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Summary Report
for
Hydrogeologic Study At The Tank Farm

Naval Submarine Base New London
Groton, Connecticut

Northern Division
Naval Facilities Engineering Command
Contract Number N62472-90-D-1298
Contract Task Order 0204

February 1999

TETRA TECH NUS, INC.

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SUMMARY REPORT FOR HYDROGEOLOGIC STUDY AT THE TANK FARM FOR NAVAL SUBMARINE BASE - NEW LONDON GROTON, CONNECTICUT

COMPREHENSIVE LONG-TERM
ENVIRONMENTAL ACTION NAVY (CLEAN) CONTRACT

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1.0 INTRODUCTION

This report summarizes the purpose and results of the tasks completed by Tetra Tech NUS, Inc. (TtNUS), formerly Brown & Root Environmental, to evaluate the hydrogeologic conditions at the Tank Farm, Naval Submarine Base-New London (NSB-NLON), Groton, Connecticut in support of finalization of the design of the new storm sewer system. This work is being conducted by TtNUS for the U.S. Department of the Navy (Navy) under the Comprehensive Long-Term Environmental Action Navy (CLEAN), Contract Number N62472-90-D-1298, Contract Task Order 204.

1.1 PURPOSE

The Navy is planning to replace a majority of the existing storm sewer/underdrain system in the vicinity of the Tank Farm. The system is old and deteriorated and is currently contributing to environmental problems (i.e., contaminant migration). The Navy would like to design and install a new system that will efficiently and cost-effectively convey storm water to the Thames River, minimize the migration of contamination from the Tank Farm to the Thames River, and maintain the current depressed water table in the vicinity of the Tank Farm.

The Navy can not finalize the design of the new storm sewer/underdrain system until the impact of replacing the existing storm sewer system on the local groundwater table is thoroughly evaluated. Insufficient information is available regarding the condition of the existing storm sewer/underdrain system, the flow rate of groundwater removed by the storm sewer/underdrain system, and the hydrogeologic conditions to finalize the design. Therefore, additional field work and groundwater modeling tasks are required to address the data gaps. The goals of the additional field work and groundwater modeling tasks are to answer the following questions:

- Is the current underdrain system working to depress the water table in vicinity of the Tank Farm?
- What is the groundwater flow rate in the current underdrain system?
- Is the bedrock a significant source of recharge to the overburden at the Tank Farm?
- Will replacement of the current underdrain system with one that is water-tight result in the water table rising to levels that will adversely impact the ballfields and the surrounding roads and buildings?

- Will revisions to the current underdrain system, as proposed in the preliminary design package, result in the water table rising to levels that will adversely impact the ballfields and the surrounding roads and buildings?

1.2 BACKGROUND INFORMATION

The Tank Farm at NSB-NLON was constructed in the 1940s to store No. 6 and No. 2 fuel oils. The fuel oils were used to refuel submarines and for heating oil. A total of nine underground storage tanks (USTs) [OT-1 through OT-9] were originally constructed. A tenth tank (OT-10) was constructed later to store waste oils. OT-10 is comprised of a 30,000-gallon, double-walled UST, an oil/water separator, and a 10,000-gallon waste oil tank. All of the tanks, except OT-10, have been demolished in place.

The nine concrete USTs were constructed in the location of the former Crystal Lake. This lake was created naturally by a stream discharging into a bedrock depression. The Navy diverted the stream that fed Crystal Lake into a storm sewer which runs along Crystal Lake Road. It is also likely that groundwater from bedrock hillsides to the north and south helped to recharge the lake.

Because the tanks were constructed in an area prone to collect water, five of the nine tanks (i.e., OT-1, OT-2, OT-3, OT-4, and OT-6) had perimeter underdrains installed around them during their construction to depress groundwater levels. In addition, the storm sewers which the underdrains tie into were constructed of perforated corrugated metal pipe to help de-water the area. The underdrain at OT-6 was subsequently abandoned by the Navy around 1966 during the completion of improvements to the storm sewer system.

1.3 REPORT ORGANIZATION

This report is organized into five sections. Section 1.0 summarizes introductory and background information. Section 2.0 describes the field activities completed for the project and the results of the activities. Modeling tasks completed for the project are discussed in Section 3.0. Conclusions and recommendations for the project are summarized in Sections 4 and 5, respectively. All tables and figures are included at the end of the text for each section. Other relevant information (i.e., field forms, calculations, etc.) is included in appendices.

2.0 FIELD WORK

TtNUS performed field activities to address the remaining data gaps for finalizing the design of a new storm sewer/underdrain system, as defined in Section 1.0. The field tasks were conducted in two phases as described in the Internal Letter Work Plan (B&R Environmental, May 1998). Phase 1 was completed between May 20, 1998 to May 22, 1998 and included one round of water level measurements from 37 existing monitoring wells, estimation of groundwater flow rates into the existing storm sewer/underdrain system, and surveying water level elevations of the stream east of Building 447. Phase 2 was completed between July 6, 1998 to August 7, 1998, and included installation of four bedrock monitoring wells along the perimeter of the Tank Farm and collection of one round of water levels from 37 existing wells and the four newly installed bedrock wells. The following sections describe the methods and results of Phase 1 (Section 2.1) and Phase 2 (Section 2.2) field activities.

2.1 PHASE 1

2.1.1 Water Level Measurements

Groundwater levels were measured in monitoring wells in the vicinity of the Tank Farm, Goss Cove Landfill, and the south end of Lower Subase to provide an understanding of hydrogeologic conditions and the data necessary to develop and calibrate a groundwater flow model. Water levels were measured in 37 existing monitoring wells on May 20, 1998 during Phase 1 field work. The methodology used to take the measurements and the results are discussed below.

2.1.1.1 Methodology

Water levels were measured in the monitoring wells listed in Table 2-1 and illustrated on Drawing 2-1. No measurements were taken at two of the proposed 40 wells; HNUS-16 was unable to be located and 15MW4S had been destroyed. An accurate water level could not be obtained from 8MW8S because the well had been altered (i.e., PVC riser pipe had been cut) since it was installed. Water levels were measured to the nearest 0.01 foot from the reference point of the top of each well casing using an electronic water level indicator. Water level measurements were recorded on Groundwater Level Measurement Sheets (Appendix A).

Water levels were measured between 11:45 am and 6:20 pm on May 20, 1998. Water levels were first measured in the wells at the Goss Cove Landfill and the Lower Subase that are tidally influenced by the Thames River. Low tide on May 20, 1998 at the Smith Cove Entrance of the Thames River was 0.2 feet and occurred at 11:49 pm based on information obtained from NOAA (Appendix A). Information obtained from the Groton Utilities Water Treatment Plant, which is included in Appendix A, confirmed that no rainfall had occurred in the area since May 17, 1998.

2.1.1.2 Results

The water level measurements and elevations are summarized in Table 2-1. Groundwater elevation data from shallow overburden wells were used to create a potentiometric surface map (Drawing 2-2). The contours shown on the drawing indicate that the shallow overburden potentiometric surface is generally depressed in the vicinity of the Tank Farm and that the overall groundwater flow direction is westward toward the Thames River.

The potentiometric surfaces developed from water levels measured on May 20, 1998 (Drawing 2-2) and November 20, 1995 (Drawing 2-3) show the same overall groundwater flow pattern. The water levels shown on these two maps are not directly comparable because of the different survey datums referenced for each data set. The datum for the 1998 water levels is the Base 1982 datum and the datum for the 1995 water levels is the 1988 North American Vertical Datum (NAVD). The difference between the 1982 and 1988 datums is approximately +2.39 feet. By applying this conversion factor, it can be shown that the water levels measured in November 1995 are slightly lower than those measured in May 1998.

Several anomalies (mounds or sinks) are apparent in both sets of data. A groundwater mound occurs near OT-8 (HNUS-17 and HNUS-18) and groundwater sinks occur near OT-3 (HNUS-7) and OT-5 (HNUS-11). The groundwater mound at OT-8 may be related to organic (peat-like) material that was reportedly encountered in the area during remediation activities or to differences in hydraulic conductivities of fill material and natural material. The sinks at OT-3 and OT-5 may be the result of the tank underdrains and storm sewers in the vicinity.

2.1.2 <u>Flow Rate Measurements</u>

Measurements were taken in the storm sewer/underdrain system of the Tank Farm and at upgradient locations during the period of May 20, 1998 to May 22, 1998. The objective of the measurements was to provide an estimate of the groundwater discharge rate into the storm sewer/underdrain system of the Tank Farm. The methodology used to collect the flow rate measurements and the results are discussed below.

2.1.2.1 Methodology

Measurements were taken or attempted to be taken at 19 manholes/inlets and 1 stream to estimate the flow rate at each location. The sample locations are illustrated on Drawing 2-1. The objective of taking measurements at locations within and upgradient of the Tank Farm was to determine the magnitude of the groundwater collection rate of the Tank Farm storm sewer/underdrain system versus the upgradient storm sewer systems. A flow rate measurement was taken in the stream east of Building 447 to determine its percent contribution to the total flow rate at manhole C567.

As discussed in Section 2.1.1.1, the most recent rainfall event prior to the flow rate measurements occurred on May 17, 1998, 3 days prior to the measurements. It was assumed that all measured flow rates within the storm sewer/underdrain system represented the base flow of groundwater collected by the system.

A mechanical flow meter was used to measure the water velocity at two locations, the stream east of Building 447 and C567. These two locations were the only locations out of the 20 sampled that had sufficient flow depths to use the meter. The measurements were taken at the center of each channel at a depth approximately six-tenths of the total flow depth. The cross-sectional flow area of the stream was estimated by measuring the flow width, depths, and the geometry of the stream channel. The cross-sectional flow area of the pipe exiting C567 was estimated by measuring the flow depth and using the known pipe diameter. Flow rates were calculated by multiplying the measured velocity by the flow area.

A float was used to attempt to estimate velocities at several locations where the depth of flow was insufficient to use the flow meter. This method proved to be unreliable because the floats would get hung up in the pipes and would not pass by the downstream monitoring location. No accurate velocity measurements were able to be obtained with this method.

For nine of the twenty locations (C568, C1096, C557, C1038, C556, C549, C550, C1011, C567), the depth of flow in the exiting pipe was measured. These measurements were used with the known pipe diameters from utility drawings obtained from the Public Works office at NSB-NLON (and confirmed in the field, if possible) to estimate cross-sectional flow areas. Velocities for each section were estimated using Manning's Equation. Slopes used in the equation were estimated from known inverts of manholes/inlets and pipe lengths between the manholes/inlets. Manning's coefficients for the pipes were taken from Open Channel Hydraulics (Chow, 1959). Flow rates were calculated by multiplying the velocity by the flow area.

No measurements were able to be taken at 9 locations. The locations and the reasons for not being able to take measurements are provided in Table 2-2.

Flow measurement data was recorded in the site logbook. Pipe conditions, the stream bottom sediment and profile information, weather conditions, and any other applicable information was recorded in the site logbook. Photographs of the stream were also taken and are provided in Appendix A.

2.1.2.2 Results

The flow rates that were calculated from the field measurements are summarized in Table 2-2. Detailed calculations are provided in Appendix B. The rationale for selection of flow rates is also provided in Appendix B.

The estimated flow rates can be summarized as follows:

- The total flow rate from the storm sewer systems upgradient of the Tank Farm is approximately 1.1 cubic feet per second (cfs).
- The groundwater flow discharge into the Tank Farm storm sewer/underdrain system is approximately 0.4 cfs.
- The surface water flow rate in the stream east of Building 447 is approximately 2.5 cfs.
- The total flow rate exiting C567 is approximately 4.0 cfs.

2.1.3 Surveying

The elevation of the water level in the stream east of Building 447 was surveyed by TtNUS. The survey was completed on May 21, 1998. The methodology used to complete the survey and the results are discussed below.

2.1.3.1 Methodology

The water level elevations at five locations along the creek east of Building 447 and the elevations of five other reference locations were surveyed by TtNUS personnel. The benchmark used for the survey was Benchmark 50 of the Base Traverse System by David L. Stein, October 1994 and revised April 1997. The elevation of Benchmark 50 is in the NAVD 1988 system. The survey was completed with a TOPCON AT-

F2 Autolevel and stadia rod. Elevations were measured to an accuracy of 0.01 foot. All survey information was recorded in the field log book.

2.1.3.2 Results

The survey results and pictures of the stream are provided in Appendix A. All elevations originally referenced to the NAVD 1998 system were subsequently converted to the 1982 Base system by a conversion factor of +2.39 feet. This conversion factor was obtained from the Public Works Department at NSB-NLON.

Water level elevations at five locations in the stream ranged from 28.19 feet to 28.66 feet. These elevations correspond well with the available topographic survey information for NSB-NLON. It was assumed that this stream is tied into the local groundwater table. The water level elevation taken at Location 6 in the stream (28.23 feet msl) was included on Drawing 2-2 to develop the shallow overburden potentiometric surface map.

2.2 PHASE 2

2.2.1 Monitoring Well Installation and Development

Four bedrock monitoring wells (23MW01D through 23MW04D) were installed along the perimeter of the Tank Farm between July 6, 1998 and August 7, 1998. Locations of the bedrock wells are illustrated on Figure 2-4. Monitoring wells 23MW01D and 23MW03D were located along the northern and eastern boundaries, respectively, of the Tank Farm. The locations of 23MW02D and 23MW04D were selected so that they were clustered with existing overburden wells (i.e., HNUS-14 and HNUS-20, respectively).

The bedrock monitoring wells were installed by Maxim Technologies, Inc., using a Failing F-10 truck-mounted drilling rig and air rotary drilling techniques. The overburden at each well was permanently cased to bedrock using 6-inch diameter steel casing, which was sealed in place using either a bentonite or cement-bentonite mixture. After installation of the overburden casing, a 6-inch diameter borehole was reamed into bedrock using a 5-7/8-inch diameter air hammer. The borehole was advanced to the first water-bearing fracture encountered. Boring logs for the bedrock wells are provided in Appendix A.

Well borings were converted to monitoring wells with PVC well screen and riser or open borehole screen intervals. PVC well screen and riser pipe were installed in wells 23MW01D and 23MW04D to improve the integrity of the wells because only bentonite was used to seal the overburden casing in place. PVC well screen of 2-inch diameter with lengths of 6.5 feet and 30.0 feet, respectively, and slot size of 0.010 inches were installed in these wells. A filter pack was installed in each well annulus of 23MW01D and 23MW04D to approximately 1.0 to 1.5 feet above the top of the well screen. A bentonite seal was installed above the filter pack, approximately 4 feet into the overburden casing to improve the seal between the overburden and bedrock. A grout-bentonite seal was installed from the top of the bentonite seal to approximately ground surface within the overburden casing. Wells 23MW02D and 23MW03D were constructed with open borehole screen interval. All wells were completed at the surface with flush-mount protective casings and concrete pads. Well Construction Sheets for the bedrock wells are provided in Appendix A.

The bedrock rock wells were developed after installation to remove drilling cuttings from the filter packs or bedrock fractures. Wells with PVC well screen and riser were developed by overpumping with a submersible pump. Open borehole wells were developed by air lifting using the drilling rod stem and air compressor. The wells were developed until the discharge water was visibly clear.

Soil cuttings and water generated during well installation were containerized in 55-gallon drums for disposal off-site as non-hazardous waste by Capitol Environmental Services, Inc. Water from well development was discharged directly to the sanitary sewer system on base, as directed and approved by the NSB-NLON Environmental office. Well development water was screened with a PID monitor and visually inspected prior to disposal to the sanitary sewer system.

All bedrock wells were surveyed for horizontal and vertical position by Diversified Land Surveyors, Inc. of Watertown, Connecticut. Survey information for the wells is provided in Appendix A. Photographs of the completed monitoring wells are also provided in Appendix A.

2.2.1 Water Level Measurements

During Phase 2 groundwater levels were measured in 37 existing monitoring wells and in three of the four newly installed bedrock wells in the vicinity of the Tank Farm, Goss Cove Landfill, and the south end of Lower Subase on August 4 and 5, 1998. The methodology used to take the measurements and the results are discussed below.

2.2.1.1 Methodology

Water levels were measured in the monitoring wells listed in Table 2-1 and illustrated on Drawing 2-4. Water levels were measured in the same wells as measured during Phase 1, with the exception of 13MW12, and three of the four newly installed bedrock wells described above. Well 13MW12 could not be located during the sampling event but 13MW17, which is located in close proximity to 13MW12, was sampled in its place. 23MW04D was not completed or surveyed at the time of the water level sampling event; therefore, an accurate water level measurement could not be obtained from this well. Water level measurements for Phase 2 were recorded on Groundwater Level Measurement Sheets (Appendix A).

Water levels were measured on August 4 and 5, 1998. Water levels in wells at the Goss Cove Landfill and the Lower Subase that are tidally influenced by the Thames River were measured between 2:01 p.m. and 3:52 p.m. on August 5, 1998. Low tide on August 5, 1998, at the Smith Cove Entrance of the Thames River occurred at 2:28 p.m. and was 0.5 feet, based on NOAA tide prediction tables (Appendix A).

2.2.1.2 Results

The Phase II water level measurements and elevations are summarized in Table 2-1. Groundwater elevation data from shallow overburden wells were used to create a potentiometric surface map (Drawing 2-4). The contours shown on the drawing indicate that the shallow overburden potentiometric surface is generally depressed in the vicinity of the Tank Farm and that the overall groundwater flow direction is westward toward the Thames River.

The potentiometric surfaces developed from water levels measured on May 20, 1998 (Drawing 2-2) and November 20, 1995 (Drawing 2-3) show the same overall groundwater flow pattern as the water levels measured on August 4 and 5, 1998 (Drawing 2-4). The water levels shown on Drawing 2-2 and 2-4 are directly comparable because the same survey datum was referenced for each data set. However, as noted in Section 2.1.1.2, the water levels shown on Drawing 2-3 are not directly comparable to the other two drawings because different survey datums were referenced for the data sets. By applying a conversion factor of +2.39 feet to the 1995 data set, it can be shown that the water levels measured in November 1995 (Drawing 2-3) are slightly lower than those measured in May 1998 (Drawing 2-2), but they are higher than those measured in August 1998 (Drawing 2-4). Therefore, the May 1998 water levels were the highest of the three data sets and the August 1998 water levels were the lowest of the three data sets.

The same anomalies in the potentiometric surface [i.e., groundwater mound near OT-8 (HNUS-17 and HNUS-18) and groundwater sinks near OT-3 (HNUS-7) and OT-5 (HNUS-11)] seen in November 1995 and May 1998 were also obvious in the August 1998 potentiometric surface. As discussed in Section 2.1.1.2, the cause of the groundwater mound at OT-8 is probably the organic (peat-like) material that was reportedly encountered in the area during remediation activities or differences in hydraulic conductivities of fill material and natural material. The sinks at OT-3 and OT-5 are the result of the tank underdrains/storm sewers in the vicinity.

Comparison of the August 1998 water levels from the newly installed bedrock wells and the existing overburden wells provides an indication of the vertical flow direction of the groundwater between the bedrock and overburden units. Water levels measured in 23MW02D (17.64 feet) and HNUS-14 (17.62 feet), which are located along the southeast side of the Tank Farm, were very similar, indicating a good hydraulic connection between the units and relatively no vertical flow component. Along the northern side of the Tank Farm, measured water levels indicate that the vertical flow component is downward between both the shallow and deep overburden [15MW1S (22.52 feet) versus 15MW1D (17.90 feet)] and the deep overburden and bedrock [15MW1D (17.90 feet) versus 23MW03D (16.78 feet)]. The downward groundwater flow component in this area is probably related to the underdrain/storm sewer system and the groundwater sinks that occur at OT-3 and OT-5. Monitoring well 23MW04D was not completed at the time of the August 1998 round of water level measurements; therefore, a comparison between the water levels in this well and the overburden well that it is clustered with (HNUS-20) can not be made.

TABLE 2-1

MONITORING WELL INFORMATION AND WATER LEVELS
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT
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Monit ring Well	Ground Surface Elevation (feet msl)	Reference Point Elevation (feet msl)	Depth to Top of Screen (feet bgs)	Depth to Bottom of Screen (feet bgs)	Screened Interval (Formation)	Phase 1 May 1998 Depth To Water (feet brp)	Phase 1 May 1998 Water Elevation (feet msl)	Phase 2 Aug 1998 Depth To Water (feet brp)	Phase 2 Aug 1998 Water Elevation (feet msl)
13MW10	8.73	8.44	5.00	15.00	Overburden (Alluvium)	NA	NA	8.96	- 0.52
13MW12	9.55	9.21	5.30	15.30	Overburden (Fill)	5.89	3.32	8.90	0.31
13MW17	7.71	7.47	3.50	13.50	Overburden (Alluvium)	6.00	1.47	NFD	NFD
15MW1D	28.25	28.05	36.00	46.00	Overburden (Alluvium)	7.55	20.50	10.15	17.90
15MW1S	28.35	28.08	5.00	15.00	Overburden (Alluvium)	3.17	24.91	5.56	22.52
15MW2S	29.28	28.90	5.00	15.00	Overburden (Alluvium)	3.76	25.14	6.21	22.69
15MW4S	26.37	26.24	4.00	14.00	Overburden (Alluvium)	NFD	NFD	NFD	NFD
8MW2D	10.17	9.77	54.00	64.00	Overburden (Alluvium)	7.02	2.75	7.63	2.14
8MW2S	9.91	9.43	5.90	15.90	Overburden (Fill)	4.83	4.60	5.91	3.52
8MW5S	11.51	10.94	6.00	16.00	Overburden (Fill)	9.01	1.93	9.53	1.41
8MW6D	9.90	9.62	60.00	70.00	Overburden (Alluvium)	6.80	2.82	7.48	2.14
8MW6S	10.10	9.66	4.00	14.00	Overburden (Fill)	5.95	3.71	6.99	2.67
8MW7S	10.84	10.45	4.00	14.00	Overburden (Fill)	6.69	3.76	7.54	2.91
8MW8D	19.83	19.53	48.00	78.00	Bedrock	16.20	3.33	17.18	2.35
8MW8S	NR	NR	7.00	17.00	Overburden (Alluvium)/Bedrock	14.73	NR	15.37	NR
8MW9S	21.85	21.40	14.00	19.00	Bedrock	14.69	6.71	15.93	5.47
ERM-2	21.96	21.46	3.71	13.21	Overburden (Fill)	3.23	18.23	3.74	17.72
ERM-13	25.92	25.52	5.50	15.05	Overburden (Fill)	5.41	20.11	6.31	19.21
ERM-15	22.82	22.63	2.25	11.75	Overburden (Fill)	3.01	19.62	3.89	18.74
ERM-17	22.33	22.15	2.72	12.22	Overburden (Fill)	4.89	17.26	5.68	16.47
HNUS-2	21.02	20.70	4.00	14.00	Overburden (Fill)	3.80	16.90	4.67	16.03
HNUS-4	21.62	21.24	4.00	14.00	Overburden (Fill)	4.04	17.20	5.06	16.18
HNUS-5	21.81	21.35	4.00	14.00	Overburden (Fill)	4.07	17.28	5.05	16.30
HNUS-6	22.33	22.09	5.00	15.00	Overburden (Fill)	3.60	18.49	5.54	16.55
HNUS-7	22.91	22.62	5.00	15.00	Overburden (Fill)	7.91	14.71	8.28	14.34
HNUS-9	22.50	22.04	4.00	14.00	Overburden (Fill)	2.65	19.39	5.00	17.04
HNUS-10	23.85	23.25	5.00	15.00	Overburden (Fill)	8.18	15.07	9.12	14.13

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TABLE 2-1

MONITORING WELL INFORMATION AND WATER LEVELS
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT

M nitoring Well	Ground Surface Elevation (feet msl)	Reference Point Elevation (feet msl)	Depth to Top of Screen (feet bgs)	Depth to Bottom of Screen (feet bgs)	Screened Interval (Formation)	Phase 1 May 1998 Depth To Water (feet brp)	Phase 1 May 1998 Water Elevation (feet msl)	Phase 2 Aug 1998 Depth To Water (feet brp)	Phase 2 Aug 1998 Water Elevation (feet msl)
HNUS-11	22.59	22.23	5.00	15.00	Overburden (Fill)	8.24	13.99	8.43	13.80
HNUS-12	26.89	26.47	5.00	15.00	Overburden (Fill)	2.39	24.08	4.29	22.18
HNUS-13	25.97	25.71	5.00	15.00	Overburden (Fill)	0.67	25.04	4.23	21.48
HNUS-14	23.31	22.96	5.00	15.00	Overburden (Fill)	3.57	19.39	5.34	17.62
HNUS-15	23.52	23.13	5.00	15.00	Overburden (Fill)	4.46	18.67	5.63	17.50
HNUS-16	21.77	21.09	5.00	15.00	Overburden (Fill)	NFD	NFD	NFD	NFD
HNUS-17	22.45	22.08	4.00	14.00	Overburden (Fill)	2.68	19.40	5.35	16.73
HNUS-18	22.60	22.23	5.00	15.00	Overburden (Fill)	3.51	18.72	5.32	16.91
HNUS-20	22.94	22.51	5.00	15.00	Overburden (Fill)	5.33	17.18	7.46	15.05
HNUS-21	22.38	22.35	5.00	15.00	Overburden (Fill)	5.95	16.40	8.11	14.24
HNUS-22	28.08	27.70	10.00	20.00	Overburden (Fill)	8.82	18.88	11.26	16.44
HNUS-23	20.53	20.42	7.00	17.00	Overburden (Fill)	5.75	14.67	9.18	11.24
HNUS-24	24.59	27.11	5.00	15.00	Overburden (Fill)	10.78	16.33	10.92	16.19
MW1-4RI	8.27	7.95	4.00	9.50	Overburden (Fill)	4.41	3.54	5.05	2.90
23MW01D	37.07	36.83	50.00	56.50	Bedrock	NA	NA	4.66	32.17
23MW02D	23.55	23.19	18.60	28.50	Bedrock	NA	NA	5.55	17.64
23MW03D	23.30	22.91	39.00	55.00	Bedrock	NA	NA	6.13	16.78
23MW04D	22.26	21.89	65.50	95.50	Bedrock	NA	NA	8.32*	13.57*

Notes:

Elevations based on 1982 Base Datum.
msl = Mean Sea Level.
bgs = Below Ground Surface.
brp = Below Reference Point.
NA = Not Available.
NFD = Well was not found or was destroyed.
NR = No Reference Point, well was modified by Navy and not resurveyed.
* = Estimated values

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TABLE 2-2

STORM SEWER/STREAM FLOW RATES
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT

Manhole/Inlet Number	Methodology	Flow Rate (cfs)	Comments
C568	Manning's Equation	0.08	Flow Depth = 0.18 feet
C1096	Manning's Equation	0.49	Flow Depth = 0.57 feet
C1097	NA	NA	Unable to locate
C1097-1	NA	NA	Dry
C1098	NA	NA	Standing water
C1099	NA	NA	Dry
C558	NA	NA	Dry
C557	Manning's Equation	0.37	Flow Depth = 0.20 feet
C1038	Manning's Equation	0.45	Flow Depth = 0.20 feet
C835	NA	NA	Board covering outlet
C556	Manning's Equation	0.65	Flow Depth = 0.21 feet
C549	Manning's Equation	0.02	Flow Depth = 0.11 feet
C550	Manning's Equation	0.35	Flow Depth = 0.44 feet
C551	NA	NA	Unable to locate
C552	NA	NA	Unable to locate
C554	NA	NA	Unable to locate
C562	NA	NA	Unable to locate
C1101	Manning's Equation	1.52	Flow Depth = 0.48 feet
Stream (Bldg. 447)	Mechanical Flow Meter	2.50	Flow Area = 2.56 $feet^2$
C567	Mechanical Flow Meter	3.31	Flow Depth = 0.77 feet
	Manning's Equation	5.36	Flow Depth = 0.77 feet

cfs = cubic feet per second

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DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL BASE
PHILADELPHIA, PA

NORTHERN DIVISION

FLOW MEASUREMENT AND MONITORING WELL LOCATIONS
HYDROGEOLOGIC STUDY FOR TANK FARM
NSB-NLON, GROTON, CONNECTICUT

APPROVED | DATE | NORTHDIV FOR COMMANDER, NAVFAC

SEAL AREA

Tetra Tech NUS, Inc.
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SUPV: | CH. ENG.
OFFICER IN CHARGE

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DEPARTMENT OF THE NAVY
NAVAL BASE

NORTHERN DIVISION

NAVAL FACILITIES ENGINEERING COMMAND
PHILADELPHIA, PA

SHALLOW OVERBURDEN POTENTIOMETRIC SURFACE (MAY 20, 1998)
HYDROGEOLOGIC STUDY FOR TANK FARM
NSB-NLON, GROTON, CONNECTICUT

NORTHDIV FOR COMMANDER, NAVFAC

DATE

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Tetra Tech NUS, Inc.
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CH ENG:
SUBMITTED BY:
NORTHDIV
OFFICER IN CHARGE
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Tetra Tech NUS, Inc.

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SUBMITTED BY:
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APPROVED
DATE

DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
NAVAL BASE PHILADELPHIA, PA

NORTHERN DIVISION

SHALLOW OVERBURDEN POTENTIOMETRIC SURFACE (AUGUST 4 & 5, 1998)
HYDROGEOLOGIC STUDY FOR TANK FARM
NSB-NLON, GROTON, CONNECTICUT

APPROVED DATE NORTHDIV FOR COMMANDER, NAVFAC

SEAL AREA

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DEPARTMENT OF THE NAVY	NAVAL FACILITIES ENGINEERING COMMAND
NORTHERN DIVISION	
NAVAL BASE	PHILADELPHIA, PA.
NAVAL SUBMARINE BASE, NEW LONDON	GROTON, CT.
UST FARM INVESTIGATION	
SHALLOW OVERBURDEN GROUNDWATER POTENTIOMENTRIC SURFACE MAP	
NOVEMBER 20, 1995	
APPROVED	DATE
NORTHDIV FOR COMMANDER, NAVFAC	
SEAL AREA	
SAT TO	DATE
CODE I.D. NO.	80091
SCALE :	
SPEC. NO. 04 -	
CONSTRN. CONTR. NO.	N62472- -C-
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3.0 GROUNDWATER MODELING

This section presents technical information and results for the groundwater modeling completed for the Tank Farm at NSB-NLON, Groton, Connecticut. The modeling task was conducted to predict the impact of modifying the existing storm sewer/underdrain system on the local groundwater table. It is anticipated that the proposed modifications to the underdrains will eliminate or reduce the contaminant migration problem that exists between the Tank Farm and the Thames River, but may result in flooding problems. The groundwater flow modeling results will provide information to assist in finalizing the design of the replacement storm sewer system through the Tank Farm.

The objectives of the groundwater modeling at the Tank Farm are:

- Complete a 3-dimensional groundwater modeling study to determine groundwater levels under current conditions (with underdrains) and under two preliminary design scenarios [i.e., (1) the entire Tank Farm underdrain/storm sewer system is eliminated, and (2) only the OT-2 and OT-3 underdrains are removed from the Tank Farm underdrain/stormsewer system].

- Determine groundwater discharge rates to the existing underdrain system, as well as the predicted flow rates for the preliminary design scenarios.

- Assess model sensitivity by varying model input parameters.

- Provide technical support for the design of the replacement storm sewer system under both normal and extreme weather conditions.

Section 3.0 has been divided into six subsections. In addition to the introduction, Section 3.1 briefly describes the computer code selected for simulating the groundwater flow regime. Section 3.2 describes the conceptual groundwater flow model, including the model structure, initial model input parameters and boundary conditions. Section 3.3 presents the results of the model calibration and validation. Sections 3.4 and 3.5 provide the results of model simulations and sensitivity analysis. Section 3.6 presents a summary of the results.

3.1 MODEL SELECTION

3.1.1 Modflow

MODFLOW was selected to perform groundwater flow modeling for this project. MODFLOW is a quasi three-dimensional finite-difference model code that was developed by the U.S. Geological Survey (USGS) (McDonald and Harbaugh, 1988). MODFLOW solves groundwater flow equations that are based on the conservation of fluid mass coupled with Darcy's law. The finite difference method leads to a numerical approximation which allows the description and solution of complex groundwater flow problems. A rectangular grid is superimposed over the study area to discretize the region into a large number of rectangular blocks called cells. Groundwater flow is formulated as a differential water balance for every model cell and solved for the hydraulic head at the center of every cell.

The model allows specification of flows associated with wells, areal recharge, evapotranspiration, drains, and streams. It is important to realize that all model input parameters and predictions represent averages for an entire block. Therefore, a smaller grid spacing typically allows a better representation of site conditions and also leads to more accurate results.

The model can simulate both steady-state and transient groundwater flow conditions. For the purposes of this project, for which long-term predictions of the water table elevation are required, a steady-state model was selected.

