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Phase I
Laboratory Evaluation Report

Detection of Newly Deposited Sediments via Frequency Response Measurements: Dredging Residuals Density Profiler (DRDP)

RESEARCH AND DEVELOPMENT

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Laboratory Evaluation Report

Detection of Newly Deposited Sediments via Frequency Response Measurements: Dredging Residuals Density Profiler (DRDP)

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Notice

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PREFACE

The laboratory evaluation of the DRDP summarized in this report was conducted for the U.S. Environmental Protection Agency (EPA). Dr. Brian Schumacher of the EPA's Environmental Sciences Division (ESD) of the Office of Research and Development's National Exposure Research Laboratory - Las Vegas (ESD-LV) is the Project Officer responsible for direction and oversight of the project. George Brilis, ESD-LV, is the Quality Assurance (QA) Manager responsible for ensuring that the project conforms to the quality standards set by the EPA.

The evaluation was conducted by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL) from 12 August to 17 September 2009, under the direct supervision of William Martin, Director CHL; Jack Davis, Acting Chief, Navigation Division; Ed Russo, Chief, Coastal Engineering Branch; and Tim Welp, ERDC Project Manager, Dredging Group. Derek Wilson, Dredging Group, was the ERDC Quality Assurance Coordinator. Chris Callegan and Michael Tubman, Field Data Collection Branch, assisted in the evaluation and Michael Tubman compiled this report.

Dr. Norbert Greiser of Sediment Management Consultants, Emden, Germany, and Marcus Uhle, of Synergetik, Illingen, Germany, represented the design team of the DRDP prototype and assisted in the laboratory evaluation.

ERDC's primary contractor for developing the DRDP is Evan's Hamilton, Incorporated (EHI). Paul Trapier Puckett of EHI provides contractual coordination and technical oversight on Sediment Management Consultants and Synergetik and assisted in the laboratory evaluation.

At the time of the study, COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

EXECUTIVE SUMMARY

An EPA Interagency Agreement (IAG) was signed between the ERDC and EPA's Environmental Sciences Division (ESD) of the Office of Research and Development's National Exposure Research Laboratory, the objective of which is to have ERDC modify the ADMODUS probe (a navigation fluid mud survey system successfully demonstrated in the Gulfport, MS, navigation channel and in the laboratory) for use in characterizing dredge residuals for environmental dredge projects. Specifically, the system is to be optimized to identify the dredging residuals and facilitate sediment sampling efforts in conjunction with EPA's new Undisturbed Sediment Sampler (USS) designed for environmental dredging projects.

Evaluation tests included both static testing of water and mud for density measurement accuracy and precision, and dynamic testing for density measuring accuracy and vertical resolution. Evaluation tests were performed in rectangular tanks filled with combinations of Gulfport Navigation Ship Channel sediments, sea water, and/or kaolinite (to act as denser bottom sediment).

The DRDP is capable of delineating fluid mud layers of 2-cm thickness or greater, when it profiles these layers at an insertion speed of 1.27 cm/s or less. The average difference between the DRDP measured thicknesses and those measured with a measuring tape was -0.34 cm with a standard deviation of 0.69 cm.

In comparison to the densimeter, the average difference between the DRDP density measurements (for Type A, Type D, and Type E tests at insertion speeds of 1.27 cm/s or less) and the densimeter readings is 0.0023 g/cm^3 with a standard deviation of 0.0063 g/cm^3. In comparison to the sediment laboratory sample analyses, the average difference between the DRDP density measurements (for Type D and Type E tests at insertion speeds of 1.27 cm/s or less) and the sample analyses is 0.0095 g/cm^3 with a standard deviation is 0.0156 g/cm^3. The average precision of the DRDP measurements during the evaluation was 0.0007 g/cm^3.

The initial prototype of the DRDP was successful in delineating the mud layer thicknesses and in determining the density of each mud layer. The fastest profiling speed that would produce reasonable results may be higher when the DRDP operates at a sample output speed greater than the 8 Hz needed for this laboratory evaluation. The results of this evaluation will be incorporated into recommendations to modifying the Phase I prototype during Phase II and in the subsequent delivery of the final DRDP prototype.

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List of Acronyms and Abbreviations

ASTM	American Society for Testing and Materials
CHL	Coastal and Hydraulics Laboratory
CMB	Characterization and Monitoring Branch
CV	Coefficient of Variation
DOER	Dredging Operation and Environmental Research
DRDP	Dredging Residuals Density Profiler
EHI	Evan’s Hamilton, Incorporated
EPA	United Stated Environmental Protection Agency
ERDC	Engineering Research and Development Center
ESD	Environmental Sciences Division
IAG	Interagency Agreement
LV	Las Vegas, Nevada
NRC	National Research Council
OT	Operations Technology
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RSD	Relative Standard Deviation
SID	Sensor Insertion Device
USACE	United States Army Corps of Engineers
USS	Undisturbed Sediment Sampler

1.0 INTRODUCTION

Fluid mud and dredging residuals are found in dredging projects on the Atlantic, Gulf of Mexico, and Pacific coasts. Fluid mud is a high concentration aqueous suspension of fine grained sediment (i.e., silt and clay size material with grain-sizes less than 0.06 mm) in which settling is substantially hindered by the proximity of sediment grains and flocs, but which has not formed an interconnected matrix of bonds strong enough to eliminate the potential for mobility, leading to a persistent suspension (McAnally et al. 2007). Fluid mud can be characterized as suspensions with density gradations that range from slightly greater than that of the overlying water in its upper layers, to densities of 1.30 g/cm^3 in the lower layers with total layer thicknesses ranging from several decimeters to approximately 3 m. As per Bridges et al. (2008) "dredging residuals refer to contaminated sediment found at the post-dredging surface of the sediment profile, either within or adjacent to the dredging footprint. After the initial consolidation period (i.e., within a period of several days to a few weeks, depending on sediment characteristics and site conditions), generated residuals (excluding sloughed materials) typically occur as a thin veneer (1 to 10 cm thick) of fine-grained material, with relatively low dry bulk density (ranging from approximately 0.2 to 0.5 gm/cm^3), the typical dry bulk density for fine-grained sediment is 0.5 to 0.9 gm/cm^3."

No standardized method exists in the U.S. Army Corps of Engineers (USACE) to survey fluid mud or dredging residuals. Ambiguous depth measurements resulting from the presence of fluid mud have resulted in navigation dredging contract payment disputes. The lack of a method to quantify the presence of dredging residuals has hindered complete site characterizations of environmental dredging site sediment conditions.

An EPA Interagency Agreement (IAG) was signed between the ERDC and EPA's Environmental Sciences Division (ESD) of the Office of Research and Development's National Exposure Research Laboratory, the objective of which is to have ERDC modify the ADMODUS probe (a navigation fluid mud survey system successfully demonstrated in the Gulfport, MS, navigation channel and in the laboratory) for use in characterizing dredge residuals for environmental dredge projects. Specifically, the system is to be optimized to identify dredging residuals and facilitate sediment sampling efforts in conjunction with EPA's new Undisturbed Sediment Sampler (USS) designed for environmental dredging projects by the EPA's Characterization and Monitoring Branch (CMB). In the environmental arena, it would be of great benefit to know *a priori* the exact locations and thicknesses of the dredging residual layers without having to actually sample the sediment and visually examine the collected sediment column. Dredging residuals (e.g., newly deposited sediments from an upstream dredging event) of thicknesses as thin as 1 cm are of interest to meet the needs identified in the National

Research Council (NRC) report (2001). The increased resolution of a modified ADMODUS probe will allow accurate characterization of fluid mud and thinner layers of dredging residuals, and enhance environmental dredging site characterization efforts.

