Planning of Dredging Operations utilizing deposited Siltation Vertical and Horizontal Sediment Mapping

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PART ONE

(Part Two provides sediment geoacoustic backscatter metrics used to compute geotechnical parameters shown on the maps in Part One)

Sea Floor Strata

To non-sedimentologists there are many misconceptions with regard to estuarine and sea bottoms. It is a common misbelief that a sea floor consists of a single layer of homogeneous material; with little geotechnical and geochemical variation in both vertical and horizontal spatial expanse.

The word "Sedimentation" is generally understood to denote the movement of water and sediment across a water body; along the way depositing as much as 90% or more of the incoming sediment load in horizontal strata or thin bands across the bottom of the water body. In the strict sense, "Sediment" means all particle sizes ranging from rocks and gravel down to suspended clay. In reality, the most troublesome sediment types consists of silt sizes mixed with large amounts of clays. *So, for purposes of discussion herein, we are using the term "Siltation" to refer to the process and material which causes the need for dredging.*

In heavy sand bottoms or along rocky coasts, vertical homogeny of sediments may be prevalent. However, in many other sea floor types, bottom structure is more complex. For example, some sea floors have a relatively "soft" (unconsolidated) layer over a "harder" (consolidated) layer. The boundaries and thickness of these two layers is defined by the wet bulk density and other geotechnical parameters; as measured by calibrated sonar signals. The top of the unconsolidated layer is referred to as "Surficial" sediment.

In nature, some sea floor bottoms are even more complex. In some cases, above the surficial layer beginning, the bottom is topped with very low density fluid sediment termed Nepheloid layering; from Greek *nephos*, "cloud". To be useful, sonar systems must be capable of being able to differentiate the actual surficial layer from the nepheloid layer.

Once the nepheloid and surficial layers are defined, the next step is to determine the depth of the consolidated layer. Between these two layers is usually where "liquid mud" and other such very soft sediment material resides. *Knowing the thickness of this layer, as it varies over the dredging area, is vital so the dredge operator knows the geoposition and the exact depth he must go to remove most all of the soft material.*

Siltation: Simple Facts

The term "siltation" has been used to describe a process in every type of water body in the world; from mountain lakes, to tropical rivers, to coastal sounds, to various estuaries. Regardless of the water body type, silt is introduced into the body by fluvial sediment input, shoreline erosion, watershed run off, migration of marine sediments inland, tides, and various currents. While there are varying definitions of "silt", it is generally thought of as a mixture of material smaller than small sand sizes together with some amount of clay minerals. Since there are many clay types, each with its own chemical characteristics, other minerals and organic matter are sometimes bound to the silt particles.

Siltation: The Problems

Due to the particle sizes contained in silt and the tendency of such to flocculate, prior to the time the silt settles and becomes part of the surficial sediment, turbidity increases in the water body. This can have a negative impact on phytoplankton. Further, chemicals bound into the silt particles can alter, in a negative way, the water body's water quality.

In cases where the silt is not flushed by tides or currents from the water body, the settling silt adds to the surficial sediment layer. This creates a softer, loose surficial sediment layer which is less stable than the underlying harder consolidated water bottom. Over time, unless cleared by currents or other water movement, this soft silt layer can grow from a few centimeters to a layer measured in meters. If this layer is thick enough, it can hamper the transit of boats, alter the microbial balance of the sediment, and alter the water chemistry above the bottom. In some cases, particularly in cases of a fresh water, land locked lake, with phosphate run off, eutrophication can result causing the entire lake to experience reduced water depths.

Defining the Problem Area

In the past, silt removal by dredges was largely guided by random grab samples and 200 Khz. single channel echo sounders. Both methods were inadequate at defining the actual soft sediment distribution in the water body. It was common to believe the surficial sediment type was mainly homogenous over a large water bottom area; and the thickness of the soft sediment layer was pretty much constant over the area. As noted previously in this paper, both assumptions are usually incorrect. In short, in most cases, the surficial sediment's physical properties tend to be non-uniform with respect to both horizontal and vertical distribution.

Developing a Dredging Planning Map

Unabara's Hydro-2F™ Multi-Frequency Synthetic Beam Bathymetric & Sea Floor Sonar provides the surficial water bottom depth as the dredge operator typically observes. It does, however, also provide the depth of the hard consolidated bottom layer upon which the soft silt layer covers. *At the same time, the Hydro-2F™ provides a map presentation which denotes the soft silt layer thickness at each point in the work area*. *The dredge operator then knows exactly how much sediment to remove at each place in the work area.*

Lastly, the planning map shows the calculated Bulk Density, Porosity,and Acoustic Bottom Loss (a measure of the softness of the bottom) at each place to be dredged. These physical parameters (geotechnical data) are calculated by Unabara's proprietary machine learning algorithm which provides geotechnical metrics by analyzing geoacoustic backscatter signatures from the sea bottom and sub-bottom. Unabara's algorithm is based upon datasets from over eight thousand sea floor locations throughout the world.

Example of a Planning Survey

A coastal fishing boat and yacht harbor (Gulfport, Mississippi) was selected in which to perform a survey example. The harbor has several docks, each of which has multiple boat slips. Between each dock, there is a short channel to exit the dock area. The harbor is subjected to water movement by tides, wind driven surface currents, and an east to west longshore current. Concrete jetties are present on two sides of the harbor to serve as weather protection. These jetties however also serve to trap siltation in the harbor area.

