Raritan Bay and Sandy Hook Bay
Highlands, New Jersey
Coastal Storm Risk Management
Feasibility Study

Final Feasibility Report
May 2020

Appendix B3:

Geotechnical Engineering

Raritan Bay and Sandy Hook Bay, Borough of Highlands, New Jersey
Coastal Storm Risk Management Feasibility Study

Appendix B: Geotechnical Engineering

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Chapter 1: General

1.1 Scope of Geotechnical Investigation and Design.

This Geotechnical Appendix presents the results of studies and investigations completed by the New York District (CENAN) and St. Louis District (CEMVS) Corps of Engineers for the Highlands project.

CENAN completed a site specific, field geotechnical exploration and soils sampling/testing program in 2013. CEMVS used the results of this exploration and testing program to make project recommendations.

CEMVS reviewed geological data posted on-line by the New Jersey Department of Environmental Protection (NJDEP). CEMVS also reviewed soils survey data posted on line by the National Resources Conservation Service (NRCS) of the US Department of Agriculture.

CEMVS reviewed the Final Geotechnical Engineering and Foundation Investigation Report prepared by Hardesty and Hanover, LLP for the Route 36 Highlands Bridge Replacement over the Shrewsbury River. This report was prepared for the New Jersey Department of Transportation and submitted to Jacobs Civil, Inc. in January, 2007.

Chapter 2: Background Geological and Soils Information

2.1 Results of Search of NJDEP On-Line Resources.

The NJDEP on-line GIS database now contains a Geological layer. Figure B3- 1 is a screen shot from the website. The NJDEP site identifies the major geologic units that outcrop throughout the state of New Jersey.

The soils from the shore line to about 4th street are identified as "Kml". This unit is the Mount Laurel Formation and is described as being "quartz sand, fine to coarse-grained, and slightly glauconitic." Glauconitic refers to a greenish micaceous mineral in the sands.

From 4th Street and further inland, the soils are identified as "Kns" the Navesink formation which is clayey, glauconitc sand. And further inland, the soils are identified as "Krbsh", the Sandy Hook Member which is clayey, micaceous, fine grained, quartz sand.

Figure B3- 1: Surficial Geology NJDEP

2.2 Results of Search of NRCS On-Line Resources.

The National Resource Conservation Service (NCRS) website provides all soil surveys throughout the state of New Jersey. The soil survey report for Monmouth County is available and represents conditions as they existed in 1983. The General Soils Map from this report is shown on Figure B3- 9. The Highland Project is located in an area dominated by surface soils that belong in the Tinton, Phalanx, and Urban Land series.

The Tinton series consists of well drained soils on uplands and terraces. The Phalanx series consists of well drained soils on uplands. The Tinton and Phalanx series are probably not the dominant series in the shoreline region of the Highlands project.

The Urban Land series consists of areas more than 85 percent of which are covered by impermeable surfaces such as dwellings, roads and streets, shopping centers, parking lots and industrial parks. Based on the development apparent in the Highlands area, the Urban Land series must be the dominant series. The manmade improvements shield the true nature of the sub-surface soils. Onsite investigations and evaluations are needed for most uses.

The NRCS now maintains an interactive website for their soil surveys. In this tool, the area identified in the 1983 report as being dominated by the Tinton, Phalanx, and Urban Land series is now identified as "UdauB", Udorthents-Urban Land Complex. An image of the project area in the current tool tool showing and the dominant UdauB series is included in Figure B3- 2.

Figure B3- 2: 2014 NCRS Soil Survey – "UdauB", Udorthents-Urban Land Complex

The "UdauB", Udorthents-Urban Land Complex description refers to 12 inches of loam underlain by 12 to 72 inches of loamy sand, all of which are well drained. Its parent material is identified as buildings, pavement, and other impervious surfaces!

Chapter 3: Detailed Site Specific Soils Exploration and Testing Programs

3.1 CENAN Geotechnical Exploration and Soils Sampling/Testing Program.

Neither the NJDEP nor the NCRS descriptions provide enough detail for USACE feasibility level investigations. The best advice occurs in the 1983 NRCS description which recommends that "Onsite investigations and evaluations are needed for most uses".

In January and February of 2013, the Baltimore District Corps of Engineers (CENAB) completed 17 borings along the proposed alignment of the Highlands project for CENAN. These borings are named HL-08-01 through HL-08-17. These borings may be found at the end of this section. Each boring was advanced vertically 30 to 32 feet below ground surface with a CME-55 (Central Mining Equipment) drill rig. The soils were sampled with a standard 1-3/8 inch split spoon sampler driven by an automatic trip hammer (140-lb weight falling 30-inches). All samples were visually classified by the USACE Unified Soils Classification System.

CENAN provided the coordinates of the as drilled boring location to CEMVS. These latitude and longitude coordinates were measured using a hand-held GPS device and should be considered approximate. CEMVS plotted the horizontal boring locations within the Google Earth application. Those locations are shown on Figure B3- 3. No vertical elevations have been provided for the as-drilled locations. A virtual tour of the project using the "Street View" capability of Google Earth indicates the area is relatively flat.

The information from this exploration and testing program was entered into the gINT data base and the CENAB standard Form 1836 was plotted for each boring. CEMVS assembled these 1836 forms side by side assuming that the ground surface at each boring was the same. The assembled borings were inspected to determine continuity of major soil units between borings. The standard penetration blow counts in the sands were contoured and compared between the borings in order to develop a more nuanced interpretation of the foundation. Based on these interpretations, the foundation along the proposed alignment was separated into five discrete geotechnical reaches containing similar soils, thickness and density. Figure B3- 5 through Figure B3- 10 present these graphical constructions and the general boundaries between these reaches. In general, beginning at the ground surface, the stratigraphy consists of:

- Zero to two or zero to four feet of pavement and/or manmade fill. Those borings where the fill extends to a depth of 4-feet may indicate low lying areas that have been filled.

