NBC Phase III CSO Program
OF-217
Consolidation Conduit
Contract IIIA-5

Geotechnical Design Summary Report

Report Status (90% Design)
Revision No. 2

McMILLEN JACOBS ASSOCIATES

April 16, 2021

This page intentionally left blank.

Table of Contents

List of Tables

List of Figures

Appendices

Distribution

To:	William Skerpan, Jr BETA Group, Inc
From:	Tennyson M. Muindi, PE McMillen Jacobs Associates
Prepared By:	Katherine R. O'Hara McMillen Jacobs Associates
Reviewed By:	Daniel J. Dobbels, PE McMillen Jacobs Associates

Revision Log

Revision No.	Date	Revision Description
0	December 7, 2020	Internal Draft – Design Team
1	December 28, 2020	60% Design Submittal
2	April 16, 2021	90% Design Submittal

1.0 Introduction

1.1 General

This Geotechnical Design Summary Report (GDSR) presents the results of engineering evaluations of the subsurface information collected for design of the consolidation conduit and associated near surface structures for the Narraganset Bay Commission (NBC) Consolidation Conduit Contract IIIA-5 (the Project). This GDSR presents interpretations and conclusions with respect to generalized soil, rock, and groundwater conditions, significant engineering properties of soil and rock; and geotechnical design and construction considerations for the proposed facilities.

The Project is one component of the NBC Phase III Combined Sewer Overflow (CSO) Program. The Phase III CSO Program is being managed by Stantec, along with Pare Corporation (PM/CM) as a subconsultant under contract with NBC. BETA Group, Inc. (BETA) is the Project Design Consultant. McMillen Jacobs Associates (McMillen Jacobs) is providing geotechnical and structural engineering services under contract with BETA.

1.2 Purpose and Scope

The purpose of this report is to present the following:

- Interpretation of geotechnical data collected to date, and characterization of the subsurface soil, rock, and groundwater conditions along the consolidation conduit alignment as related to the proposed construction;
- Evaluations of the significant engineering properties of the subsurface materials with respect to the proposed structures;
- Geotechnical related design and construction considerations for the Project;
- Recommendations for additional subsurface investigations and laboratory testing to be completed prior to finalizing the construction contract documents.

The data that provided the basis for these interpretations and considerations are described in Section 2.

1.3 Project Description

This Project is part of the NBC Phase III CSO Program located in Rhode Island, which began in 2016 and is focused primarily on the Bucklin Point Service Area (BPSA) in the communities of Pawtucket (the City) and Central Falls. The overall NBC CSO Program is aimed at lowering annual CSO volumes and reducing annual shellfish bed closures in accordance with a 1992 Consent Agreement with the Rhode Island Department of Environmental Management (RIDEM). Phases I and II of this program, which focused on the Field's Point Service Area (FPSA) in Providence, were completed in 2008 and 2015, respectively.

This Project includes the design and construction of a consolidation conduit, a diversion structure, manholes, and other ancillary facilities necessary to convey flow from outfall OF-217 to the future Pawtucket Tunnel via Drop Shaft 213 (DS-213) and connecting adit set to be constructed under separate contract. Refer to Figure 1 for a Project Locus and Figures 2 through 4 for locations of the various project elements.

The selection of the horizontal and vertical alignment for the Project was developed jointly by the BETA design team and the PM/CM. Several alignment alternatives were evaluated due to the changed conditions requested by the PM/CM and NBC as well as the proposed development within the Tidewater property and the City sites, with the preferred alignment being as indicated herein. A partial list of evaluation criteria used in selecting the preferred alignment included:

- Maintenance of hydraulically acceptable gradients on the vertical consolidation conduit alignment and keep the diversion structure depth as shallow as practical.
- Locating the consolidation conduit alignment and diversion structure in areas that reduce the potential for impact to adjacent structures and utilities.
- Coordination with National Grid, the owner of the Tidewater property, which the consolidation conduit and OF-217 will traverse.
- Relocation of outfall OF-217 from beneath the existing National Grid Electrical Substation (Substation) to a discharge point just north of the Substation.
- Coordination with the City of Pawtucket, the proposed soccer stadium developer, and National Grid with regard to the future development at “Tidewater Landing” including the City’s Bike Path project.
- Location of the structures in public right-of ways and easements where possible.

All elevations indicated in this GDSR are referenced to National Geodetic Vertical Datum (NVGD) 1929, in feet. Horizontal control for the project is based on Rhode Island Mainland State Plane, North American Datum (NAD) 1983. All stationing referred to in this GDSR is referenced as shown on the 90 percent Design Drawings, and Figures 2 through 4 herein.

1.4 Limitations

This GDSR has been prepared for specific application to the proposed facilities for the NBC Phase III Consolidation Conduit Contract IIIA-5 project in Pawtucket, Rhode Island, configured as referenced herein, in accordance with generally accepted geotechnical engineering practice. In the event that changes in the nature, design, or location of the project elements are made, the interpretations, conclusions, and recommendations presented herein should not be considered valid unless the changes are reviewed and the conclusions of this GDSR are modified or verified in writing by McMillen Jacobs.

The analysis and recommendations presented in this GDSR are based in part on the data obtained from the referenced explorations. The nature and extent of variations between explorations may not become evident until or during final design or construction. If variations then appear, the conclusions of this GDSR should not be considered valid unless the conclusions are re-evaluated and modified or verified in writing by McMillen Jacobs.

2.0 Field and Laboratory Investigations

2.1 General

This section presents a high level summary of the data that provided the basis for the interpretations and recommendations presented in this GDSR. It is beyond the scope of this GDSR to provide a detailed summary of all the field and laboratory investigations that have been conducted for the Project. Such information can be found in various other project reports as referenced herein.

2.2 Final Design Phase

A design phase field and laboratory investigation program was undertaken for the Project in 2019 and 2020 by McMillen Jacobs. The program consisted of drilling 13 widely spaced test borings, eight of which are located along this Project alignment. In addition, groundwater monitoring wells were installed, and soil laboratory testing was conducted. The results of the investigation program are presented in the report entitled "Geotechnical Data Report, NBC Phase III CSO Program, Consolidation Conduits IIIA-4 and IIIA-5", dated June 2020, hereafter referred to as the GDR. This GDSR was prepared utilizing data from that report.

Additional subsurface investigations and laboratory testing to be completed prior to finalizing the construction contract documents are recommended as described in Section 8.9.

2.3 Planning and Design Phase

A planning and design phase for the overall NBC CSO Phase III Program was performed by the PM/CM. The following information was provided and reviewed:

- Report entitled "NBC CSO Phase IIIA Contract No. 308.01 C, Request for Proposal, Appendix C, Geotechnical Data Report", prepared by and Stantec and Pare Corporation., dated December 23, 2019.

The borings that were judged to be representative of conditions along the Project alignment included test borings B17-41 and B17-42. Data from these test borings were utilized in the evaluations made in this GDSR.

2.4 Historic Borings

Geotechnical subsurface explorations have been performed along or adjacent to the Project alignment for various purposes. The following information was reviewed:

- Drawing set entitled "State of Rhode Island and Providence Plantations, Blackstone Valley Sewer District Commission, Taft St. – Pleasant St. Branch Interceptor, Section B, Contract 18" prepared by Metcalf & Eddy Engineers, dated 1950.
- Report entitled "Site Investigation Data Report, Former Tidewater MGP and Power Plant Site Pawtucket, Rhode Island RIDEM Case No. 95-022" prepared by GZA GeoEnvironmental, Inc., dated January 2011.

The borings that were judged to be representative of conditions along the Project alignment included the following test borings: 215, 214, 213, 212, MW-206, MW-208, MW-209, MW-7/TB-20, and MW-5/TB-14. Data from these borings were used in preparation of this GDSR where indicated.

3.0 Site Geology

3.1 General

This section describes the general geology, site topography and land use in the vicinity of the proposed Project. Technical terminology used in this section and throughout this GDSR to describe soil units, rock types, and geologic features are defined in the Glossary of Technical Terminology provided in Appendix A. The Subsurface Investigation Key used for McMillen Jacobs test borings is provided in Appendix B.

3.2 Geologic Setting

The Project is in the New England physiographic province of the Appalachian Highland physiographic division, lying within the Seaboard lowland section (Denny 1982). The physiographic area is referred to as the Narragansett Basin, the result of a complex sequence of a geosynclinal sedimentation, volcanism, plutonism, and erosion (Quinn 1971). The basin is made up of several thousand feet of non-marine sedimentary rock that has been folded, faulted, and slightly to moderately metamorphosed.

The geologic history of the proposed project area is one of weathering, erosion, and deposition. Periods of glaciation have shaped much of the visible landscape and the Project area is characterized by the adjacent Blackstone/Seekonk River valley. Glacial and post glacial deposits dominate the landscape and generally consist of stratified layers of sand, silt, gravel, cobbles, and boulders.

The soil stratigraphy in the overall area from the ground surface downward is anticipated to consist of Fill material, Alluvium deposits, Glaciofluvial deposits, and Glacial Till deposits overlying the bedrock. The bedrock is the Rhode Island Formation, a Pennsylvania-age sandstone with lessor amounts of conglomerate sandstone and siltstone. Quartz filled fractures are common. Evidence of faulting in the wider area is present, but not expected along this Project alignment.

3.3 Site Topography and Land Use

The topography in the area is the result of a long and complex history of glaciation and site filling, which has had an influence on the current site and subsurface conditions. The topography is generally rolling to flat, with less than 200 feet of relief, sloping downwards towards the east. The ground surface along the Project alignment varies from approximately elevation El. 40 to El. 10, rising upward from just south of the Division Street Bridge to a maximum before sloping gradually downward before reaching OF-217 at the river's edge. The bedrock surface topography from north to south is expected to range from about 10 feet to 30 feet below existing grade with the highest rock in the area of MH217-6.

Land use along the Project alignment appears to be generally residential, public land, a school, and the Tidewater property, a former manufactured gas plant (MGP) and power plant site currently owned by National Grid that is classified as a "State Site" under RIDEM's Remediation Regulations. Refer to Section 8.4 for additional information pertaining to the Tidewater property. It is anticipated that the existing structures along the Project alignment are founded on spread footings bearing on the Glacial deposits.

4.0 Engineering Properties of Soil and Rock

4.1 General

This section presents a characterization of the subsurface conditions encountered within the immediate vicinity along the Project alignment, including a brief description of these deposits and selected engineering properties.

4.2 Soil

The soil stratigraphy from the existing ground surface downward includes the following:

- Unit 1 Fill
- Unit 2 Alluvium
- Unit 3 Glaciofluvial
- Unit 4 Glacial Till

All geologic units may not be encountered at all locations along the Project alignment.

Histograms of Standard Penetration Test (SPT) N-values and composite grain size distribution curves for each geologic unit are provided in Appendix C.

4.2.1 Unit 1 – Fill

Fill material is present surficially along the Project alignment from the existing ground surface to depths ranging from about 5 to 20 feet. The Fill consists of variable composition, uncontrolled man-made materials and other construction debris.

Based on the test borings, the Fill encountered consists of loose to very dense, brown to black, coarse to fine sand with varying amounts of silt and gravel and contains fragments of glass, brick, and concrete. SPT N-values ranged from less than 4 to greater than 50 blows per foot (bpf), with values typically greater than 10 bpf.

Vacuum excavation was performed in the upper 6 feet of the test borings drilled along this alignment. Therefore, the nature and quality of the Fill may not be fully described herein.

4.2.2 Unit 2 – Alluvium

Alluvium deposits were encountered in some of the test borings beneath the Fill and ranged in thickness from about 5 to 16 feet. This deposit may indicate the former adjacent river flood plain that was present in the more recent past. The Alluvium consists of medium dense, silty sand to stiff clayey silt. SPT N-values ranged from 5 to 31 bpf. The Alluvium is discontinuous and is not expected in all areas along the alignment.

4.2.3 Unit 3 – Glaciofluvial

Glaciofluvial deposits were encountered in some test borings below the Fill and above the Glacial Till and ranged in thickness from about 7 to 10 feet. These Glaciofluvial sediments were produced by water flowing on, in, or under a retreating glacier and are characterized by sorted and stratified sand and gravel. The sediments are the result of erosion and have formed terraces from being trapped between the glacier ice and the sides of the river valley walls. Occurrences of cobbles and boulders are also common.

Based on the test boring performed, the Glaciofluvial deposits encountered generally consist of loose to medium dense, brown, coarse to fine sand or coarse to fine gravel. SPT N-values ranged from 7 to greater than 38 bpf.

4.2.4 Unit 4 – Glacial Till

Glacial Till deposits were encountered beneath the Fill or Glaciofluvial deposits directly over the bedrock The Glacial Till is variable in nature due to the complex process of deposition beneath the moving glacial ice (lodgment till).

Based on the test borings, the Glacial Till encountered generally consists of an unsorted mix of very dense, sand and gravel with lessor amounts of silt and clay and includes occurrences of cobbles, boulders and rock fragments from the underlying bedrock. SPT N-values ranged from 30 to greater than 50 bpf.

4.2.5 Engineering Properties for Soil

Table 1 summarizes the engineering properties for each soil unit encountered. The location of the contacts between the overburden soils within borings along the Project alignment are shown on Figures 2 through 4. No attempt has been made to interpolate the location of the contacts between the borings.

Table 1 Summary of Engineering Properties for Soil

Property/Parameter	Fill	Alluvium	Glaciofluvial	Glacial Till
Unit Weight (pcf)	125	120	125	135
Friction Angle (Φ)	32	30	32	34
At-Rest Earth Pressure Coefficient (K_o)	0.47	0.5	0.47	0.44
Active Earth Pressure Coefficient (Ka)	0.31	0.33	0.31	0.28
Passive Earth Pressure Coefficient (Kp)	3.26	3.00	3.26	3.54

4.3 Bedrock

The bedrock consists of the Rhode Island Formation of the Narragansett Bay Group. The Rhode Island Formation consists of predominantly sandstone with lessor amounts of conglomerate sandstone and siltstone.

The top of bedrock along the Project alignment is anticipated to vary as shown in the individual boring sticks on Figures 2 through 4. As indicated, the top of bedrock represents the surface of material that has been geologically classified as bedrock on the test boring logs, regardless of the quality the bedrock. The top of bedrock line shown on Figure 2 is based on a top of bedrock developed from the geophysical evaluation conducted by the PM/CM as part of the conceptual design of the Phase III Project. Typically, there is some variation from the top of bedrock estimated from geophysical methods to the top of bedrock determined from conducting test borings.

Of the seven test borings taken in close proximity to the consolidation conduit alignment that encountered bedrock, completely to highly weathered rock ranging from 4 to 12 feet thick was encountered in five borings (B-1, B-3, B-11, B-12, and B17-41). Standard descriptions of completely to highly weathered rock are provided on Figure 5 and the Subsurface Investigation Key provided in Appendix B, and completely to highly weathered rock can be further characterized by observed core recovery being generally less than 30 percent. The bedrock below the completely to highly weathered zone in borings B-1, B-3, B-11, B-12 and B17-41 and below the top of bedrock in borings B-9 and B-10 is generally described on the test boring logs as slightly weathered to fresh, laminated sandstone to siltstone. In the bedrock cored, bedding plane joints dipping 20 to 50 degrees were observed frequently and were described as smooth to slightly rough, highly weathered to fresh, and soft to medium hard.

About 50 percent of all the bedrock cored had an RQD of greater than 50 but less than 90 percent, indicating a fair to good quality rock as defined by Deere (1988). At the soil-bedrock interface, about 30 percent of the all the bedrock cored had an RQD of less than 25 percent, indicating a very poor quality rock (Deere 1988). Refer to Appendix C for a RQD histogram.

As part of the subsurface investigation, a limited laboratory testing program was conducted on selected rock core samples obtained from the borings. Table 2 presents a summary of the results of the testing. Two tests were completed for each type of test.