3.1.2 GMS Graphical Interface for MODFLOW

Groundwater Modeling System (GMS) from BOSS International was used as a graphical interface for MODFLOW for this project. GMS is a comprehensive graphical user environment for numerical modeling. The interface for the GMS system consists of nine separate modules, including a number of analysis codes (MODFLOW, MT3D, MODPATH, and Femwater). The Department of Defense sponsored the implementation of GMS which was developed by the Engineering Computer Graphics Laboratory of Brigham Young University in cooperation with the US Army Corps of Engineers Waterways Experiment Station. The post-processor included in GMS was also used to process the output of MODFLOW.

3.2 CONCEPTUAL MODEL

The following subsections present a comprehensive description of the conceptualization of the natural processes that govern groundwater flow at the site. The first subsection briefly describes the geology and hydrogeology at the Tank Farm. The second subsection provides the details of the model structure. Model input parameters are described in the third subsection and the fourth subsection briefly describes the existing tank underdrain system. The final subsection describes the boundary conditions selected for the model.

3.2.1 Geology and Hydrogeology

The overburden at the Tank Farm generally consists of fill and re-worked soils, as determined from soil borings completed in this area. These soils are generally silty, fine- to medium-textured sands with trace amounts of rock fragments. These soils are generally classified as SM under the Unified Soil Classification System. Soil color varied from shades of brown to gray, and soil density was variable. The thickness of the overburden ranges from approximately 10 feet to 50 feet.

Surficial deposits in the areas surrounding the Tank Farm are typically unconsolidated glacial materials that were deposited during the Pleistocene Age. There are two types of glacial deposits at the facility: stratified drift and glacial till. Stratified drift consists of sorted silt, sand, and gravel that were deposited by meltwater streams. Stratified drift is located on terraces of the Thames River and is mapped along the western portion of the facility (USGS, 1960). Glacial till consists of a dense, heterogeneous mixture of clay, silt, sand, and rock fragments as large as boulders. Glacial till is exposed on most bedrock highs and most likely underlies outwash materials in the valleys. The thickness of glacial till varies considerably but averages less than 10 feet.

The depth to groundwater in the Tank Farm area varies seasonally, but is generally between 4 to 10 feet below the ground surface. The surficial aquifer is unconfined. Hydraulic conductivities determined from slug tests performed in wells screened in the overburden at the Tank Farm were generally similar ranging from 1.7 feet/day (5.9×10^{-4} cm/sec) to 6.8 feet/day (2.4×10^{-3} cm/sec). The hydraulic conductivities are summarized in Table 3-1.

Hydraulic conductivities estimated from slug tests completed in shallow wells installed in the alluvium at the Spent Acid Storage and Disposal Area, which is north of the Tank Farm, ranged from 0.07 feet/day (2.47×10^{-5} cm/sec) to 6.64 feet/day (2.34×10^{-3} cm/sec). Hydraulic conductivities estimated from slug tests completed in wells installed in fill material at the Goss Cove Landfill, which is to the west of the Tank Farm along the Thames River, ranged from 3.93 feet/day (1.39×10^{-3} cm/sec) to 109 feet/day (3.85×10^{-2} cm/sec) for shallow wells. One slug test was also completed in a deep well installed in alluvium at this location and the resulting hydraulic conductivity was 0.41 feet/day (1.45×10^{-3} cm/sec). All available hydraulic conductivities are summarized in Table 3-1.

The overburden/surficial deposits are underlain by metamorphic bedrock (gneiss and granite). Based on available regional bedrock maps, the Tank Farm is located in a bedrock valley which is surrounded by bedrock highs to the north, south, and east. To the west, a bedrock outcrop generally isolates the Tank Farm from the Goss Cove Landfill and Thames River. A small channel has been cut into the bedrock at the entrance to the Nautilus Museum and Goss Cove Landfill to allow storm sewers from upgradient areas to pass to the Thames River. Groundwater also discharges through this channel.

Four borings were advanced to bedrock in the vicinity of the Tank Farm during Phase 2 field work. From the borings it was determined that the elevation of the top of bedrock ranges between 8.35 feet msl (15.2 feet below ground surface at 23MW02D) to –32.04 feet msl (54.3 feet below ground surface at 23MW04D). These elevations are similar to those provided on the available regional bedrock maps. As discussed in Section 2.2.1.2, water levels measured in the overburden and bedrock wells indicate that there is no vertical flow component in the groundwater along the southeast portion of the Tank Farm and there is a downward vertical flow component in the groundwater along the north-central portion of the Tank Farm.

Three bedrock wells have been installed to the west of the Tank Farm near the entrance gate to the Goss Cove Landfill and Nautilus Museum. In this area, bedrock was encountered between 7 and 12 feet below the ground surface. Groundwater was encountered in these wells approximately 14 to 16 feet below the ground surface.

3.2.2 Model Structure

The rationale for the selection of the model area and grid size are discussed in this subsection. The details of the number and type of layers included in the model are also provided below.

Model Area and Grid Size

The model area was selected to encompass horizontally, the Tank Farm and adjacent areas and, vertically, the overburden/fill material. Adjacent areas include Goss Cove Landfill, the southern portion of the Lower Subase, the Thames River, areas east of Route 12, and a portion of the hill side to the immediate south of Crystal Lake Road. The top of bedrock forms the bottom of the model boundary. Figure 3-1 presents the model domain. The model area was selected to be large enough to minimize the effects of the boundary conditions on model output for the interior portions of the model, which are of most interest to this study.

The model's grid orientation is generally northwest relative to true north. This orientation was selected so that one axis of the model is parallel to the direction of groundwater flow. A uniform, rectangular model grid was chosen. As shown on Figure 3-1, the model domain was subdivided into grids with constant spacing of 40 feet by 40 feet. The model layer has 100 cells in the X direction and 50 cells in the Y direction. The model domain covers an area 4,000 feet by 2,000 feet. The model thickness varies depending on location and the depth to bedrock.

Inactive flow cells were specified east of Goss Cove Landfill where the bedrock ledge exists. Cells east of Tautog Avenue as well as cells west of river nodes are also specified as inactive cells. The inactive cells define the limits of the area in which groundwater flow is simulated. Inactive flow cells are not shown on Figure 3-1, but are distinguishable as the blank areas of the rectangular model domain.

Model Layers

Because the overburden's hydrogeologic properties are generally uniform with depth and no confining units are present the surficial aquifer in the MODFLOW model is represented by a single model layer. This model layer is specified as an unconfined layer. In the unconfined model layer, the transmissivity of the layer varies. It is calculated from the saturated thickness and hydraulic conductivity of each cell in MODFLOW. The bottom elevations at the center of each cell included in the model were approximated from the available ground surface topography and bedrock topography maps.

3.2.3 Initial Model Input Parameters

Initial model input parameters required for simulating groundwater flow using MODFLOW are recharge rate, hydraulic conductivity, storm sewer/underdrain conductance, and boundary conditions. Initial input values for infiltration rates and hydraulic conductivity are discussed below. The details of the storm sewer/underdrain system and its conductance are discussed in Section 3.2.4 and boundary conditions are defined in Section 3.2.5.

Recharge Rate

In the model, areal recharge is applied to the model layer. This recharge rate accounts for both recharge from the bedrock aquifer to the overburden aquifer and vice versa as well as infiltrating precipitation.

Annual rainfall is approximately 44 inches per year as measured at New London over an 81-year period. Evapotranspiration averages approximately 23 inches per year. Initially, a recharge rate of 4 inches per year was assigned in areas with buildings, pavement, or roadways; whereas, a recharge rate of 12 inches per year was applied in areas with vegetation. Recharge rates for specific areas were adjusted (within a reasonable range) during model calibration to achieve a good fit between the calculated and observed water levels and to account for groundwater recharge. The remaining rainfall is assumed to be surface water runoff.

Hydraulic Conductivity

As described in Section 3.2.2, Model Layers, the transmissivity in the unconfined layer is automatically computed from the saturated thickness and hydraulic conductivity. Therefore, the hydraulic conductivity and bottom elevation of the model are required as input parameters. For the current modeling, a non-uniform, isotropic hydraulic conductivity distribution was applied in the horizontal direction.

Table 3-1 presents a summary of the hydraulic conductivities that have been estimated from the results of previous slug tests conducted in the Tank Farm, Goss Cove Landfill ,and Spent Acid Storage and Disposal Area. Horizontal hydraulic conductivities determined from 12 slug tests in wells screened in overburden material ranged from 0.07 feet/day (2.47×10^{-5} cm/sec) to 109 feet/day (3.85×10^{-2} cm/sec). Geometric mean hydraulic conductivities for these three areas are 17 feet/day (6.0×10^{-3} cm/sec), 0.68 feet/day (2.4×10^{-4} cm/sec), 4 feet/day (1.4×10^{-3} cm/sec).

A hydraulic conductivity of approximately 6 feet/day (2.1×10^{-3} cm/sec) was used as an initial input for a majority of the model cells. Higher values were used as input for model cells with low heads and lower values were used as input for model cells with higher heads.

3.2.4 Storm Sewer/ Underdrain System

The former UST tank farm consists of nine tanks which were used to store petroleum products. Each tank was approximately 110 feet in diameter and 11 feet in depth. USTs of this type were designed and constructed with a permanent groundwater drainage system to lower the groundwater water table thereby preventing the tank from floating out of the ground under hydraulic pressure. In addition, the storm sewers in the Tank Farm area which the underdrains tie into were constructed of perforated metal pipe to help de-water the area.

The existing storm sewer/underdrains are incorporated into the model using the drain package of MODFLOW. Figure 3-1 shows the location of all storm sewer/underdrain cells in the model. The configuration, size, material, length, and invert elevations of the storm sewer/underdrain system were obtained from Navy design drawings (Tank Farm Plot Plan, Drawing No. N-15, April 1946; Utility Map of Storm Drainage, Drawing No. 1142295, July 1967; Plan Showing Proposed Design For Drainage of Yard Area, Storm-013; Existing Storm Sewer System, Drawing Numbers 2049851 and 2049852, April 1981; and Repair Storm Drainage Tank Farm Area, Drawing Numbers 2138709, 2112967, 2138708, 2138709, and 2138710, December 1991) and recently obtained information (i.e., Fuss & O'Neill catch basin survey and Foster Wheeler camera study). Based on the existing information, only the 4 northern USTs (OT-1 through OT-4) appear to have functional underdrains.

The existing information indicate that the underdrains were constructed with either 6- or 8-inch diameter vitrified tile pipe. However, no design information was available regarding the depth, slope or backfill material used for the underdrains. The depth of each underdrain was estimated using the invert elevation at the downgradient storm sewer manhole/inlet which the underdrain discharges to and an assumed underdrain slope of 1 percent. This method resulted in the depths of the underdrains being approximately equal to the tank bottom.

The storm sewers that act as underdrains in the Tank Farm were constructed of either perforated corrugated metal pipe or vitrified tile pipe. The diameters of the sewers vary from 6 inches to 30 inches. Inverts for manholes/inlets were available for most of the storm sewer system. For those manholes/inlets without inverts, the inverts were estimated using known pipe inverts upgradient and downgradient of the manhole/inlet in question.

Another model input parameter required for the MODFLOW drainage package for the storm sewer/underdrain system is conductance. This parameter accounts for the permeability of the backfill material placed around the underdrain during construction and the size and spacing of the holes in the underdrain. Initial underdrain conductance entered into the model ranged from 200 to 600 feet^2/day.

As discussed in Section 2.0, the base groundwater flow rate in the storm sewer/underdrain system was estimated by field measurements. The estimated groundwater flow rate was 0.4 cfs. This value was used as the initial flow rate target and was calibrated along with other parameters to fit existing information.

3.2.5 Boundary Conditions

In order to obtain a unique solution of a set of partial differential equations corresponding to the given groundwater flow process, additional information about the groundwater flow process is required. This information is described by boundary and initial conditions. For a steady-state flow simulation, only boundary conditions are required. For transient problems, both boundary and initial conditions are required. Because this project only required a steady-state flow simulation, only boundary conditions are required. Mathematically, the boundary conditions include the geometry of the boundary and the values of the dependent variable or its derivative normal to the boundary.

MODFLOW allows for the specification of three general types of boundary conditions: (1) specified value; (2) specified flux; or (3) value-dependent flux, where the value is the hydraulic head. Specified value and no-flow boundary conditions were used for this project. In addition, interior boundary conditions were identified in the model using the River Package to account for the interaction between the groundwater and the stream east of Building 447.

Specified Head Boundary Conditions

River nodes define the western boundary of the domain model domain. These cells represent the Thames River and are specified as constant hydraulic head cells. A constant head of 1.2 feet msl was used as an input to the model for calibration and predictions and a head of 0.2 feet msl was used for validation. The value of 1.2 feet represents an average low tide condition, while the value of 0.2 feet represents a low tide condition specific to August 5, 1998. Cells west of the river nodes are specified as inactive cells. Figure 3-1 shows the location of all river nodes in the model.

Model cells defining the eastern and southern boundaries of the model domain were also defined with constant heads. The heads included in the model for calibration were defined using potentiometric surface data collected during Phase 1 field work (Drawing 2-2) and the heads included in the model for validation were defined using potentiometric surface data collected during Phase 2 field work (Drawing 2-4). The cells with specified heads are shown on Figure 3-1.

No-Flow Boundaries

A groundwater divide which runs approximately northeast to southwest is located north of the model domain. This divide, which forms the northern boundary of the model, was simulated as a no-flow boundary condition. No groundwater flow occurs across this boundary based on existing groundwater potentiometric surface maps.

Interior Boundary Conditions

The interaction between the groundwater and the stream east of Building 447 was accounted for in the model by specifying internal boundary conditions using the River Package. Stream bed and water level elevations obtained during Phase 1 field work were used to set the internal boundary conditions. The initial value of conductance for the stream bed was estimated and was then updated during model calibration.

3.3 MODEL CALIBRATION AND VALIDATION

3.3.1 Model Convergence Criteria

A steady-state groundwater flow model was developed for this project. Three solution packages are provided with MODFLOW to solve the simultaneous linear equations. The Preconditioned Conjugate-Gradient 2 (PCG2) numerical method package was selected for this modeling effort. The PCG2 numerical method is efficient and is capable of solving difficult problems. Convergence criteria was set at a maximum head change of 0.01 feet. The maximum number of iterations was set such that the model would be able to converge rather than terminate prematurely.

3.3.2 Calibration Targets and Calibration Criteria

Calibration Targets

The steady-state flow model was calibrated against water level data collected on May 20, 1998. The objective of calibration of the groundwater flow model was to achieve a good fit of simulated versus observed hydraulic heads. During model calibration, the input parameters are adjusted through trial-and-error within a predetermined range until the model produces results that are close to the field measurements selected as calibration targets.

A total of 32 measured water levels were used as calibration targets for the groundwater flow model. The water levels and sampling locations are provided in Table 3-2. Drawing 2-2 shows the potentiometric surface that was created using the measured heads. Twenty-five water level measurements were from the Tank Farm area and the adjacent SASDA, 5 water level measurements were from the Goss Cove Landfill area, and 2 water level measurements were from the Lower Subase. The observed water levels range from 1.9 to 25.1 feet, resulting in a total head difference of 23.2 feet.

The groundwater discharge rate to and through the storm sewer/underdrain system was also considered as a calibration target during model calibration. As discussed in Section 2.0, field measurements were conducted to measure this flow rate and the results indicate that the flow rate is approximately 0.4 cfs.

Calibration Criteria

Model calibration results were confirmed using the following generally accepted criteria:

- Maximum positive and negative residual < 5% of calibration targets range
- Mean Error (ME) < $\pm$ 0.5 feet
- Root Mean Squared Error (RMSE) < 10% of calibration targets range

The residual error is the head difference between targets (observed head) and calculated heads. The ME is computed as the average value of the total residuals (i.e. summation of the residuals divided by the total number of samples). The ME should always be close to zero in order to show that the calibration residuals are unbiased. An ME of zero would indicate that the model generally overpredicts at some wells and underpredicts at other wells. The root mean squared error (RMSE) is also used to evaluate the overall calibration results. The RMSE can be expressed as:

$$RMSE = \sqrt{\frac{\sum (h_c - h_0)^2}{n}}$$

where h_c is the calibrated hydraulic head from the flow model, h_o is the observed head, and n is the number of data points. A rule-of-thumb is that the RMSE should be less than about 10 percent of the maximum variation in head across the model layer of interest.

3.3.3 Calibration Results

The groundwater flow model calibration produced a good match between observed and calculated hydraulic head values. The following text summarizes the calibration results.

Calibrated Hydraulic Conductivity

Figure 3-2 shows the distribution of calibrated hydraulic conductivities for the model. These conductivities are the result of trial-and-error adjustments made during the calibration process to reduce the uncertainties of conductivity values by comparing target heads with predicted heads. The adjusted hydraulic conductivities range from 0.1 to 30 feet/year. The calibrated hydraulic conductivity for a majority of the model area is approximately 6 feet/year (2.1 x 10^{-3} cm/sec).

Calibrated Recharge Rate

Figure 3-3 shows the distribution of calibrated recharge rates. The calibrated recharge rates range from 3 to 12 inches per year (in/yr). The rate for most of the model area is approximately 4 in/yr. The rates for the Tank Farm area range between 9 in/yr and 12 in/yr.

Calibrated Hydraulic Heads

Table 3-2 presents a comparison between the calibrated heads and the observed heads for the 32 available water level measurements. The results show that 20 data points are underpredicted and 12 data points are overpredicted. Table 3-3 summarizes the statistics for the model calibration including maximum error, relative error, ME, and RMSE. All of calibration statistics are within the criteria. The maximum error is less than 5%, the ME is much lower than 0.5 feet, and the RMSE is below 10%. In summary, the model calibration represents an error of less than 3% over the range of measurements.

Figure 3-4 presents a plot of calculated versus observed heads for the 32 water level measurements. As the figure shows all data point generally fall along the 45 degree line indicating a good match between measured and predicted heads.

Figure 3-5 shows the predicted potentiometric surface for existing conditions. This figure compares well to Drawing 2-2 which shows the potentiometric surface created using measured heads.

3.3.4 Model Validation and Results

Model Validation

The steady-state flow model was validated against water level data collected on August 4 and 5, 1998. The objective of validation of the groundwater flow model is to confirm the validity of the model calibration. During model validation, the constant head boundary conditions for the model were modified to the August 4 and 5, 1998 levels and all other input parameters were maintained at the same values included in the calibrated model. The results of model validation should show that by only changing the boundary conditions, the model achieves a good match between simulated and observed hydraulic heads. If the results do not show a good match, then additional model calibration is required.

A total of 32 measured water levels were used as validation targets for the groundwater flow model. The water levels and sampling locations are provided in Table 3-4. Drawing 2-4 shows the potentiometric surface that was created using the measured heads. Twenty-five water level measurements were from the Tank Farm area and the adjacent SASDA, 5 water level measurements were from the Goss Cove Landfill area, and 2 water level measurements were from the Lower Subase. The observed water levels range from 0.3 to 22.7 feet, resulting in a total head difference of 22.4 feet.

Validation Results

Table 3-4 presents a comparison between the calibrated heads and the observed heads for the 32 available water level measurements. The results show that 14 data points are underpredicted and 18 data points are overpredicted. The maximum positive residual error was 1.94 feet and the maximum negative residual error was –2.6 feet. These residual errors are adequate for model validation.

Figure 3-6 presents a plot of calculated versus observed heads for the 32 water level measurements. As the figure shows all data point generally fall along the 45 degree line indicating a good match between measured and predicted heads.

Figure 3-7 shows the predicted potentiometric surface for existing conditions. This figure compares well to Drawing 2-4 which shows the potentiometric surface created using measured heads.

3.3.5 Flow Balance for Existing Conditions (Scenario 1)

MODFLOW calculates water balance and flux information for model boundaries. At the completion of model calibration, the groundwater inflow rates as well as the groundwater outflow rates for the model area were determined. The water balance results are summarized in Table 3-5. Under existing conditions (Scenario 1), the inflow from the upgradient boundary is 0.46 cfs, the net groundwater recharge is 0.07 cfs, the outflow through the downgradient boundary is 0.29 cfs, the groundwater discharge to the stream is 4.8×10^{-3} cfs, and the total groundwater discharge to the storm sewer/underdrain system is approximately 0.24 cfs.

The estimated storm sewer/underdrain flow rate is approximately 40 percent lower than the measured flow rate. This margin of error is considered acceptable because of the limitations of the field methods used to measure the flow rates and the accuracy of the model's predictions.

3.4 PREDICTIONS

The calibrated flow model was used to predict groundwater flow conditions under two preliminary design scenarios. The first scenario (Scenario 2) assumes that the existing system is removed and replaced with a water-tight storm sewer system and backfill with low-permeability that does not provide a preferential pathway for groundwater flow. The second scenario (Scenario 3) assumes that the existing underdrain systems at OT-2 and OT-3 are removed, but the remaining underdrain/storm sewer system is refurbished and continues to collect groundwater from the Tank Farm area. These two scenarios represent two possible alternatives for finalizing the storm sewer system design. The results of the predictions are discussed below.

3.4.1 Potentiometric Surface

The predicted potentiometric surfaces for Scenarios 2 and 3 are shown on Figures 3-13 and 3-12, respectively. These two figures can be compared to Figure 3-5 to determine the impact of the scenarios on the water table. Figure 3-13 shows a uniform flow pattern across the Tank Farm that is significantly elevated when compared to Figure 3-5. Therefore, the model's results indicate that removal of the existing storm sewer/underdrain will eliminate the depressed water table in the Tank Farm. Figure 3-12 shows that the removal of the OT-2 and OT-3 underdrains results in an increase in the water table in the northern part of the Tank Farm, but a depressed water table will remain in the southern part of the Tank Farm. The predicted groundwater elevations within the Tank Farm area vary from 35 feet (to the west near Tang Avenue) to 10 feet (near Shark Boulevard). Groundwater levels are predicted to rise between approximately 2 and 16 feet for Scenario 2 and 2 and 6 feet for Scenario 3, depending on the location within the Tank Farm.

For comparison purposes Figures 3-9 through 3-11 present the predicted water levels for Scenarios 1, 2, and 3 in the Tank Farm on Cross-Sections A-A', B-B', and C-C' (Figure 3-8). These figures depict the impact of each design scenario on the water table at various locations within the Tank Farm. Figures 3-9 and 3-11 show that under Scenarios 2 and 3, it is likely that the water table will reach or exceed the ground surface in the northern and eastern portions of Tank Farm. Figure 3-10 shows that under Scenarios 2 and 3, the western portion of the Tank Farm will not be flooded, but the groundwater table will be very near the ground surface.

3.4.2 Flow Balance for Design Scenario Conditions

Flow balance information for the preliminary design scenarios is summarized in Table 3-5. Highlights of the information are provided below.

- Scenario 2 - Inflow from the upgradient boundary is approximately 0.31 cfs, the net recharge is 0.07 cfs, the discharge to the stream is 5.7 x 10^{-3} cfs, and the outflow through the downgradient boundary is about 0.37 cfs.

- Scenario 3 - Inflow from the upgradient boundary is approximately 0.41 cfs, the net recharge is 0.07 cfs, the total discharge to the storm sewer/underdrain system is 0.18 cfs, the discharge to the stream is 4.8 x 10^{-3} cfs, and the outflow through the downgradient boundary is about 0.30 cfs.

3.5 SENSITIVITY ANALYSIS

The sensitivity of the model to various input parameters was evaluated by performing additional model simulations. The sensitivity analysis was performed on the calibrated model under existing conditions. Model input parameters that were evaluated during the sensitivity analysis include boundary head conditions, hydraulic conductivity, and drain conductance. A total of nine cases were evaluated during the sensitivity analysis and the details of each case are summarized below.

- Case 1 - Low Updgradient Boundary Conditions (38 to 33 feet) and Normal Downgradient Boundary Conditions (1.2 feet).

- Case 2 - Low Upgradient Boundary Conditions (38 to 33 feet) and High Downgradient Boundary Conditions (1.2 to 3 feet).

- Case 3 - Low Updgradient Boundary Conditions (38 to 33 feet) and Low Downgradient Boundary Conditions (1.2 to 0.2 feet).

- Case 4 - High Updgradient Boundary Conditions (38 feet) and High Downgradient Boundary Conditions (1.2 to 3.0 feet).

- Case 5 - High Updgradient Boundary Conditions (38 feet) and Low Downgradient Boundary Conditions (1.2 to 0.2 feet).

- Case 6 - High Hydraulic Conductivity (increase by factor of 10).

- Case 7 - Low Hydraulic Conductivity (decrease by factor of 10).

- Case 8 - Low Drain Conductance (decrease by factor of 10).

- Case 9 - High Drain Conductance (increase by factor of 10).

The results of these simulations are presented in Table 3-5. The results show that the effects of varying boundary head conditions on the flow balance are not very significant. The model results indicate that the flow rates for inflow, outflow, and tank underdrains only change by 25 percent or less when compared to baseline conditions.

The effects of varying hydraulic conductivity on the flow balance are more significant. Figures 3-14 through 3-16 present the groundwater table elevations under different hydraulic conductivity values. The results presented in Table 3-5 and on these figures, indicates that the flow rates appear to respond proportionally to the change in hydraulic conductivity.

The effects of varying drain conductance on the flow balance are also relatively significant. Figures 3-17 through 3-19 present the groundwater table elevations under high and low drain conductance values. The order of magnitude changes in drain conductance resulted in water level changes from less than 1 foot up to approximately 9 feet. The most significant water level changes were associated with low drain conductance. The flow rates provided in Table 3-5 for Cases 8 and 9 show that a 50 percent change in flow rate was predicted as a result of lowering the drain conductance by ten fold, but only a 13 percent change in flow rate was predicted as a result of increasing the drain conductance by a factor of ten. Therefore, the model is much more sensitive to low drain conductance than high drain conductance.

3.6 SUMMARY

A groundwater flow model was developed for the Tank Farm at NSB-NLON, Groton, Connecticut. The modeling task was conducted to predict groundwater levels in the vicinity of the Tank Farm as well as the flow rates through the storm sewer/underdrain system. The main goal of the modeling was to determine groundwater levels in the Tank Farm under preliminary design scenarios. The main features of the flow model along with the simulation results are summarized as follows:

- A groundwater flow model was developed using the MODFLOW code and GMS software.

- Existing ground surface topography, bedrock surface topography, hydrogeologic data, rainfall and evapotranspiration data, and Thames River water levels were used to develop the model.

- The flow model was calibrated against water levels and groundwater flow rates collected during the Phase 1 field effort. The model was also validated against water levels collected during the Phase 2 field effort. Calibration statistics and validation results showed that the model was adequately calibrated.

- Model predictions under two preliminary design scenarios indicate that portions of the Tank Farm may be flooded if the existing storm sewer/underdrain system is modified as proposed.

- A sensitivity analysis was performed with the calibrated model under existing conditions to evaluate its uncertainty. Boundary heads, hydraulic conductivities, and drain conductance were varied to determine the impact to the model's predictions. The results indicate that the model is most sensitive to changes in hydraulic conductivity and drain conductance and not as sensitive to changes in boundary conditions.

TABLE 3-1

SUMMARY OF HYDRAULIC CONDUCTIVITIES
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT

Well ID	Hydraulic Conductivity		Location	Date	Test Type
	ft/day	cm/sec			
8MW1S	109	3.85E-02	Goss Cove	2/92	Rising Head
8MW2S	3.93	1.39E-03	Goss Cove	3/94	Rising Head
8MW2D	0.41	1.45E-04	Goss Cove	3/94	Average
8MW3S	101	3.56E-02	Goss Cove	2/92	Rising Head
8MW4S	78	2.75E-02	Goss Cove	2/92	Rising Head
15MW1S	6.64	2.34E-03	SASDA	3/94	Rising Head
15MW3S	0.07	2.47E-05	SASDA	3/94	Rising Head
HNUS-4	4.51	1.59E-03	Tank Farm	11/95	Rising Head
HNUS-8	3.7	1.31E-03	Tank Farm	11/95	Rising Head
HNUS-12	5.9	2.08E-03	Tank Farm	11/95	Rising Head
HNUS-18	1.67	5.89E-04	Tank Farm	11/95	Rising Head
HNUS-22	6.76	2.38E-03	Tank Farm	11/95	Rising Head

SASDA - Spent Acid Storage and Disposal Area.

