GBA
ENGINEERS ★ SURVEYORS

GAHAGAN & BRYANT ASSOCIATES, INC.

THE DELAWARE RIVER ROCK PROBES: AN INNOVATIVE, OBJECTIVE METHOD FOR DETERMINING A ROCK SURFACE

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PHILADELPHIA
REGIONAL PORT AUTHORITY

WEDA

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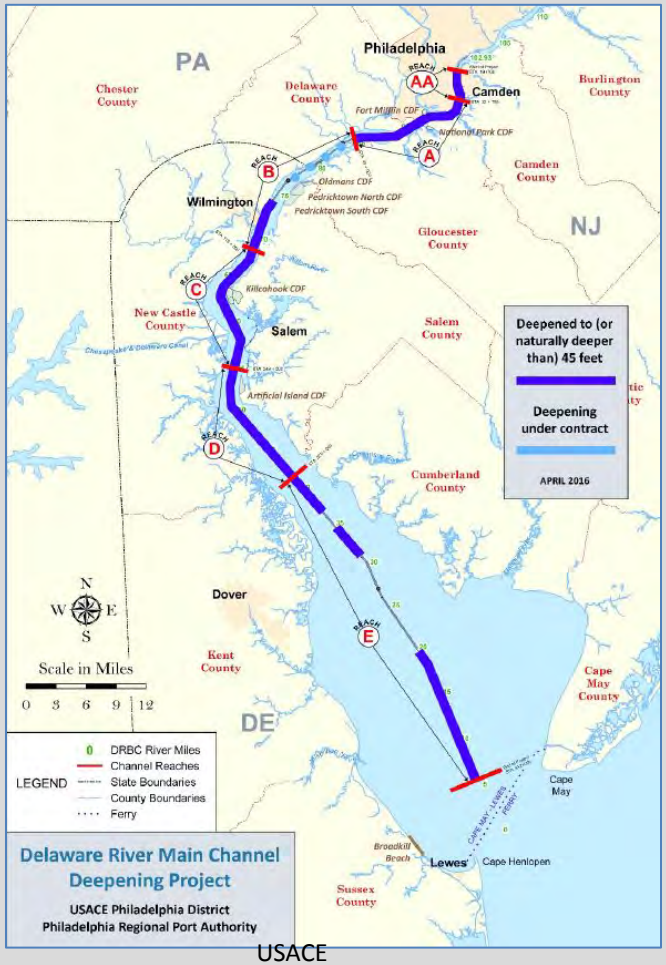
Project Location/Overview

- Delaware River Main Channel Deepening
- Initiated in 2010
- 102.5 (165 km) miles from Camden NJ to deep water in the Delaware Bay
- -45’ (-13.7 m) Mean Lower Low Water
- Rock probe project located in Reach B



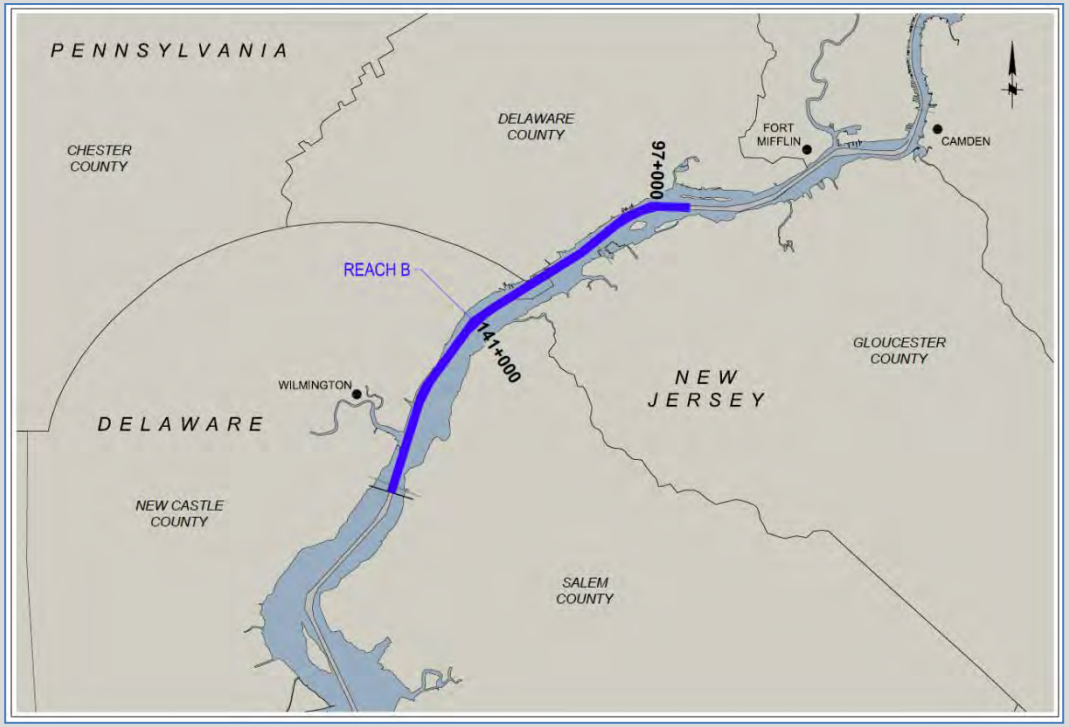
USACE

Presentation Overview

- Project Location
- Introduction
- Project Objective/Goal
- Equipment
- Methods
- Probing Investigation Operations
- Top of Rock Selection Procedures
- Results/Conclusions
- Further Analysis/Looking Back
- Acknowledgements