Table 2 Summary of Engineering Properties for Rock

Property/Parameter	Results
Unit Weight (pcf)	170, 173
Unconfined Compressive Strength (psi)	7325, 14240
Brazilian (Splitting) Tensile Strength (psi)	1290, 1440
CERCAR (CAI)	3.76, 3.87

Based on ASTM D7625, the CERCAR Abrasivity Index (CAI), the abrasivity of the bedrock is in the “high” range.

4.3.1 Potential for Hazardous Gas

Although not encountered in the test borings performed for this Project, coal deposits are known to be preset within the Rhode Island Formation. The coal is derived from the accumulation of organic matter during rapid fluvial sedimentation in swampy areas (Frimpter and Maevsky 1979). Therefore, the location, trend, and extend of the coal deposits are difficult to predict. The coal is known to have the capacity to retain methane, although the content is estimated to be low.

During the Phase I subsurface investigation performed for the Main Spine Tunnel Project, which is located approximately five miles southwest of the project area, measurements of combustible gas were recorded over a riser pipe installed as part of a geotechnical instrument (Haley & Aldrich 1995). The test boring log for the borehole indicated a “probable coal bed”. The combustible gas detector reading over a riser pipe can indicate that gas is present but may not be a reliable indicator of the actual gas concentration that is present at the source.

The potential exists for discharge of methane from the carbonaceous rock. The contract documents for the Pawtucket Tunnel Project classified excavations in rock as “potentially gassy”.

5.0 Groundwater Conditions

5.1 General

Regional groundwater flow in the vicinity of the Project is anticipated to be north-south, along the Blackstone River/Seekonk River. The Blackstone River flows south from Worcester, Massachusetts to the Main Street Dam in Pawtucket, RI. At this point, it becomes the headwater for the Seekonk River, which is a tidal estuary that flows south before combining with the Providence River. The Blackstone River is the second largest source of freshwater to Narragansett Bay. The average annual precipitation is approximately 47 inches per year (Frimpter and Maevsky 1979).

The principal aquifer in the Project area is in the Glaciofluvial Deposits, comprised mainly of sand and gravel. These materials were deposited in the stream valley, are irregularly shaped, and form an unconfined aquifer. The Glaciofluvial aquifer is separated from the bedrock aquifer by the Glacial Till. The Glacial Till layer is of variable thickness that does not yield significant quantities of water. Specific yield of the Glaciofluvial aquifer is estimated to be approximately 20 percent (Frimpter and Maevsky 1979).

The bedrock aquifer is partially confined. Specific yield is greatest near top of bedrock and decreases to a negligible amount at depths over 300 feet. Specific yield of the upper 300 feet of bedrock is estimated to be less than 0.5 percent (Frimpter and Maevsky 1979).

Municipal and industrial water wells in the Project area are generally located at depths ranging from about 70 to 550 feet in bedrock. Yield from water wells located in bedrock are estimated to range from about 5 to 200 gallons per minute (gpm), with a median yield of about 30 gpm (Halberg, Knox, and Pauszek 1961).

5.2 Groundwater Levels

Based on the groundwater monitoring performed for the Project from September 2019 to November 2020, measured groundwater levels along the Project alignment ranged in elevation from approximately El. 8.5 to El. 18, corresponding to a depth below the existing ground surface of about 8 to 15 feet. Groundwater monitoring within the recently installed groundwater monitoring wells has not been conducted for a sufficient duration to provide seasonal water level fluctuations at these locations.

Groundwater levels in the Project area are expected to be influenced by the Blackstone River/Seekonk River, which varies due to the presence of three historic dams The river level average is anticipated at approximately El. 2. The river is tidal, with an anticipated normal daily tidal range of about 2.3 feet above and below the average.

Groundwater levels are also expected to vary seasonally, as a result of changing weather patterns and precipitation. In addition, groundwater levels in the Project area may be influenced by local construction activities and drainage into and out of existing underground utilities.

5.3 Hydraulic Conductivity of Rock

The hydraulic conductivity of the bedrock aquifer is mainly due to the fractures present within the rock mass. Based on the results of the hydraulic conductivity testing (packer testing) in bedrock completed for the Pawtucket Tunnel Project, estimated hydraulic conductivities at the interface between the soil and bedrock are on the order of 1×10^{-4} to 6×10^{-3} cm/sec. In addition, the data suggests that the hydraulic conductivities estimated in testing performed in boreholes drilled near the river were generally higher than testing performed in boreholes located some distance away from the river.

5.4 Groundwater Impacts

Detrimental impacts to the ground and existing structures from construction related groundwater management is not anticipated. Impacts from groundwater drawdown generally occur due to long-term groundwater lowering away from excavations. The most significant of such impacts typically include ground and existing structure settlements as a result of consolidation of compressible soil deposits. The soil deposits anticipated to be encountered during construction of the Project elements include Fill materials underlain by dense to very dense Glacial deposits followed by bedrock. These deposits are generally granular and are not anticipated to consolidate or respond significantly due to groundwater lowering.

Construction considerations relative to groundwater control are discussed in Section 8.3.

6.0 Geotechnical Design Considerations for Shafts

6.1 General

The primary purpose of this section is to discuss how geotechnical issues may affect design of the shafts. The term shafts used herein refers to cut and cover excavations that will be used to conduct microtunneling operations, and construct the diversion structure and manholes The locations of the shafts are shown on Figures 2 through 4. Approximate location, dimensions, depth, and planned usage are described below.

Diversion Structure 217 (DS-217) is located on the Tidewater property off the paved surface and west of the existing National Grid Substation. DS-217 serves to divert wet weather flow from OF-217 to the Pawtucket Tunnel via the downstream facilities. DS-217 has a wye shape with maximum plan dimensions of 15-feet by 10-feet, is a cast-in-place reinforced concrete structure, and is about 12-feet deep.

Four manholes are located along the consolidation conduit designated MH217-4, MH217-5, MH217-6, MH217-7, and two along the outfall pipe designated MH217-8 and MH217-10. Connection to the existing OF-217 outfall pipe will be made at MH217-8 located downstream of the junction manhole where the pipe from Merry Street joins the pipe on Tidewater Street. The new structure will redirect all flow to the DS-217. The manholes are 8-foot diameter precast reinforced concrete structures with installation depths slightly below the pipelines at each discrete manhole location.

In addition, a temporary shaft is planned at Sta. 16+68, the location of the transition from microtunneling pipeline installation to open cut pipeline installation.

6.2 Excavation and Initial Support

6.2.1 Excavation

Excavations ranging from about 15 to 40 feet will be required to construct the permanent structures. Refer to Figures 2 through 4, which indicate the soil units and groundwater anticipated to be encountered at each structure location. Excavation of bedrock will be required at MH217-6 and may be required at the invert excavation depths for DS-217, MH217-8, MH217-10, and the temporary shaft constructed at Sta. 16+68.

Descriptions and engineering properties of the soil units and bedrock are provided above in Section 4. Boulders or completely to highly weathered bedrock should be expected at the top of rock surface.

Excavation will likely be accomplished using mechanical excavation equipment, such as an excavator or a clam shell bucket. Due to the limited amount of bedrock to be removed and anticipated quality of rock at the top of rock surface, its anticipated that rock removal can be accomplished by mechanical means using hydraulic hammers and rippers.

6.2.2 Initial Support

Excavation support will be designed by the Contractor subject to the performance criteria included in the contract documents. At microtunneling launching shafts (MH217-6 and MH217-7), rigid, impermeable temporary support will be required. Likely feasible systems include circular secant pile walls, slurry diaphragm walls, or cutter soil mix wall socketed into rock. Circular shafts resist lateral loads through ring compression and may be designed as unreinforced without any internal bracing. Maximum installation tolerances of 1 inch within in-plan design location and 1 percent out-of-verticality are recommended to ensure contact between adjacent panels for water cut-off and for the bearing area to act as a compression ring.

At the remaining shaft locations, flexible temporary support may be used. Likely feasible methods include, but are not limited to, steel soldier piles and timber lagging with internal bracing consisting of steel struts and walers. Bracing levels should be kept to a minimum to maximize efficiency when constructing the structures. The Contractors design will need to consider installation tolerances to ensure build-out of the permanent structures can be accomplished. Where the manhole braced excavation is also being used to support MTBM operations (MH217-5 and the temporary receiving shaft at Sta. 16+68), the footprint size will need to be adjusted accordingly to allow for MTBM retrieval.

For planning purposes, where excavations penetrate bedrock, it would be reasonable to assume the use of rock dowels and mesh/shotcrete for temporary rock support.

6.3 Foundation Support for Structures

Based on the results of the test borings completed for the Project, it is anticipated that dense Glacial Till or bedrock will be encountered at the planned invert elevations for the new structures. It is expected that these materials will provide adequate foundation support and that special preparation or treatment of subgrade bearing surfaces will not be required. Settlement of the structures founded in these materials is anticipated to be negligible assuming good construction workmanship. Refer to Section 8.4 for additional considerations with regard to subgrade preparation and backfill.

7.0 Geotechnical Design Considerations for Consolidation Conduits

7.1 General

The primary purpose of this section is to discuss how geotechnical issues will affect design of the consolidation conduit and the new outfall pipe.

The consolidation conduit will be a reinforced concrete pipe (RCP) constructed using a combination of trenchless methods and open cut methods. Segments (reaches) requiring trenchless installation were determined based on line and grade requirements, depth of installation, pipe size, installation lengths, presence of glacial soils and bedrock, groundwater table above pipe invert, ground cover, presence of contaminated soil and groundwater, impacts to adjacent structures and managing surface disruptions. Microtunneling was evaluated and considered as the preferred trenchless method.

A summary of the RCP pipe reaches for IIIA-5 is provided in the following Table 3.

Table 3 Summary of Pipe Reaches

Pipe Reach	Location	Installation Method	Nominal Diameter of Pipe (in)	Approximate Length (ft)	Approximate Depth Range to Invert (ft)
MH217-4 to MH217-5	Sta. 0+00 to 1+27	Open Cut	48	127	14 to 15
MH217-5 to MH217-6	Sta. 1+27 to 7+97	Microtunneling	48	670	17 to 36
MH217-6 to MH217-7	Sta. 7+97 to 12+57	Microtunneling	48	460	25 to 36
MH217-7 to Sta. 16+65	Sta. 12+57 to 16+65	Microtunneling	48	408	25
Sta. 16+65 to DS 217	Sta. 16+65 to 18+27	Open Cut	48	162	14 to 18
DS 217 to MH217-8	Sta. 18+27 to 18+88	Open Cut	48	61	7 to 13
OF 217 to DS 217	Sta. 0+00 to 4+47	Open Cut	42	447	6 to 13

A brief description and discussion of microtunneling and open cut methods is provided in the following sections.

7.2 Microtunneling

Microtunneling is a slurry-based pipe jacking process that employs a remotely controlled, closed face tunneling shield commonly referred to as a Microtunnel Boring Machine (MTBM). Closed face slurry-based shields can exert a positive mechanical and fluid (slurry) pressure against the excavation face to maintain face stability. The pressurized slurry, also referred to as Engineered Drilling Fluid (EDF) counterbalances the hydrostatic head to prevent uncontrolled ground movement from unbalanced groundwater pressures that can lead to over-excavation and ground settlement. Because a pressurized EDF is used to counterbalance groundwater, contaminant migration can be mitigated with pressurized EDF and subsequently the pressurized lubricant. The need to mitigate contaminant migration during mining reinforces the importance that microtunneling cannot be performed with water only in the soil materials described above as some contractors are prone to do.

The remote-control nature of the system does not require personnel entry for the tunneling operations. The pipe diameter range for microtunneling is generally from 36 to 144-inches, with the most common pipe diameter range between 42 to 72-inches.

Microtunneling Layout

The primary advantages of microtunneling are that the product pipe is often installed directly behind the machine in a one-pass installation. Considerations for microtunneling pipe selection and cutter head design include, but are not limited to soil type, strength, consistency, ground abrasivity, potential for encountering obstructions or cobbles and boulders, groundwater levels, and drive distance.

Based on the subsurface explorations, portions of the alignments are expected to encounter mixed ground conditions, such as glacial deposits overlying rock, which can be very challenging and cause difficulty in maintaining line and grade of the pipeline. Where the vertical alignment cannot be adjusted to avoid mixed ground or mixed face conditions, which is the case for this Project, the risk can be reduced by utilizing appropriate cutterhead tooling that is adaptable to the anticipated ground conditions and tunneling from hard to soft ground (bedrock to soil). The disadvantage to that is different tooling is required for the rock and the soil and that can impact the efficiency in mining through those conditions.

Another advantage of microtunneling is that advanced guidance coupled with sophisticated steering allows the method to develop horizontal curves to optimize alignments and overcome constraints inherent with straight alignments. Based on the anticipated drive lengths for the three reaches, Intermediate Jacking Stations (IJS) along the pipe string to distribute jacking loads may not be needed.

7.3 Trenchless Reaches

This section provides a brief description and discussion for the reaches of the consolidation conduit that is recommended to be constructed using microtunneling. From a microtunnel point of view, the challenging ground conditions suggest consideration should be given to completing the two short drives first before tunneling the longer drive. This gives a contractor the opportunity to fine tune their means and methods and adjust to the ground conditions before the longer drive that could be more challenging.

Anticipated ground behavior relative to soft ground tunnel construction is described according to the “Tunnelman’s Ground Classification," as originally developed by Terzaghi’s (1950) and modified by Heuer (1974), and presented in Appendix E, Table E.1. The Tunnelman's Ground Classification is an empirical classification of behavior wherein general soil types are categorized into different groups based on typical behavior at the face of an open-face soft ground tunneling shield above and below the groundwater.

Ground behavior relative to rock tunneling is described in general accordance with the descriptive classification scheme developed by Terzaghi (1946) as presented in Table E.2 included in Appendix E. This classification scheme was originally developed to estimate rock loads for design of steel supports for 10 to 20-foot diameter tunnels excavated by drill and blast methods. While this classification scheme is not widely used for estimating loads for design of tunnel linings of the type anticipated for the consolidation conduit, the descriptive terminology is useful for describing dominant rock mass behavior, particularly for rock masses where gravity is the dominant driving force.

7.3.1 MH217-5 to MH217-6

The consolidation conduit between MH217-5 and MH217-6 is located adjacent and parallel to Taft Street from just south of the Division Street Bridge to just south of the Community Gardens and is approximately 670 feet in length. Existing ground surface ranges from approximately El. 15 to El. 36 with a depth to invert ranging from about 17 to 36 feet.

It should be noted that no test borings have been taken to date along this pipe reach and the only available reach specific subsurface information consists of surface geophysical investigations along Taft Street undertaken by the PM/CM. It should also be noted that the elevation of the top of bedrock based on the surface geophysical investigations varies from the top of bedrock elevation determined by the test borings at locations where the test borings were done in close proximity to the geophysical survey line. Accordingly, there is much uncertainty in subsurface conditions in this reach and additional subsurface investigations and laboratory testing are recommended to be completed prior to finalizing the construction contract documents as described in Section 8.9.

Based on the very limited subsurface information near this reach, subsurface conditions within the tunnel horizon from MH217-5 to MH217-6 are anticipated to range from a full face of soil to mixed face of soil over rock to a full face of rock.

The Glacial Deposits are anticipated to consist of very dense, coarse to fine gravel with varying amounts of sand and silt. The upper portion of the bedrock is anticipated to be completely to highly weathered and below this zone the bedrock is anticipated to consist of strong, greenish gray, slightly weathered Siltstone or Sandstone. Groundwater levels are anticipated to be above the tunnel crown.

The Glacial Deposits that are present within the pipeline horizon are anticipated to exhibit firm to fast raveling behavior except where siltier horizons of the deposit are present at the face, in which case cohesive running conditions would be anticipated. Zones of completely to highly weathered rock at the top of the bedrock will exhibit attributes of both soil-like and rock-like behavior depending on the degree of weathering. The more heavily weathered zones will exhibit soil-like fast raveling behavior. Below the completely to highly weathered zone the rock is anticipated to exhibit blocky and seamy to intact behavior.