Unabara Hydro-2F™ derived sonar echo data and acoustic backscattering information was processed using HydroMagic™ mapping software (by Eye4Software from The Netherlands). All points on the maps are RTK GPS geoposition referenced. Scaled satellite photographs have been overlaid upon the survey maps to provide both video and color hard copies which result in an augmented reality presentation. (Note: To eliminate clutter on these example maps, the GPS grid has not been shown thereupon). Digital maps can be transferred directly to the dredge operations computer for easy access by the dredge operator.

For this paper, the multi-color display of HydroMagic™ was used to illustrate the functionality of the Hydro-2F™. It should be noted HydroMagic™ can also generate isobaths (depth) contour lines or provide tabular XYZ format data. Data may also be exported as AutoCad™ DXF or Google™ KML files. Sonar derived information may be overlayed with not only satellite photographic maps but also existing grid maps, customer generated maps and state plane grid maps; to provide both video and hard-copy augmented reality maps.

Interpretation of Maps

Map A represents the measured depths of the Unconsolidated Surficial (Soft) Sediment Layer (Bottom). As will be demonstrated in other maps, this layer is very soft fluid mud-type material. The depth of this layer varies about 7.1 feet over the entire harbor area. Note the digital depth readings range from 5.0 to 12.1 feet. (Note the placement of a yellow line on this map and maps which follow denoted "Survey Line Example". This is the location of an echogram labeled "Echogram # 1: Survey Line # 5", which is found later in this document).

Map B represents the measured depths beneath the water's surface of the Consolidated (Hard) Sediment Layer which lies beneath the Surficial Sediment Layer. Depths of this consolidated layer range from a most shallow depth of 5.0 feet to 13.8 feet at its deepest point.

Map C using the depth metrics shown on Maps A & B shows the calculated thickness of the surficial (soft) sediment layer. This "thickness" is comprised of soft fluid sediment made up mostly of silt and clay with some organic matter trapped within such. *It is this layer which is most often targeted for removal by dredging.* If one reviews the thickness measurements, it will be noticed the thickness of this soft layer varies widely over the harbor. At best, the soft fluid layer is less than 0.1 feet while at worst, 3.8 feet. *This presentation is truly a unique tool as it shows the dredge operator precisely how much material to remove at various places in the harbor so that only the harder consolidated sediment remains.*

Map D shows the wet Bulk Density distribution of the surficial layer, expressed in grams per cubic centimeter. Regardless of depth, the density varies between 1.04 g/cc and 1.51 g/cc. Densities near 1.04 g/cc mean the top of the surficial bottom sediment is very fluid as it is composed mostly of water and some high porosity mud-like material.

Map E shows the wet Bulk Density distribution of the hard consolidated layer. Note that densities are much higher than for the surficial layer, meaning the consolidated layer is much more firm and less likely to cause turbidity problems in the water column when exposed to currents.

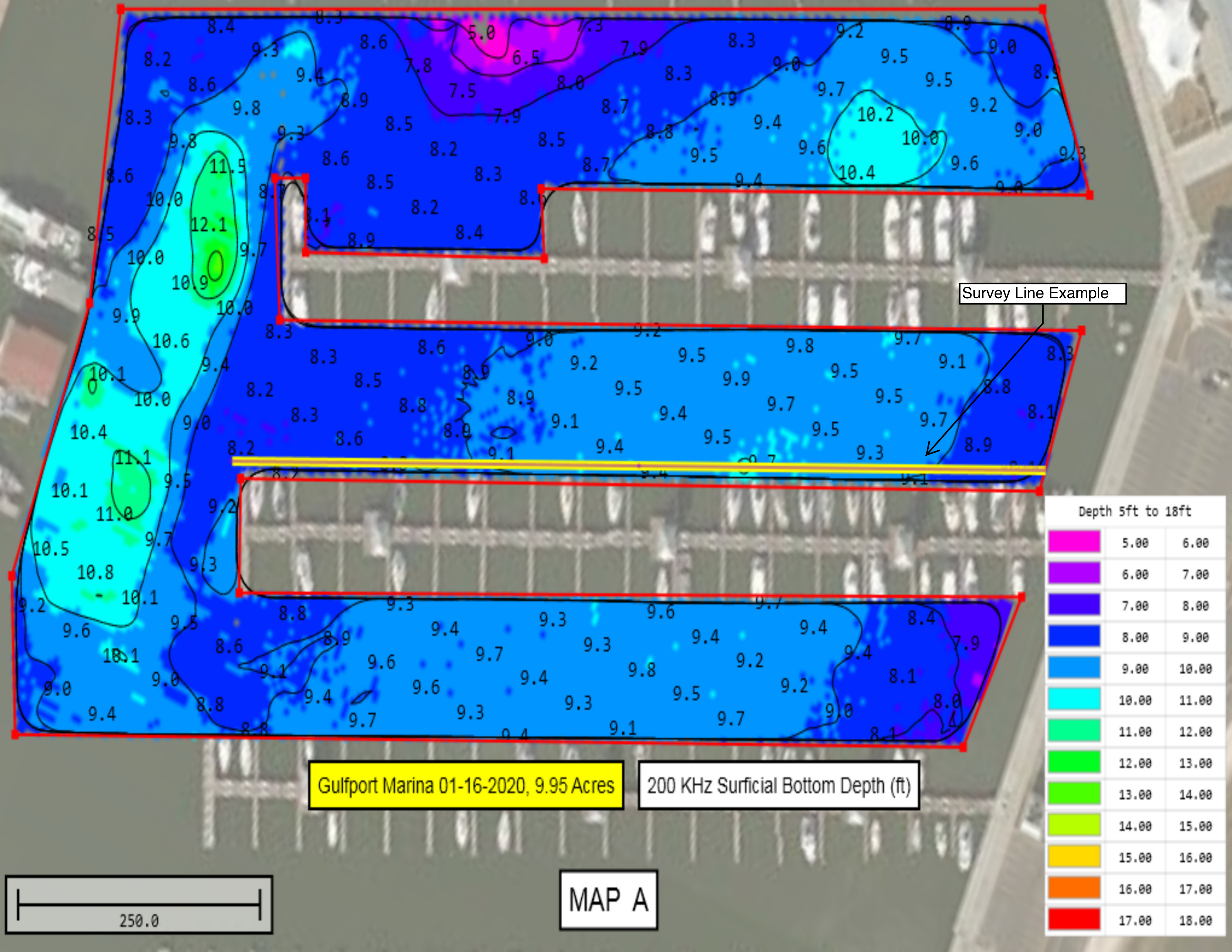
Map F shows the surficial sediment layer porosities. Porosity is defined as the ratio of the volume of water-filled void spaces in a sediment to the total volume of the sediment. Porosity and wet Bulk Density are related by first order equation. Since most of the surficial layer porosity values are in the 90's (percent), this supports the conclusion from Bulk Densities (Map D) that the surficial layer is soft mud-like material with a high water content.