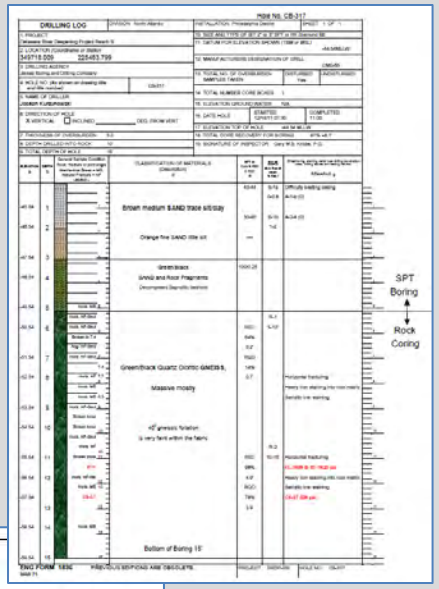
Introduction

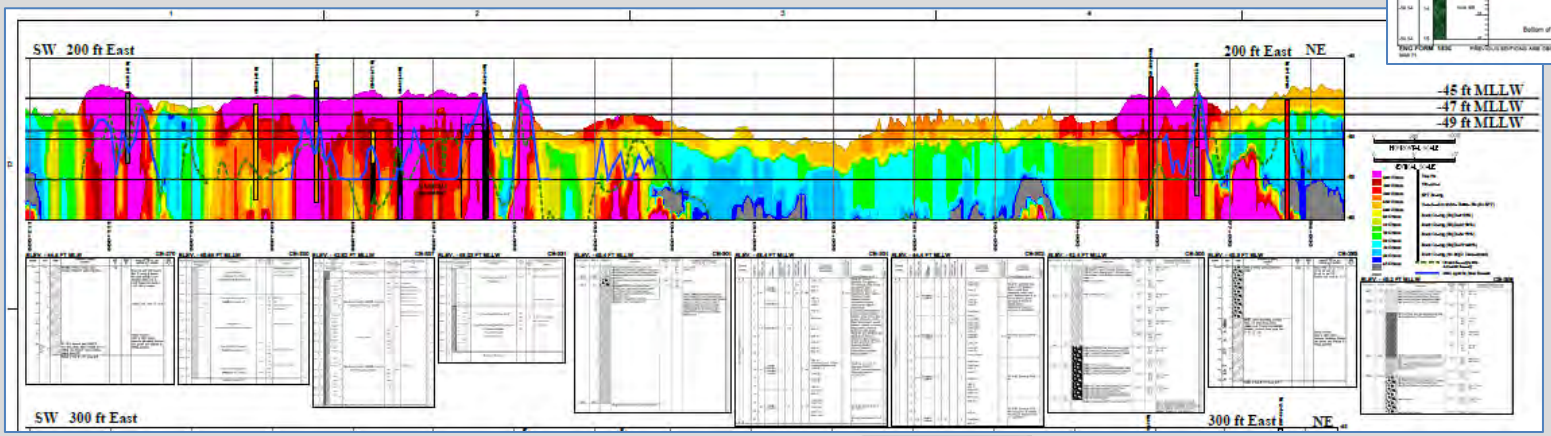
- Reach B of the Delaware River
- Contains rock outcrop areas
- Irregular rock surface



Introduction

- Many previous geophysical and geotechnical investigations performed
- Rock estimates varied greatly
- In order to further quantify the volume and location of rock an additional investigation was needed
- Investigation was to be performed in areas where previous investigations identified rock





Project Objective/Goal

Problem: The variation in volume estimates generated an unacceptable amount of uncertainty in project cost estimates.

Solution: Greatly reduce the level of uncertainty surrounding the project estimates, in order to ensure that acceptable bids would be submitted for the project.

- Physically document the depth to the top of competent rock within the dredging boundaries of Reach B with a desired precision of +/- 0.5' (0.15 m)
- Straight drill, without sampling, until certain conditions that indicate contact with the top of rock (TOR) were met
- Wanted to show evidence through objective methodology that we effectively measured the TOR, or did not encounter rock at all
- Data from the investigation would aid in developing plans and specifications and be furnished to prospective bidders as part of the Reach B rock removal solicitation

Equipment

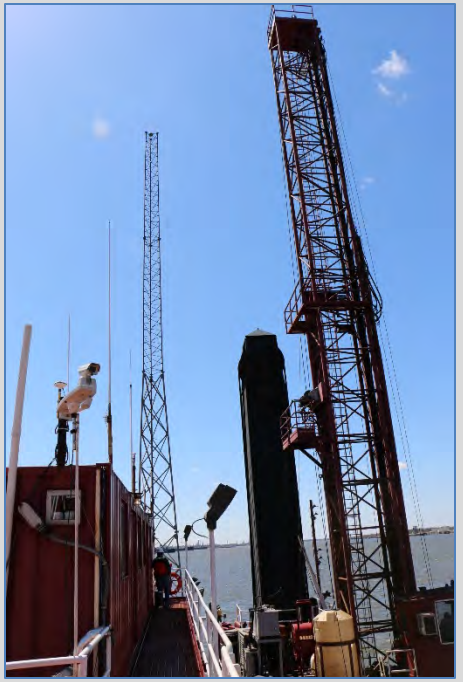
Drillboat

- Great Lakes Dredge & Dock (GLDD) drillboat Apache
- Three separate drill frames with Atlas Copco 1838 series single pass drilling systems
- Assisted by the tug Layla Renee
- Crew boat Swiftrunner

