GREAT LAKES FISHERY & ECOSYSTEM RESTORATION (GLFER)

RIVER RIPARIAN CONNECTIVITY & HABITAT

APPENDIX F – GEOTECHNICAL ANALYSIS

U.S. Army Corps of Engineers, Chicago District
Geotechnical & Survey Section

7 January 2016

GEOTECHNICAL APPENDIX

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Attachment 1: Draft River Riparian Ecosystem Subsurface Investigation SOW
Attachment 2: Stone Size Determination for Timber Erosion Protection

GEOTECHNICAL APPENDIX

INTRODUCTION

1. The Great Lakes Fishery & Ecosystem Restoration (GLFER) was authorized in Section 506 of the Water Resources Development Act of 2000. The purpose is to restore fishery, ecosystem, and beneficial uses of the Great Lakes in cooperation with non-Federal interests. This specific project is located along the north branch of the Chicago River, between Lawrence Ave and Peterson Ave in Chicago, Illinois.

2. The proposed project consists of three contiguous parks along the north branch of the Chicago River (NBCR) and North Shore Channel (NSC); Ronan Park, River Park, and Legion Park (south to north). The total area of this project is about 93 acres and consists of both river bank, river, and riparian zones. It also includes the River Park Dam, which is a defunct structure blocking the North Branch of the Chicago River. The goals of this project are to increase species richness by creating a greater connectivity, removing invasive species, adding high quality vegetation, and increasing the connectedness of the river with the riparian areas.

Figure 1. Project Location

3. The existing river banks are steep and create a barrier between the land and water, with large, invasive vegetation along the banks. These have increased bank erosion. The existing dam is constructed out of concrete, but is showing significant signs of degradation. It still effectively prevents the majority of species movement up the NBCR.

4. This study was conducted to ascertain the feasibility of restoring the river, banks, and upstream areas by altering the hydrology, eliminating invasive plant species, planting native vegetation, and stabilizing river slopes. The existing dam may be modified/ removed to increase the quality of habitat. Once these measures are implemented, then invasive plant species can be replaced with native vegetation.

PROJECT AREA BACKGROUND

5. With the arrival of permanent settlers in the 1770s, the Chicago area's prairies, savannas, and sloughs underwent numerous changes induced by two centuries of rapid population growth. Prairies were changed to vacant lots between buildings, while woodland areas dwindled to the outskirts of the expanding community. Marshland was drained and filled to create suitable foundations and brick for new construction. The Chicago and Calumet rivers were dredged, straightened, moved and/or reversed for industrial purposes. The natural shorelines of Lake Michigan and other large hemi-marsh basins were filled with an assortment of waste materials.

6. The North Shore Channel was dug in the early 1900's, connecting the North Branch of the Chicago River to Lake Michigan at Wilmette. Most of this project is along this channel. To control the grade of the river after completing the channel, the River Park Dam was installed on the NBCR at the confluence with the NSC. This dam is a concrete, low-head spillway dam which has degraded over the past century. However, it still reduces the connectivity of the river, and grade control is not necessary anymore.

Figure 2. Photo Looking Upstream at Dam

GEOLOGY

7. The geology of the Chicago area is largely a consequence of a series of continental glacial advances and retreats. During the most recent glaciations, the Wisconsinan, the area was covered by several thousand feet of ice of the Lake Michigan lobe. The area had been covered with surficial deposits up to 300 feet thick that were deposited by glaciers and higher level stages of Lake Michigan. Bedrock typically consists of sedimentary dolomitic limestone, dolomite shale, and sandstone.

8. The Illinois State Geological Survey compiles previous subsurface investigations (http://isgs.illinois.edu/?q=ilwater), which included a few within several hundred feet of this project. These borings did not include any information on the overburden, other than calling it 'glacial drift' with a thickness between 40 to 85 feet. More information was included on the bedrock, and the uppermost bedrock layer was described on the logs as Silurian Niagran series dolomitic limestone. The bedrock elevation was around 550 ft NAVD88. Based on these depths and the proposed work for this project, bedrock encounters during construction are very unlikely.

9. Based on the Illinois State Geological Survey, Surficial Geology of the Chicago Region Map (1970), the majority of the project is within the Carmi Member of the Equality Formation. This formation is characterized by largely quiet water lake sediments; dominantly well bedded silt, locally laminated and containing thin beds of clay; local lenses of sand and sandy gravel along beaches. A small portion of the project area is within the Dolton Member of Equality Formation, which is defined as largely shallow water, near shore lake sediments in beaches, bars, spits, and deltas; dominantly medium grained sand; contains beds of silt where gradational to Carmi Member; local lenses of sandy gravel along beaches. As shown in the map below, the Dolton area is on the east side of the river, near the confluence of NBCR and NSC.

