October 20, 2009
19998179

Mr. Charles F. Sutphen, P.G.
Department of the Army
Philadelphia District, Corps of Engineers
Wanamaker Building
100 Penn Square East
Philadelphia, Pennsylvania 19107-3390

Re: Geophysical Investigation of Selected Areas of the Delaware River
Marcus Hook, Pennsylvania
Delaware River Deepening
Contract Number W912BU-08-D-0001, Task Order 0006

Dear Mr. Sutphen:

We are pleased to present this brief report summarizing work performed for USACE in support of the Geophysical Investigation of Selected Areas of the Delaware River in the vicinity of Marcus Hook, Pennsylvania for the Delaware River Deepening. This work was performed in accordance with Task Order 0006 dated January 9, 2009.

The scope of work consists of a Geophysical Investigation of selected river channel locations, where bedrock is anticipated to be encountered during the proposed future dredging operations, which will be performed to deepen the Delaware River near Marcus Hook, Pennsylvania.

We utilized Demco NV of Belgium for this geophysical Aquares survey.

Background

The USACE has previously investigated the Delaware River channel bottom as part of the yearly maintenance dredging program conducted to maintain the Delaware River channel at a minimum depth of 40 feet below mean low water (MLW) level.

As part of this maintenance program, USACE obtained hydrographic and seismic reflection data along the channel in 1994, which encountered some resolution problems in areas containing organic (and gaseous) sediments. The near surface organic rich gaseous sediments often inhibited the seismic penetration limiting the ability of the subbottom profiler to actively identify the underlying subsurface acoustic reflectors. Subsequent seismic reflection mapping in 1994 using a pinger and boomer system provided somewhat better resolution and indicated that bedrock was present closer to the surface in several areas in the vicinity of Marcus Hook, extending from the Tinicum to the Marcus Hook Ranges along the river. The bedrock outcrops in this reach occur relatively intermittently at the surface and are encountered primarily between stations 96+500 and 140+000 along this section of the river. The bedrock outcrop occurrences on the river bed are primarily situated near the center and on the right side of the 800 feet wide channel, but some outcrops are also situated on the left side of the channel as viewed downstream.

The bedrock was previously determined to be primarily below the current 40-feet depth of the channel, however occasionally it was encountered very close to this level and had to be blasted for removal. The bedrock occurrences are widely spaced and although subsequent surveys indicated that all bedrock had been removed to at least the 40-feet depth limit, the actual distribution of the bedrock pinnacles below this level has not been accurately determined. The information acquired by the previous geophysical surveys was also inconclusive in evaluating the rock quality and depth relationships.

USACE also previously retained a contractor to perform exploratory borings and vibracores in various locations in the river. Several of the borings were performed in locations where bedrock was suspected and rock cores were obtained to assist in evaluating the bedrock conditions. In addition, several rock cores were subjected to laboratory unconfined compressive strength tests to further evaluate the bedrock quality.

Based upon examination of the recovered rock core samples and information provided by the Pennsylvania Geological Survey, the river in this study area is underlain by the Wilmington Complex, which is classified as a metaigneous complex of various rock types ranging from granitic, to gabbronoritic to gneissic in lithology.

Congress has recently authorized the deepening of the Delaware River channel to a new depth of 45 feet below the mean lower low water (MLLW) level, therefore sediment and rock materials that had never been removed before will now have to be excavated to permit the channel deepening.

In the past various sections of the channel in the Marcus Hook area had to be blasted to remove bedrock in order to cut the channel to the original design depth of 40 feet. Therefore, it is assumed that these areas will also require additional rock removal in order to deepen the channel to the new depth of 45 feet. In view of the fact that some of these areas were blasted previously, the rock in some of the proposed dredging areas may already be fractured from the previous blasting operations and may not require blasting for removal. This geophysical investigation was conducted to determine the extent and existing condition of the sediment and bedrock below the current channel bottom, and the excavation procedures required to remove these materials during the channel deepening operations.

SCOPE OF WORK

The proposed Delaware River Deepening Project will be performed along the entire length of the river channel from Philadelphia to Delaware Bay. The proposed new design depth is 45 feet as discussed above, however, in the rock cut areas the design excavation depth will be 47 feet below MLLW to assure the rock has been removed to a satisfactory depth below the river bottom. The geophysical investigation and analysis will be performed in the areas where rock excavation is anticipated to be required, and where bedrock is believed to be in close proximity to the final cut elevation to determine its location and orientation near the proposed new river bottom level.

Therefore, the objective of this current study is to investigate and analyze the subsurface geological conditions below the current river bottom to assist in identifying the materials present, their estimated quantity and determine the type of dredging equipment and procedures that will be required to excavate the river channel to the design elevation of -47 feet below MLLW in the rock cut areas.

Summary of Work

The work for this task order consisted of the following:

- Setting up and coordinating the project including review of existing data and preparation of a work plan which included a health and safety plan,
- Retaining and supervising the services of the geophysical subcontractor, Demco NV, to perform the required geophysical investigation,
- Coordinating with USACE's Survey Division, which will provide a survey vessel, operator and crew to assist the geophysical subcontractor in performing the investigation,
- Providing oversight and inspection of the geophysical investigation,
- Reviewing the geophysical subcontractor's data acquisition, interpretations and report, and prepare a brief summary report for the project, which will include the geophysical subcontractor's report.

Geophysical Survey Area Table

The areas investigated by the performance of a geophysical investigation are summarized in the following table.

Area	**Range**	**Station**		**Offset**	
ID		**Start (North)**	**End (South)**	**West (Right)**	**East (Left)**
1	Tinicum, Eddystone, Chester & Marcus Hook	96+000	120+000	+400	-400
2	Marcus Hook	127+000	141+000	+400	-400

Length of Area 1 = 24,000 feet = 4.55 miles
Length of Area 2 = 14,000 feet = 2.65 miles
Total Area = 30,400,000 sq. ft. = 1.09 sq. mi.

GEOPHYSICAL INVESTIGATION

The geophysical investigation consisted of a resistivity survey using procedures of the Aquares Resistivity System. The geophysical investigation examined and reported on the details of the quality and physical characteristics of rock and sediment stratigraphy to an elevation of at least -60 feet below MLLW. The rock/sediment interface (top of rock), rock features and fractures or other structural features that are present from the surface to the minimum elevation indicated were estimated. The investigation also evaluated the type of sediments and relative degree of rock weathering to assist in determining the procedures required to remove this material.

The data was interpreted and presented as both a contour/location map and profile lines, vertical geophysical cross-sections showing vertical seabed structure, horizontal geophysical cross-sections showing lateral geological variation, thickness maps and volume calculations and conclusions. The graphical data provided included color-coded horizontal and vertical resistivity sections at each location and comparative resistivity scale.

