APPENDIX C3: GEOLOGICAL AND SOILS INVESTIGATIONS

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1.0 GEOTECHNICAL INTRODUCTION
This appendix summarizes the review of available geological and geotechnical data from the site area, describes the anticipated foundation conditions along the alignment of the proposed improvements, and provides preliminarily estimated soil parameters for the general design of typical cut channel slopes and structure foundations. All data was obtained from existing geological records and from previous field investigations and laboratory soil and rock testing. No new subsurface investigations were performed as part of this work.

2.0 PROJECT LOCATION, DESCRIPTION, & IMPROVEMENTS
The Mamaroneck and Sheldrake Rivers watershed is 23.63 square miles in area, and is located along the northwestern coast of Long Island Sound within the New York City metropolitan area. The Mamaroneck and Sheldrake Rivers Basin lies entirely within Westchester County, New York and contains portions of the Village and Town of Mamaroneck, the City of White Plains, the Village and Town of Harrison, Village of Larchmont, the City of Rye, North Castle, and the Village of Scarsdale. Specifically, the study area is defined by the flood damage areas located in the Village of Mamaroneck and the Town of Harrison. On the Mamaroneck River, the area of concern extends from below Tompkins Avenue upstream to the Westchester County Joint Water Works Dam. On the Sheldrake River the area of concern extends from the confluence with the Mamaroneck River upstream to the Village line at the New England Thruway (I-95) Bridge.

The geotechnical items of concern on the project include: replacement of Ward Avenue and Waverly Place Bridges; removal of one footbridge and replacement of two others; installation of a bypass culvert under the railroad station parking lot; and channel deepening and widening, which may require construction of retaining walls where insufficient space is available to safely slope regarded banks.
3.0 GEOLOGIC & GEOTECHNICAL STUDY

3.1 Overview

The geologic, soil, and materials study consisted of a review of all available geologic information including topographic maps, geologic and tectonic maps, site reconnaissance, and a comprehensive review of available subsurface exploration data. Upon completion of review of all available data, it was determined that additional investigations will be required along the Sheldrake River and other areas to further define or determine the soil and rock strata along the channel. Previous borings were drilled along Fennimore Road for the tunnel alignment to divert the Sheldrake River into the West Basin of Mamaroneck Harbor. The tunnel was eliminated from the proposed plan due to high costs. Borings were drilled in 1987/1988 along Mamaroneck and Sheldrake Rivers to for the previous river improvements analyzed in the 1989 General Design Memorandum. For the new proposed plan, the existing subsurface explorations were used to estimate the soil and rock parameters for preliminary design of the proposed typical project features, but additional borings will be needed during subsequent phases of work to further refine the parameters.

3.2 Regional Geology

Lower Westchester County is within the New England Upland Physiographic Province, and its extension, the Manhattan Prong. The ridges, valleys and streams trend to north to northeast. The
eastern side of Westchester County rests on the upper edge of the submerged portion of the Continental Shelf of the United States which scoured out to form Long Island Sound. The deposition of the oldest sedimentary rocks occurred during the pre-Cambrian era. This was followed by intrusion of granite and diorite, which were metamorphosed into gneiss and marble and were elevated and eroded. During the Paleozoic era, the sea covered the area and deposited lime and mud into the deposits of the Ordovician period. These later deposits consolidated into sandstone, limestone, and shale, which were then subject to cycles of folding metamorphism, elevation, and erosion during the Taconic orogeny. Erosion and deposition continued for the remainder of the Paleozoic period. The rock was then folded (northeast and southwest), broken and faulted during the Appalachian revolution. There were more igneous intrusions at this time and the area was again eroded. The sandstone and limestone were metamorphosed into quartzite and marble and were again elevated and eroded. In the Pleistocene period the glaciers advanced 2 or 3 times in a southeasterly direction. At times the ice sheets covered the highest points in the county. Thick deposits of till, unsorted, and unconsolidated, ranging from clay to boulders, were laid down by the ice, gravel, sand and silt were deposited in the stream valleys. At some places, these deposits blocked the stream channels forming small lakes in which were deposited silt, clay and peat. The land was partially re-elevated, thus rejuvenating the streams which are cutting and eroding at the present time.

