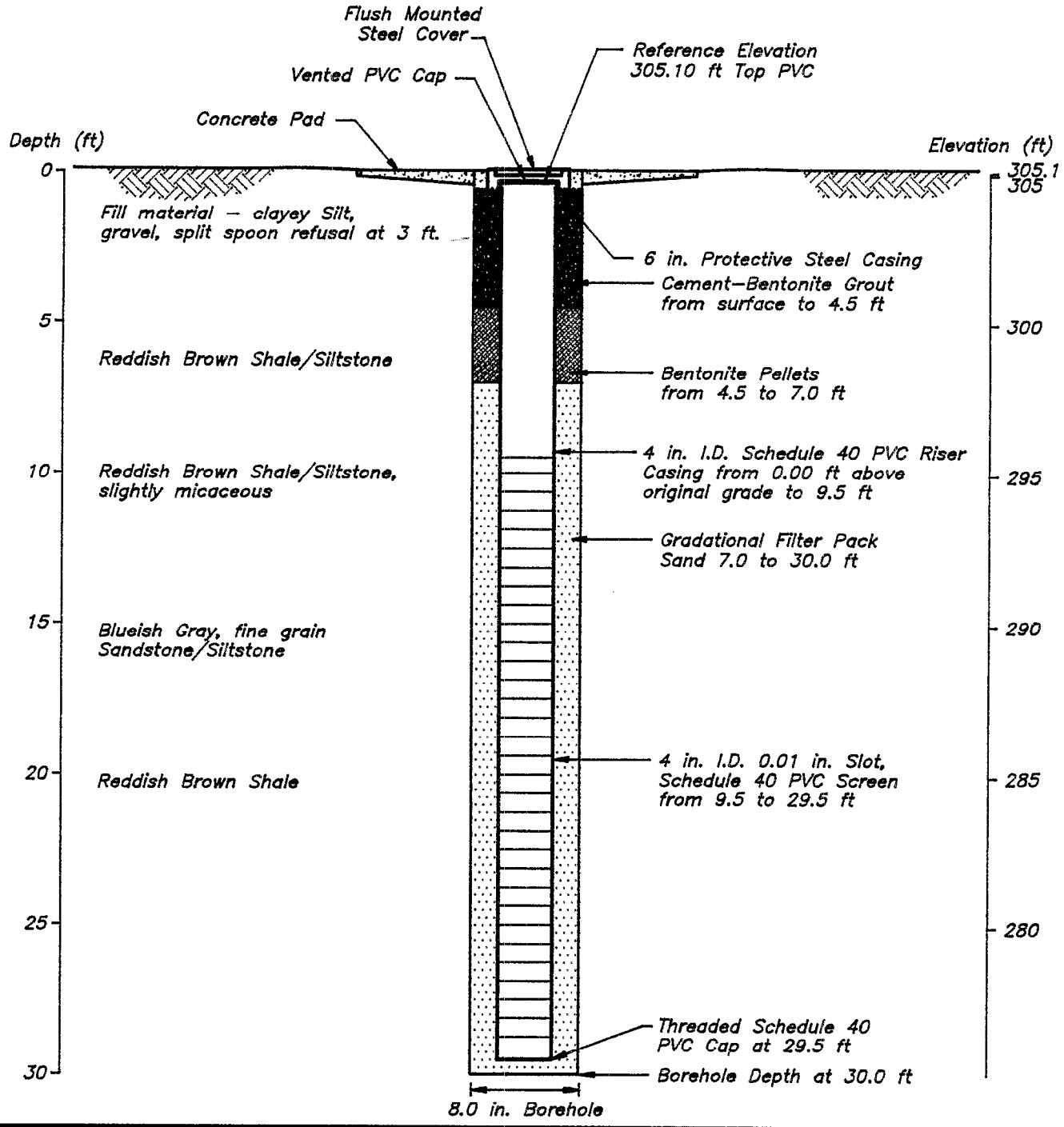
Start Date: 2/22/90 Completion Date: 2/22/90

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS / SOIL DESCRIPTION
							20		
						0/0			REDDISH BROWN SHALE
						40/0	25		HYDROCARBON SMELL
							30		TERMINATE BORING AT 30 FT.
							35		
							40		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-13
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.