URS, along with it's subcontractor, coordinated with the USACE's Survey Division that provided the survey vessel, operator and crew to assist the geophysical subcontractor in performing the investigation. USACE transported the geophysical crew and equipment and URS representative from Fort Mifflin near the Philadelphia International Airport to the geophysical survey area, the beginning of which is located just south (down-river) of the fort, using one of USACE's marine survey vessels. USACE also towed the Aquares resistivity equipment behind the survey boat and continually recorded the exact location of the vessel using USACE's GPS navigational system

URS provided continual oversight and inspection of the geophysical survey investigation from February 23 through March 1, 2009. This included providing an experienced geotechnical professional, Mr. Carl DiNicolantonio, to observe the geophysical survey on a full time basis as the marine survey was being conducted.

URS also monitored the data processing and evaluation work conducted by the geophysical subcontractor and preparation of the geophysical report that was required from the geophysical subcontractor.

GEOPHYSICAL REPORT

Demco's geophysical report dated August 2009 is attached. This report was reviewed by URS and USACE and it was revised to further evaluate the results and data. The report includes the following:

(1) Detailed description of the resistivity survey method and explanation of the investigation conducted.
(2) Description of all equipment used.
(3) Description of the accuracy of methods, equipment and calibration information.
(4) Data interpretations, including a detailed description and evaluation of the sediment and rock materials evaluated during the geophysical survey.
(5) Determination of the volumes of each distinct geologic material.
(6) Detailed description of the results of the geophysical survey, and evaluation of the sediment and rock materials detected during the investigation.
(7) Figures and maps presenting the geophysical survey results.

It is URS observation that the work was performed in general conformance with the scope-of-work. This does not release DEMCO from errors, omissions, or liability for their work product.

RECOMMENDATIONS

Based on the review of available information and the results of the Aquares survey, URS concurs that blasting will be required in the greater than 300 Ohm-m resistivities (high resistivity) and perhaps some of the material noted as medium resistivity (80 to 300 Ohm-m).

Due to the difficulties encountered in distinguishing the intact bedrock's high resistivity from the high resistivity sand, gravel, cobble, and boulder layer of sediments that are believed to overlie a portion of the river bottom, it is also recommended to perform additional investigation to truth the excavatability of the various high and medium resistivity rock. Several test borings in the near vicinity of the present survey would assist in this determination.

We sincerely appreciate the opportunity to be of service to you on this project. If you have any questions on the contents of this report, or if we may be of additional service, please call me at 215.367.2480.

Very truly yours,

URS Group, Inc.

John C. Volk, P.E.
Principal Engineer/ Project Manager

Delaware Deepening Project
Resistivity Survey

DEMCO
Dredging
Exploration
Mining
Consultants

Delaware Deepening Project
Resistivity Survey

Report: R090310a5
August 2009
Delaware Deepening Project Resistivity Survey

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1. Introduction

As requested by the US Army Corps of Engineers Philadelphia District a geophysical survey was carried out by Demco NV in cooperation with URS Group, Inc on the Delaware River from Tinicum Range to Marcus Hook Range.

The aim of the survey was to acquire information regarding the geological structures of the riverbed in view of future dredging operations.

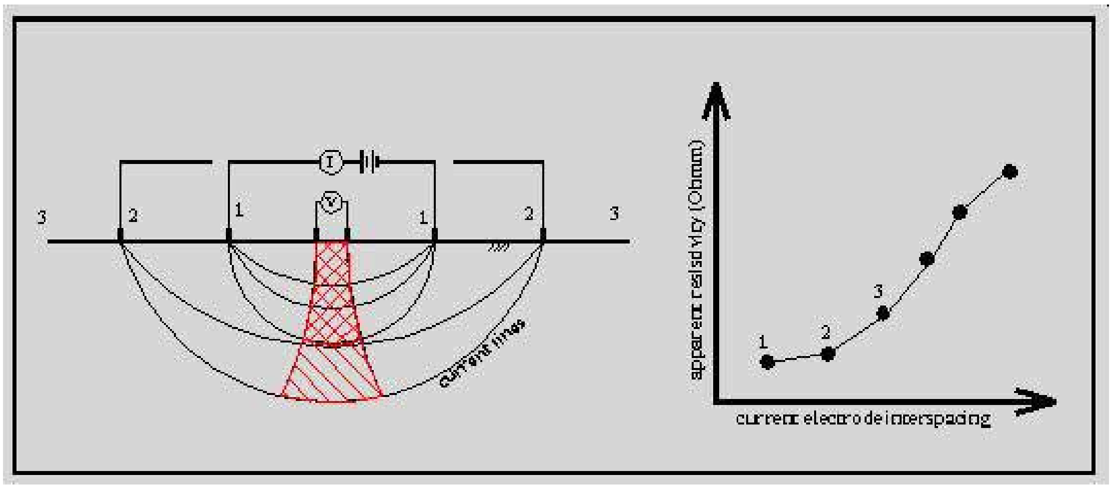
The resistivity survey was carried out in March 2009. In all, a total of 585,000 resistivity line feet were investigated.

2. Method(s)

For the requested survey the Aquares resistivity method was applied. A bottom towed multichannel cable was used, which is suitable for penetration depths of about 10 m.

2.1. Land based applications

An electrical current is injected into the subsurface by means of two current electrodes. The voltage gradient associated with the electrical field of this current is measured between two voltage electrodes placed in between the current electrodes (see Figure A). Based on the measured values of current and voltage the average resistivity of the subsurface is calculated for a subsurface volume down to a certain penetration depth. The penetration depth depends on the distance between the current electrodes. Larger electrode distances are associated with increasing penetration depths.



Figures A: Principles of Vertical Electrical Sounding

If the measurements are repeated with progressively increasing current electrode distances, information is obtained from progressively deeper geological structures (Figure A). As such, a field curve is obtained showing the resistivity as a function of the (horizontal) distance between the current electrodes. After computer modeling this field curve is transformed into a real geophysical subsurface section showing the resistivity as a function of depth.

The resistivity of a geological structure depends on its porosity, water saturation and the water resistivity. Gravel usually has a lower porosity than sand and its resistivity thus is higher. Clay with generally very high porosities shows very low resistivities. Solid limestone has a low porosity and shows very high resistivities. Weathered limestone tends to show lower resistivities. Every geological structure thus has its own specific resistivity.

2.2. *Fluvial and marine applications*

For water based applications the electrodes are placed on a multichannel cable trailing behind the survey vessel (Figure B). The electrode geometry is chosen such that good quality data may be obtained even for shallower targets.