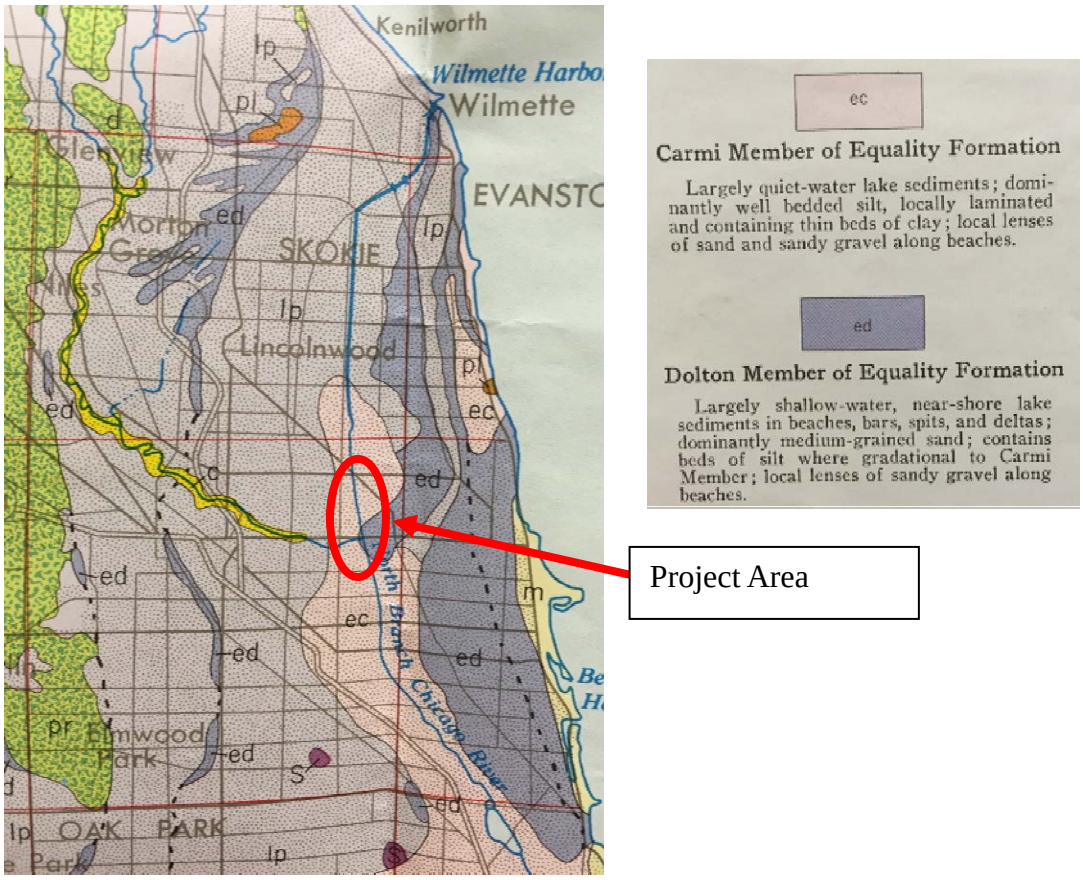


Figure 3. Soil Type Map of Project Area

10. These soil formations are likely buried and/or disturbed by manmade modifications. The proposed soil borings will assist in delineating where native material starts in the stratum, as well as, determining the makeup of the fill materials likely placed onsite.

SITE HISTORY

11. Since the project is in the urban area of Chicago, the surface soils have been heavily altered within the last 200 years. The soils excavated from the North Shore Channel in the early 1900's are likely to have been placed along the channel and spread out to fill in low spots and create the flat, urban environment now present. Thickness of fill soils will likely vary over the course of the project, but are likely to consist of materials similar to those native to the area.

12. As shown on the 1901 and 1929 quad map below, the North Shore Channel was constructed sometime between this timeframe. Prior to 1901, several small creeks were present, which were ostensibly filled in during construction of the North Shore Channel. It appears the NBCR was also straightened and rerouted to accompany the growing city. These locations of former creeks are of particular concern, as the subsurface conditions may include high groundwater, organic soils, and a thick layer of fill soil.

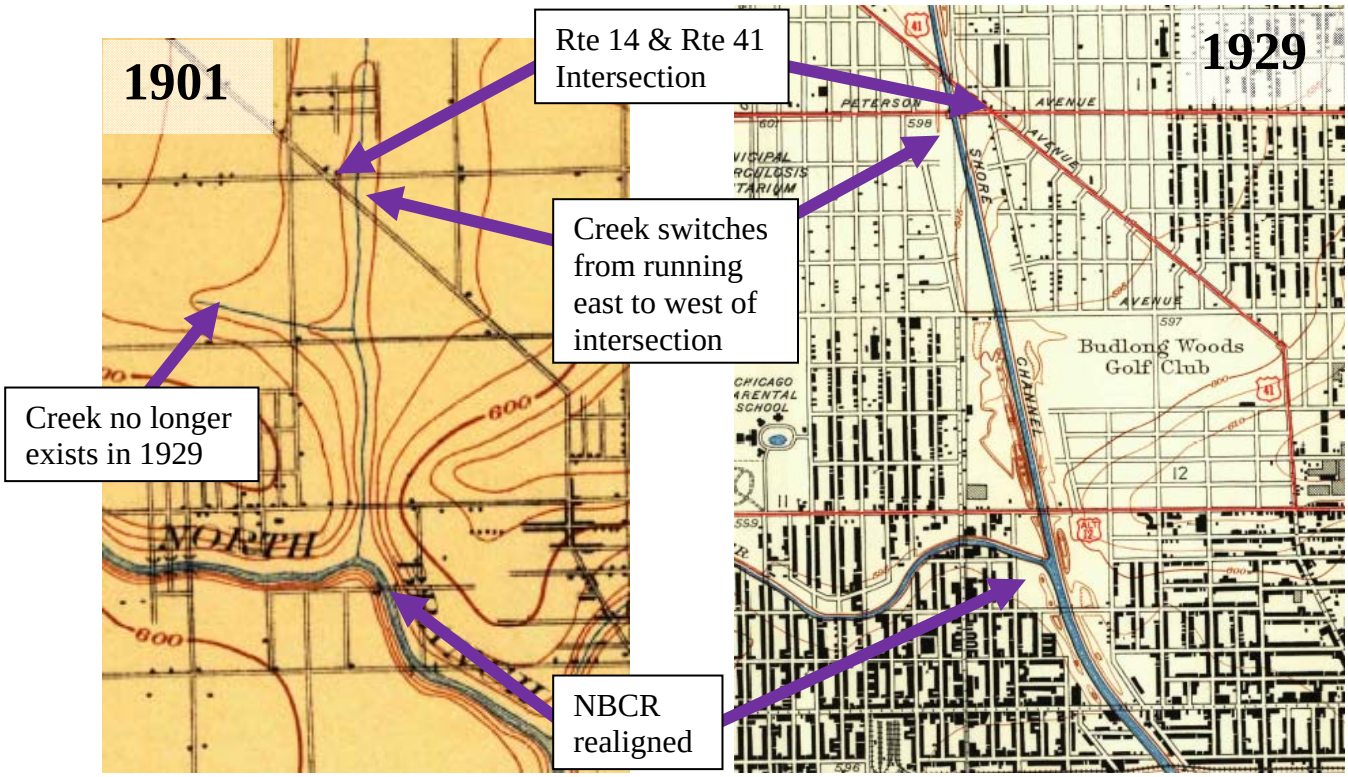


Figure 4. 1901 Versus 1929 Quad Map

13. To determine where the 1901 creek is located, the map was overlain on an aerial map, which is shown in *Figure 5*. This map indicates the original 1901 channel intersects the North Shore Channel in two places; about halfway between Foster Ave and Bryn Mawr Ave, as well as, just north of Bryn Mawr Ave. These locations will be of particular interest during the subsurface investigation.