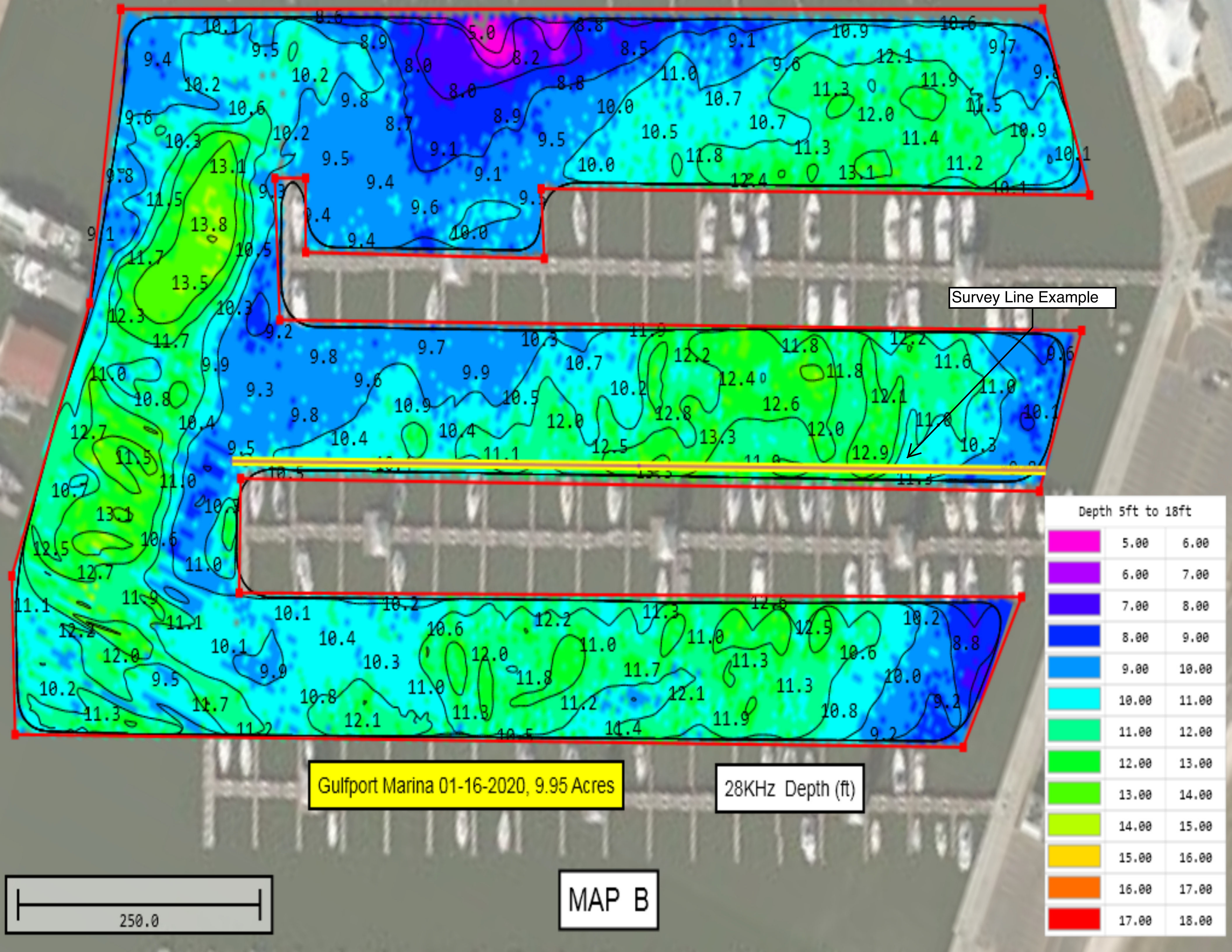
Map G shows the consolidated sediment layer porosities. Various locations of low porosity, hard consolidated sediments are plainly shown.