Equipment

Positioning

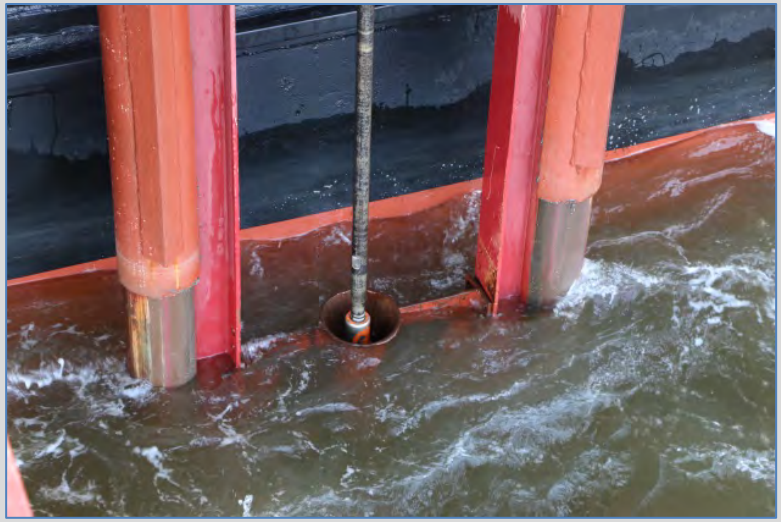
- Dual Trimble real time kinematic (RTK) receivers
- Individual drill frame locations are determined from horizontal offsets along the drillboat and then translated into northing and eastings
- Trimble R8 rover used for control checks
- Crew boat Swiftrunner equipped with a Trimble SPS 855 was used to perform vertical quality control checks to compare to tide readings



Equipment

Elevation Measurements

- Drill bit elevations were recorded using an optical encoder mounted on the drill winch with a chain and sprocket
- Drill bit was calibrated by positioning it at the water surface and setting the encoder to zero at the beginning of each hole



Equipment

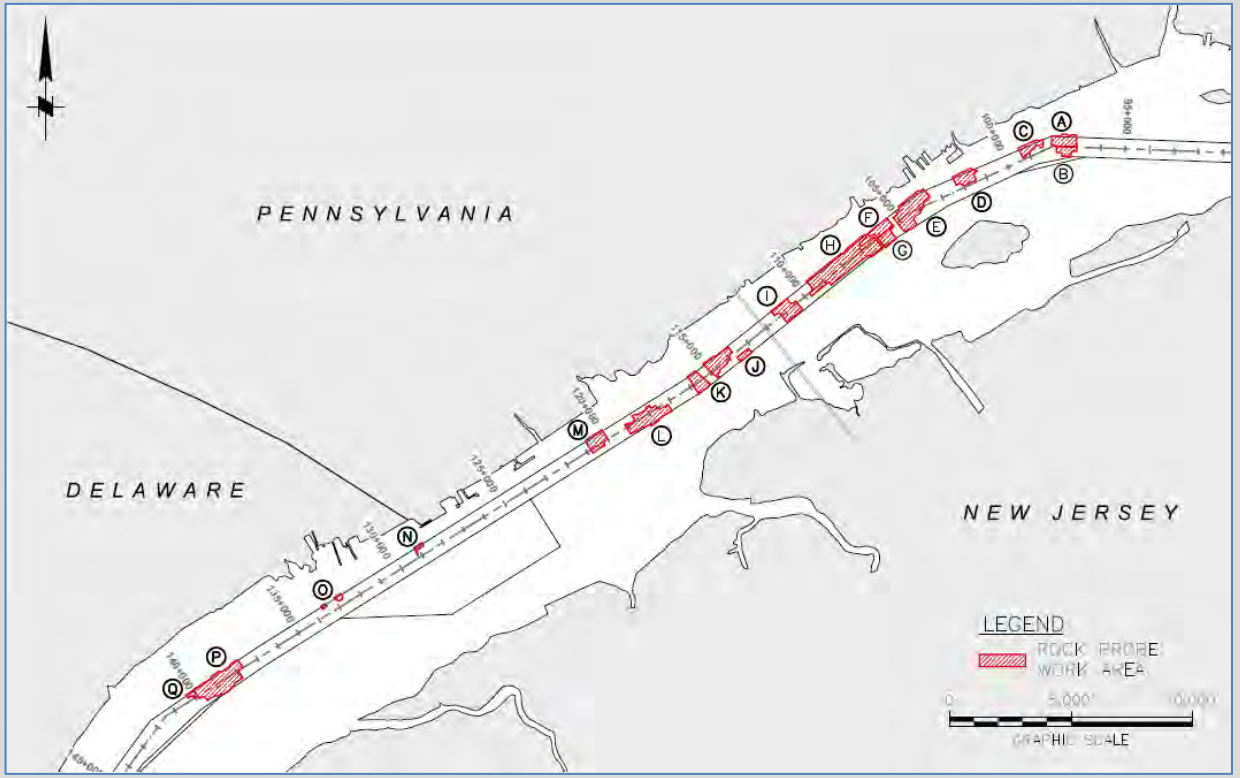
Thunderbird Mining System Drilling Efficiency Plus System

- Touch screen computers in each drill cab
- Central database computer in the survey office
- Pressure sensors on each drill frame monitoring weight on bit and torque values
- Optical encoder on each winch monitoring rate of penetration (ROP)