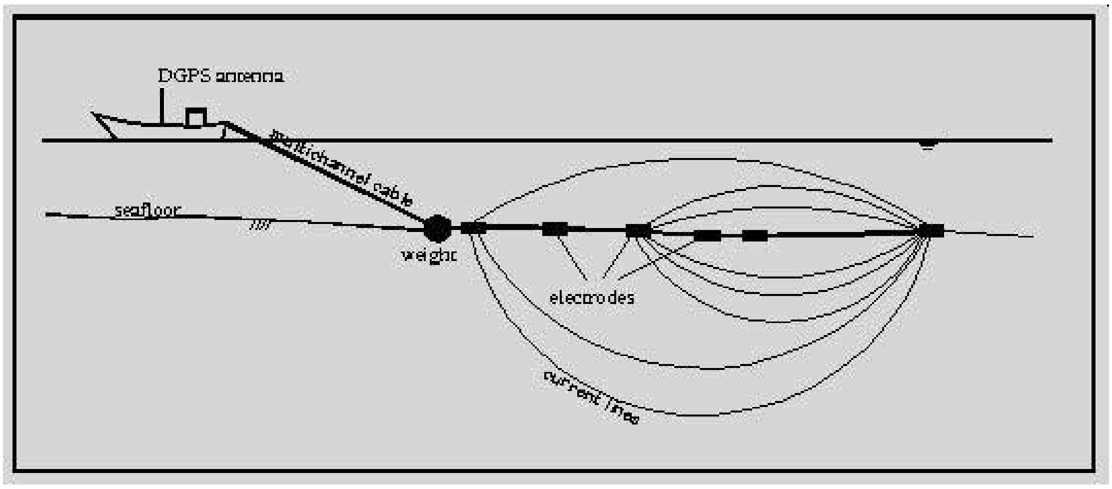


Figure B: Marine/Fluvial applications

While the survey vessel is sailing the measurements are carried out and stored automatically without any intervention from the operator. As such, an entire electrical sounding may be obtained every 4 seconds. At a boat speed of 1 m/s this corresponds to a horizontal resolution of 1 sounding every 4 meters. In applications concerning the exploration of alluvial diamonds this resolution is needed to detect even the smallest diamond-bearing “potholes” and gullies.

The time of measurement is stored with each single resistivity measurement. This gives the opportunity to synchronize the resistivity data with the positioning data (DGPS or theodolite), bathymetric information (echo-sounder) and tidal information.

During the field survey qualitative results are immediately shown on the computer screen. The quality of the field data may thus be monitored on line so the operator can intervene at any moment to adjust and optimize the survey parameters.

2.3. Data processing and interpretation

A complicated sequence of mathematical operations has to be followed before interpretable results are obtained.

First, the resistivity field data are edited and filtered to increase the signal/noise ratio. The bathymetric and positioning data are edited as well. Then, the resistivity data, positioning data and bathymetric data are combined.

Geometrical corrections are applied to correct for the fact that the sailed line (and the cable as well) may show more or less significant curvatures. Measurements made with a strongly curved cable are rejected. In case of a bottom towed cable other corrections are made to account for the water depth. A correct water correction requires homogeneous vertical water column resistivities or a detailed knowledge of vertical resistivity layering.

An important phase in the processing sequence is the resistivity data inversion. In this step, the apparent resistivity data is transformed into a vertical section of the subsurface showing depths and thicknesses of each geological structure.

The resistivity information is interpolated into a regular grid either on a cross section or in two dimensions. Each interpolated grid point represents a complete geological profile of the subsurface conditions showing the resistivity as a function of depth. The results are visualized in color on cross sections showing the different geological structures as a function of depth and geographical position. The results can be calibrated with information from a limited number of boreholes in order to correlate the data with, and verify each geological structure.

The processing procedure described above is an interactive process. In order to extract the maximum amount of information out of the raw survey data, the processing sequence has to be repeated several times to determine the optimum processing parameters.

3. Data acquisition

A bottom towed cable was used with a penetration depth of about 10 m. A special cable protection was constructed to protect the cable from getting damaged or caught on obstructions or unknown objects that may be present on the riverbed.

During this survey the cable got stuck twice: first due to abrupt course changes in an area ridden with large rock boulders on the riverbed and then on the ballast weight of a buoy marking the navigation channel.

4. Results

4.1. Bathymetry

Figure 1 shows the bathymetry of the entire survey area as acquired by the client during the resistivity survey and digitized into a 20x20 ft^2 grid. The survey lines were sailed more or less parallel to the channel axis at about 60 ft intervals. Bathymetric levels are given relative to the NAVD 88 reference. Tide levels were acquired on line during the survey from local NOAA tide gauges. Bathymetric levels are color coded following the legend with blue colors for areas deeper than 48 ft NAVD 88 and yellow, green and red for the shallower areas.

The sailed lines are shown on this map as well as the borehole locations and vertical resistivity section locations of Figures 2a-b-c. For reference purposes the vertical resistivity sections shown on figures 2a-b-c are started along the southern end of the study area and increase northward for a distance of approximately 45,000 feet. This is in contrast to the established Stationing along the river that increases towards the south from around Station 95+000 at the north end of the study area to around Station 140+000 on the southern end. In the description of locations below, reference to locations are indicated in accordance with the length along the vertical resistivity sections.

4.2. Vertical resistivity sections

After the application of geometrical and water corrections the water-corrected apparent resistivities are inverted and interpolated into a regular grid in order to obtain a 3D model of the subsurface. This allows a number of vertical and horizontal cross sections to be presented.

Figure 2a shows a number of vertical resistivity sections in the dredge area at 400 ft, 300 ft and 200 ft west of the centerline. Figure 2b shows a number of vertical resistivity sections in the dredge area at 100 ft west of the centerline, the centerline itself and 100 ft east of the centerline. Figure 2c shows a number of vertical resistivity sections in the dredge area at 200 ft, 300 ft and 400 ft east of the centerline. The location of these vertical sections is shown in Figure 1.

The vertical resistivity sections are color coded following the legend shown. A vertical exaggeration of 50x is applied. High resistivities are shown in green, yellow and red (40-300 Ohmm), very high resistivitity values in magenta (>300 Ohmm) and lower resistivities are shown in blue and grey (<40 Ohmm). The borehole results are plotted onto each of the sections including the offset from each of the borehole locations to the location of the vertical section. Boreholes located west of a vertical section are marked with negative offsets while boreholes located east of the section are marked with positive offsets.