- Below the manmade fill, a layer of sand ranging from poorly graded sands (SP), sands with silt (SP-SM), to silty sands (SM), exist to a depth of 25 to 30-feet. Within this sand layer, some borings showed thin, non-continuous layers of silt (ML) or sands (SW). These sands exhibit widely varying gradations (course to fine) and varying density (very loose to medium dense).

- Below the sands, a layer of fine grained soils, silts (ML) or clays (CL or CH) exist to the bottom of the boring.

The field standard penetration blow counts measured within each boring were studied and contoured according to standard ASTM description of blow counts versus assumed density. Those ASTM assumptions and an assumed range of the shear strength of sands per Meyerhof (see section 3.3 below) are provided below.

0 blows (Weight of Hammer) to 4 blows:	Very loose.	$\varnothing < 30^{\circ}$
4 to 10 blows:	Loose.	$30^{\circ} < \varnothing < 35^{\circ}$
10 to 30 blows:	Medium	$35^{\circ} < \varnothing < 40^{\circ}$
30 to 50 blows:	Dense	$40^{\circ} < \varnothing < 45^{\circ}$
Greater than 50 blows:	Very dense	$\varnothing > 45^{\circ}$

Figure B3- 3: Locations of CENAN Highlands Exploration

The five discrete geotechnical reaches are identified on Figure B3- 4 and described below:

Reach 1. (Figure B3- 10) Includes area between borings HL-08-01 HL-08-03.
4-feet of manmade fill
4 to 6-feet of very loose sands.
13 to 15-feet of medium dense sands.
ML/CL layer at depth.

Reach 2. (Figure B3- 10) Includes area between borings HL-08-03 HL-08-06.
4-feet of manmade fill
6-feet of loose sands.
7-feet of very loose sands
8 to 14-feet of medium dense sands.
ML/CL layer at depth.

Reach 3. (Figure B3- 9) Includes area between borings HL-08-06 HL-08-09.
6-feet of manmade fill
6-feet of loose sands.
8-feet of very loose sands
15-feet of loose sands.
ML/CL layer at depth.

Reach 4. (Figure B3- 8) Includes area between borings HL-08-09 HL-08-13.

3-feet of manmade fill
4-feet of loose sands.
10-feet of very loose sands
14-feet of medium sands.
ML/CL layer at depth.

Reach 5 (Figure B3- 7). Includes area between borings HL-08-13 HL-08-16.

2-feet of manmade fill
5-feet of loose sands.
7-feet of very loose sands
6-feet of loose sands.
ML/CL layer at depth.

3.2 Review of Site Specific Soils Testing.

CENAN completed a limited amount of soils testing on samples obtained during their Geotechnical Exploration and Soils Sampling/Testing program. The results of the testing is summarized in Table B3- 3. Certain results from the limited testing program provide some information on the shear strength of the foundation materials.

The Tri-Axial test on the Shelby Tube sample taken from a depth of 28 to 30 feet in boring HL-08-15. Although the visual classification on the plotted 1836 form identifies this layer as a silt (MH), the laboratory classification based on Atterberg limits testing and mechanical sieve analyses classify the sample as a silty sand (SM). The Tri-Axial Consolidated – Undrained with Pore Pressure measurements (CU w/pp) measures an internal friction angle of 26.2° with a cohesion intercept of 3.89 PSI (0.28 TSF).

Two unconfined compression tests (UCT) were completed on clay samples obtained from boring HL-08-04 (30 to 32 feet bgs) and HL-08-05 (28 to 30 feet bgs). The sample from boring HL-08-04 classifies as a CL clay although it was visually identified as an SC. The strength test on this CL sample yielded an undrained shear strength (Cohesion) of .21 TSF. The sample from boring HL-08-05 classifies as a CH clay although it was visually identified as an SC. The strength test on this CH sample measured an undrained shear strength (Cohesion) of 1.07 TSF.

3.3 Results of Route 36 Exploration and Soils Sampling/Testing Program.

CEMVS reviewed the Final Geotechnical Engineering and Foundation Investigation Report prepared by Hardesty and Hanover, LLP for the Route 36 Highlands Bridge Replacement over the Shrewsbury River. This report was prepared for the New Jersey Department of Transportation and submitted to Jacobs Civil, Inc. in January, 2007. Although the exploration completed for this major infrastructure project is located just beyond the eastern extent of the Highlands project, the bridge exploration provides insights into the foundation conditions existent below the 32-foot deep borings completed for the Highlands project.

Figure B3- 10 is the Geologic Subsurface Profile created by Hardesty and Hanover, LLP for the Route 36 Bridge. On the Highlands side of the bridge, at bridge project station 106+00, the profile indicates a 3 to 5 foot thick layer of Tidal Marsh materials near elevation -10. Immediately below the Tidal Marsh layer is the Navesink Formation (45-foot thick) which is underlain by the Wendnah – Mt. Laurel formation (50-foot thick). The Hardesty and Hanover report describe the Tidal Marsh deposit as a layer of soft, organic, clayey silt. Although occurring at a different elevation, the clay (CH), silt (ML), and elastic silt (MH) layer encountered near the bottom of most of the Highlands borings represents the Tidal Marsh layer.

If the Highland project borings have encountered the Tidal Marsh layer, than it is likely this layer will be underlain by the Navesink and the Wendnah – Mt. Laurel formations as identified in the Rt 36 profile. This is useful for estimating the foundation conditions for 95-feet below that identified by the Highland 32-foot deep borings.