Methods

Project Layout

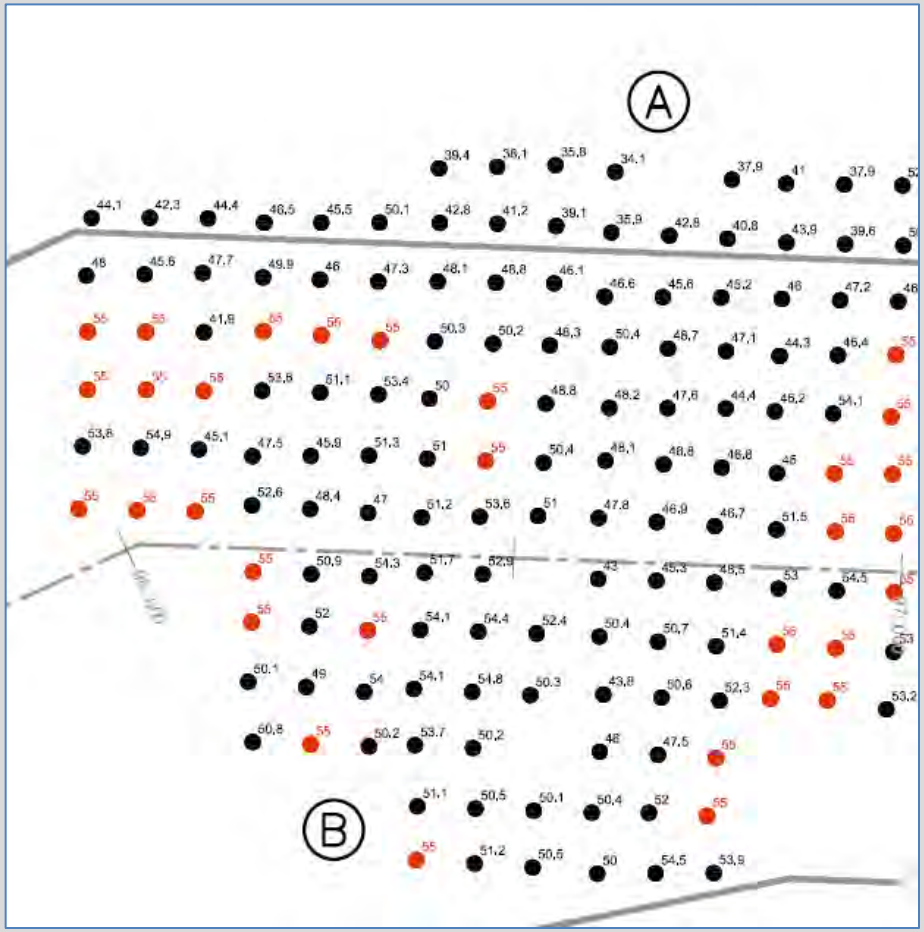
- Probing investigation areas were developed by the USACE and GBA
- Seventeen areas labeled A-Q



Methods

Project Layout

- 75’ x 75’ (22.9 x 22.9 m) grid
- Pattern files loaded into TMS computer
- Final depth of -55’ (-16.8 m) MLLW
- If rock was encountered above -50’ (-15.2 m) along the outside edge of a work area, additional probes were added to the area



Methods

Control Checks

- Horizontal control checks were performed by measuring QC points with a Trimble R8 rover at known offsets from the GPS antennas on the Apache
- Tide readings were checked against RTK tide readings aboard the crew boat Swiftrunner
- Additional post-project quality control analysis was performed on the tide readings

Methods

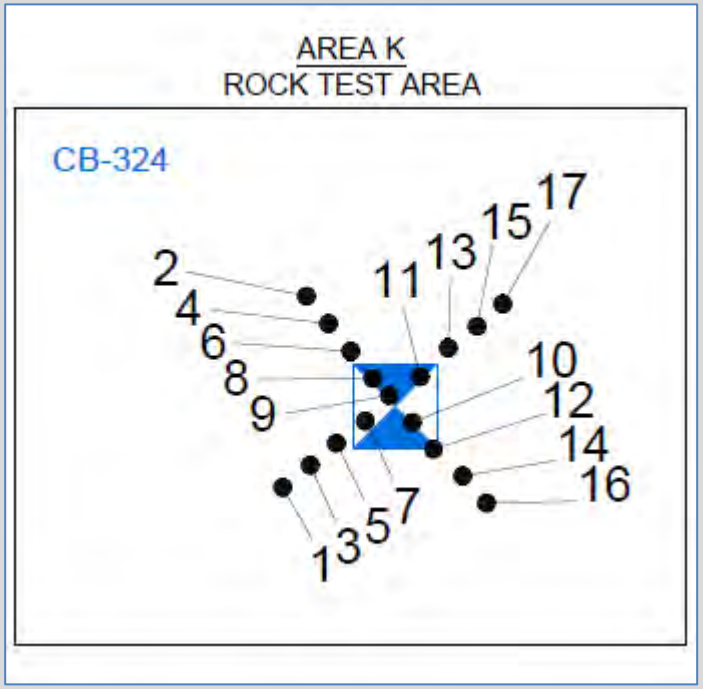
Drilling Procedure

1. Driller logs on to the TMS system at the beginning of each shift
2. Driller completes pre-shift inspection
3. Driller selects and confirms the area pattern from the list on the display
4. Driller selects the hole from a dropdown list of all the holes within the area pattern
5. Once the *Apache* has been moved within the horizontal tolerance of the hole location, the driller lowers the drill bit to the waterline and presses the "start" of hole button on the screen. The driller then enters the tide value, provided by the survey crew, into a pop-up menu on the screen
6. Once the tide is entered the driller is given a target depth -55' (-16.8 m) MLLW adjusted for the tide)
7. The hole is drilled following the instructions given in the Drilling Protocol and all data is recorded on the central database
8. Driller ends hole location
9. Once all holes for that setup have been completed, the drillboat is moved to the next location

Methods

Test Program

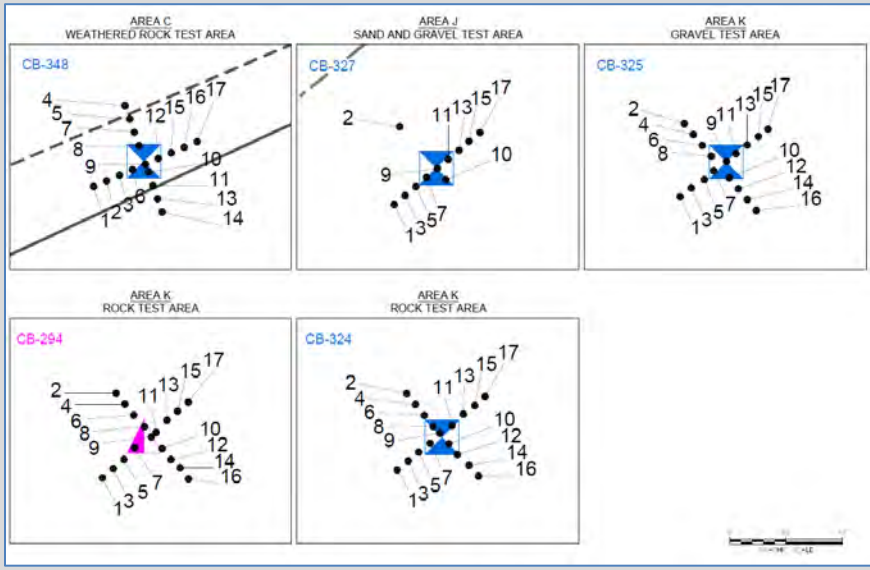
- Three day test program
- Probes performed at five previously sampled boring locations
- Analyze rate of penetration in known material types: Rock, Weathered Rock, Gravel, Sand and Gravel
- Compare TOR elevations during the test program to TOR elevations in the boring logs
- Monitored repeatability of TOR results by taking multiple measurements within close proximity