7.3.2 MH217-6 to MH217-7

The consolidation conduit between MH217-6 and MH217-7 is located adjacent and parallel to Taft Street and is approximately 460 feet in length. Heading up-station, existing ground surface ranges from approximately El. 40 to El. 27, with a depth to invert of ranging from about 25 to 36 feet.

Heading up-station from MH217-6, the subsurface conditions within the tunnel horizon are anticipated to range from a full face of rock to mixed face of soil over rock to a full face of soil. Alluvium Deposits overlying Glacial Deposits are expected. The Alluvium is expected to consist of medium stiff dark gray clayey silt. The Glacial Deposits are anticipated to consist of very dense, coarse to fine gravel with varying amounts of sand and silt. The upper portion of the bedrock is anticipated to be completely to highly weathered and below this zone the bedrock is anticipated to consist of strong, greenish gray, slightly weathered Siltstone or Sandstone Groundwater levels are anticipated to be above the tunnel crown.

Zones of completely to highly weathered rock at the top of the bedrock will exhibit attributes of both soil-like and rock-like behavior depending on the degree of weathering. The more heavily weathered zones will exhibit soil-like fast raveling behavior. Below the completely to highly weathered zone the rock is anticipated to exhibit blocky and seamy to intact behavior.

The Glacial Till that are present within the pipeline horizon are anticipated to exhibit firm to fast raveling behavior except where siltier horizons of the deposit are present at the face, in which case cohesive running conditions would be anticipated. The Alluvium Deposits that are present within the pipeline horizon are anticipated to exhibit firm to fast raveling behavior except where siltier horizons of the deposit are present at the face, in which case cohesive running conditions would be anticipated.

7.3.3 MH217-7 to Sta. 16+65

The consolidation conduit between MH217-7 and Sta. 16+65 is located within the Tidewater property and is approximately 408 feet in length. Heading up-station, existing ground surface ranges from approximately El. 27 to El. 23 with a depth to invert ranging from about 18 to 25 feet.

Heading up-station from MH217-7, the subsurface conditions within the tunnel horizon are expected to consist of Alluvium and Glacial Deposits transitioning to a full face of Fill. The Fill consists of dense brown sand with varying amounts of gravel and silt and contains fragments of brick. The Alluvium is expected to consist of medium stiff dark gray clayey silt. The Glacial Deposits consist of dense, coarse to fine, gravel and sand and may include fragments of fractured rock. Groundwater levels are anticipated to be above the tunnel crown.

The Glacial Deposits that are present within the pipeline horizon are anticipated to exhibit firm to fast raveling behavior except where siltier horizons of the deposit are present at the face, in which case cohesive running conditions would be anticipated. The Fill materials that are present within the pipeline horizon are anticipated to exhibit fast raveling conditions.

Although trenchless construction of the consolidation conduit along this reach limits the exposure to the contaminants present in the soil and groundwater, the Tidewater cap system will be disturbed. In addition, the potential exists for encountering remnant foundations and other demolition debris. Refer to Section 8.4 for additional considerations related to the Tidewater property.

7.4 Line and Grade Control and Jacking Loads

Based on the subsurface conditions encountered in the test borings, special consideration relative to control of line and grade are not anticipated. The contract documents will include required submittals to be prepared by the contractor addressing line and grade control measures and contingency plans that describe the operational changes that will be made to make the necessary corrections to the alignment.

It is anticipated that jacking loads can be managed to acceptable levels through the continuous use of lubricants along the pipe exterior during jacking. During stoppages, temporary increases in startup jacking force loads may occur. Carefully monitored of the jacking force load is required during microtunneling as increases could be an indication of adverse ground behavior that may warrant 24/7 mining to prevent the pipe from locking up and not advancing.

7.5 Open Cut Reaches

Open cut methods will be used along the remaining reaches of the consolidation conduit as well as the new OF-217 outfall pipe where the depth of the required excavation is generally between about 6 to 18 feet and the existing utility conflicts are less restrictive. Refer to Figures 2 through 4, which indicate the soil units and groundwater conditions anticipated to be encountered along these reaches. Descriptions and engineering properties of the soil units are provided above in Section 4. Excavation will likely be accomplished using mechanical excavation equipment, such as an excavator or a clam shell bucket.

Excavation support will be selected and designed by the Contractor. Applicable excavation support systems include, but are not limited to, steel soldier piles and timber lagging with soldier piles set in predrilled-holes spaced from 6 to 10 feet on-center. Drill-holes should be backfilled with lean mix concrete to final excavation subgrade after each soldier pile is in-place. Above the excavation subgrade, the drill holes should be backfilled with excavatable flow fill to the existing site grade. The excavation support system should be internally braced with steel struts and walers. Bracing levels should be kept to a minimum to maximize efficiency.

As indicated on Figures 2 and 3, remnant foundations and features of the former gas and power plant structures, including concrete and brick foundations, tanks, piping, and other miscellaneous debris are anticipated to be encountered along some segments of the alignment within the Tidewater property. The use of trench boxes or slide rail systems for temporary support can be considered for locations where the excavation depth is about 20 feet or less. However, due to unknowns associated with man-made obstructions expected below grade, this may be prohibitive.

Refer to Section 8.5 for additional considerations related to the Tidewater property.

7.6 Foundation Support for Pipelines

Based on the results of the test borings completed for the Project, it is anticipated that dense Glacial Till or bedrock will be encountered at the planned invert elevations for the consolidation conduit. Along the outfall pipe from DS-217 to the outfall, Fill materials are anticipated at pipe invert and are assumed to have been placed to reclaim land along the previous river shoreline or as backfill following demolition of previously existing structures.

It is expected that the Glacial Till and bedrock will provide adequate foundation support and that special preparation or treatment of subgrade bearing surfaces will not be required. Crushed stone encapsulated in geotextile fabric can be placed over bedrock to provide bedding and even out irregular bedrock features. Settlement of the consolidation conduit founded in these materials is not anticipated if they are properly placed on undisturbed soils and adequately backfilled.

Where Fills are encountered along the alignments at the proposed pipe invert, it is recommended that the trench be over-excavated a minimum of two feet below normal design subgrade and backfilled with compacted sand and gravel, crushed stone, or screened gravel. A geotextile filter fabric should completely encapsulate the over-excavated section if crushed stone or screened gravel is used. Refer to Section 8.4 for additional considerations with regard to subgrade preparation and backfill.

8.0 Construction Considerations

8.1 General

The purpose of this section is to provide recommendations and comments on geotechnical aspects of the proposed construction. While it is not possible to foresee all geotechnical-related problems that may arise during construction, several potential issues suggested by site and subsurface conditions, proposed construction, and the results of geotechnical field and laboratory investigations and studies are discussed.

Prospective contractors for this Project should evaluate potential construction issues based on their own knowledge and experiences with similar ground conditions in the area, taking into account their own proposed construction methods.

8.2 Working Space

The launching shafts for microtunneling operations were located where there is adequate working space on the surface to accommodate support equipment and for staging and material laydown. Typical microtunneling support surface area requirements need to accommodate the following:

Operator Control Room	Slurry Separation System
Shaft Crane	Crew Change Trailer
Pipe Storage	Lubrication System
Material and Parts Storage	Temporary Muck Storage
Generator and Backup Power Supply	Field Office

The Project is located in an urban area and restrictions on construction traffic routes and work hours around the sites may be imposed. The staging areas will be confined to areas identified on the contract drawings. As a general guide, a launching shaft staging area requires about 7,000 square feet (sq. ft.) and a receiving shaft staging area requires about 4,000 sq. ft. It is anticipated that the Tidewater property will be used for contractor staging and for ingress/egress of construction vehicles. Final determination of the launching shaft sites should account for the stockpiling of spoils prior to off-site disposal. Traffic management plans should be developed with the goal of limiting impact to local traffic, residents, and businesses, as well cyclists and pedestrians.

8.3 Groundwater Control

The choice of groundwater control will be dependent on the specific temporary excavation support systems selected and the observed groundwater conditions. Groundwater control can be assumed to be by pumping from open sumps in the bottom of the excavations. This ensures maintenance of a suitable subgrade to work from.

8.4 Subgrade Preparation

Bedding and backfill requirements for the new structures and pipelines may vary depending upon the method of construction. If the structures are precast, the bedding should consist of a material recommended by the precast manufacturer. Typically, compacted fill behind and beneath new structures and pipelines consist of bank-run sand and gravel, crushed stone, or screened gravel free of organic material, snow, ice, or other unsuitable materials. Other materials could be acceptable for bedding and backfill and should be evaluated on a case-by-case basis if proposed by the contractor. Backfill above the bedding should consist of suitable material excavated from the shafts or trenches or off-site borrow.

Backfill should be placed in lift thicknesses not exceeding 12-inches loose measure and compacted to at least 95% of the maximum dry density. In confined areas, hand guided equipment such as a large vibratory plate compactor should be used, and the loose lift thickness should not exceed 6-inches. Cobbles or boulders having a size exceeding 2/3 of the loose lift thickness should be removed prior to compaction.

The subgrade surface should be firm, dry, and undisturbed to provide for adequate support. Until the subgrade is protected, incidental traffic of workers and equipment across the final subgrade should be prohibited. Disturbed subgrade surfaces should be excavated to undisturbed soils. In addition, a geotextile filter fabric should be used to provide a separation barrier between bedding materials and the natural subgrade soils. The filter fabric used should be fully encapsulating, extending up the sides of the excavation and over the top of the bedding.

Precautions should be taken if work takes place during any time temperatures fall below freezing. Soil bearing surfaces below new structure foundations or pipelines must be protected against freezing.

8.5 Special Consideration on the Tidewater Property

As indicated previously, about 1411 feet of the consolidation conduit will be installed within the National Grid properties, located east of Taft Street and north of Tidewater Street. The site is a former MGP that is known to have soil and groundwater contamination associated with its former use and is listed as a “state site” under Rhode Island Department of Environmental Managements (RIDEM’s) Remediation Regulations (RIDEM Case No. 95-022). To produce coal gas at the plant, coal was used as the principal fuel for operations from the 1880s until 1954 followed by oil and propane from 1954 until the late 1960s.

The site is secured with a locked perimeter chain-link fence and is generally vacant except for an active natural gas regulating station, a former power plant currently used as an active switching station, and an electric substation.

National Grid is currently progressing forward with two projects at the site, 1) a plan to construct a cap over the site as part of their sitewide remedy design, and 2) construction of a new substation. Following completion of the two National Grid projects, it is understood that part of the site will be leased to a private developer as part of the potential development for the area.

The plan to construct the cap is expected to be completed in advance of this Project. Therefore, further coordination will be required as these projects advance, specifically with respect to cap disruption and subsequent repair as well as closure phasing and provisions to allow construction of these Project facilities. In addition, at the request of National Grid, no environmental investigations were conducted on the site as part of this Project. It is anticipated that the Project contract documents will include requirements jointly developed with National Grid for work related to soil management, dewatering treatment, cap reconstruction, and material disposal for work performed on this site.

8.5.1 Existing Foundations

As indicated previously, remnant foundations and features of the former gas and power plant structures, including concrete and brick foundations, tanks, piping and other miscellaneous debris are anticipated to be encountered along some segments of the alignment within the Tidewater property. Provisions will be made within the contract for the management and disposal of these materials, as necessary. Refer to Figures 2 and 3 for locations of known remnant tank foundations.

At the transition from microtunnel to open-cut construction, the depth of construction will range between 10 and 20 feet. These depths carry through the 365 feet section of pipeline between the microtunnel/open-cut interface and the tie-in point with the existing CSO pipe to the west. It is anticipated that foundations for the former Meter Room and Relief Holder No. 4 will be encountered during this stretch, as well as any potential subsurface debris related thereto.

8.5.2 Management of Contaminated Soils and Groundwater

Per National Grid's directive, no environmental investigations were conducted on the Tidewater property as part of this Project. Although environmental investigations were not completed, evidence of contamination was observed during the geotechnical investigation program. Oil sheen was noted on some of the split spoon samples along with elevated PID readings.

Based on review of investigations previously completed by National Grid, historic releases on the Tidewater property include spills, overflows and releases of oils, tars, and process residuals. Review of the information indicates that soil and groundwater contamination can be expected at the site.

Special considerations relative to stockpiling and testing excavated materials and groundwater, handling and disposal of excavated materials and groundwater, treatment of groundwater prior to discharge, and environmental documentation will need to meet the applicable federal, state, and local regulations. In addition, to reduce the potential migration of contaminants from the site, any segments of pipe installed below the groundwater table must be constructed watertight with gaskets specifically designed for the anticipated contaminants. The impact to pipe joints can be eliminated with a two-pass installation where the carrier pipe is installed in a casing that isolates the pipe from any external contamination, but this method has a significant cost increase over a one-pass microtunneling method. The current proposal is to line the pipe upon completion of the one-pass microtunnel.

Additional information with respect to environmental considerations is provided in the Project Environmental Data Report.

8.6 Protection of Structures

As indicated on Figures 2 through 4, utilities exist along the Project alignment. Some utilities are planned to be relocated and discussions are ongoing with the utility owners. Utilities not being relocated prior to excavation will need to be supported in-place during construction.

On the Tidewater property, utility information is limited. National Grid has provided a plan that depicts existing utilities, but they were careful to note that the information was schematic. Further investigation will be required. Relocation of utilities may be required for the installation of MH217-8.

Final design should include additional work to more accurately evaluate that the construction does not affect the structural integrity of the existing structures and utilities within the predicted zone of influence from tunneling and near surface structure construction. In cases where risk of damage is unacceptable, mitigation measures such as ground modification and adjustments to mining methods may be specified.

8.7 Geotechnical Instrumentation

A geotechnical instrumentation program for the near surface structure sites and along the tunneled alignments is recommended to determine if ground movements are as anticipated. If unanticipated ground movements are observed,, the data can be used to assist in evaluation of required modified construction methods to reduce the ground movement to acceptable levels. Presented below is a summary of general recommendations:

- Deformation monitoring points
- Inclinometers installed adjacent to the shaft walls to measure the horizontal deflections of the wall and soil;
- Structure monitoring points s should be installed on all above ground structures within the construction zone of influence;
- Groundwater observation wells should be installed along reaches where dewatering is implemented to monitor the groundwater levels during construction;
- Seismographs to monitor ground vibrations adjacent to existing structures and utilities.

8.8 Construction Monitoring

It is recommended that an experienced geotechnical engineer or technician qualified by training and experience be present during pertinent construction phases, such as microtunneling, excavation, and preparation of near surface structure and open cut pipeline foundation subgrades. The general purpose of the on-site monitoring program is to provide accurate documentation of construction activities. This will allow an overall perspective of the construction progress and verify compliance with the Project Documents and the Building Code. It is recommended that a representative be on site to:

- Observe trenchless construction.
- Observe and test, if necessary, the exposed soils at subgrade levels to confirm that in-situ conditions are consistent with those predicted for design, and to observe that the natural soils are not disturbed by construction activities.
- Observe and document the installation of the foundation elements.

In order to clearly document potential changed conditions claims, a qualified field representative should prepare accurate day-to-day documentation of construction conditions and the work performed by the contractor. This is particularly important during tunneling, excavation for near surface structures, and foundation construction. This will enable the design team to observe compliance with the design concepts and specifications, help resolve construction problems, and to facilitate design changes in the event that subsurface conditions differ from those anticipated prior to the start of construction.

8.9 Recommendations for Additional Investigations

The purpose of this section is to provide general recommendations for additional subsurface investigations for the Project. The recommendations are based on the results and findings of the subsurface investigation program regarding geotechnical issues of importance to the Project.

Recommendations are as follows:

- A minimum of one additional test boring should be performed along the microtunnel alignment between MH217-5 and MH217-6. The additional test boring will be used to mitigate risk by helping to define the top of bedrock surface as well as the transition from soft ground tunneling to rock tunneling. Collected data will assist in the cutterhead design of the MTBM.
- One test boring each at the launching/receiving shaft at MH217-7 and MH 217-6. A groundwater monitoring well should also be installed in the completed borehole at MH 217-7. Obtained information will assist with design and construction planning and costing of the secant pile wall

shaft which will be keyed into bedrock to provide groundwater cut-off. Collected data will also be used to evaluate ground conditions as they relate to the potential of construction related vibrations.