Table B3- 1: Shear Strength of Sands versus Standard Penetration Blow Count (Virginia Tech)

Table 3. Relationship Among Relative Density, Penetration Resistance and Angle of Internal Friction of Cohesionless Soils

State of Packing	Relative Density	Standard Penetration Resistance N	Static Cone Resistance q_c	Angle of Internal Friction ϕ'
	Percent	blows/ft	tsf or kgf/cm^2	degrees
Very Loose	< 20	< 4	< 20	< 30
Loose	20 - 40	4 - 10	20 - 40	30 - 35
Compact	40 - 60	10 - 30	40 - 120	35 - 40
Dense	60 - 80	30 - 50	120 - 200	40 - 45
Very Dense	> 80	> 50	> 200	> 45

3.4 Shear Strength and Unit Weight of Foundation Materials.

Table 3 from the document titled "*Shear Strength Correlations for Geotechnical Engineering*" (Virginia Tech Department of Civil Engineering, 1989, Duncan, Horz, and Yang) is presented in Table B3- 1. The table presents the estimated shear strength of sands given its density as estimated by the standard penetration blow counts. These have been summarized above for the various layers and densities obtained from the site specific exploration program.

For the very loose, loose, and medium dense sands encountered in the CENAN exploration program, internal friction angles of 30° to 35° are appropriate. The one tri-axial test on the silty sand material yielded a friction angle of 26°.

The strength testing on the Tidal Marsh layer at the 28 to 30 foot depth yielded two very different samples with widely varying shear strength. The CL material was much weaker (0.21 TSF) than the CH material (1.07 TSF). A higher strength in the CH (fat clay) is not surprising. More sampling and testing must be completed to correctly identify the locations and nature of the soils in the Tidal Marsh layer.

Table B3- 2 is taken from the Final Geotechnical Engineering and Foundation Investigation Report prepared by Hardesty and Hanover, LLP. This table presents their selected foundation shear strengths for the materials encountered by their exploration and testing program. Their selection of friction angle Ø = 30° for the alluvial deposits (sand) is in line with the Meyerhof recommendations shown in Table B3- 2 and estimated density of the foundations sands encountered by the Highlands site specific exploration program.

Table B3- 2: Shear Strength Selections for Rt 36 Bridge Foundation Materials (Hardesty and Hanover, LLP)

Stratum	Unit weight (pcf)	Shear Strength Parameters	
		Friction ϕ (Deg)	Cohesion (psf)
Stratum A (Alluvial Deposits, Sand)	120	30	--
Stratum A-1 (Tidal marsh)	90	--	300
Stratum B (Upper: Navesink Formation)	120	34	--
Stratum B (Lower: Wenonah-Mount Laurel Aquifer)	125	36	--
Stratum C (Marshalltown-Wenonah Confining Bed)	120	--	2000
Stratum D (Englishtown Aquifer)	130	40	--
Stratum E (Fill)	110	26	--

CEMVS-EC-G recommends using a internal friction angle of 26° for the very loose soils and 30° for the medium dense foundation materials. The foundations materials have sufficient shear strength to support the surface features associated with the sand dunes or to support the subterranean features associated with the bulkhead related features.

Chapter 4: Highland Project Features.

4.1 General.

The proposed project includes construction of I-type and T-type floodwalls, and raising ground surfaces. Feature selection is based in part on existing installed features and the undeveloped space available along the alignment to construct the proposed features. Table B3- 4 outlines the features included in each of the geotechnical reaches defined above. Table B3- 4 identifies the boring closest to the feature. The table also indicates the analyses needed to complete the feature design. Slope Stability/Seepage Analyses could be done with the commercially available GeoStudio suite of products including the Slope/W and Seep/W applications. Final sheetpile analyses for bulkheads would be done using the USACE program CWLSheet.

Table B3- 3: Summary of Soils Testing

Boring	Sample Depth ft bgs*	Test	Class'y	%pass #200	w_{LL}	w_{PL}	Friction Angle	Cohesion (TSF)
HL-08-02	20-21.4	Sieve	SP	2	-	-	-	-
HL-08-04	30-32	Sieve	SC	28	-	-	-	-
		UCT	CL	-	36	15	-	0.21
HL-08-05	28-30	Sieve	SC	30	63	43	-	-
		UCT	CH		63	43	-	1.07
HL-08-12	18-20	Sieve	SM	24	41	27	-	-
HL-08-13	28-30							
HL-08-15	28-30	Sieve	SM	28.7	16	16		
		Cu'	SM				26.2	0.28
bgs – below ground surface								

4.2 Details of Project Features.

Raising the Ground. Raising the ground to achieve the required level of protection is the most straightforward technique. The materials used should be of a fine-grained nature to prevent through seepage. An adequate supply of suitable fine-grained borrow material must be identified.

New Concrete T-Wall or I-Wall. The concrete T-walls and I-Walls should be designed according to all existing USACE criteria for such structures. These will be supported by sheetpile driven deep enough to provide the necessary lateral support. The foundations materials have sufficient shear strength to provide the necessary lateral support. The sheet piling should be driven deep enough to penetrate the underlying layer of fine grained, Tidal Marsh materials to provide seepage cutoff.