Methods

Test Program Results

- TOR elevations from probes were within 1-2 ft. of TOR elevations from borings
- Rock- ROP of less than 4 ft./min. (1.2 m/min.
- Weathered Rock- ROP of 6-12 ft./min. (1.8-3.7 m/min.
- Gravel- erratic ROP
- Sand and Gravel- ROP of 12-25 ft./min. (3.7- 7.6 m/min.)
- From the results we developed a drilling protocol for the rest of the project



Methods

Drilling Protocol

1. Lower the drill string until the river bottom is encountered, and then pause

2. Drill without the hammer until there is no advancement

3. When a Rate of Penetration, with the hammer on, of less than or equal to 4 ft./min. (1.2 m/min.) is achieved this will mark the top of rock.

4. Drill 1 foot (0.3 m) into the rock or drill until -55 (-16.7 m) feet MLLW is reached

Methods

Drilling Protocol

Water Column

River Bottom

Drops in ROP due to hole reaming , stopping advancement

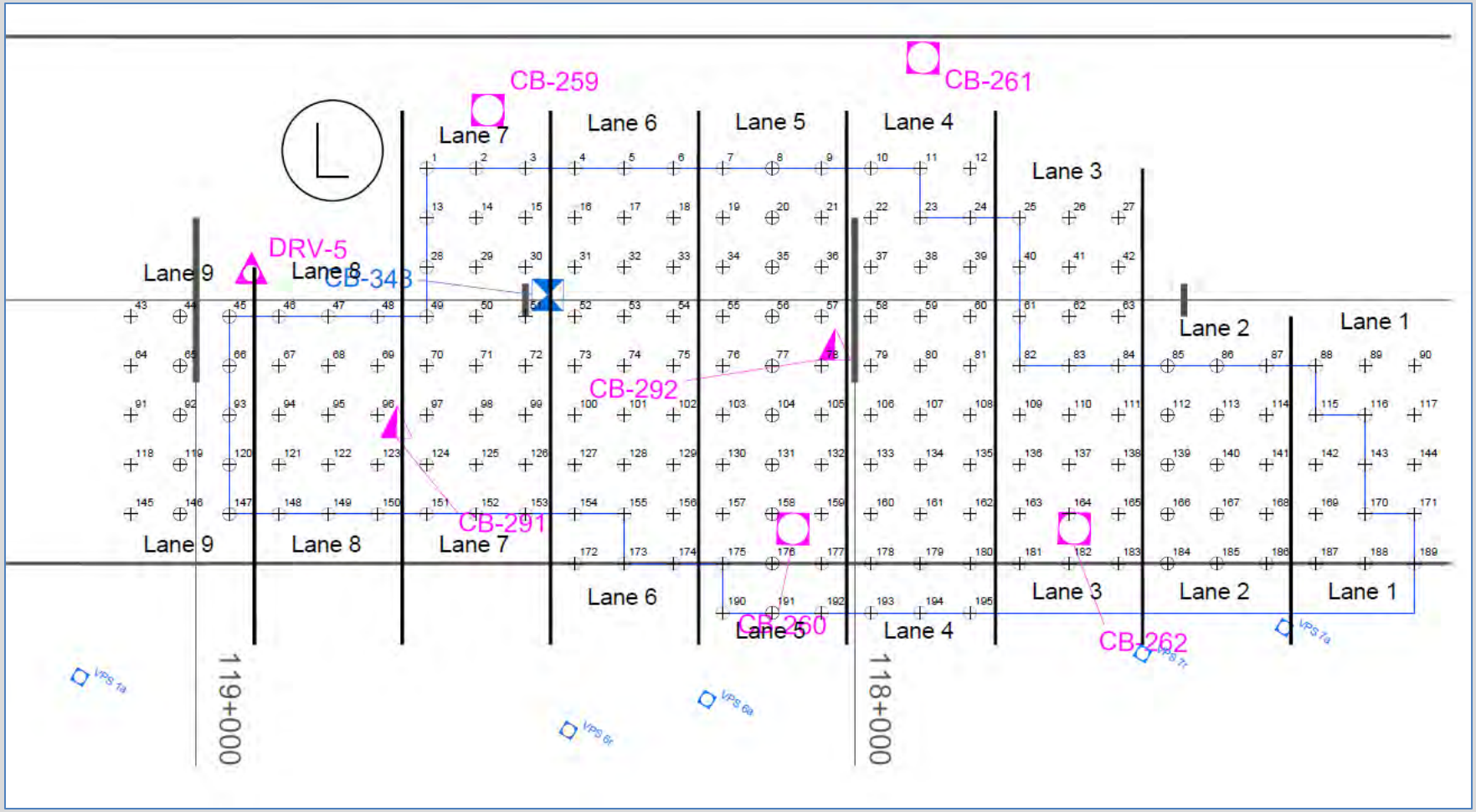
Drilled approximately 1' into rock

TOR

Probing Investigation Operations

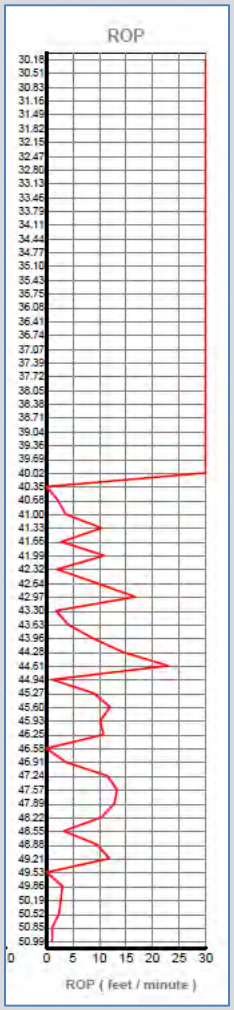
- Probing Investigation began on April 16, 2015
- Probes were performed 24 hours a day seven days a week
- GBA and USACE personnel were onboard 24/7 monitoring and directing the investigation
- Kept detailed production logs with field interpreted TOR elevations
- Probing investigation was completed on May 4, 2015
- Averaged 142 probes per day for a total of 2,326 probes

Probing Investigation Operations



TOR Selection Procedures

- GBA and USACE personnel reviewed the data for each hole and the field recorded TOR elevations
- Post project analysis showed consistent ROP values of less than 6 ft./min. (1.8 m/min.) could indicate TOR



Hole: D27 - Log

Timestamp (EDT)	Raw Depth (feet)	Corr. Depth (feet)	ROP (m / h)	WOB (kN)	Torque (kNm)	ROP (feet / min)
4/19/2015 3:49:49	34.78	30.18	625	1.53	0.13	34.2
4/19/2015 3:49:49	35.11	30.51	608	1.53	0.13	33.3
4/19/2015 3:49:50	35.43	30.83	608	1.52	0.13	33.3
4/19/2015 3:49:50	35.76	31.16	626	1.52	0.13	34.2
4/19/2015 3:49:51	36.09	31.49	622	1.53	0.13	34.0
4/19/2015 3:49:52	36.42	31.82	619	1.53	0.13	33.8
4/19/2015 3:49:52	36.75	32.15	636	1.53	0.13	34.8
4/19/2015 3:49:53	37.07	32.47	628	1.53	0.13	34.3
4/19/2015 3:49:53	37.40	32.80	631	1.53	0.13	34.5
4/19/2015 3:49:54	37.73	33.13	621	1.52	0.13	33.9
4/19/2015 3:49:54	38.06	33.46	631	1.52	0.13	34.5
4/19/2015 3:49:55	38.39	33.79	612	1.53	0.13	33.4
