"*Draining the Mississippi*". . . . .

Determination of River Bed Bottom Geotechnical Sediment Characteristics and Bathymetry using Geoacoustic Sea Floor Backscattering Information Processing

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INTRODUCTION

The study of many of the world's great rivers are important for navigational, scientific, and environmental reasons. More and more surveyors and scientists would like to have technology which "drains away" unwanted images in the water column and just shows them a clear view of how the sea floor appears. Unfortunately, because of the size and characteristics of many of these rivers, they are difficult to study using acoustic methods. Many contain very heavy suspended sediment loads throughout the water column. Further, they can have significant bedload material which will settle to the bottom surficial sediment due to siltation when water flow currents are slow; and become re-suspended when current speeds are high. This alternating settlement and re-suspension, together with bed load movement downstream by traction and saltation, alter the surficial sediment layer's bathymetry and geotechnical characteristics (i.e. bulk density, porosity, grain size distribution, etc.). It is generally believed that the Amazon, Yellow (Huangho), Ganges/Bramaputra, and Yangtze (Changiang) rivers, followed by the Mississippi River contain the highest sediment loads. For our study area, we have chosen a section of the Mississippi River between Baton Rouge and Port Allen, Louisiana. At this point the river is traversed by the Horace Wilkinson Bridge which is part of the Interstate-10 highway system. Our survey area is a rectangular area around the East Bridge Pier of the bridge (as shown in Figure 1). In this area, average water depths are in the 40's of feet except in areas of bridge pier scour holes which can be significantly deeper. The main navigation channel of the river is closer to the Port Allen side and has an average depth of about 80 feet. In addition to obtaining precision bathymetric information, geoacoustic sea floor backscattering is used to determine geotechnical sediment characteristics.

SURVEY CHALLENGES & METHODS

A survey to collect acoustic echo return data was performed during May 2018 at a time when river currents were near seven knots; and sediment load was high. Flow distortion around various structures in the river also aggravated acoustic measurements. Further, the more sediment in the water column, the more acoustic volume reverberation occurs. To acoustically reach and penetrate the river bottom, it is necessary to mitigate the water column material effects, in other words "to drain" (eliminate) the Mississippi's water column effects. To accomplish this, Unabara employs multi-frequency synthetic beam non-linear acoustics. Equipment utilized was Unabara's Hydro-2F™ Multi-Frequency Synthetic Beam Bathymetric & Sea Floor Sonar with RTK GPS to provide geoposition. Data from both of these systems was logged using a Windows-based PC running Unabara's Hydro-2F™ Software with

HydroMagic™ Mapping Software (Eye4Software B.V., The Netherlands) for post-processing. It should be noted the HydroMagic™ software can also generate isobaths (depth) contour lines or provide tabular XYZ format data. Data may also be exported as AutoCad™ DXF or Google™ KML format data. Sonar derived information may be overlayed with existing grid maps and/or satellite photographic maps to provide both video and hard-copy augmented reality maps.

Unabara's proprietary signal processing removes unwanted returned signals so only true river bottom derived information is recorded. The Hydro-2F utilizes 230 Khz. echoes to define the surficial bedload sediment layer depth and characteristics. For determining the bathymetry and geotechnical characteristics of the more consolidated sediment layer below the surficial bedload, a new approach is needed; as compared to conventional analog sonar/echo sounding systems.

For studying the deeper consolidated sediment layer, one must eliminate ("drain away the effects of the Mississippi's water column") negative effects to the acoustic measurements due to suspended sediment in the river's water column. To accomplish this the Hydro-2F can be user in-field selected to produce 10, 12, 18, 24, 28 or 30 Khz.. These lower frequencies, such as 12 Khz. which was used in this study, easily penetrate water column suspended sediment and then penetrates the surficial bedload river bottom to reveal depth and geotechnical data of the consolidated sediment layer.

Conventional analog echo sounding equipment employ a similar method but their linear design requires large, expensive, wide beam width transducers for their lower frequency. Such a transducer design typically has a wide-angle beam width of 26 to 30 degrees. This results in a very wide ensonified area of the river bottom meaning poor spatial resolution of both water depth and sediment characteristics. In many cases, such poor spatial resolution causes the equipment to "miss" important features in the river bottom such as narrow scour holes.

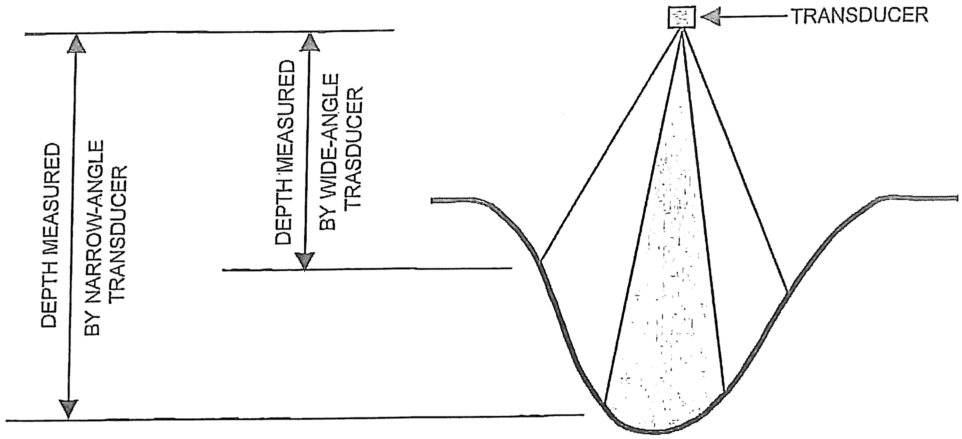
In contrast, the Hydro-2F produces a very narrow (3 degree) beam width at low frequencies. This results in a much smaller ensonified area of each echo pulse. Spatial resolution is greatly improved. Figure 2 (A & B) show the resolution to which a narrow scour hole or sloping river bed would be measured by a narrow-angle transducer (i.e. Hydro-2F) as compared to a wide-angle transducer (i.e. conventional analog). It follows that in addition to higher spatial resolution of bottom depths, the Hydro-2F provides a very high spatial differentiation between geotechnical bottom characteristics.

Bridge scour holes (largely not yet back-filled) are discussed in this paper because there exists both a large scour hole near the East Pier and a number of smaller scour holes in the survey area. It should be noted that this same technology and display type can be used for applications in dredging, marine construction, shellfish reef surveys, and other such.