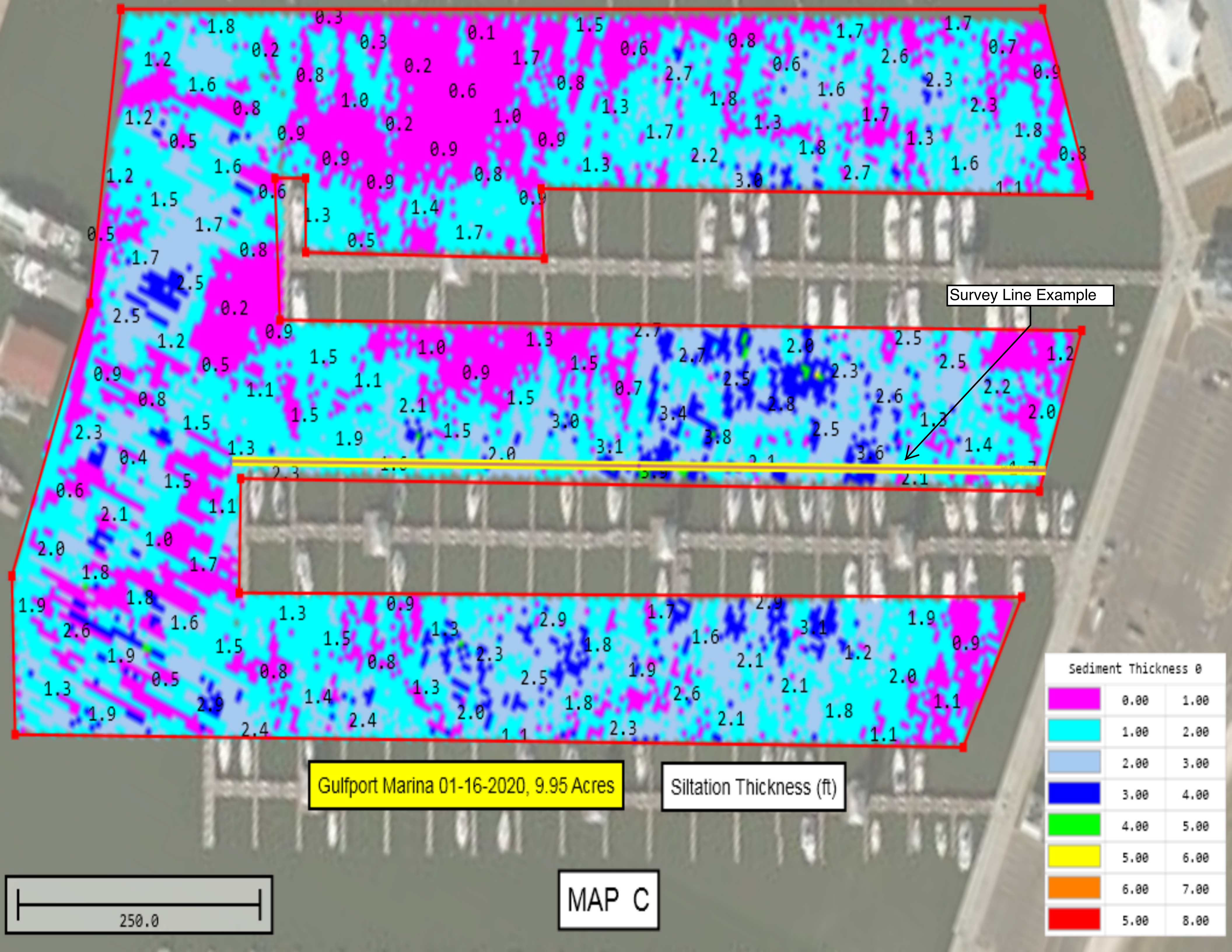
Echogram # 1 Following Map G is an echogram (top display on page) of the surficial layer depth (using 200 KHz. acoustic beam, shown in RED) and consolidated layer depth (using 28 KHz. acoustic beam, shown in GREEN). *See any map in the A thru G series for the location of the survey line for which this echogram shows depth tracings.*

The display at the bottom of the echogram page shows sub-bottom strata along Survey Line # 5 (same line as water depth echogram at top of page). The water column has been removed from the display, thus 0.00 represents the start of the surficial bottom. The depth echogram at top of page is a standard feature of the basic Hydro-2F™/Hydromagic™ system. *The sub-bottom strata display was generated using Sediment View™.*