The anticipated dredge elevation of –51.2 ft relative to NAVD 88 (-48 ft MLLW) is shown on each of the sections. The distance along the lowermost section is shown for each of the Figures 2a, 2b and 2c.

Most of the areas covered show relatively high resistivity values (green-yellow-red: 40-300 Ohmm) with very low resistivity values (grey-blue:<40 Ohmm) restricted to i.e. most sections between 10,000 and 14,300 ft, between 37,000 and 41,500 ft, and above 44,000 ft. The fact that the resistivity values of the low resistivity structures downstream generally are lower (grey: <15 Ohmm) than those in the upstream low resistivity structures (blue: 20-40 Ohmm) most probably are explained by the slightly higher water salinity at the southern end of the study area.

Section P1, located along the western limits of the channel should be considered with caution because it may have been influenced by geometrical effects linked to the presence of the nearby channel slope.

Almost everywhere the top layer appears to show higher resistivity values as compared to the main structures below. When the main structures below show low resistivity values (blue: <40 Ohmm) the top layer shows values between 40 and 300 Ohmm (green-yellow-orange). When the main structures below show high resistivity values (green-yellow-red: 40-300 Ohmm) the top layer shows very high resistivityu values (magenta-brown: > 300 Ohmm).

Looking at the borehole results the very high resistivity top structure appears to correlate with a sand and gravel top layer overlying gneisses with varying degrees of weathering (quartzitic gneiss with very high resistivity; chlorite-muscovite and weathered gneisses with lower resistivity values). The low resistivity structures have not been sampled by boreholes. They could possibly correlate with soft sediments (low resistivity: blue-grey) covered with sand and gravel (high resistivity: green-yellow-orange).

The fact that the gravel deposits on top of the gneisses in general show higher resistivity values than the gneisses themselves is typical for gravel deposits in fresh water where only the hardest (quartzitic gneiss) gravel remains while the softer micaceous and/or weathered gneisses have been disintegrated during transport on the river bed.

On various locations very high resistivity values (magenta: >400 Ohmm) are seen within the gneisses, i.e. at 2,000 ft, 21,000 ft, 25,000-26,000 ft, 30,000 ft, 32,000 ft, 35,000 ft, 43,000 ft on most sections. These high resistivity anomalies coincide with abnormally steep rising resistivity curves which can not be explained by normal horizontal layering. This type of resistivity curves can be generated by measurements in the neighborhood of large boulders or rock pinnacles sticking out from the river bed. As such these structures define areas of increased risks for encountering solid rock pinnacles above dredge level.

4.3. Horizontal resistivity sections

Figure 3 shows a number of horizontal resistivity sections at 48, 52 and 54 ft below NAVD 88 reference level. The same color scale is used as for the vertical resistivity sections. The location of the boreholes is provided as well.

At -48 ft (NAVD 88) most areas show either the very high resistivity values (black-dark brown: >300 Ohmm) of the gravel/sand deposits (potential rock pinnacles?) above the gneisses and high resistivity values (green-yellow-orange: 40-200 Ohmm) above the sediments. In the central area near Marcus Hook Range very low resistivity values (grey: <15 Ohmm) are found most probably correlating with soft sediments.

At -52 ft, which is slightly below the dredge level as currently planned (-51.2 ft NAVD 88), the picture is very similar to the one at -48 ft with obviously a considerably higher percentage of surface area hitting the river bed.

At -54 ft the high resistivity gneisses (green-yellow-red: 40-300 Ohmm) and soft sediment deposits (grey-blue: < 40 Ohmm) appear underneath the sand/gravel cover. The very high resistivity areas (magenta: >400 Ohmm) mark either areas with very high resistivity rock types (quartzitic gneiss) or steeply rising resistivity curves caused by a highly irregular river bed surface with large boulders and/or rock pinnacles or a combination of both.

The 4^{th} section below the one at -54 ft marks the location of the steeply rising resistivity curves. There appears to be an excellent correlation with the very high resistivity spots (magenta: >400 Ohmm) of the horizontal section at -54 ft.

5. Volume Calculations

5.1. Procedures

The following procedure was followed in order to determine the volume of 1) high resistivity rock, 2) intermediate resistivity rock and 3) gravel and low resistivity rock.

All resistivity sections along the sailed lines were generated using the same colorscale as in the main report. For each of the vertical sections the top of high resistivity rock was manually digitised (in Autocad) using the following assumptions.

The resistivity limit between high resistivity rock and intermediate resistivity rock is assumed to be situated around 300 Ohmm while the limit between intermediate and low resistivity rock is assumed to be 80 Ohmm as this appears to be a relatively well-marked boundary.

The relatively thin gravel layer covering most of the survey area tends to show resistivity values similar to those of the high resistivity rock. In general the gravel resistivity values are higher as compared to the underlying rock but if the rock resistivity values are very high (magenta: > 400 Ohmm) the contrast between gravel and high resistivity rock isn't clear. In these cases the digitised top of high resistivity rock is assumed to be situated at riverbed level. This assumption is realistic because if high resistivity rock corresponds to harder quartizitic rock it tends to be associated with rock pinnacles sticking out above the riverbed gravels as suggested by steeply rising apparent resistivity curves (see appendix).

After digitising all vertical resistivity sections, the digitised top of high resistivity rock level as well as the high-intermediate resistivity boundary were interpolated over the entire survey area.

The difference between the 80 Ohmm rock level and the -47 ft MLLW level (-50.2 ft NAVD) as well as the -48 ft MLLW level (-51.2 ft NAVD) defines the rock thicknesses of high and intermediate resistivity rock to be removed down to the corresponding dredge levels. The difference between the 300 Ohmm rock level and the -47 ft MLLW level (-50.2 ft NAVD) as well as the -48 ft MLLW level (-51.2 ft NAVD) defines the rock thicknesses of high resistivity rock to be removed down to the corresponding dredge levels

The intermediate resistivity rock volumes to be removed is obtained by subtracting above thicknesses (thicknesses obtained for the 300 Ohmm boundary subtracted from thicknesses obtained for the 80 Ohmm boundary).

The total dredge volumes to be removed is easily obtained by taking the difference between the bathymetry and the -47 ft or -48 ft levels.

The volume of gravel and low resistivity rock to be dredged is obtained by subtracting the high and intermediate resistivity rock volumes from the total dredge volumes.

5.2. Volumes

After following the above described procedures the following volumes are obtained.