TABLE 3-2

COMPARISON BETWEEN OBSERVED HEADS AND CALIBRATED HEADS
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT

Model Row	Model Column	Observed Head (ft msl)	Calibrated Head (ft msl)	Residual Error (Observed - Calibrated Head) (ft msl)	Well Name
7	18	3.3	4.2	-0.89	13MW12
59	39	24.9	24.7	0.17	15MW1S
58	40	25.1	25.8	-0.7	15MW2S
51	7	4.6	3.6	0.96	8MW2S
44	10	1.9	2.2	-0.25	8MW5S
55	6	3.7	2.9	0.78	8MW6S
59	9	3.8	3.3	0.47	8MW7S
59	14	6.7	6.3	0.44	8MW9S
46	30	20.1	20 2	-0.06	ERM-13
49	29	19.6	18.7	0.92	ERM-15
52	31	17.3	18	-0.79	ERM-17
46	24	18.2	17.3	0.93	ERM-2
68	37	15.1	15.2	-0.14	HNUS-10
70	36	14	13.2	0.83	HNUS-11
80	36	24.1	25	-0.89	HNUS-12
79	34	25	24.1	0.98	HNUS-13
72	32	19.4	19.1	0.25	HNUS-14
71	29	18.7	17.7	0.97	HNUS-15
59	26	19.4	18.8	0.56	HNUS-17
61	25	18.7	19.1	-0.4	HNUS-18
47	22	16.9	16	0.88	HNUS-2
52	22	17.2	16.9	0.31	HNUS-20
54	20	16.4	17.1	-0.74	HNUS-21
53	18	18.9	18.2	0.65	HNUS-22
59	18	14.7	15.4	-0 71	HNUS-23
64	24	16.3	16.8	-0.46	HNUS-24
53	29	17.2	16.9	0.26	HNUS-4
52	26	17.3	17	0.3	HNUS-5
57	34	18.5	17.6	0.91	HNUS-6
56	31	14.7	15.4	-0.67	HNUS-7
64	35	19.4	18.5	0.89	HNUS-9
16	14	3.5	2.8	0.73	MW1-4RI

msl = mean sea level

TABLE 3-3

FLOW MODEL CALIBRATION STATISTICS
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT

Maximum Error						
Higher Than Target (feet)	Relative Error (%)	Lower Than Target (feet)	Relative Error (%)	Mean Error (feet)	RMSE (feet)	RMSE/Target Range (%)
0.98	4	0.89	4	0.2	0.68	3

RMSE = Root Mean Square Error

TABLE 3-4

COMPARISON BETWEEN OBSERVED HEADS AND VALIDATED HEADS
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT

Model Row	Model Column	Observed Head (ft msl)	Validated Head (ft msl)	Residual Error (Observed - Validated Head) (ft msl)	Well Name
7	18	0 3	2.9	-2.6	13MW12
59	39	22.5	22.9	-0.38	15MW1S
58	40	22.7	23.9	-1.18	15MW2S
51	7	3.5	2.6	0.9	8MW2S
44	10	1.4	1.4	0.04	8MW5S
55	6	2.7	1.9	0.81	8MW6S
59	9	2.9	1.8	1.09	8MW7S
59	14	5 5	4.8	0.69	8MW9S
46	30	19.2	18.7	0.55	ERM-13
49	29	18.7	17.6	1.13	ERM-15
52	31	16.5	17.2	-0.73	ERM-17
46	24	17.7	16	1.69	ERM-2
68	37	14 1	14.6	-0.48	HNUS-10
70	36	13 8	12.8	0.99	HNUS-11
80	36	22 2	23	-0.81	HNUS-12
79	34	21.5	22.1	-0.66	HNUS-13
72	32	17.6	18.2	-0.57	HNUS-14
71	29	17.5	17	0 52	HNUS-15
59	26	16 7	17.7	-0.99	HNUS-17
61	25	16.9	17.2	-0.32	HNUS-18
47	22	16	14 9	1.16	HNUS-2
52	22	15.1	15.8	-0.77	HNUS-20
54	20	14.2	16	-1.81	HNUS-21
53	18	16.4	17.5	-1.01	HNUS-22
59	18	11.2	12.6	-1.37	HNUS-23
64	24	16.2	14.3	1.94	HNUS-24
53	29	16.2	16.3	-0.1	HNUS-4
52	26	16.3	16.1	0.21	HNUS-5
57	34	16.5	16.9	-0.38	HNUS-6
56	31	14.3	14.9	-0.59	HNUS-7
64	35	17	17.7	-0.62	HNUS-9
16	14	2 9	1 7	1.24	MW1-4RI

msl = mean sea level

TABLE 3-5

FLOW BALANCE FOR MODEL AREA FOR DIFFERENT SCENARIOS
HYDROGEOLOGIC STUDY AT TANK FARM
NSB-NLON, GROTON, CONNECTICUT

Scenario	Inflow From Upgradient Boundary (cfs)	Outflow through Downgradient Boundary (cfs)	Recharge (cfs)	Underdrain Flow Rate (cfs)	Discharge to Stream (cfs)
Model Predictions					
Scenario 1	0.46	0.29	0.07	0.24	4.76E-03
Scenario 2	0.31	0.37	0.07	0.00	5.71E-03
Scenario 3	0.41	0.30	0.07	0.18	4.77E-03
Sensitivity Analysis					
Case 1	0.37	0.25	0.07	0.18	2.11E-03
Case 2	0.36	0.24	0.07	0.18	2.11E-03
Case 3	0.38	0.27	0.07	0.18	2.12E-03
Case 4	0.44	0.27	0.07	0.24	4.76E-03
Case 5	0.47	0.29	0.07	0.23	4.76E-03
Case 6	3.97	2.93	0.07	1.11	5.24E-03
Case 7	0.04	0.05	0.07	0.05	4.46E-03
Case 8	0.38	0.32	0.07	0.12	5.22E-03
Case 9	0.49	0.27	0.07	0.27	4.65E-03

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COST/SCHED-AREA			APPROVED BY	DATE
SCALE AS NOTED			DRAWING NO. FIGURE 3-1	REV. 0

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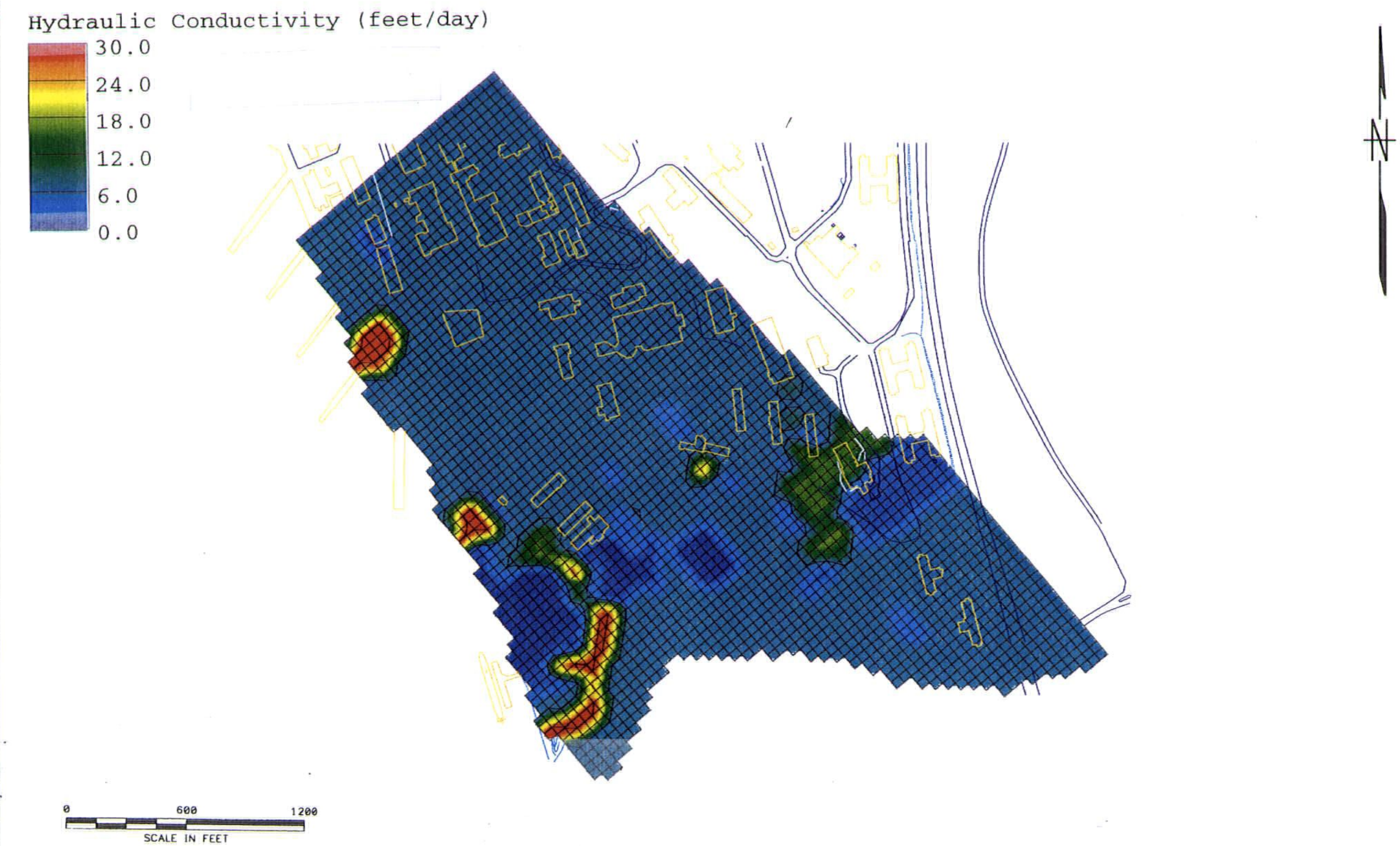

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COST/SCHED–AREA			APPROVED BY	DATE
SCALE: AS NOTED			DRAWING NO. FIGURE 3–2	REV. 0

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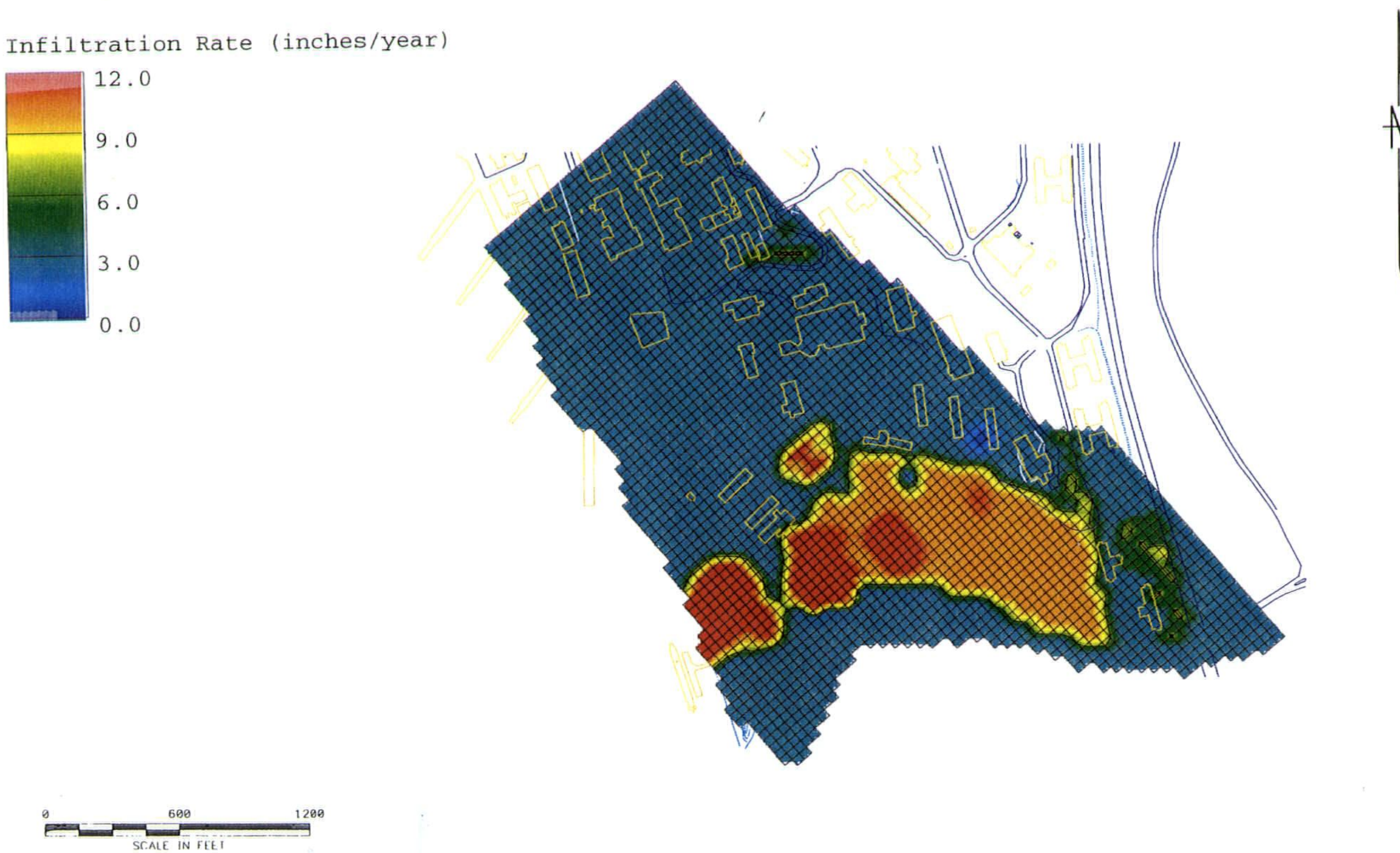

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COST/SCHED-AREA			APPROVED BY	DATE
SCALE AS NOTED			DRAWING NO. FIGURE 3-3	REV. 0

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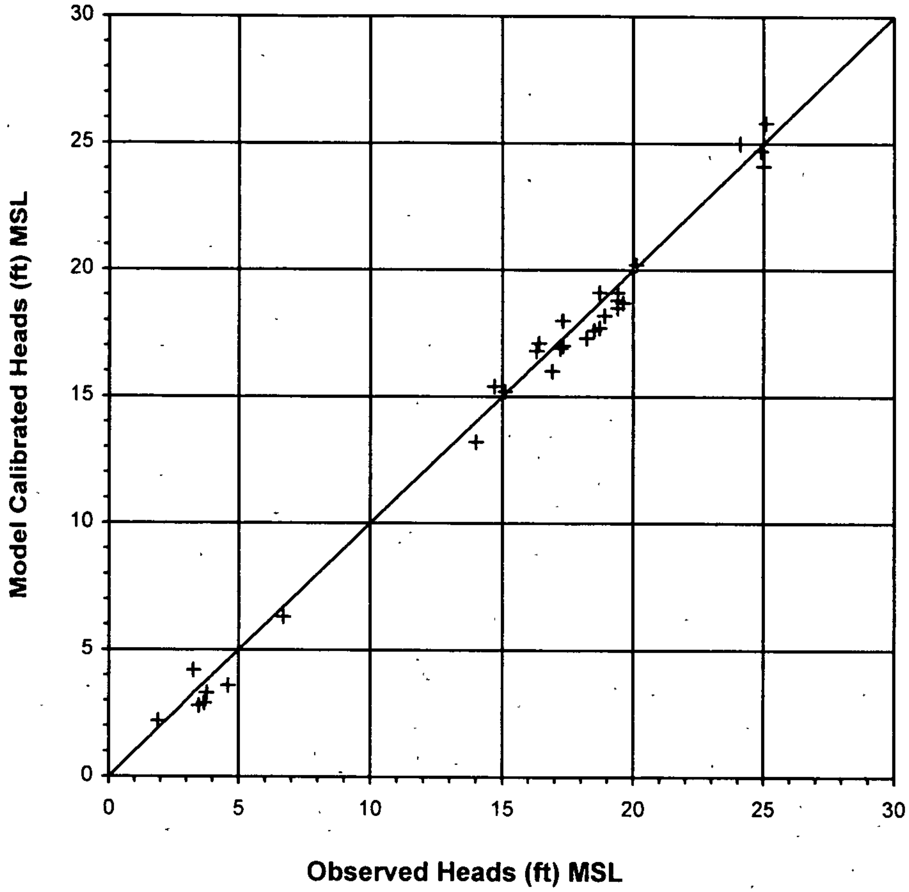

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COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-4	REV. 0

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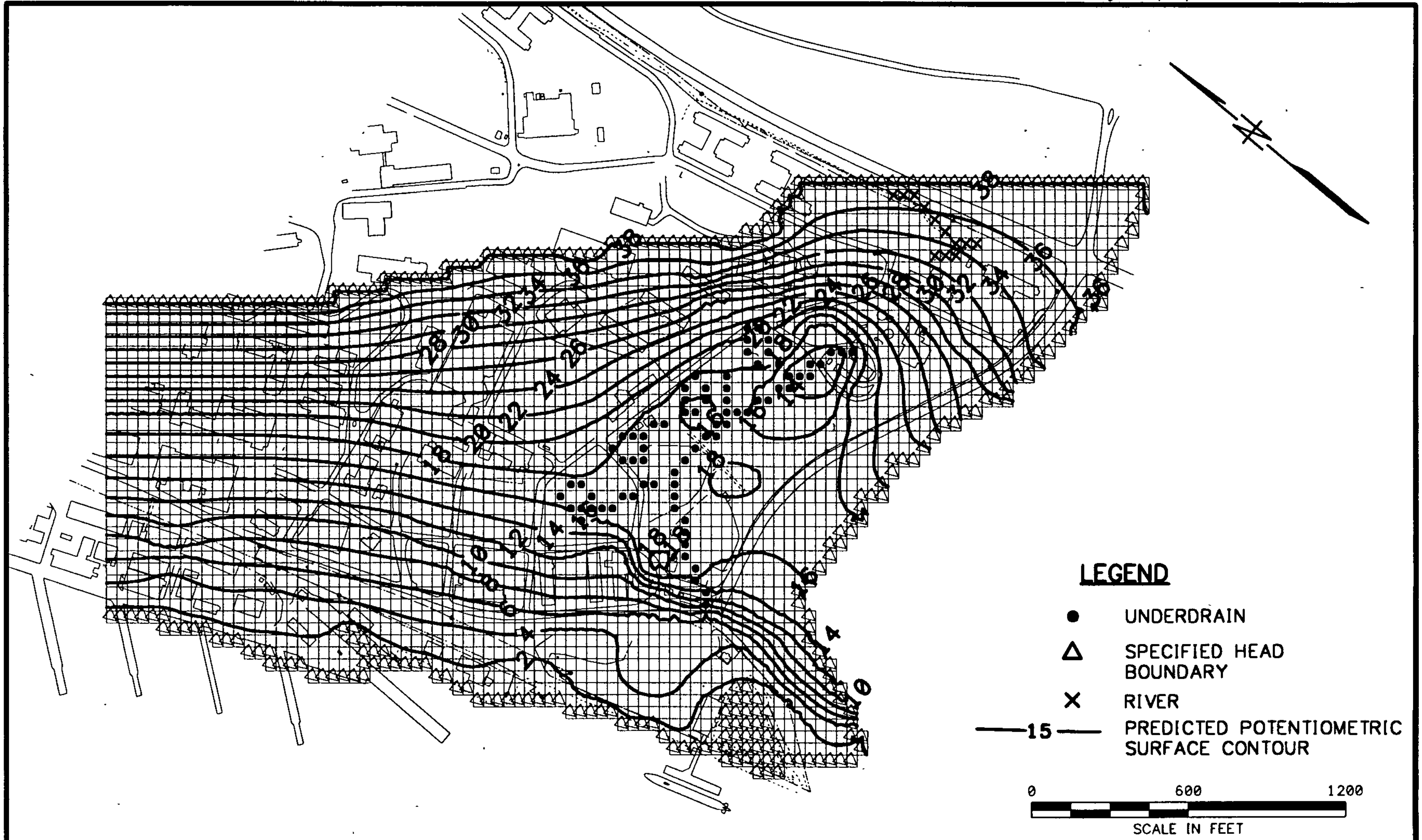

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COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-5	REV. 0

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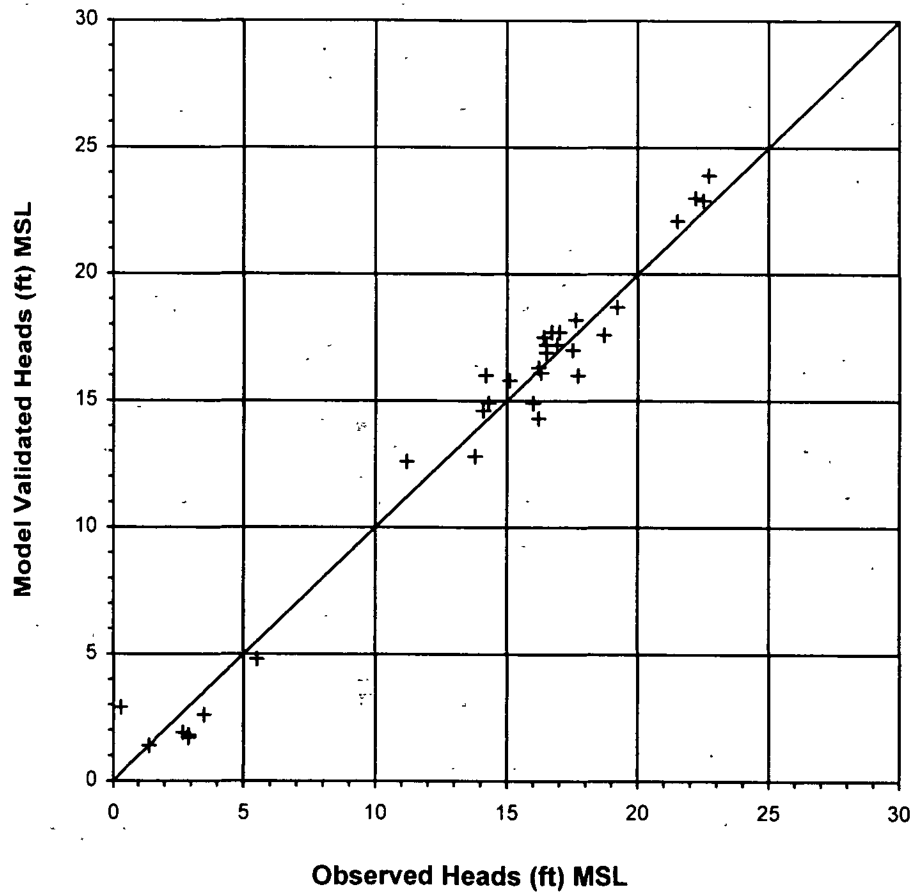

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COST/SCHED-AREA			APPROVED BY	DATE
SCALE AS NOTED			DRAWING NO. FIGURE 3-6	REV. 0

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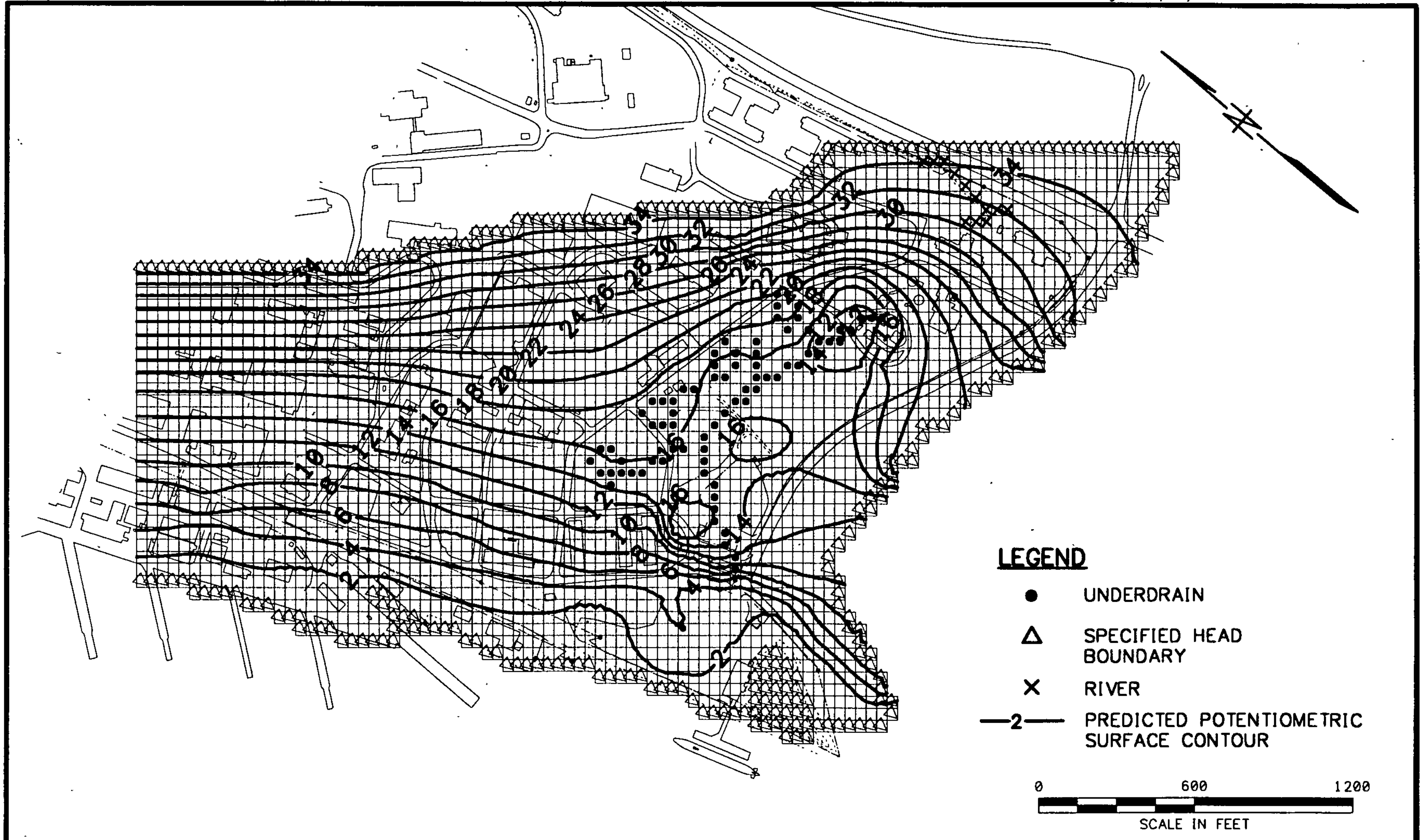

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COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-7	REV. 0

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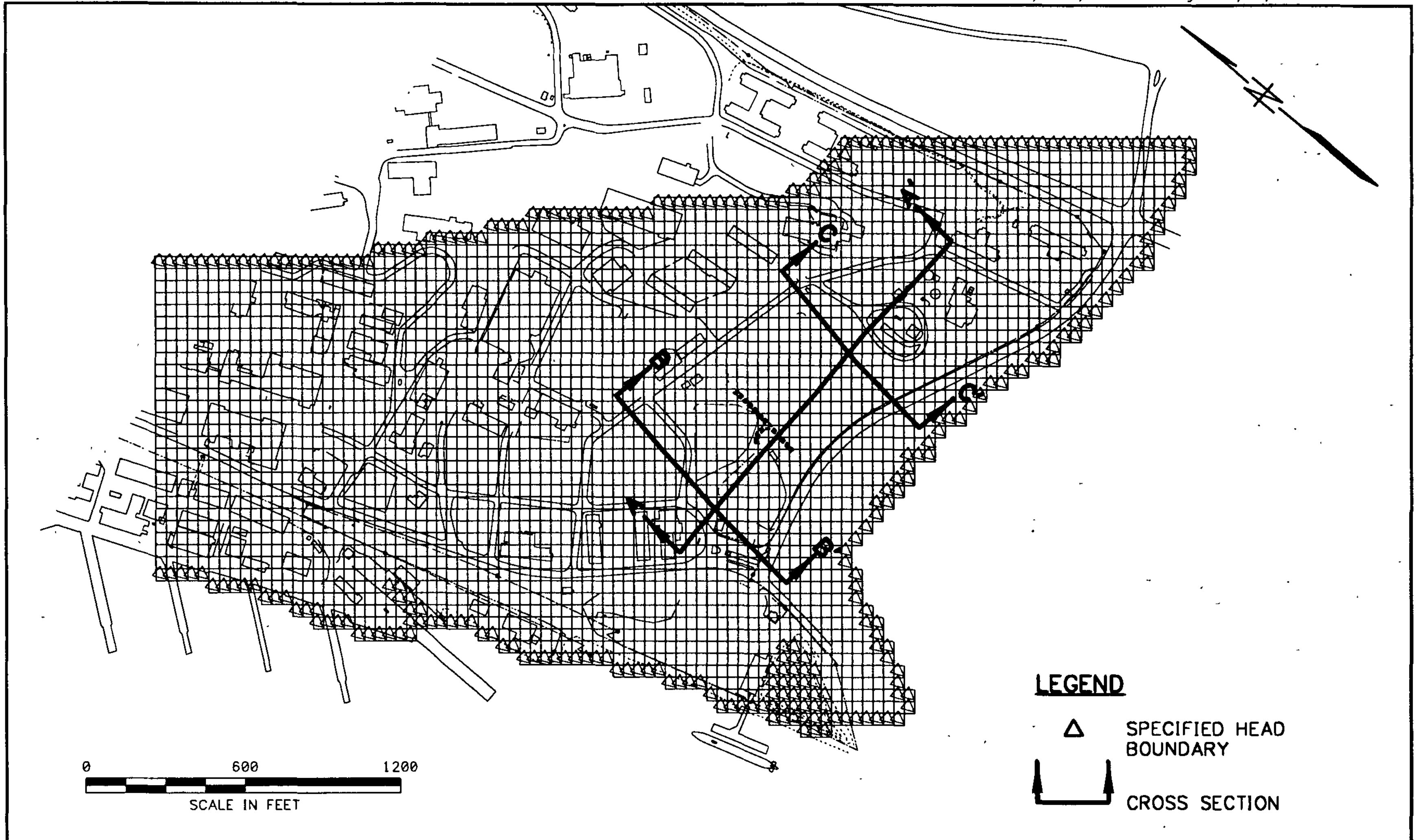

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COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-8	REV. 0

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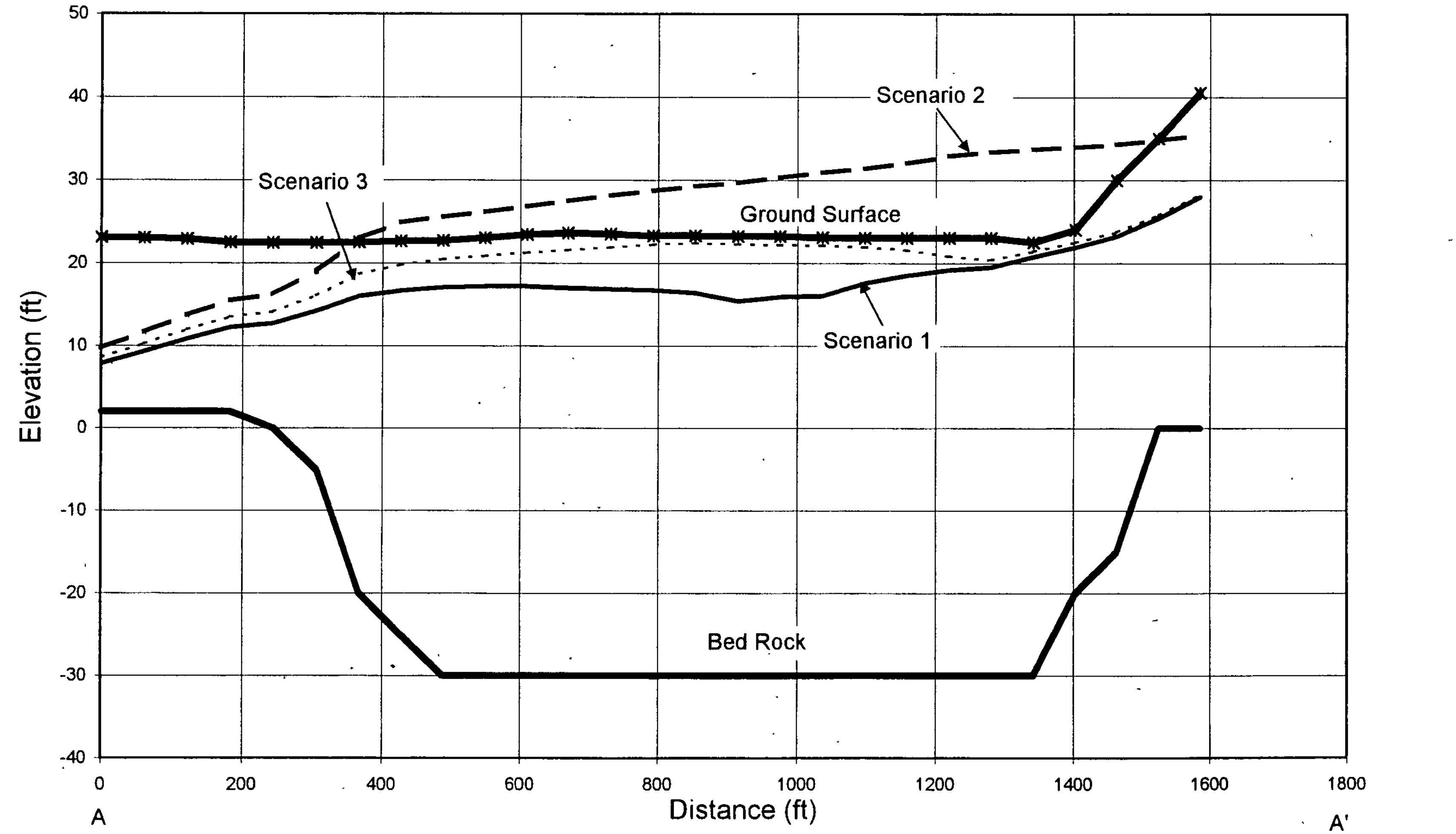

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CHECKED BY / DATE	PREDICTED GROUNDWATER TABLE AT CROSS SECTION A–A' FOR SCENARIOS 1, 2, AND 3 HYDROGEOLOGIC STUDY FOR TANK FARM NSB–NLON, GROTON, CONNECTICUT	APPROVED BY CAR	DATE 12/21/98
COST/SCHED–AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3–9	REV. 0

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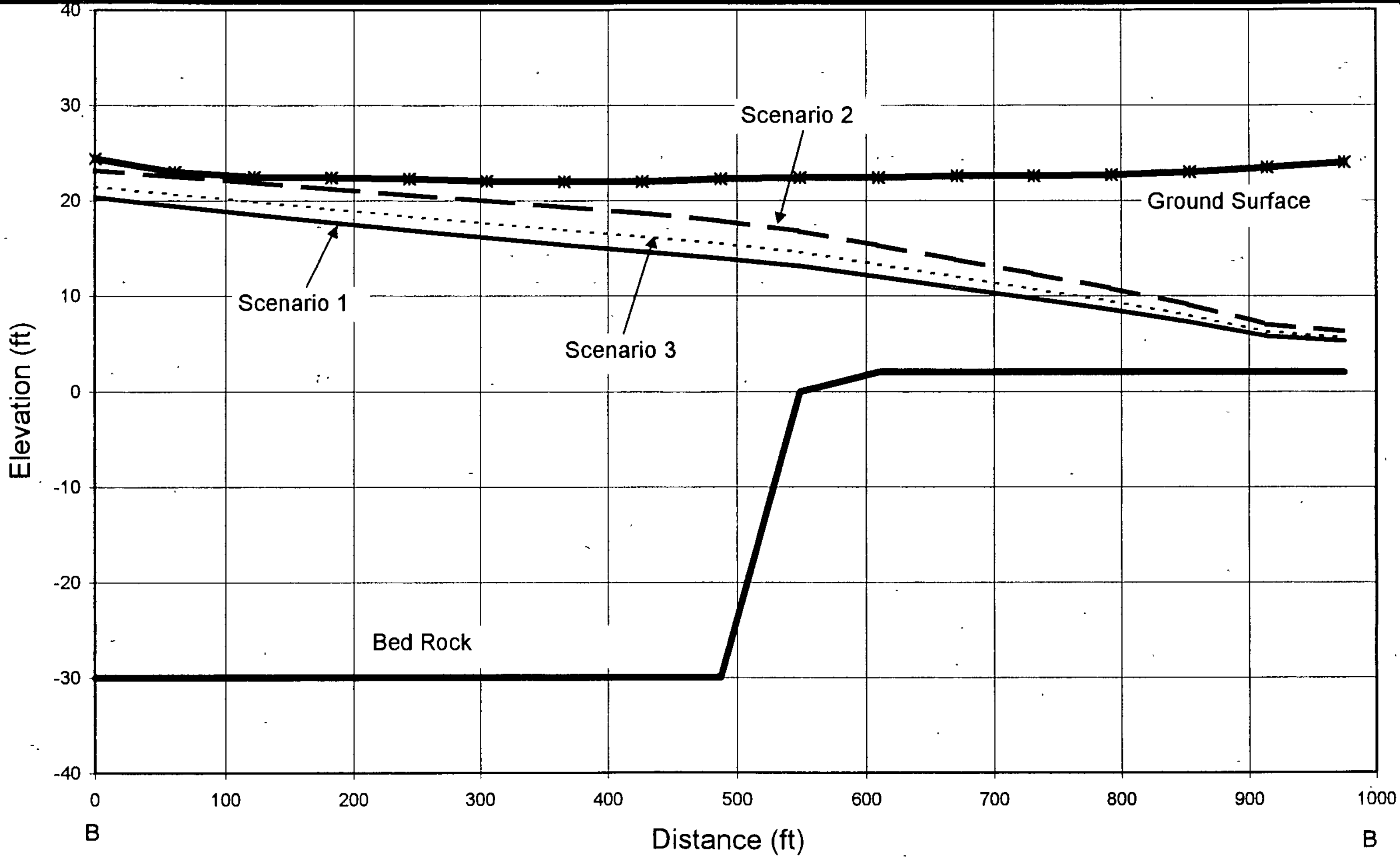