3.3 Bedrock Geology

The principal bedrock that underlies and influences the topography of the surrounding region includes: Fordham gneiss, Manhattan schist, Inwood limestone (marble and dolomite) and numerous massive granite or diorite dykes. The geologic map of the project area (included in the Geology of New York State, 1962, State Education Department, Albany, New York) shows one type rock “schist and gneiss undivided”, which is directly bounded on the east and west by the southerly reaching two prongs of the Harrison dioritic and granodioritic gneisses. The Harrison granodiorite, whose identity is still debatable, was intruded into that complex sequence of gneiss and schist in the east Bronx and southeastern Westchester County. An area of mica schist about one and three-quarter miles wide separates the two prongs of this igneous unit. Typically gneissic in appearance, the Harrison granodiorite is medium-coarse in texture. Biotite, hornblende, plagioclase feldspar and quartz are the principal mineral constituents. Sub-parallel alignment of the biotite and hornblende imparts a foliated structure to the rock. The Hartland metamorphic formation may also be present in the area and consists of gneisses, schists, and amphibolites.

3.4 Unconsolidated Materials

Unconsolidated surface materials are predominantly of glacial origin. Stratified drift deposits occupy the lower lands, while till deposits of varying thickness cover the hillsides. Recent alluvial deposits of sand, gravel and clay lenses are also found along most of the streams.

3.5 Specific Geology of Mamaroneck and Sheldrake Rivers

The lower courses of the Mamaroneck and Sheldrake Rivers along the general alignment of the considered improvements in Mamaroneck flow over moderately thin alluvial deposits. Bedrock under the channels and along the valley slopes is of metamorphic origin ranging in age from pre-Cambrian to Ordovician. The alluvial deposits are variable in composition and are predominantly gravelly sand with some boulders and a minor amount of clay and silt. Along the Mamaroneck River channel, bedrock crops out at several localities and it is estimated that its maximum depth below the surface is about 40 feet. Fewer outcrops are observed along the Sheldrake River in its
lower course, but upstream from Larchmont Garden Lake, bedrock is generally exposed or under a thin sheet of overburden. Bedrock outcrops are visible along the Lower Mamaroneck just upstream of the Ward Avenue Bridge downstream to the Tompkins Avenue Bridge.

### 3.6 Regional Stress and Seismicity

Monitoring seismic activity in the New York Metro area has only recently been established. A list of seismic events recorded by the New York-New Jersey seismic events recorded by the New York-New Jersey Seismic Network, December 1970-November 1986, is presented in Annex C5. There are a number of events contained in the list. However, the list of activity should not be considered complete. Also, the effects of seismicity are poorly understood for this section of the country. Historically, the largest event to occur in southern New York took place in New York City in 1889. This event had a felt area magnitude of 4.9. On October 19, 1985 an earthquake with a magnitude (ml) of 4.0 occurred in the Ardsley area of Westchester County. Most of the events are located west of Mamaroneck. Two rather small events did occur in the immediate vicinity of the town: Rye, January 21, 1983 (Magnitude 2.2); and Mamaroneck, August 29, 1983 (Magnitude 0.8). The two issues of Quarterly Bulletin of the Lamont-Doherty Seismic Network, 1 January-31 March 31 and 1 July-30 September 1983, which contain information concerning the two smaller events, are included in Annex C5. (Personal communication with Russell Such of Lamont-Doherty Geological Observatory of Columbia University, 27 January 1988, and April 15, 1988.)

Isachsen and McKendree (1977) indicate a strike-slip fault with relative movement shown in a north-south direction. A linear topographic feature is observed west of the site crossing western Connecticut, Westchester and Bronx Counties in general N30E direction.