This development effort is jointly-funded by the EPA and the USACE's Operations Technologies (OT) Focus Area of the Dredging Operation and Environmental Research (DOER) Program.

A requirements analysis questionnaire was sent to various personnel involved in environmental dredging projects and dredging residuals and the following design goals for the Dredging Residuals Density Profiler (DRDP) were identified:

- 10 mm or less vertical resolution.
- Density accuracy of less than +/- 0.5 percent of the density (i.e., approximately +/- 0.005 g/cm^3)
- Density range of 0.977 g/cm^3 to 1.300 $g/cm^{3.}$
- No site specific instrument calibration.
- Repeatability of measurements of less than 1 percent.
- Resolution of 0.001 $g/cm^{3.}$
- Operating depth of up to 100 m.
- Real-time output.

A two phased approach is being used to develop this sensor system with commencement of Phase II being dependant upon successful completion of Phase I. Under Phase I, the DRDP prototype (Figure 1) was developed to improve the capability to accurately characterize environmental dredging projects where fluid mud/residual conditions occur. The laboratory evaluation of the DRDP described in this report is part of the Phase I development project, and is designed to evaluate the systems accuracy, precision, and applicability to USACE surveying practices under controlled conditions.

The Quality Assurance Project Plan (QAPP - Appendix A), calls for placing samples of fluid mud collected from the Gulfport Navigation Ship Channel (Gulfport, MS) in containers which are then vertically profiled by the DRDP. As specified, the samples are to be placed in the containers with varying densities and thicknesses to evaluate the system's performance.

Figure 1. The Dredging Residuals Density Profiler (DRDP).

2.0 APPROACH

2.1 Design of Laboratory Evaluation Program

The evaluation program was designed to determine system accuracy, precision and vertical resolution, defined as:

- Accuracy – measure of overall agreement of the DRDP density measurement to a known value.

- Precision – measure of agreement among repeated measurements of the same property under substantially similar conditions expressed in terms of the standard deviation.

- Vertical resolution – measure of the agreement of the DRDP determination of thickness of a fluid mud layer and the thickness of the layer measured with a measuring tape.

Gulfport Navigation Ship Channel sediment is generally a fine-grained cohesive sediment with density profiles (in the dredging template) ranging from 1.006 to 1.250 g/cm^3. The source of the samples tested in the laboratory was mud collected and stored in two 55-gallon drums (Barrels 1 and 2). In the drums, the mud was allowed to consolidate and needed to be diluted with seawater (taken from the same location as the mud) to create a range of densities for testing. Preparing the samples required an independent means of quickly measuring the densities during the evaluation process. The means of doing this was a portable handheld densimeter, the Mettler-Toledo Densito 30PX. The densimeter operates upon the vibrating "U-tube" principle, is temperature compensated, has a stated accuracy of +/- 0.001 g/cm^3, and has a resolution of 0.0001 g/cm^3. The calibration of the densimeter was checked daily using distilled water. It was found to be accurate in these calibration tests to 0.0001 g/cm^3 (one standard deviation).

To obtain relatively homogeneous sediment samples for testing, the fluid mud in the two 55 gallon (208 L) drums (Barrels 1 and 2) were stirred with a paddle stirrer. One liter samples of material were then scooped from the surface of each drum. These 1-liter samples of the source mud from the drums were taken at the start of the sensor evaluation (triplicates) on 13 August 2009, at mid-point in the evaluation (triplicates) on 16 August 2009, and at the end of the evaluation (five samples) on 19 August 2009. The organic contents of these samples were tested using the American Society for Testing and Materials (ASTM) D 2974–071 (ASTM 2009c). Three 1-liter samples from Barrel 2 underwent grain-size analysis using the Standard Test Method for Particle-Size Analysis of Soils (ASTM 2009a). The procedures for the Bulk Density Analysis-Pycnometer Method are given in Appendix B.

The QAPP stated that the solids specific gravity and density would be determined by performing the ASTM D 854–06 Standard Test Method for Determining Specific Gravity of Soil Solids by Water Pycnometers (ASTM 2009b), but this test was later deemed inappropriate because it was designed for dry and moist soil samples, not the high water contents of the range of slurry density mixtures in which the DRDP was evaluated. Various alternative laboratory test methods were considered, such as the American Public Health Association et al. (1998), a standardized test for determining specific gravity of sludge. This method (involving measuring the weight of a given volume of sample to calculate specific gravity) was deemed to be too inaccurate. The best methods were determined to be the Bulk Density Analysis-Pycnometer Method, developed by Dr. Allen Teeter of ERDC, in conjunction with the Pycnometer Volume Calibration procedure.

To verify the precision of the Bulk Density Analysis-Pycnometer Method, five 1-liter sample replicates from each 55 gallon drum of mud were tested and analyzed. Replicate variances were calculated by dividing the standard deviations of the sediment laboratory density results by the mean (i.e., the relative standard deviation (RSD) or coefficient of variation (CV) and multiplying by 100 to express as a percentage). For Barrel 1, the RSD was 0.2 percent, while for Barrel 2, it was 0.26 percent. Sediment laboratory tests of particle size distribution and total organic content were also conducted on 1-liter samples collected from the homogenized 55 gallon drums.

The evaluation testing included both static testing of water and mud for density measurement accuracy and precision, and dynamic testing for density measuring accuracy and vertical resolution. The static testing was conducted by lowering the DRDP into samples in 20-liter buckets (Figure 2), and allowing the system to record samples at 8 Hz for several minutes. While the DRDP could sample at 20 Hz, it was constrained to sampling at 8 Hz because of the data stream requirement of merging this parameter with vertical position data. The dynamic testing of samples required that a substrate be constructed in a rectangular tank, upon which a layer of fluid mud was placed. The substrate needed to have properties that would result in system readings that clearly differentiate it from the fluid mud. A layer of kaolinite, 18 cm thick, was chosen to construct the substrate (Figure 3). For a yet undetermined reason, the DRDP was unable to get an accurate sound velocity measurements in the kaolinite. This was a factor in the DRDP measuring densities of the kaolinite greater than 1.3 g/cm^3, which were inaccurate, but which clearly differentiated the substrate from the mud layer. The mud layers were of varying thicknesses and densities. For some of these tests, a layer of salt water was placed on top of the fluid mud. The samples in these rectangular tanks were then vertically profiled by the DRDP. Figure 4 shows a rectangular tank with a substrate, a layer of fluid mud with a uniform thickness, and a layer of seawater ready to be profiled by the DRDP. The DRDP, while recording data at 8 Hz, was lowered through the water (when water was placed on top), through the fluid mud, and into the kaolinite substrate (Figure 5). Once embedded in the substrate, data recording was stopped and the sensor was retracted. This process was repeated three to five times in each tank.