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COST/SCHED-AREA		APPROVED BY DATE	
SCALE AS NOTED		DRAWING NO. FIGURE 3-10	REV. 0

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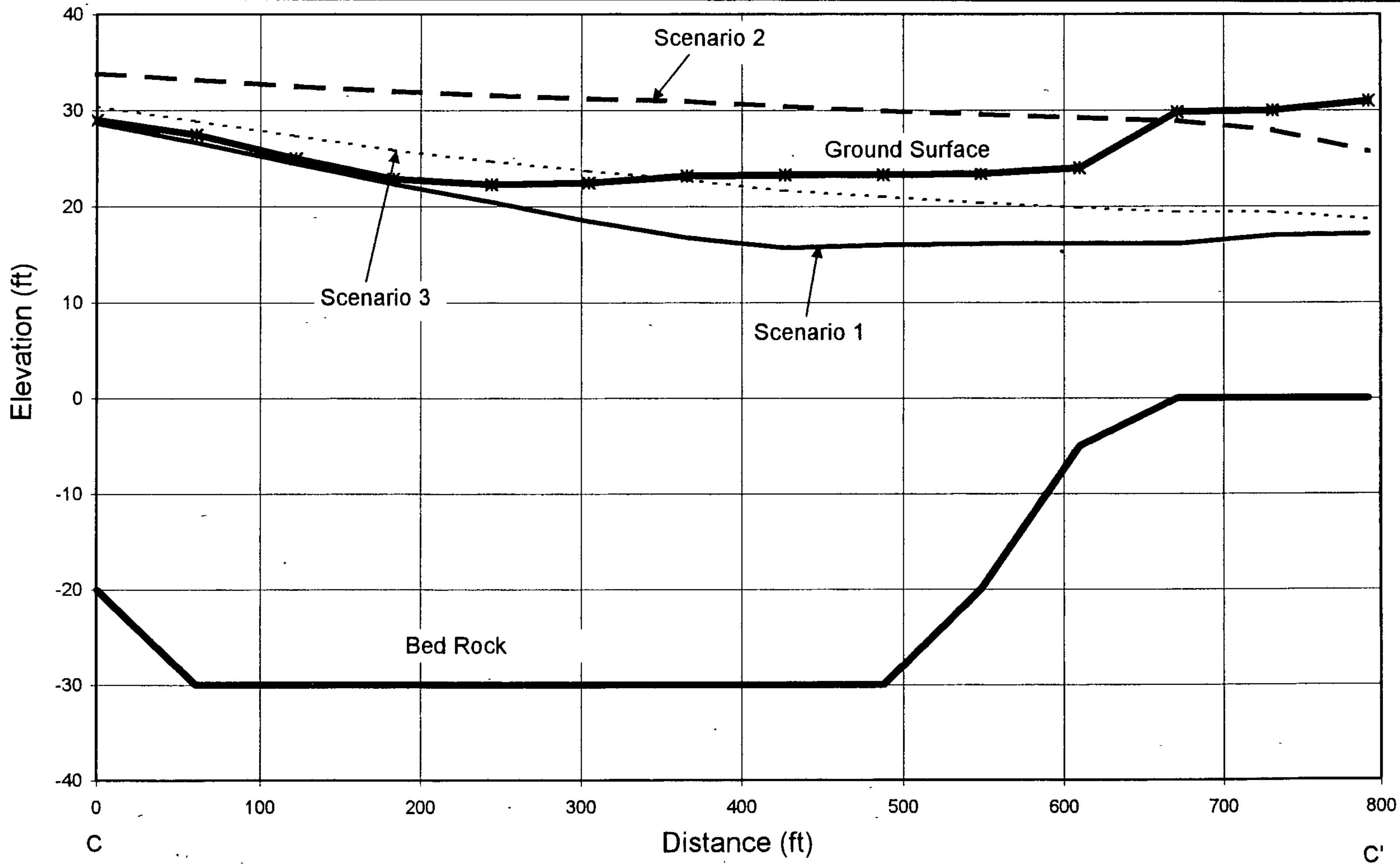

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CHECKED BY	DATE	**PREDICTED GROUNDWATER TABLE AT CROSS SECTION C-C' FOR SCENARIOS 1, 2, AND 3 HYDROGEOLOGIC STUDY FOR TANK FARM NSB-NLON, GROTON, CONNECTICUT**	APPROVED BY CAR	DATE 12/21/98
COST/SCHED-AREA			APPROVED BY	DATE
SCALE AS NOTED			DRAWING NO. FIGURE 3-11	REV. 0

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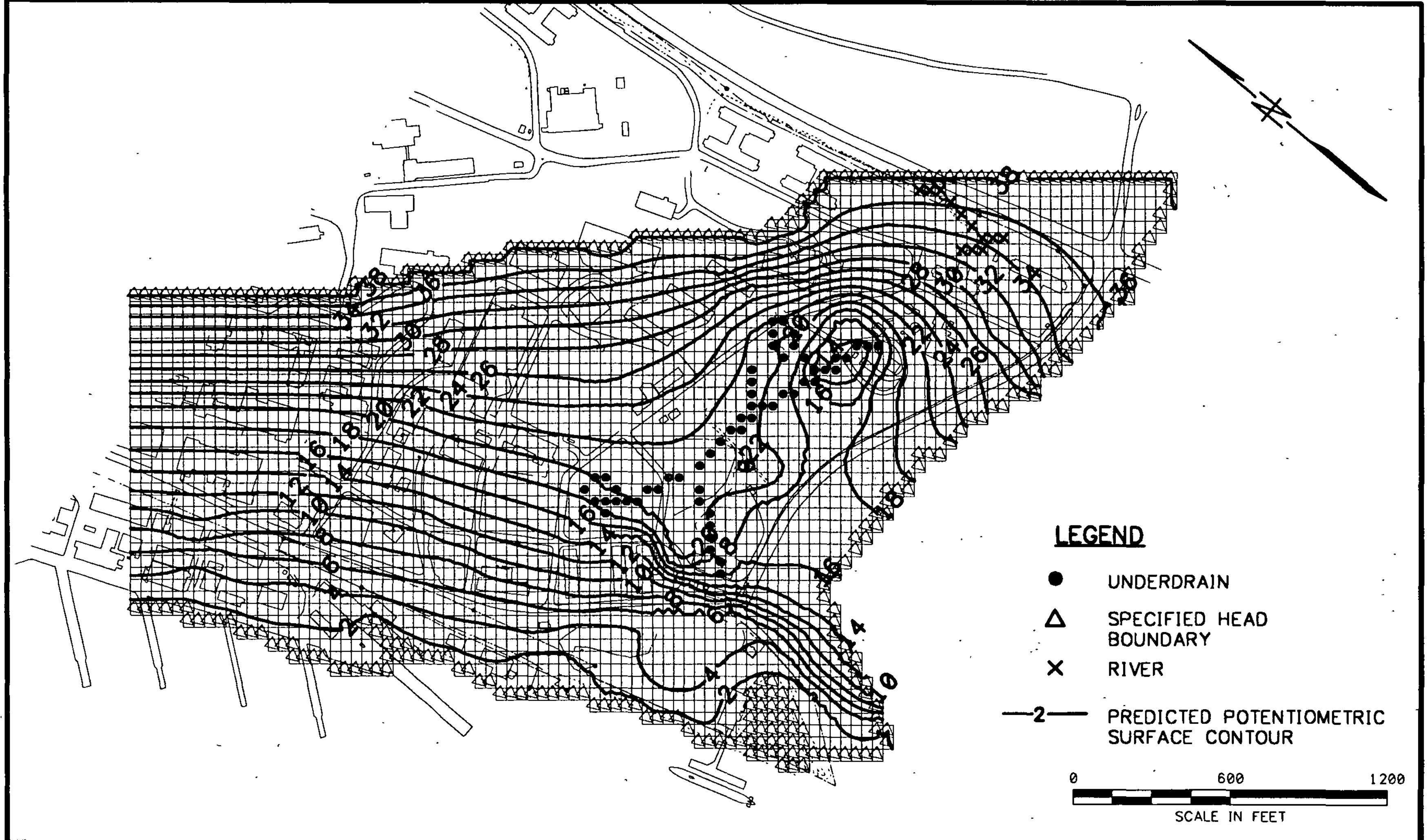

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CHECKED BY DATE	PREDICTED POTENTIOMETRIC SURFACE WITH OT-2 AND OT-3 UNDERDRAINS REMOVED HYDROGEOLOGIC STUDY FOR TANK FARM NSB-NLON, GROTON, CONNECTICUT	APPROVED BY CAR	DATE 12/21/98
COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-12	REV. 0

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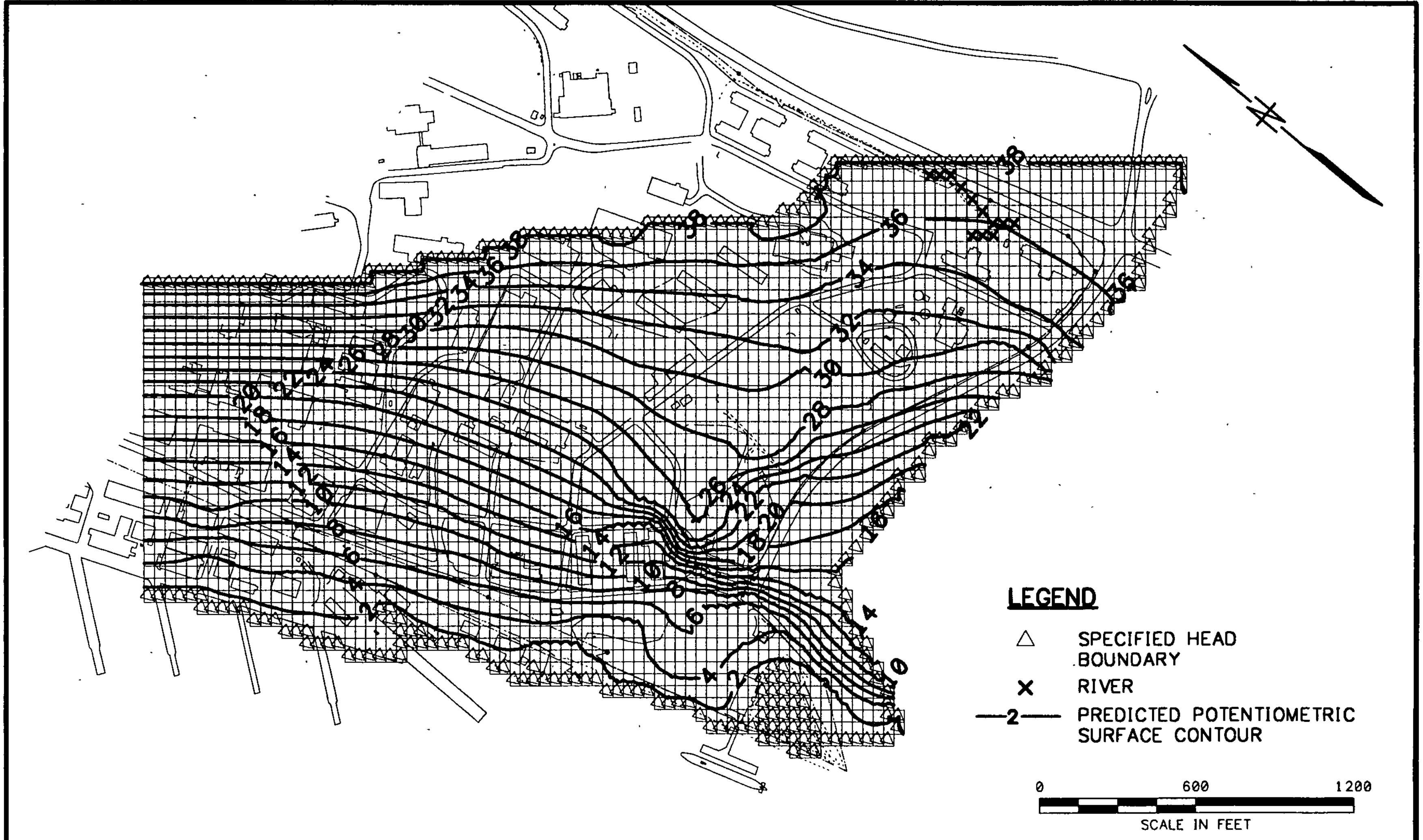

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COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-13	REV. 0

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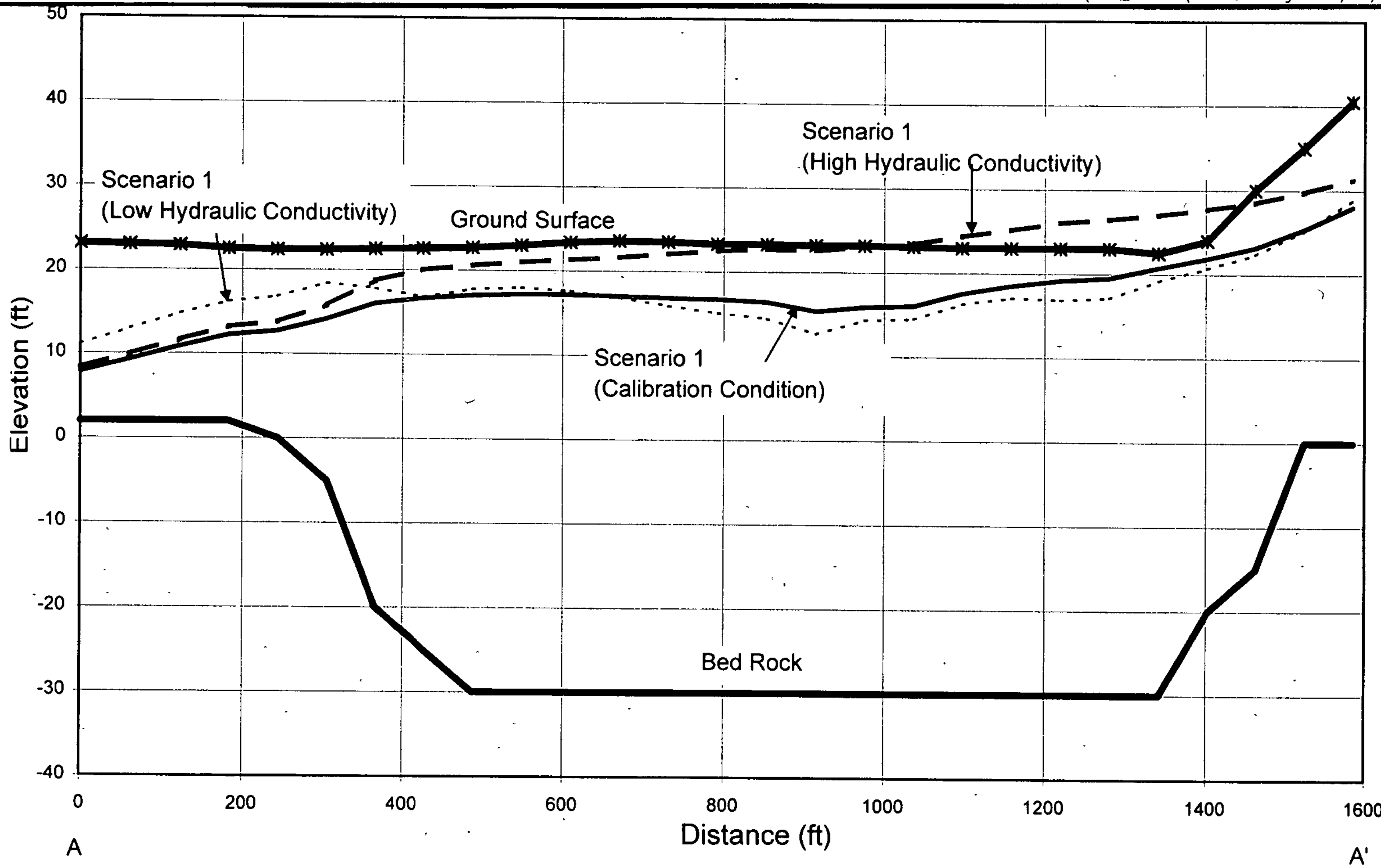

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COST/SCHED-AREA			APPROVED BY	DATE
SCALE AS NOTED			DRAWING NO. FIGURE 3-14	REV. 0

FORM CADD NO. TtNUS_AH DWG - REV 0 - 1/22/98

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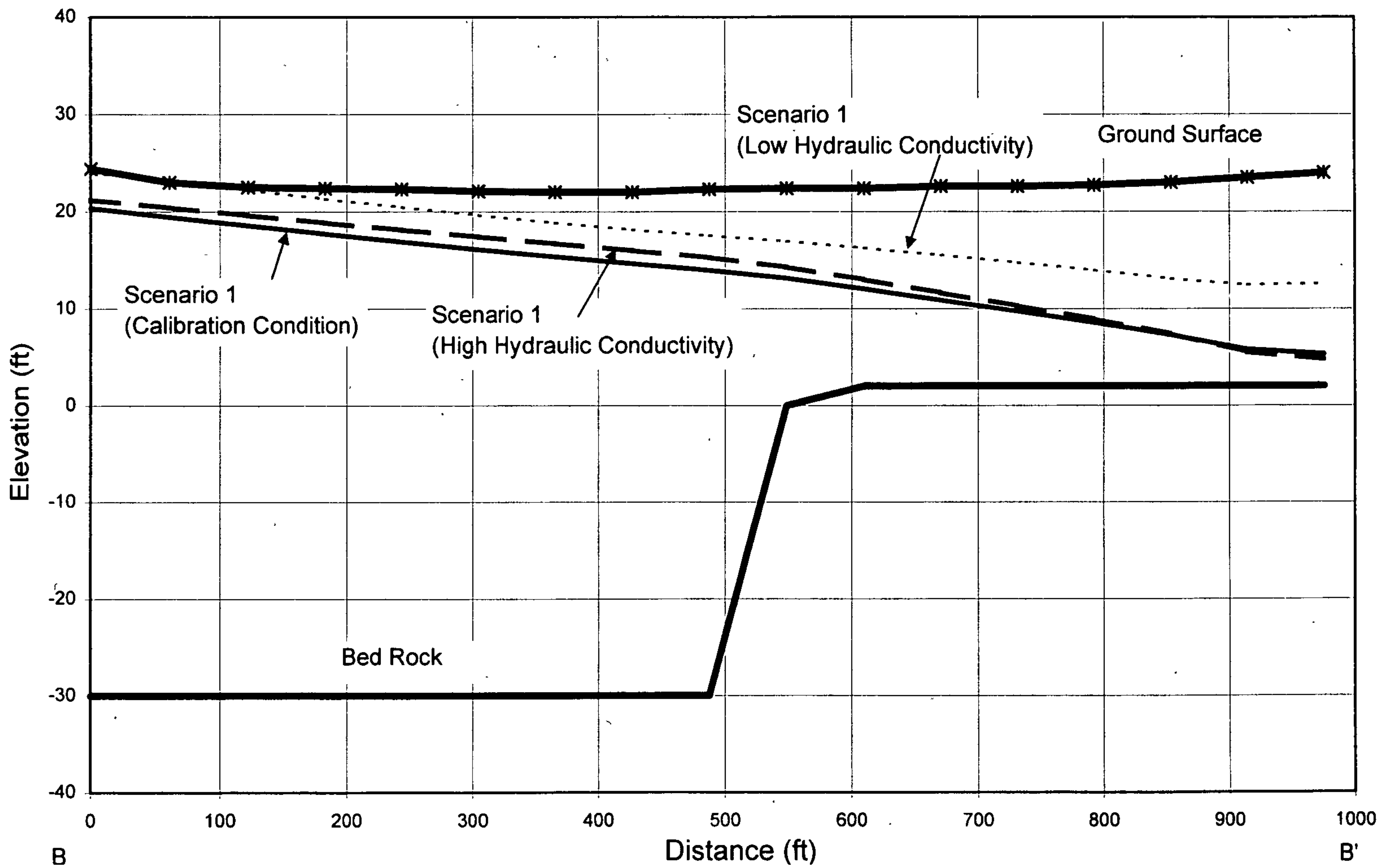
ACAD: 5083\CUT_PASTE\5083Q20.dwg 12/15/98 HJP

069811/P



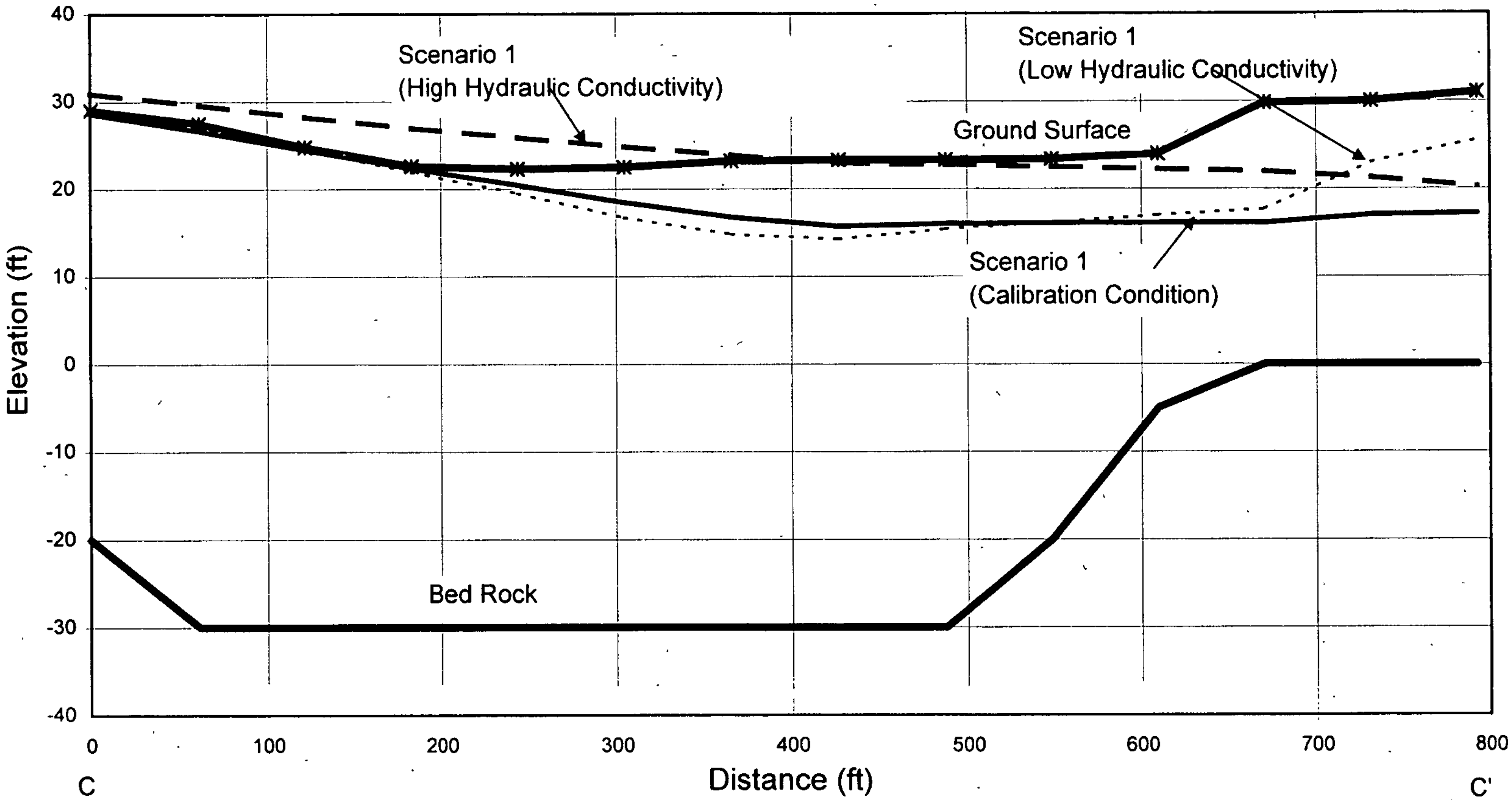
DRAWN BY HJP	DATE 12/15/98	Tetra Tech NUS, Inc.	CONTRACT NO. 5083	OWNER NO. -----
CHECKED BY	DATE	SIMULATED GROUNDWATER TABLE AT CROSS SECTION B-B' UNDER DIFFERENT HYDRAULIC CONDUCTIVITY CONDITIONS HYDROGEOLOGIC STUDY FOR TANK FARM NSB-NLON, GROTON, CONNECTICUT	APPROVED BY CAR	DATE 12/21/98
COST/SCHED-AREA			APPROVED BY	DATE
SCALE AS NOTED			DRAWING NO. FIGURE 3-15	REV. 0

FORM CADD NO TtNUS_AH DWG - REV 0 - 1/22/98

CTO 0204

DRAFT

069811/P



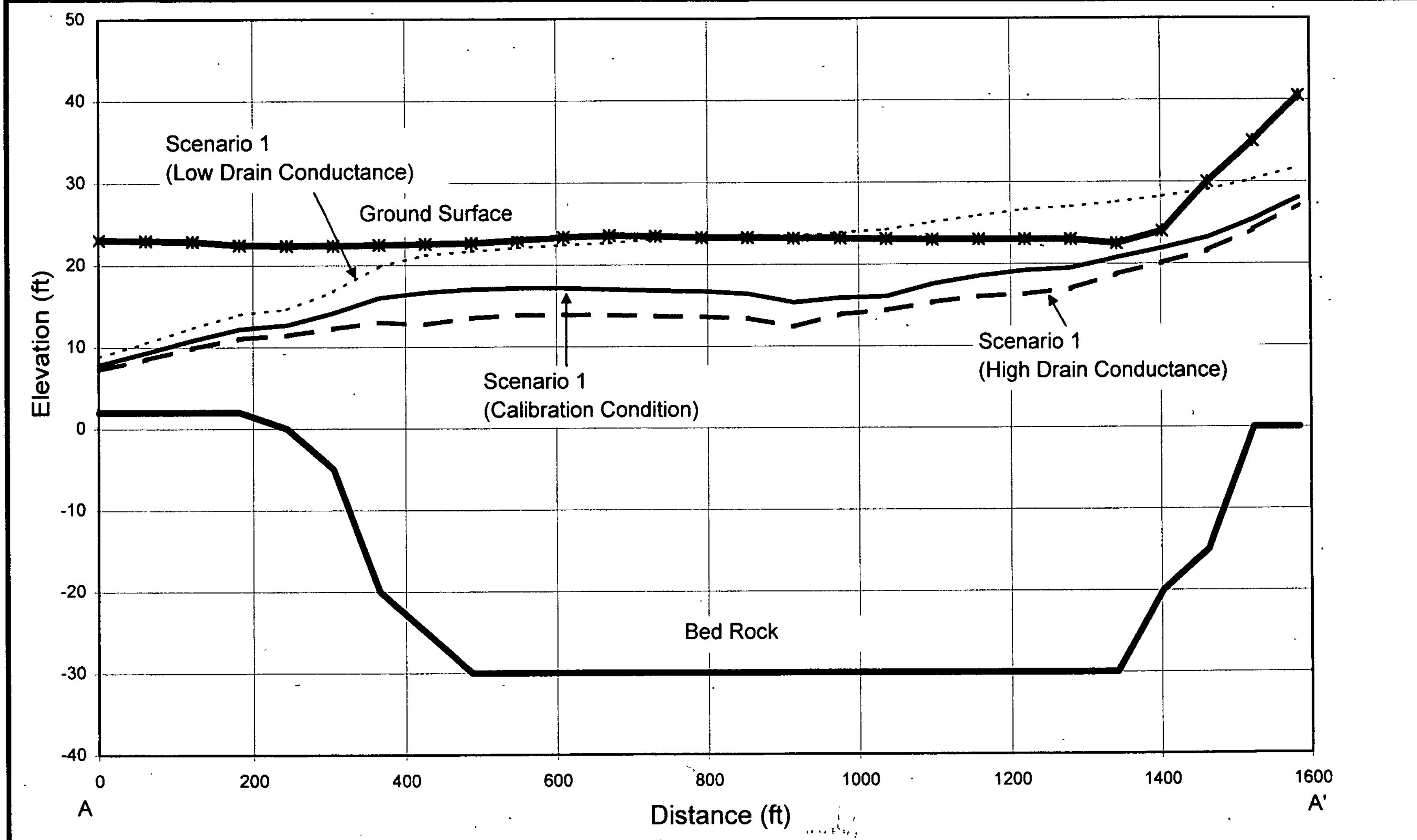
DRAWN BY HJP DATE 12/15/98	Tetra Tech NUS, Inc.	CONTRACT NO. 5083	OWNER NO. ----
CHECKED BY DATE	SIMULATED GROUNDWATER TABLE AT CROSS SECTION C-C' UNDER DIFFERENT HYDRAULIC CONDUCTIVITY CONDITIONS HYDROGEOLOGIC STUDY FOR TANK FARM NSB-NLON, GROTON, CONNECTICUT	APPROVED BY CAR	DATE 12/21/98
COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-16	REV. 0

FORM CADD NO. TtNUS_AH.DWG - REV 0 - 1/22/98

CTO 0204

DRAFT

ACAD: 5083\CUT_PASTE\5083Q23.dwg 12/15/98 HJP

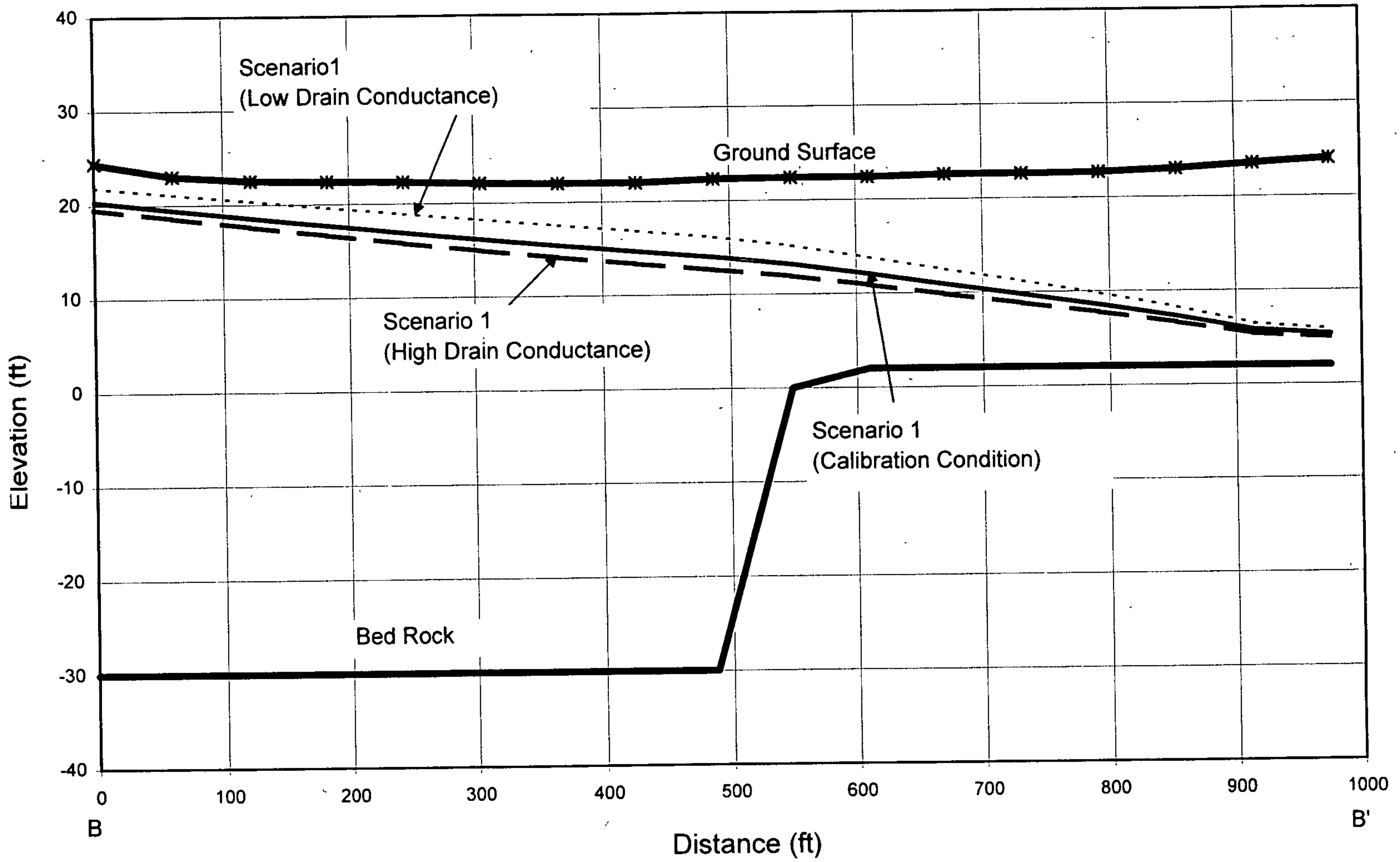


DRAWN BY HJP DATE 12/15/98	Tetra Tech NUS, Inc.	CONTRACT NO. 5083	OWNER NO. ----
CHECKED BY DATE	SIMULATED GROUNDWATER TABLE AT CROSS SECTION A-A' UNDER DIFFERENT DRAIN CONDUCTANCE CONDITIONS HYDROGEOLOGIC STUDY FOR TANK FARM NSB-NLON, GROTON, CONNECTICUT	APPROVED BY CAR DATE 12/21/98	
COST/SCHED-AREA		APPROVED BY DATE	
SCALE AS NOTED		DRAWING NO. FIGURE 3-17	REV. 0