Figure 5. Project Map with 1901 River Channel Overlain

LOCAL GEOLOGY

14. A subsurface investigation is planned for this project to identify the soil types likely to be encountered during earthwork. Soil borings will focus on the areas where bank grading is most likely. Areas around the previously filled in creeks and within the small area attributed to the Dolton Member formation will also be investigated. The draft SOW is included in Attachment 1, and the work will be completed by TTL in early 2016.

15. The investigation will also include coring through the concrete-lined channel upstream of the dam to quantify the concrete thickness, as well as, a boring just upstream of the dam to determine materials behind it.

RECOMMENDATIONS

16. There are several features included in this project that require some geotechnical design and considerations to develop a proper plan and estimate. These features include grading the banks of the river and removing the dam.

Bank Grading

17. There are several areas being considered for bank grading along this project. These banks should be graded to a minimum 3H:1V slope and vegetated to minimize erosion. It should be noted that a similar bank grading project was completed about 1 mile south of this project; at Horner Park in 2014 (*Figure 1*). During the grading portion of the work in May, several locations with groundwater seepage were noted (*Figure 6*), which were classified as a differing site condition. Based on the rate of flow, location, and clarity of water, it was determined that the water could be the result of exposing groundwater. This groundwater would have endangered the slope stability, so to reduce the risk at these locations, erosion protection was added (*Figure 7*).

Figure 6. May 2014 Photo of Seepage

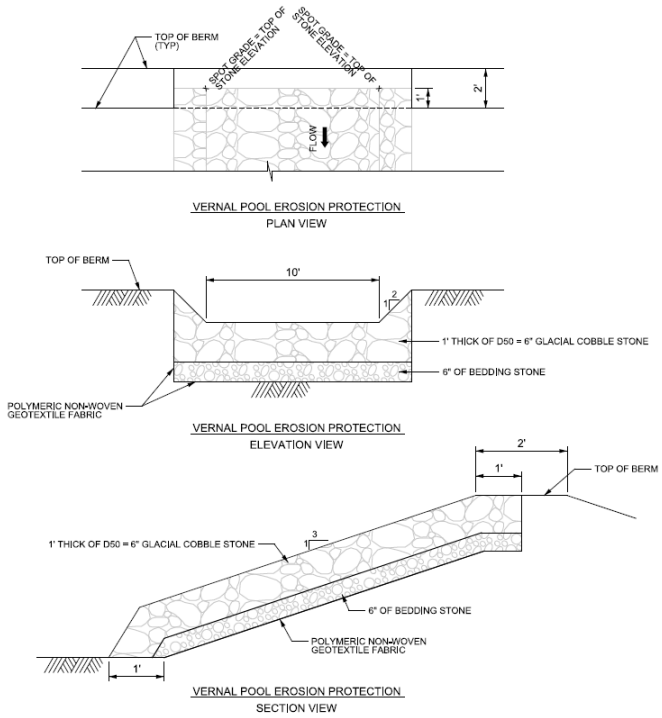


Figure 7. Plans for vernal pool erosion protection added to seep areas

18. If this issue occurred again at River Riparian, it would probably occur at the old stream alignments shown on *Figure 4*. The historic use of the Horner Park site was an old brick factory that was since filled in. The River Riparian site does not appear to have any industrial sites per the aerial maps and topographic maps in the environmental appendix. The subsurface investigation will help identify if the proposed bank grading areas would exhibit similar issues that would affect construction.

Erosion Control

19. There are at several locations that were observed to be subjected to bank erosion. Two locations are likely due to discharge from the opposite bank. The first is on the east bank, opposite from the dam and the second is on the west bank, opposite a CSO outfall. Other areas considered are near bridge piers. The stabilization technique planned for these areas are shown on *Figure 8* below using buried timbers and stone beneath fill. This solution appears that it would meet stability standards, but the final design will need to be reviewed by a geotechnical engineer to examine actual grades and construction techniques.

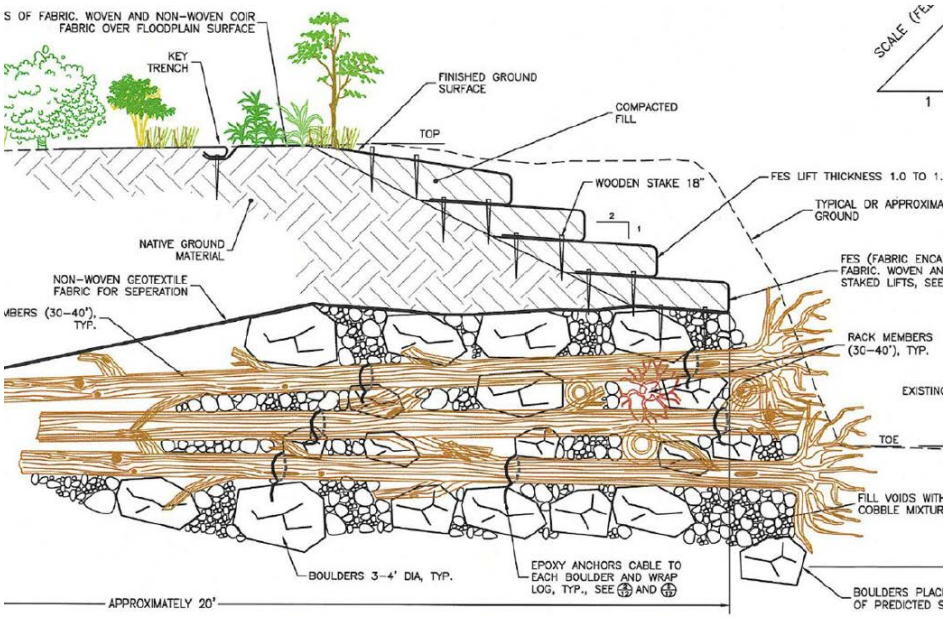


Figure 8. Typical Timber/Stone Revetment

20. To provide a stone size to TS-DC for the stone depicted in the drawing above, it was assumed that the larger stone would be the same as specified by TS-HH for erosion protection at the toe; RR-6. The gradation of RR-6 was compared to smaller stone in order to find a gradation that would be able to sit on top and not fall through the cracks. This smaller stone layer will be used on top of the RR-6 as a filter between the large stone and ground material. Per the analysis in Attachment 2, the appropriate stone size is CA-5.

Dam Removal

21. In order to remove the dam, significant amount of concrete will need to be hauled either offsite, or buried in an approved location onsite. The subsurface investigation in Attachment 1 will core the concrete-lined channel to quantify the concrete volume.