4/19/2015 3:49:56	38.71	34.11	612	1.53	0.13	33.4
4/19/2015 3:49:56	39.04	34.44	615	1.53	0.13	33.7
4/19/2015 3:49:57	39.37	34.77	615	1.53	0.13	33.7
4/19/2015 3:49:57	39.70	35.10	616	1.53	0.13	33.7
4/19/2015 3:49:58	40.03	35.43	612	1.53	0.13	33.5
4/19/2015 3:49:59	40.35	35.75	629	1.53	0.13	34.4
4/19/2015 3:49:59	40.68	36.08	633	1.53	0.13	34.6
4/19/2015 3:50:00	41.01	36.41	615	1.53	0.13	33.6
4/19/2015 3:50:00	41.34	36.74	615	1.53	0.13	33.6
4/19/2015 3:50:01	41.67	37.07	618	1.53	0.13	33.8
4/19/2015 3:50:01	41.99	37.39	625	1.53	0.13	34.2
4/19/2015 3:50:02	42.32	37.72	625	1.52	0.13	34.2
4/19/2015 3:50:02	42.65	38.05	617	1.52	0.13	33.7
4/19/2015 3:50:03	42.98	38.38	627	1.53	0.13	34.3
4/19/2015 3:50:04	43.31	38.71	621	1.53	0.14	34.0
4/19/2015 3:50:04	43.64	39.04	618	1.55	0.13	33.8
4/19/2015 3:50:05	43.96	39.36	621	1.53	0.13	34.0
4/19/2015 3:50:05	44.29	39.69	615	1.53	0.13	33.6
4/19/2015 3:50:06	44.62	40.02	622	1.52	0.13	34.0
4/19/2015 3:50:29	44.95	40.35	0	1.62	1.03	0.0
4/19/2015 3:50:43	45.28	40.68	40	1.71	1.17	2.2
4/19/2015 3:50:47	45.60	41.00	66	1.65	1.22	3.6
4/19/2015 3:50:49	45.93	41.33	190	1.67	1.24	10.4
4/19/2015 3:51:20	46.26	41.66	52	1.68	1.14	2.8
4/19/2015 3:51:22	46.59	41.99	199	1.68	1.09	10.9
4/19/2015 3:51:47	46.92	42.32	37	1.67	0.95	2.0
4/19/2015 3:51:48	47.24	42.64	173	1.68	1.13	9.5
4/19/2015 3:51:50	47.57	42.97	306	1.70	1.18	16.8
4/19/2015 3:52:17	47.90	43.30	33	1.68	1.07	1.8
4/19/2015 3:52:30	48.23	43.63	74	1.59	0.88	4.1
4/19/2015 3:52:30	48.56	43.96	160	1.57	0.78	8.7
4/19/2015 3:52:31	48.88	44.28	263	1.55	0.78	14.4
4/19/2015 3:52:32	49.21	44.61	420	1.59	1.05	22.9
4/19/2015 3:52:45	49.54	44.94	20	1.68	1.17	1.1
4/19/2015 3:52:46	49.87	45.27	164	1.73	1.18	9.0
4/19/2015 3:52:48	50.20	45.60	219	1.71	1.51	12.0
4/19/2015 3:52:50	50.53	45.93	185	1.71	1.11	10.1
4/19/2015 3:52:51	50.85	46.25	196	1.69	1.12	10.7
4/19/2015 3:54:05	51.18	46.58	0	1.98	1.45	0.0
4/19/2015 3:54:07	51.51	46.91	67	1.71	1.15	3.6
4/19/2015 3:54:08	51.84	47.24	210	1.72	1.08	11.5
4/19/2015 3:54:10	52.17	47.57	243	1.73	1.38	13.3
4/19/2015 3:54:11	52.49	47.89	234	1.73	1.13	12.8
4/19/2015 3:54:13	52.82	48.22	190	1.76	1.52	10.4
4/19/2015 3:54:25	53.15	48.55	60	1.72	1.15	3.3
4/19/2015 3:54:27	53.48	48.88	175	1.74	1.18	9.6
4/19/2015 3:54:29	53.81	49.21	217	1.74	1.17	11.9
4/19/2015 3:54:38	54.13	49.53	0	1.74	1.34	0.0
4/19/2015 3:54:44	54.46	49.86	55	1.79	1.32	3.0