FORM CADD NO TtNUS_AH.DWG - REV 0 - 1/22/98

DRAFT

ACAD: 5083\CUT_PASTE\5083Q26.dwg 12/15/98 HJP



DRAWN BY HJP DATE 12/15/98	Tetra Tech NUS, Inc.	CONTRACT NO. 5083	OWNER NO. ----
CHECKED BY DATE	SIMULATED GROUNDWATER TABLE AT CROSS SECTION B-B' UNDER DIFFERENT DRAIN CONDUCTANCE CONDITIONS HYDROGEOLOGIC STUDY FOR TANK FARM NSB-NLON, GROTON, CONNECTICUT	APPROVED BY CAR	DATE 12/21/98
COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-18	REV. 0

FORM CADD NO. TtNUS_AH.DWG - REV 0 - 1/22/98

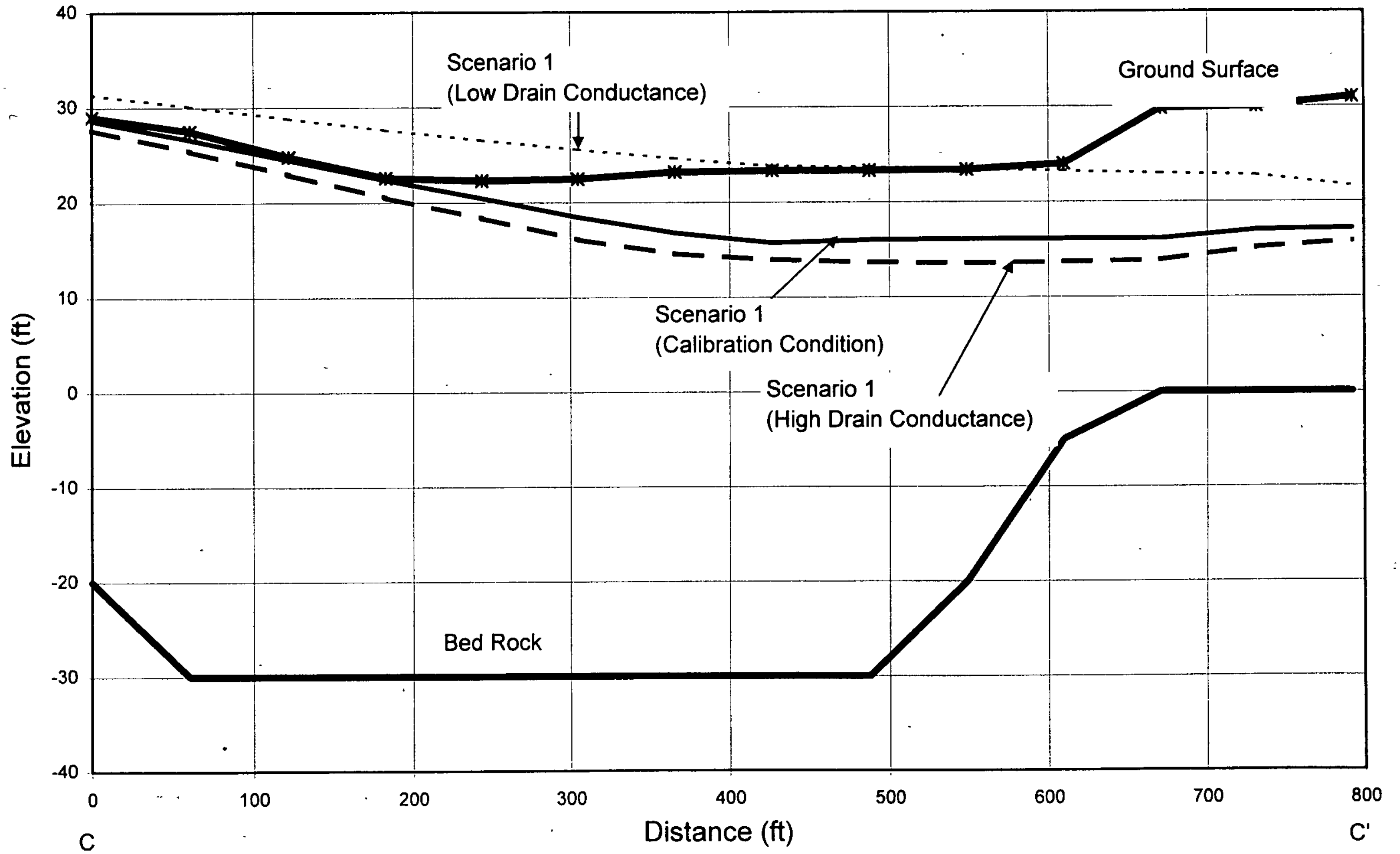
069811/P

3-43

CTO 0204

DRAFT

ACAD:5083\CUT_PASTE\5083Q24.dwg 12/15/98 HJP



DRAWN BY HJP DATE 12/15/98	Tetra Tech NUS, Inc.	CONTRACT NO. 5083	OWNER NO. -----
CHECKED BY DATE	SIMULATED GROUNDWATER TABLE AT CROSS SECTION C-C' UNDER DIFFERENT DRAIN CONDUCTANCE CONDITIONS HYDROGEOLOGIC STUDY FOR TANK FARM NSB-NLON, GROTON, CONNECTICUT	APPROVED BY CAR	DATE 12/21/98
COST/SCHED-AREA		APPROVED BY	DATE
SCALE AS NOTED		DRAWING NO. FIGURE 3-19	REV. 0

FORM CADD NO TtNUS_AH.DWG - REV 0 - 1/22/98

DRAFT

4.0 CONCLUSIONS

TtNUS completed field work and groundwater modeling to answer several questions that required resolution prior to finalizing the design of the new storm sewer system. The results of the effort are summarized below.

- **Question 1:** Is the current underdrain working to depress the water table in the vicinity of the Tank Farm?

  Results: The results of the field work and modeling indicate that the current storm sewer/underdrain system is working and it depresses the water table at the Tank Farm.

- **Question 2:** What is the current groundwater discharge rate into the current underdrain system?

  Results: The results of the field work were used to estimate a current groundwater discharge rate into the underdrain system of 0.4 cfs. During model calibration this parameter was refined to better match existing conditions and the calibrated flow rate is 0.24 cfs.

  The difference in the flow rates could be related to the limitations of the field techniques used to measure the flow rates or the hydrogeologic properties used in the model. During model calibration, hydraulic conductivities for the soil at the Tank Farm were only varied between the actual range of measurements. The sensitivity analysis results indicate that a higher value of hydraulic conductivity would result in a higher flow rate that better matches the flow rate estimated from the field effort.

- **Question 3:** Is the bedrock a significant source of recharge to the overburden at the Tank Farm?

  Results: The water levels collected from two overburden/bedrock well clusters (i.e., HNUS-14/23MW02D and 15MW1S/23MW03D) during Phase 2 field work indicate that the bedrock and overburden units are hydraulically connected (i.e., similar hydraulic heads and no vertical gradient) in the southeast and disconnected (i.e., dissimilar hydraulic heads and significant downward vertical gradient) in the north-central portions of the Tank Farm. These results indicate that bedrock may only provide recharge to the overburden in certain areas of the Tank Farm. Additional data would be required to confirm the regions of the Tank Farm that receive recharge from the bedrock and to quantify the amount of recharge.

- **Question 4:** Will replacement of the current underdrain system with one that is water-tight result in the water table rising to levels that will adversely impact the ballfields and the surrounding roads and buildings?

  Results: This design scenario (Scenario 2) was evaluated by removing the storm sewer/underdrain system from the model. The predicted groundwater table for Scenario 2 is significantly higher (i.e., 2 to 16 feet) than the existing water table (May 1998). The predictions show that it is highly likely that the northern and eastern portions of the Tank Farm will be flooded if the existing storm sewer/underdrain system is removed and replaced with a water-tight system.

  There is some uncertainty associated with these results because limited hydrogeologic data was available for the model area. During model calibration, hydraulic conductivities for the soil at the Tank Farm were only varied between the actual range of measurements (i.e., values determined from slug tests). The results of the sensitivity analysis show that the model is sensitive to both order-of-magnitude increases and decreases in hydraulic conductivity. Therefore, if actual hydraulic conductivities vary from the calibrated values more significant changes in water levels may occur in the Tank Farm.

- **Question 5:** Will revisions to the current underdrain system, as proposed in the preliminary design package, result in the water table rising to levels that will adversely impact the ballfields and the surrounding roads and buildings?

  Results: This design scenario (Scenario 3) was evaluated by removing only the OT-2 and OT-3 underdrains from the model. The predicted groundwater table for Scenario 3 is higher (i.e., 2 to 6 feet) than the existing water table (May 1998), but not as high as the predicted groundwater table for Scenario 2. The predictions show that groundwater levels will almost reach the ground surface in most of the northern and eastern portions of the Tank Farm and that flooding may occur in localized areas of the Tank Farm as a result of the proposed change.

  There is some uncertainty associated with these results because of the limited information that is known about the conductance of the underdrain system. The results of the sensitivity analysis indicate that the model is not very sensitive to increases in drain conductance, but is sensitive to decrease in drain conductance. Therefore, if the actual drain conductance is less than the value that was estimated during model calibration, larger changes in the water table would be expected.

5.0 RECOMMENDATIONS

The results of the field work and groundwater modeling effort show that the existing storm sewer/underdrain system is currently working to depress the water table in the vicinity of the Tank Farm. The following recommendations are made regarding additional groundwater modeling and finalization of the storm sewer system design.

- The results indicate that a de-watering system must be maintained in the Tank Farm or flooding may occur. Foster Wheeler's preliminary design recommends refurbishing the existing underdrain/storm sewer lines and maintaining the lines at their current depths as the method for de-watering the groundwater from the Tank Farm area. The design also recommends construction of a new, shallow storm sewer system to separate surface water flow from groundwater flow. The new system will divert surface water flow around the perimeter of the Tank Farm. This preliminary design should be finalized and the final design details of the rehabilitated storm sewer/underdrain system should be incorporated into the existing model to verify the effect it will have on the local water table.

- Additional data could be collected and used to improve the existing model and reduce the uncertainty and conservativeness of it. An improved model could be used to refine the preliminary design and more accurately predict the impact of removing specific portions of the underdrain system. Removal of the underdrains located in contaminated areas could result in substantial decreases in the operation and maintenance costs associated with the oil/water separator that is included in the preliminary design. Additional field work including a combination of slug tests, pumping tests, drain conductance tests, and water level measurements would be required to refine the understanding of hydrogeologic conditions at the Tank Farm.

REFERENCES

B&R Environmental (Brown & Root Environmental), March 1997. Phase II Remedial Investigation Report for Naval Submarine Base-New London, Groton, Connecticut. Wayne, Pennsylvania.

B&R Environmental (Brown & Root Environmental), September 1997. Site Investigation Report for Tank Farm Investigation for Naval Submarine Base-New London, Groton, Connecticut. Wayne, Pennsylvania.

B&R Environmental (Brown & Root Environmental), May 1998. Internal Letter Work Plan for Hydrogeologic Study at the Tank Farm for Naval Submarine Base-New London, Groton, Connecticut. Pittsburgh, Pennsylvania.

Chow, V. T., 1959. Open-Channel Hydraulics. McGraw-Hill Book Company, Inc., New York.

Foster Wheeler Environmental Corporation, November 13, 1998. Draft Conceptual Design Report, SUBASENLON, Groton, CT - Storm Sewer Rehabilitation Project. Boston, Massachusetts.

Personal Communication from Glenn Mirtl of Fuss & O'Neill, Inc. to Corey Rich of Tetra Tech NUS. November 3, 1998. Summary of Catch Basin Survey Results.

APPENDIX A

FIELD INFORMATION

- Groundwater Level Measurement Sheets
- NOAA Tide Tables
- Rainfall Data From Groton Utilities Water Treatment Plant
- Survey Information
- Boring Logs
- Monitoring Well Construction Diagrams
- Site Photographs

GROUNDWATER LEVEL MEASUREMENT SHEETS

- **Phase 1 - May 1998**
- **Phase 2 - August 1998**

PHASE 1 - MAY 1998

Tetra Tech NUS, Inc.

GROUNDWATER LEVEL MEASUREMENT SHEET

Project:	NSB-NLON	Site:	Tank Farm
Project No.:	5083	Personnel:	T Evans/T Dickson
Temperature:	65 - 75°F	Date:	5/20/98
Precipitation:	ø	Level Indicator Type:	Slope
~~Barometric Pressure:~~	Low Tide @ 1139 hrs	Serial Number:	

Well/Piezometer Number	Time	(A) Elevation of Reference Point (feet)*	(B) Water Level Indicator Reading (feet)*	=(A)-(B) Groundwater Elevation (feet)*	Total Well Depth (feet)*	Tidally Influenced	Comments
13MW12	1145	9.21	5.89	3.32		REVISIONS BY CAR 11/18/98	
MW1-4RS	1150	7.95 ~~4.61~~	4.41	~~0.20~~	3.54		
13MW17	1205	7.47	6.00	1.47			
8MW2D	1219	9.77	7.02	2.75			
8MW2S	1221	9.43	4.83	4.60			
8MW5S	1228	10.94	9.01	1.93			
8MW6D	1242	9.62	6.80	2.82			
8MW6S	1245	9.66	5.95	3.71			
8MW7S	1249	10.45 ~~9.45~~	6.69	3.76			
8MW8D	1255	19.53	16.20	3.33			
8MW8S	1259	19.68	14.73	X		←	PVC riser appears cut dow
15MW1S	1423	28.08	3.17	24.91			
15MW1D	1423	28.05	7.55	20.50			
15MW2S	1429	28.90	3.76	25.14			
15MW4S	1433	26.24	Destroyed	X			
HNUS-6	1437	22.09 ~~19.70~~	3.60	~~16.10~~	18.49		
HNUS-7	1445	22.62 ~~20.23~~	7.91	~~12.32~~	14.71		
ERM-17	1452	22.15 ~~19.76~~	4.89	~~14.87~~	17.26		

* Measurements to the nearest 0.01 foot.

Tetra Tech NUS, Inc. GROUNDWATER LEVEL MEASUREMENT SHEET

Project:	NSB-NLON	Site:	Tank Farm
Project No.:	5083	Personnel:	T. Evans / T. Dickson
Temperature:		Date:	5/20/98
Precipitation:		Level Indicator Type:	
Barometric Pressure:		Serial Number:	

Well/Piezometer Number	Time	(A) Elevation of Reference Point (feet)*	(B) Water Level Indicator Reading (feet)*	=(A)-(B) Groundwater Elevation (feet)*	Total Well Depth (feet)*	Tidally Influenced	Comments
ERM-15	1455	22.63 ~~20.24~~	3.01	~~17.23~~	19.62		
ERM-13	1502	25.52 ~~23.13~~	5.41	~~17.72~~	20.11		
ERM-2	1504	21.46 ~~19.64~~	3.23	~~16.41~~	18.23		
HNUS-2	1516	20.70 ~~18.31~~	3.80	~~14.51~~	16.90		
HNUS 4	1524	21.24 ~~18.85~~	4.04	~~14.81~~	17.20		
HNUS 5	1531	21.35 ~~18.96~~	4.07	~~14.89~~	17.28		
HNUS 20	1540	22.51 ~~20.12~~	5.33	~~14.79~~	17.18		
HNUS 22	1547	27.70 ~~25.31~~	8.82	~~16.49~~	18.88		
HNUS 21	1554	22.35 ~~19.95~~	5.95	~~14.00~~	16.40		
HNUS 23	1602	20.42 ~~18.03~~	5.75	~~12.28~~	14.67		
HNUS 16	1620	—	Unable	to locate —			
HNUS 17	1622	22.08 ~~19.69~~	2.68	~~17.01~~	19.40		
HNUS 18	1630	22.23 ~~19.84~~	3.51	~~16.33~~	18.72		
HNUS 24	1649	27.11 ~~24.72~~	10.78	~~13.94~~	16.33		
HNUS 15	1700	23.13 ~~20.74~~	4.46	~~16.28~~	18.67		
HNUS 14	1753	22.96 ~~20.57~~	3.57	~~17.00~~	19.39		
HNUS 11	1758	22.23 ~~19.84~~	8.24	~~11.60~~	13.99		
HNUS 10	1807	23.25 ~~20.86~~	8.18	~~12.68~~	15.07		

* Measurements to the nearest 0.01 foot.

Tetra Tech NUS, Inc.

GROUNDWATER LEVEL MEASUREMENT SHEET

Project:	NSB-NLON	Site:	Tank Farm
Project No.:	5083	Personnel:	T Evans / T Dickson
Temperature:		Date:	5/20/98
Precipitation:		Level Indicator Type:	
Barometric Pressure:		Serial Number:	

Well/Piezometer Number	Time	(A) Elevation of Reference Point (feet)*	(B) Water Level Indicator Reading (feet)*	=(A)-(B) Groundwater Elevation (feet)*	Total Well Depth (feet)*	Tidally Influenced	Comments
HNUS 13	1815	25.71 ~~23.32~~	0.67	~~22.65~~	25.04		
HNUS 12	1820	26.47 ~~24.08~~	2.39	~~21.69~~	24.08		
HNUS 9	1950	22.04 ~~19.65~~	2.65	~~17.00~~	19.39		
8MW9S	2000	21.40 ~~19.01~~	14.69	~~4.32~~	6.71		
stream east of Bldg 447	5/21/98 0705	–	–	~~25.80~~ ~~24.85~~ (~~NGVD 29~~) ~~28.71~~ 28.23 CAR 11/18/98	~~CAR 6/18/98~~		@ culvert

* Measurements to the nearest 0.01 foot.

PHASE 2 - AUGUST 1998

GROUNDWATER LEVEL MEASUREMENT SHEET

Brown & Root Environmental

Project: NSB - NLON, TANK FARM
Location: GROTON, CT
Weather: SUNNY 85° / SUNNY 85°
Date: 8/4/98 / 8/5/98

Project No.: 5083
Personnel: COREY RICH / KEITH HENN
Measuring Device: HERON - DIPPER T
~~Remarks~~ PAGE: 1 OF 3

Well Number	Time	(A) Elevation of Reference Point (feet)*	(B) Water Level Indicator Reading (feet)*	=(A)-(B) Groundwater Elevation (feet)*	Total Well Depth (feet)*	Comments
13MW10	8/5/98 15:52	8.44	8.96	-0.52	14.89	
13MW12	8/5/98 15:35	9.21	8.90	0.31	15.80	REPLACED 13MW17 W/ THIS WELL
13MW17	–	7.47	NFD	NFD	–	COULD NOT FIND
15MW1D	8/5/98 7:45	28.65	10.15	17.90	45.26	BAILER IN WATER (1.15')
15MW1S	8/5/98 16:27	28.08	5.56	22.52	14.54	
15MW2S	8/5/98 7:35	28.90	6.21	22.69	15.08	BAILER IN WELL PARTIALLY IN WATER (1
15MW4S*	8/5/98 7:15	26.24	3.92	NFD	8.78*	NO PROTECTIVE CASING
8MW2D	8/5/98 15:08	9.77	7.63	2.14	62.08	BAILER IN WELL
8MW2S	8/5/98 14:01	9.43	5.91	3.52	15.15	
8MW5S	8/5/98 14:24	10.94	9.53	1.41	12.68	BAILER LOST IN WELL (?)
8MW6D	8/5/98 14:37	9.62	7.48	2.14	66.40	BROKEN CAP/NO LOCK BAILER LOST IN BOTTOM OF WELL
8MW6S	8/5/98 14:33	9.66	6.99	2.67	10.06	BAILER LOST IN WELL (?)
8MW7S	8/5/98 14:47	10.45	7.54	2.91	13.98	
8MW8D	8/5/98 14:57	19.53	17.18	2.35	77.65	ADJ. TO NEWLY INSTALLED MONUMENT
8MW8S	8/5/98 1502	?	15.37	–	15.80	NO LOCK, PVC CUTTINGS ON BOTTOM
8MW9S	8/4/98 18:28	21.40	15.93	5.47	18.30	NO LOCK

Notes: ALL TIDALLY INFLUENCED WELLS WERE SAMPLED ON 8/5/98. LOW TIDE ON 8/5/98 WAS AT 14:28 (NOAA TIDE TABLES SMITH COVE)

*All measurements to the nearest 0.01 foot

GROUNDWATER LEVEL MEASUREMENT SHEET

Brown & Root Environmental

Project: NSB-NLON, TANK FARM
Location: GROTON, CT.
Weather: SUNNY 85° / SUNNY 85°
Date: 8/4/98 / 8/5/98

Project No.: 5083
Personnel: COREY RICH / KEITH HENN
Measuring Device: HERON-DIPPORT
~~Remarks:~~ PAGE 2 OF 3

Well Number	Time	(A) Elevation of Reference Point (feet)*	(B) Water Level Indicator Reading (feet)*	=(A)-(B) Groundwater Elevation (feet)*	Total Well Depth (feet)*	Comments
ERM-2	8/4/98 16:55	21.46	3.74	17.72	12.90	NO LOCK, NO PROTECTIVE CASING
ERM-13	8/4/98 17:21	25.52	6.31	19.21	14.17	NO KEY FOR LOCK
ERM-15	8/4/98 17:07	22.63	3.89	18.74	11.40	NO LOCK
ERM-17	8/5/98 16:34	22.15	5.68	16.47	12.21	
HNUS-2	8/4/98 16:37	20.70	4.67	16.03	13.59	BAD LOCK AND CAP
HNUS-4	8/4/98 17:41	21.24	5.06	16.18	13.82	NO KEY FOR LOCK
HNUS-5	8/4/98 17:57	21.35	5.05	16.30	13.78	NO KEY FOR LOCK
HNUS-6	8/5/98 13:31	22.09	5.54	16.55	14.78	SOFT BOTTOM LOT OF SILT
HNUS-7	8/5/98 13:15	22.62	8.28	14.34	15.47	
HNUS-9	8/5/98 13:36	22.04	5.00	17.04	13.60	
HNUS-10	8/5/98 8:58	23.25	9.12	14.13	14.59	
HNUS-11	8/5/98 8:45	22.23	8.43	13.80	14.58	
HNUS-12	8/5/98 9:09	26.47	4.29	22.18	14.80	
HNUS-13	8/5/98 9:05	25.71	4.23	21.48	14.42	
HNUS-14	8/5/98 8:13	22.96	5.34	17.62	14.50	BAD LOCK AND CAP
HNUS-15	8/5/98 12:20	23.13	5.63	17.50	14.71	
HNUS-16	—	21.09	NFD	—	—	COULD NOT FIND

Notes: LOW TIDE ON 8/5/98 WAS AT 14:28 (NOAA TIDE TABLES SMITH COVE)

*All measurements to the nearest 0.01 foot

GROUNDWATER LEVEL MEASUREMENT SHEET

Brown & Root Environmental

Project:	NSB-NLON, TANK FARM	Project No.:	5083
Location:	GROTON, CT.	Personnel:	COREY RICH / KEITH HENN
Weather:	SUNNY 85° / SUNNY 85°	Measuring Device:	HERON - DIPPER-T
Date:	8/4/98 / 8/5/98	Remarks:	3 OF 3

Well Number	Time	(A) Elevation of Reference Point (feet)*	(B) Water Level Indicator Reading (feet)*	=(A)-(B) Groundwater Elevation (feet)*	Total Well Depth (feet)*	Comments
HNUS-17	8/5/98 12:36	22.08	5.35	16.73	13.53	
HNUS-18	8/5/98 12:39	22.23	5.32	16.91	14.33	
HNUS-20	8/4/98 16:10	22.51	7.46	15.05	14.68	
HNUS-21	8/4/98 16:20	22.35	8.11	14.24	14.89	BAD LOCK AND CAP
HNUS-22	8/4/98 16:29	27.70	11.26	16.44	20.03	BAD LOCK AND CAP
HNUS-23	8/4/98 18:09	20.42	9.18	11.24	13.90	BAD LOCK AND CAP
HNUS-24	8/5/98 12:26	27.11	10.92	16.19	14.36	LOT OF SILT ON BOTTOM
MW1-4RI	8/5/98 15:23	7.95	5.05	2.90	9.26	
23MW01D	8/5/98 7:00	36.83	4.66	32.17	56.76	
23MW02D	8/5/98 7:59	23.19	5.55	17.64	27.70	
23MW03D	8/5/98 7:15	22.91	6.13	16.78	54.66	
23MW04D	8/4/98 15:50	21.89	10.82*	13.57	94.50	*WELL NOT FINISHED APPROX. 2.5' STICKUP.

Notes: LOW TIDE ON 8/5/98 WAS AT 14:28 (NOAA TIDE TABLES SMITH COVE)

*All measurements to the nearest 0.01 foot

NOAA TIDE TABLES

NOAA National Ocean Service OPSD

How to apply differences (+ , -) and ratios (*)

Tidal Differences and Other Constants

CONNECTICUT, Long Island Sound

Station	Time Diff. High	Time Diff. Low	Hgt. Diff. High	Hgt. Diff. Low	Ref. Station
Stonington, Fishers Island Sound	-0 32	-0 41	*1.05	*1.05	New London
Noank, Mystic River entrance	-0 22	-0 08	*0.89	*0.90	New London
West Harbor, Fishers Island, N.Y.	0 00	-0 06	*0.97	*0.97	New London
Silver Eel Pond, Fishers Island, N.Y.	-0 16	-0 04	*0.89	*0.89	New London
Thames River					
NEW LONDON, State Pier	Daily Predictions				New London
Smith Cove entrance	0 00	+0 10	*0.97	*0.95	New London
Norwich	+0 13	+0 25	*1.16	*1.15	New London
Millstone Point	+0 09	+0 01	*1.05	*1.05	New London
Connecticut River					
Saybrook Jetty	+1 11	+0 45	*1.36	*1.35	New London
Saybrook Point	+1 11	+0 53	*1.24	*1.25	New London
Lyme, highway bridge	+1 25	+1 10	*1.20	*1.20	New London
Essex	+1 39	+1 38	*1.16	*1.15	New London
Connecticut River					
Hadlyme #7	+2 19	+2 23	*1.05	*1.05	New London
East Haddam	+2 42	+2 53	*1.12	*1.10	New London
Haddam #7	+2 48	+3 08	*0.97	*0.95	New London
Higganum Creek	+2 55	+3 25	*1.01	*1.00	New London
Portland #7	+3 51	+4 28	*0.85	*0.85	New London
Rocky Hill #7	+4 44	+5 44	*0.78	*0.80	New London
Hartford #7	+5 30	+6 52	*0.74	*0.75	New London
Westbrook, Duck Island Roads	-0 24	-0 32	*0.61	*0.60	Bridgeport
Duck Island	-0 26	-0 35	*0.67	*0.68	Bridgeport
Madison	-0 21	-0 30	*0.73	*0.72	Bridgeport
Falkner Island	-0 14	-0 25	*0.80	*0.80	Bridgeport
Sachem Head	-0 11	-0 15	*0.80	*0.80	Bridgeport
Money Island	-0 12	-0 23	*0.83	*0.84	Bridgeport
Branford Harbor	-0 08	-0 18	*0.88	*0.88	Bridgeport
New Haven Harbor entrance	-0 09	-0 14	*0.92	*0.92	Bridgeport
New Haven (city dock)	+0 01	-0 01	*0.89	*0.88	Bridgeport
Milford Harbor	-0 08	-0 10	*0.98	*0.96	Bridgeport
Stratford, Housatonic River	+0 26	+1 01	*0.82	*0.80	Bridgeport
Shelton, Housatonic River	+1 35	+2 44	*0.74	*0.72	Bridgeport
BRIDGEPORT	Daily Predictions				Bridgeport
Black Rock Harbor entrance	-0 04	-0 03	*1.02	*1.04	Bridgeport
Saugatuck River entrance	-0 02	+0 01	*1.04	*1.04	Bridgeport
South Norwalk	+0 09	+0 15	*1.05	*1.04	Bridgeport
Greens Ledge	-0 02	-0 01	*1.07	*1.08	Bridgeport
Stamford	+0 03	+0 08	*1.07	*1.08	Bridgeport
Cos Cob Harbor	+0 05	+0 11	*1.07	*1.08	Bridgeport
Greenwich	+0 01	+0 01	*1.10	*1.08	Bridgeport
Great Captain Island	0 00	+0 01	*1.08	*1.08	Bridgeport

NEW YORK

Long Island Sound, north side

Station	Time Diff. High	Time Diff. Low	Hgt. Diff. High	Hgt. Diff. Low	Ref. Station
Port Chester	-0 03	-0 14	*1.01	*1.01	Willets Point
Rye Beach	-0 22	-0 31	*1.01	*1.01	Willets Point
Mamaroneck	-0 02	-0 13	*1.02	*1.04	Willets Point
New Rochelle	-0 18	-0 21	*1.02	*1.04	Willets Point
Davids Island	+0 04	-0 09	*1.01	*1.00	Willets Point
City Island	+0 03	-0 05	*1.01	*1.00	Willets Point
Throgs Neck	+0 08	+0 12	*0.98	*0.98	Willets Point

All times listed are in Local Time, and all heights are in Feet.

New London, Connecticut
Tide Predictions (High and Low Waters) May, 1998
NOAA, National Ocean Service

Daylight Saving Time

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 F	148am H	3.2	833am L	.0	232pm H	2.5	848pm L	.4
2 Sa	249am H	3.0	932am L	.2	337pm H	2.5	951pm L	.5
3 Su	354am H	2.7	1030am L	.3	443pm H	2.5	1054pm L	.6
4 M	500am H	2.6	1126am L	.4	544pm H	2.5	1154pm L	.6
5 Tu	601am H	2.5	1217pm L	.4	637pm H	2.6		
6 W	1248am L	.5	654am H	2.5	105pm L	.4	721pm H	2.7
7 Th	137am L	.4	740am H	2.5	148pm L	.4	759pm H	2.8
8 F	221am L	.3	819am H	2.5	230pm L	.4	835pm H	2.9
9 Sa	303am L	.2	857am H	2.5	309pm L	.4	909pm H	3.0
10 Su	344am L	.2	933am H	2.6	348pm L	.4	944pm H	3.1
11 M	425am L	.1	1010am H	2.6	427pm L	.4	1018pm H	3.2
12 Tu	506am L	.1	1048am H	2.6	507pm L	.5	1053pm H	3.2
13 W	548am L	.1	1127am H	2.5	548pm L	.5	1130pm H	3.2
14 Th	631am L	.1	1209pm H	2.5	631pm L	.6		
15 F	1210am H	3.1	718am L	.2	1254pm H	2.5	719pm L	.7
16 Sa	1254am H	3.0	807am L	.3	143pm H	2.5	813pm L	.8
17 Su	146am H	3.0	858am L	.3	239pm H	2.5	913pm L	.8
18 M	244am H	2.9	952am L	.3	338pm H	2.6	1014pm L	.7
19 Tu	349am H	2.8	1046am L	.3	438pm H	2.7	1115pm L	.5
20 W	455am H	2.8	1139am L	.2	537pm H	3.0		
21 Th	1214am L	.3	559am H	2.8	1231pm L	.2	632pm H	3.2
22 F	110am L	.1	658am H	2.8	122pm L	.1	725pm H	3.5
23 Sa	204am L	-.1	754am H	2.9	212pm L	.0	816pm H	3.7
24 Su	256am L	-.3	847am H	2.9	302pm L	-.1	906pm H	3.8
25 M	347am L	-.4	939am H	3.0	351pm L	-.1	956pm H	3.8
26 Tu	438am L	-.4	1031am H	2.9	442pm L	.0	1045pm H	3.8
27 W	529am L	-.4	1122am H	2.9	534pm L	.1	1136pm H	3.6
28 Th	620am L	-.2	1215pm H	2.8	628pm L	.2		
29 F	1228am H	3.4	712am L	-.1	110pm H	2.7	725pm L	.4
30 Sa	122am H	3.2	806am L	.1	207pm H	2.6	823pm L	.5
31 Su	219am H	2.9	900am L	.2	306pm H	2.6	924pm L	.6

PHASE 1

THIS IS TIDE INFO FOR NEW LONDON - USE CONVERSION FACTORS PROVIDED ON P. 1 OF 5 TO DETERMINE SMITH COVE TIDE INFO.