22. Both dam abutments are extend about 100 ft away from the actual dam to support the banks. The south bank has a concrete bike path, which would have to be removed/relocated if the south dam abutment was removed. The north bank connects to a sporting field not owned by the park district, which would be affected if the north abutment was removed. Therefore, these abutments should be kept in place to avoid affecting the neighboring structures and recreation fields.

SUMMARY

23. The Geotechnical Appendix provides general site characteristics and recommendations as they are known at this time. The subsurface investigation planned for early 2016 will better identify any potential issues not apparent at this time, which would be applied to the design.

RIVER RIPARIAN ECOSYSTEM RESTORATION
Subsurface Investigation

Scope of Work

INTRODUCTION

1. The River Riparian Ecosystem Restoration project is located in Chicago, IL, along the North Shore Channel and North Branch of the Chicago River between Lawrence Ave and Peterson Ave. The project includes removing invasive species, habitat restoration, regrading the banks of the river/channel, and removal of a dam at the confluence. The general site conditions are an urban park with trees and walking path. Based on historical topographic maps, the North Shore Channel was constructed between 1901 and 1929.

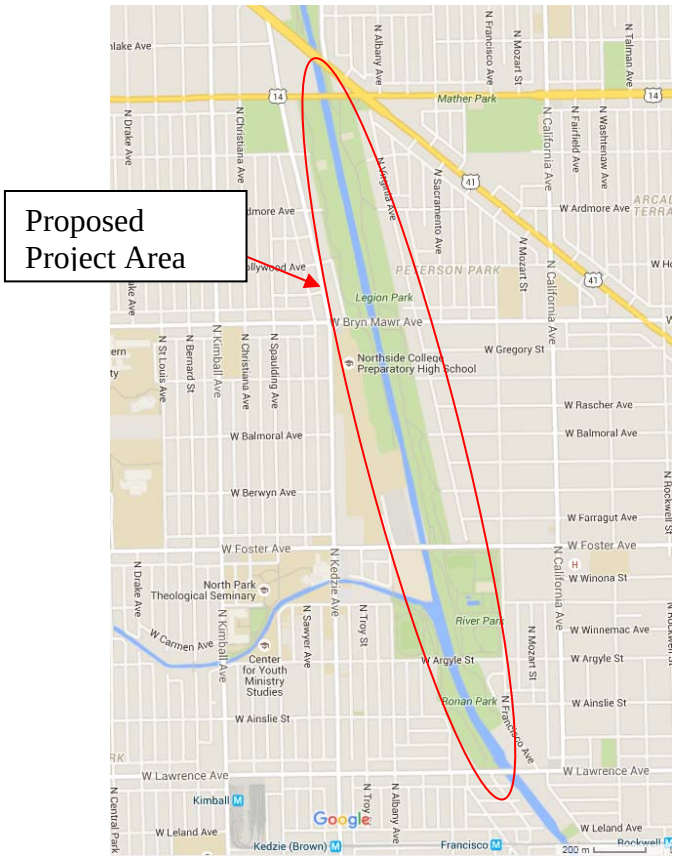


Figure 1: Site Overview

DESCRIPTION OF WORK

2. The geotechnical field investigation shall consist of drilling and sampling eight (8) holes along the river bank to a depth of 25 ft, each. The locations of these borings are shown on Plate 1 with estimated coordinates. The intent of each soil boring is to be at the top of the river bank where grading is proposed, so if there is room to shift the boring closer to the river, the contractor shall do so. If a location is inaccessible due to vegetation, structure, tree canopy, etc., offset along the river, not away if possible.

3. In addition to the river bank soil borings, the North Branch of the Chicago River channel upstream (west) of the dam shall be investigated. The channel is concrete lined and during low flow, the water level is generally about 1 ft deep. Refer to the North Branch Chicago River gage at Albany Ave (http://water.weather.gov/ahps2/hydrograph.php?wfo=lot&gage=nbai2) to determine the actual depth. Within the channel, drill five (5) locations to determine the thickness of the concrete. One of these locations (RR-16-09) will be the farthest east and include drilling and sampling to a depth of 15 ft. An aerial is provided below with descriptions.

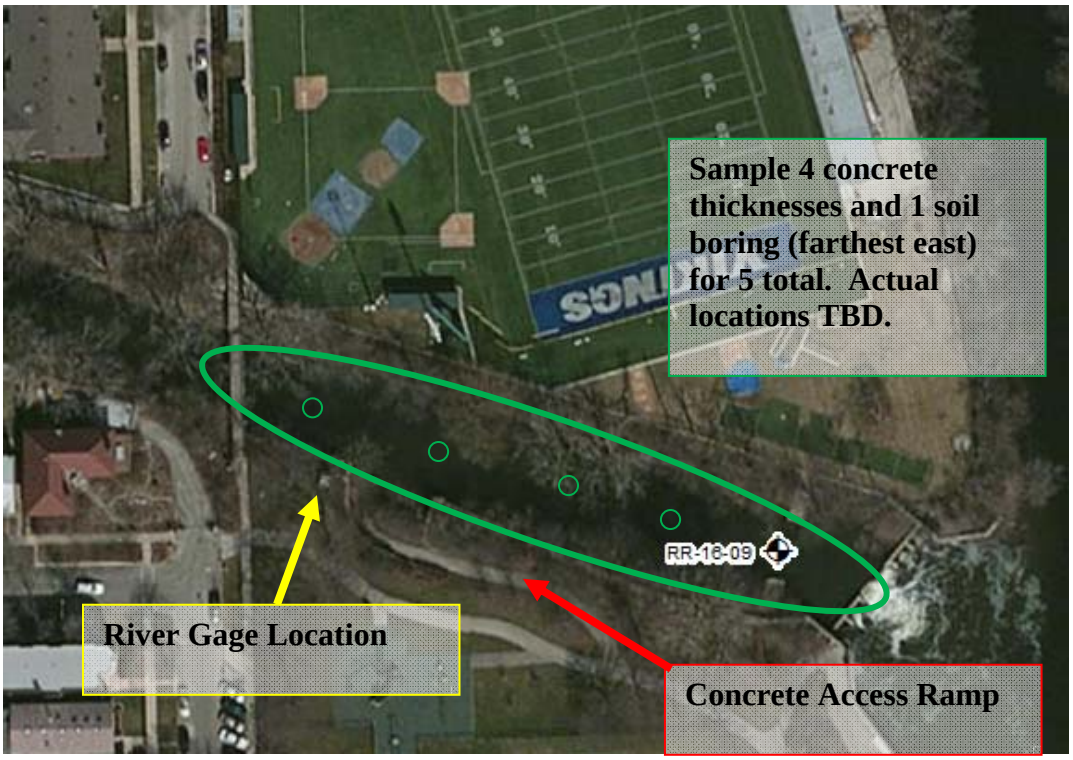


Figure 2: Aerial of Concrete Channel Investigation

4. A brief report of the field activities and laboratory test results for engineering properties shall be prepared and submitted to the Chicago District.