Sector	Dredge material	Dredgelevel MLLW	Volume yd3	Surface area yd2
North	**High resistivity rock**	47 ft	187843	277778
	> 300 Ohmm	48 ft	288738	326178
	Medium resistivity rock	47 ft	97143	
	80-300 Ohmm	48 ft	225258	
	Low resistivity rock < 80 Ohmm	47 ft	810599	
	+ gravel	48 ft	1137352	
	Total	47 ft	1095584	1541067
		48 ft	1651348	1856311
South	**High resistivity rock**	47 ft	3846	8711
	> 300 Ohmm	48 ft	7506	13333
	Medium resistivity rock	47 ft	11137	
	80-300 Ohmm	48 ft	17589	
	Low resistivity rock < 80 Ohmm	47 ft	551447	
	+ gravel	48 ft	816213	
	Total	47 ft	566431	720489
		48 ft	841308	933733

For the high resistivity rock the surface area is shown as well as this is an important factor in determining the costs of dredging using explosives. For the northern sector and especially for the southern sector it is clear that the surface area with high resistivity rock is just a small fraction of the total area to be dredged.

Figure 4 shows a map of the thicknesses of high resistivity rock to be removed down to respectively -47 and -48 ft MLLW for rock types with resistivities above 80 Ohmm as well as those above 300 Ohmm.

6. Conclusions

The resistivity results distinguish areas with high resisitivies and low resistivities. The borehole results suggest the high resistivity values to correlate with gneisses and the lower resistivity values could probably correlate with sedimentary deposits.

Both the high and the low resistivity structures are covered by a thin top layer with relatively higher resistivity values as compared to the values below. The borehole results suggest this top layer correlates with sand and gravel deposits. The gravel deposits probably contains more quartzitic gneiss fragments as compared to the average gneiss composition due to disintegration of micaceous and weathered gneiss fragments during sediment transport of gravel on the river bed.

Most of the volumes situated above dredge level appear to correlate with the above described top structure.

There appears to be a very strong correlation between very high resistivity values in the bedrock gneisses and very steeply rising resistivity curves. The latter could possibly be caused by large boulders and/or rock pinnacles on a very irregular riverbed surface. This means that the very high resistivity top structure on top of the gneisses may hide a number of larger boulders and/or rock pinnacles. These locations represent areas with an increased dredging risk and have been mapped as part of the resistivity results.

More borehole information would be required to confirm above geophysical hypotheses and to obtain more information about the true nature of the resistivity structures described above. Good quality side scan data in conjunction with resistivity results may be helpful too in further defining areas of increased dredging risks.

We recommend to verify the geotechnical parameters of above described low, intermediate and high resistivity rocks by elaborate laboratory testing of boring samples.

Appendix: Steep apparent resistivity curves

As explained in the main report R090310a4 a number of areas were pointed out marked by steeply rising resistivity curves which are believed to be associated with rock pinnacles sticking out from the seabed. The following alineas explain the theoretical phenomena behind these steep curves.

During the resistivity survey apparent resistivity curves are generated every 2.5 seconds as explained in the main report. These apparent resistivity curves contain valuable geological information geophysicists try to extract from them during processing. The inversion of apparent resistivity curves into vertical geological sections showing thicknesses, depths and qualities is done using a number of assumptions. The most important assumption is the assumption of horizontal layering in the vicinity of the voltage electrodes in the riverbed sediments as well as in the watercolumn.

In a situation where the assumption of horizontal layering in the watercolumn is respected it can be mathematically proven that the resulting apparent resistivity curves can not rise steeper than 45 degrees on a logarithmical scale (apparent resistivity versus horizontal electrode distance). If apparent resistivity curves are measured rising steeper than 45 degrees this is a sure sign of high resistivity volumes within the water column. This can happen f.e. if the resistivity cable is towed close to a steep channel slope, a quaywall or, as in this particular case, rock pinnacles rising up from the river bed.

Modelling such steeply rising apparent resistivity curves result in very high resistivity values extending down to very deep penetration levels. Figure 5 shows an example of a steeply rising resistivity curve and how it is modelled.