Table B3- 4: Proposed Project Feature by Geotechnical Reach

Geotechnical Reach	Project Feature	Boring	Slope Stability/ Seepage Analys	CWLSheet
Reach 6	Raised Grd Surf			
	Concr T-Wall	HL-08-15 & -16	Y	Y
	Raised Grd Surf			
Reach 5	On-Shore Dune	HL-08-14 to-13	Y	
	Raised Blk-Head	HL-08-12	Y	Y
	On-Shore Dune	HL-08-11	Y	
	Raised Blk-Head	HL-08-11	Y	Y
	On-Shore Dune	HL-08-10	Y	
	Raised Blk-Head	HL-08-10	Y	Y
	On-Shore Dune	HL-08-09	Y	
Reach 4	Cap Exist Blk-Hd	HL-08-09 & -08	Y	Y
	New Blk-Hd	HL-08-09 & -08	Y	Y
	Cap Exist Blk-Hd	HL-08-09 & -08	Y	Y
Reach 3	New Blk-Hd	HL-08-08	Y	Y
	On-Shore Dune	HL-08-07	Y	
	New Blk-Hd	HL-08-07	Y	Y
Reach 2	On-Shore Dune	HL-08-06 & -05	Y	
	Raised Blk-Head	HL-08-05, -04, -03	Y	Y
Reach 1	On-Shore Dune	HL-08-02 & -01	Y	

4.3 Additional Geotechnical Information Needed to Complete Design.

The most pressing need is to complete additional high quality exploration during the Plans and Specifications phase that penetrates much deeper into the underlying Navesink formation in the vicinity of the T-wall and bulk head features. These borings should include sample locations at 5-foot centers, with Atterberg limits tests run on all fine grained samples, mechanical sieve analyses run on all coarse grained samples, and all samples classified by the laboratory according to the Unified Classification system. Additional undisturbed samples and tri-axial strength testing of the Tidal Marsh layer should be completed to support the design of the T-wall and I-Wall features.

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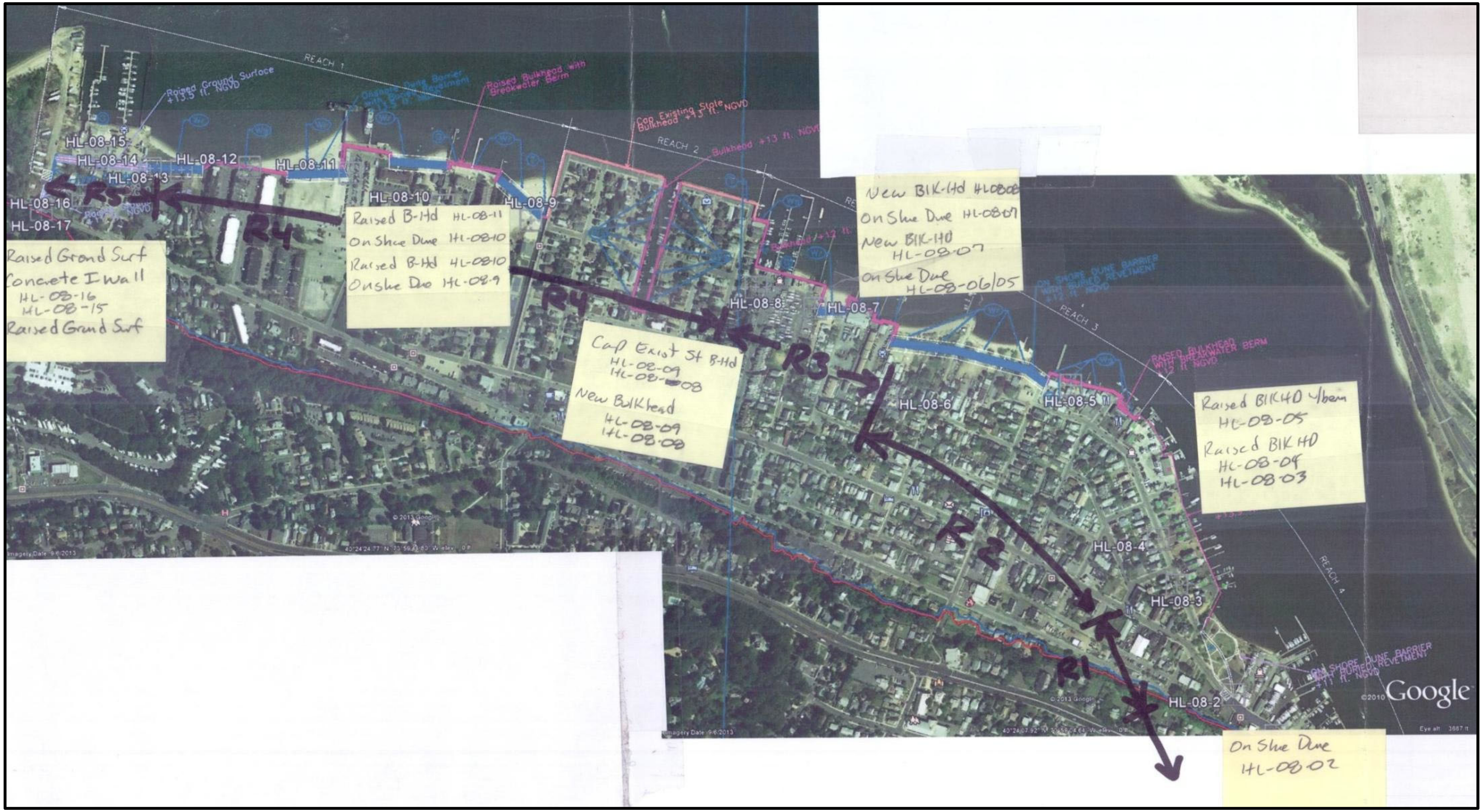

Figure B3- 4: Limits of Geotechnical Reaches Based on Site Specific Exploration and Testing