New London, Connecticut
Tide Predictions (High and Low Waters) June, 1998
NOAA, National Ocean Service

Daylight Saving Time

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 M	319am H	2.7	954am L	.4	406pm H	2.6	1024pm L	.7
2 Tu	419am H	2.5	1047am L	.4	504pm H	2.6	1122pm L	.7
3 W	518am H	2.4	1138am L	.5	555pm H	2.7		
4 Th	1216am L	.6	611am H	2.4	1226pm L	.5	641pm H	2.8
5 F	106am L	.5	659am H	2.4	111pm L	.5	722pm H	2.9
6 Sa	151am L	.4	743am H	2.4	154pm L	.5	759pm H	3.0
7 Su	235am L	.3	824am H	2.4	236pm L	.5	836pm H	3.1
8 M	317am L	.2	903am H	2.5	316pm L	.5	912pm H	3.2
9 Tu	358am L	.1	943am H	2.5	357pm L	.5	949pm H	3.3
10 W	440am L	.1	1022am H	2.6	438pm L	.5	1026pm H	3.3
11 Th	522am L	.0	1103am H	2.6	521pm L	.5	1106pm H	3.3
12 F	606am L	.0	1147am H	2.6	606pm L	.6	1149pm H	3.3
13 Sa	651am L	.1	1233pm H	2.6	656pm L	.6		
14 Su	1236am H	3.2	739am L	.1	123pm H	2.7	751pm L	.6
15 M	128am H	3.1	830am L	.2	217pm H	2.7	851pm L	.6
16 Tu	226am H	2.9	922am L	.2	315pm H	2.8	953pm L	.5
17 W	329am H	2.8	1017am L	.2	415pm H	3.0	1055pm L	.4
18 Th	434am H	2.7	1111am L	.2	514pm H	3.2	1155pm L	.3

19 F	539am H	2.7	1205pm L	.2	611pm H	3.3		
20 Sa	1253am L	.1	640am H	2.7	1258pm L	.2	706pm H	3.5
21 Su	148am L	-.1	737am H	2.7	150pm L	.1	759pm H	3.6
22 M	240am L	-.2	832am H	2.7	242pm L	.1	850pm H	3.7
23 Tu	331am L	-.2	924am H	2.8	333pm L	.1	939pm H	3.7
24 W	420am L	-.3	1014am H	2.8	423pm L	.1	1028pm H	3.6
25 Th	509am L	-.2	1104am H	2.8	515pm L	.2	1117pm H	3.5
26 F	558am L	-.1	1153am H	2.8	607pm L	.3		
27 Sa	1205am H	3.3	646am L	.0	1244pm H	2.7	700pm L	.4
28 Su	1255am H	3.1	735am L	.1	135pm H	2.7	756pm L	.5
29 M	146am H	2.8	826am L	.3	229pm H	2.7	852pm L	.6
30 Tu	239am H	2.6	916am L	.4	323pm H	2.7	949pm L	.7

New London, Connecticut
Tide Predictions (High and Low Waters) July, 1998
NOAA, National Ocean Service

Daylight Saving Time

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 W	334am H	2.4	1007am L	.5	417pm H	2.7	1045pm L	.7
2 Th	430am H	2.3	1058am L	.5	509pm H	2.7	1140pm L	.7
3 F	525am H	2.3	1147am L	.6	557pm H	2.8		
4 Sa	1231am L	.6	617am H	2.3	1234pm L	.6	641pm H	2.9
5 Su	119am L	.5	705am H	2.3	120pm L	.6	723pm H	3.0
6 M	204am L	.4	749am H	2.4	203pm L	.5	802pm H	3.1
7 Tu	247am L	.2	832am H	2.4	246pm L	.5	842pm H	3.2
8 W	330am L	.1	914am H	2.5	328pm L	.4	922pm H	3.3
9 Th	412am L	.0	956am H	2.6	412pm L	.4	1003pm H	3.4
10 F	455am L	.0	1039am H	2.7	457pm L	.4	1046pm H	3.4
11 Sa	539am L	-.1	1123am H	2.8	545pm L	.3	1131pm H	3.4
12 Su	624am L	.0	1210pm H	2.9	636pm L	.3		
13 M	1220am H	3.3	712am L	.0	100pm H	3.0	732pm L	.3
14 Tu	113am H	3.1	802am L	.1	154pm H	3.0	831pm L	.4
15 W	210am H	2.9	855am L	.1	251pm H	3.1	932pm L	.3
16 Th	312am H	2.8	950am L	.2	352pm H	3.2	1035pm L	.3
17 F	417am H	2.6	1047am L	.3	453pm H	3.2	1136pm L	.2
18 Sa	523am H	2.5	1143am L	.3	553pm H	3.3		
19 Su	1236am L	.1	626am H	2.5	1239pm L	.2	651pm H	3.4
20 M	132am L	.0	725am H	2.6	134pm L	.2	746pm H	3.5
21 Tu	224am L	.0	819am H	2.6	226pm L	.2	837pm H	3.5
22 W	314am L	-.1	910am H	2.7	317pm L	.2	926pm H	3.5
23 Th	401am L	-.1	958am H	2.7	407pm L	.2	1012pm H	3.4
24 F	447am L	.0	1043am H	2.8	456pm L	.2	1057pm H	3.3
25 Sa	532am L	.0	1128am H	2.8	545pm L	.3	1142pm H	3.1
26 Su	617am L	.1	1213pm H	2.8	635pm L	.4		
27 M	1226am H	2.9	702am L	.2	1259pm H	2.8	725pm L	.5
28 Tu	111am H	2.8	749am L	.3	147pm H	2.8	818pm L	.6
29 W	158am H	2.6	837am L	.5	236pm H	2.7	912pm L	.7
30 Th	249am H	2.4	927am L	.6	327pm H	2.7	1006pm L	.7
31 F	342am H	2.3	1018am L	.6	419pm H	2.7	1101pm L	.7

New London, Connecticut
Tide Predictions (High and Low Waters) August, 1998
NOAA, National Ocean Service

Daylight Saving Time

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 Sa	439am H	2.2	1108am L	.7	510pm H	2.7	1154pm L	.7
2 Su	534am H	2.2	1158am L	.7	558pm H	2.8		
3 M	1244am L	.5	627am H	2.3	1246pm L	.7	645pm H	2.9
4 Tu	132am L	.4	716am H	2.4	133pm L	.6	729pm H	3.1
5 W	217am L	.3	801am H	2.5	218pm L	.5	813pm H	3.2
6 Th	300am L	.1	845am H	2.6	303pm L	.4	856pm H	3.4
7 F	343am L	.0	928am H	2.8	348pm L	.2	941pm H	3.5
8 Sa	426am L	-.1	1012am H	3.0	435pm L	.1	1026pm H	3.5
9 Su	510am L	-.1	1058am H	3.1	524pm L	.1	1114pm H	3.4
10 M	556am L	-.1	1145am H	3.2	616pm L	.1		
11 Tu	1204am H	3.3	644am L	-.1	1236pm H	3.3	712pm L	.1
12 W	1257am H	3.2	734am L	.0	129pm H	3.3	810pm L	.1
13 Th	154am H	3.0	828am L	.1	227pm H	3.3	912pm L	.2
14 F	256am H	2.8	926am L	.3	329pm H	3.3	1015pm L	.2
15 Sa	402am H	2.6	1025am L	.3	433pm H	3.3	1118pm L	.2
16 Su	509am H	2.5	1125am L	.4	537pm H	3.3		
17 M	1218am L	.2	615am H	2.5	1224pm L	.4	639pm H	3.3
18 Tu	115am L	.2	715am H	2.5	121pm L	.3	735pm H	3.3
19 W	207am L	.1	808am H	2.6	214pm L	.3	826pm H	3.3

PHASE 2

All times listed are in Local Time, and all heights are in Feet.

New London, Connecticut
Tide Predictions (High and Low Waters) August, 1998
NOAA, National Ocean Service

Daylight Saving Time

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 Sa	439am H	2.2	1108am L	.7	510pm H	2.7	1154pm L	.7
2 Su	534am H	2.2	1158am L	.7	558pm H	2.8		
3 M	1244am L	.5	627am H	2.3	1246pm L	.7	645pm H	2.9
4 Tu	132am L	.4	716am H	2.4	133pm L	.6	729pm H	3.1
5 W	217am L	.3	801am H	2.5	218pm L	.5	813pm H	3.2
6 Th	300am L	.1	845am H	2.6	303pm L	.4	856pm H	3.4
7 F	343am L	.0	928am H	2.8	348pm L	.2	941pm H	3.5
8 Sa	426am L	-.1	1012am H	3.0	435pm L	.1	1026pm H	3.5
9 Su	510am L	-.1	1058am H	3.1	524pm L	.1	1114pm H	3.4
10 M	556am L	-.1	1145am H	3.2	616pm L	.1		
11 Tu	1204am H	3.3	644am L	-.1	1236pm H	3.3	712pm L	.1
12 W	1257am H	3.2	734am L	.0	129pm H	3.3	810pm L	.1
13 Th	154am H	3.0	828am L	.1	227pm H	3.3	912pm L	.2
14 F	256am H	2.8	926am L	.3	329pm H	3.3	1015pm L	.2
15 Sa	402am H	2.6	1025am L	.3	433pm H	3.3	1118pm L	.2
16 Su	509am H	2.5	1125am L	.4	537pm H	3.3		
17 M	1218am L	.2	615am H	2.5	1224pm L	.4	639pm H	3.3
18 Tu	115am L	.2	715am H	2.5	121pm L	.3	735pm H	3.3
19 W	207am L	.1	808am H	2.6	214pm L	.3	826pm H	3.3
20 Th	255am L	.1	856am H	2.7	303pm L	.2	913pm H	3.2
21 F	340am L	.1	939am H	2.8	351pm L	.2	956pm H	3.2
22 Sa	422am L	.1	1020am H	2.9	437pm L	.2	1036pm H	3.1
23 Su	504am L	.2	1100am H	2.9	522pm L	.3	1116pm H	3.0
24 M	545am L	.2	1140am H	2.9	608pm L	.4	1156pm H	2.9
25 Tu	628am L	.3	1221pm H	2.9	654pm L	.5		
26 W	1236am H	2.7	712am L	.4	103pm H	2.9	743pm L	.6
27 Th	119am H	2.6	758am L	.6	147pm H	2.8	834pm L	.7
28 F	206am H	2.4	846am L	.7	235pm H	2.7	927pm L	.7
29 Sa	258am H	2.3	938am L	.8	326pm H	2.7	1022pm L	.7
30 Su	355am H	2.3	1031am L	.8	420pm H	2.7	1117pm L	.7
31 M	454am H	2.2	1124am L	.8	514pm H	2.8		

New London, Connecticut
Tide Predictions (High and Low Waters) September, 1998
NOAA, National Ocean Service

Daylight Saving Time

Day	Time	Ht.	Time	Ht.	Time	Ht.	Time	Ht.
1 Tu	1209am L	.6	551am H	2.3	1215pm L	.8	607pm H	2.9
2 W	1258am L	.5	642am H	2.4	104pm L	.6	657pm H	3.0
3 Th	144am L	.3	730am H	2.6	152pm L	.5	745pm H	3.2
4 F	228am L	.1	816am H	2.9	239pm L	.3	832pm H	3.4
5 Sa	312am L	.0	901am H	3.1	327pm L	.1	919pm H	3.5
6 Su	356am L	-.1	946am H	3.3	415pm L	-.1	1007pm H	3.5
7 M	441am L	-.2	1032am H	3.5	505pm L	-.2	1056pm H	3.5
8 Tu	527am L	-.2	1120am H	3.6	557pm L	-.2	1146pm H	3.3
9 W	616am L	-.1	1211pm H	3.6	652pm L	-.1		
10 Th	1240am H	3.2	708am L	.0	105pm H	3.6	750pm L	.0
11 F	137am H	2.9	803am L	.2	204pm H	3.5	851pm L	.1
12 Sa	240am H	2.7	903am L	.3	307pm H	3.3	954pm L	.2
13 Su	347am H	2.6	1006am L	.4	414pm H	3.2	1057pm L	.3
14 M	457am H	2.5	1109am L	.5	522pm H	3.1	1158pm L	.3
15 Tu	604am H	2.5	1210pm L	.5	626pm H	3.1		
16 W	1254am L	.3	704am H	2.6	108pm L	.4	724pm H	3.1
17 Th	145am L	.3	755am H	2.7	200pm L	.4	813pm H	3.0
18 F	231am L	.3	838am H	2.8	248pm L	.3	857pm H	3.0
19 Sa	314am L	.3	917am H	2.9	333pm L	.3	936pm H	3.0
20 Su	354am L	.3	954am H	3.0	416pm L	.3	1013pm H	2.9
21 M	433am L	.3	1030am H	3.0	458pm L	.3	1049pm H	2.9
22 Tu	513am L	.4	1106am H	3.1	541pm L	.3	1126pm H	2.8
23 W	553am L	.4	1143am H	3.0	624pm L	.4		
24 Th	1204am H	2.7	635am L	.5	1221pm H	3.0	710pm L	.5
25 F	1245am H	2.6	719am L	.7	101pm H	2.9	759pm L	.6
26 Sa	130am H	2.5	807am L	.8	145pm H	2.8	850pm L	.7

NOAA National Ocean Service OPSD

How to apply differences (+,-) and ratios (*)

The publication of full daily tide predictions is necessarily limited to a comparatively small number of stations. These stations are referred to as "reference stations". Tide predictions for more than 3000 other locations can be obtained by applying certain differences to the daily tide predictions for the reference stations.

These pages provide a listing of the more than 3000 "subordinate stations" for which such predictions can be made, the differences or ratios to be used, and a link to the appropriate reference station. The stations in the listing are arranged in geographical order to make it possible to find stations which are available for an area you are interested in.

Caution: The time and height differences and ratios are derived from a comparison of simultaneous tide observations at the subordinate station and it reference station. Because these figures are constant, they may not always provide for the daily variations of the actual tide, especially if the subordinate station is some distance from the reference station. Therefore, although the application of time and height differences will generally provide reasonably accurate approximations, they cannot result in predictions as accurate as those listed for the reference stations which are based on much larger periods of analysis.

Time Differences: To determine the time of high and low tide at any station listed in this table there is given the columns headed "Time Differences"in which the hours and minutes to be added or subtracted from the time of high or low tide of the reference stations. A plus sign (+) indicates that the tide at the subordinate station occurs later than at the reference station and the difference should be added; a minus sign (-) indicates that it is earlier and should be subtracted.

To obtain the tide at a subordinate station on any date, apply the difference to the tide at the reference station for that same date. In some cases, however, to obtain an AM tide it may be necessary to use the preceding day's PM tide at the reference station or to obtain a PM tide it may be necessary to use the following day's AM tide. For example, if a high tide at a reference station occurs at 0200 on July 17, and the tide at the subordinate station occurs 5 hours earlier, the high tide at the subordinate station will occur at 900 PM on July 16. For the second case, if the high water at a reference station occurs at 1000 PM, and the tide at the subordinate station occurs 3 hours later, then high tide will occur at 100 AM on July 3 at the subordinate station.

The results obtained by application of the time differences will be in local time for the subordinate station. The necessary allowances for the change in date when crossing the international date line, or for different time zones have been included in the time differences listed.

Height Differences: The height of the tide, referred to the datum of nautical charts, is obtained by means of the height difference or ratios. A plus sign (+) indicates that the difference should be added to the height at the reference station, and a minus sign (-) indicates that it should be subtracted. For most stations, use of a predicted height difference would give unsatisfactory predictions. In such cases they have been omitted and one or two ratios, indicated by an asterisk (*), are given. To obtain the height of tide at the subordinate station in these cases, multiply the height of tide at the reference station by the ratio listed. The result is normally rounded to the nearest .1 foot.

For some subordinate stations there is given, in parentheses, a ratio as well as a correction. In those instances, each predicted high and low water at the reference station should be first multiplied by the ratio and then the correction is added or subtracted from each product.

Example Tide Calculations

For Atlantic City, New Jersey, the time and height adjustments listed in the tables are:

```
-0 27    -0 35    *0.88    *0.88
```

and the reference station is Sandy Hook, New Jersey. If the times in column 1 are the tides for a day at Sandy Hook, column 2 are the time corrections and column 3 are the height corrections, column 4 will be the predicted tides at Atlantic City.

(1)	(2)	(3)	(4)
446am 0.3ft	-0 35	*0.88	411am 0.3ft
1052am 4.2ft	-0 27	*0.88	1025am 3.7ft
502pm 0.2ft	-0 35	*0.88	427pm 0.2ft
1127pm 4.3ft	-0 27	*0.88	1100pm 3.8ft

For Monterey California, the time and height adjustments listed in the tables are:

```
-1 08    -0 47    -0.5    0.0
```

and the reference station is San Francisco, California. If the times in column 1 are the tides for a day at San Francisco, column 2 are the time corrections and column 3 are the height corrections, column 4 will be the predicted tides at Monterey.

(1)	(2)	(3)	(4)
237am 5.1ft	-1 08	-0.5	129am 4.6ft
828am 1.9ft	-0 47	0.0	741am 1.9ft
231pm 4.2ft	-1 08	-0.5	323pm 3.7ft
820pm 1:6ft	-0 47	0.0	733pm 1.6ft

CONNECTICUT 846 1490

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

TIDAL BENCH MARKS

NEW LONDON (STATE PIER), THAMES RIVER

LATITUDE: 41ø 21.3' N LONGITUDE: 72ø 5.2' W
NOAA CHART: 13213 USGS QUAD: NEW LONDON

To reach the tidal bench marks from Interstate 95 take exit 84E to Crystal Avenue, continue on Crystal Avenue for 0.3 mile (0.5 km) to State Pier Road, follow the road for 0.8 mile (1.3 km) to State Pier. The tide house is located at the south of State Pier and the bench marks are located within 1 mile (1.6 km) radius of the tide station along the surrounding roads.

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BENCH MARK STAMPING: 12 1938

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Base

The bench mark is located at the northern end of State Pier on the NE side of the railroad tracks. The bench mark is set in concrete base of steel column which supports span over railroad tracks, 22.5 feet (6.9 m) WSW of power pole 11067 with three transformers, 4.6 feet (1.4 m) east of the easternmost rail at the entrance to State Pier, 0.7 foot (0.2 m) north of the steel column support, and set flush in a concrete base 1.1 feet (0.3 m) above asphalt ground level.

BENCH MARK STAMPING: 13 1938

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Base

The bench mark is located on the grounds of State Pier, set in concrete base of the NE leg of the only water tower in this area, 93.9 feet (28.6 m) SE of the SE corner of a two-story white warehouse #2, 40.0 feet (12.2 m) east of the NW leg of the water tower, 12.7 feet (3.9 m) west of the west rail of the railroad tracks leading to State Pier, 0.7 foot (0.2 m) east of the steel base plate of the NE tower leg, 1.2 feet (0.4 m) above ground level.

BENCH MARK STAMPING: 14 1938

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Foundation

The bench mark is located at the inshore end of State Pier in the NW corner of the concrete foundation around the weighing scales north of State Pier office building, 74.8 feet (22.8 m) ENE of the most easterly railroad track leading to State Pier, 59.0 feet (18.0 m) NNE of power pole #8887, 26.5 feet (8.1 m) NW of the NW corner of State office building, set flush in concrete, and level with the parking lot.

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NEW LONDON (STATE PIER), THAMES RIVER

BENCH MARK STAMPING: 1490 J 1978

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Bridge Abutment

The bench mark is located at the intersection of Winthrop Street and State Pier Road, 23.5 feet (7.2 m) west of the extended centerline of State Pier Road, 15.0 feet (4.6 m) north of the centerline of the bridge, and 3.0 feet (0.9 m) below the bridge surface.

BENCH MARK STAMPING: 1490 K 1979

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: NOS Tidal Bench Mark
SETTING CLASSIFICATION: Bedrock

The bench mark is located on the north side of State Pier Road, 199.5 feet (60.8 m) west of the NW bridge abutment of the steel span over railroad tracks, 31.8 feet (9.7 m) north of the centerline of State Pier Road, 25.0 feet (7.6 m) south of the south rail of the southernmost railroad tracks, 12.0 feet (3.7 m) north of power pole #110H 1939 with the fire alarm box, and 9.7 feet (2.9 m) south with power pole marked with a white cross.

BENCH MARK STAMPING: 15 1947

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Retaining Wall

The bench mark is located on the west side of the concrete road leading from Winthrop Street to State Pier, 156.5 feet (47.7 m) NW of Bench Mark 14 1938, 22.1 feet (6.7 m) north of the south end of a chain link guard fence, 0.5 foot (0.1 m) east of the west face of the ramp, set in top of a concrete retaining wall, and 3.5 feet (1.1 m) above ground level.

BENCH MARK STAMPING: 17 1965

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Handrail

The bench mark is located in the concrete underpass leading from Winthrop Street to State Pier, 900 feet (274 m) NW of Bench Mark 15 1947, 14.0 feet (4.3 m) east of the centerline of Winthrop Road, 4.5 feet (1.4 m) west of the east face of the southern bridge abutment, 1.2 feet (0.4 m) SE of a 6-inch steel vertical I Beam, and set flush in a concrete abutment, 1 inch below street level.

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NEW LONDON (STATE PIER), THAMES RIVER

BENCH MARK STAMPING: Y 10 1935

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Granite Step

The bench mark is at the NE corner of the intersection of Captains Walk and Union Street, 93.0 feet (28.3 m) east of the extension of Union Street, 35 feet (10 m) north of the centerline of Captains Walk, 23 feet (7 m) east of the centerline of Union Street, set in the top of the east end of the third step from the bottom of the Captains Walk entrance to City Hall, 2 feet (1 m) higher than State Street.

BENCH MARK STAMPING: Y 5 1922 ELEV. 32.575 FT

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Granite Step

The bench mark is located at the intersection of Captains Walk and Union Street, set in the west end of the second step from the bottom of Captains Walk entrance of City Hall, 56.0 feet (17.1 m) east of the extended centerline of Union Street, 35.0 feet (10.7 m) north of the center of Captains Walk, 15.0 feet (4.6 m) west of the west-south face entrance to City Hall.

BENCH MARK STAMPING: Z 10 1935

MONUMENTATION: Survey Disk
AGENCY/DISK TYPE: USC&GS Tidal Bench Mark
SETTING CLASSIFICATION: Concrete Base

The bench mark is located 190 feet (65 m) SE of the intersection of Water Street and Gov. Winthrop Blvd., 0.2 mile (0.3 km) north from the ralroad station in New London, 100.5 feet (30.6 m) SE of the block signal No. 123.2, 69 feet (20.4 m) south of the entrance to the two-story red brick office, 37.5 feet (11.4 m) east of the chain link fence, 6.4 feet (1.9 m) north of the track switch, set in the top of the east corner of a concrete base formerly used to support the block signal.

PUBLICATION DATE: 11/25/1985

CONNECTICUT 846 1490

NEW LONDON (STATE PIER), THAMES RIVER

Tidal datums at NEW LONDON (STATE PIER), THAMES RIVER are based on the following:

LENGTH OF SERIES	=	17 YEARS
TIME PERIOD	=	1960-1978
TIDAL EPOCH	=	1960-1978
CONTROL TIDE STATION	=	FIRST REDUCTION

Elevations of tidal datums referred to mean lower low water (MLLW) are as follows:

HIGHEST OBSERVED WATER LEVEL (09/21/1938)	=	10.76 FEET
MEAN HIGHER HIGH WATER (MHHW)	=	3.08 FEET
MEAN HIGH WATER (MHW)	=	2.78 FEET
MEAN TIDE LEVEL (MTL)	=	1.49 FEET
*NATIONAL GEODETIC VERTICAL DATUM-1929 (NGVD)	=	1.07 FEET
MEAN LOW WATER (MLW)	=	0.20 FEET
MEAN LOWER LOW WATER (MLLW)	=	0.00 FEET
LOWEST OBSERVED WATER LEVEL (02/02/1976)	=	-3.82 FEET

*NGVD reference based on adjustment of 1967 and NOS levels of 1985.

Bench mark elevation information:

	ELEVATION IN FEET ABOVE:	
BENCH MARK STAMPING	MLLW	MHW
12 1938	10.67	7.89
13 1938	10.36	7.58
14 1938	10.54	7.76
1490 J 1978	31.36	28.58
1490 K 1979	31.01	28.23
15 1947	12.67	9.89
17 1965	32.77	29.99
Y 10 1935	33.65	30.87
Y 5 1922 ELEV. 32.575 FT	33.65	30.87
Z 10 1935	8.70	5.92

PUBLICATION DATE: 11/25/1985

CONNECTICUT 846 1490

NEW LONDON (STATE PIER), THAMES RIVER

MSL is the local mean sea level and should not be confused with the fixed datums of NGVD (sometimes referred to as Sea Level Datum of 1929) or NAVD 88.

NGVD is a fixed datum adopted as a standard geodetic reference for heights. It was derived from a general adjustment of the first order leveling nets of the U.S. and Canada. Mean sea level was held fixed as observed at 26 stations in the U.S. and Canada. Numerous adjustments have been made since originally established in 1929.

NAVD 88 involved a simultaneous, least squares, minimum-constraint adjustment of Canadian-Mexican-United States leveling observations. Local mean sea level at Father Point/Rimouski, Canada was held fixed as the single constraint.

These fixed datums do not take into account the changing stands of sea level and because they represent a "best" fit over a broad area, their relationship to local mean sea level is not consistent from one location to another.

RAINFALL DATA FROM GROTON UTILITIES WATER TREATMENT PLANT

FACSIMILE COVER PAGE

Date: 5/26/98
Time: 15:47:36
Pages: 2

To: Mr. Tom Dickson
Company: TetraTech, NUS
Fax #: (412) 921-4040

From: Laboratory
Company: Groton Utilities, Water Treatment Plant
Address: 295 Meridian Street
Groton, CT 06340
Fax #: (860) 446-4084
Voice #: (860) 446-4082

Message:

Here is the rainfall for the month of May 1998 to date, as you requested.

Groton Water Treatment Plant Groton, CT
Rainfall, May 1998 month-to-date

5/26/98

Date	Rainfall (in inches)
1	0.13
2	0.55
4	0.43
5	0.15
6	0.22
7	0 54
8	. T
9	1.25
10	1.13
11	0.55
17	0.11
25	0.30

Total rainfall: 5.36 inches

T= trace (less than 0.01 inches)

SURVEY INFORMATION

DIVERSIFIED LAND
SURVEYORS, INC.

August 8, 1998

TANK FARM SITE
NAVAL SUBMARINE BASE (NSB)
NEW LONDON, GROTON, CT

Subcontract Number: GCDB-98-626-1298

All work provided under the subcontract complies with all requirements of the specifications and engineer approved deviations.

David J. Rode, P.L.S. President

8/8/98
Date

An Equal Opportunity Employer M/F
220 FARMDALE RD., P.O. BOX 789, WATERTOWN, CT 06795-0789
(860) 274-5053 FAX (860) 274-7740

NAD 1983 NAVD 1988

WELLS	NORTHING	EASTING	GROUND	PVC/STEEL	OUTER CASING
23MW01D	702,867.493	1,183,945.293	34.68	34.44	34.68
23MW02D	702,937.986	1,183,145.844	21.16	20.80	21.16
23MW03D	703,528.051	1,182,814.493	20.91	20.52	20.91
23MW04D	703,270.160	1,182,275.243	19.87	19.50	19.87

GCDB-98-626-1298 TANK FARM SITE

WELL LOCATION 7-31-98 and 8-7-98

9820-tank farm

CLIENT: NSB-NLON – HYDROGEOLOGIC STUDY AT TANK FARM	JOB NUMBER: 5083
SUBJECT: ELEVATION OF WATER LEVELS IN STREAM EAST OF BLDG 447	
BASED ON: SURVEY COMPLETED BY T. EVANS 5/21/98	DRAWING NUMBER:
BY: CAR 6/15/98	CHECKED BY: SWR 6-15-98
APPROVED BY:	DATE:

OBJECTIVE: USING A TOPCON AT-F2 AUTOLEVEL AND STADIA ROD DETERMINE THE ELEVATION OF WATER LEVELS AT VARIOUS LOCATIONS IN THE STREAM EAST OF BLDG 447.

PROJECT INFORMATION:

- BENCH MARK #50 OF THE BASE TRAVERSE AND MONUMENT SYSTEM, U.S. NAVAL SUBMARINE BASE, GROTON, CONNECTICUT COMPLETED BY DAVID L. STEIN, LAND SURVEYOR OCTOBER 1994 (REVISED: APRIL 16, 1997) WAS USED AS THE BENCHMARK FOR THIS PROJECT.