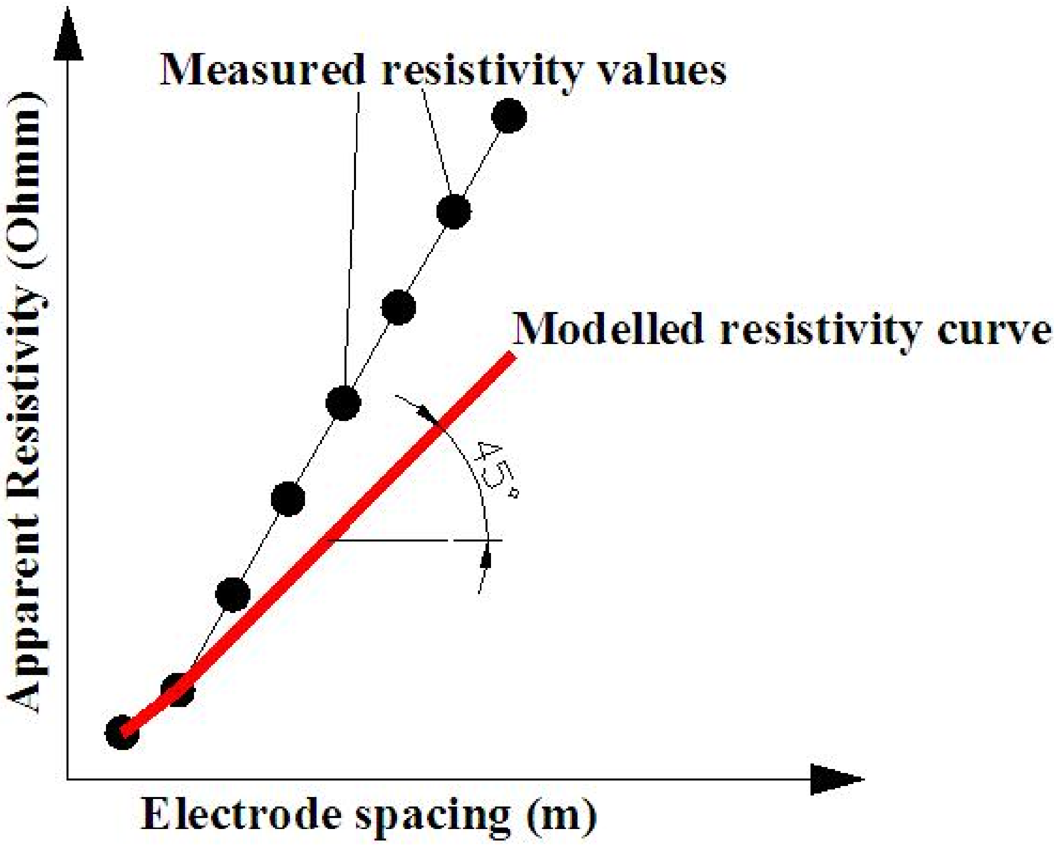
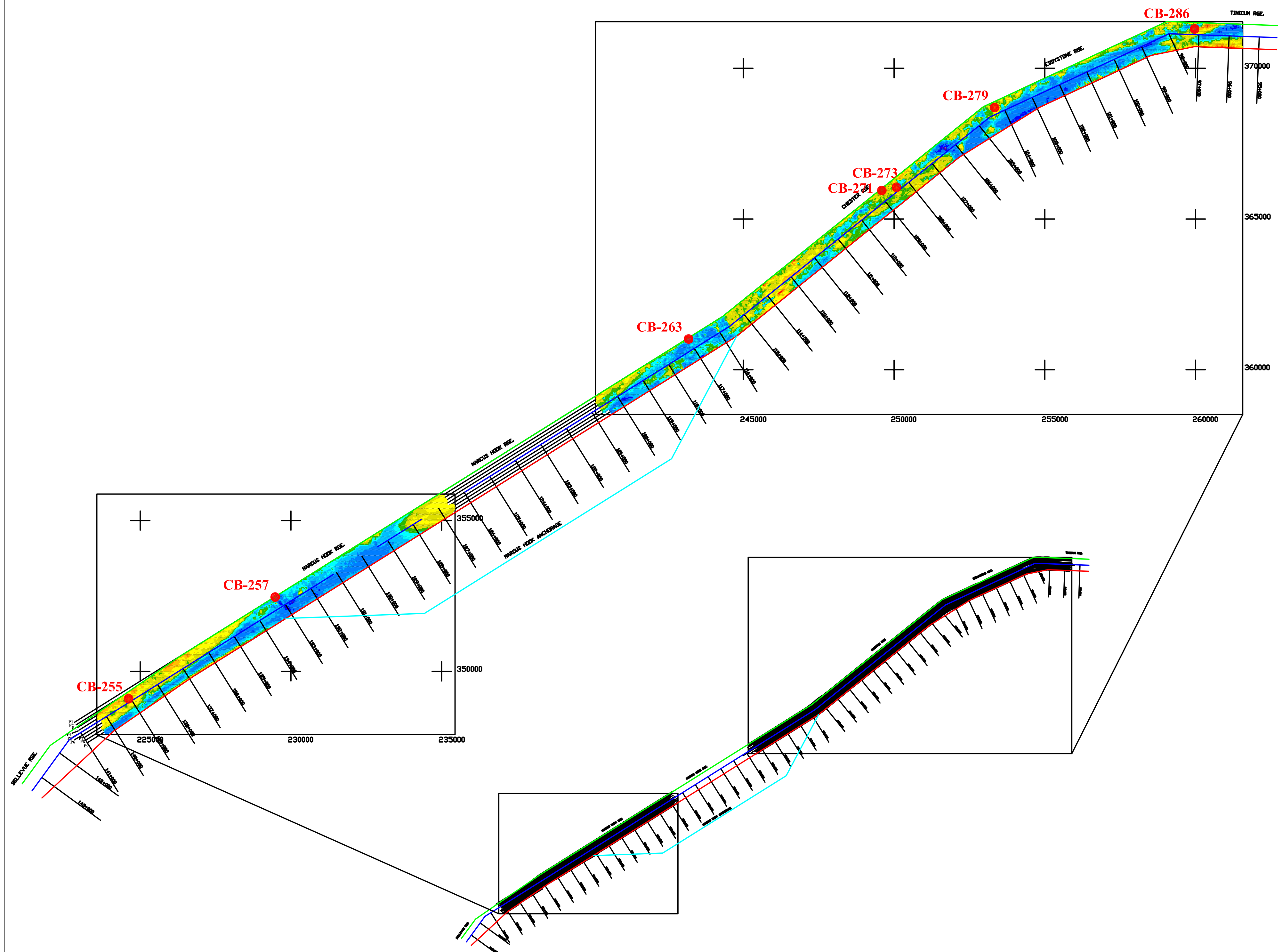


Figure 5: Steeply rising resistivity curve

The above described very high modelled resistivity values can hardly be distinguished from high resistivity values related to quartzitic gneisses which are known to exist in some areas along the river bed. However, as both the rock pinnacle related high resistivities as well as the quartzitic gneiss related high resistivities may indicate the presence of hard bedrock, both are an indication of an increased dredge risk.



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C:\Demco-safe\usace.jpg **USACE**

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Project:

Delaware Deepening Project
Resistivity Survey

Contract Number: W912BU-08-D-0001

Bathymetric Map

Projection system: NAD83 New Jersey State Plane 2900

Vertical Datum: NAVD88
based on echosounding data
acquired during the resistivity survey

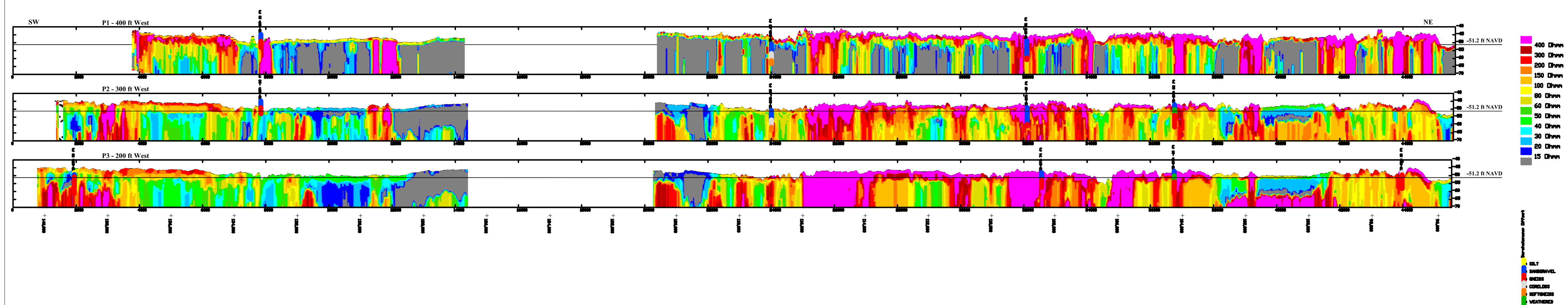
CB-255 : borehole

: sailed resistivity line

P3 vertical resistivity section (figures 2a-b-c)

File: MAP3.DWG	
Date: March 2009	
Scale: 1" : 2000 ft	Figure 1
Report: R090310a	

-42 ft
-43 ft
-44 ft
-45 ft
-46 ft
-47 ft
-48 ft
-49 ft
-50 ft
-51.2 ft
-54 ft
-56 ft
-58 ft