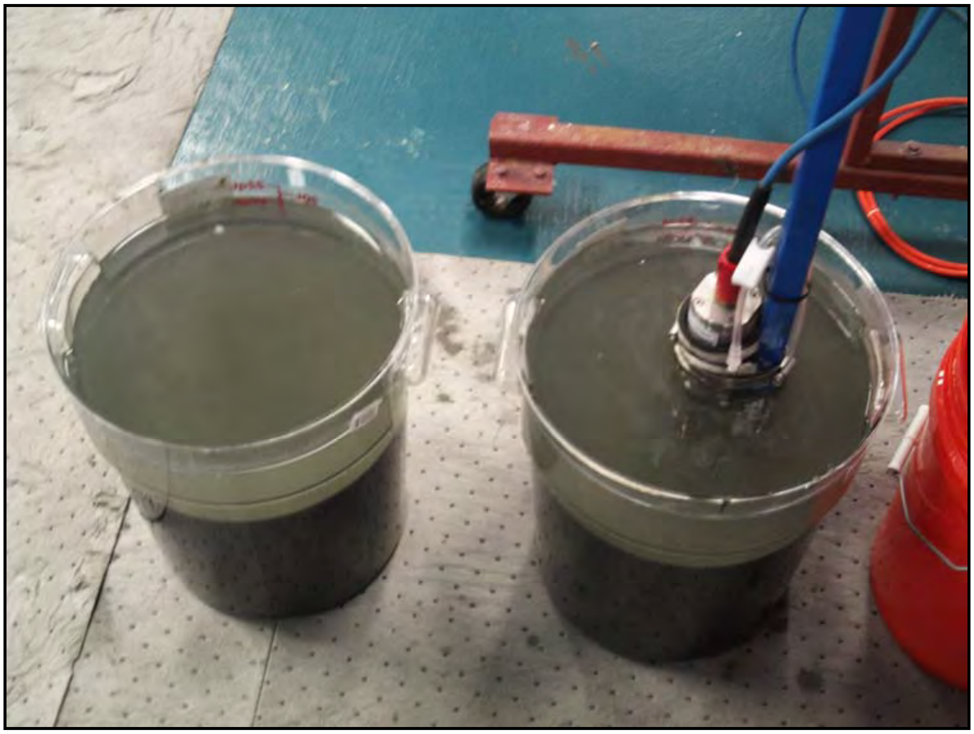

Figure 2. Static testing of samples in 1-1 buckets.

Figure 3. Kaolinite substrate in rectangular test tank.

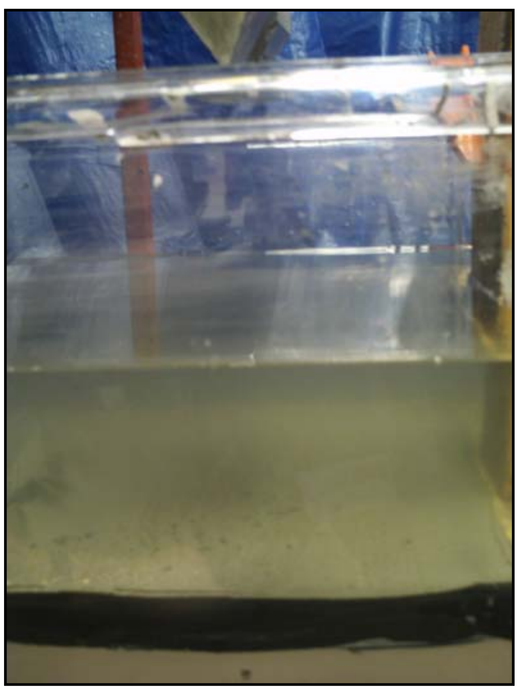

Figure 4. A layer of seawater and mud over a kaolinite substrate in a rectangular test tank.

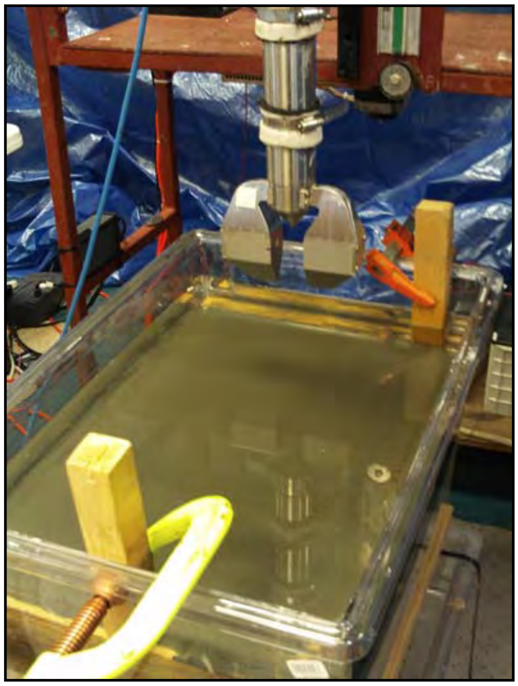

Figure 5. DRDP ready to be lowered into rectangular test tank.

Figure 6. Custom designed Sensor Insertion Device (SID).

Lowering and raising the DRDP was conducted by mounting it on a rigid bracket which was on a sliding track suspended over the sample containers. A custom-designed Sensor Insertion Device (SID, Figure 6) was equipped with castors to allow it to be moved over the samples after they were prepared. The SID used an adjustable-speed programmable linear actuator (XLA-9 T35LS 500-ENC Specialty Motors, Inc.) to raise and lower the bracket on its track; thereby, lowering the DRDP into the samples to precise vertical locations at controlled and measureable descent rates. The ability of the SID to lower the DRDP to precise locations was checked daily by having it lower the sensor 75 cm to a location marked on the frame. The SID was able to do this with an accuracy better than the plus-or-minus 1 mm as measured with a measuring tape. The SID output was the sensor vertical position data recorded with the DRDP output data at 8 Hz.

During discussions about DRDP performance prior to laboratory evaluation testing, a concern was identified regarding the effect of air bubbles in the samples being tested. This concern was evaluated in the testing by introducing air bubbles into one of the samples.

2.2 DRDP Measuring Principles

The operating frequency of the DRDP is 2 MHz. The functioning of the DRDP is based on the measurement of three ultrasound parameters:

- Acoustic impedance of the medium (Z_{med}).
- Sound speed within the medium (c_{med}).
- Ultrasound transmission characteristics (attenuation) of the medium.

For the measurement of the acoustic impedance, ultrasound is emitted by the transducer of the left sensor (S1, Figure 7). The ultrasound waves propagate to both sides (a1 and a2) and are reflected at both ends of the sensor. The amplitudes of the reflected ultrasound waves correspond to the acoustic impedance of the medium outside the sensor (Z_{med}) and the acoustic impedance of the reference medium within the sensor (Z_{ref}).