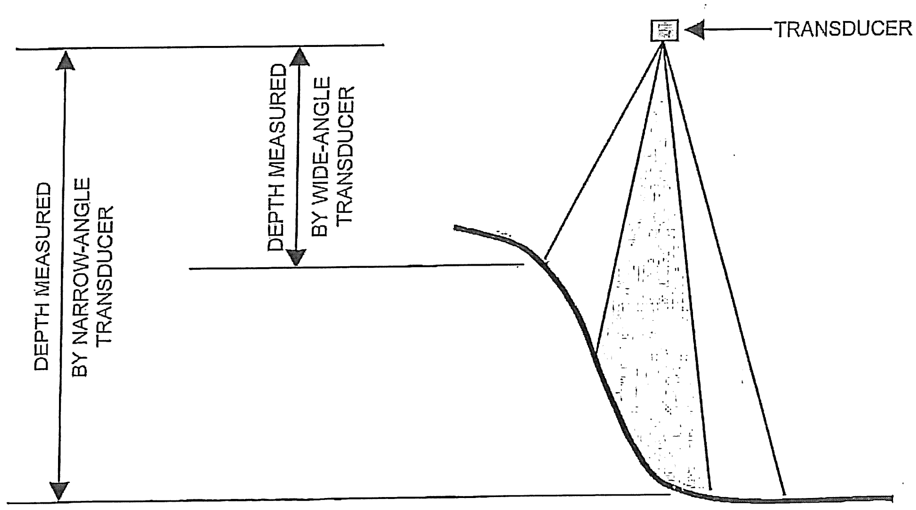
East Pier

Figure 1

Horace Wilkinson Bridge
Baton Rouge, Louisiana



(A) NARROW SCOUR HOLE



(B) SLOPING BED

Figure 2

BRIDGE PIER SCOUR: OVERVIEW

Bridge scour is the removal of sediment such as sand and gravel from around bridge abutments or piles/piers. Scour, caused by fast moving water, can scoop out "scour holes" which can compromise the integrity of the bridge pile. In some cases, over time, when low or no water current is present, these scour holes may be "back-filled" with less dense material such as clay or silt which cannot support the bridge pile. Once back-filled, even using a 200 to 400 Khz. echo sounder/sonar cannot detect that the scour event and back-filling had occurred. Only low-frequency sonar equipment such as the Hydro-2F can detect and display the back-filled scour hole.

In the United States, bridge scour is one of the three main causes of bridge failure; the others being collision and overloading. It has been estimated 60% of all bridge failures result from scour and other hydraulic related causes. It is the most common cause of highway bridge failure in this country. Between 1961 and 1976, 46 of 86 major bridge failures resulted from scour.

It should be noted most bridge failures occur when the bridge is supported by multiple small concrete piles of small diameter which are anchored shallow. These type of piles/piers are the type mostly likely to fail. In the case of the 1-10 Mississippi River pier, this pier is very large and supported by multiple piles which extend hundreds of feet into the river bottom. Scour is not a danger in this case. It is shown and discussed in this paper solely to demonstrate to the reader how scour of any amount can be detected and quantified.

GEOTECHNICAL PREDICTIONS

Acoustic backscattering metrics from returned echoes, which originate from the Hydro-2F's™ calibrated acoustic source, are logged for each survey track in the survey. Prediction of geotechnical sediment values presented on the charts herein are based upon Unabara's proprietary algorithm with first and second order parameters derived from Reflection Coefficients. Previous research of Reflection Coefficient significance in predicting physical characteristics of sediments were published by Akal (1972), Hamilton (1970), Tegowski (2005) and others.

EXPLANATION OF RIVER BOTTOM CHARTS

The attached charts are mostly self-explanatory. Some annotation has been added for the purpose of clarification. The GPS geoposition grid has not been overlayed upon the charts as to prevent clutter to the viewer. In actual surveys, the user may include this information on the chart hard-copy or denote such on the video presentation via the PC's mouse pointer.

CHART A shows the depth values of the surficial bottom as measured by the high frequency acoustic channel. This is referred to as "surficial sediment" as it is the first detectable layer at the bottom of the water column. In a fast moving river, this would essentially be the "bedload".

CHART B shows the depth values of the consolidated (hard) sediment layer as measured by the low frequency acoustic channel. This low frequency penetrates the surficial sediment layer and does not return an echo until it detects a difference in acoustic impedance representing a "hard" consolidated bottom layer. You will note in the annotated encircled area, the depth of the consolidated sediment (very dark blue and dark green) is significantly deeper than the surrounding area. These deeper measurements define a major size (horizontal wise) scour hole. All depth values both inside and surrounding this scour hole are shown in feet. You will note there is a vertical line running from what is denoted as Upstream Survey Boundary (USB) and Downstream Survey Boundary (DSB). This vertical line denotes the location of a conventional display echogram (see **CHART D).**

CHART C indicates the thickness (in feet) of the surficial sediment layer (bedload). This thickness is calculated by measuring the depth between the top of the surficial sediment layer and the depth of the hard consolidated layer. You will note in addition to one large scour area/hole, there are many smaller but deeper scour holes as shown in deep red color.

CHART D is a conventional type display of an echogram as generated by HydroMagic™. The RED trace representing the depth of the surficial sediment bottom defined by the 230 Khz. echo data. The GREEN trace represents the depth of the consolidated bottom. You will note the major size scour hole is clearly defined.

CHART E is a plot of wet bulk density of the Surficial Sediment layer. Density is expressed in grams per cubic centimeter. Over the years, numerous researchers have established the relationship between porosity and bulk (wet) density of a sediment. This relationship was summarized by Nafe and Drake (1963). A brief example table of the densities associated with various predominant grain sizes/types is given below:

Density (g/cc)	Predominant Sediment Type
1.2	Silt
1.3	Very Fine Sand
1.5	Fine Sand
1.7	Medium Sand
2.0	Course Sand

CHART F is a plot of the wet bulk density of the Consolidated Sediment layer. Note the densities of the deepest parts of the main scour hole are all 2.0 g/cc or greater (dark blue on color scale); indicating a more dense (harder) material.

CHART G & CHART H respectably are plots of the porosity of the Surficial Sediment layer and Consolidated Sediment layer. As expected, the areas of higher porosity contain the softest material while the areas of lowest porosity contain the hardest, most consolidated material. Relationships between porosity and other geotechnical parameters were established by Breslau (1965), Faas (1969), and later by others.