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In cooperation with:
URS Group, Inc

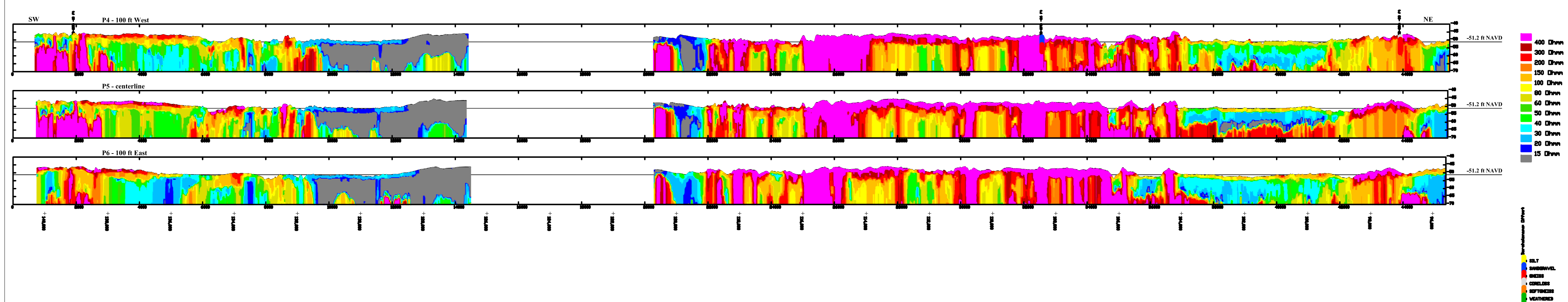
Client:
USACE

Project:
Delaware Deepening Project
Resistivity Survey

Contract Number: W912BU-08-D-0001

Vertical Resistivity Sections
at 400, 300 and 200 ft West of the centerline

File: PROF123a.DWG	
Date: March 2009	
Scale: horizontal: 1" : 1000 ft vertical: 1" : 20 ft	Figure 2a
Report: R090310a	



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Client:

USACE

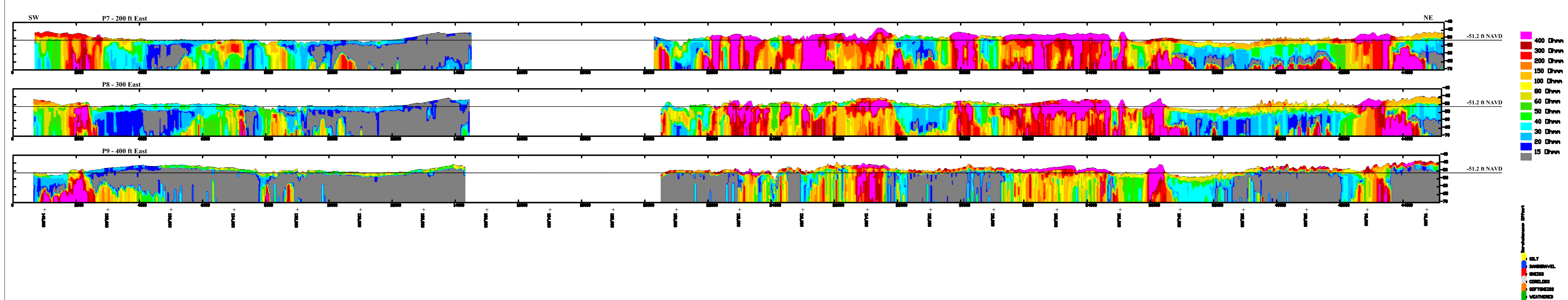
Project:

Delaware Deepening Project
Resistivity Survey

Contract Number: W912BU-08-D-0001

Vertical Resistivity Sections
at 100 ft West of the centerline, centerline and
100 ft East of the centerline

File: PROF456b.DWG	
Date: March 2009	
Scale: horizontal: 1" : 1000 ft vertical: 1" : 20 ft	Figure 2b
Report:	



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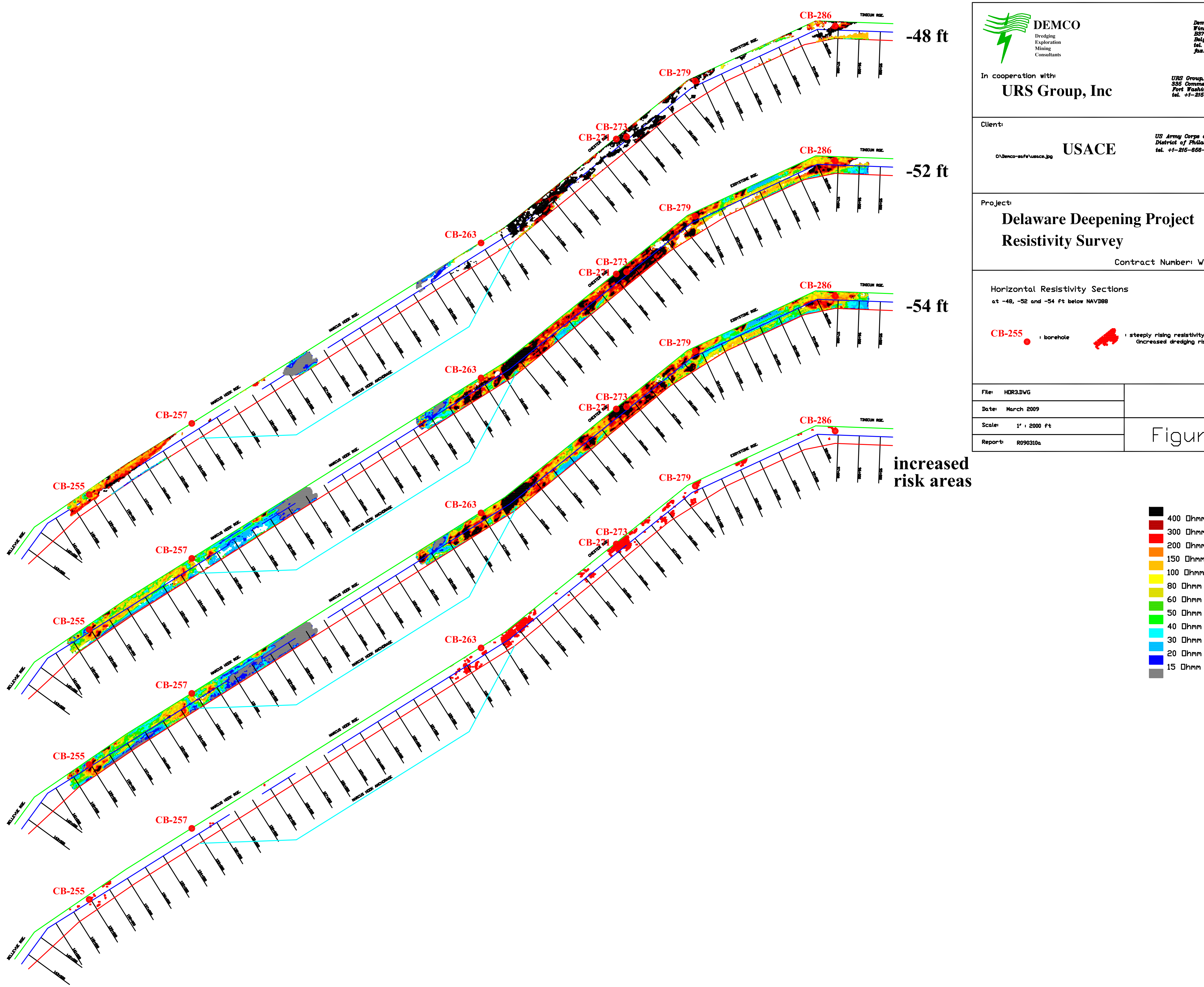
District of Philadelphia