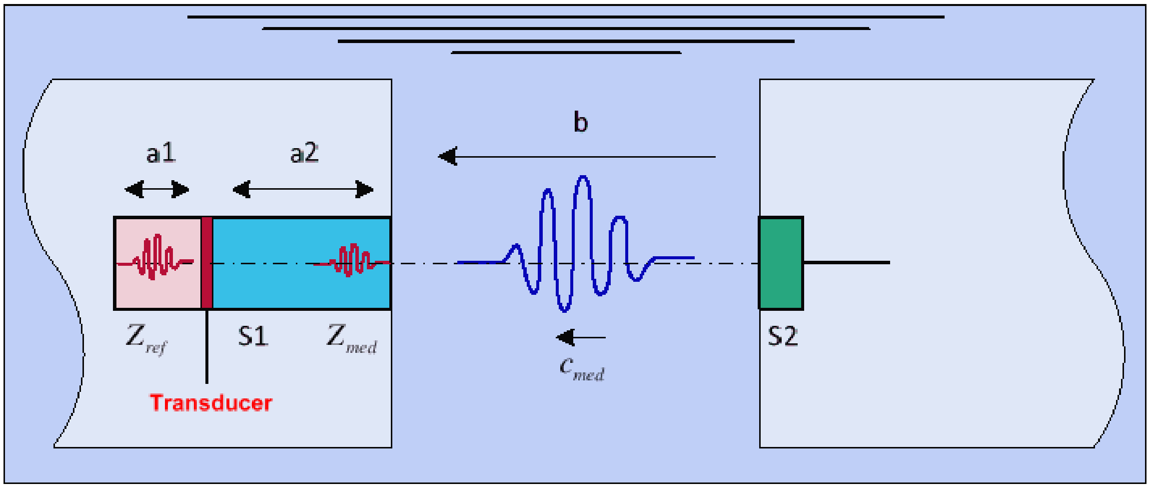

Figure 7. DRDP measuring principles.

The acoustic impedance of the medium (Z_{med}) is calculated from the following equation:

$$Z_{med} = \rho_{sensor} \cdot c_{sensor} \cdot \frac{1+r}{1-r}$$

Where, r is the reflection coefficient, ρ_{sensor}, is the density of the sensor medium, and, c_{sensor}, is the sound speed within the reference medium of the sensor.

To calculate the reflection coefficient (r), it is also necessary to measure the amplitudes of the reflected sound waves (A_{med} and A_{ref}). Then, r, is given by:

$$r = \frac{A_{med}}{A_{ref}} \cdot \frac{-1}{\kappa}$$

Where, κ, is the sensor calibration coefficient.

The corresponding sound wave signals are shown in Figure 8. The x-axis in Figure 8 is distance in centimeters within the DRDP sensor S1 (Figure 7). Supplementary calculations are done by some special algorithms needed for compensation of temperature dependent changes of the measured sound speed within the reference material, which will alter the amplitudes, A_{med} and A_{ref} (described in German Patent DE 101 12 583 C2, issued to Siemens AG on 27 March 2003). The determination of the required temperature compensation is based on the relation of the temperature dependent changes of the sound speed and the attenuation of the sensor reference medium. The most accurate density measurement will occur when the temperature of the sensor material is the same as that of measured medium outside the sensor. It is recommended that the specific temperature dependent numerical relation of sound speed and attenuation be experimentally determined for each DRDP sensor manufactured.

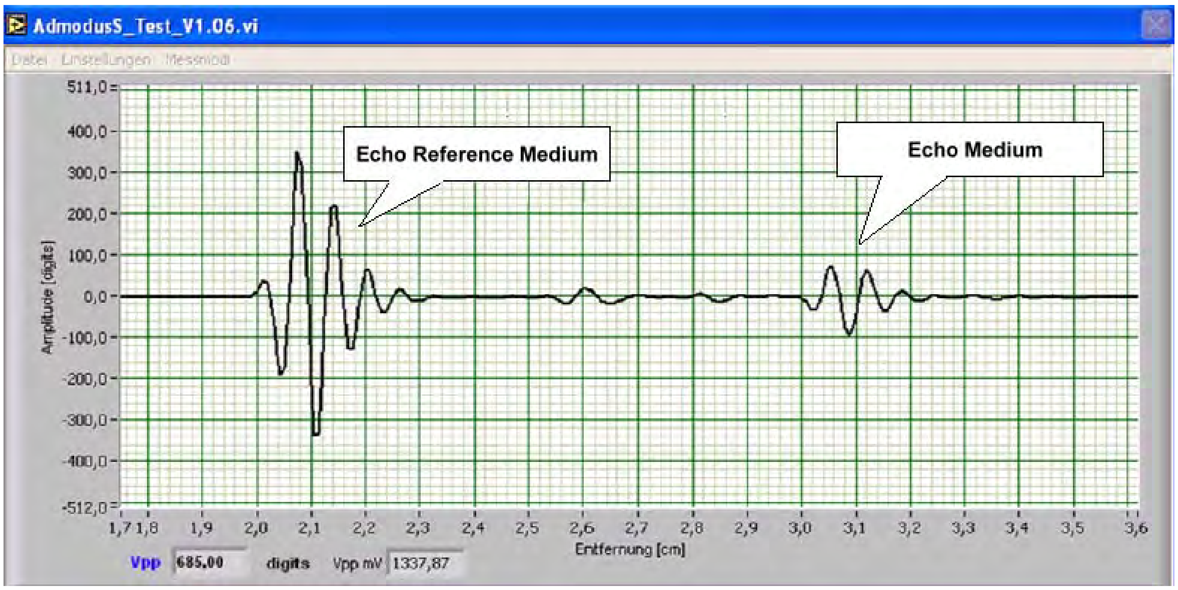

Figure 8. Relation of the ultrasound wave signals reflected at the left and right sides of the sensor.

The sound speed within the medium is based on the measurement of the transmission time of the ultrasound signal emitted from the second sensor (S2) on the right to the receiver (transducer) of the left sensor (S1). This measurement is corrected by the time the transducer needs for reaching maximum signal emission intensity, and by subtracting the additional travel time through sensor section, a2. The sound speed within the medium (section b) is then given by the following equation:

$$c_{med} = \frac{d_b}{t_b}$$

Where, d_b, is the distance between S1 and S2 and, t_b, is the travel time between S1 and S2.

The density of the medium, measured directly at the right window of the impedance sensor is calculated as:

$$\rho_{med.surface} = \frac{Z_{med}}{c_{med}}$$

This density determination is valid for homogeneous media. For inhomogeneous (multi-phase) media, this density value may not exactly correspond to the mean density of a certain larger volume of such media. Therefore, a correction factor has been experimentally determined from the medium related modifications of the sound waves that have been emitted by the S2-transducer after they have passed through the medium. In this respect, the DRDP output density value is a combination of the density values, one measured directly at the surface of the sensor window and a second density (integral density value) that is more closely related to the acoustic properties of the sample volume that is penetrated by the ultrasound waves.

2.3 Evaluation Tests

Four types of evaluation tests were conducted. They were:

Type A. Static tests of fresh water at three temperatures and saltwater at one temperature. The densities of the water were determine from the handheld densimeter and by calculating them based on temperature measurements using a laboratory thermometer and salinity measurements using a YSI XLM 600 CTD.

Type C. Static density measurements with the DRDP and handheld densimeter before and after bubbles had been introduced into a sample by vigorous stirring.

Type D. Static DRDP density measurements in homogeneous mud mixtures. The densities of the mixtures were measured using the handheld densimeter and from 1-liter samples sent to the sediment laboratory for pycnometer analysis.

Type E. Dynamic testing of density and vertical resolution through mud mixtures of various densities and thicknesses in rectangular test chambers. The densities of the mixtures were measured using the handheld densimeter and, in most cases, from 1-liter samples sent to the sediment laboratory.

The specific conditions for test types A, D, and E are given in Tables 1 through 3, respectively.

Table 1. Type A tests.