List of References

Akai, T., (1972) The relationship between the physical properties of underwater sediments that affect bottom reflection. Marine Geology, Vol. 13, p. 251-266

Breslau, L. (1965) Classification of sea floor sediments with a ship-borne acoustical system; Symposium “Le Petrole et La Mer,” Monaco, Vol. 132, p. 1-9

Faas, R.W. (1969) Analysis of the relationship between acoustic reflectivity and sediment porosity. Geophysics, Vol. 34, No. 4, p. 546-553

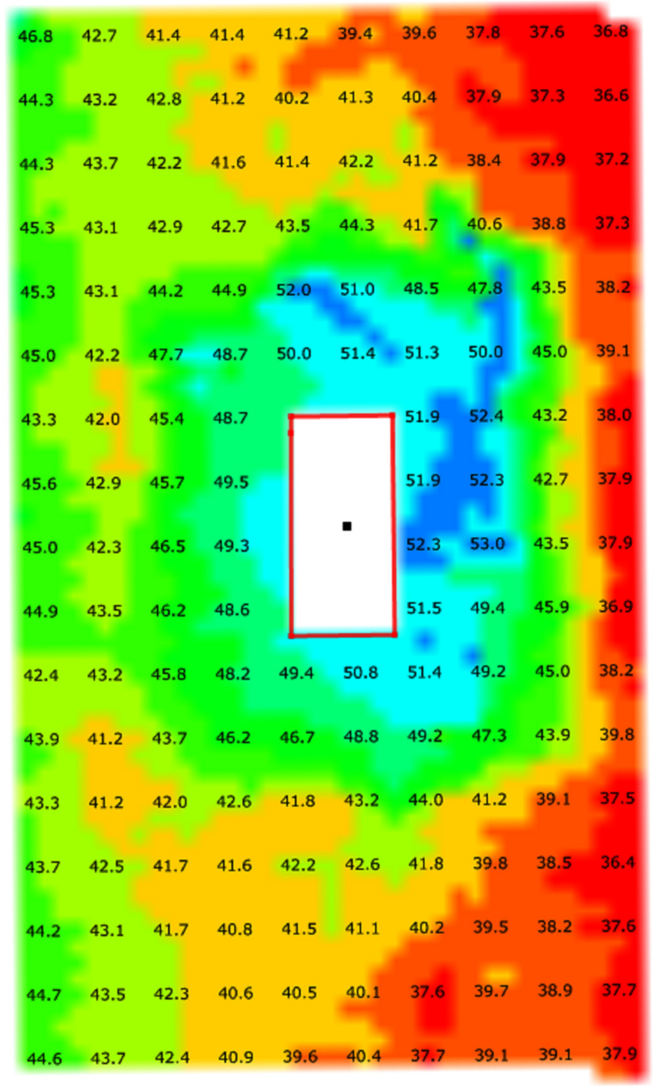
Hamilton, E.L., (1970) Reflection coefficients and bottom losses at normal incidence computed from Pacific sediment properties. Geophysics, Vol. 35, No. 6, p. 995-1004

Nafe, J.E. and Drake, C.L. (1963) Physical properties of marine sediments; The Sea, Vol. 3, p. 794-815; New York, John Wiley & Sons.

Tegowski, J. (2005) Acoustical classification of the bottom sediments of the southern Baltic Sea. Quaternary International, Vol. 130, p. 153-161.

For a comprehensive reference as an aid to understanding the terms and principles mentioned herein, we suggest the book:

High-Frequency Seafloor Acoustics
Authors: Darrell R. Jackson, University of Washington, Seattle, Washington
Michael D. Richardson, Naval Research Laboratory, Stennis Space Center, MS
E-Book: e-ISBN-13: 978-0-387-36945-7 Library of Congress Control # 200692906 © 2007



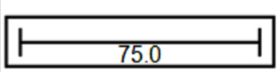
SURFICIAL SEDIMENT DEPTH

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

230 KHz DEPTH (ft)

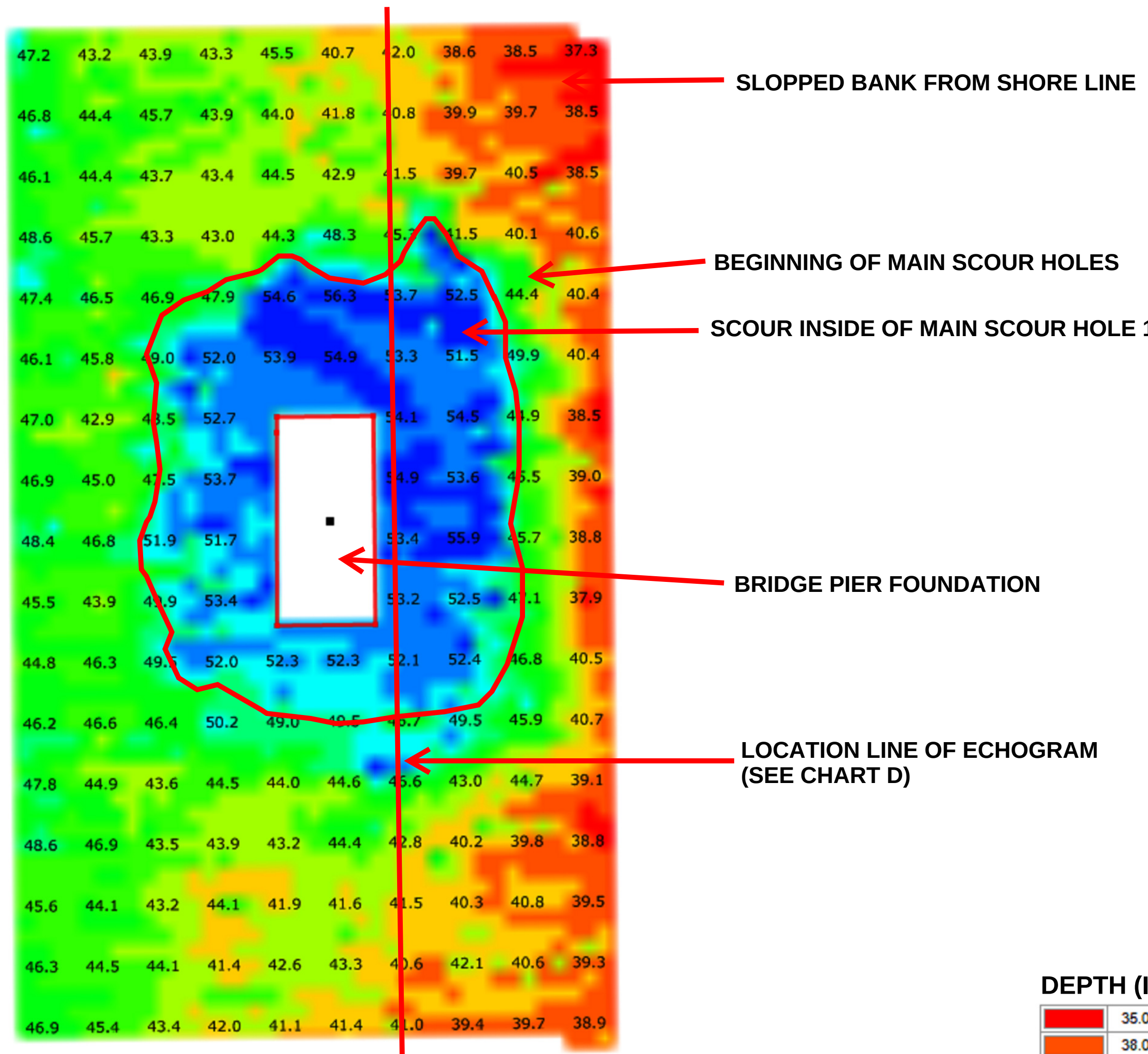
DEPTH (IN FEET)