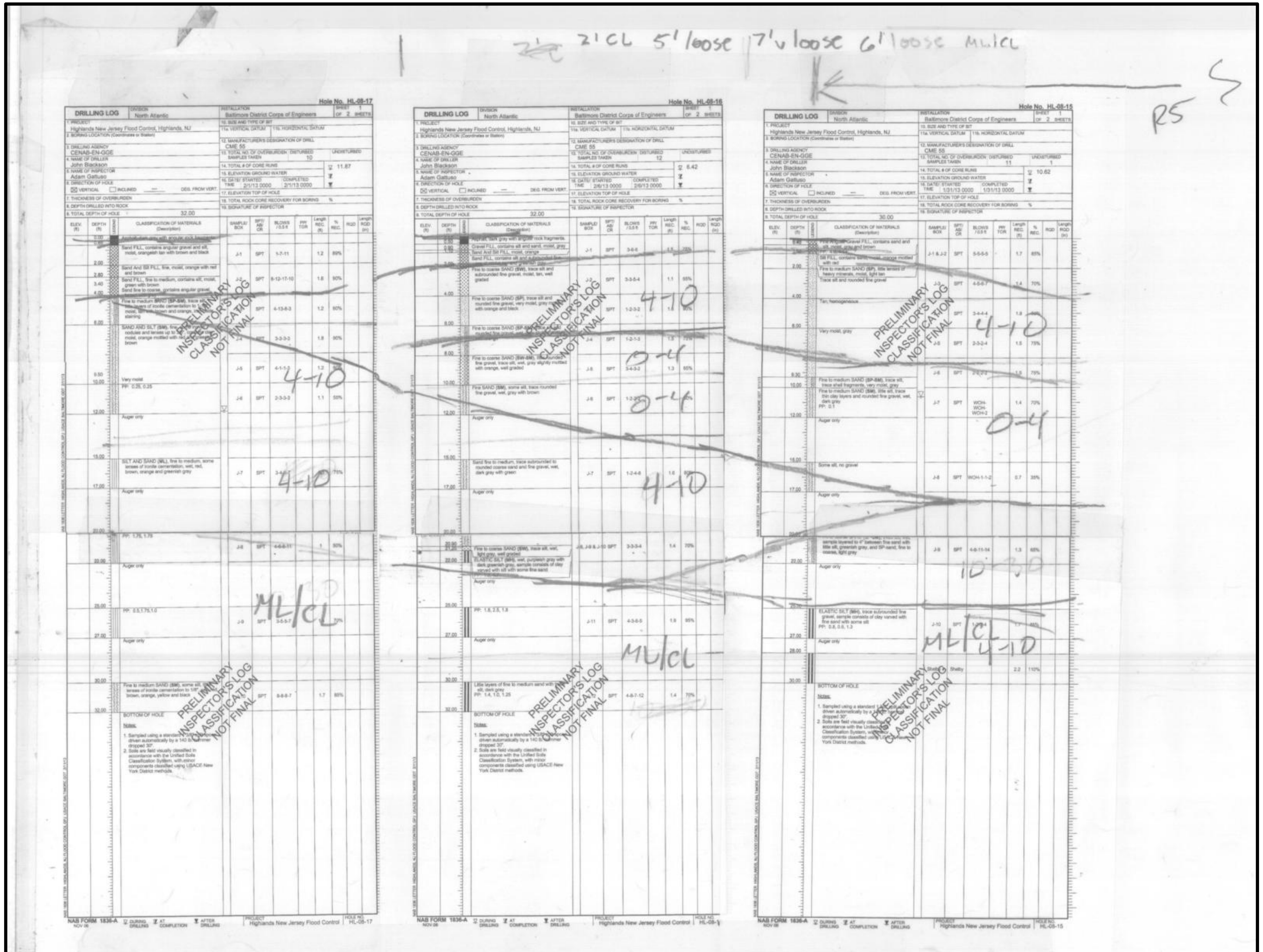

Figure B3- 5: Geotechnical Reach R5

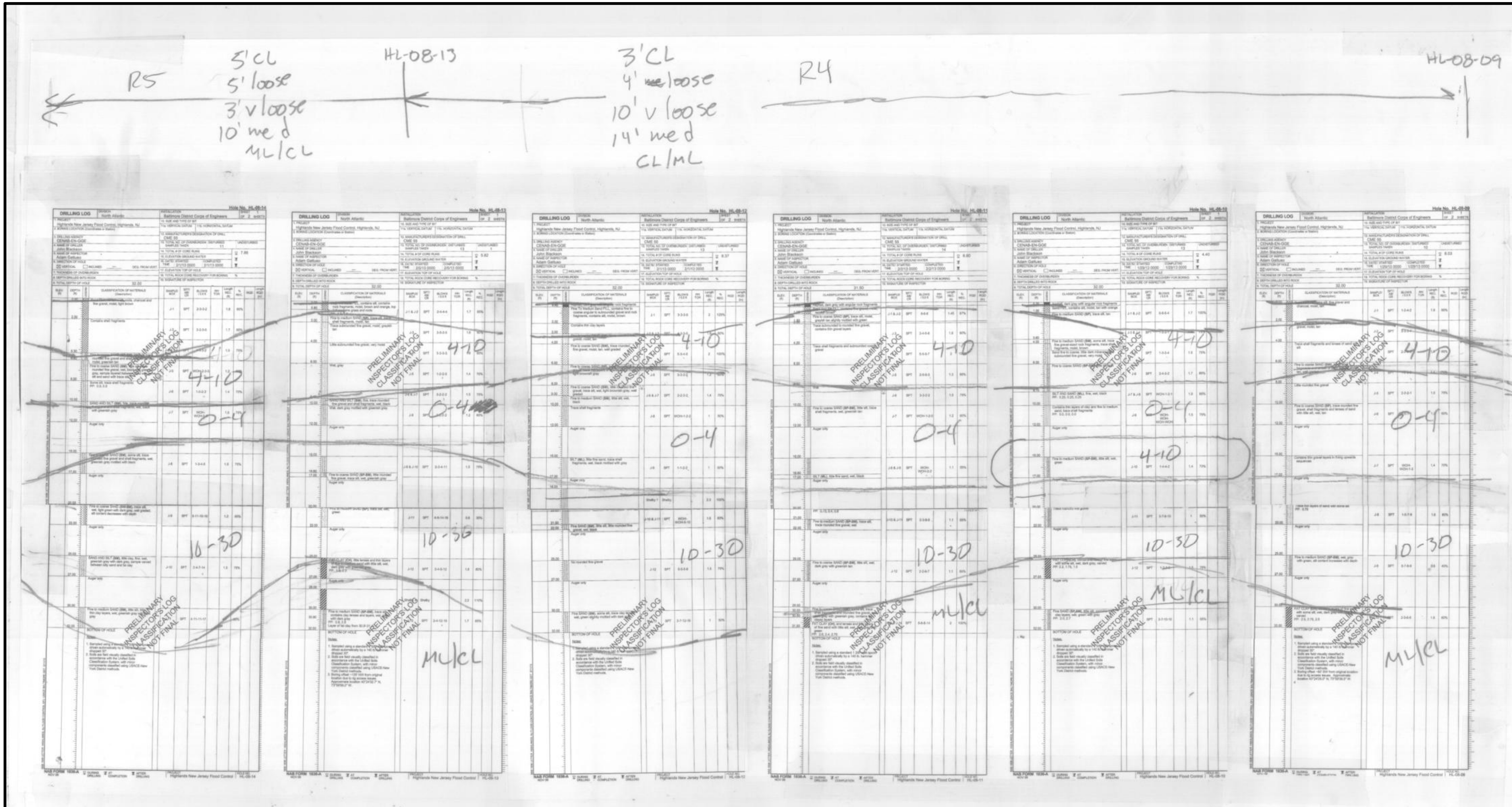