The seismic risk factors for southeastern Westchester County are low. Maximum ground accelerations of about 0.4g to 0.1g are possible which could have some impact on structures. (United States Earthquake Zones, Kinematics Research Ltd., 1976.)

Stress relaxation of in situ tectonic stress has resulted in movement of rock shaft walls at numerous locations within the southeastern region of New York State, particularly in deep rock excavation within Long Island and New York City. These movements have occurred in Ravenswood Granodiorite which is a pinkish or gray foliated rock found mixed with Fordham Gneiss throughout Queens and Kings Counties, New York. The combination is called “Brooklyn Injection Gneiss.” There is no evidence of this formation being found along Fenimore Road. In addition, one characteristic of high in situ stressed rock is that it can produce dicing of rock core samples due to stress relief related tension failures. Dicing of rock cores refers to the formation of discs or wafers of relatively uniform thickness which fracture on surfaces normal to the axis of the core. Although fractures normal to the core axis were observed during evaluation of core discontinuities, the pattern of closely spaced discs was not observed.

The seismic loading and impacts on the project structures were not evaluated at this phase. As the designs are refined and additional loading is added to the calculations, the seismic impacts and vibrations will be included. The following maps from the American Society of Civil Engineers (ASCE) 7-10, “Minimum Design Loads for Buildings and Other Structures” will be considered for the project based on the project location:
The structures in this project are considered to fall within the risk category III as per the ASCE 7-10. Risk category III includes buildings and other structures with the “potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure,” (ASCE 7-10, Table 1.5-1). The retaining walls, bridge, and culvert fall into this category for the significant flood that would result in a failure, as well as the loss of roadways and buildings if river slopes collapsed. The following seismic loads will be considered for the project:

<table>
<thead>
<tr>
<th>Risk Category</th>
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<tr>
<td>Importance Factor, Ie</td>
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<tr>
<td>System Over-strength Factor, ( \Omega_0 )</td>
<td>2</td>
</tr>
<tr>
<td>Deflection Amplification Factor, ( C_d )</td>
<td>2</td>
</tr>
</tbody>
</table>

3.6.1 Liquefaction Potential

Loose soils below the water table are typically analyzed for liquefaction potential. Given that the majority of the soils in the project vicinity consist of compact granular soils, the liquefaction potential would be expected to be low. However, this should be further analyzed upon completion of additional geotechnical studies to be performed at the site.
3.7 Subsurface Explorations

3.7.1 General
The subsurface exploration programs performed for previous flood protection projects were used for the updated plan. The previous subsurface exploration programs are described in the following paragraphs. Boring locations are shown on Plate 2 and the previous flood control alignment is shown on Plate 1.

3.7.2 Upper Mamaroneck and Sheldrake River Channel
Soil conditions along the upper Mamaroneck River were previously investigated during the summer of 1945. The explorations consisted of two drill holes (DH-1 and DH-2), auger holes (AH-3 through AH-5), and test pits (TP-1, 1A, 2 through 6, 26 and 27). The locations of these explorations are shown on Plate C2 and the logs are shown on Plates C4.1 and through C4.4. In June 1976, two additional drill (DH-6 and DH-7) were made. The locations and logs of these two borings are shown on Plates C2 and C4.5, respectively. Other subsurface information was obtained from test borings (APB-1 and APB-12 taken in July, 1975) for the existing A&P Supermarket between Jefferson Avenue and Willow Street on the right bank and the New York State Thruway (Boring NY-5 through NY-10 taken in August through November 1953 and Boring NY-1 and NY-4 taken in April 1954). The locations of these borings and logs are shown in Plates C2 and C5.3 respectively. Sixty-eight probings comprising the LM and WM series were taken in this area in September and October 1986 (Plate 5.5). Twenty three test borings (Borings BM-1 through BM-7 and BM-9 through BM-24) were taken along the river in October, 1986. The locations and logs of these borings are presented in Plate C2 and Plates C3.2 and C3.3, respectively. Permeability tests were made in boreholes at Borings BM-17 and BM-23.