Red	35.00	38.00
Orange-red	38.00	40.00
Orange	40.00	42.00
Yellow-green	42.00	44.00
Green	44.00	46.00
Green	46.00	48.00
Sea green	48.00	50.00
Cyan	50.00	52.00
Light blue	52.00	54.00
Blue	54.00	58.00



DISTANCE (IN FEET)

CHART A



CONSOLIDATED SEDIMENT DEPTH

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

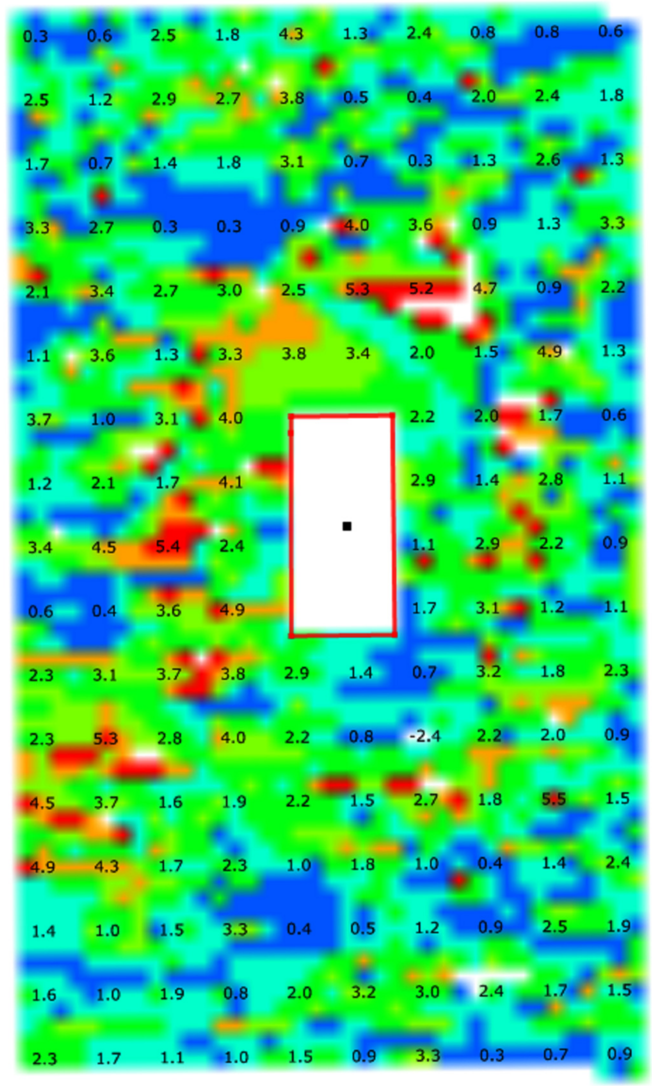
12 KHz DEPTH (ft)

DEPTH (IN FEET)

(red)	35.00	38.00
(orange-red)	38.00	40.00
(orange)	40.00	42.00
(yellow-green)	42.00	44.00
(green)	44.00	46.00
(green)	46.00	48.00
(light green)	48.00	50.00
(cyan)	50.00	52.00
(light blue)	52.00	54.00
(blue)	54.00	58.00

75.0 **DISTANCE (IN FEET)**

CHART B



SURFICIAL SEDIMENT THICKNESS

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

SEDIMENT LAYER THICKNESS (ft)

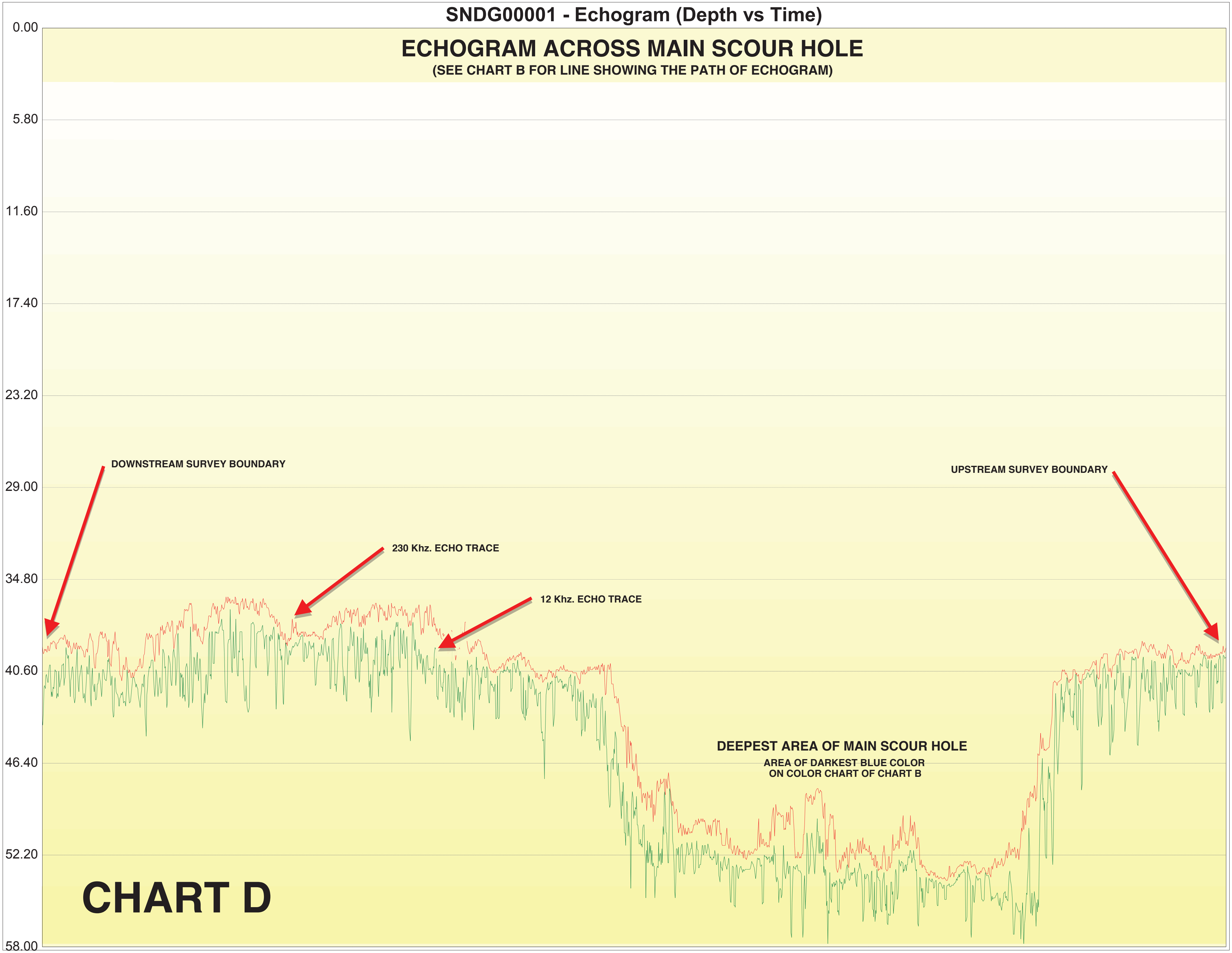
THICKNESS (IN FEET)