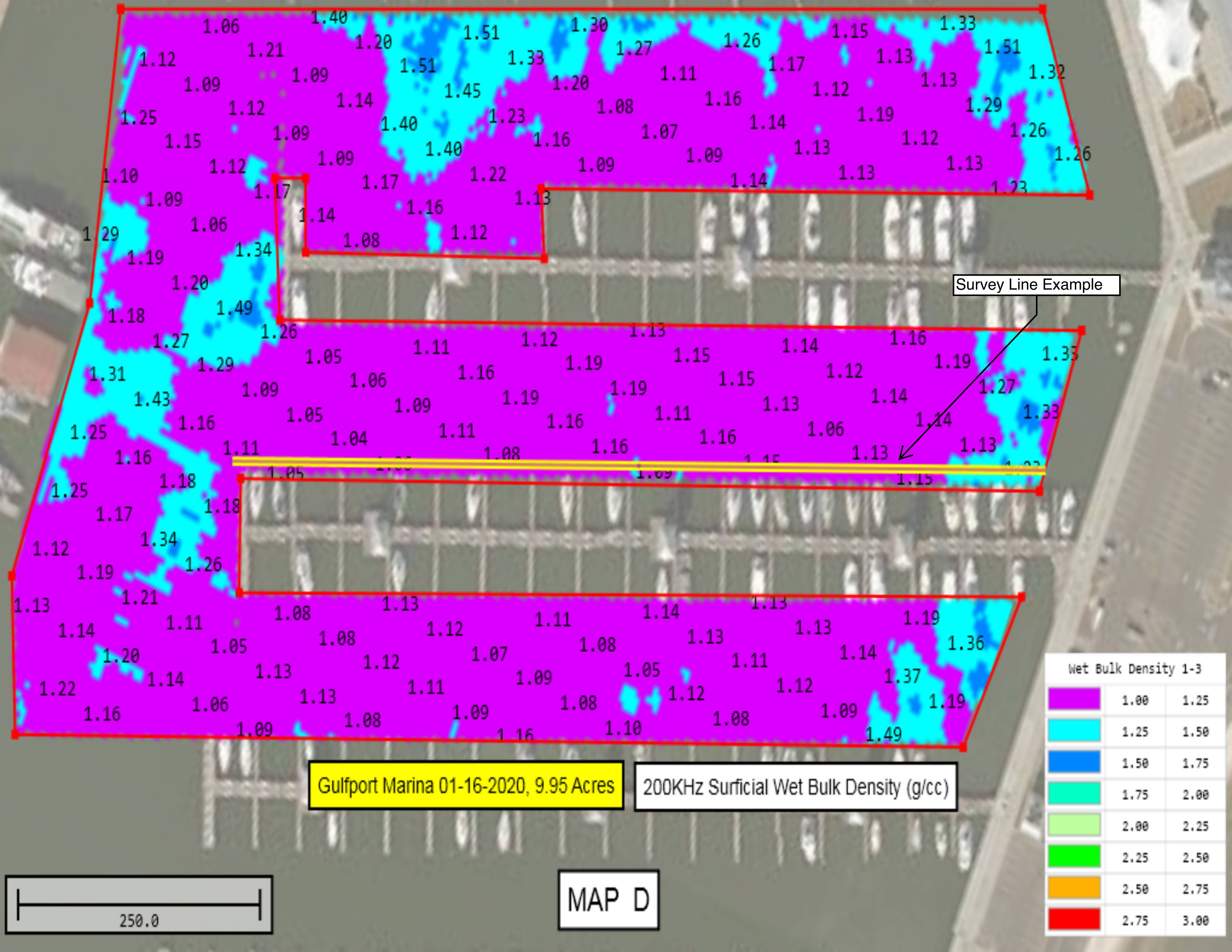
Sediment View™ is an option to the basic Hydro-2F. This option allows the user to select a survey line and display (via HydroMagic™) a vertical "slice" of the sub-bottom. This displays weaker reflection sub-bottom sediment layers between the surficial bottom and the consolidated bottom. In this Sediment View example, relative Reflection Coeficient/Reflection/Acoustic Impedance is used to characterize the various sub-bottom layers using the color codes. Sediment View™ also offers vertical slices which display other geoacoustic and geotechnical metrics.