3.7.3 Sheldrake River Channel
Foundation conditions along the Sheldrake River were previously investigated during summer of 1945. The explorations consisted of two auger holes (AH-1 and AH-2) and ten pits (TP-8, 9, 16 through 21, 23, and 25). The location are shown on Plate C2 and the logs are shown on Plates C4.3 through C4.6. Other subsurface information was obtained from the New York State Thruway Authority’s work (Borings NY-11 through NY-18) performed in August through September, 1953. The locations of these borings and logs are presented in Plates C2 and Plates 5.3, respectively.

Five additional borings (BS-1 through BS-5) along the Sheldrake River channel were obtained in October, 1986. These borings are just south of the project alignment. Many borings were taken for the Sheldrake River Diversion Tunnel which is no longer a feature in the update project plans.

3.7.4 Upper Mamaroneck River Bridges
Borings were drilled in 1986 near bridges previously considered for replacement on Hillside Avenue and Station Plaza Road. Four borings (LB-1 through LB-4) were taken at Hillside Avenue, and four borings (LB-5 through LB-8) at Station Plaza Road Bridge. The locations of these borings are shown on Plate C2 and the logs are presented in Plate C5.2.

3.7.5 Lower Mamaroneck River Channel Improvements
Foundation conditions along the lower Mamaroneck River were initially investigated in the summer of 1945. The exploration consisted of eight test pits (TP-7, 7A, 10 through 15) between
the New Haven Railroad and Tompkins Avenue. The locations of these pits are shown on Figure C2 and the logs are summarized and presented in Plates C4.3 through C4.6.

3.7.6 Lower Mamaroneck Bridges
Foundation conditions at the Tompkins Avenue Bridge, Ward Avenue Bridge and Halstead Avenue Bridge were investigated by test borings between December 1984 and January 1985. Four borings (B-1 through B-4) were taken at Halstead Avenue Bridge, four borings (B-5 through B-8) at Ward Avenue Bridge, and four borings (B-9 and B-12) at Tompkins Avenue Bridge. Foundation conditions at the Valley Place Bridge were investigated between August and September, 1986 by test borings LB-9 and LB-10. The locations of these borings are shown on Plate C2 and the logs are presented in Plate C5.2.

3.8 Soil and Rock Profiles
A number of soil and rock profiles were generated from the existing borings using Bentley’s gINT and In-Roads programs. An alignment was drawn from the surfaces along the Mamaroneck River Channel using the northing and easting borings coordinates as points for the alignment. Profiles for the borings along the Mamaroneck River were generated using the boring coordinates for the baseline distances. The profiles are shown on Plates 9 to 14. These profiles are supplement to the existing borings and from the 1989 GDM. Little subsurface exploration and profiles are available for the Sheldrake River since in the original GDM most of the subsurface exploration were drilled along the alignment of the diversion tunnel which is no longer being considered as an option. Additional exploration will have to be performed to determine the soil and rock profiles along the Sheldrake from New England Thruway exit to the confluence with the Mamaroneck River at Station Plaza or the New Haven Railroad Station.

3.9 Laboratory Testing
Laboratory testing was performed on selected samples from the drilling programs on H-, BS-, and BM-series borings made between September and October, 1986 in order define foundation parameters for use in analysis and design of the previous planned improvements. This laboratory soils and rock testing program consisted of liquid and plastic limits, specific gravity, unit weight, sieve & hydrometer analysis, strength tests, consolidation tests, rock compression tests and unit weight. The results of the tests are summarized and presented in Plate C7.

3.10 Field Permeability Tests
In-situ permeability tests were performed in borehole BS-5 on Upper Sheldrake River channel and in BM-17 and BM-23 on Upper Mamaroneck River channel.

4.0 FOUNDATION CONDITIONS
4.1 Foundation Conditions - General
Based on the review of available geologic and geotechnical information, the anticipated foundations conditions for the project elements are described in the following paragraphs.