- Sampling intervals for the additional borings should be consistent with those used for this phase of the Project.
- Supplemental laboratory soil and rock testing. With respect to laboratory rock testing, specific emphasis should be placed on determination of strength and the abrasiveness of rock for use in estimating MTBM cutterhead wear.

9.0 References

Chute, N.E. 1949. Surficial Geology of the Pawtucket Quadrangle, Rhode Island-Massachusetts, US Geological Survey.

Denny, C. 1982. Geomorphology of New England. U.S. Geological Survey Professional Paper 1208. Washington, D.C.: U.S. Govt. Printing Office.

Deere, D. U., and D. W. Deere. 1988. The Rock Quality Designation (RQD) Index in Practice. In Rock Classification Systems for Engineering Purposes. Edited by L. Kirkaldie. Philadelphia: American Society for Testing and Materials.

Frimpter, M. H., and A. Maevsky. 1979. Geohydrologic impacts of coal development in the Narragansett Basin, Massachusetts and Rhode Island. Geological Survey Water-Supply Paper 2062. Washington, D.C.: U.S. Govt. Printing Office.

GZA GeoEnvironmental Inc., report entitled “Site Investigation Data Report, Former Tidewater MGP and Power Plant Site, Pawtucket, Rhode Island, RIDEM Case No. 95-022”, dated January 2011.

GZA GeoEnvironmental, Inc., report entitled “Remedial Action Work Plan, National Grid, Former Tidewater Facility, 200 Taft Street, Pawtucket, Rhode Island”, dated June 2018.

GZA GeoEnvironmental, Inc., report entitled “Former Tidewater Facility, Pawtucket, Rhode Island, Sitewide Remedy Design, Permit Set, dated August 2019.

Haley & Aldrich report entitled “Geotechnical Data Report – Section 1; Main Spine and Seekonk Tunnels and Shafts, Vol. IV of IV of the Geotechnical Preliminary Design Report, Phase IB – Preliminary Design; CSO Control Facilities Program; Providence, Rhode Island, dated 1995.

Halberg, H. N., C. E. Knox, and F. H. Pauszek. 1961. Water resources of the Providence area, Rhode Island. Water resources of industrial areas. Geological Survey Water-Supply Paper 1499-A. Washington, D.C.: U.S. Govt. Printing Office.

Heuer, Ronald E. 1974, “Important Ground Parameters in Soft Ground Tunneling”, Subsurface Explorations for Underground Excavation and Heavy Construction, ASCE Specialty conference, pp. 41-55.

Quinn, A. W. 1959. Bedrock Geology of the Providence Quadrangle, Rhode Island, U.S. Geological Survey.

Quinn, A.W., Ray,R.G., and Seymour,W.L. 1949, Bedrock Geology of the Pawtucket Quadrangle, Rhode Island-Massachusetts. U.S. Geological Survey.

Skehan, J. W., N. Rast, and S. Mosher. 1986. Paleoenvironmental and tectonic controls of sedimentation in coal-forming basins of southeastern New England. In Paleoenvironmental and tectonic controls in coal-forming basins of the United States. GSA Special Paper 210. Ed. P. C. Lyons and C. L. Rice; p. 9-30. Boulder, Colorado: Geological Society of America.

Smith, J. H. 1956. Surficial Geology of the Providence Quadrangle, Rhode Island, US Geological Survey.

Stantec and Pare Corporation, report entitled “NBC CSO Phase IIIA Contract No. 308.01 C, Request for Proposal, Appendix C, Geotechnical Data Report”, dated December 23, 2019.

State of Rhode Island and Providence Plantations, Blackstone Valley Sewer District Commission, Taft St. – Pleasant St. Branch Interceptor, Section B, Contract 18, prepared by Metcalf & Eddy Engineers, dated 1950.

State of Rhode Island, Department of Public Works, Division of Roads and Bridges, Plan, Profile and Sections of Proposed State Highway, Division St. Project, Contract Three, Rhode Island FA Project No.1-01(11), Contract No. 5737, dated 1957.

State of Rhode Island, Department of Transportation, Plans, Profiles, and Section of Proposed Bridge Replacement, Pawtucket Bridge No. 550, I-95 Over the Seekonk River, Volume 3 Bridge Plans, Rhode Island Contract No. 2010-CB-004, FA Project Nos.BRO-0550(003), IM-0550(004), IMG-0550(005), prepared by Commonwealth Engineers & Consultants Inc., dated April 2010.

Terzaghi, K.1946. Rock Defects and Loads on Tunnel Supports. Edited by Proctor and White. In Rock Tunneling with Steel Supports. Youngstown, Ohio: Commercial Shearing and Stamping Company.

FIGURES

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

Narragansett Bay Commission

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

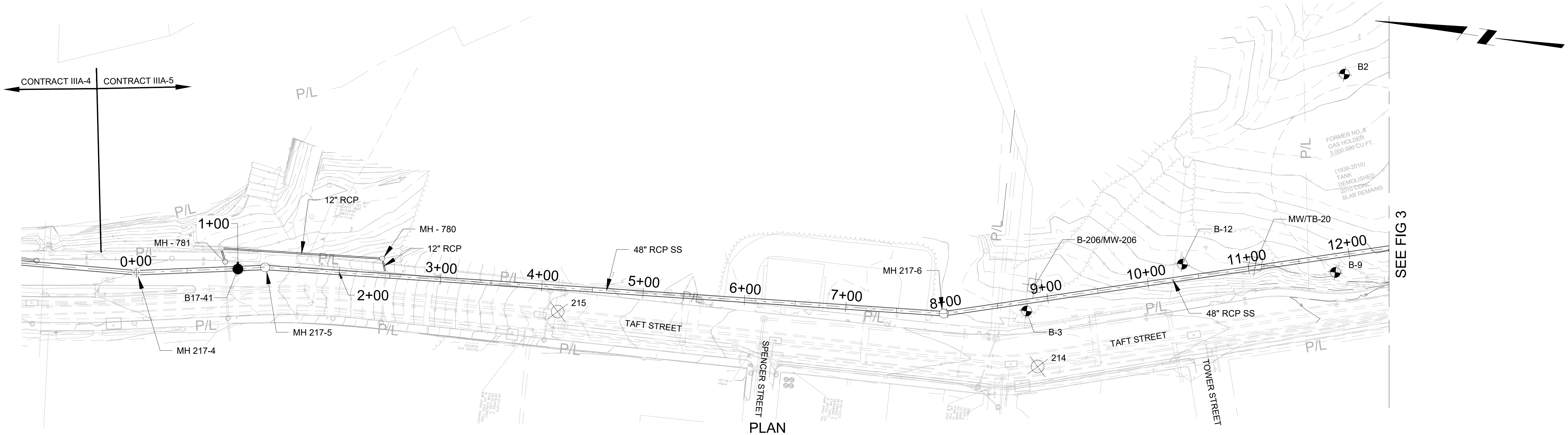
Stantec

PARE

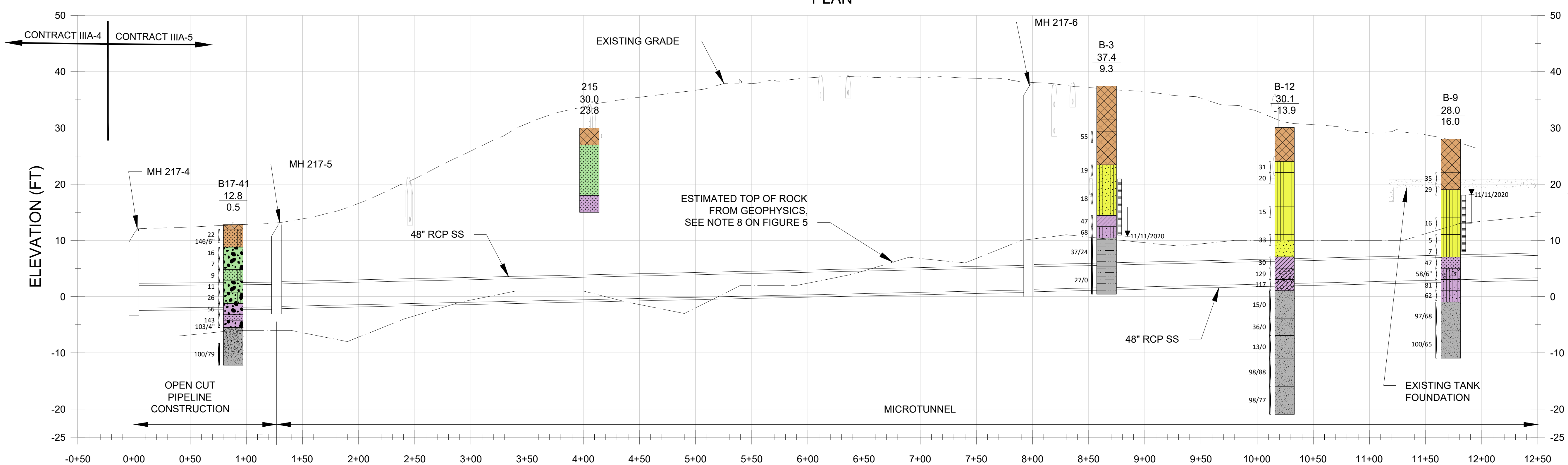
GEOTECHNICAL DESIGN SUMMARY REPORT
CONSOLIDATION CONDUIT IIIA-5
PROJECT LOCUS
PAWTUCKET, RHODE ISLAND

DATE
APRIL 2021

FIGURE
1



PLAN



PROFILE

NOTE:

SEE FIGURE 5 FOR GENERAL LEGEND AND NOTES.

VERT SCALE IN FEET
SCALE 1" = 20'

HORZ SCALE IN FEET
SCALE 1" = 100'

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

Stantec

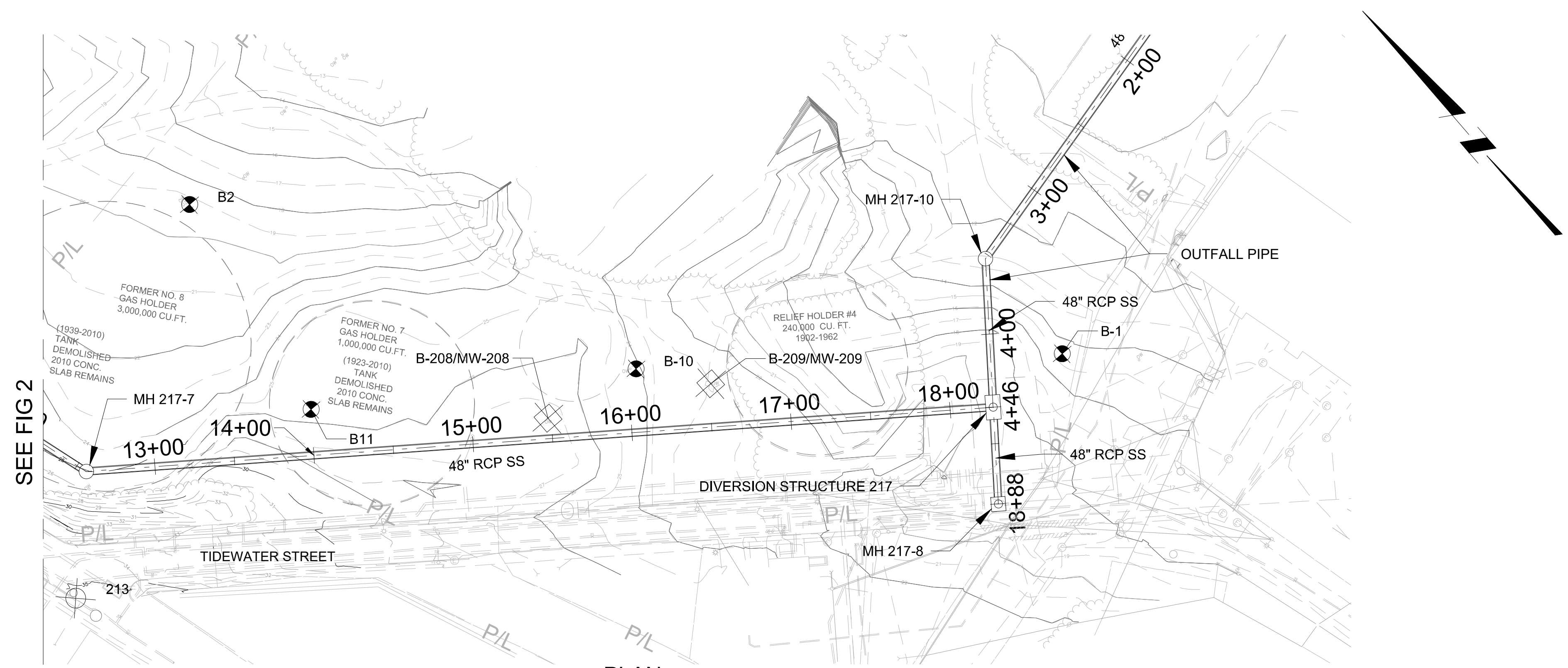
PARE

GEOTECHNICAL DESIGN SUMMARY REPORT

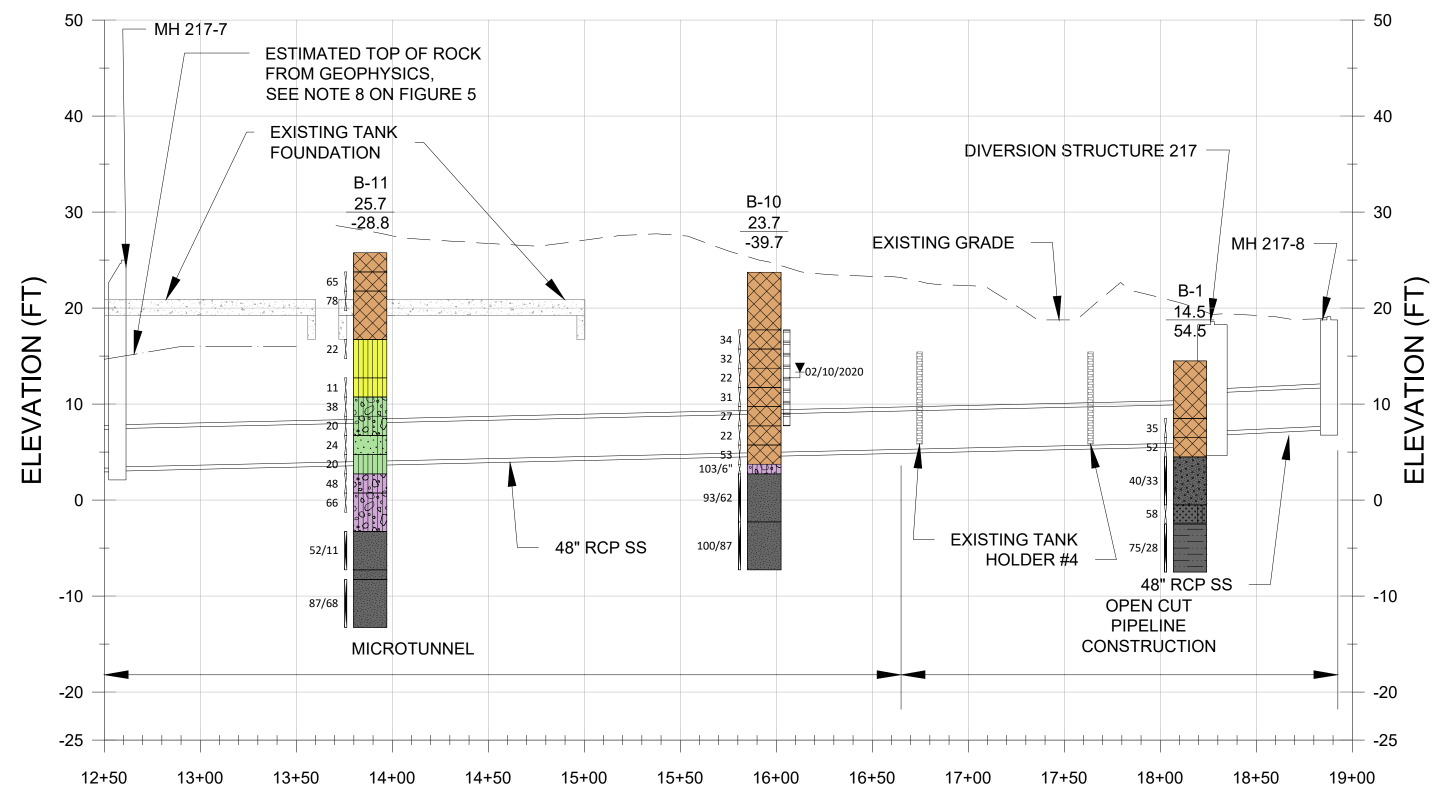
CONSOLIDATION CONDUIT IIIA-5
GEOTECHNICAL PLAN AND PROFILE STA 0+00 TO STA 12+50

DATE
APRIL 2021

FIGURE
2



PLAN



PROFILE

VERT SCALE IN FEET SCALE 1" = 20'

HORZ SCALE IN FEET SCALE 1" = 100'

NOTE:

SEE FIGURE 5 FOR GENERAL LEGEND AND NOTES.