Client: U.S. Navy

Job No. 10388.06

Location: Willow Grove NAS

Coordinates X: 2726494
Y: 328749

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-14

Coordinates:

Surface Elevation:

Casing Above Surface:

Reference Elevation:

Reference Description:

Location: NAS WILLOW GROVE

Job No. 10388.07

Client: NAVY

Drilling Method: 10" AIR HAMMER, MOBILE B-80 DRILL RIG

Sampling Method: NA

Start Date: 4-29-91 Completion Date: 4-30-91

SURFACE CONDITIONS: FLAT PAVED, LOCATED EAST OF BUILDING 345, IN CORNER OF PARKING LOT

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
								FILL	
						0/0			DARK REDDISH BROWN, S. MOIST, SAPROLITE, MICACEOUS
							5		
						0/0			DARK REDDISH BROWN, S. MOIST, SAPROLITE/SHALE, SOFT MICACEOUS
							10		
						0/0			DARK REDDISH BROWN, SHALE, SLIGHLTLY DARKER, MORE WATER, MOIST, MICACEOUS
							15		
									SLIGHT COLOR CHANGE TO LIGHTER RED.
						2/0			DARK REDDISH BROWN, MOIST SHALE FRAGMENTS.
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-14

Coordinates:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 10" AIR HAMMER, MOBILE B-80 DRILL RIG

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Sampling Method: NA

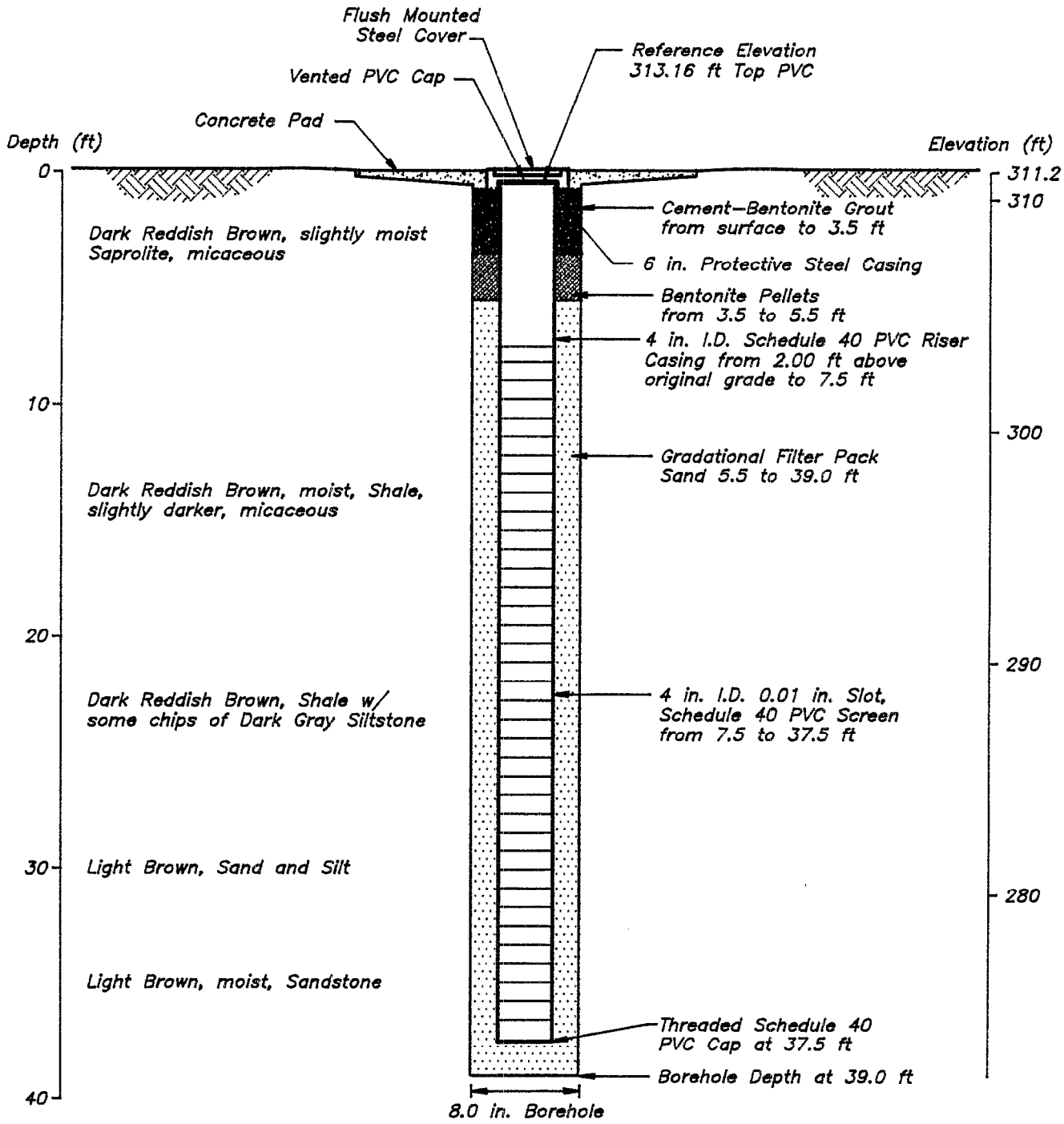
Start Date: 4-29-91 Completion Date: 4-30-91