4.2 Upper Mamaroneck River
The soil conditions along the Upper Mamaroneck River in general, consists of sand with varying amounts of silt and gravel. Occasional layers of silt are found interbedded with the sandy soils. These layers are usually less than one foot in thickness, except in the vicinity of the confluence of the Sheldrake River where the silt attains a maximum depth 12 feet and extends below the stream
bed level. The material in the stream bed generally consists of sand and gravel throughout with occasional boulders and cobbles in the upstream section. Bedrock outcrops in several areas along the channel and banks through the proposed alignment. The river banks from First Street to downstream of Hillside Avenue are lined with riprap protection and masonry walls.

4.3 Sheldrake River
The general soil profile along the Sheldrake River indicates sand and sand-gravel materials with varying amount of silt, cobbles and boulders. Generally, the overlying soils consist of silty sand and sand, and sand-gravel soils occur in the lower strata. Sand-gravel material is generally found below the silty sand and the stream bed channel and the sand material is found below the stream bed level. The gneissic bedrock, which is exposed at several areas adjacent to the channel, is generally close to the river bottom. The river banks downstream of Fennimore Road are composed of miscellaneous overbank fill and debris to a point in the vicinity of Center Avenue and below this area the banks are composed of dry masonry walls.

4.4 Lower Mamaroneck River
The surficial soils in the Lower Mamaroneck River are glacial in origin and consist essentially of outwash and till deposits. In general, the soils are compact and consist of silt through boulders with some clay. Recent thin alluvial deposits of sand and gravel, with occasional cobbles and boulders, line the river bottom and are essentially visible near the existing bridge abutments. Weathered bedrock in the form of sandy micaceous silt was intercepted in three borings located on the left bank between Ward Avenue Bridge and Halstead Avenue Bridge. The bedrock underlying the site consists of metamorphic rock with pegmatitic intrusions.

5.0 PRELIMINARY GEOTECHNICAL DESIGN PARAMETERS
5.1 Preliminary Bearing Capacity of New Bridge at Waverly Place
Soil bearing capacity calculations for three bridges previously being considered for replacement are included in Computation C1. Similar calculations will be performed for the Ward Avenue Bridge, Waverly Place Bridge, and two footbridges currently planned for replacement during future work once subsurface information is available at each location.

5.2 Preliminary Soil Design Parameters
The generalized soil strength parameters summarized below were estimated based on review of widely spaced geotechnical subsurface explorations and testing information from the project vicinity. These parameters and experience in the project vicinity were considered to estimate stable cut slopes and for preliminary design of typical retaining walls. Additional explorations will be needed prior to final design.

### Estimated Soil Parameters for Preliminary Design

<table>
<thead>
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<th>SOIL TYPE</th>
<th>UNIT WEIGHT (SAT)</th>
<th>UNIT WEIGHT (MOIST)</th>
<th>PHI ANGLE</th>
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<tbody>
<tr>
<td></td>
<td>(lbs/cubic foot)</td>
<td>(lbs/cubic foot)</td>
<td>(Degrees)</td>
<td>(psf)</td>
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</tbody>
</table>

Mamaroneck & Sheldrake Rivers
April 2017

Geotechnical Appendix
5.3 Preliminary Design of Channel Banks Side Slopes

The existing soils in the project area are typically granular with occasional silt or clay deposits which would have an estimated angle of internal friction of about 32 degrees. These materials are typically stable on a 1:2.5 slope. Most USACE levees are constructed on a 1:2.5 slope without any negative issues, so no major slope stability concerns are anticipated on this project. The presence of highways and structures in close proximity to the project features in some areas may require slopes as steep as 1:2, or else construction of retaining walls will be necessary. Along the reach of the Upper Sheldrake River just upstream of Fenimore Road and Mamaroneck River in the vicinity of Hillside Avenue, the channel deepening is such that it may expose a silt stratum in the slope. The silt stratum may be exposed in other areas of the channel as well. This will require riprap or stone protection depending upon the hydraulics of the new channel. Side slope stability analysis will have to be performed in the next design phase of this project to determine if 1:2 slopes will work or if 1:2.5 slopes with retaining walls will be needed to achieve satisfactory stability where structures are too close.