REFERENCES

5. The publications listed below form a part of this scope-of-work to the extent referenced. The publications are referred to in the text by basic designation only.

- Safety and Health Requirements Manual, EM 385-1-1, November 2003
- Survey Markers and Monumentations, EM 1110-1-1002, September 1990
- Laboratory Soils Testing, EM 1110-2-1906, August 1986
- ASTM D 1586, “Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils”
- ASTM D 1587, “Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes”
- ASTM D 422, “Standard Test Method for Particle-Size Analysis of Soils”
- ASTM D 2216, “Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass”
- ASTM D 2488, “Standard Practice for Description and Identification of Soils”
- ASTM D 4318, “Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils”
- ASTM D 5434-93, "Standard Guide for Field Logging of Subsurface Explorations of Soil and Rock"

COORDINATION OF WORK

6. The Technical POC for this task order is Dan Ferris, (312) 846-5477 or daniel.j.ferris@usace.army.mil. The Contracting Officer’s Representative (COR) is Yuki Galisanao at (312) 846-5458 or yuki.j.galisanao@usace.army.mil.

7. The Technical POC will coordinate the technical aspects of the work. The Contractor shall advise the Technical POC at least two (2) working days prior to commencement of new field activities and of any changes to the performance schedule. In the event information or guidance provided to the Contractor is unclear, the question shall be referred to the COR before proceeding with the work item. All submittals required by this task order shall be addressed to the COR.

SCHEDULE

8. An ACCIDENT PREVENTION PLAN (APP) shall be submitted within 7 calendar days of Contractor's acceptance of the task order. The Government will notify the Contractor of acceptance of the required APP. Upon notification of acceptance of the Plan and receipt of any required permits, the Contractor shall begin work immediately. The Contractor shall deliver the required work items to the COR complete and in the required form. The number of days specified below refers to calendar days after the effective date of the task order.

- Complete APP (7 days)
- Establish borehole locations and conduct utility clearance. (14 days)
- Complete drilling of boreholes and sand sampling. (28 days)
- Complete laboratory testing. (42 days)
- Submit draft report. (49 days)
- Submit final report. (7 days after completed review by POC)

QUALITY CONTROL

9. A Quality Control Plan (QCP) shall be submitted as part of the fee proposal. The QCP shall include the names and duties of the team members assigned to work on this project, a quality control checklist for the final product, and a brief description of the specific equipment and procedures to be implemented for this work.

10. An experienced field engineer or geologist shall be identified in the QCP, to inspect and interpret the information obtained from the soil sampling. The individual shall be responsible for logging the boreholes, maintaining a daily log, and ensure that all work involved in the overall program is done in a professional manner and the information obtained is representative of the subsurface conditions encountered, in general conformance to ASTM D 5434.

GOVERNMENT FURNISHED ITEMS

11. Government reference publications are available at http://www.publications.usace.army.mil/. No Government furnished equipment will be available for the work required by this contract.

12. All contractor and all associated sub-contractors' employees shall comply with applicable installation, facility, and area commander installation/facility access and local security policies and procedures (provided by government representative, as needed).

DRILLING PROGRAM

13. Utilities. The Contractor shall be responsible for confirming the location of utilities that may interfere with acquisition of the data. Locations of potential buried utility lines and facilities such as water, gas, sewer, power, telephone, TV cable, etc. must be established within the areas to be drilled. Boreholes shall be positioned so as to avoid these underground utilities.

14. Onsite Meeting. A USACE representative will be meet the Contractor onsite the day the channel cores are scheduled to jointly select the locations. The proposed channel core locations would be selected based on access, water level, and safety. If requested, the riverside boring locations can be reviewed as well.

15. Drilling. Borings shall be performed at the approximate locations on Plate 1. The static water level shall be measured during and immediately after drilling is completed.

16. Borehole Survey. After drilling completion, USACE will survey the eight borehole locations and provide coordinates and elevations for the final logs.

17. Channel Concrete Drilling Survey. The locations of the concrete drilling shall be documented and measured by the Contractor via tape from a fixed point on land, via handheld device, or another method specified in the QCP. If using a fixed point on land, USACE can provide the coordinates.

18. Clean-Up and Restoration. All work areas around the borings, as part of this investigation, shall be restored to a condition essentially equivalent to that prior to the work. This includes the disposal of borehole cuttings and evening out any major ruts. Backfill of the borings shall be completed via grouting. Cleanup procedures, including backfill, shall be included in the QCP.

19. Soil Sampling. Borings shall be sampled via SPT at a maximum of 2.5 foot intervals. Eight (8) total undisturbed cohesive samples shall be collected via ASTM D 1587 (Shelby Tubes) in the river bank locations. The locations of these undisturbed samples shall capture representative samples throughout the substrata. The remaining samples shall be collected via ASTM D 1586 (split-barrel). A representative soil specimen shall be taken for each interval sampled, including any changes within an interval. A label shall be affixed to the sample container with the information shown on the sample label below. Pocket Penetrometer and Pocket Torvane readings shall be taken on all cohesive samples and shown on the final logs. Storage, packaging, and shipment instructions for all samples shall be described in the QAP. At a minimum, each sample container will be marked with the following information:

a. Project Name
b. Boring Number
c. Sample Number
d. Depth of Sample
e. Sampling Date

LABORATORY TESTING PROGRAM

20. Laboratory Testing. Laboratory geotechnical analysis of drilling samples shall be conducted in accordance with appropriate testing procedures indicated. The samples to be tested shall be determined jointly by the Contractor and the COR after review of the field boring logs. The testing required for the samples collected are indicated in the table below.