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

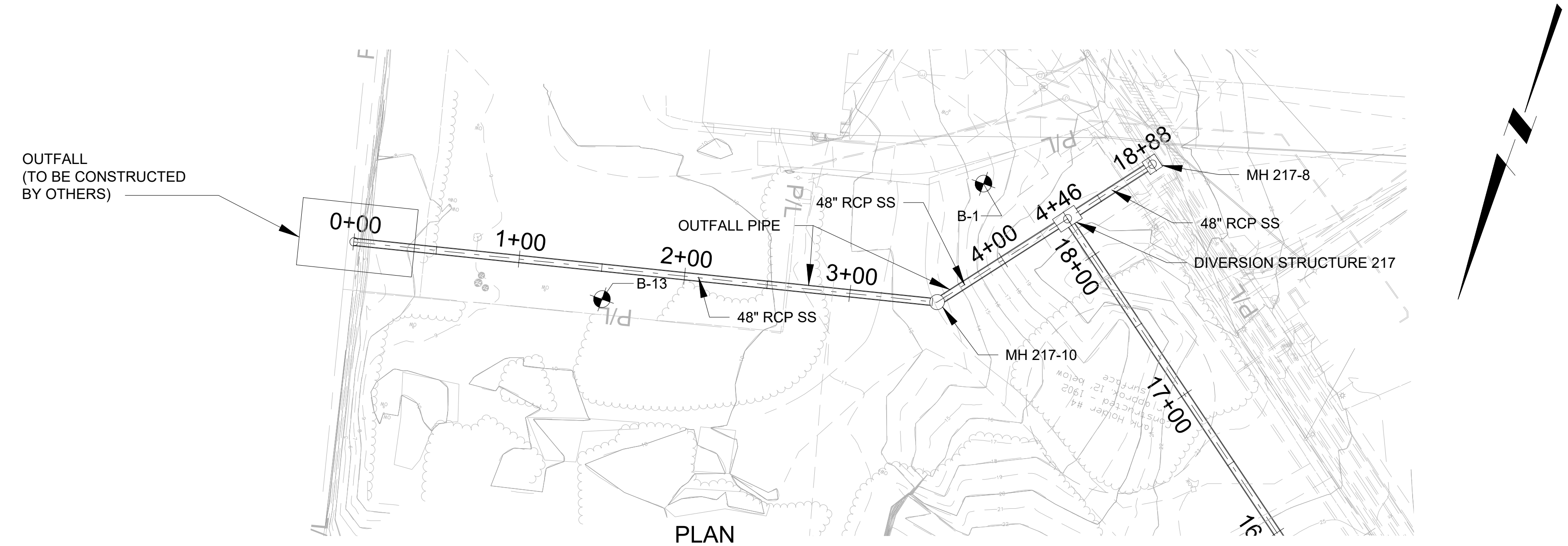
Stantec PARE

GEOTECHNICAL DESIGN SUMMARY REPORT

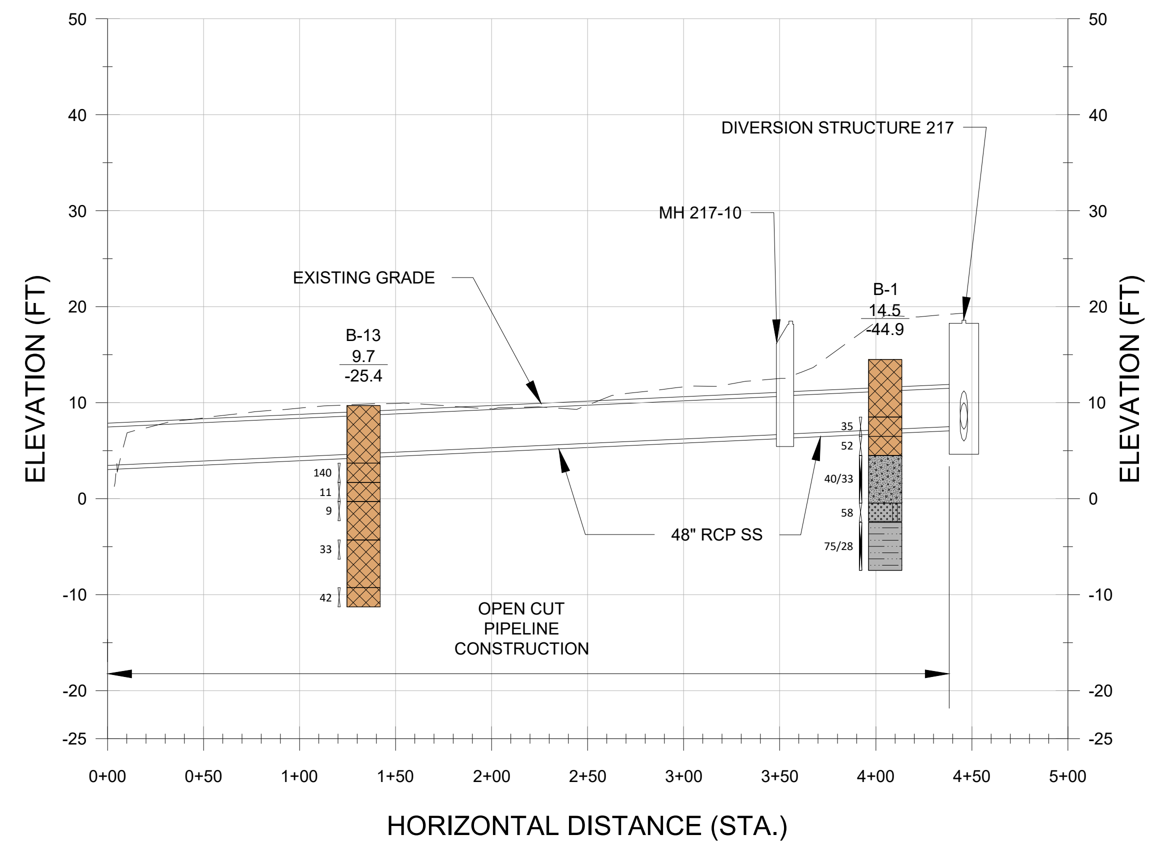
CONSOLIDATION CONDUIT IIIA-5
GEOTECHNICAL PLAN AND PROFILE STA 12+50 TO STA 19+00

DATE
APRIL 2021

FIGURE
3



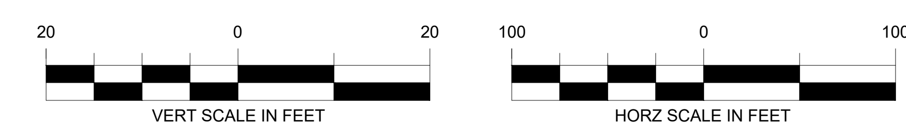
PLAN



PROFILE

NOTE:

SEE FIGURE 5 FOR GENERAL LEGEND AND NOTES.



PROJECT 5980

McMILLEN JACOBS ASSOCIATES

Narragansett Bay Commission

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

Stantec

PARE

GEOTECHNICAL DESIGN SUMMARY REPORT

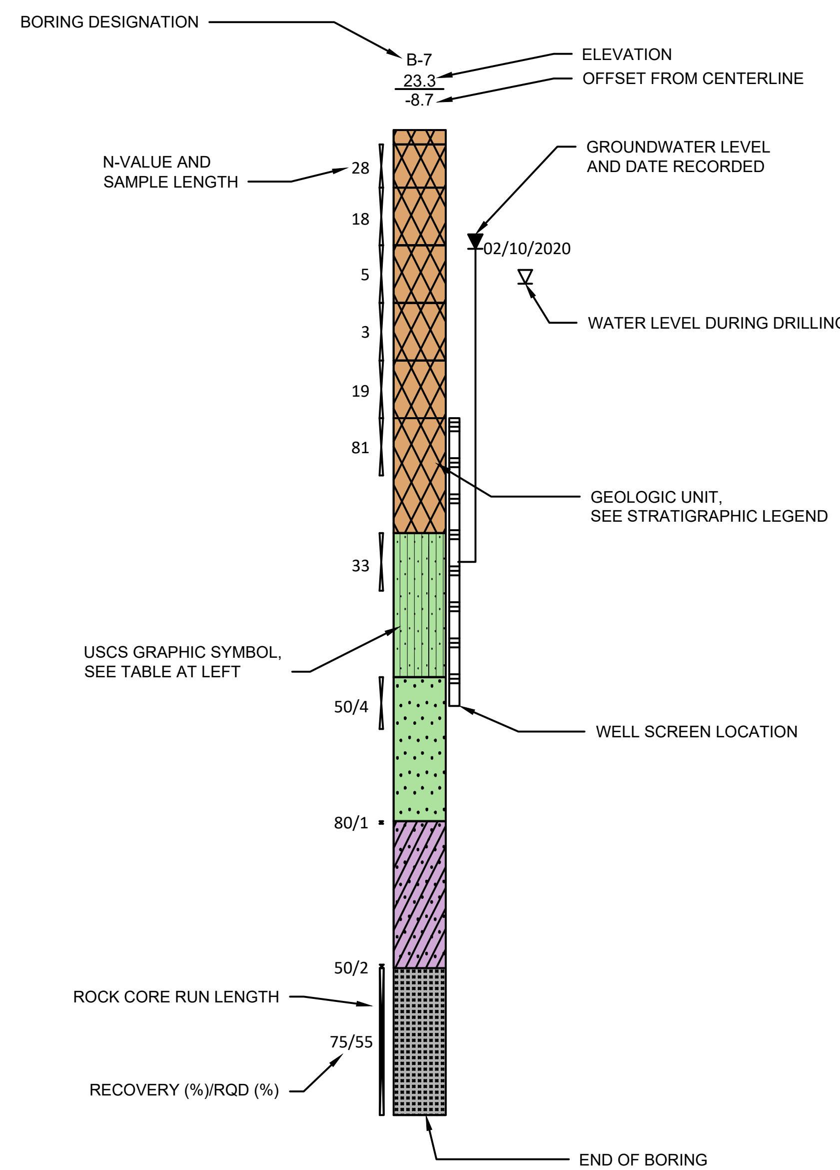
CONSOLIDATION CONDUIT IIIA-5
GEOTECHNICAL PLAN AND PROFILE STA 0+00 TO STA 4+47

DATE
MARCH 2021

FIGURE
4

UNIFIED SOIL CLASSIFICATION SYSTEM (Based on ASTM D2488 & D2487)				
MAJOR DIVISIONS			GROUP/GRAPHIC SYMBOL	TYPICAL DESCRIPTION
COARSE-GRAINED SOILS (50% or more retained on No. 200 sieve)	GRAVELS (more than 50% retained on No. 4 sieve)	CLEAN GRAVELS (less than 5% fines)	GW	WELL-GRADED GRAVEL
			GP	POORLY GRADED GRAVEL
		GRAVELS (with 5 to 12% fines)	GW-GM	WELL-GRADED GRAVEL WITH SILT
			GW-GC	WELL-GRADED GRAVEL WITH CLAY
			GP-GM	POORLY GRADED GRAVEL WITH SILT
			GP-GC	POORLY GRADED GRAVEL WITH CLAY
		GRAVELS WITH FINES (more than 12% fines)	GM	SILTY GRAVEL
			GC	CLAYEY GRAVEL
			GC-GM	SILTY CLAYEY GRAVEL
	SANDS (less than 50% retained on No. 4 sieve)	CLEAN SANDS (less than 5% fines)	SW	WELL-GRADED SAND
			SP	POORLY GRADED SAND
		SANDS (with 5 to 12% fines)	SW-SM	WELL-GRADED SAND WITH SILT
			SW-SC	WELL-GRADED SAND WITH CLAY
			SP-SM	POORLY GRADED SAND WITH SILT
			SP-SC	POORLY GRADED SAND WITH CLAY
		SANDS WITH FINES (more than 12% fines)	SM	SILTY SAND
			SC	CLAYEY SAND
			SC-SM	CLAYEY SAND WITH SILT
FINE-GRAINED SOILS (50% or more passes No. 200 sieve)	SILTS & CLAYS (liquid limit less than 50)	INORGANIC	ML	SILT
			CL	LEAN CLAY
			CL-ML	CLAY WITH SILT
		ORGANIC	OL	LOW PLASTICTIY ORGANIC CLAY
	SILTS & CLAYS (liquid limit greater than 50)	INORGANIC	MH	ELASTIC SILT
			CH	FAT CLAY
		ORGANIC	OH	HIGH PLASTICTIY ORGANIC CLAY
HIGHLY ORGANIC SOILS	PRIMARILY ORGANIC MATTER		PT	PEAT

BORING LEGEND:



NOTES:

1. BASE PLAN USED FOR THIS FIGURE WAS A CAD-GENERATED DRAWING TITLED "PAWT_SITE_PLAN_&_PROFILE_IIIA-5_ALT3 " PREPARED BY BETA GROUP, INC. AND OBTAINED ON 2/24/2020 BY MCMILLEN JACOBS ASSOCIATES VIA PROJECTWISE SHAREPOINT.
2. ALL ELEVATIONS ARE IN FEET AND REFER TO THE NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NVGD29).
3. NORTH ARROW ALIGNED WITH GRID NORTH, RHODE ISLAND STATE PLANE COORDINATE SYSTEM, NORTH AMERICAN DATUM OF 1983 (NAD83).
4. POSITIVE OFFSET = RIGHT OF CENTERLINE, LOOKING UP STATION.
5. NEGATIVE OFFSET = LEFT OF CENTERLINE, LOOKING UP STATION.
6. THE SOIL STRATIGRAPHY SHOWN IS GENERALIZED INTERPRETATION BASED ON THE SAMPLES COLLECTED WITHIN EACH BORING. NO ATTEMPT WAS MADE TO INTERPOLATE SOIL STRATIGRAPHY BETWEEN BORINGS AS THE DISTRIBUTION OF MATERIALS IS VARIABLE AND NON-UNIFORM IN BOTH VERTICAL AND HORIZONTAL DIRECTIONS.
7. AS DRILLED LOCATIONS OF THE B-SERIES TEST BORINGS CONDUCTED IN 2019 AND 2020 WERE SURVEYED BY BRYANT AND ASSOCIATES, INC. IN NOVEMBER 2019 AND FEBRUARY 2020 AND PROVIDED TO MCMILLEN JACOBS ASSOCIATES BY BETA GROUP, INC.
8. GEOPHYSICS INFORMATION OBTAINED FROM THE NBC PHASE IIIA, PAWTUCKET TUNNEL GDR, PREPARED BY STANTEC/PARE, DATED DECEMBER 23, 2019. ACTUAL GEOPHYSICS STATIONING AND ESTIMATED TOP OF ROCK OBTAINED FROM APPENDIX C, LAND GEOPHYSICS SURVEY, SEISMIC REFRACTION SURVEY FOR THE NARRAGANSETT BAY COMMISSION, COMBINED SEWER OVERFLOW PROJECT, PAWTUCKET MAIN TUNNEL SECTION, WEST LINE SCAN, PLATES 1 AND 3, PREPARED BY HAGER-RICHTER GEOSCIENCE, INC., DATED NOVEMBER 2017.