Test	Sample	Data File	Handheld Densimeter Reading (g/cm³)	Calculated Density (g/cm³)
A1	Fresh tap water at room temperature (28.5°C)	A1-FW-ST	0.9968	0.9961
A2	Fresh hot tap water (40.0°C)	A2-FW-ST	0.9946	0.9922
A3	Fresh tap water with ice melted in it (3.0°C)	A3-FW-ST	1.0010	0.9999
A4	Gulfport seawater (24.5 ppt salinity, 24.0°C)	A4-SW-ST	1.0177	1.0179

Table 2. Type D tests.

Test	Sample (Each Sample Contained Gulfport Navigation Ship Channel Mud)	File	Handheld Densimeter Reading (g/cm³)
D1	Directly from Barrel 1	D1-MS1-ST	Too dense for densimeter
D2	Barrel 1 diluted with seawater	D2-MS2-ST	1.1474
D3	Sample used for Test D2 diluted again with seawater	D3-MS3-ST	1.0867
D4	Barrel 1 diluted with seawater	D4-MS4-ST	1.1675
D5	Barrel 1 diluted with seawater	D5-MS5-ST	1.1210
D6	Barrel 1 diluted with seawater	D6-MS6-ST	1.107

Table 3. Type E tests.

Test	Sample (Each Sample Contained Gulfport Navigation Ship Channel Mud)	Files	Handheld Densimeter Reading (g/cm3)	DRDP Insertion Speed (cm/s)
E1	10-cm layer of mud directly from Barrel 1 over kaolinite substrate with no water on top	E1-MS1-DY E2-MS1-DY E4-MS1-DY E5-MS1-DY	Too dense for densimeter	1.27
E2	2-cm layer of mud directly from Barrel 1 over kaolinite substrate with no water on top	E7-MS2-DY E9-MS2-DY	Too dense for densimeter	1.27
E3	10-cm layer of mud directly from Barrel 1 over kaolinite substrate with 5.7 cm of saltwater on top	E11-MS3-DY E13-MS3-DY E15-MS3-DY	Too dense for densimeter	1.27
E4	3-cm layer of diluted Barrel-1 mud over kaolinite substrate with 3.5 cm of saltwater on top	E20-MS4-DY E21-MS4-DY	1.1675	0.63
E5	2-cm layer of diluted Barrel-1 mud over kaolinite substrate with no water on top	E28-MS8-DY E29-MS8-DY E30-MS8-DY	1.0900	0.63
E6	6-cm layer of diluted Barrel-2 mud over kaolinite substrate with 4.5 cm of saltwater on top	E31-MS12-DY E32-MS12-DY E33-MS12-DY E34-MS12-DY	1.1510	0.63 for files E31, E32 and E33 6.35 for file E34
E7	2-cm layer of sample used in Test E6 over kaolinite substrate with 4 cm of saltwater on top	E36-MS12-DY E37-MS12-DY E38-MS12-DY E39-MS12-DY E40-MS12-DY	1.1510	0.63 for files E36, E37 and E38 6.35 for files E39 and E40
E8	5.85-cm layer of diluted Barrel-2 mud over kaolinite substrate with no water on top	E41-MS13-DY E42-MS13-DY E43-MS13-DY E44-MS13-DY E45-MS13-DY	1.0884	0.63 for files E41, E42 and E43 6.35 for files E44 and E45
E9	3-cm layer of sample used in Test E8 over kaolinite substrate with no water on top	E46-MS13-DY E47-MS13-DY E48-MS13-DY E49-MS13-DY E50-MS13-DY E50-MS13-DY	1.0886	0.63 for files E46, E47 and E48 6.35 for files E49 and E50

3.0 RESULTS AND DISCUSSION

For the three samples of the mud in Barrel 2 that underwent grain-size analysis (Appendix C), the average content was 0.5 percent fine sand, 33.6 percent silt and 65.9 percent clay. The average D_{50} and D_{90} values were 0.0021 and 0.0188 mm. The sediment laboratory analysis of the organic content (Appendix C) in the three sets of samples of mud taken from both barrels at the beginning, mid-point, and end of the DRDP evaluation, resulted in an average organic matter content of 4.39 percent with 95 percent confidence levels of 3.80 and 4.98 percent and a variance of 0.77 with 95 percent confidence levels of 0.27 and 2.19 percent for Barrel 1. For the mud in Barrel 2, the average organic matter content was 4.31 percent, with 95 percent confidence levels of 3.66 and 4.96 percent, and a variance of 0.71, with 95 percent confidence levels of 0.35 and 2.82 percent. The organic matter contents of these samples were much smaller than the expected value of 12 percent as found from previous tests and experiments using Gulfport Navigation Ship Channel sediment.

The results of the Type A tests are summarized in Table 4 and plotted in Figures 9 through 12. In the figures, the DRDP readings are plotted in black, the densimeter reading is plotted in red, and the calculated density is plotted in blue.

Table 4. Results of Type A tests.

Test	DRDP Mean Reading*	DRDP Reading Standard Deviation*	DRDP Mean Minus Densimeter Reading*	DRDP Mean Minus Calculated Density*
A1	0.9960	0.0007	-0.0007	<0.0001
A2	0.9959	0.0005	0.0013	0.0037
A3	1.0077	0.0003	0.0067	0.0078
A4	1.0206	0.0009	0.0029	0.0027
* Values are in g/cm^3.				

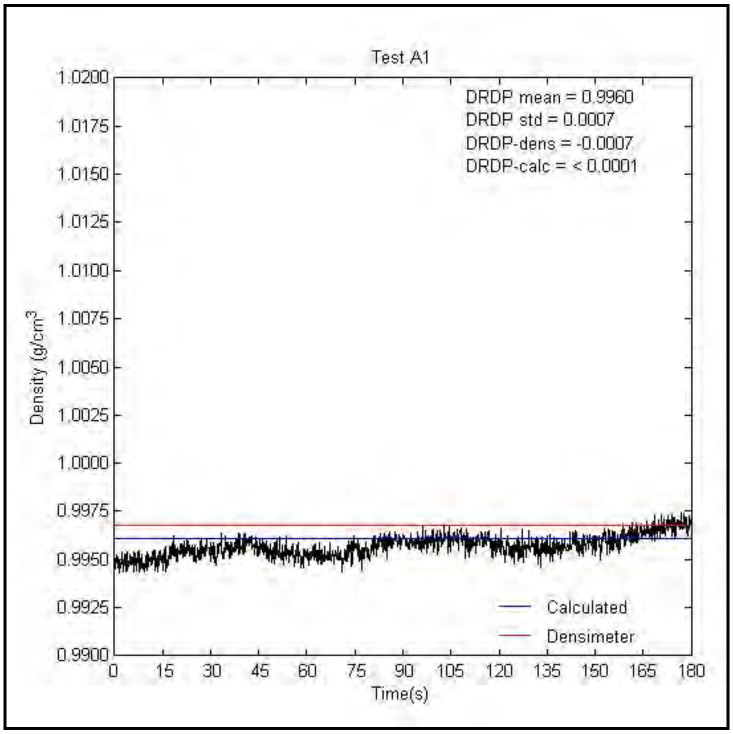

Figure 9. Results of Test A1, fresh tap water at room temperature.