Table 1. Laboratory Testing Program

Test Description	Test Method	Number of Tests	Remarks
Visual Classifications	ASTM D 2488	90	All samples
Moisture Content	ASTM D 2216	90	All samples
Hand Penetrometer/Torvane		65	Cohesive samples
Atterberg Limits	ASTM D 4318	3	Cohesive samples
Combined Analysis	ASTM D 422	5	Coarser grained samples
Dry Density	ASTM D 2937	8	Shelby Tubes
Unconfined Compression	RIMAC	8	Shelby Tubes

REPORT

21. The SUBSURFACE INVESTIGATION REPORT shall include all the information collected with respect to the drilling, laboratory testing, and conclusions summarized under one cover for approval, record purposes, site characterization, and future design. As a minimum, the REPORT shall consist of the following outline:

a) Authorization and Purpose of Investigation
b) Project Location
c) Subsurface Exploration (include a table providing the following information: Project, Boring_No, Northing, Easting, State_Plane, Hole_Depth, Drilling_Firm, Date_Drilled, Borehole_Status)
d) Subsurface Conditions
e) Engineering Properties
f) Drawings
    - Boring Location Plan
    - Concrete Drilling Plan
    - Geotechnical Data Sheet
g) Raw Data
    - Boring Logs
    - Concrete Thicknesses
    - Laboratory Testing Data
h) Photographic log of borings and concrete drilling

SUBMITTALS

22. Quality Control Plan. The QUALITY CONTROL PLAN shall be prepared and submitted as part of the cost proposal. If permits are needed that require a fee, these permits shall be identified in the initial QCP and following award of the work shall be submitted to the COR immediately upon receipt.

23. Accident Prevention Plan. The Contractor shall comply with all pertinent provisions of EM 385-1-1. The Contractor shall submit an ACCIDENT PREVENTION PLAN (APP), per paragraph 01.A.11, for the specific work and hazards of the contract. An Activity Hazard Analysis, per paragraph 01.A.13, shall be included in the Accident Prevention Plan for each hazard anticipated in the work. Submit the APP by e-mail to the Technical POC for review and revised as needed until final approval.

24. Progress Payments. The Contractor shall submit Progress Payments to the COR using ENG Form 93 on a monthly basis. A retainage of 10% shall be withheld until the work performed has been accepted. The Final payment request shall include a "Release of Claims".

25. Subsurface Investigation Report. The SUBSURFACE INVESTIGATION REPORT shall include the information as described above. A Draft REPORT shall be submitted via e-mail to the COR and Technical POC for review and comments. The information can be posted to a FTP site that the Technical POC will set up if requested by the contractor. Two copies of the Final REPORT (with CD or DVD) shall be printed following resolution of comments.

26. Format. The submittals shall be printed head to head on both sides of the paper to reduce filing space requirements. The submittals shall also be bound.

- Table of Contents. To facilitate reference and review, the submittals shall include a Table of Contents, which identifies the text, tables, figures, exhibits, appendices, and enclosures.

- Text. All text paragraphs shall be numbered in consecutive order. The text shall be printed on 8-1/2" x 11" paper, single spaced, with a 1" binding margin.

- Exhibits. Exhibits shall be prepared using the Chicago District's standards for Preparation of Drawings. Plates shall be provided on sheets no larger than 11"x17".

- Digitized Data. Information submitted digitally shall be saved onto a CD-R or DVD-R. Text shall be prepared in Microsoft Word2007 compatible format. Spreadsheets shall be prepared in Microsoft Excel2007 compatible format. Drawings shall be prepared in MicroStation V8 compatible format. GIS drawings shall be prepared in ArcGIS compatible format and include Metadata, which should be ISO 19115 or FGDC compliant. Soil boring logs shall be prepared in gINT compatible format. In addition, the entire report, including boring logs and test results, shall be presented in PDF format with appropriate bookmarking. The CD or DVD shall be labeled with the minimum information:

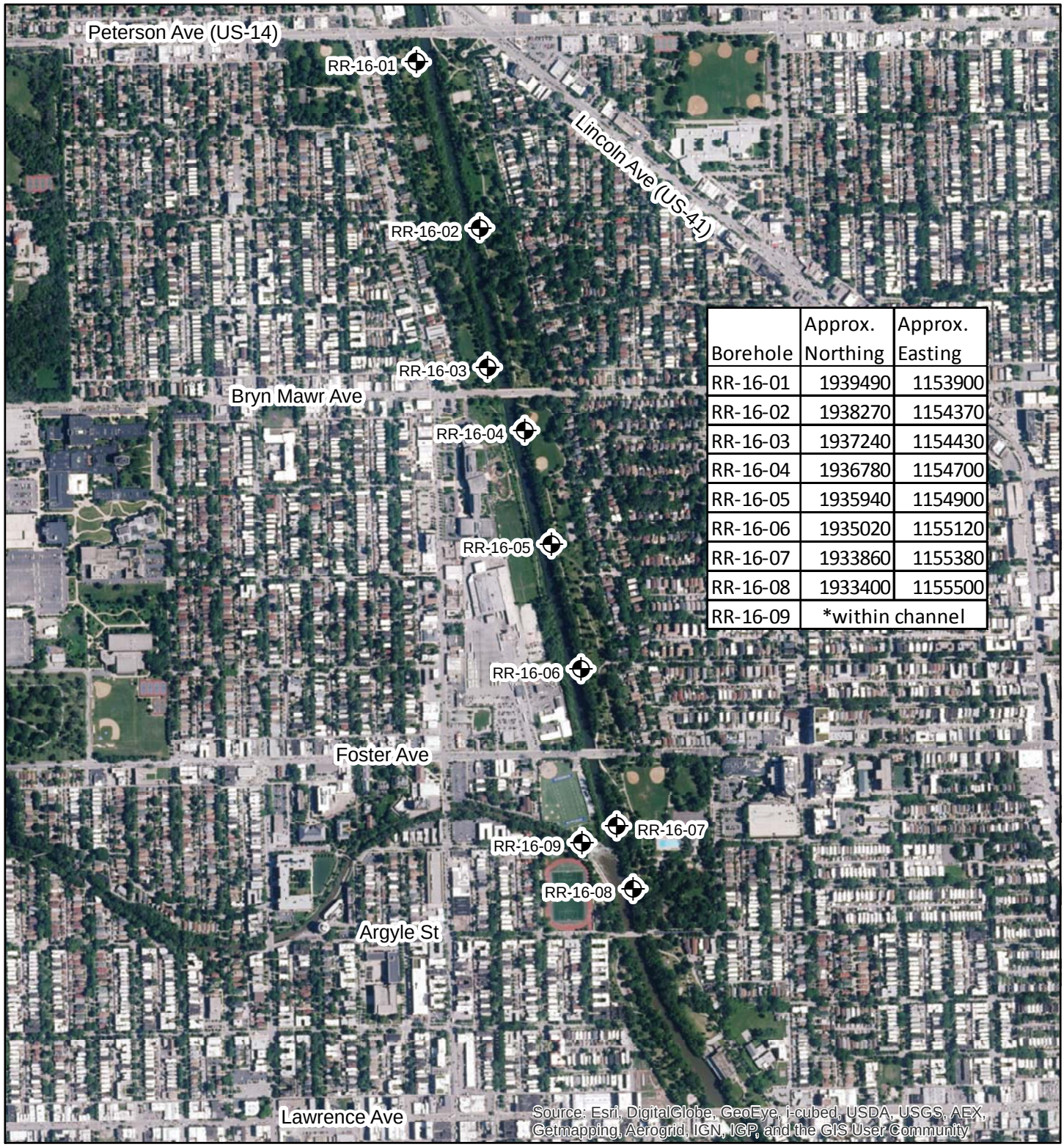
a. Project Title
b. Project Location
c. Contract Number
d. Firm Name
e. Firm Address
f. Report Date