Figure B3- 6: Geotechnical Reach R5 and R4

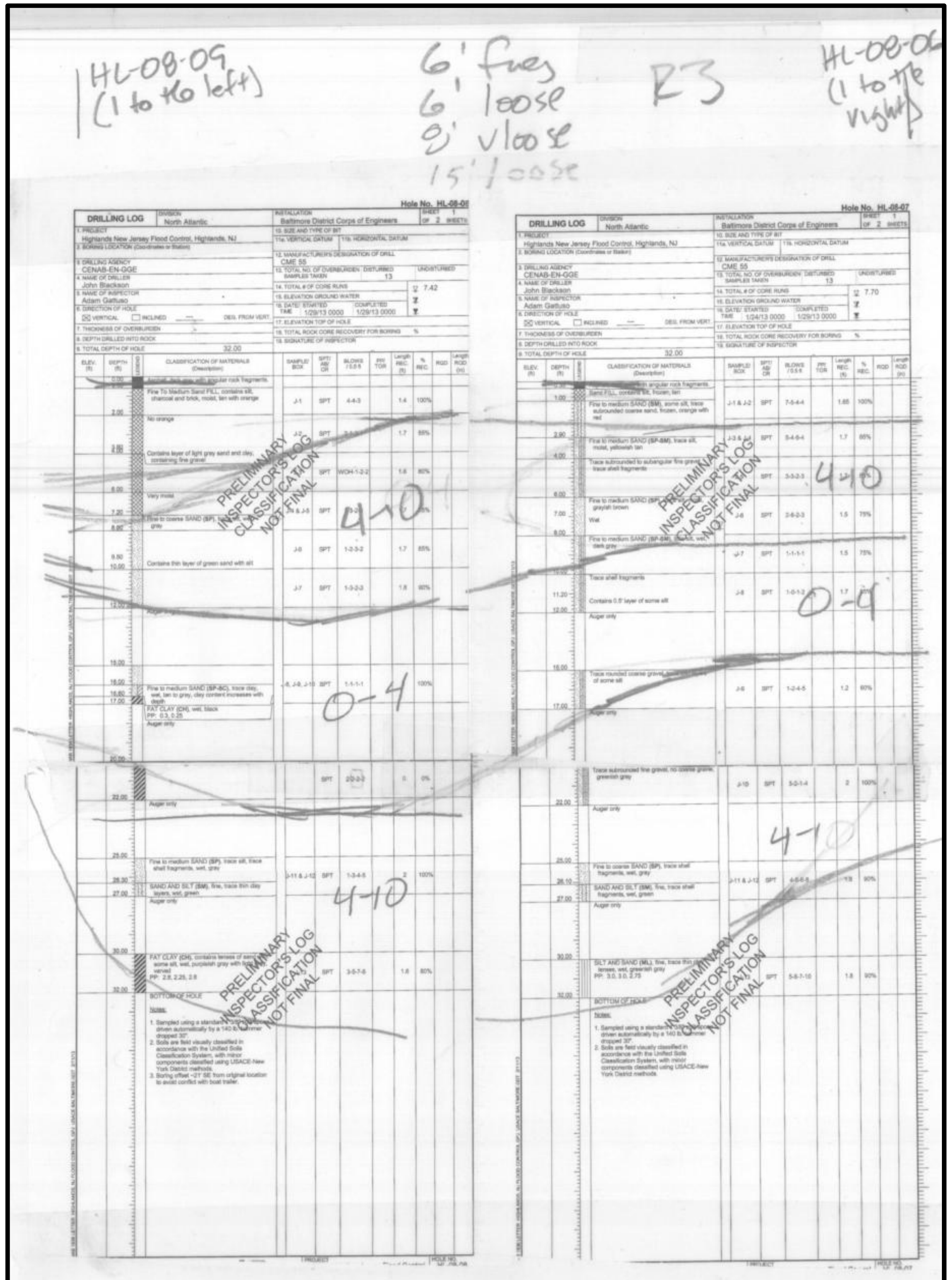

Figure B3- 7: Geotechnical Reach R3

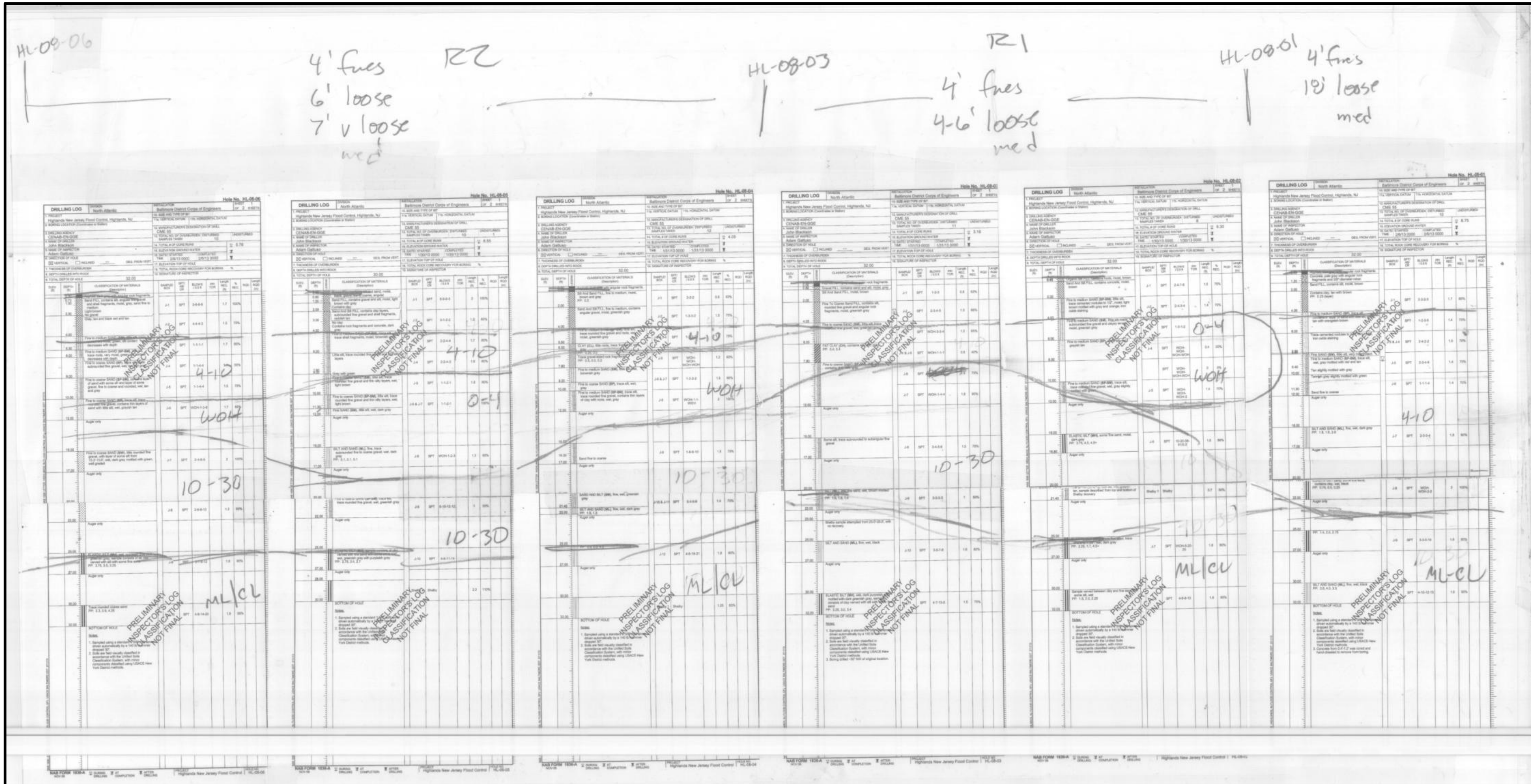