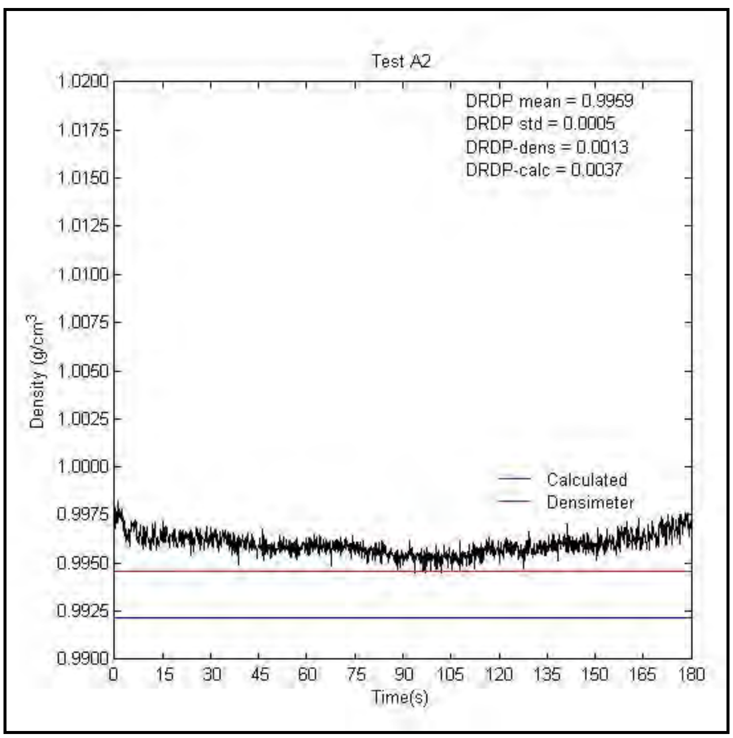

Figure 10. Results of Test A2, fresh, hot tap water.

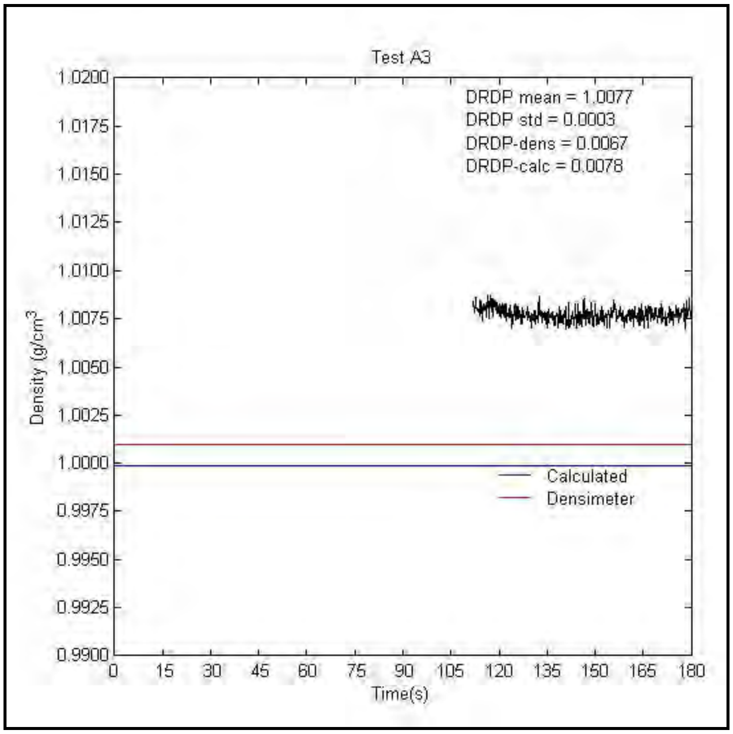

Figure 11. Results of Test A3, fresh tap water with melted ice.

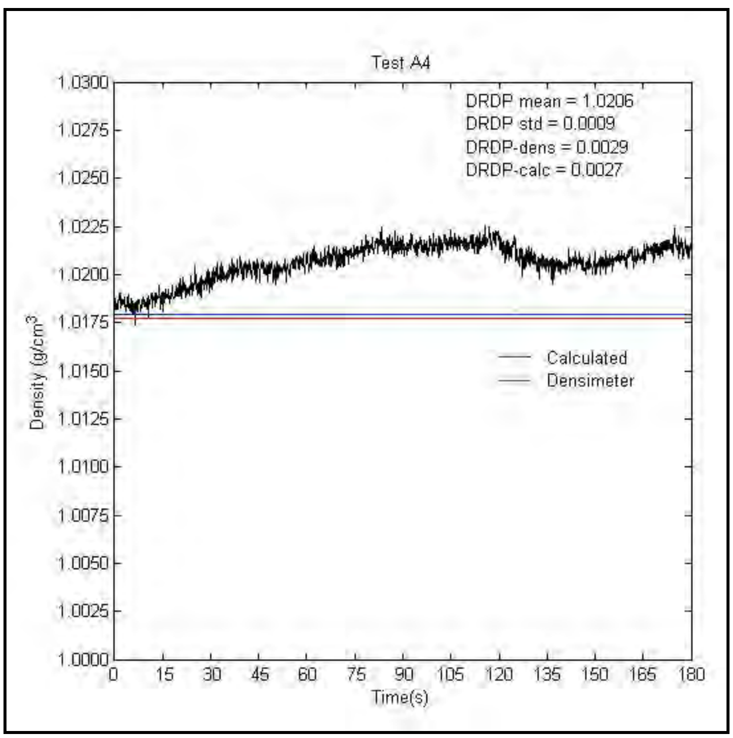

Figure 12. Results of Test A4, Gulfport seawater at room temperature.

All the statistics shown in Table 4, are based on 2 min of sampling time, with the exception of Test A3. Test A3 took the DRDP from room temperature (about 25.0°C), when the sensor was positioned above the ice-water sample, down to 3.0°C in the sample, in a few seconds. This situation of sharp temperature differences would not occur during an application in the field. In the field, before deployment, the sensor would be kept in a bucket of water taken from body of water in which it would be deployed. Therefore, it would be close to the temperature of the water and fluid mud when it began profiling. The DRDP needs to have the temperature of its internal calibration chamber close to the temperature of what it is sampling to give its most accurate readings. The DRDP did not achieve this for the large temperature change imposed by Test A3, and it was only after about 13 min of letting it sit in the sample that the internal sensor temperature was close enough to give reasonable readings. For this reason, Figure 11 shows only about the last 1 min of the approximately 14 min A3 test. The summary statistics shown in Table 4 are based only on the results shown in the figures. However, it is believed that when Test A3 was terminated, the DRDP still had not fully adjusted to the large temperature change. It was also noted that, for est A3, the densimeter took a very long time to adjust before giving a density reading of the cold water captured in its small sampling tube. According to the densimeter readings, this only occurred when the temperature of water in its sampling tube rose to 18.7°C. It is for these reasons that the results from Test A3 are excluded from the summary statistics.

Only Test A1 had individual (i.e., 8 Hz) DRDP readings that were distributed about the densimeter readings, so the standard deviations of the differences between the two were not calculated (Figure 9). Excluding Test A3, in the Type A tests the average difference between the average DRDP readings and the calculated densities is 0.0022 g/cm^3, with a standard deviation of 0.0019 g/cm^3. In comparison to the densimeter readings, the average difference between the average DRDP readings and the densimeter readings is 0.0012 g/cm^3, with a standard deviation of 0.0018. The Type A tests, conducted in water samples, showed an average DRDP precision (i.e., the standard deviation of the individual DRDP readings) of 0.0007 g/cm^3.