Project:
Delaware Deepening Project
Resistivity Survey

Contract Number: W912BU-08-D-0001

Vertical Resistivity Sections
at 200, 300 and 400 ft Eest of the centerline

File: PROF789b.DWG	
Date: March 2009	
Scale: horizontal: 1" : 1000 ft vertical: 1" : 20 ft	Figure 2c
Report: R090310a	



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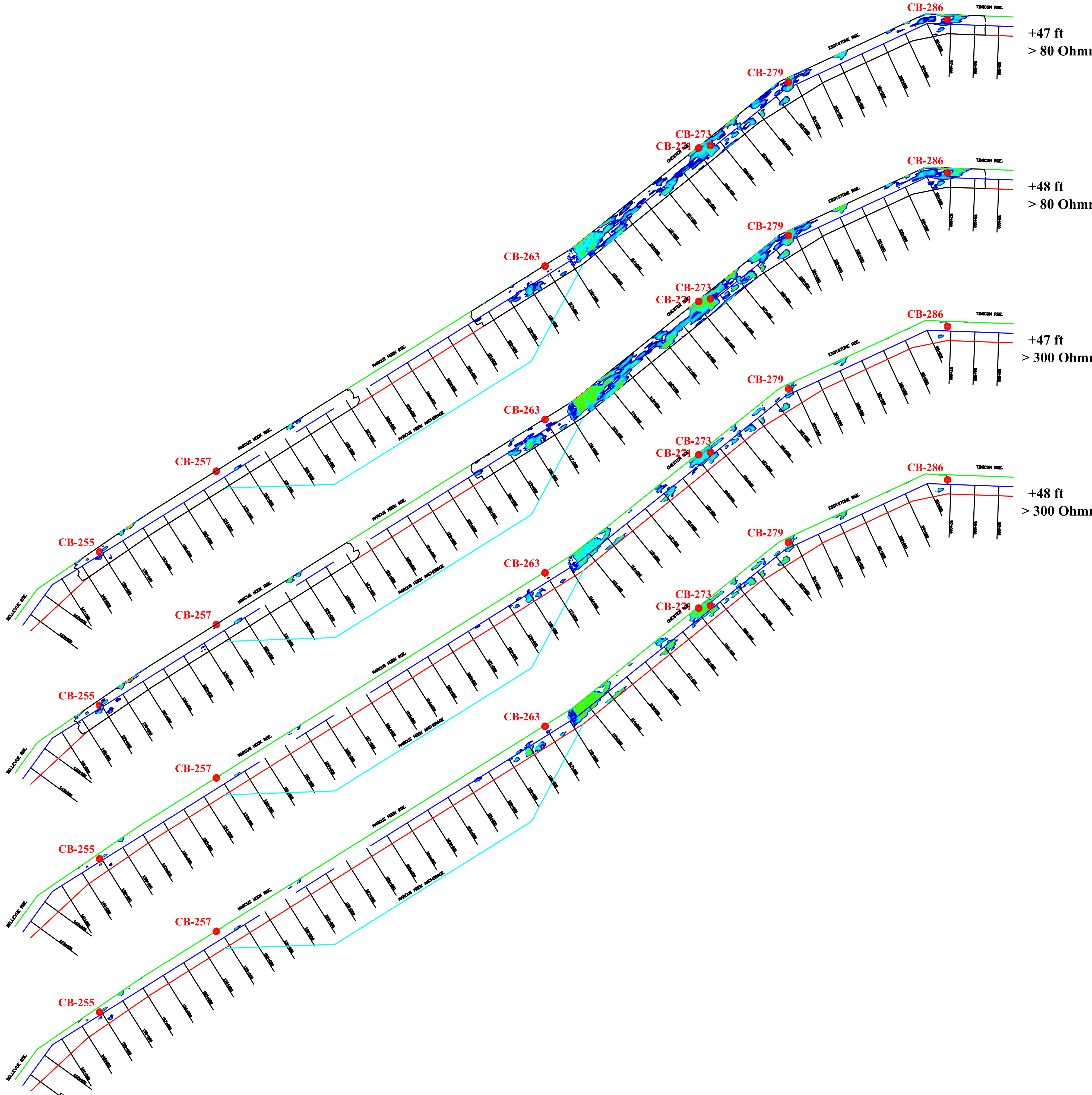
Client: C:\Demco-safe\usace.jpg USACE	US Army Corps of Engineers District of Philadelphia tel. +1-215-656-6697
Project: Delaware Deepening Project Resistivity Survey	Contract Number: W912BU-08-D-0001
Horizontal Resistivity Sections at -48, -52 and -54 ft below NAVD88 CB-255 : borehole	: steeply rising resistivity curves (increased dredging risks)
File: HDR3.DWG Date: March 2009 Scale: 1" : 2000 ft Report: R090310a	Figure 3



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USACE

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District of Philadelphia
tel. +1-215-656-6697

Project:

Delaware Deepening Project
Resistivity Survey

Contract Number: W912BU-08-D-0001

Rock thicknesses above -47 ft and -48 ft MLLW
for rock types above 80 Ohmm and above 300 Ohmm

CB-255 : borehole

File: HARDROCK.DWG	
Date: March 2009	
Scale: 1" : 2000 ft	Figure 4
Report: R090310a5	

Thicknesses
6 ft
5 ft
4 ft
3 ft
2 ft
1 ft