ATTACHMENTS

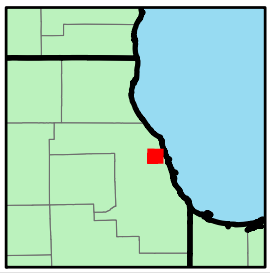
Plate 1: Proposed Boring Location Map

Proposed Boring Locations

U.S. Army Corps of Engineers
Chicago District



Borehole	Approx. Northing	Approx. Easting
RR-16-01	1939490	1153900
RR-16-02	1938270	1154370
RR-16-03	1937240	1154430
RR-16-04	1936780	1154700
RR-16-05	1935940	1154900
RR-16-06	1935020	1155120
RR-16-07	1933860	1155380
RR-16-08	1933400	1155500
RR-16-09	*within channel	



Legend

Proposed Borehole

0 1,000 2,000
Feet

N

*feet in NAD83 Illinois East State Plane

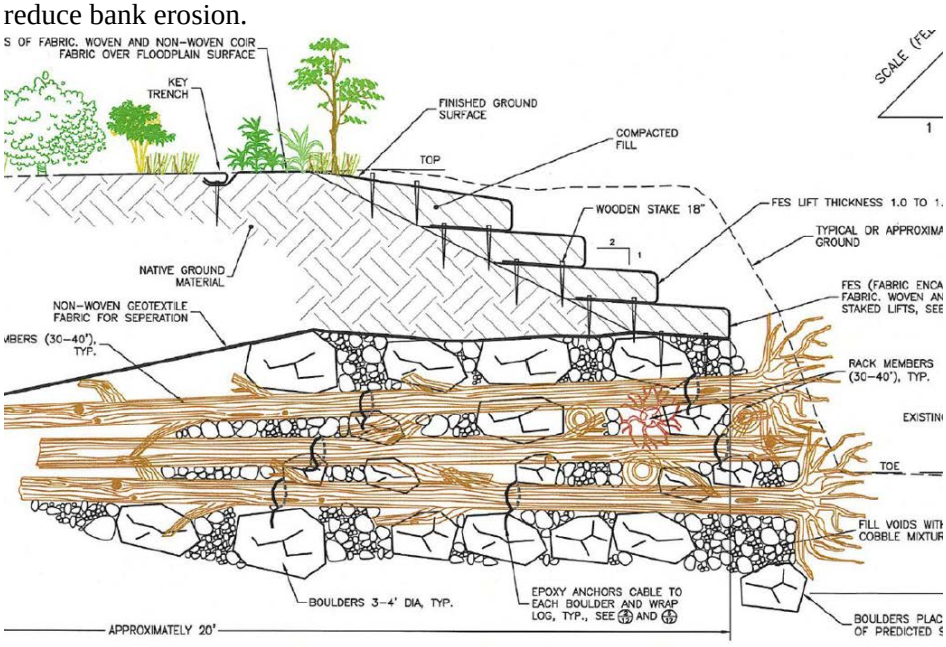
PLATE 1

US Army Corps of Engineers Chicago District	PROJECT TITLE: River Riparian Ecosystem Restoration	COMPUTED BY: DJF	DATE: 12/10/15	SHEET: 1 of 4
	COMPUTATION TITLE: Stone Gradation Compatibility	CHECKED BY: YG	DATE: 12/10/15	

Appendix F - Attachment 2

Introduction

1. As part of the River Riparian Ecosystem project, a cross section such as shown below will be used to reduce bank erosion.



1/7 TYPICAL BANK STABILIZATION SECTION
STA 1+98 TO STAT 4+52

2. A mix of large and small stone is necessary to backfill around the timbers to make sure it retains the structure and settlement does not occur. RR-6 is recommended as the larger sized stone by TS-HH to reduce the chance of erosion. Therefore, the smaller size stone will be adjusted to fit RR-6.

Assumptions

3. The following tables from the IDOT specifications are used to determine gradations.

Grad No.	COARSE AGGREGATE GRADATIONS (metric) Sieve Size and Percent Passing												
	75 mm	63 mm	50 mm	37.5 mm	25 mm	19 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	300 µm	75 µm 1/
CA 1	100	95±5	60±15	15±15	3±3								
CA 2		100	95±5		75±15		50±15		30±10		20±15		8±4
CA 3		100	93±7	55±20	8±8		3±3						
CA 4			100	95±5	85±10		60±15		40±10		20±15		8±4
CA 5				97±3 2/	40±25		5±5		3±3				
CA 6				100	95±5		75±15		43±13		25±15		8±4
CA 7				100	95±5		45±15 3/8/		5±5				
CA 8				100	97±3	85±10	55±10		10±5		3±3 4/		
CA 9				100	97±3		60±15		30±15		10±10		6±6
CA 10					100	95±5	80±15		50±10		30±15		9±4
CA 11					100	92±8	45±15 5/8/		6±6		3±3 4/ 6/		
CA 12						100	95±5	85±10	60±10		35±10		9±4
CA 13						100	97±3	80±10	30±15		3±3 4/		
CA 14							90±10 7/	45±20	3±3				
CA 15							100	75±15	7±7		2±2		
CA 16							100	97±3	30±15		2±2 4/		
CA 17	100								65±20		45±20	20±10	10±5
CA 18	100				95±5				75±25		55±25	10±10	2±2
CA 19	100				95±5				60±15		40±15	20±10	10±5
CA 20							100	92±8	20±10	5±5	3±3		

4. RR-6 is defined by IDOT according to the following table. Since the weight is used in the gradation, it had to be converted to diameter. This was accomplished by assuming a solid unit weight of 155 pcf.