A Type C test was designed to evaluate the potential for air bubbles in the material to affect the DRDP reading. The influence of air bubbles in the matrix became a concern during Test A2 when air coming out of solution in the hot water taken from the tap for the test formed air bubbles on the surfaces in the test bucket. Bubbles also formed on the DRDP and had to be wiped off the face of the sensor before good density readings of the hot water were obtained. Test C consisted of taking a sample that had just been used for Test D3, during which the DRDP gave a reading of 1.091 g/cm^3, and the densimeter gave a reading of 1.0864 by stirring it vigorously with a kitchen whisk to aerate it. The densimeter reading of this sample was then 1.0561 g/cm^3, showing the decrease in sample densities due to the incorporation of air into the sample, however, the DRDP reading increased to 1.153 g/cm^3.

The results of the Type D tests are shown in Figures 13 through 18 and summarized in Table 5. For Test D1, the mud taken directly from Barrel 1 was too dense to get a densimeter reading (this was also true for some of the Type E tests). Only Test D4 has some individual DRDP readings that are distributed about the densimeter reading; therefore, the standard deviations of the differences between the individual (i.e., 8 Hz) DRDP readings and the densimeter readings were not calculated. The average difference between the mean densities measured by the DRDP and the densimeter readings is 0.0033 g/cm^3, and the standard distribution is 0.0074 g/cm^3. The average difference between the mean densities measured by the DRDP and the densities determined from the sediment laboratory analyses of the mud samples is 0.005 g/cm^3 with a standard distribution of 0.010 g/cm^3. The average DRDP precision (i.e., the standard deviation of the individual DRDP readings) for all six Type D tests was 0.0006 g/cm^3, which is in close agreement with that found for the Type A tests (i.e., 0.0006 versus 0.0007).

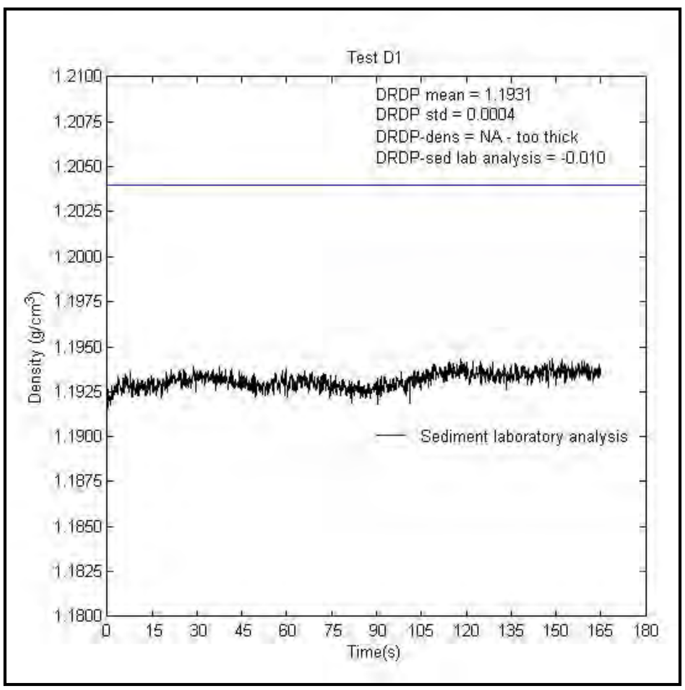

Figure 13. Results of Test D1, static test of mud from Barrel 1.

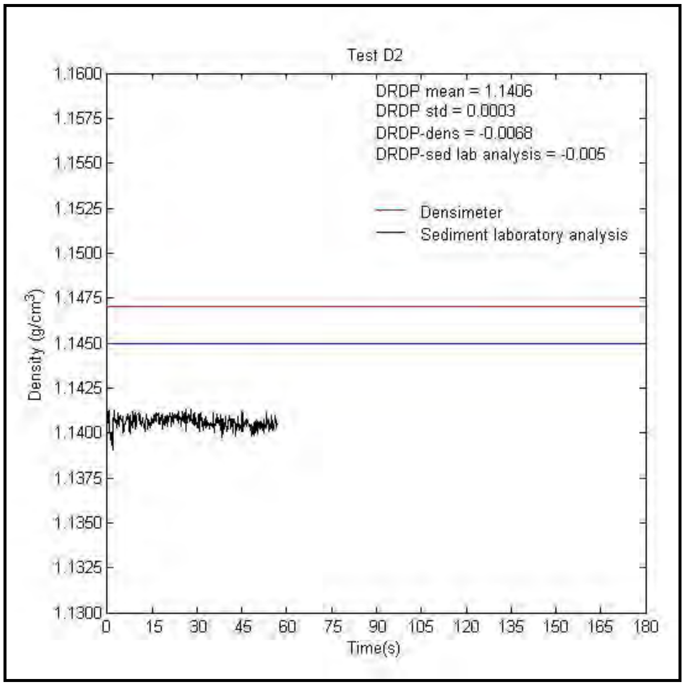

Figure 14. Results of Test D2, static test of Barrel 1, mud diluted with seawater.

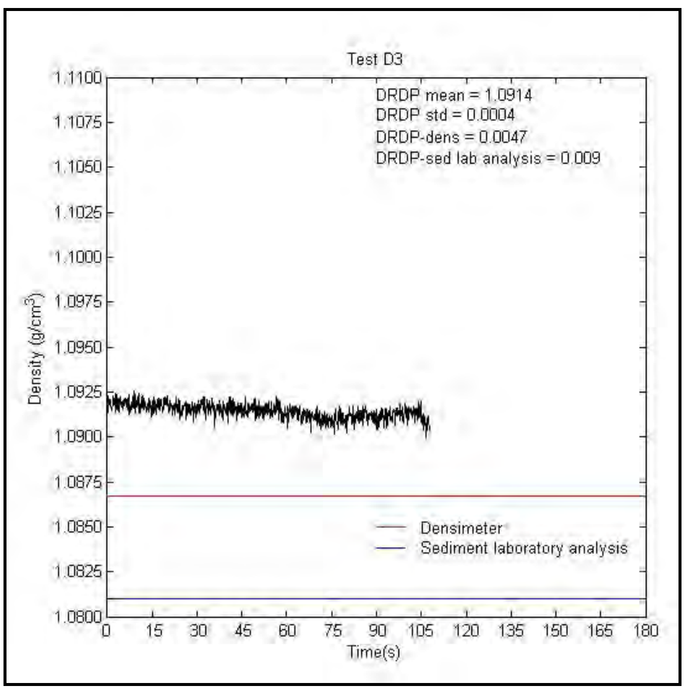

Figure 15. Results of Test D3, static test of Barrel 1, mud diluted with seawater.