Blue	0.00	1.00
Cyan	1.00	2.00
Green	2.00	3.00
Light green	3.00	4.00
Orange	4.00	5.00
Red	5.00	6.00

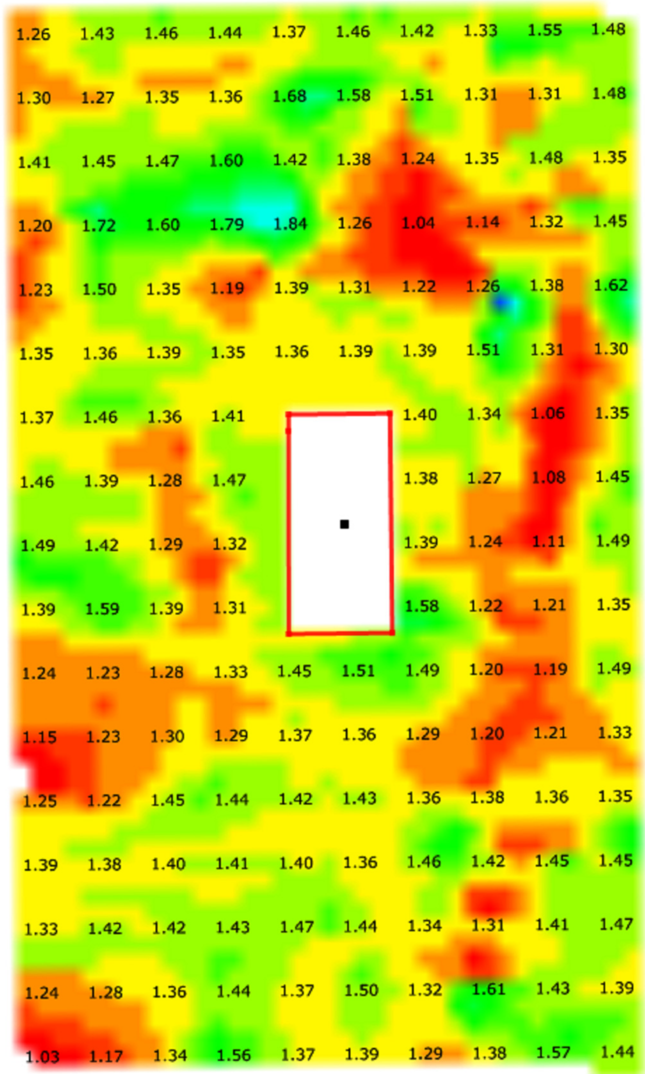
75.0

DISTANCE (IN FEET)

CHART C



SNDG00001 - Echogram (Depth vs Time)
ECHOGRAM ACROSS MAIN SCOUR HOLE
(SEE CHART B FOR LINE SHOWING THE PATH OF ECHOGRAM)
0.00
5.80
11.60
17.40
23.20
29.00
34.80
40.60
46.40
52.20
58.00
DOWNSTREAM SURVEY BOUNDARY
UPSTREAM SURVEY BOUNDARY
230 Khz. ECHO TRACE
12 Khz. ECHO TRACE
DEEPEST AREA OF MAIN SCOUR HOLE
AREA OF DARKEST BLUE COLOR
ON COLOR CHART OF CHART B
CHART D



SURFICIAL SEDIMENT DENSITY

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

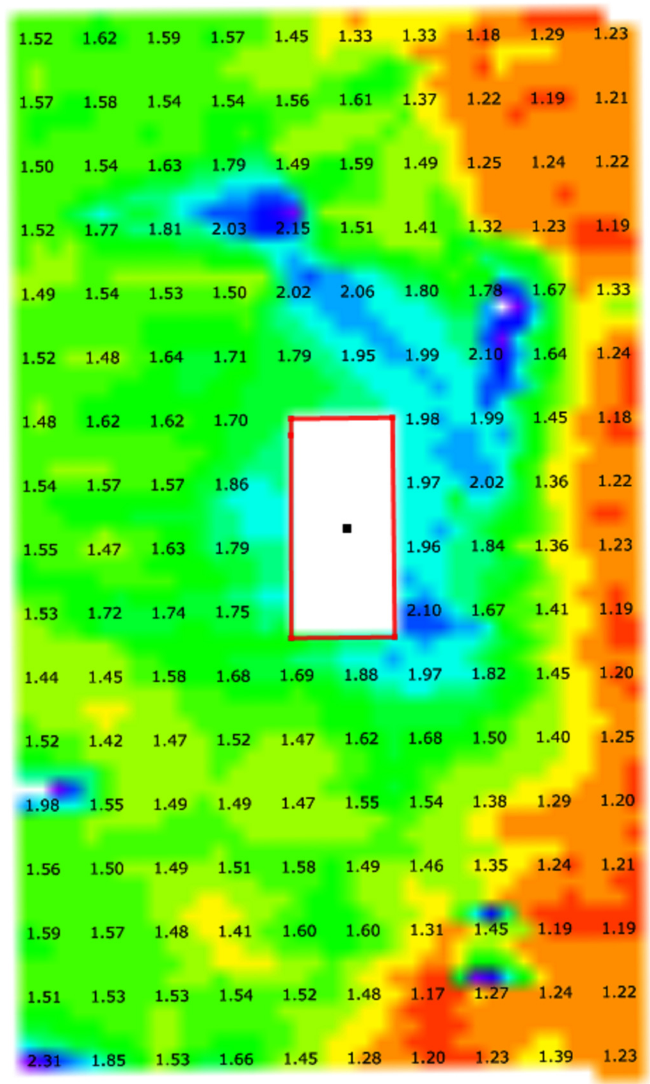
230 KHz BOTTOM DENSITY (g/cc)