Figure B3- 8: Geotechnical Reaches R2 and R1

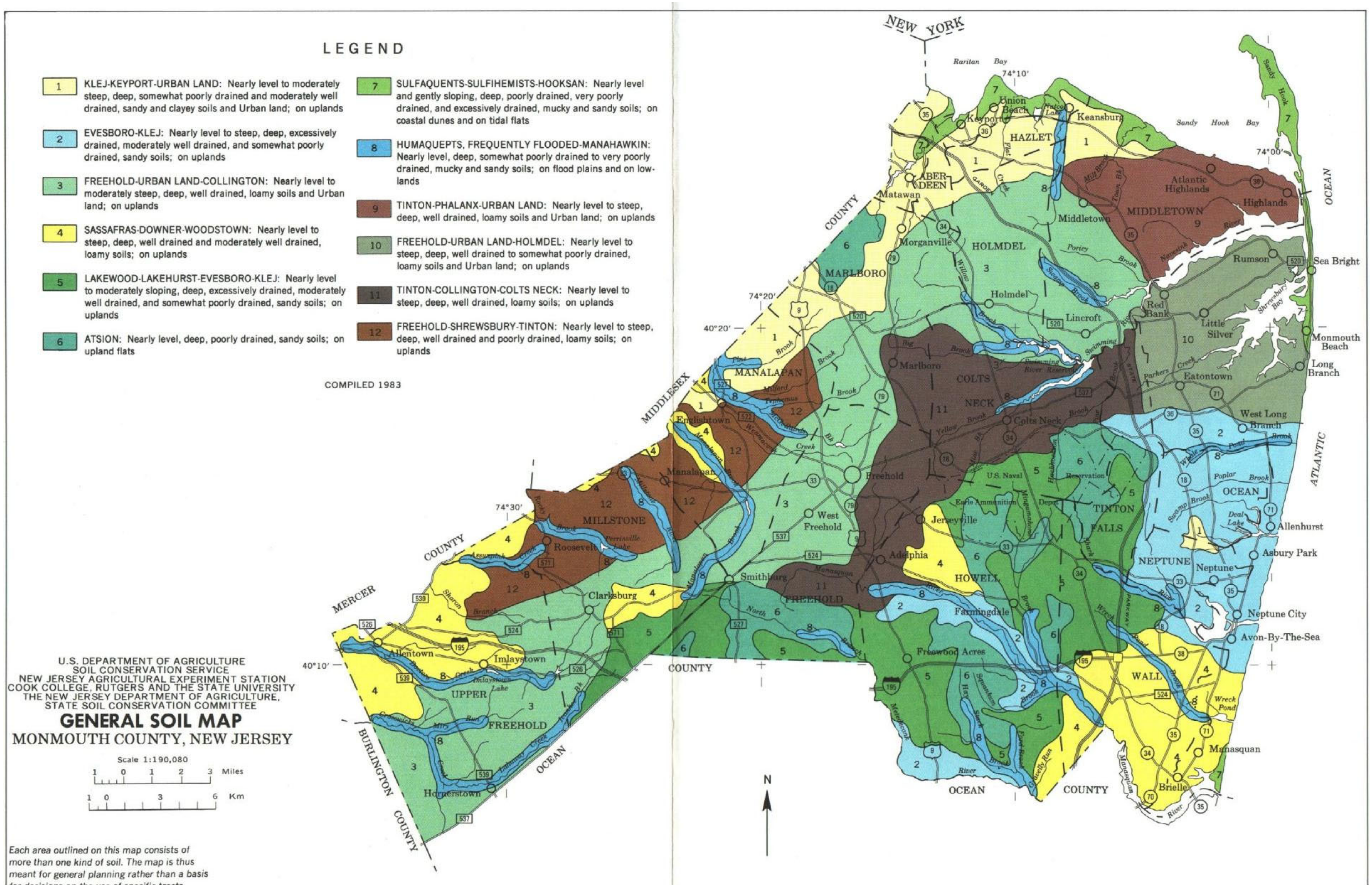

Figure B3- 9: General