STRATIGRAPHIC LEGEND:

COLOR	GEOLOGIC UNITS	GRAPHIC SYMBOL	DESCRIPTION
	FILL		SILTSTONE
	ALLUVIUM		SANDSTONE
	GLACIOFLUVIAL DEPOSITS		CONGLOMERATE
	GLACIAL TILL DEPOSITS		
	BEDROCK		

BORING SYMBOL KEY:

B-7	DESIGNATION AND LOCATION OF TEST BORING PERFORMED BY GEOLOGIC EARTH EXPLORATION, INC. DURING THE PERIODS 27 AUGUST THROUGH 18 SEPTEMBER 2019 AND 04 FEBRUARY THROUGH 12 FEBRUARY 2020 UNDER THE SUPERVISION OF MCMILLEN JACOBS ASSOCIATES.
BH-35	DESIGNATION AND LOCATION OF TEST BORING PERFORMED FOR THE PAWTUCKET BRIDGE AND PAWTUCKET BRIDGE REPLACEMENT PERFORMED IN 1955 AND 2010.
B17-39	DESIGNATION AND LOCATION OF TEST BORING PERFORMED BY NEW ENGLAND BORING CONTRACTORS, INC. PERFORMED BETWEEN 04 MAY 2018 AND 08 AUGUST 2019 UNDER THE SUPERVISION OF PARE CORPORATION.
221	DESIGNATION AND LOCATION OF TEST BORING PERFORMED FOR THE TAFT ST. - PLEASANT ST. BRANCH INTERCEPTOR SECTION B DATED 1950.
MW/TB-20	DESIGNATION AND LOCATION OF PREVIOUS TEST BORING CONDUCTED ON THE FORMER TIDEWATER FACILITY.

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

Narragansett Bay Commission

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER OVERFLOW PROGRAM

Stantec

PARE

GEOTECHNICAL DESIGN SUMMARY REPORT
CONSOLIDATION CONDUIT IIIA-5
GENERAL LEGEND AND NOTES FOR GEOTECHNICAL PLANS AND PROFILES

DATE
APRIL 2021

FIGURE
5

APPENDICES

APPENDIX A
Glossary of Technical Terminology

Glossary of Technical Terminology

Abrasivity: Characteristic of rock that contributes to the wearing down of tool or equipment surfaces that are in frictional contact with the rock.

Alluvium. Material, such as sand, silt, or clay, deposited on land by streams.

Aquifer: A saturated stratum, formation, or group of formations of soil or rock capable of storing and transmitting water in economically significant quantities to wells and/or springs.

Bedrock. The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

Boulders. Rock fragments larger than 2 feet (60 centimeters) in diameter.

Dip: The angle at which any planar feature is inclined from the horizontal; always perpendicular to strike.

Discontinuity: A general term for any naturally occurring fracture in a rock mass having zero to low tensile strength. It is the collective term for most types of joints (bedding joints, foliation joints) and faults.

Flood plain. A nearly level alluvial plain that borders a stream and is subject to flooding unless protected artificially.

Formation: The basic or fundamental rock stratigraphic unit in the local classification of rocks consisting of a body of rock generally characterized by some degree of internal lithologic homogeneity or distinctive lithologic features by mappability at the surface or near subsurface.

Fracture: Any break in rock along which no significant movement has occurred.

Glaciofluvial deposits. Material moved by glaciers and subsequently sorted and deposited by streams flowing from the melting ice. The deposits are stratified and occur as kames, eskers, deltas, and outwash plains.

Glacial Till: (Hardpan) Unsorted, nonstratified glacial drift consisting of clay, silt, sand, and boulders transported and deposited by glacial ice.

Gravel. Rounded or angular fragments of rock up to 3 inches (2 millimeters to 7.5 centimeters) in diameter. An individual piece is a pebble.

Ground behavior: Reactions or manifestations of the ground as it is excavated and exposed.

Groundwater. Water filling all the unblocked pores of underlying material below the water table.

Hydraulic Conductivity: The potential rate of groundwater flow through a unit area of saturated soil or rock under a unit hydraulic gradient, measured at right angles to the groundwater flow direction.

N-Value: Standard penetration resistance defined as the number of blows required to drive the standard 1-3/8 in. I.D. split-spoon sampler with a 140-lb. hammer falling freely through a distance of 30 in. for a distance of 12 in., typically counted from the 6^{th} to the 18^{th} inch that the sampler is driven

Outwash, glacial. Stratified sand and gravel produced by glaciers and carried, sorted, and deposited by glacial melting.

Physiographic Province: A region of which all parts are similar in geologic structure and climate and which has consequently had a unified geomorphic history.

Reach: A single continuous portion of tunnel alignment.

Relief. The elevations or inequalities of a land surface, considered collectively.

Rock: Naturally occurring, coherent aggregate of one of more minerals; for example, limestone composed mainly of the mineral calcite.

Rock fragments. Rock or mineral fragments having a diameter of 2 millimeters or more; for example, pebbles, cobbles, stones, and boulders,

Sand: As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter.

Silt: As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter As a soil textural class, soil that is 80 per cent or more silt and less than 12 percent clay.

Specific Yield: The ratio of the volume of water drained by gravity for a material to the volume of the material.

Stratigraphy: A branch of geology dealing with the classification, nomenclature, correlation, and interpretation of stratified rocks.

Weathering: The physical disintegration and chemical decomposition of rock in situ.

APPENDIX B
Subsurface Exploration Key

SOIL

Soil description on logs of subsurface explorations are based on Standard Penetration Test (SPT) results, visual-manual examination of exposed soil samples, and the results of laboratory tests on selected samples. The criteria, descriptive terms, and definitions are presented herein.
The natural soils are identified and described by visual-manual procedures (ASTM D2488) and in accordance with the United Soil Classification System (USCS) (ASTM D2487) as practiced by McMillen Jacobs Associates. Fill materials may not be classified by USCS criteria.

PENETRATION RESISTANCE

Standard penetration resistance (SPT) (ASTM D1586) - Number of blows required to drive a standard 2 in. O.D. split spoon sampler one foot with a 140 lb. weight falling 30 inches freely downward.

DENSITY / CONSISTENCY

Coarse - Grained Soils	
Apparent Density	SPT Resistance, N (BPF)
Very Loose	0 - 4
Loose	5 - 10
Medium Dense	11 - 30
Dense	31 - 50
Very Dense	> 50

Fine - Grained Soils	
Apparent Consistency	SPT Resistance, N (BPF)
Very Soft	0 - 2
Soft	2 - 4
Medium Stiff	4 - 8
Stiff	8 - 15
Very Stiff	15 - 30
Hard	>30

Notes: BPF = Blows Per Foot (uncorrected)

WOR = Weight of Rod

COLOR

Basic colors (black, brown, gray, olive, red, and yellow) and combinations (i.e. gray-brown, olive-brown, olive-gray, red-gray, red-brown, yellow-brown, and red-yellow). Modifiers such as light and dark may be used.

SUPPLEMENTAL SOIL DESCRIPTIONS AND STRUCTURE:

Laminating	- 0 to 1/16 in. thick (cohesive)
Parting	- 0 to 1/16 in. thick (granular)
Seam	- 1/16 to 1/2 in. thick
Layer	- 1/2 to 12 in. thick
Stratum	- > 12 in. thick
Pocket	- Small, erratic deposit less than 12 in. size
Lens	- Lenticular deposit larger than a pocket
Occasional	- One or less per 12 in. of thickness
Frequent	- More than one per 12 in. of thickness
Interbedded	- Alternating soil layers of differing composition
Varved	- Alternating thin seams of silt and clay
Mottled	- Variation of color

SAMPLE SYMBOLS

⧗	SPT Sample 2 in. OD
X	SPT Sample 3 in. OD
▮	Shelby Tube Sample

ADDITIONAL GRAPHIC DESCRIPTIONS

Asphalt

Fill

SOIL IDENTIFICATION AND DESCRIPTION

UNIFIED SOIL CLASSIFICATION SYSTEM (USCS Based on ASTM D2488 & D2487)					
MAJOR DIVISIONS			GROUP/SYMBOL		TYPICAL DESCRIPTION
COARSE-GRAINED SOILS (50% or more retained on No. 200 sieve)	GRAVELS (more than 50% retained on No. 4 sieve)	CLEAN GRAVELS (less than 5% fines)	GW		WELL-GRADED GRAVEL
			GP		POORLY GRADED GRAVEL
		GRAVELS (with 5 to 12% fines)	GW-GM		WELL-GRADED GRAVEL WITH SILT
			GW-GC		WELL-GRADED GRAVEL WITH CLAY
			GP-GM		POORLY GRADED GRAVEL WITH SILT
			GP-GC		POORLY GRADED GRAVEL WITH CLAY
		GRAVELS WITH FINES (more than 12% fines)	GM		SILTY GRAVEL
			GC		CLAYEY GRAVEL
	SANDS (less than 50% retained on No. 4 sieve)	CLEAN SANDS (less than 5% fines)	SW		WELL-GRADED SAND
			SP		POORLY GRADED SAND
		SANDS (with 5 to 12% fines)	SW-SM		WELL-GRADED SAND WITH SILT
			SW-SC		WELL-GRADED SAND WITH CLAY
			SP-SM		POORLY GRADED SAND WITH SILT
			SP-SC		POORLY GRADED SAND WITH CLAY
		SANDS WITH FINES (more than 12% fines)	SM		SILTY SAND
			SC		CLAYEY SAND
FINE-GRAINED SOILS (50% or more passes No. 200 sieve)	SILTS & CLAYS (liquid limit less than 50)	INORGANIC	ML		SILT
			CL		LEAN CLAY
		ORGANIC	OL		LOW PLASTICITY ORGANIC CLAY
	SILTS & CLAYS (liquid limit greater than 50)	INORGANIC	MH		ELASTIC SILT
			CH		FAT CLAY
		ORGANIC	OH		HIGH PLASTICITY ORGANIC CLAY
	SILT/CLAY (liquid limit between 12 and 25)	INORGANIC	CL-ML		CLAYEY SILT / SILTY CLAY
HIGHLY ORGANIC SOILS	PRIMARILY ORGANIC MATTER		PT		PEAT

Notes:

1. Dual symbols (symbols separated by a hyphen, e.g. SP-SM, slightly silty fine SAND) are used for soils between 5% and 12% fines or when liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart.

ROCK

Rock descriptions noted on logs of subsurface explorations are based on visual-manual examination of exposed rock outcrops and core samples. The criteria, descriptive terms and definitions used are as follows:

FIELD HARDNESS / STRENGTH

(after ISRM, 1978; CGS, 1985; Marinos & Hoek, 2001)

Extremely Strong	Cannot be scratched with a knife point or sharp pick; can only be chipped with repeated heavy hammer blows.
Very Strong	Cannot be scratched with a knife point or sharp pick; core breaks with repeated heavy hammer blows.
Strong	Can be scratched with a knife or pick; core breaks with heavy hammer blow.
Moderately Weak	Can be grooved 1/16 in. deep by knife or sharp pick; core breaks with light hammer blow.
Weak	Can be grooved easily with a knife or pick; can be scratched with fingernail; core breaks with light pressure.
Very Weak	Can be readily indented; grooved with fingernail or carved with a knife; core beaks with light pressure.

WEATHERING (after ISRM, 1978)

The action of organic and inorganic chemical and physical processes resulting in alteration of color, texture, and composition

Fresh	No visible sign of alteration, except perhaps slight discoloration on major discontinuity surfaces
Slight	Discoloration of rock material and discontinuity surfaces
Moderate	Less than half the rock material decomposed to soil. Some fresh rock; continuous "framework".
High	More than half the rock material decomposed and/or disintegrated to soil.
Completely	All rock material disintegrated to soil, but mass still intact
Residual Soil	All rock material converted to soil. Material has not been significantly transported.

COLOR:

Basic colors and combinations: gray, light gray, brown, red-brown

TEXTURE

Size, shape and arrangements of constituents

Aphantic	Individual grains invisible
Fine-grained	Grains barely visible to the unaided eye, up to 1/16 in. dia.
Medium Grained	Grains between 1/16 and 3/16 in. dia.
Coarse Grained	Grains between 3/16 and 1/4 in. dia.
Very Coarse Grained	Grains larger than 1/4 in. dia.

LITHOLOGY

Rock Classification and modifiers; accepted formation names

DISCONTINUITIES:

Type	Definition
Joint	A natural fracture along which no displacement has occurred. May occur in parallel groups called sets.
Shear	A natural fracture along which displacement has occurred. Surface may be slickensided or striated.
Fault	A natural fracture along which displacement has occurred. Usually lined with gouge and slickensides.
Shear or Fault Zone	Zone of fractured rock and gouge bordering the displacement plane.

ORIENTATION / ATTITUDE

Term	Angle (degrees)
Horizontal	0-5
Low Angle	6-35
Moderately Dipping	36-55
High Angle	56-85
Vertical	86-100

SPACING

Term	Inches
Extremely Close	<3/4
Very Close	3/4 - 2-1/2
Close	2-1/2 - 8
Moderate	8 - 24
Wide	24 - 80
Very Wide	80- 20 ft.
Extremely Wide	> 20 ft.

ROUGHNESS OF DISCONTINUITY SURFACE

Term	Abbreviation	Description
Very Rough	VR	Near-vertical steps and ridges
Rough	R	Ridges, side-steps, and asperities evident; abrasive to the touch
Slightly Rough	SR	Asperities can be felt.
Smooth	SM	Smooth to the touch
Slickensided	SL	Smooth glossy finish with visible striations

APERTURE/GAP

Term	MM
Very Tight	< .1
Tight	0.1 - 0.25
Partly Open	0.25 - 0.5
Open	0.5 - 2.5
Moderately Wide	2.5 - 10
Wide	> 10
Very Wide	10 - 100
Extremely Wide	100 - 1000
Cavernous	> 1000

INFILLING

Material	Abbreviation
Clay	CL
Silt	SI
Sand	SA
Serpentine	SE
Sulfide	SL
Calcite	CA
Pyrite	PY
Quartz	QZ
Chlorite	CH
Iron Oxide Staining	FE
Could not be determined	X