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS / SOIL DESCRIPTION
									DARK REDDISH BROWN, SHALE, SOME CHIPS OF DARK GREY SILTSTONE
						0/0			
							25		
						15/0			DRILL RATE SLOWED.
							30	SS	COLOR CHANGE TO LIGHT BROWN, SAND AND SILT
						25/0			
							35		
						100/0			LIGHT BROWN, MOIST SANDSTONE, HARD.
						200/0			4-30-91 WASH HOLE, DARK PRODUCT PRESENT. TERMINATE DRILLING AT 39 FT.
							40		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-14
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.	Client: U.S. Navy	Location: Willow Grove NAS
	Job No. 10388.06	Coordinates X: 2726636 Y: 328596

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-16

Coordinates:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 10" AIR HAMMER, MOBILE B-80 DRILL RIG
Sampling Method: NA

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Start Date: 4-30-91 Completion Date: 4-30-91

SURFACE CONDITIONS: FLAT GRASSY, LOCATED ACROSS FROM FUEL FARM ADJACENT TO SURFACE DRAINAGE DITCH.

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SOIL DESCRIPTION
								ML	MED. BROWN, MOIST, CLAYEY SILT, ML, SLIGHT PLASTICITY.
							5		
								SAP	REDDISH BROWN, MOIST, CLAYEY SILT/ SAPROLITE, ML
							10		
								SS	HARD ROCK AT 12 FT. DARK REDDISH BROWN W/ DARK GREY FRAGMENTS OF VERY FINE GRAINED SANDSTONE, MICACEOUS, HARD.
							15		
									HYDROCARBON SMELL
								SHALE	COLOR CHANGE, MORE REDDISH, EASIER DRILLING, SHALE.
							20		

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 HRS. FT.
AFTER 24 HRS. FT.

EA ENGINEERING, SCIENCE, AND TECHNOLOGY

LOG OF SOIL BORING

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

BORING NO. NFFW-16

Coordinates:

Location: NAS WILLOW GROVE
Job No. 10388.07
Client: NAVY
Drilling Method: 10" AIR HAMMER, MOBILE B-80 DRILL RIG

Surface Elevation:
Casing Above Surface:
Reference Elevation:
Reference Description:

Sampling Method: NA

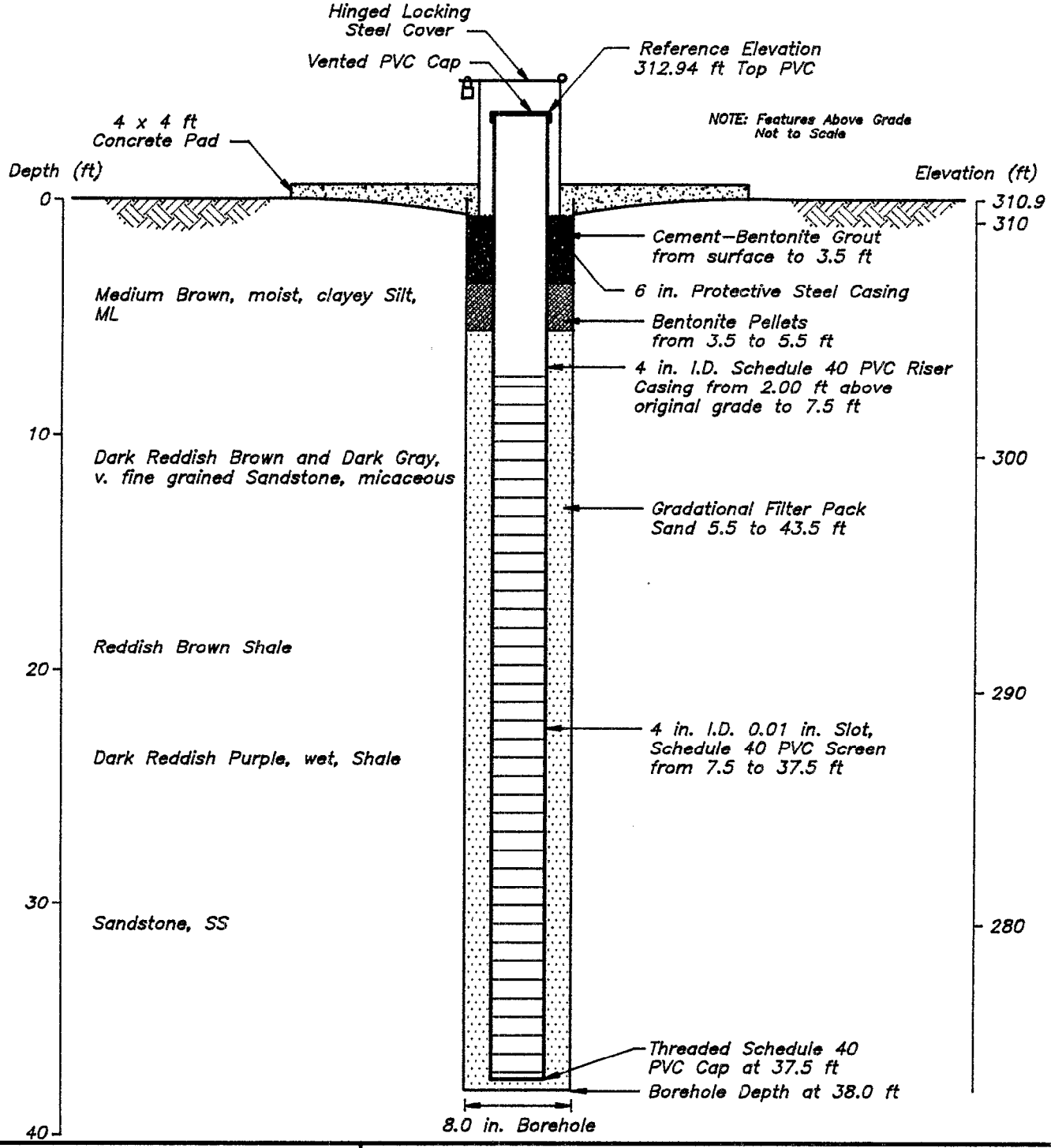
Start Date: 4-30-91 Completion Date: 4-30-91

SAMP TYPE	IN DRVN	IN RCVD	SAMP NO.	SAMP DPTH	BLOWS/6"	HNU/ CGI	DEPTH FEET	GRAPH LOG	SURFACE CONDITIONS / SOIL DESCRIPTION
									DARK REDDISH PURPLE, WET, SHALE, HYDROCARBON SMELL.
							25		WATER PRESENT
									STRONG HYDROCARBON SMELL
							30	SS	HARD DRILLING, SANDSTONE.
							35		
									DRILLING TERMINATED AT 38 FT.
							40		

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 HRS. FT.
AFTER 24 HRS. FT.

WELL NO: NFFW-16
WELL COMPLETION DIAGRAM



EA ENGINEERING, SCIENCE, AND TECHNOLOGY, INC.	Client: U.S. Navy	Location: Willow Grove NAS
	Job No. 10388.06	Coordinates X: 2726872 Y: 328742