DENSITY (GRAMS/CC)

	1.00	1.10
	1.10	1.20
	1.20	1.30
	1.30	1.40
	1.40	1.50
	1.50	1.60
	1.60	1.70
	1.70	1.80
	1.80	1.90
	1.90	2.00
	2.00	2.10
	2.10	2.20
	2.20	2.30
	2.30	2.40
	2.40	2.50
	2.50	2.60

75.0 **DISTANCE (IN FEET)**

CHART E



CONSOLIDATED SEDIMENT DENSITY

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

12 KHz BOTTOM DENSITY (g/cc)

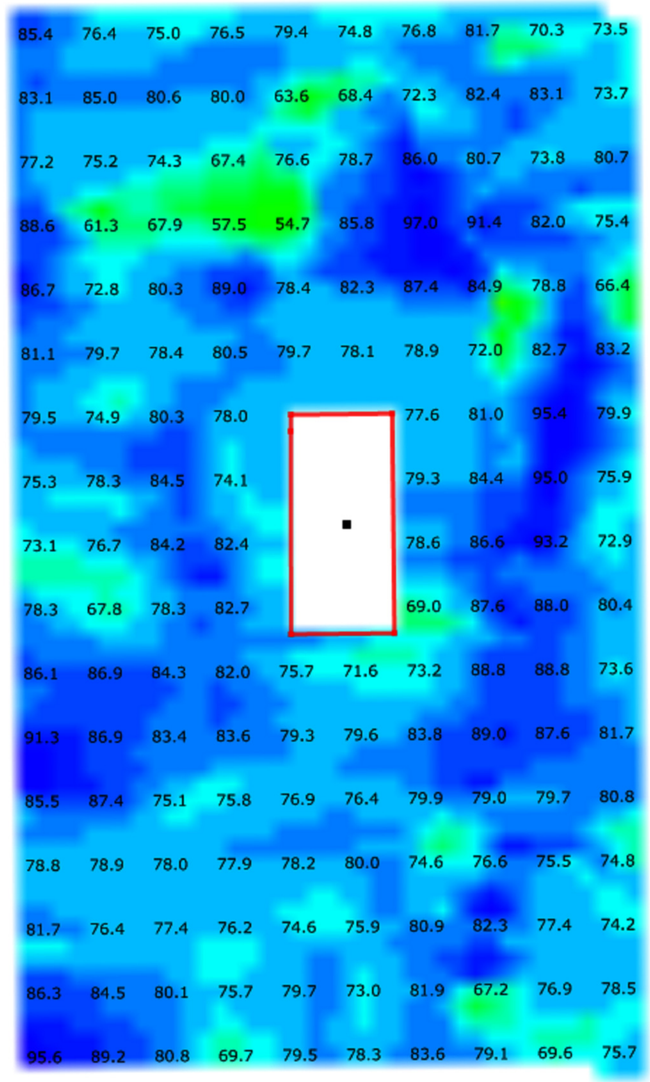
DENSITY (GRAMS/CC)

red	1.00	1.10
red-orange	1.10	1.20
orange	1.20	1.30
yellow	1.30	1.40
yellow-green	1.40	1.50
green	1.50	1.60
green	1.60	1.70
green	1.70	1.80
green	1.80	1.90
cyan	1.90	2.00
light blue	2.00	2.10
blue	2.10	2.20
blue	2.20	2.30
blue	2.30	2.40
violet	2.40	2.50
magenta	2.50	2.60

75.0 **DISTANCE (IN FEET)**

CHART F

N
W E
S



SURFICIAL SEDIMENT POROSITY

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

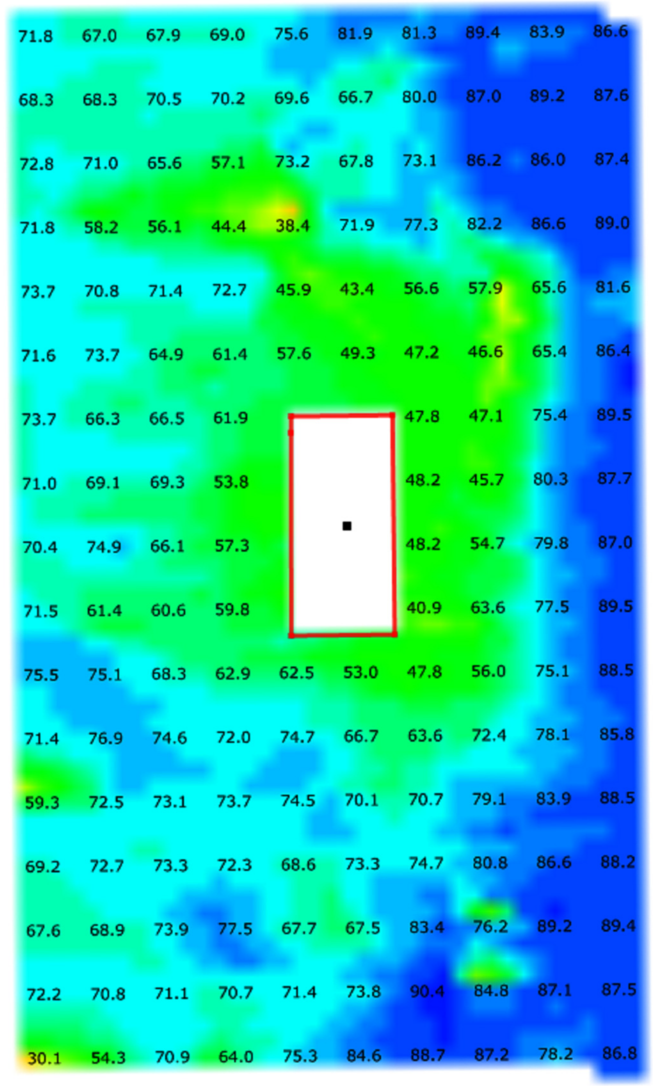
230 KHz BOTTOM POROSITY (%)

POROSITY (%)