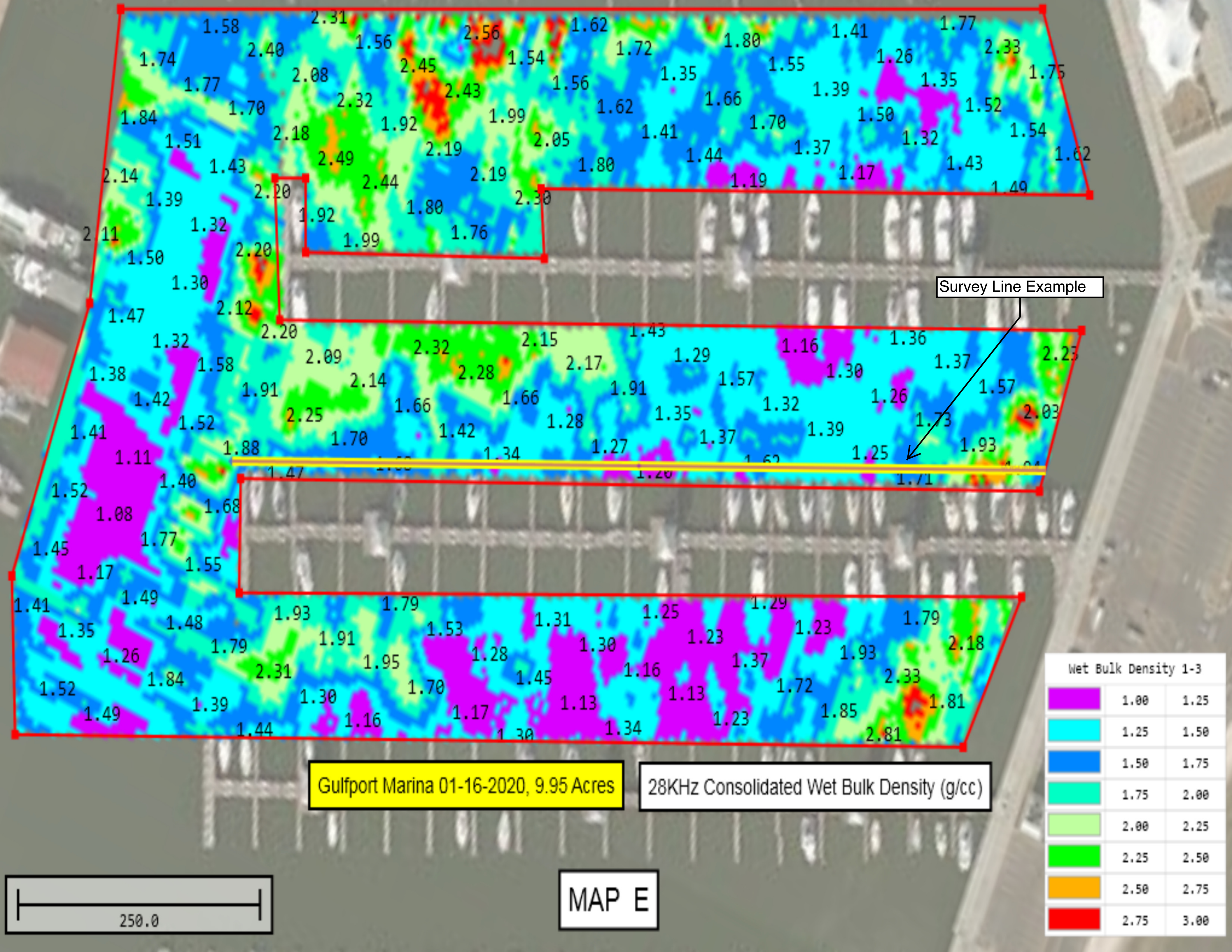

Survey Line Example
Depth 5ft to 18ft
5.00 6.00
6.00 7.00
7.00 8.00
8.00 9.00
9.00 10.00
10.00 11.00
11.00 12.00
12.00 13.00
13.00 14.00
14.00 15.00
15.00 16.00
16.00 17.00
17.00 18.00
Gulfport Marina 01-16-2020, 9.95 Acres
200 KHz Surficial Bottom Depth (ft)
250.0
MAP A

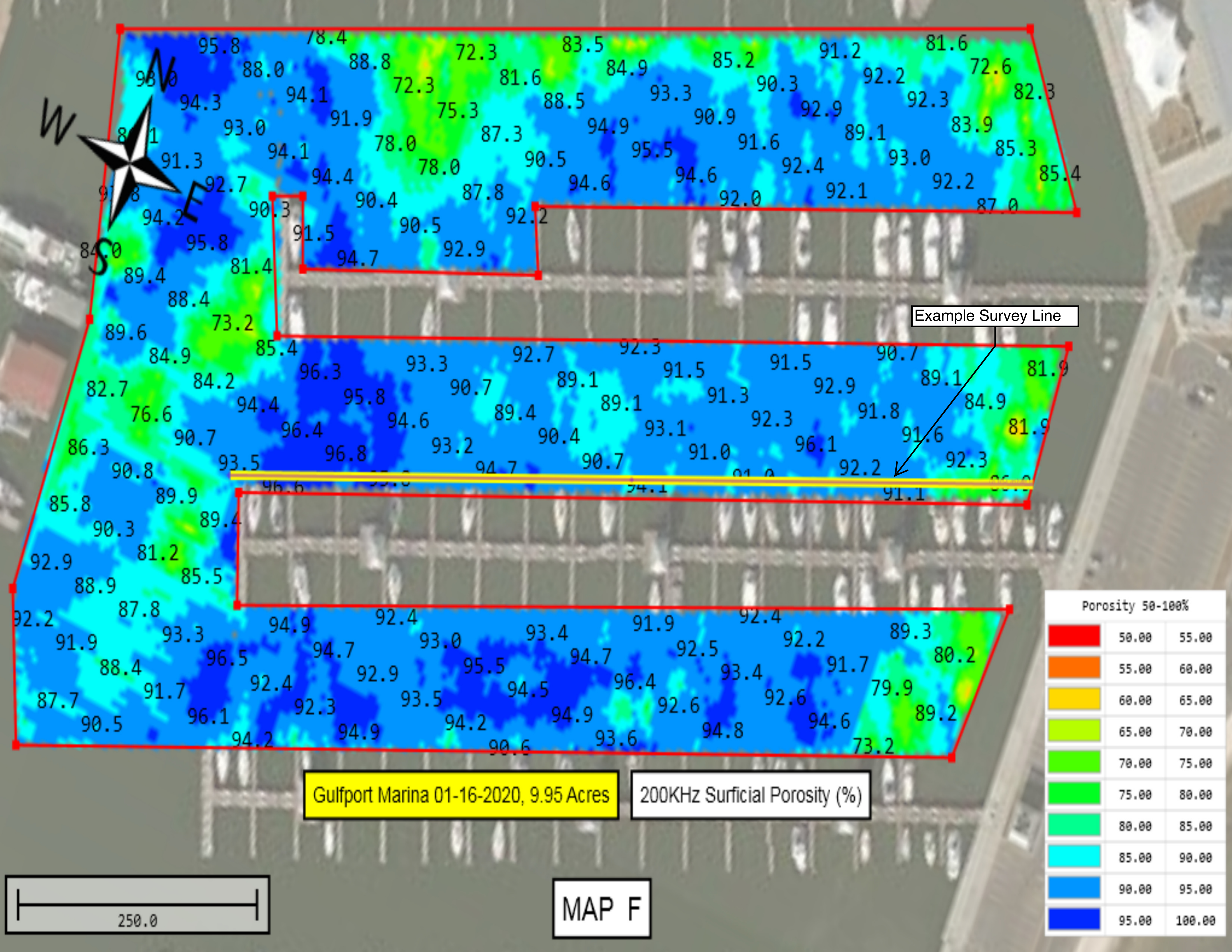

Survey Line Example
Depth 5ft to 18ft
5.00 6.00
6.00 7.00
7.00 8.00
8.00 9.00
9.00 10.00
10.00 11.00
11.00 12.00
12.00 13.00
13.00 14.00
14.00 15.00
15.00 16.00
16.00 17.00
17.00 18.00
Gulfport Marina 01-16-2020, 9.95 Acres
28KHz Depth (ft)
250.0
MAP B