BEDDING

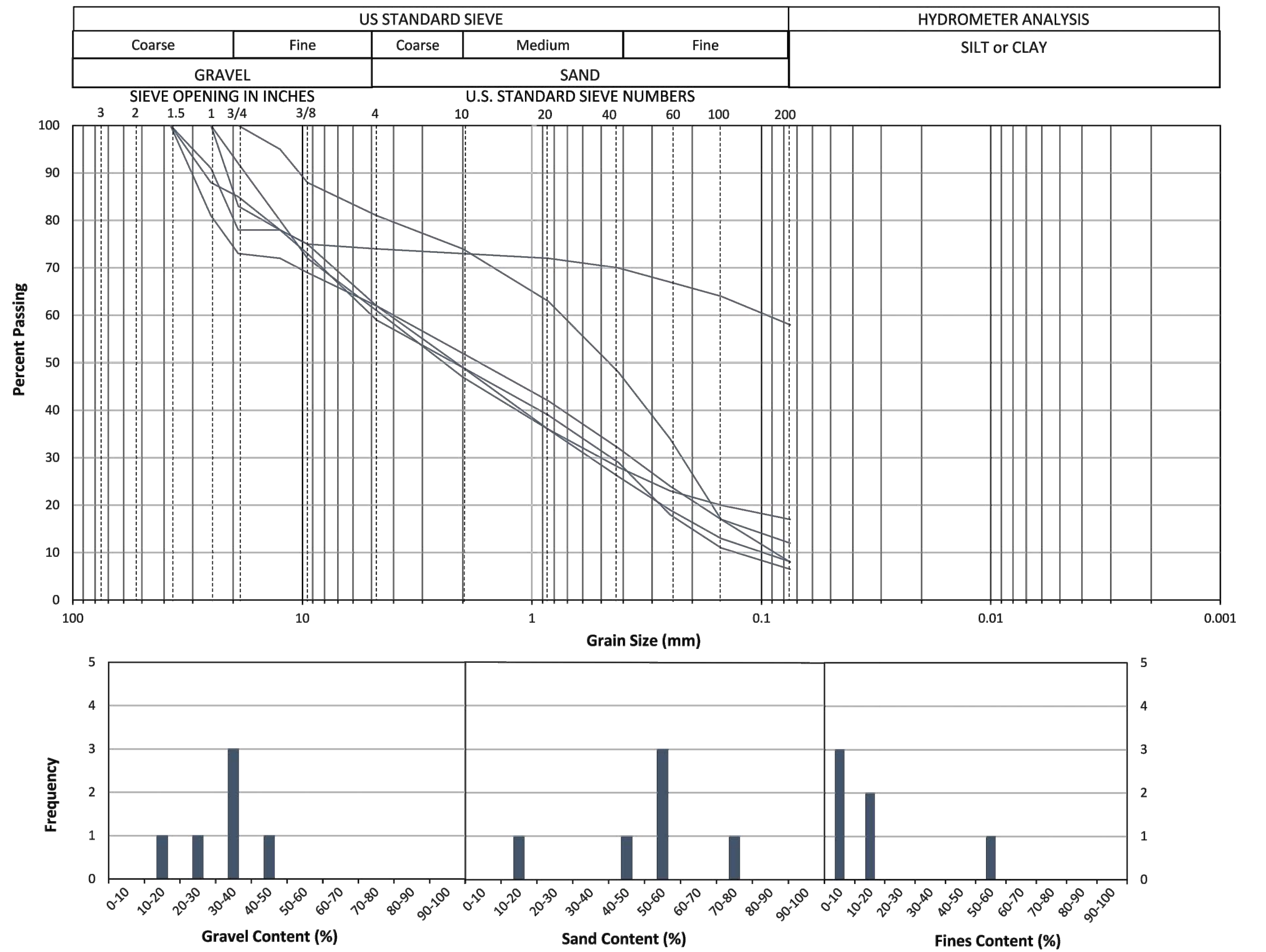
Term	Inches	Term	Inches
Very Thin	< 2.5	Thick	25-36
Thin	2.5 - 8	Very Thick	< 36
Medium	9 - 24		

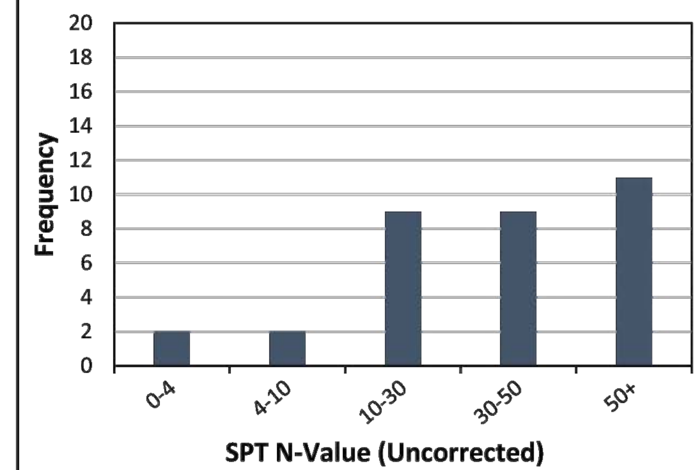
GENERAL NOTES:
1. Logs of subsurface exploration depict soil, rock and groundwater conditions only at the boring locations specified on the dates indicated. Subsurface conditions may vary at other locations and at other times.
2. Water levels, where noted on the logs, were measured at the times under the conditions indicated. During test boring drilling, these water levels could have been affected by the introduction of water in to the borehole, extraction of tools or other procedures and thus may not reflect actual groundwater levels at the test boring location. Groundwater level fluctuations may also occur as a results of variations in precipitation, temperature, season, tides, river stage, adjacent construction operations, construction dewatering systems, water supply well pumping, and other conditions.

McMILLEN JACOBS ASSOCIATES

SUBSURFACE EXPLORATION KEY

APPENDIX C
Soil Data Summaries
(IIIA-5 Data)





Notes:
1: Histogram prepared using data from the following borings: B-1, B-2, B-3, B-9, B-10, B-11, B-13, B17-41, B17-42, and MW-5/TB-14.

Notes:
1: Plot and histograms prepared using data from the following borings: B-1, B-2, B-10, B-13, B17-41, and B17-42.

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

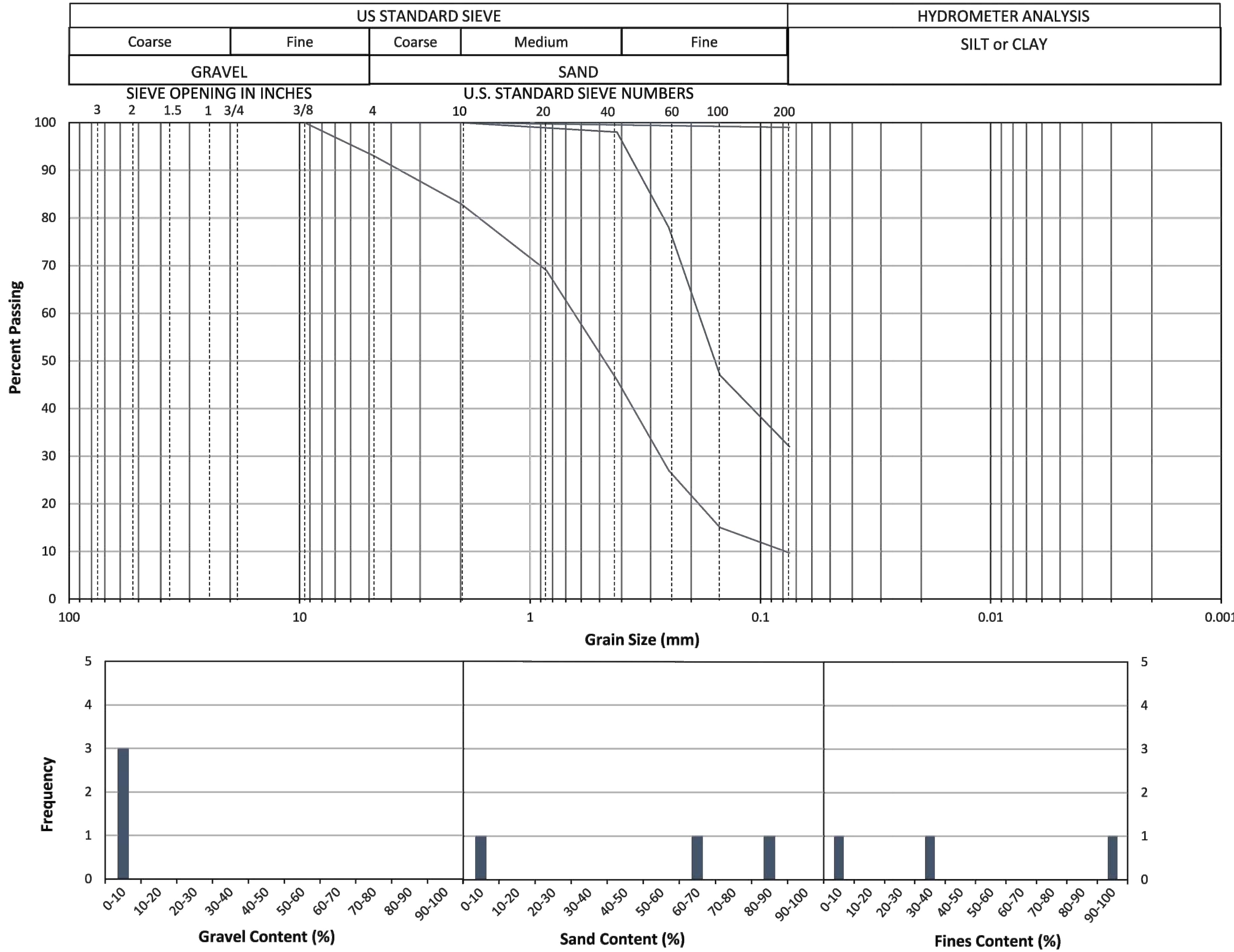
NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

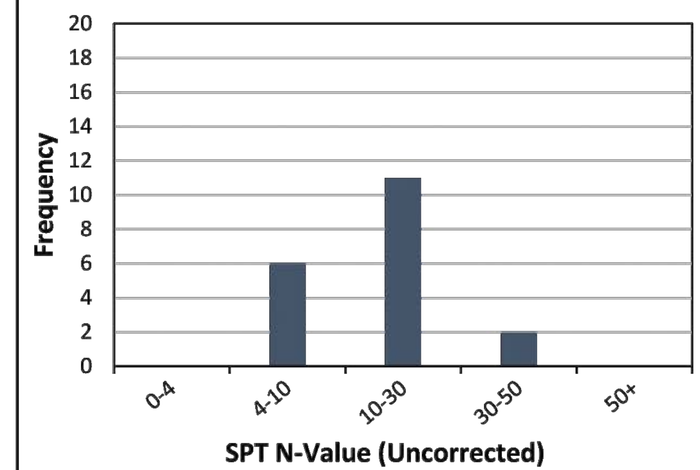
Stantec PARE

NBC PHASE III CSO PROGRAM
CONSOLIDATION CONDUIT IIIA-5
GEOTECHNICAL DESIGN SUMMARY REPORT
SOIL PROPERTY SUMMARY - FILL

DATE
FEBRUARY, 2021

FIGURE
C-1





Notes:

1: Histogram prepared using data from the following borings: B-2, B-3, B-9, B-11, B-12, and MW-5/TB-14.

Notes:

1: Plot and histograms prepared using data from the following borings: B-2, B-3, and B-9.

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

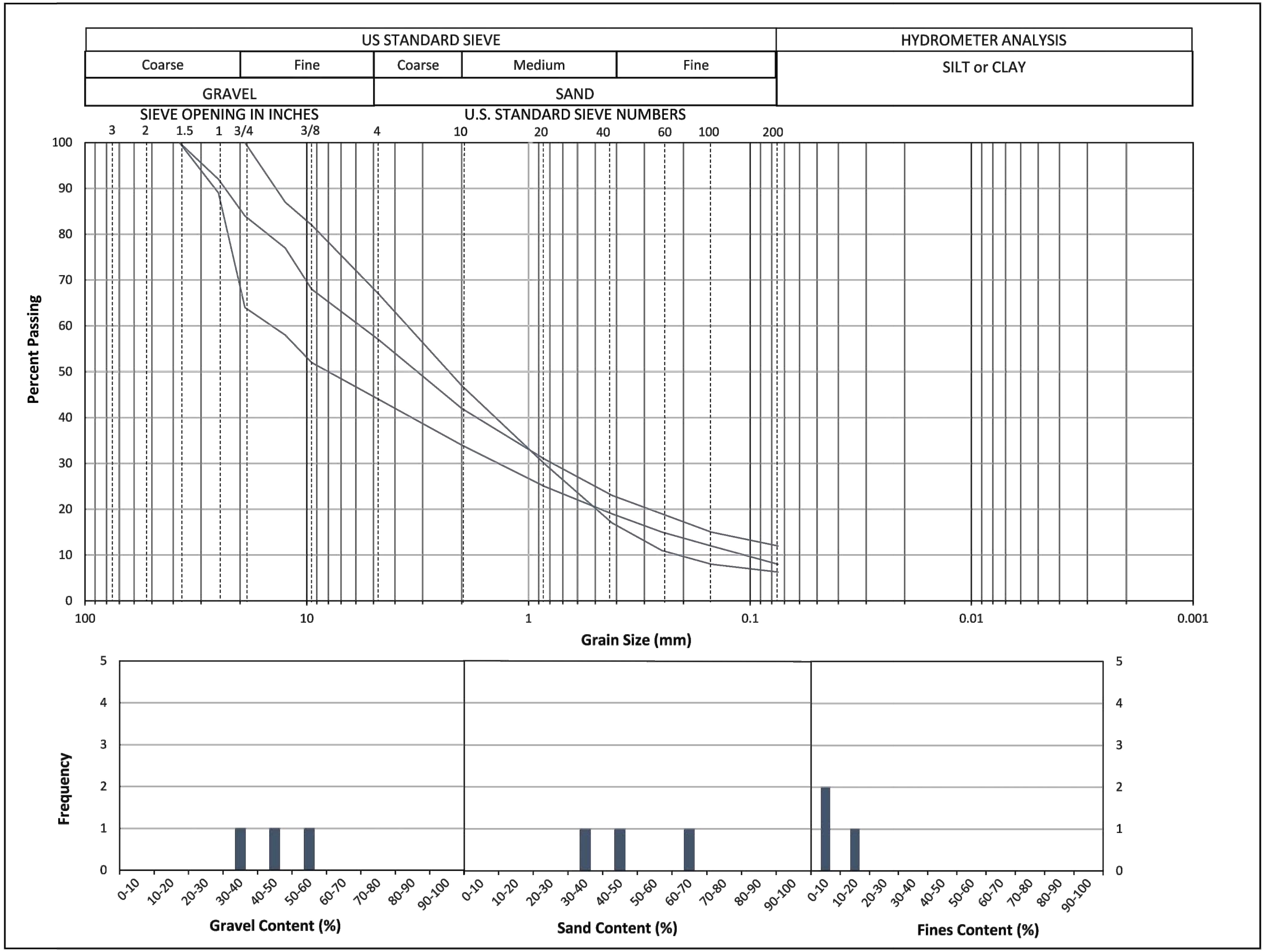
Stantec

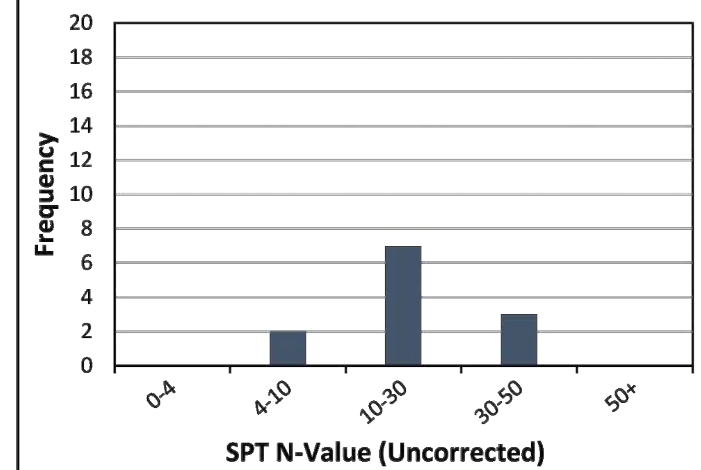
PARE

NBC PHASE III CSO PROGRAM
CONSOLIDATION CONDUIT IIIA-5
GEOTECHNICAL DESIGN SUMMARY REPORT
SOIL PROPERTY SUMMARY - ALLUVIUM

DATE
FEBRUARY, 2021

FIGURE
C-2





Notes:
1: Histogram prepared using data from the following borings: B-11, B17-41, MW/TB-20, and MW-5/TB-14.

Notes:
1: Plot and histograms prepared using data from the following borings: B-11 and B17-41.