	0.00	5.00
	5.00	10.00
	10.00	15.00
	15.00	20.00
	20.00	25.00
	25.00	30.00
	30.00	35.00
	35.00	40.00
	40.00	45.00
	45.00	50.00
	50.00	55.00
	55.00	60.00
	60.00	65.00
	65.00	70.00
	70.00	75.00
	75.00	80.00
	80.00	85.00
	85.00	90.00
	90.00	95.00
	95.00	100.00

75.0 **DISTANCE (IN FEET)**

CHART G



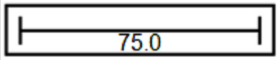
CONSOLIDATED SEDIMENT POROSITY

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

12 KHz BOTTOM POROSITY (%)

POROSITY (%)

	0.00	5.00
	5.00	10.00
	10.00	15.00
	15.00	20.00
	20.00	25.00
	25.00	30.00
	30.00	35.00
	35.00	40.00
	40.00	45.00
	45.00	50.00
	50.00	55.00
	55.00	60.00
	60.00	65.00
	65.00	70.00
	70.00	75.00
	75.00	80.00
	80.00	85.00
	85.00	90.00
	90.00	95.00
	95.00	100.00

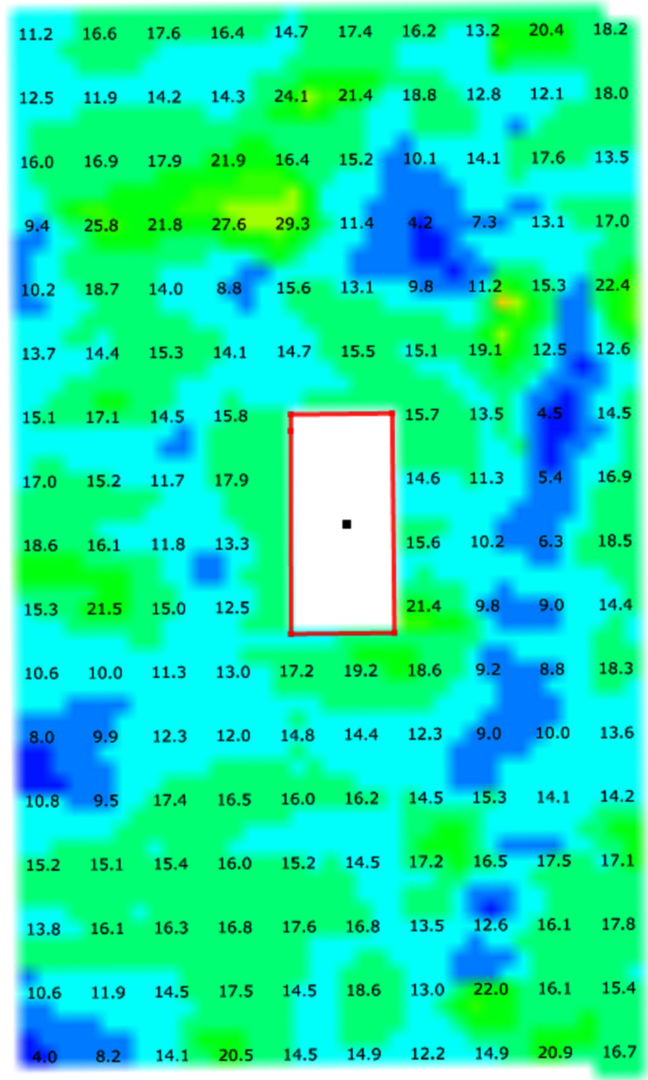


DISTANCE (IN FEET)

CHART H

Sea Floor Acoustic Absorption & Reflectivity Measurements

(The following CHARTS I, J, K, & L provide plots of the acoustic data used to calculate the values of the various geotechnical parameters shown in this report; note that Bottom Contrasting™ can simply be accomplished by comparing acoustic sea bottom losses in sediments at various geographic locations)



SURFICIAL SEDIMENT REFLECTIVITY

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

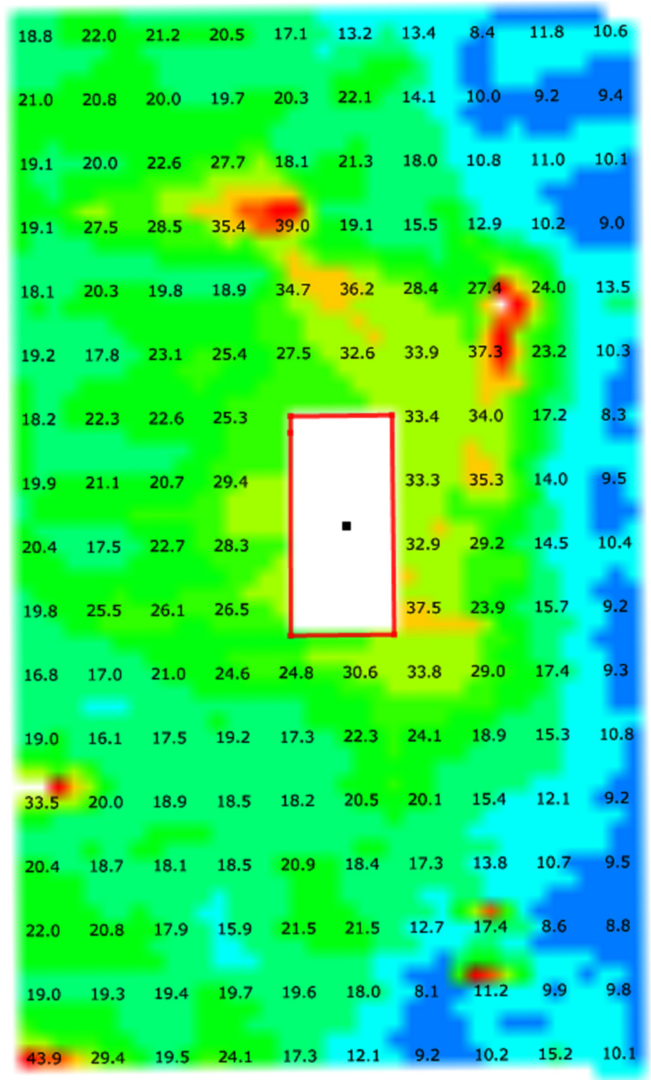
230 KHz BOTTOM REFLECTIVITY (%)

REFLECTIVITY (%)

(color)	0.00	5.00
(color)	5.00	10.00
(color)	10.00	15.00
(color)	15.00	20.00
(color)	20.00	25.00
(color)	25.00	30.00
(color)	30.00	35.00
(color)	35.00	40.00
(color)	40.00	45.00
(color)	45.00	50.00