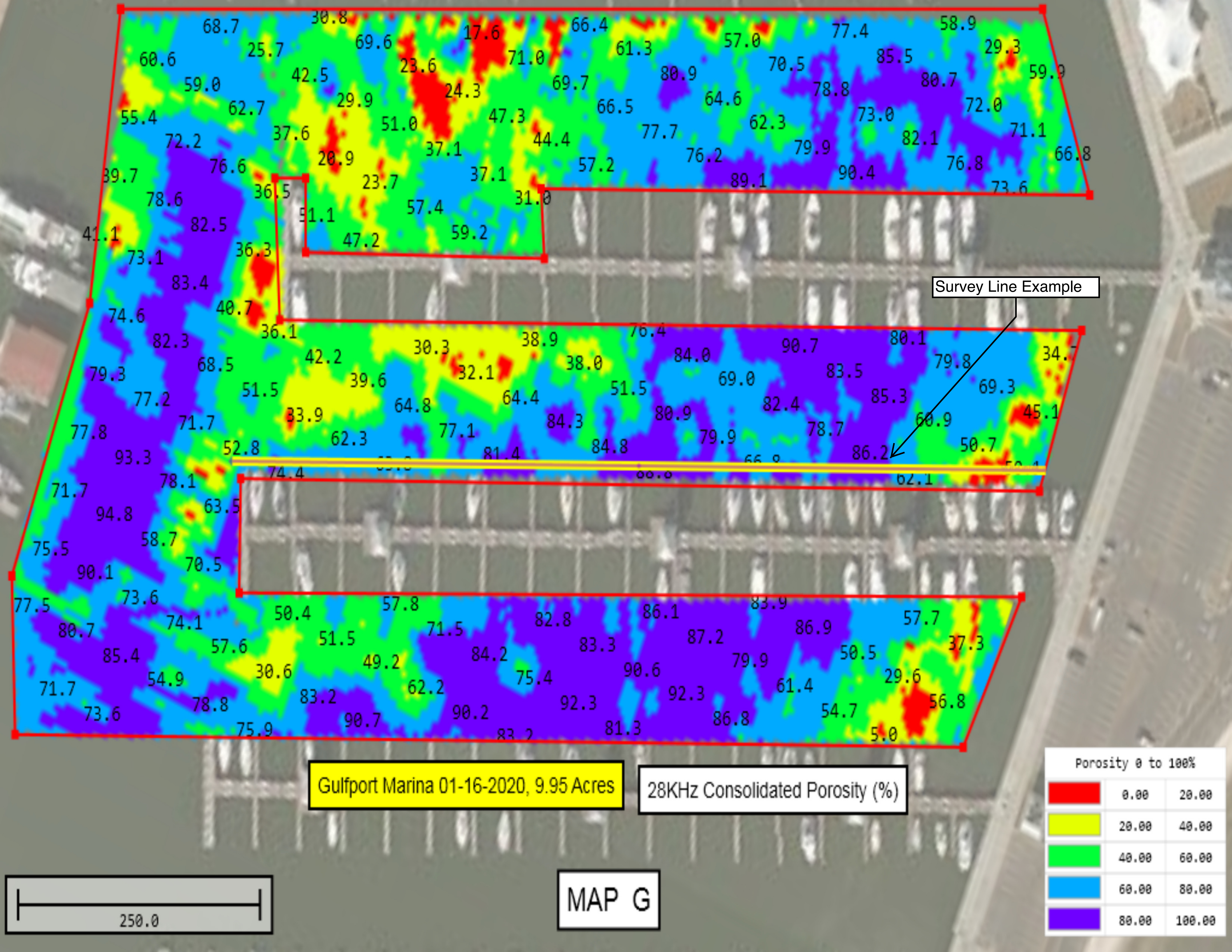
Survey Line Example
Sediment Thickness 0
0.00 1.00
1.00 2.00
2.00 3.00
3.00 4.00
4.00 5.00
5.00 6.00
6.00 7.00
5.00 8.00
Gulfport Marina 01-16-2020, 9.95 Acres
Siltation Thickness (ft)
250.0
MAP C