Depending upon the side slopes, underpinning may be required for some structures that are in close proximity to the retaining walls. One method maybe of underpinning is to excavate beneath short sections of the existing footing down to rock or the elevation of the bottom of the required retaining wall, and then construct a new concrete footing and foundation wall. Sheeting and shoring may be required if excavations extend greater than about five feet below the bottom of the existing footings, and temporary timber bracing of the new foundation may be required until the backfill for the new retaining wall is placed. The actual foundation conditions at each structure will need to be evaluated during the excavation.

5.4 Preliminary Design & Construction Considerations for Culvert

A 25 foot wide by 8 foot high, 350 foot long culvert will be installed under the railroad station parking lot (where the Upper Mamaroneck River and Lower meet) to alleviate the poor channel alignment. The soils in this area are anticipated to consist of medium dense to dense sandy soils. Bedrock is anticipated at depths greater than 15 feet below existing grades. Rock profiles prepared by interpolation between available borings indicates that the bottom of the culvert is anticipated to be several feet above the top of rock. However, it is likely that some rock excavation will be required. Given the proximity to the river, it is likely that construction dewatering will be required. Shoring could also be necessary depending on the depths of excavations and the proximity to existing structures or utilities.
5.5 Preliminary Construction Considerations for Rock Excavation

Rock excavation will be necessary in some areas to attain proposed site grades. Excavations into rock will likely only extend a few feet below the rock surface into weathered/fractured bedrock. It is likely that this work would be performed using hoe rams mounted on large excavators, though the means and methods of rock removal would be up to the contractor. Blasting would not be allowed due to the close proximity of buildings and other improvements.

The limits of rock excavation are unknown at this time due to the limited amount of subsurface explorations throughout the site vicinity. Limited rock depth information was superimposed over available topographic survey to give a rough estimate of potential rock issues. The rock line was conservatively estimated in order to include an allowance for rock excavation in the cost estimate. A geotechnical engineer from NAN visited the site to perform a limited amount of “ground proofing” of the rock line, and the estimated rock surface was further refined, though conservatively. Since the rock line used for cost estimating is considered to be conservative, the risk of large project cost increases due to unknown rock excavation is reduced. Additional borings and test pits will need be needed to further define the rock limits and confirm/evaluate its ability to be excavated by conventional means.

6.0 CONCLUSIONS

Based on review of the existing information, the overall project site is generally geologically feasible for construction of the proposed channel improvement, along with retaining walls, bridge replacements, and reconstructed side slopes.

7.0 FUTURE WORK

Additional geotechnical borings and laboratory testing will be necessary prior to final design of all project features to gather initial design information where no data currently exists, or to better define the soil and rock conditions in areas where some previous exploration has occurred. For planning purposes, an initial round of borings should be performed every 250 feet along the length of the improvements. An additional round of borings, plate dilatometer testing (DMT’s), or cone penetrometer testing (CPT’s) will subsequently be performed to further define any questionable soil or rock conditions, delineate problem areas, obtain additional design parameters, collect soil/rock samples for laboratory testing, etc. In-situ permeability testing and laboratory gradation and strength testing will be performed on soil/rock samples collected from the field.

8.0 APPLICABLE GUIDANCE

The geotechnical elements of this project shall have designs that conform to all applicable guidance including, but not limited to, the following:

- USACE EM 1110-1-1804 Geotechnical Investigations
- USACE EM 1110-2-1906 Laboratory Soils Testing
- USACE EM 1110-2-1913 Design and Construction of Levees
- USACE EM 1110-2-2502 Retaining and Flood Walls
- USACE EM 1110-2-1902 Slope Stability
- USACE EM 1110-1-1904 Settlement Analysis
- USACE EM 1110-1-1905 Bearing Capacity of Soils
- USACE EM 1110-2-2906 Design of Pile Foundations