CHART I

75.0 **DISTANCE (IN FEET)**



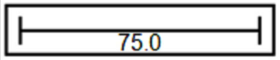
CONSOLIDATED SEDIMENT REFLECTIVITY

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

12 KHz BOTTOM REFLECTIVITY (%)

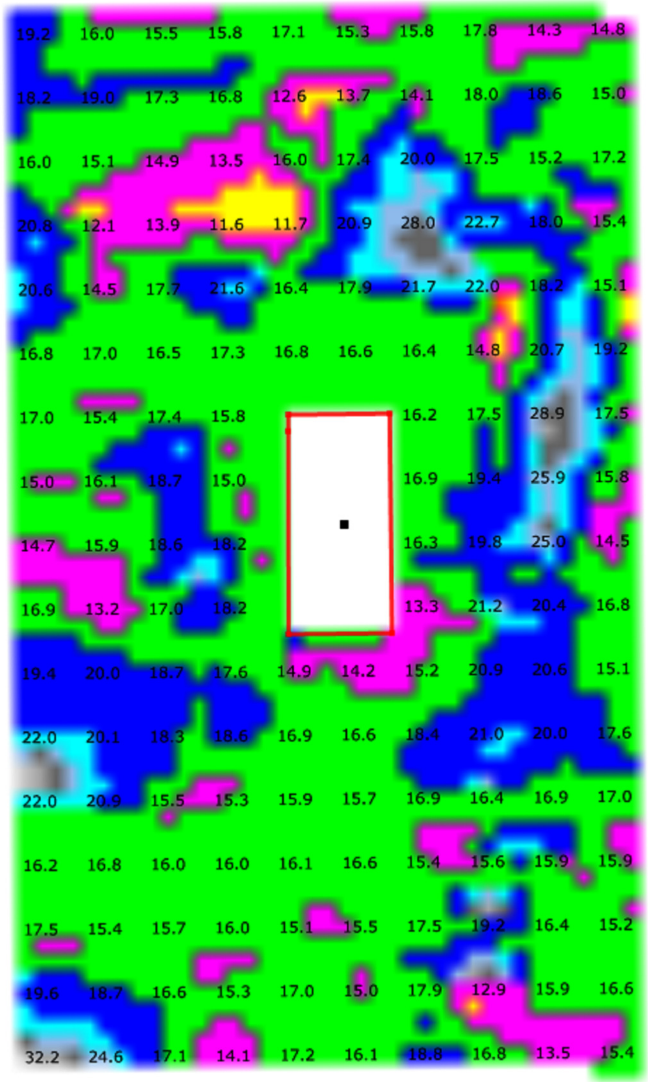
REFLECTIVITY (%)

(dark blue)	0.00	5.00
(blue)	5.00	10.00
(cyan)	10.00	15.00
(light green)	15.00	20.00
(green)	20.00	25.00
(green)	25.00	30.00
(yellow-green)	30.00	35.00
(yellow)	35.00	40.00
(orange)	40.00	45.00
(red)	45.00	50.00



DISTANCE (IN FEET)

CHART J



SURFICIAL SEDIMENT ACOUSTIC BOTTOM LOSS

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

230 KHz BOTTOM LOSS 3dB

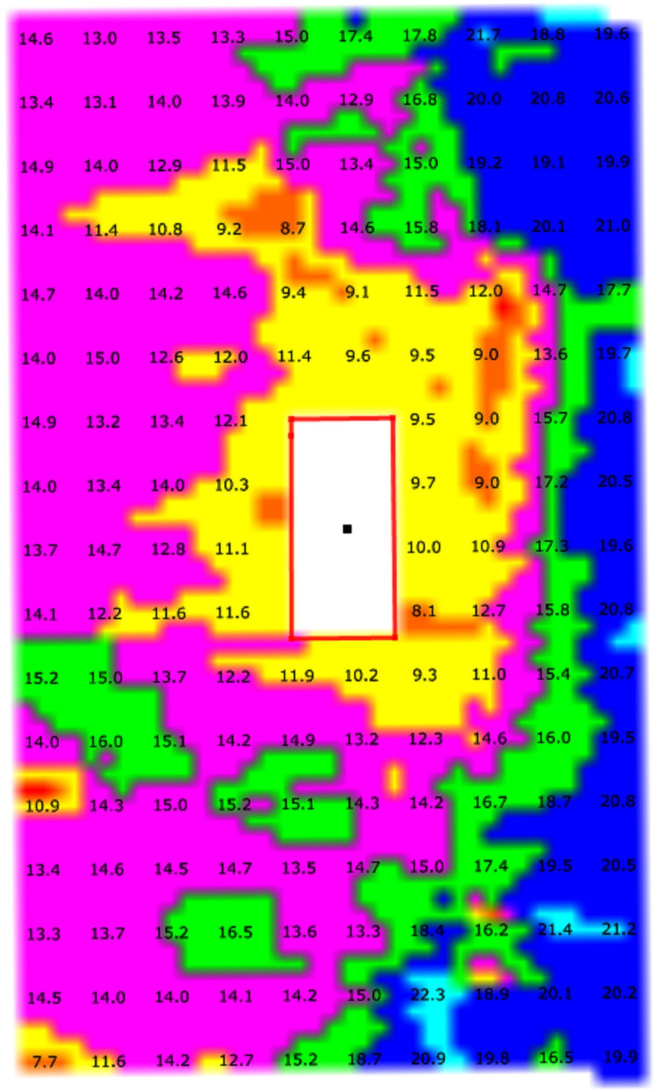
BOTTOM LOSS (in dB)

(dark purple)	0.00	3.00
(red)	3.00	6.00
(orange)	6.00	9.00
(yellow)	9.00	12.00
(magenta)	12.00	15.00
(green)	15.00	18.00
(blue)	18.00	21.00
(cyan)	21.00	24.00
(light blue)	24.00	27.00
(dark grey)	27.00	30.00
(grey)	30.00	33.00
(light grey)	33.00	40.00

75.0

DISTANCE (IN FEET)

CHART K



CONSOLIDATED SEDIMENT ACOUSTIC BOTTOM LOSS

BATON ROUGE I-10 BRIDGE, EAST PIER - 1.4 Acres

12 KHz BOTTOM LOSS 3dB

BOTTOM LOSS (in dB)

	0.00	3.00
	3.00	6.00
	6.00	9.00
	9.00	12.00
	12.00	15.00
	15.00	18.00
	18.00	21.00
	21.00	24.00
	24.00	27.00
	27.00	30.00
	30.00	33.00
	33.00	40.00

75.0 **DISTANCE (IN FEET)**

CHART L