Grad. No.	EROSION PROTECTION AND SEDIMENT CONTROL GRADATIONS Percent Passing Rock Size (lb)													
	1000 1/	600 1/	400 1/	300	170	150 1/	90	50 1/	40	12	10	6	3	1
RR 3								100			50±20			8±8
RR 4						100			50±20					8±8
RR 5			100				50±20						8±8	
RR 6		100			50±20							8±8		
RR 7	100			50±20						8±8				

Analysis

5. This analysis was run according to Cedergren, Harry. "Seepage, Drainage, and Flow Nets" Third Ed. Page 156. 1989. It states that to prevent smaller stone from leaching into larger stone, it should meet these two diameter ratios.

$$\frac{D_{15bottom}}{D_{85top}} < 5 \quad \text{and} \quad \frac{D_{50bottom}}{D_{50top}} < 25$$

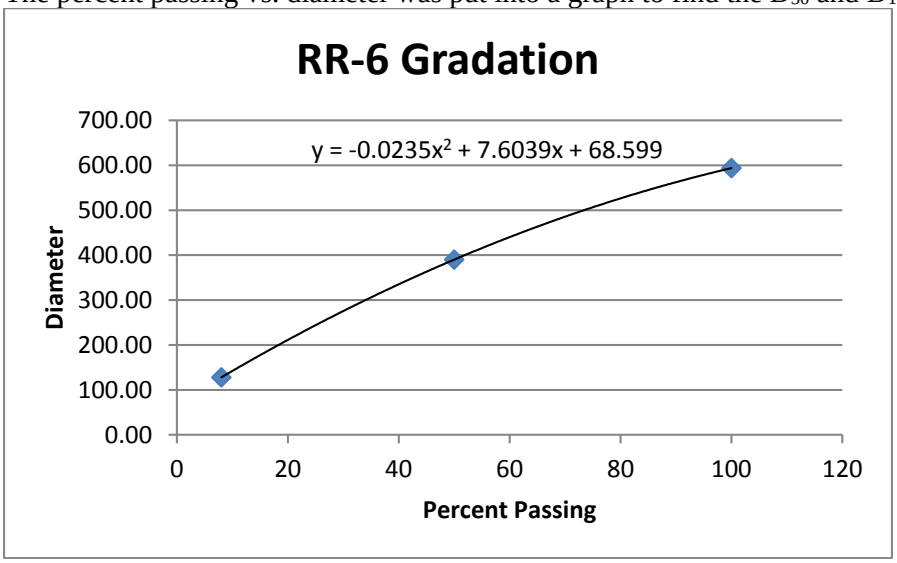
Calculation

6. The calculation to determine the diameter of the RR-6 is shown in the table below. 1 ft = 304.8 mm. The table below shows what the diameter/side if the RR-6 is considered to be a sphere and cube, respectively. Since the more conservative number is larger, this analysis assumes the stones are spheres.

$$V = \frac{4}{3}\pi(\frac{D}{2})^3$$

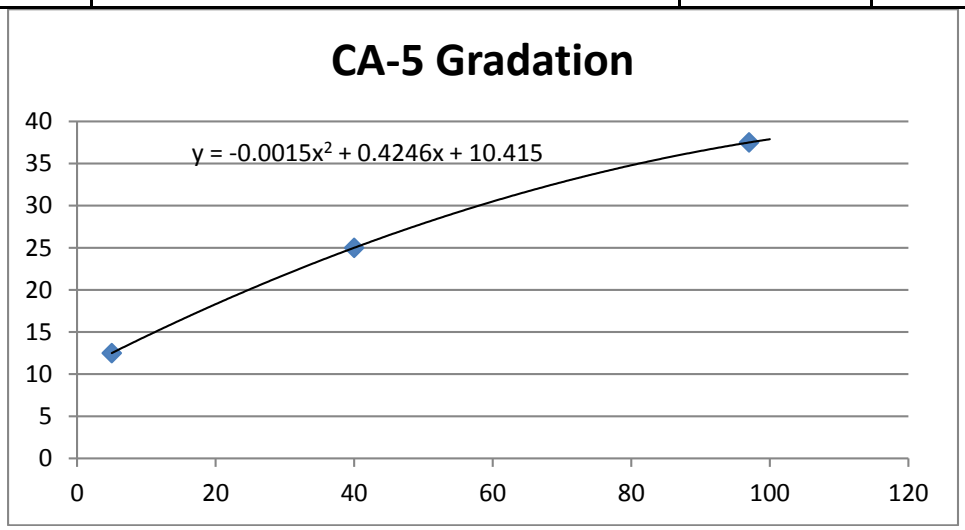
Percent Passing	RR-6 Gradation (lbs)	Volume (ft^3)	Side if cube (ft)	Diameter if sphere (ft)	Diameter if sphere (mm)
100	600	3.87	1.57	1.95	593.78
50	170	1.10	1.03	1.28	389.99
8	6	0.04	0.34	0.42	127.92

7. The percent passing vs. diameter was put into a graph to find the D_{50} and D_{15}.



8. By plugging in 15 and 50 into the above equation, the D_{15} for RR-6 is 177.4 mm and D_{50} is 390.0 mm.

9. The CA-5 graph ignored the top constraint at 100% passing and produced the below graph.



10. By plugging in 85 and 50 into the above equation, the D_{85} for CA-5 is 35.7 mm and D_{50} is 27.9 mm.

11. $\frac{D_{15RR-6}}{D_{85CA-5}} = \frac{177.4}{35.7} = 4.9 < 5\ OK$

12. $\frac{D_{50RR-6}}{D_{50CA-5}} = \frac{390.0}{27.9} = 14.0 < 25\ OK$

13. Therefore, it is acceptable to place CA-5 over RR-6.