- DETAILS OF BM #50:

SPCS NAD 83

NORTH = 702908.529

EAST = 1183973.900

NAVD 88

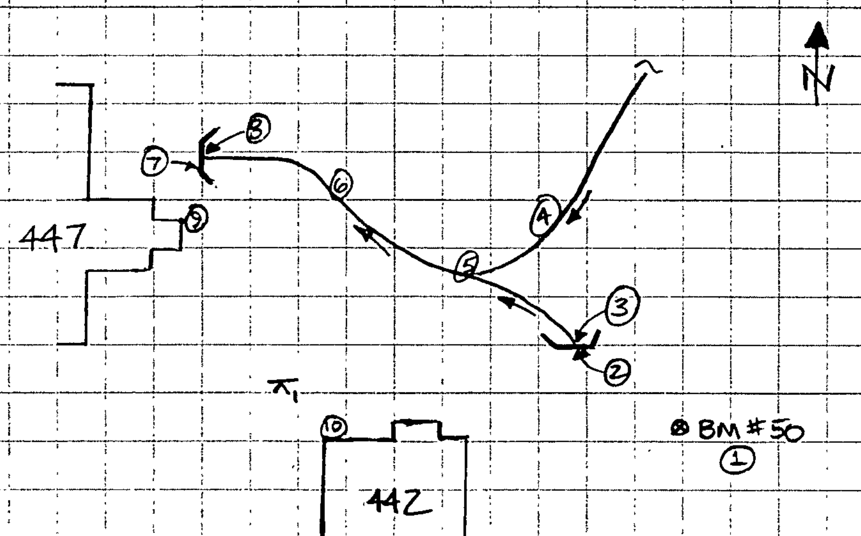
ELEVATION = 34.002 FEET

CALCULATION WORKSHEET Order No. 19116 (01-91)

CLIENT: NSB-NLON - HYDROGEOLOGIC STUDY AT TANK FARM	JOB NUMBER: 5083
SUBJECT: ELEVATION OF WATER LEVELS IN STREAM EAST OF BLDG 447	
BASED ON: SURVEY COMPLETED BY T. EVANS 5/21/98	DRAWING NUMBER:

BY	CHECKED BY	APPROVED BY	DATE
CAR 6/15/98	SUR 6-15-98		

SCHEMATIC OF AREA: (NOT TO SCALE)



SURVEY INFO:

	STATION		BS	HI	FS	ELEV	COMMENTS
π_1	1	L	5.87				BM #50
		M	6.75	40.75		34.0	BEARING = 0°
		H	7.64				
	2	L			10.39		TOP OF E.
		M		40.75	10.95	29.80	CULVERT
		H			11.50		BEARING = 345°
	3	L			13.94		WATER @
		M		40.75	14.48	26.27	E. CULVERT
		H			15.01		BEARING = 344°
	4	L			13.90		
		M		40.75	14.59	26.16	WATER LEVEL @ NORTH
		H			15.22		BRANCH OF STREAM
	5	L			14.43		BEARING = 299°
		M		40.75	14.81	25.94	CONFLUENCE
		H			15.19		BEARING = 299°

CLIENT: NSB-NLON – HYDROGEOLOGIC STUDY AT TANK FARM	JOB NUMBER: 5083
SUBJECT: ELEVATION OF WATER LEVELS IN STREAM EAST OF BLDG 447	
BASED ON: SURVEY COMPLETED BY T. EVANS 5/21/98	DRAWING NUMBER:
BY: CAR 6/15/98	CHECKED BY: JMR 6-15-98
APPROVED BY:	DATE:

SURVEY INFO (CONT'D):

STATION		BS	HI	FS	ELEV	COMMENTS
6	L			14.38		FLOW MEASUREMENT
	M		40.75	14.91	25.84	POINT
	H			14.43		BEARING = 253.5°
7	L			8.99		TOP OF W.
	M		40.75	9.59	31.16	CULVERT
	H			10.18		BEARING = 244°
8	L			14.35		
	M		40.75	14.95	25.80	WATER @ W. CULVERT
	H			15.54		BEARING = 245°
9	L			1.74		NE CORNER
	M		40.75	2.24	38.51	OF BLDG 447
	H			2.73		BEARING = 235°
10	L			2.96		NW CORNER
	M		40.75	3.34	37.41	OF BLDG 442
	H			3.81		BEARING = 48°

SUMMARY:

STATION	NAVD 88 ELEVATION (FEET)	1982 BASE COORD SYSTEM (FEET)
1	34.00	~~36.27~~ 36.39
2	29.80	~~32.07~~ 32.19
3	26.27	~~28.54~~ 28.66
4	26.16	~~28.43~~ 28.55
5	25.94	~~28.21~~ 28.33
6	25.84	~~28.11~~ 28.23
7	31.16	~~33.43~~ 33.55
8	25.80	~~28.07~~ 28.19
9	38.51	~~40.78~~ 40.90
10	37.41	~~39.68~~ 39.80

CAR 11/18/98

(NOTE: CONVERSION FACTOR = ~~2.27 ft~~ 2.39 ft ; M. SCHULTZ ~~12/12/97~~ 7/14/98)

BORING LOGS

BORING LOG

PROJECT NAME: NSB-NLON
BORING NUMBER: 23MW01D
PROJECT NUMBER: CTO 204 5083
DATE: 7/25/98 - 7/29/98
DRILLING COMPANY: MAXIM Technologies, Inc.
GEOLOGIST: ~~Becky Cleaver~~ D. MacDougall/V.S.
DRILLING RIG: Failing F-10
DRILLER: A. Kimball

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	USCS *	Remarks	PID/FID Reading (ppm) Sample	Sampler BZ	Borehole**	Driller BZ**
7/25 0835							Augers @ start			0	0	0	0
							Dark Brown Silt + Sand						
							Large pieces of rock						
0850	3.5						3.5 ft. Large boulder is found						
	5									0	0	0	0
	7.5						Break through boulder						
1120	10						Dk. Brown sand, trace silt			0	0	0	0
							Large (2-in rocks)						
	15						Dk. Brown sand, traces			0	0	0	0
							~~Large~~ [illegible] fines						
1130	20						Dk. Brown sand,			0	0	0	0
							Trace fines						
	25						Dk. Brown sand, trace fine			0	0	0	0

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm):

Remarks: 7/25 - 0-3.5 ft augers, 3.5-7.5 ft boulder. 7.5-42 ft. using air hammer

Converted to Well: Yes X No ____ Well I.D. #: 23MWO_D

BORING LOG

PROJECT NAME: NSB - NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10

BORING NUMBER: 23MW01D
DATE: 7/25/98 - 7/29/98
GEOLOGIST: ~~Becky Cleaver~~ [illegible]
DRILLER: A. KIMBALL / T. DORGAN

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	U S C S *	Remarks	Sample	Sampler BZ	Borehole**	Driller BZ**
1145	30						BROWN SAND			0	0	0	0
	35						BROWN SAND			0	0	0	0
	40						BROWN SAND			0	0	0	0
1420	42												
				BEDROCK									
	45									0	0	0	0
1510	47						GRANITIC GNEISS						
1630	50									0	0	0	0

* When rock coring, enter rock brokeness.

** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm):

Remarks: 7/25 DRILL 5-FT INTO ROCK
7/28 - DRILL 47 FT - 52 FT

Converted to Well: Yes X No ____ Well I.D. #: 23MW0_D

BORING LOG

PROJECT NAME: NSB-NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG:
BORING NUMBER: 23MW01D
DATE: 7/25/98 - 7/29/98
GEOLOGIST: Becky Cleaver, D. McDougall, J. Shikula, T. Duncan
DRILLER: A. Kindall

Sample No. and Type or RQD	Depth (Ft.) or Run No	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	USCS *	Remarks	Sample	Sampler BZ	Borehole**	Driller BZ**
7/28													
1815	52					Gray	Gneiss w/ Quartz + Biotite			0	0	0	0
7/29													
0855	55					Gray	Gneiss w/ Quartz + Biotite			0	0	0	0
	57.2			EOB		Gray	Gneiss w/ Quartz + Biotite			0	0	0	0

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals borehole. Increase reading frequency if elevated reponse read.

Remarks: - 7/29/98 END OF BORING AT 57.2 FT

Drilling Area Background (ppm):

Converted to Well: Yes X No

Well I.D. #: 23MW0_D

BORING LOG

PROJECT NAME: NSB - NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10 WT

BORING NUMBER: 23MW02D
DATE: Start: 7/7/98 End: 7/16/98
GEOLOGIST: Becky Cleaver
DRILLER: Nathan (Ed) Cole

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	MATERIAL DESCRIPTION: Soil Density/ Consistency or Rock Hardness	Color	Material Classification	USCS*	Remarks	PID/FID Reading (ppm): Sample	Sampler BZ	Borehole**	Driller BZ**
NO SAMPLES		N/A	N/A										
							Augers @ 1 foot: soils		[No SAMPLES]	0	0	0	0
							are brown, f-m SAND						
							Augers @ 5feet: soils						
	5						are gray, silty fine SAND, some gravel.			0	0	0	0
							Augers @ 8 feet: soil cuttings		Augers grinding @ 8'				
							are gray, silty fine SAND w/						
	10						gravel + cobbles up to 3" (subangular).			0	0	0	
							From 10 to 15 feet with						
							augers, soil cuttings are						
							gray, silty fine SAND, WET.						
	15			15.2'			Gray, silty fine SAND, WET		Augers grinding hard @ 15'	0	0	0	0
				Bedrock			Bedrock as logged from		Driller converts to				
				Casing			cuttings from roller bit is gneiss		roller bit using air				
				to			(quartz, feldspar, biotite)		@ 15.2 feet.				
				18.6'					Roller bit to 18.6' and				
	20			OPEN HOLE			Driller reports minor fracture		set 6" permanent casing	0	0	0	0
				↓			@ ≈20' (little water).		at 18.6'. Convert to				
							Driller reports rate of advance		8" air hammer @ 18.6'.				
							as ≈ 15 minutes/foot @ ≈ 21 feet.						
							At 24.5 feet hit water-bearing		Water is very rusty brown,				
	25						fracture ≈ 3-5 GPM		silty, weathered fracture zone.	0	0	0	0

* When rock coring, enter rock brokeness.

** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm): 0

Remarks: Hollow-stem auger to 15.2 feet using 8.25" I.D. HSA. Roller bit to 18.6 feet using 7 7/8" O.D. tri-cone with carbide button bit. Use 8-inch Air Hammer from 18.6 to 28.5 feet.

Converted to Well: Yes X No ____ Well I.D. #: 23MW02D

BORING LOG

PROJECT NAME: NSB - NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG:
BORING NUMBER: 23MW02D
DATE: START: 7/7/98 END: 7/16/98
GEOLOGIST: Becky Cleaver
DRILLER:

Sample No. and Type or RQD	Depth (Ft.) or Run No	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	U S C S *	Remarks	PID/FID Reading (ppm) Sample	Sampler BZ	Borehole**	Driller BZ**
		N/A	N/A										
				OPEN HOLE			At ±26.5' driller reports increased water (fracture zone).						
	28			28.5'			At ±28.4' driller reports increased water (fracture zone): total flow estimated 30-40GPM. Water is still rusty brown, silty.			0	0	0	0
				EOB			BOTTOM OF BORING AT 28.5 FEET.						
							(open bedrock hole from 18.6 to 28.5 feet.)						
							(Permanent 6" steel casing set 0' to 18.6 feet.)						
							Note: Bedrock throughout boring, as noted from cuttings, is hard gneiss (quartz, feldspar, biotite grains).						

* When rock coring, enter rock brokeness.

** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm): 0

Remarks: NOTE: July 7-9: Drill to 18.6 feet and set casing to 18.6 feet.
July 15-16: Advance bedrock hole to 28.5 feet (EOB).

Converted to Well: Yes X No ______ Well I.D. #: 23MW02D

BORING LOG

PROJECT NAME: NSB-NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10 WT

BORING NUMBER: 23MW03D
DATE: START: 7/9/98 END: 7/20/9
GEOLOGIST: Becky Cleaver / Denis MacDougal
DRILLER: Nathan (Ed) Cole

Sample No. and Type or RQD	Depth (Ft.) or Run No	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	MATERIAL DESCRIPTION: Soil Density/ Consistency or Rock Hardness	Color	Material Classification	USCS *	Remarks	PID/FID Reading (ppm): Sample	Sampler BZ	Borehole**	Driller BZ**
NO SAMPLES		N/A	N/A										
							Pavement at ground surface		[No SAMPLES.]	0	0	0	0
							Augers at 1 foot: soils		Hollow-stem auger				
							are gray-brown SILT and		to 34.8 feet.				
							f. sand, moist.						
[illegible]	5						Augers at 5 feet: soils same			0	0	0	0
							as above, but damp.						
							Augers at 7 feet: soils same						
							as above, wet.						
							Augers at 9 feet: soil cuttings						
	10						are olive gray f. SAND and SILT			0	0	0	
	15						Augers at 15 feet: soil cuttings			0	0	0	0
							are same as above: olive gray						
							f. SAND and SILT, wet.						
	20						Soil cuttings same as above.			0	0	0	0
	25						Soil cuttings same as above.			0	0	0	0

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm): 0

Remarks: Hollow-stem auger to 34.8 feet using 8.25" I.D. HSA. Air hammer w/8" hammer from 34.8' to 39' - set 6-inch casing to 39 feet. Air hammer open bedrock hole from 39' to 55'.

Converted to Well: Yes X No ____ Well I.D. #: 23MW03D

BORING LOG

PROJECT NAME: NSB - NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10 WT

BORING NUMBER: 23MW03 D
DATE: START: 7/9/98 END: 7/20/98
GEOLOGIST: Becky Cleaver / Denis MacDougal
DRILLER: Nathan (Ed) Cole

Sample No. and Type or RQD	Depth (Ft.) or Run No	Blows / 6" or RQD (%) N/A	Sample Recovery / Sample Length N/A	Lithology Change (Depth/Ft.) or Screened Interval	MATERIAL DESCRIPTION: Soil Density/Consistency or Rock Hardness	Color	Material Classification	USCS*	Remarks	PID/FID Reading (ppm): Sample	Sampler BZ	Borehole**	Driller BZ**
	30						• Soil cuttings same as above,			0	0	0	0
							(olive gray f. SAND and SILT), Wet.						
									Driller converts to roller				
									bit using air @ 34.8 feet.				
	35			34.8'					Making water (20GPM±)	0	0	0	0
				Bedrock			• Bedrock as logged from		as roller bitting. Driller				
							cuttings is granitic gneiss (quartz,		converts to re-circulate				
				Casing to 39'			feldspar, biotite). Making water		water: losing water down				
							w/ color change (rusty red/silty)		the hole. Converts to				
	40			OPEN HOLE ↓			@ 34.8 feet. Drill advance rate		air hammer: 8" hammer	0	0	0	0
							is ± 17-18 minutes/foot @		from 34.8' to 39' on 7/14/98.				
							39 to 41 feet.		Set 6" permanent casing				
							• At ± 43.5 feet: water @		at 39' on 7/14/98.				
							± 0.5 GPM.		Air hammer open				
	45						• Bedrock as logged from cuttings		bedrock hole from 39'	0	0	0	0
							is a hard granitic gneiss.		to 55'.				
							• Drill advance rate is ± 20						
							minutes/foot @ 46-47 feet.						
	50									0	0	0	0

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm): 0

Remarks: NOTE: July 9-10: Drill to 34.8 feet (top of rock). July 13-14: Advance bedrock hole to 39 feet and set casing at 39 feet. July 16-17: Advance bedrock hole w/ air hammer 39 to 46 feet. July 20: Advance bedrock hole to 55 feet (EOB).

Converted to Well: Yes X No ____ Well I.D. #: 23MW03D

BORING LOG

PROJECT NAME: NSB - NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10 WT

BORING NUMBER: 23MW03D
DATE: START: 7/9/98 END: 7/20/98
GEOLOGIST: Becky Cleaver / Dewis Mac[illegible]
DRILLER: Nathan (Ed) Cole

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	U S C S *	Remarks	Sample	Sampler BZ	Borehole**	Driller BZ**
		N/A	N/A										
				OPEN HOLE									
	55			55'			. BEDROCK AT BOTTOM OF			0	0	0	0
				EOB			BORING APPEARS TO BE						
							GRANITIC GNEISS. NOT						
							VERY FRACTURED. SOME						
							WATER MADE BY HOLE						

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Remarks:

Drilling Area Background (ppm): 0

Converted to Well: Yes X No ____ Well I.D. #: 23MW03D

BORING LOG

PROJECT NAME: NSB - NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10 WT
BORING NUMBER: 23MW04 D
DATE: START: 7/15/98 END: 8/1/98
GEOLOGIST: Becky Cleaver / Denise MacDougall / Mike Shirkovzi
DRILLER: Nathan (Ed) Cole / Roger Logel

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	U S C S *	Remarks	Sample	Sampler BZ	Borehole**	Driller BZ**
NO SAMPLES		N/A	N/A										
TIME: 10:45 7/15/98							Pavement at ground surface		[NO SAMPLES] (Hollow-stem auger to 54.3 feet.)	0	0	0	0
	5						Augers @ 5 feet: soil cuttings are brown SILT and f. SAND, tr. gravel, dry to moist.			0	0	0	0
10:59	10						Augers @ 10 feet, soil cuttings brown SILT and f. SAND, Wet.			0	0	0	0
	15						Augers @ 15 feet, soil cuttings are brown SILT and f. SAND some m-c sand, tr. gravel, WET			0	0	0	0
11:05	20						Augers @ 20 feet, soil cuttings same as above, Wet.			0	0	0	0
11:17	25						Augers @ 25 feet, soils same as above, wet			0	0	0	0

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm): 0

Remarks: Hollow-stem auger to 54.3 feet using 8.25" I.D. HSA.

Converted to Well: Yes X No ____ Well I.D. #: 23MW04 D

BORING LOG

PROJECT NAME:	NSB - NLON	BORING NUMBER:	23MW04 D
PROJECT NUMBER:	CTO 204 5083	DATE:	START: 7/15/98 END: 8/1/98
DRILLING COMPANY:	MAXIM Technologies, Inc.	GEOLOGIST:	Becky Cleaver / [illegible]
DRILLING RIG:	FAILING F-10, WT	DRILLER:	Nathan (Ed) Cole / Roger Logel

TIME: continue 7/15/98)

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	USCS *	Remarks	PID/FID Reading (ppm) Sample	Sampler BZ	Borehole**	Driller BZ**
NO SAMPLES		N/A	N/A										
11:22	30									0	0	0	0
11:28	35						Augers @ 35 feet: soil cuttings are gray SILT and f. SAND, some f. gravel, some m-c sand, Wet			0	0	0	
11:32	40						Augers @ 40 feet: soil cuttings same as above.			0	0	0	0
11:37	45						Augers @ 45 feet: soil cuttings same as above.		Drillers ran out of auger flights w/augers @ 45 feet. ~~End of day~~ Rig Additional augers arrive to advance drilling on 7/16/98.	0	0	0	0
13:27	50						Augers @ 50 feet: soil cuttings are olive gray SILT and f. SAND, some m-c sand, tr. gravel up to 2", wet.			0	0	0	0

Left margin (partly cut off): [illegible] 7/15/98 … [illegible] 7/16/98

* When rock coring, enter rock brokeness.

** Include monitor reading in 6 foot intervals borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm): 0

Remarks: July 15-16: Drill to 54.3 feet (top of rock).

Converted to Well: Yes X No ____ Well I.D. #: 23MW04D

BORING LOG

PROJECT NAME: NSB-NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10 WT

BORING NUMBER: 23MW04D
DATE: START: 7/15/98 END: 8/1/98
GEOLOGIST: Becky Cleaver / [illegible]
DRILLER: Nathan (Ed) Cole, Roger Logel

Sample No. and Type or RQD	Depth (Ft.) or Run No.	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	MATERIAL DESCRIPTION: Soil Density/ Consistency or Rock Hardness	Color	Material Classification	USCS *	Remarks	PID/FID Reading (ppm): Sample	Sampler BZ	Borehole**	Driller BZ**
NO SAMPLES		N/A	N/A										
TIME continued									Hollow-stem auger				
7/16/98									50' to 54.3' on 7/16/98.				
									Augers grinding @ 54.3'				
13:34				54.3'					(probable Bedrock)				
	55			Bedrock						0	0	0	0
7/21					HARD	GRAY	GNEISS w/ QUARTZ + BIOTITE		DRY				
1240				58 FT			CASING IS SET AT THIS INTERVAL						
1450	60				HARD	GRAY	GNEISS WITH QUARTZ + BIOTITE		DRY	0	0	0	0
7/30									SOME WATER LOSS (MAY BE FROM OVERBURDEN)				
1045	62.5												
7/31													
0845	65				HARD	GRAY	GNEISS w/ QUARTZ + BIOTITE		DRY	0	0	0	0
0945	70				HARD	GRAY	GNEISS w/ QUARTZ + BIOTITE		DRY	0	0	0	0
1045	75				HARD	GRAY	GNEISS w/ QUARTZ + BIOTITE		DRY	0	0	0	0

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Drilling Area Background (ppm): 0

Remarks: 7/24/98: CASING SPUN INTO ROCK 3 FT INTO ROCK @ 58 FT. BGS. 6 INCASING

Converted to Well: Yes X No ____ Well I.D. #: 23MW04D

BORING LOG

PROJECT NAME: NSB-NLON
PROJECT NUMBER: CTO 204 5083
DRILLING COMPANY: MAXIM Technologies, Inc.
DRILLING RIG: FAILING F-10 WT
BORING NUMBER: 23MW04D
DATE: 7/15/98 - 8/1/98
GEOLOGIST: Becky Cleaver / DENIS MAC VINCE DUNK SHIKORA
DRILLER: NATHAN (END) ZOE (START), AL KIMBALL (END)

Sample No. and Type or RQD	Depth (Ft.) or Run No	Blows / 6" or RQD (%)	Sample Recovery / Sample Length	Lithology Change (Depth/Ft.) or Screened Interval	Soil Density/ Consistency or Rock Hardness	Color	Material Classification	USCS *	Remarks	Sample	Sampler BZ	Borehole**	Driller BZ**
7/31 1120	77.5						HAVE GONE AS FAR AS RODS ALLOW		DRY				
	80						GNEISS w/ QUARTZ +BIOTITE		DRY	0	0	0	0
7/1 1130	81.5												
1230	85						GNEISS w/ QUARTZ +BIOTITE		DRY	0	0	0	0
1420	90						GNEISS w/ QUARTZ +BIOTITE		DRY	0	0	0	0
1520	95						GNEISS w/ QUARTZ +BIOTITE		DRY	0	0	0	0
1530	96.5						END OF BORING			0	0	0	0

* When rock coring, enter rock brokeness.
** Include monitor reading in 6 foot intervals @ borehole. Increase reading frequency if elevated reponse read.

Remarks: 7/31; HAVE DRILLED 77.5 FT; BORING DEPTH IS 96.5 FT

Drilling Area Background (ppm): 0.8

Converted to Well: Yes X No ______ Well I.D. #: 23MWO_D

MONITORING WELL CONSTRUCTION DIAGRAMS

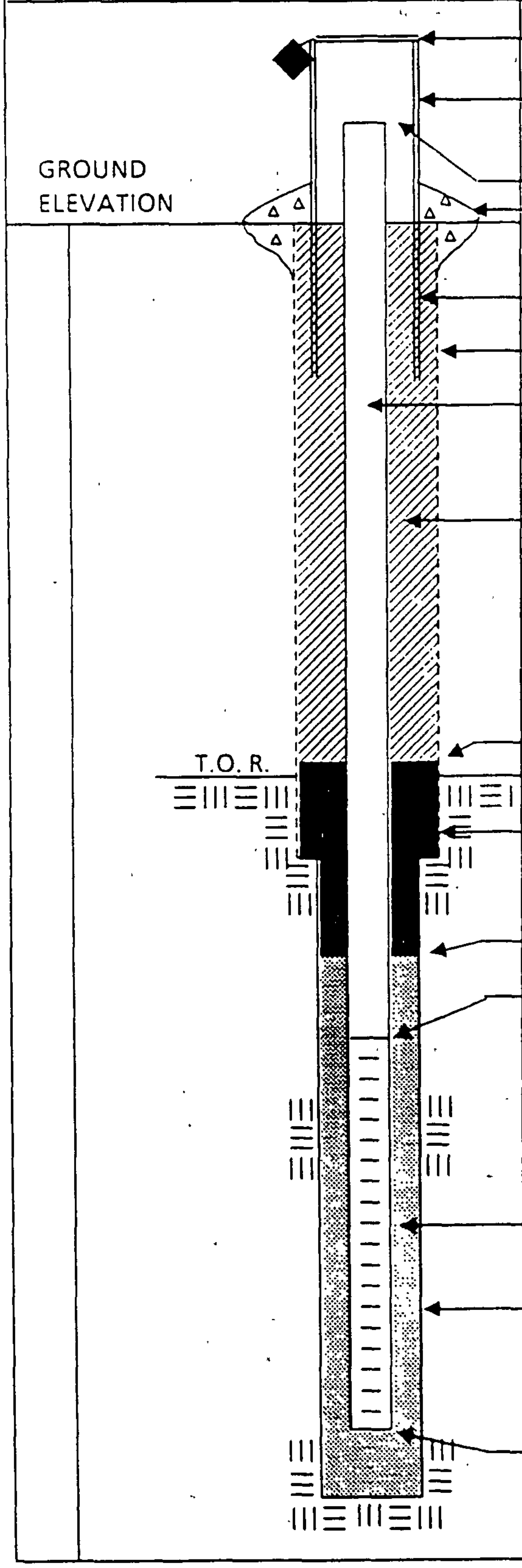
BORING NO.: 23MW01 I

BEDROCK
MONITORING WELL SHEET
WELL INSTALLED IN BEDROCK

PROJECT: NSB-NLON
PROJECT NO.: CTO 204 5083
ELEVATION:
FIELD GEOLOGIST: ~~Becky Cleaver~~

LOCATION: Groton, CT
BORING: 23MW01 D
DATE: 07/29/98

DRILLER: Maxim Technologies
DRILLING METHOD: Air rotary
DEVELOPMENT METHOD: GRUNDFOS



ELEVATION OF TOP OF SURFACE CASING: (ground)

STICK UP OF CASING ABOVE GROUND SURFACE:

ELEVATION TOP OF RISER:

TYPE OF SURFACE SEAL: Concrete

I.D. OF SURFACE CASING: 6 inch to 47 Feet BGS

DIAMETER OF HOLE:

RISER PIPE I.D.: 2 inch

TYPE OF RISER PIPE: 2 inch PVC

TYPE OF BACKFILL: 20:1 cement bentonite mixture

ELEVATION / DEPTH TOP OF SEAL: / 46 Ft.

ELEVATION / DEPTH TOP OF BEDROCK: / 42 Ft

TYPE OF SEAL: Bentonite

ELEVATION / DEPTH TOP OF SAND: / 49 Ft.

ELEVATION / DEPTH TOP OF SCREEN: / 50 Ft.

TYPE OF SCREEN: 2 inch PVC

SLOT SIZE x LENGTH: 0.010" x 6.5 Ft.

I.D. SCREEN: 2 inch

TYPE OF SAND PACK: #20

DIAMETER OF HOLE IN BEDROCK:

CORE / REAM: 5 7/8"

ELEVATION / DEPTH BOTTOM SCREEN: / 56.5 Ft.

ELEVATION / DEPTH BOTTOM OF HOLE: / 57.2 Ft

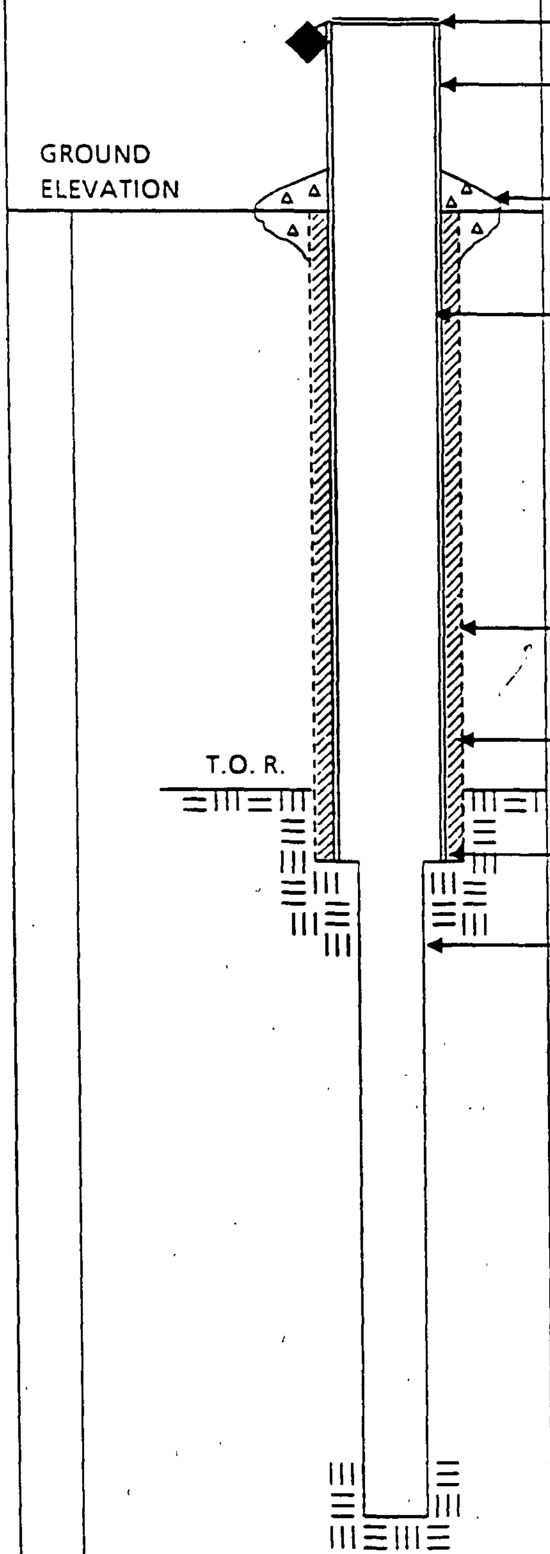
BORING NO.: 23MW02D

BEDROCK
MONITORING WELL SHEET
OPEN HOLE WELL

PROJECT: NSB-NLON
PROJECT NO.: CTO 204 5083
ELEVATION:
FIELD GEOLOGIST: Becky Cleaver

LOCATION: Groton CT
BORING: 23MW02D
DATE: START: 7/7/98 END: 7/23/98

DRILLER: MAXIM Technolog
DRILLING METHOD: Nathan (Ed) Cole, Hollow Stem Auger + Air Rotary
DEVELOPMENT METHOD: AIR JET (w/ Down-Hole Hamm



ELEVATION OF TOP OF CASING:

STICK UP OF CASING ABOVE GROUND SURFACE: (Flush-mount) 0'

TYPE OF SURFACE SEAL: Cement

I.D. OF CASING: 6-inch
TYPE OF CASING: Steel
TEMP. / PERM.: Permanent

DIAMETER OF HOLE: 12" (8.25" ID auger)

TYPE OF CASING SEAL: Cement/Bentonite

DEPTH TO TOP OF ROCK: 15.2

DEPTH TO BOTTOM CASING: 18.6

DIAMETER OF HOLE IN BEDROCK: 5 7/8"

DESCRIBE IF CORE / REAMED WITH BIT:
(N/A - Air Rotary)

DESCRIBE JOINTS IN BEDROCK AND DEPTH:
1) water-bearing zone (fracture) @ ±24.5 feet (minor
2) water-bearing zone (fracture) @ ±26.5 feet
3) water-bearing zone (fracture) @ ±28.4 feet

As Reported By Driller (increased water)

ELEVATION / DEPTH OF HOLE: / 28.5

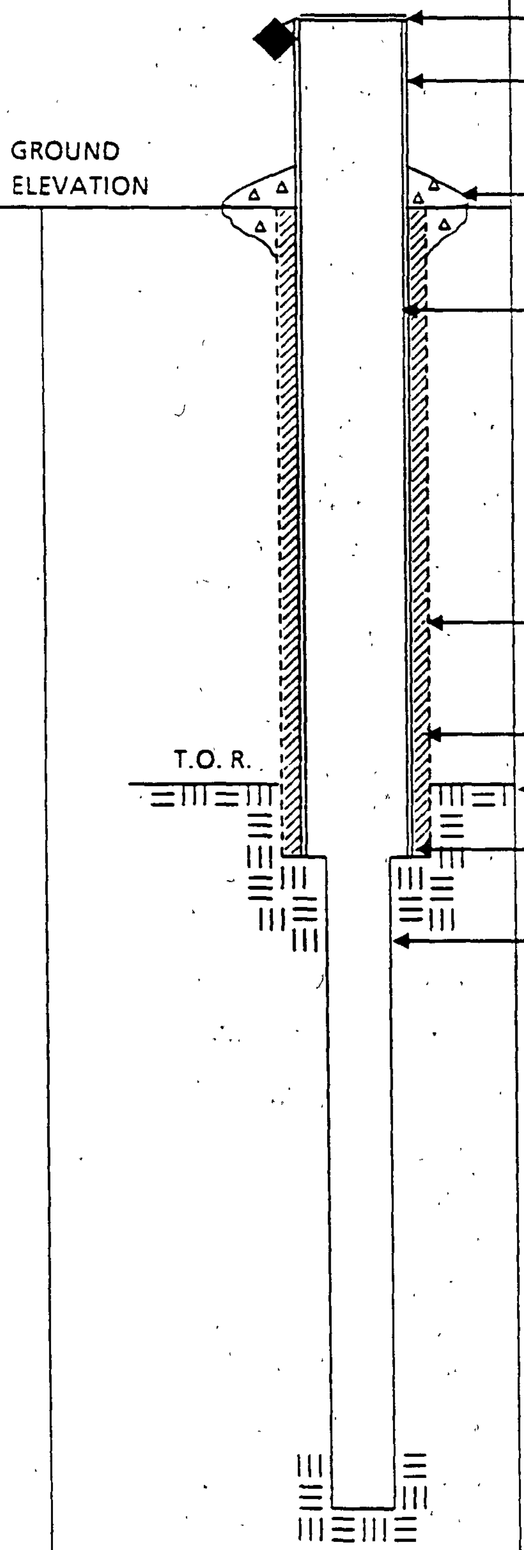
BORING NO.: 23MW03D

BEDROCK
MONITORING WELL SHEET
OPEN HOLE WELL

PROJECT: NSB-NLON
PROJECT NO.: CTO 204 5083
ELEVATION:
FIELD GEOLOGIST: Becky Cleaver, Denis MacDougal

LOCATION: Groton, CT
BORING: 23MWO D
DATE: 7/25/98

DRILLER: Maxim Technologies
DRILLING METHOD: Hollow Stem Auger + Air Rotary
DEVELOPMENT METHOD: Grundfos



ELEVATION OF TOP OF CASING:

STICK UP OF CASING ABOVE GROUND SURFACE (FLUSH MOUNT): 0'

TYPE OF SURFACE SEAL: Cement

I.D. OF CASING: 6 - inch
TYPE OF CASING: Steel
TEMP. / PERM.: Permanent

DIAMETER OF HOLE: 12" (8.25" ID Auger)

TYPE OF CASING SEAL: Cement Bentonite

DEPTH TO TOP OF ROCK: 34.8 FT

DEPTH TO BOTTOM CASING: 39'

DIAMETER OF HOLE IN BEDROCK: 5 7/8"

DESCRIBE IF CORE / REAMED WITH BIT:
(N/A - Air Rotary)

DESCRIBE JOINTS IN BEDROCK AND DEPTH:
(1) 34.8 FT Water Bearing Zone (Heavy 200GPM)
(2) 43.5 FT Water Bearing Zone (Minor 0.5GPM)

ELEVATION / DEPTH OF HOLE: 55 FT /

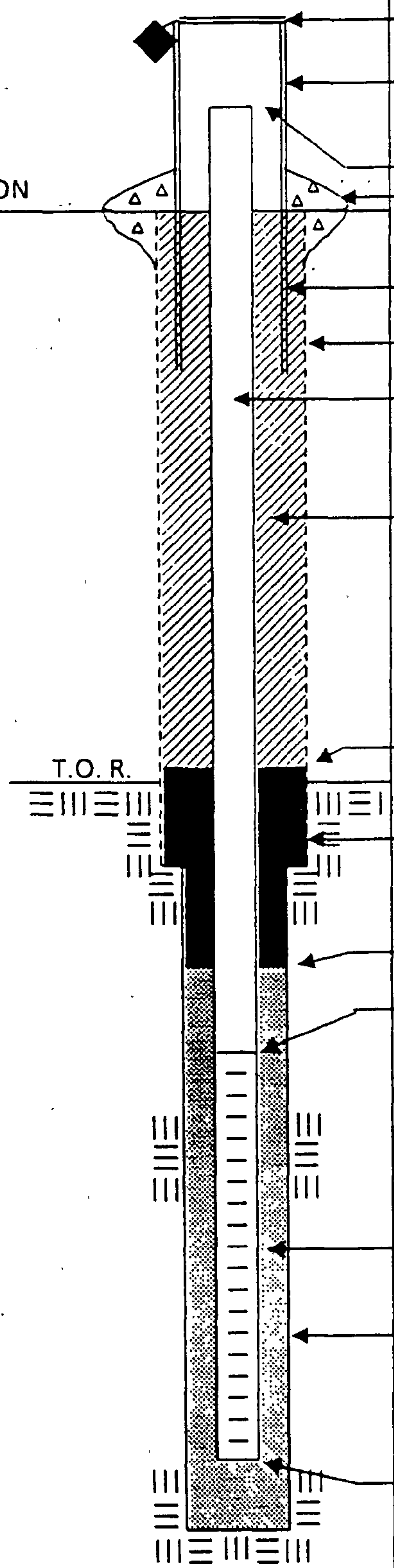
BORING NO.: 23MW04D

BEDROCK MONITORING WELL SHEET
WELL INSTALLED IN BEDROCK

PROJECT: NSB-NLON
PROJECT NO.: CTO 204 5083
ELEVATION:
FIELD GEOLOGIST: ~~Becky Cleaver~~ Becky Cleaver / RXC

LOCATION: Groton, CT
BORING: 23MW04 D
DATE: 08/01/98

DRILLER: Maxim Technolo
DRILLING METHOD: Air rotary
DEVELOPMENT METHOD:



ELEVATION OF TOP OF SURFACE CASING: (ground)

STICK UP OF CASING ABOVE GROUND SURFACE: (ground)

ELEVATION TOP OF RISER:

TYPE OF SURFACE SEAL: NA

I.D. OF SURFACE CASING: 6 inch To 58' BGS

DIAMETER OF HOLE:

RISER PIPE I.D.: 2 inch

TYPE OF RISER PIPE: 2 inch PVC

TYPE OF BACKFILL: Cement / Bentonite grout (20:1)

ELEVATION / DEPTH TOP OF SEAL: / 54'

ELEVATION / DEPTH TOP OF BEDROCK: / 58'

TYPE OF SEAL: Bentonite

ELEVATION / DEPTH TOP OF SAND: / 63'

ELEVATION / DEPTH TOP OF SCREEN: / 65.5'

TYPE OF SCREEN: 2 inch PVC

SLOT SIZE x LENGTH: 0.010" x 30'

I.D. SCREEN: 2 inch

TYPE OF SAND PACK: #20

DIAMETER OF HOLE IN BEDROCK:

CORE / REAM: 5 7/8"

ELEVATION / DEPTH BOTTOM SCREEN: / 95.5'

ELEVATION / DEPTH BOTTOM OF HOLE: / 96.5'

SITE PHOTOGRAPHS

Confluence of Drainages Along Route 12 Into Stream East of Building 447. Facing East.