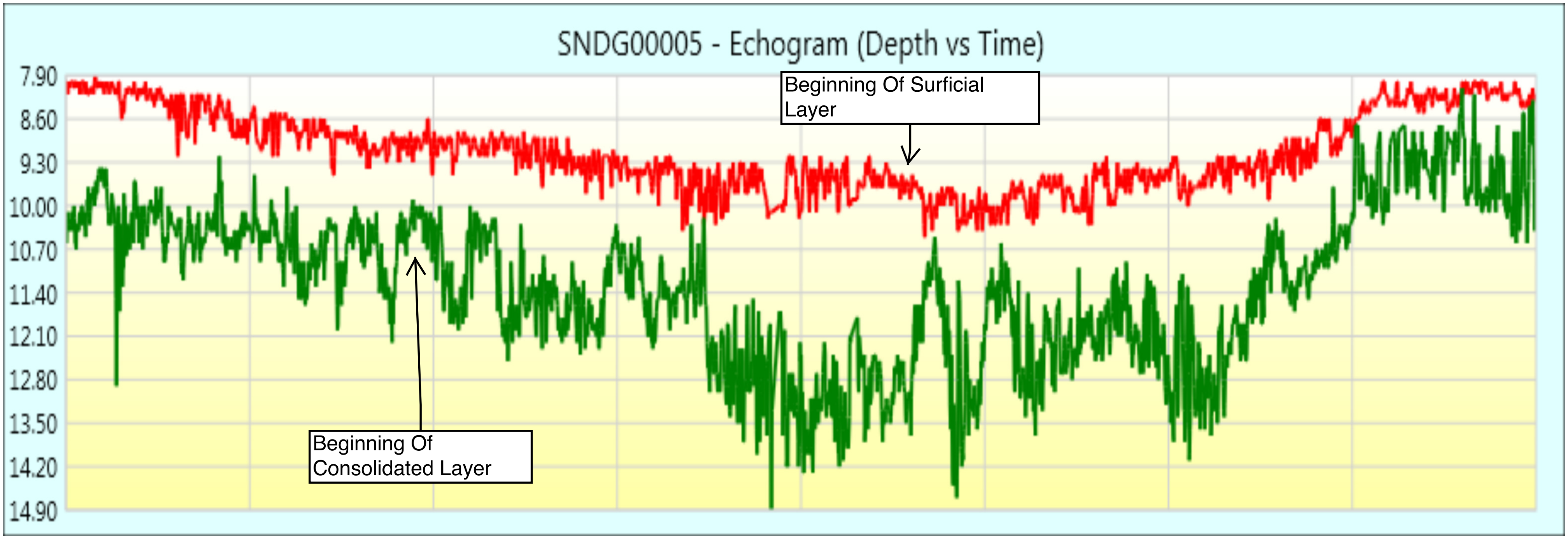

Survey Line Example
Gulfport Marina 01-16-2020, 9.95 Acres
200KHz Surficial Wet Bulk Density (g/cc)
MAP D
250.0
Wet Bulk Density 1-3
1.00 1.25
1.25 1.50
1.50 1.75
1.75 2.00
2.00 2.25
2.25 2.50
2.50 2.75
2.75 3.00

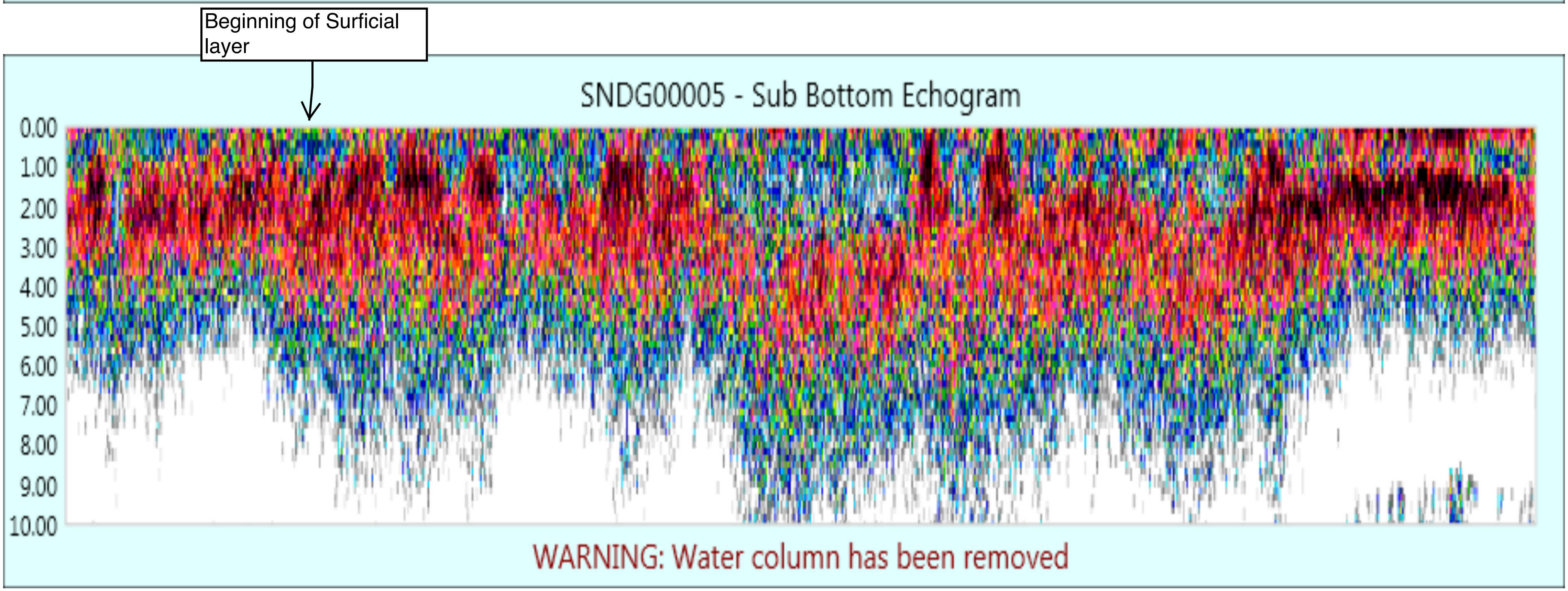

Gulfport Marina 01-16-2020, 9.95 Acres
28KHz Consolidated Wet Bulk Density (g/cc)
MAP E
250.0
Survey Line Example
Wet Bulk Density 1-3
1.00 1.25
1.25 1.50
1.50 1.75
1.75 2.00
2.00 2.25
2.25 2.50
2.50 2.75
2.75 3.00



Gulfport Marina 01-16-2020, 9.95 Acres
200KHz Surficial Porosity (%)
MAP F
Example Survey Line
250.0
N
S
E
W
Porosity 50-100%
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


Survey Line Example
Gulfport Marina 01-16-2020, 9.95 Acres
28KHz Consolidated Porosity (%)
MAP G
250.0
Porosity 0 to 100%
0.00 20.00
20.00 40.00
40.00 60.00
60.00 80.00
80.00 100.00





Note: The YELLOW highlighted line on ALL Charts denotes active survey line

Echogram #1: Survey Line #5