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

Narragansett Bay Commission

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

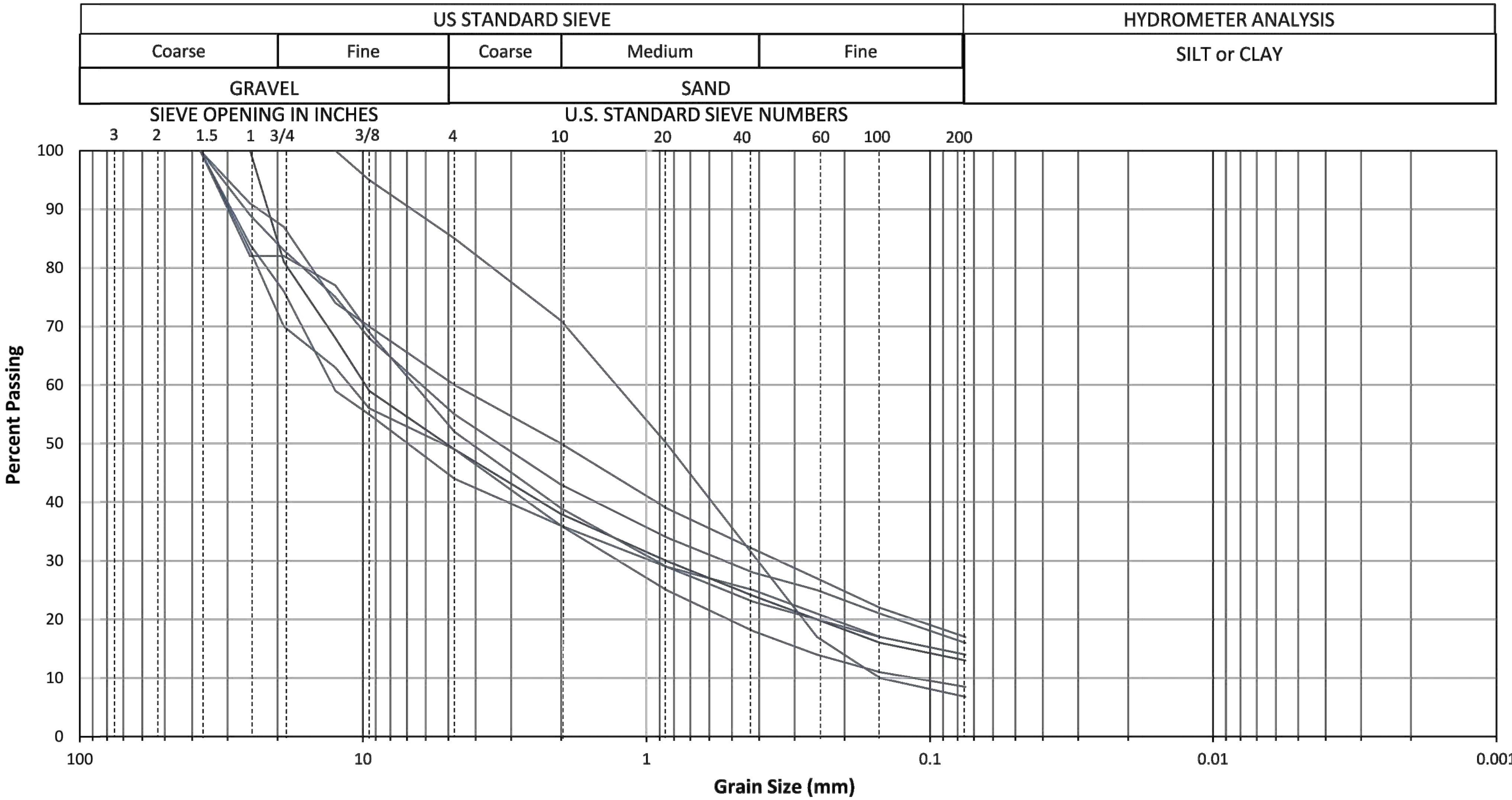
Stantec

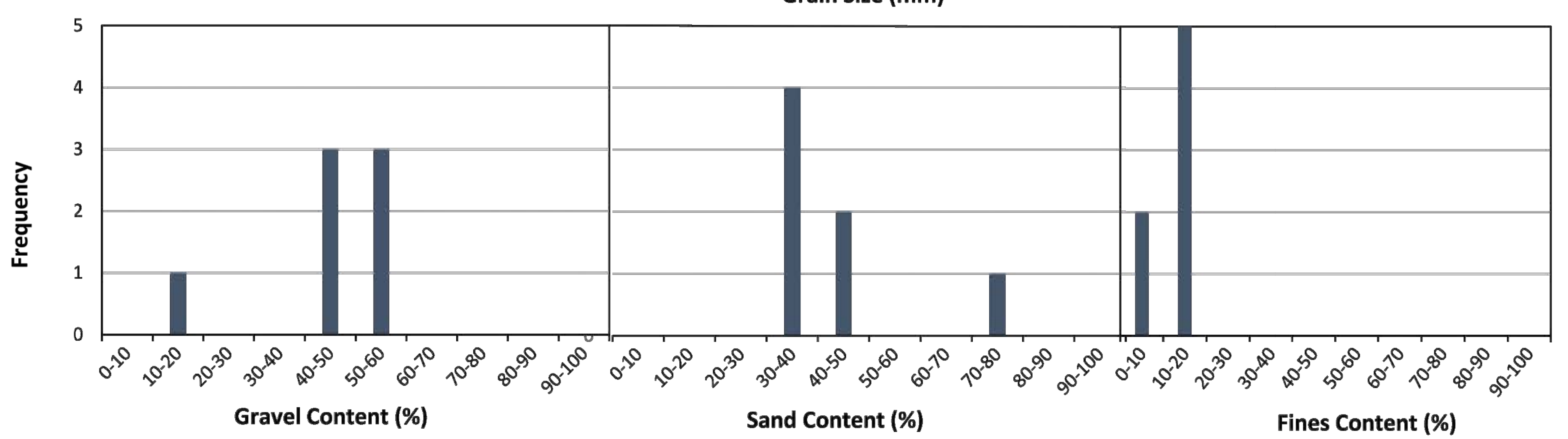
PARE

NBC PHASE III CSO PROGRAM
CONSOLIDATION CONDUIT IIIA-5
GEOTECHNICAL DESIGN SUMMARY REPORT
SOIL PROPERTY SUMMARY - GLACIOFLUVIAL

DATE
FEBRUARY, 2021

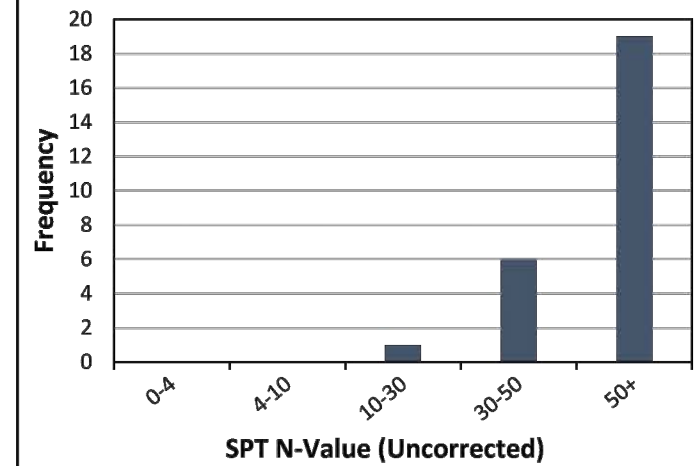
FIGURE
C-3





Notes:

1: Plot and histogram prepared using data from the following borings: B-3, B-9, B-12, B17-41, and B17-42.



Notes:

1: Histogram prepared using data from the following borings: B-2, B-3, B-9, B-10, B-11, B-12, B17-41, B17-42, MW/TB-20, and MW-5/TB-14.

PROJECT 5980

McMILLEN JACOBS ASSOCIATES

NARRAGANSETT BAY COMMISSION
PHASE III COMBINED SEWER
OVERFLOW PROGRAM

Stantec

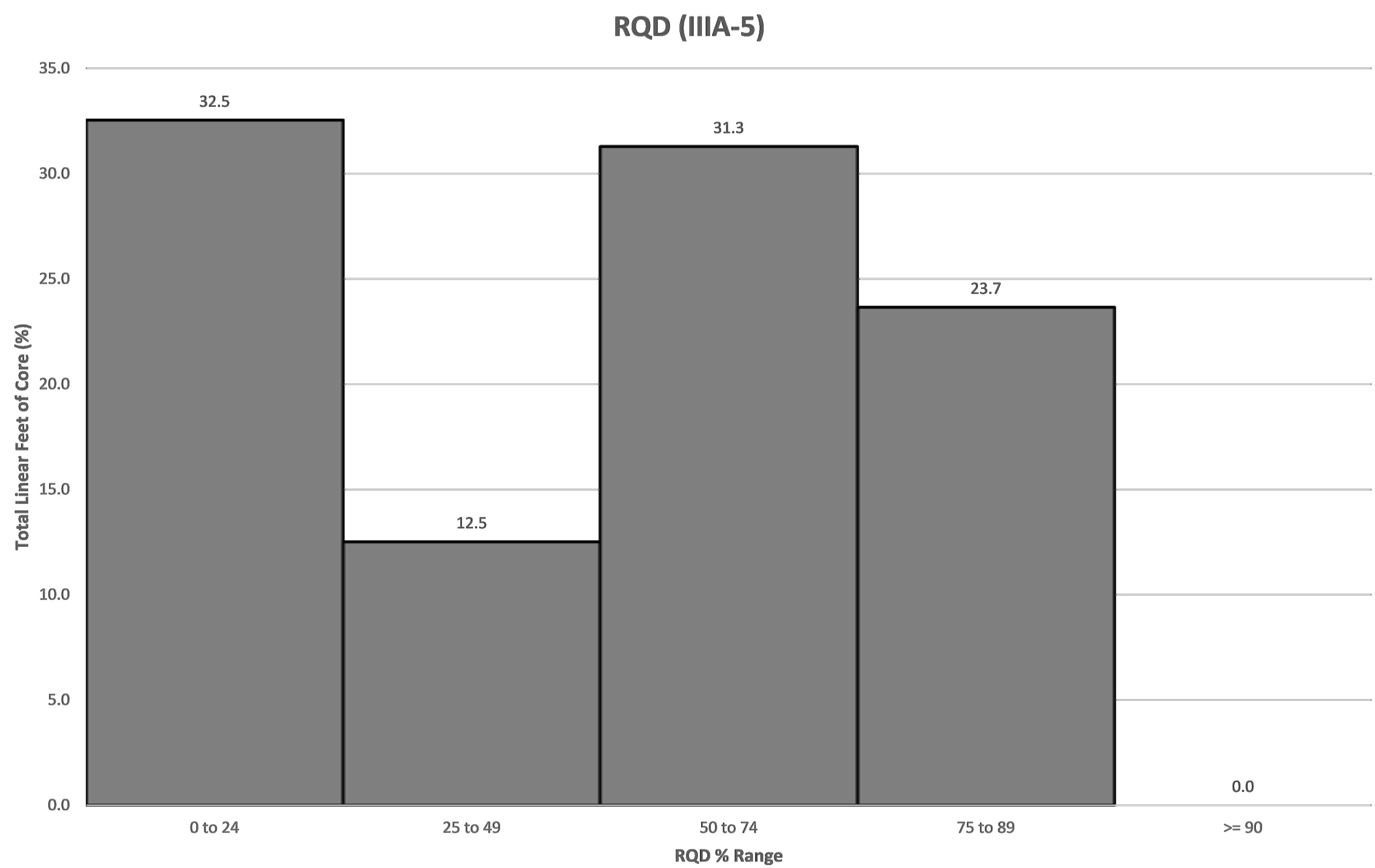
PARE

NBC PHASE III CSO PROGRAM
CONSOLIDATION CONDUIT IIIA-5
GEOTECHNICAL DESIGN SUMMARY REPORT
SOIL PROPERTY SUMMARY - GLACIAL TILL

DATE
FEBRUARY, 2021

FIGURE
C-4

APPENDIX D
RQD Histogram
(IIIA-5 Data)



Notes:

1: Histogram prepared using data from the following borings: B-1, B-2, B-3, B-9, B-10, B-11, B-12, B17-41, and B17-42.

PROJECT 5980

McMILLEN JACOBS ASSOCIATES	NARRAGANSETT BAY COMMISSION PHASE III COMBINED SEWER OVERFLOW PROGRAM Stantec PARE	NBC PHASE III CSO PROGRAM CONSOLIDATION CONDUIT IIIA-5 GEOTECHNICAL DESIGN SUMMARY REPORT ROCK QUALITY DESIGNATION (RQD) - HISTOGRAM	DATE JUNE, 2020 FIGURE D.1

APPENDIX E
Ground Behavior Classification and Descriptions

Table E.1 Tunnelman's Ground Classification
Table E.2 Rock Mass Descriptions

Table E.1 Tunnelman's Ground Classification

Classification		Behavior	Typical Soil Types
Firm		Heading can be advanced without initial support, and final lining can be constructed before ground starts to move	Loess above water table; hard clay , marl, cemented sand and gravel when not highly overstressed.
Raveling	Slow Raveling	Chunks or flakes of material begin to drop out of the arch or walls sometime after the ground has been exposed, due to loosening or to overstress and "brittle" fracture (ground separates or breaks along distinct surfaces, opposed to squeezing ground). In fast raveling ground, the process starts within a few minutes, otherwise the ground is slow raveling.	Residual soils or sand with small amounts of binder may be fast raveling below the water table, slow raveling above. Stiff fissured clays may be slow or fast depending upon degree of overstress
	Fast Raveling		
Squeezing		Ground squeezes or extrudes plastically into tunnel, without visible fracturing or loss of continuity, and without perceptible increase in water content. Ductile, plastic yield and flow due to overstress.	Ground with low frictional strength. Rate of squeeze depends on degree of overstress. Occurs at shallow to medium depth in clay of very soft to medium consistency. Stiff to hard clay under high cover may move in combination of raveling at excavation surface and squeezing at depth behind surface.
Running	Cohesive Running	Granular materials without cohesion are unstable at a slope greater than their angle of repose (30-35 degrees.) When exposed at steeper slopes they run like granulated sugar or dune sand until the slope flattens to the angle of repose.	Clean, dry granular materials. Apparent cohesion in moist sand, or weak, cementation in any granular soil, may allow material to stand for a brief period of raveling before it breaks down and runs. Such behavior is cohesive running.
	Running		
Flowing		A mixture of soil and water flows into the tunnel like a viscous fluid. The material can enter the tunnel from the invert as well as from the face, crown, and walls, and can flow for great distances completely filling the tunnel in some cases.	Below the water table in silt, sand or gravel without enough clay content to give significant cohesion and plasticity. May also occur in highly sensitive clay when such material is disturbed.
Swelling		Ground absorbs water, increases in volume, and expands slowly into the tunnel.	Highly preconsolidated clay with plasticity index in excess of about 30, generally containing significant percentages of montmorillonite.

(after Heuer, 1974)

Table E.2 Rock Mass Descriptions

Descriptive Terminology	Description and Associated Behavior
Intact	Rock contains neither joint nor hairline cracks. Therefore, if it breaks it breaks across intact solid rock. Due to rock damage resulting from blasting, spalls may drop from the roof several hours to days after blasting. This is known as spalling condition. Hard, intact rocks may also exhibit popping or slabbing conditions, involving the spontaneous, sudden, and violent detachment of rock slabs front he roof or sidewalls.
Stratified	Rock consists of individual strata with little or no resistance against separation along boundaries between strata. The strata may or may not be weakened by transverse joints. In such rock, the spalling condition is common.
Moderately Jointed	Rock contains joints and hairline cracks, but the blocks between joints are locally grown together or intimately interlocked such that vertical walls do not require lateral support. In rock of this type, both the spalling and popping (or slabbing) conditions may be encountered.
Blocky and Steamy	Rock consists of chemically intact or nearly intact rock fragments which are entirely separated from each other and imperfectly interlocked. In such rock, walls may require lateral support.
Crushed	Rock consists of crushed, but chemically intact rock that has the character of a crusher run material. If most or all of the fragments are as small as fine sand grains and no remediation or support installation has been performed, crushed rock below the water table exhibits the ground behavioral response of water bearing sand.
Squeezing	Rock slowly advances into the tunnel excavation without perceptible volume increase. A pre-requisite for squeeze is a high percentage of microscopic and sub-microscopic particles of micaceous minerals or clay minerals with a low swelling capacity.
Swelling	Rock advances into the tunnel excavation chiefly due to expansion. The capacity to swell appears to be limited to rocks that contain clay minerals such as montmorillonite, with a high swelling capacity.

(after Terzaghi, 1946)