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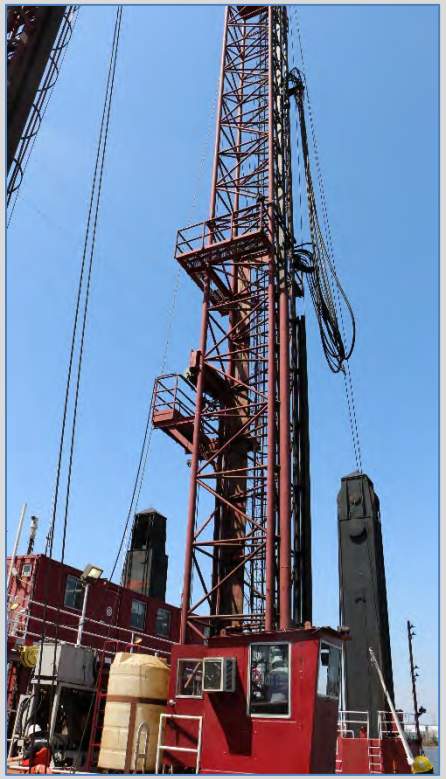
TOR Quality Control Procedures

- A geologist and engineer went through the data and selected TOR elevations for each hole
- TOR Elevations were compared and if they differed, they were further analyzed
- If the data was suspect or inconclusive in any way the hole would be removed from the data set
- TOR XYZ files were created for each area
- GBA personnel and USACE personnel met and analyzed the TOR XYZ files
- Contours based upon the agreed upon elevations at each probe for each area, were created from the XYZ files and plotted in plan-view drawings showing hole #, TOR elevation and TOR contours
- The plan view drawing of contours for each area was reviewed to look for outliers, and strange patterns in the contours

Results/Conclusions

Data Uses

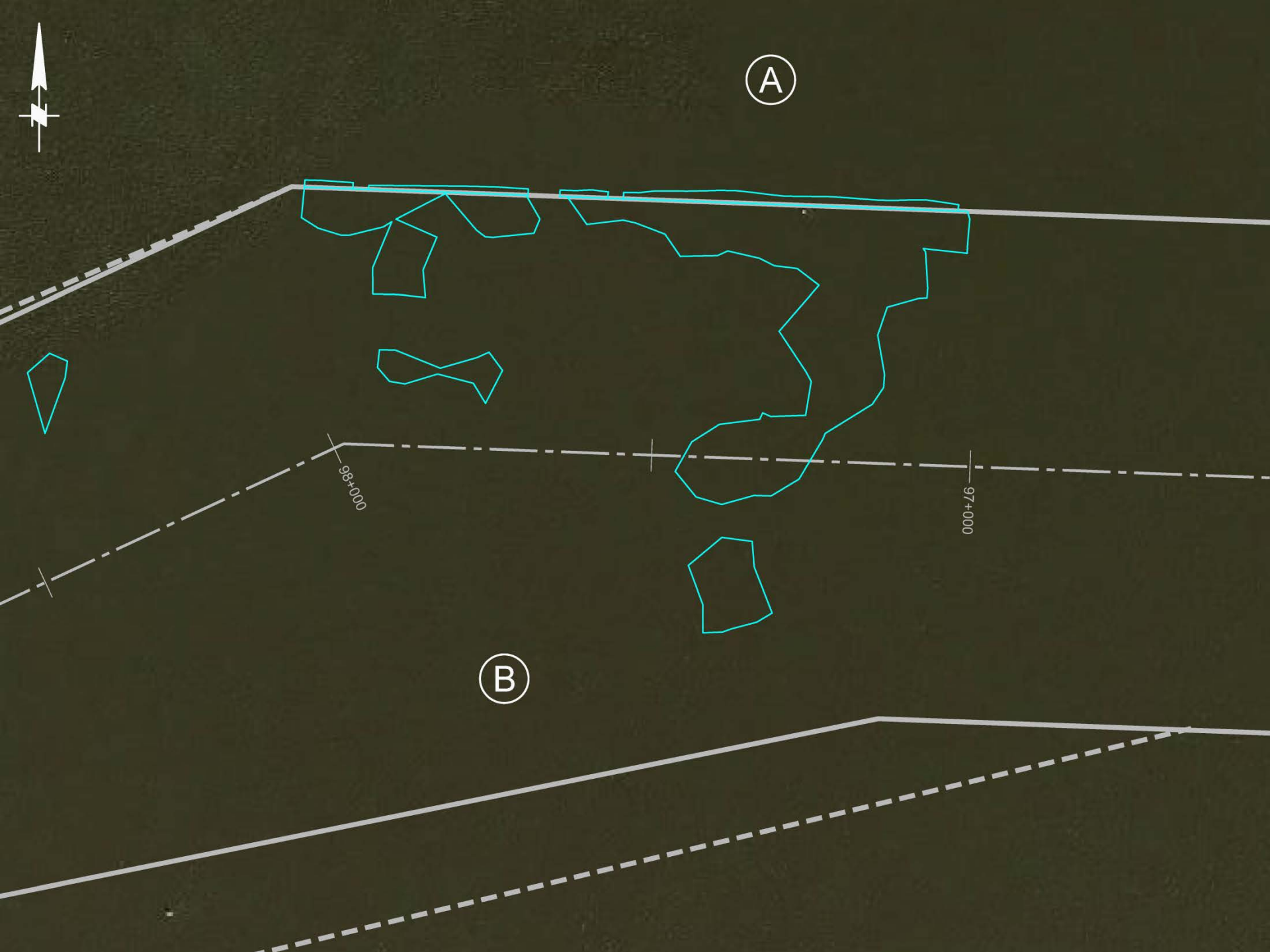
- Final TOR XYZ surface was developed
- USACE used data in developing plans and specs for Reach B Rock Removal Contract
- TOR data supplied to prospective bidders
- Project was advertised in July 2015
- Project commenced in December 2015