Entrance of Stream East of Building 447 to the Storm Sewer System. Facing Northwest.

Bedrock Well 23MW01D. Route 12 in Background.
Facing Northeast.

Bedrock Well 23MW02D. Crystal Lake Road in Background.
Facing Southeast.

Finished Surface at Bedrock Well 23MW03D.
Facing South.

Bedrock Well 23MW04D and Resurfaced Asphalt.
Facing Southeast.

APPENDIX B

STORM SEWER/STREAM FLOW RATE CALCULATIONS

CLIENT: NSB - NLON (TANK FARM)	JOB NUMBER: 5083
SUBJECT: ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM	
BASED ON: FIELD MEASUREMENTS 5/20 - 5/22	DRAWING NUMBER:
BY: CAR 5/29/98 · CHECKED BY: [signature] 6/18/98	APPROVED BY: · DATE:

① OBJECTIVE: USING INFORMATION COLLECTED IN FIELD BY T. EVANS AND T. DICKSON ON 5/20/98 - 5/22/98, ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM IN THE VICINITY OF THE TANK FARM AT NSB-NLON GROTON, CT. A SCHEMATIC OF THE SYSTEM IS SHOWN ON P. 2 OF 11

② APPROACH: (1) FOR STORM SEWERS AND STREAMS WITH SUFFICIENT WATER DEPTH, A MECHANICAL FLOW METER WAS USED TO ESTIMATE A FLOW VELOCITY (V). APPROPRIATE MEASUREMENTS WERE ALSO TAKEN TO DETERMINE THE FLOW AREA (A). THE FLOW RATE (Q) IN THE STORM SEWERS AND STREAMS WILL BE ESTIMATED WITH THE FOLLOWING EQUATION:

$$Q = V \cdot A$$

(2) FOR STORM SEWERS WITH MINIMAL FLOW DEPTHS, MEASUREMENTS OF ONLY THE FLOW DEPTH WERE OBTAINED. THESE MEASUREMENTS WITH KNOWN PIPE DIAMETERS, SLOPES, AND MATERIAL TYPE WILL BE USED TO DETERMINE FLOW RATES USING MANNING'S EQUATION.

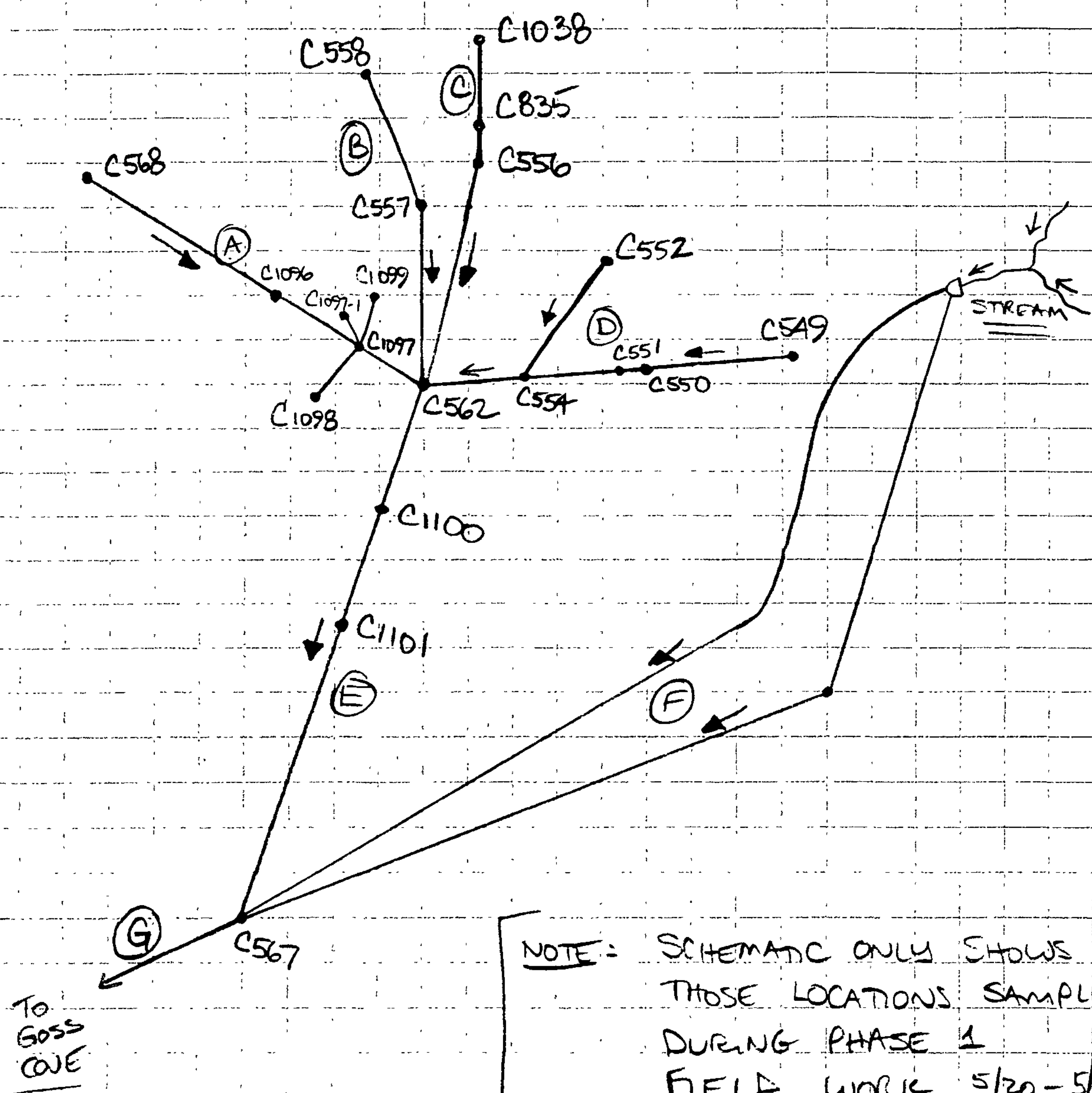
$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

CALCULATION WORKSHEET

Order No. 19116 (01-91)

CLIENT: NSB-NLON (TANK FARM)	JOB NUMBER: 5083
SUBJECT: ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM	
BASED ON: FIELD MEASUREMENTS 5/20-5/22	DRAWING NUMBER:
BY: CAR 5/29/98	CHECKED BY: [signature] 6/8/98
APPROVED BY:	DATE:

SCHEMATIC OF TANK FARM
STORM SEWER SYSTEM
(NOT TO SCALE)



NOTE: SCHEMATIC ONLY SHOWS THOSE LOCATIONS SAMPLED DURING PHASE 1 FIELD WORK 5/20-5/22

CLIENT NSB - NLON (TANK FARM)	JOB NUMBER 5083
SUBJECT ESTIMATE FLOW RATES IN EXISTING STORM SEWERS/STREAM	
BASED ON FIELD MEASUREMENTS 5/20-5/22	DRAWING NUMBER
BY CAR 5/29/98 / CHECKED BY [signature] 6/18/98	APPROVED BY / DATE

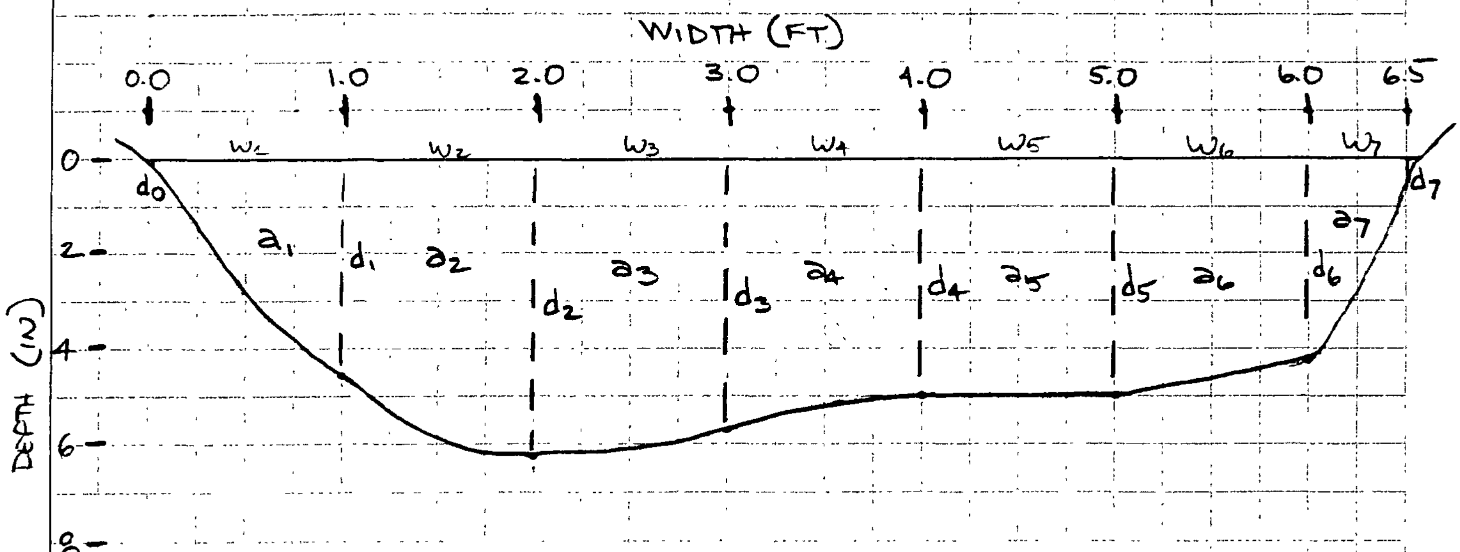
<u>WHERE</u>: n = MANNING'S COEFFICIENT

R = HYDRAULIC RADIUS

S = SLOPE

VALUES OF n WILL BE TAKEN FROM <u>OPEN-CHANNEL HYDRAULICS</u>, CHOW, 1959 (REISSUED 1988).

(3) FLOW RATE ESTIMATE FOR <u>STREAM EAST OF BLDG 447</u> :



<u>WHERE</u>: w_i = WIDTH (FT)

d_i = DEPTH (IN)

a_i = AREA (FT^2)

CLIENT	JOB NUMBER	
NSB-NLON (TANK FARM)	5083	
SUBJECT: ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM		
BASED ON: FIELD MEASUREMENTS 5/20 - 5/22	DRAWING NUMBER	
BY: CAR 5/29/98	CHECKED BY: [signature] 6/18/98	APPROVED BY	DATE

ESTIMATE AREA (A):

	d (IN)	A (FT²)
0	0	–
1	4.5	0.1875
2	6.25	0.4479
3	5.75	0.5000
4	5.00	0.4479
5	5.00	0.4167
6	4.25	0.3854
7	0	0.1771

$$A = \Sigma a_i = \sum_{i=1}^{7} (w_i) \cdot \frac{(d_i + d_{i+1})}{2} \cdot \frac{1\ ft}{12\ in}$$

TOTAL $A = 2.5625\ ft^2$

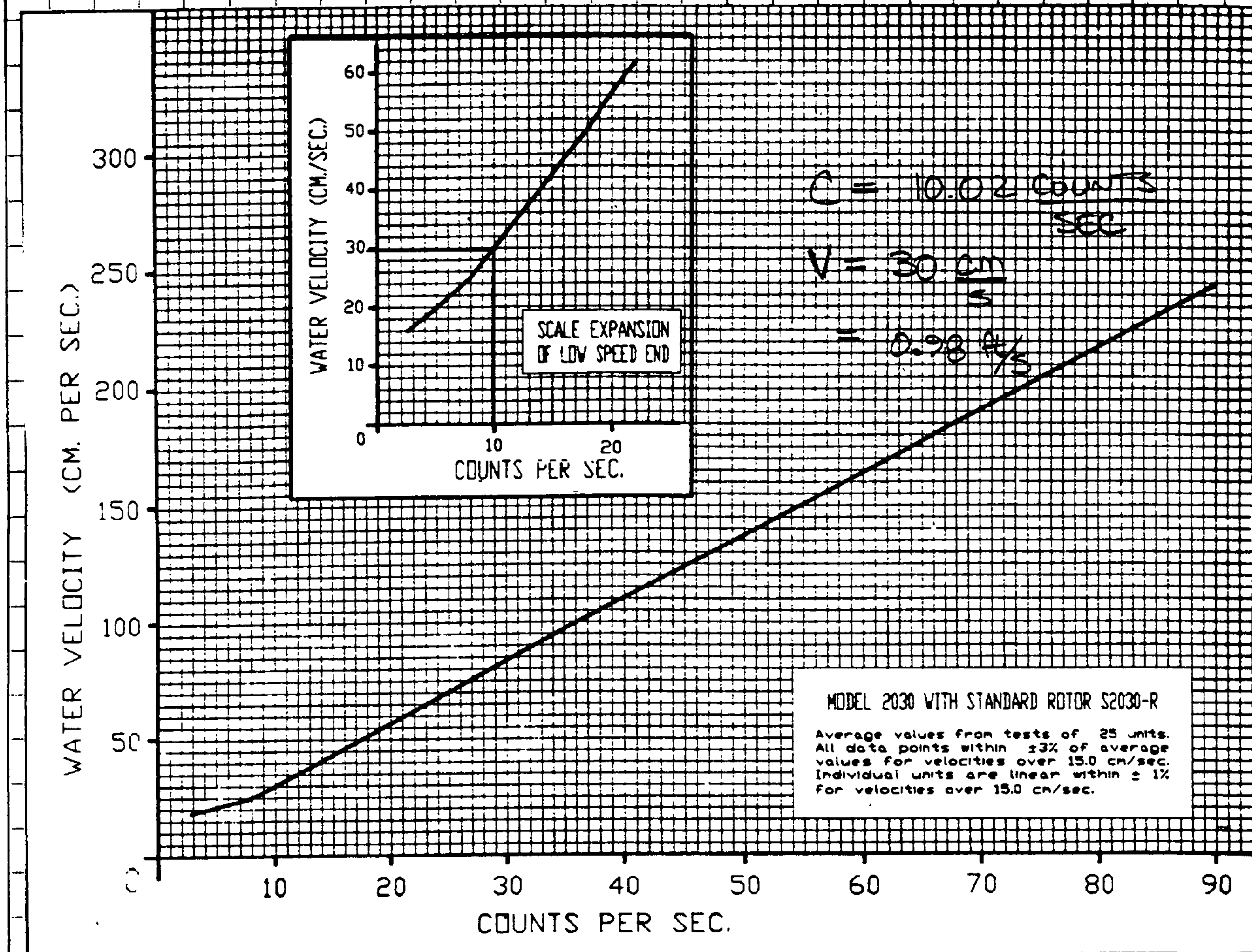
ESTIMATE VELOCITY (V): USING A MECHANICAL FLOW METER, AN AVERAGE OF 10.02 COUNTS/SEC WAS MEASURED. THIS NUMBER CONVERTS TO A VELOCITY OF 0.98 ft/s (SEE PAGE 5 OF 11).

ESTIMATE FLOW RATE (Q): $Q = (2.56\ ft^2)(0.98\ ft/s)$

$= 2.5\ ft^3/s$

CALCULATION WORKSHEET Order No. 19116 (01-91)

CLIENT: NSB-NLON	JOB NUMBER: 5083
SUBJECT: ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM	
BASED ON: FIELD MEASUREMENTS 5/20-5/22	DRAWING NUMBER
BY: CAR 5/29/98 — CHECKED BY: [signature] 6/18/98	APPROVED BY — DATE



GENERAL OCEANICS DIGITAL FLOWMETER MECHANICAL & ELECTRONIC OPERATORS MANUAL

GENERAL OCEANICS INC.
1295 N.W. 163rd Street Miami, Florida 33169-5887
FAX: (305) 621-1710 • Telex 80-8247 • Phone (305) 621-2882

CLIENT NSB-NLON (TANK FARM)	JOB NUMBER 5083
SUBJECT ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM	
BASED ON FIELD MEASUREMENTS 5/20-5/22	DRAWING NUMBER
BY CAR 5/29/98 — CHECKED BY [signature] 6/18/98	APPROVED BY — DATE

(4) ESTIMATE FLOW RATE IN 72" CMP EXITING C567 TO GOSS COVE:

ESTIMATE AREA (A):

$d = 0.77$ ft

$D = 6$ ft

$d/D = 0.128$

$A/D^2 = 0.0589$

$A = \underline{2.12 \text{ ft}^2}$

ESTIMATE VELOCITY (V): USING A MECHANICAL FLOW METER AN AVERAGE OF 17.06 COUNTS/SEC WAS MEASURED. THIS NUMBER CONVERTS TO A VELOCITY OF 1.56 ft/s. (SEE PAGE 7 OF 11).

ESTIMATE FLOW RATE (Q):

$Q = (2.12 \text{ ft}^2) \cdot (1.56 \text{ ft/s})$

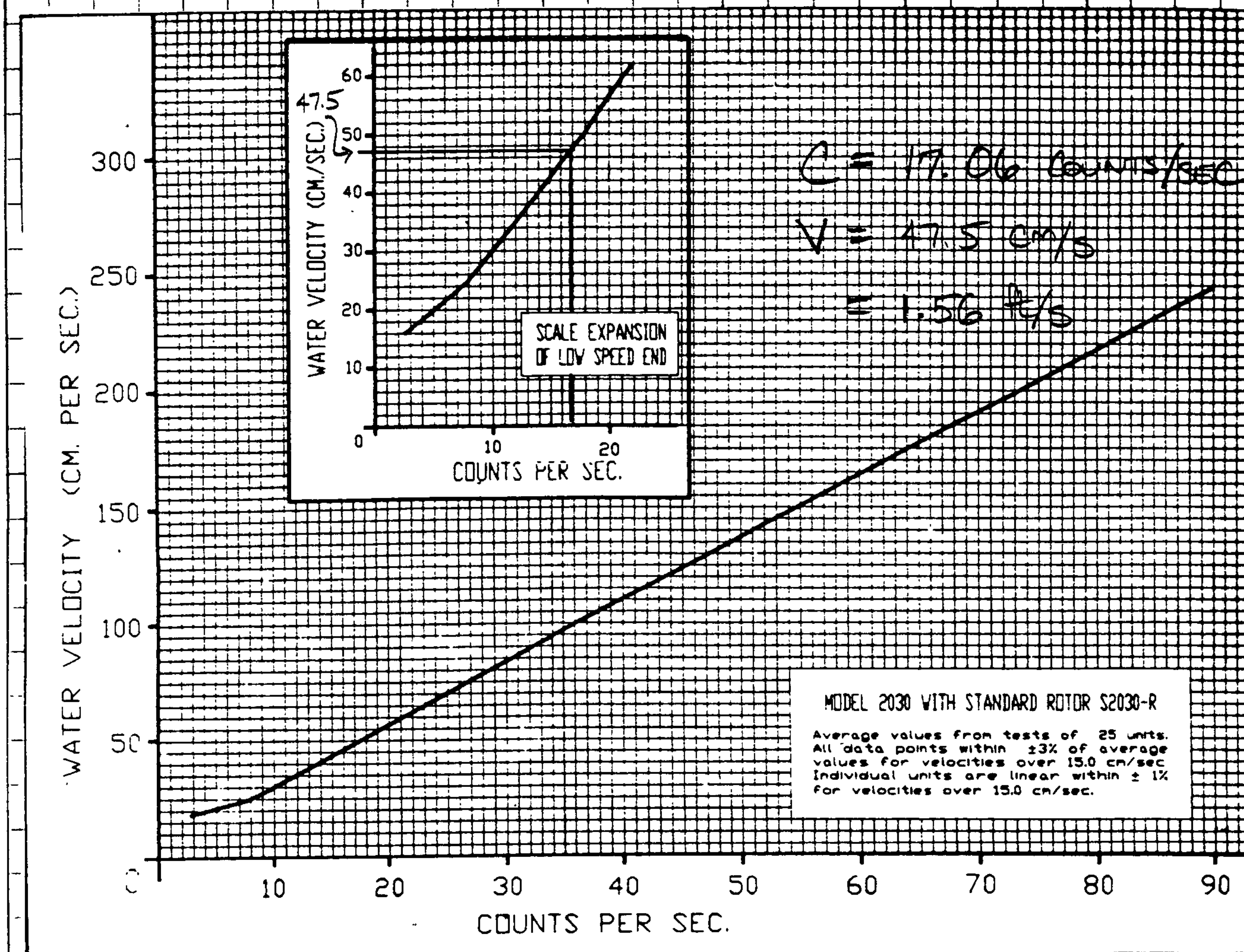
$= \underline{3.31 \text{ ft}^3/\text{s}}$

CLIENT	JOB NUMBER
NSB-NLON	5083

SUBJECT: ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM

BASED ON	DRAWING NUMBER
FIELD MEASUREMENTS 5/20-5/22	

BY	CHECKED BY	APPROVED BY	DATE
CAR 5/29/98	[signature] 6/18/98		



GENERAL OCEANICS DIGITAL FLOWMETER MECHANICAL & ELECTRONIC OPERATORS MANUAL

GENERAL OCEANICS INC.
1295 N.W. 163rd Street Miami, Florida 33169-5887
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CLIENT NSB-NLON (TANK FARM)	JOB NUMBER 5083		
SUBJECT ESTIMATE FLOW RATES IN EXISTING STORM SEWERS/STREAMS –			
BASED ON FIELD MEASUREMENTS 5/20-5/22	DRAWING NUMBER		
BY CAR 6/1/98	CHECKED BY [signature] 6/18/98	APPROVED BY	DATE

(5) ESTIMATE FLOW RATES IN REMAINING STORM SEWERS:

- USE MEASURED FLOW DEPTHS, STORM SEWER DESIGN INFORMATION, AND MANNING'S EQUATION TO ESTIMATE FLOW RATES.

- FLOW RATES NOT ESTIMATED AT THE FOLLOWING LOCATIONS:

LOCATION		REASON
C551	–	UNABLE TO LOCATE
C552	–	UNABLE TO LOCATE
C554	–	UNABLE TO LOCATE
C558	–	DRY
C562	–	UNABLE TO LOCATE
C835	–	BOARD COVERING OUTLET PIPE
C1097	–	UNABLE TO LOCATE
C1097-1	–	DRY
C1098	–	STANDING WATER
C1099	–	DRY

- THE ESTIMATED FLOW RATES ARE SUMMARIZED IN TABLE 1, P. 9 OF 11

TABLE 1

Reach	Segment	Manh le/ Inlet	Length (ft)	Pipe Diameter (in)	Pipe Material	Top of Frame Elev (ft)	Invert Elev (ft)	Depth to Exit Pipe (ft)	Depth t Water (ft)	d (ft)	A (ft^2)	R (ft)	S (ft/ft)	n	V (ft/s)	Q (ft^3/s)
A	1	C568	168	12	PCMP	20.75	9.45	11.23	11.05	0.18	0.0961	0.1097	0.00548	0.03	0.84	0.08
		C1096				20.53	8.53	12.17	11.6	0.57						
	2	C1096	230	12	PCMP	20.53	8.43	12.17	11.6	0.57	0.4625	0.2703	0.00261	0.03	1.06	0.49
		C562				NA	7.83	NA	NA	0						
B	1	C558	NA	Unknown	VCP	24.38	16.09	NA	NA	0	NA	NA	NA	NA	NA	NA
		C557				20 61	13.41	7 2	7	0.2						
	2	C557	203	12	VCP	20.61	13.31	7.2	7	0.2	0.1118	0.1206	0.027	0.018	3.32	0.37
		C562				NA	7.83	NA	NA	0						
C	1	C1038	142	21	RCP	24 15	17.11	7 05	6.85	0.2	0.1522	0.1261	0.0181	0.017	2.97	0.45
		C835				26.52	14.54	NA	NA	0						
	2	C835	8	30	RCP	26.52	14.54	NA	NA	0	NA	NA	NA	NA	NA	NA
		C556				20.86	14.16	6.72	6.51	0.21						
	3	C556	307	30	RCP	20.86	14.16	6.72	6.51	0.21	0.1977	0.1345	0.02062	0.017	3.30	0.65
		C562				NA	7.83	NA	NA	0						
D	1	C549	132	12	PCMP	21 88	10.28	11.4	11.29	0.11	0.047	0.0695	0.00273	0.03	0.44	0.02
		C550				21.02	9.92	11.29	10.85	0.44						
	2	C550	647	12	PCMP	21.02	9.92	11.29	10.85	0.44	0.3328	0.2295	0.00323	0.03	1.06	0.35
		C562				NA	7.83	NA	NA	0						
E	1	C562	292	30	PCMP	NA	7.6	NA	NA	0	NA	NA	NA	NA	NA	NA
		C1101				21.3	5.8	15.51	15.03	0.48						
	2	C1101	202	30	PCMP	21.3	5.8	15.51	15.03	0.48	0.6592	0.2907	0.0055	0.021	2.31	1.52
		C567				21.8	4.69	17.3	16.53	0.77						
G	1	C567	86	72	CMP	21.8	4.69	17.3	16.53	0.77	2.1197	0.4821	0.00686	0.03	2 53	5 36
		Goss Cove				20	4.1	NA	NA	0						

Notes:

CMP = Corrugated Metal Pipe
PCMP = Perforated Corrugated Metal Pipe
RCP = Reinforced Concrete Pipe
VCP = Vitrified Clay Pipe
A = Area
R = Hydraulic Radius
S = Slope
n = Manning's Coefficient
V = Manning's Velocity
Q = Flow Rate
Elevations on this table are referenced to the NSB-NLON 1982 vertical datum
Elevations were taken from Fuss & O'Neill data package, 1998 and Dwg No. 1142295, Utility Map, Storm Drainage, 1967
Pipe material types were taken from Camera Study Report, Foster Wheeler, November 9, 1998 and Tank Farm Plot Plan, Dwg. No. N-15, 1946.

BY: CAR
DATE: 11/18/98
CHKD: [illegible]
DATE: 12/16/98
P. 7 OF 11

CLIENT	JOB NUMBER
NSB - NLON (TANK FARM)	5083

SUBJECT: ESTIMATE FLOW RATES IN EXISTING STORM SEWERS / STREAM

BASED ON	DRAWING NUMBER		
FIELD MEASUREMENTS 5/20 - 5/22			
BY	**CHECKED BY**	**APPROVED BY**	**DATE**
CAR 6/1/98 CAR 11/18/98	6/18/98 12/16/98		

⑥ DETERMINE AMOUNT OF FLOW RATE FROM UNDERDRAINS VERSUS UPGRADIENT FLOW:

BY CONSERVATION OF MASS:

(I) $A + B + C + D = E$

(II) $E + F = G$

NOTE: REFER TO SCHEMATIC FOR DESCRIPTION OF A → G

Ⓐ FROM TABLE 1:

$A = 0.08$ cfs (C1086 → C562 NOT RELIABLE)

$B = 0.37$ cfs

$C = 0.65$ cfs

$D = 0.35$ cfs

$E = 0.08 + 0.37 + 0.65 + 0.35 = 1.45$ cfs

$E_{CALC} = 1.52$ cfs ≈ 1.45 cfs

∴ 1.5 cfs IS REASONABLE ESTIMATE

Ⓑ $E = 1.5$ cfs (TABLE 1)

$F = 2.5$ cfs (STREAM FLOW RATE)

$G = 1.5$ cfs $+ 2.5$ cfs $= 4.0$ cfs

$G_{MEASURED} = 3.31$ cfs $< G = 4.0$ cfs $< G_{CALC} = 5.36$ cfs

∴ 4.0 cfs IS REASONABLE ESTIMATE

CLIENT NSB-NLON (TANK FARM)	JOB NUMBER 5083
SUBJECT ESTIMATE FLOW RATES IN EXISTING STORM SEWERS/STREAM	
BASED ON FIELD MEASUREMENTS 5/20 - 5/21	DRAWING NUMBER
BY CAR 6/1/98 CAR 11/18/98 / CHECKED BY [signature] 6/8/98 12/16/98	APPROVED BY / DATE

(C) BASED ON THE FOLLOWING INFORMATION, THE ESTIMATED FLOW RATE IN THE TANK FARM (E) IS OVERLY CONSERVATIVE AND SHOULD BE REDUCED.

- THE CAMERA STUDY COMPLETED BY FOSTER WHEELER SHOWED THAT MANY OF THE PIPES IN THE SYSTEM ARE DETERIORATED, PARTIALLY COLLAPSED, AND HAVE DEBRIS IN THEM. SOME PIPES ALSO HAD STANDING WATER IN THEM.
- SOME FLOW IN A, C, AND D IS FROM UPGRADIENT LOCATIONS.
- THE TOTAL CONTRIBUTION FROM F IS MOST LIKELY UNDERESTIMATED BECAUSE INFLOW FROM THE STORM SEWER SYSTEM ALONG CRYSTAL LAKE ROAD IS NOT ACCOUNTED FOR IN THE CALCULATIONS.

∴ TOTAL UNDERDRAIN FLOW RATE (UQ) ≈ 0.4 cfs (APPROX. 25% OF E)

(D) FOR MODELING PURPOSES USE UQ = 0.4 cfs AS AN INITIAL, CONSERVATIVE ESTIMATE. USE THE MODEL TO REFINE THE ESTIMATE OF UQ.