Soils Map of Monmouth County, 1981

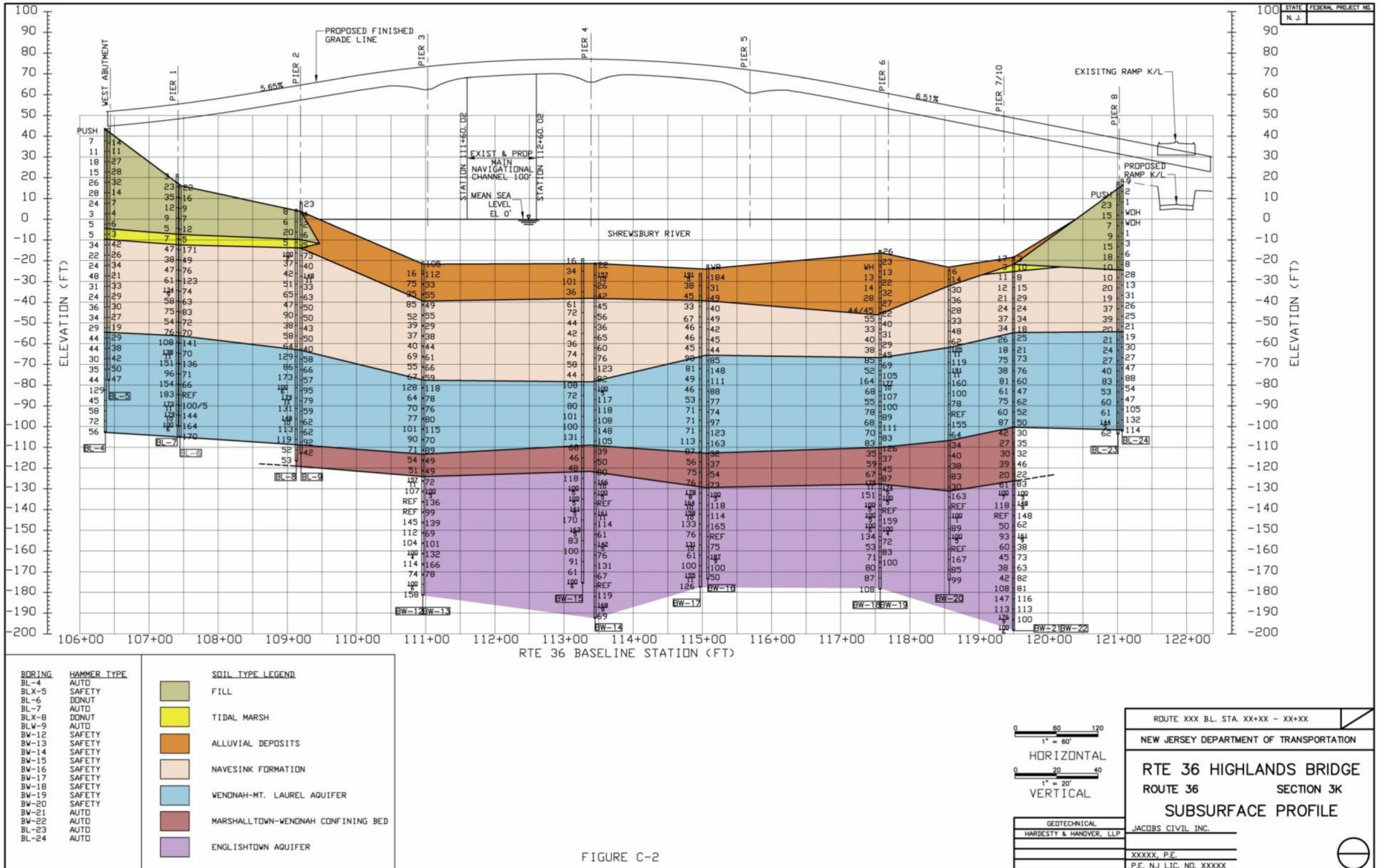

Figure B3- 10: Rt 36 Highlands Bridge Subsurface Profile