Results/Conclusions

Rock Quantity and Project Cost Uncertainties

- Prior to the probing investigation estimates on the surface area and volume of rock varied greatly
- 130,000 - 500,000 cy (99,392- 382,277 cm)
- Variation created an unacceptable amount of uncertainty
- Probing investigation greatly reduced the level of uncertainty, resulting in acceptable bids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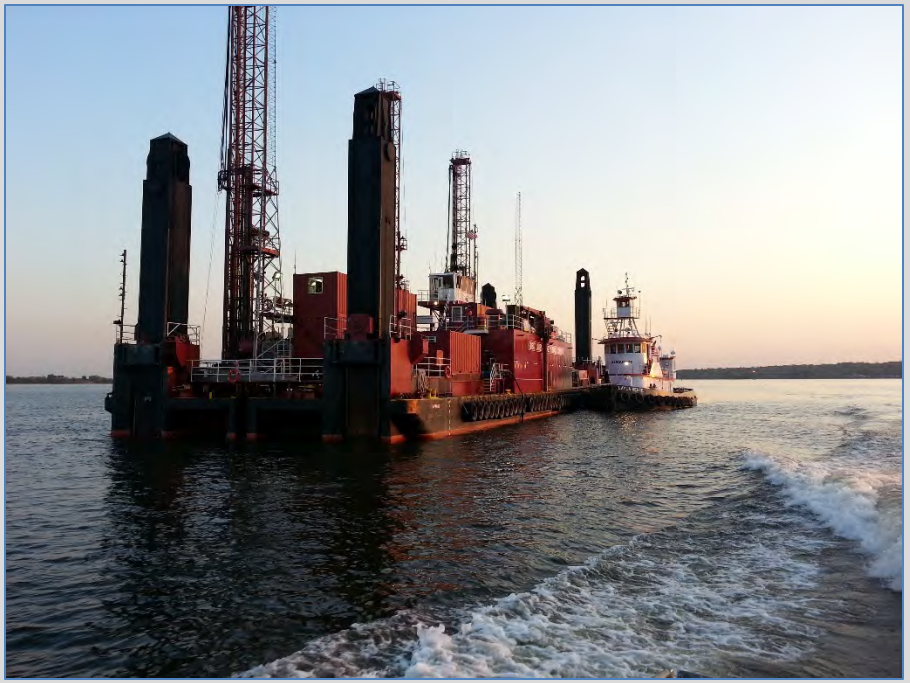
98+000
97+000
B

Results/Conclusions

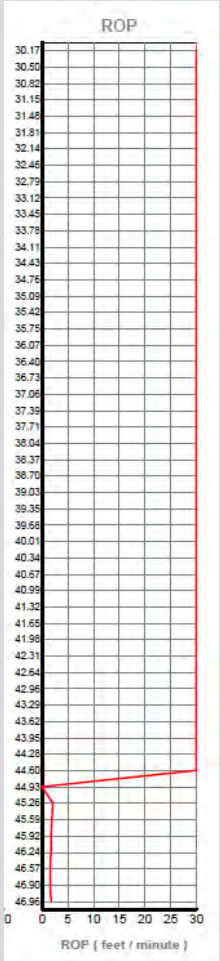
Cost

- Total cost of approximately 2 million
- Roughly $860 per probe

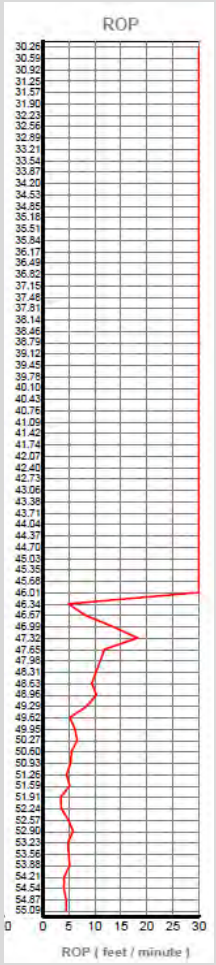


Further Analysis/ Looking Back

Project is currently under construction



Further Analysis/ Looking Back



Further Analysis/ Looking Back

What could we improve?

- Tighter Spacing
  - 50'x50' (15.2 x15.2 m)=5,119 probes= $4.4 million ($860/probe)
  - 25'x25' (7.6 x7.6 m)=19,237 probes= $16.5 million ($860/probe)
- RTK on each drill frame
- Use Specific Energy to define TOR
  - Energy required to excavate a unit volume of rock calculated from ROP, torque, pulldown, RPM, and surface area of the drill bit

Acknowledgements

- Lisa Magee and the Philadelphia Regional port Authority
- Anthony DePasquale, Peter Gori and The U.S. Army Corps of Engineers, Philadelphia District
- Great Lakes Dredge and Dock, and the crew of the Apache

Questions?