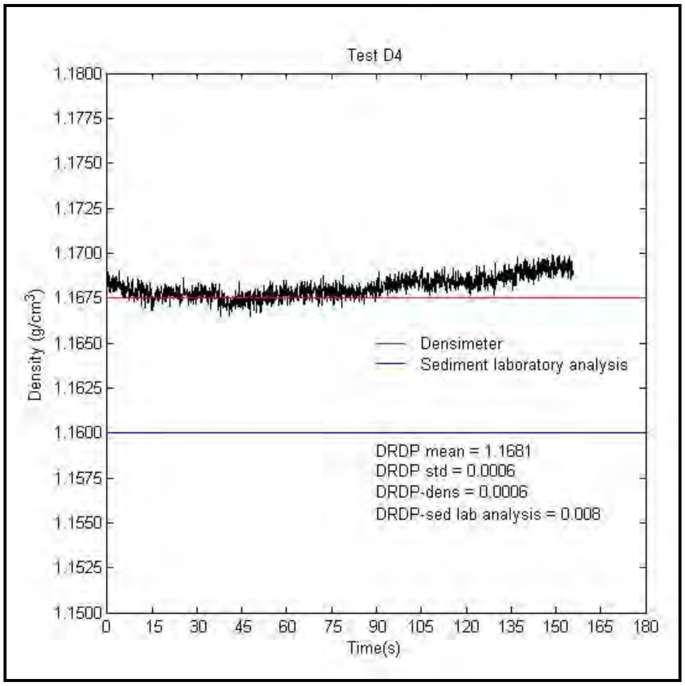

Figure 16. Results of Test D4, static test of Barrel 1, mud diluted with seawater.

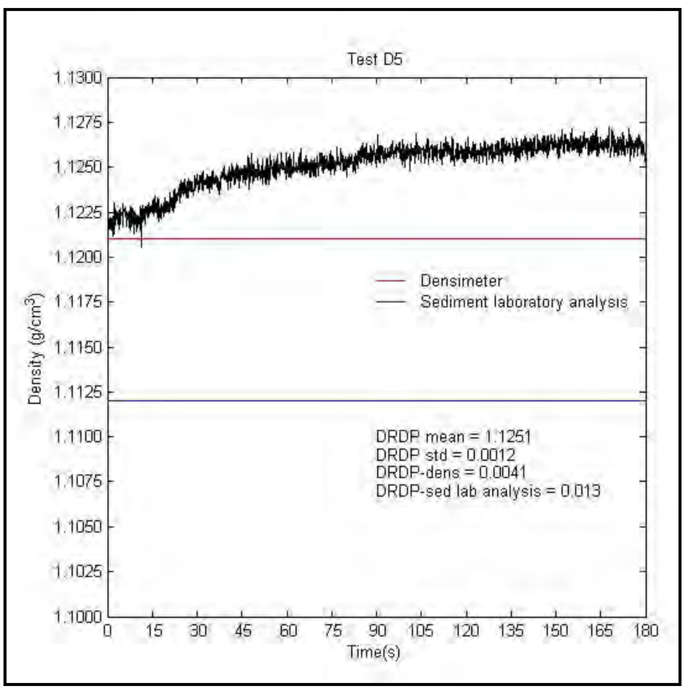

Figure 17. Results of Test D5, static test of Barrel 1, mud diluted with seawater.

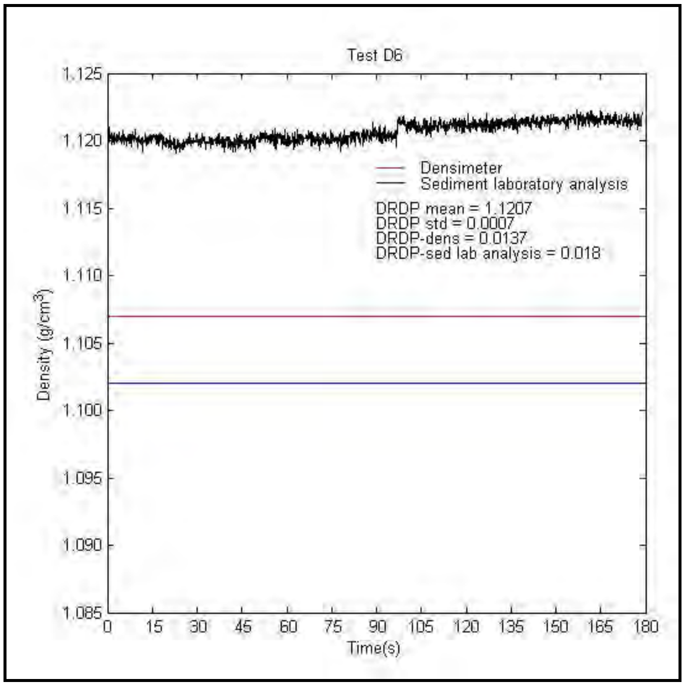

Figure 18. Results of Test D6, static test of Barrel 1, mud diluted with seawater.

Table 5. Comparison of DRDP density measurements, densimeter measurements and sediment laboratory analyses for Type D tests.

Test	DRDP mean reading*	DRDP reading standard deviation*	DRDP mean minus densimeter reading*	DRDP mean minus sediment laboratory sample analysis*
D1	1.1931	0.0004	NA-too dense	-0.010
D2	1.1406	0.0003	-0.0068	-0.005
D3	1.0914	0.0004	0.0047	0.009
D4	1.1681	0.0006	0.0006	0.008
D5	1.1251	0.0012	0.0041	0.013
D6	1.1207	0.0007	0.0137	0.018
* Values are in g/cm^3.				

The Type E tests are shown in Figures 19 through 27. In the figures, a dashed red line was drawn where it appeared that the full face of the DRDP sensor was in the mud. For this report, this was done solely on the basis of where the density values stopped rapidly increasing and appeared to stabilize. A solid redline was then drawn 1 cm above this dashed line (the approximate diameter of the DRDP sensor face). These two lines should represent where the DRDP began to enter the mud and where it was completely in the mud layer. The lines were repeated further down in the profiles at a distance equal to the measured thickness of the mud layer. These lines should represent where the DRDP began to emerge from the mud layer and enter the kaolinite layer and then where the DRDP was completely out of the mud. When the sensor insertion speed was 0.63 or 1.27 cm/s, the DRDP visually appears to clearly delineate the mud layer both at the water-mud interface and at the mud-kaolinite interface.

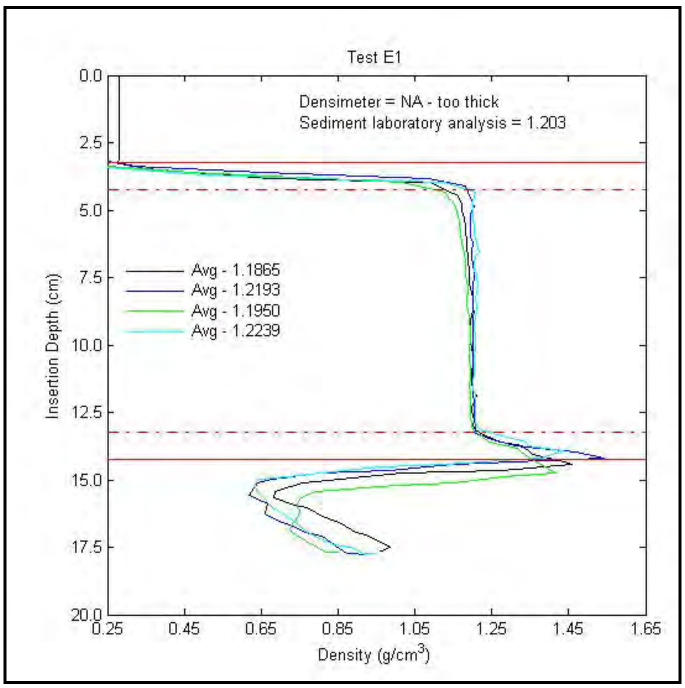

Figure 19. Results of Test E1, profile of 10-cm mud layer with no water on top.

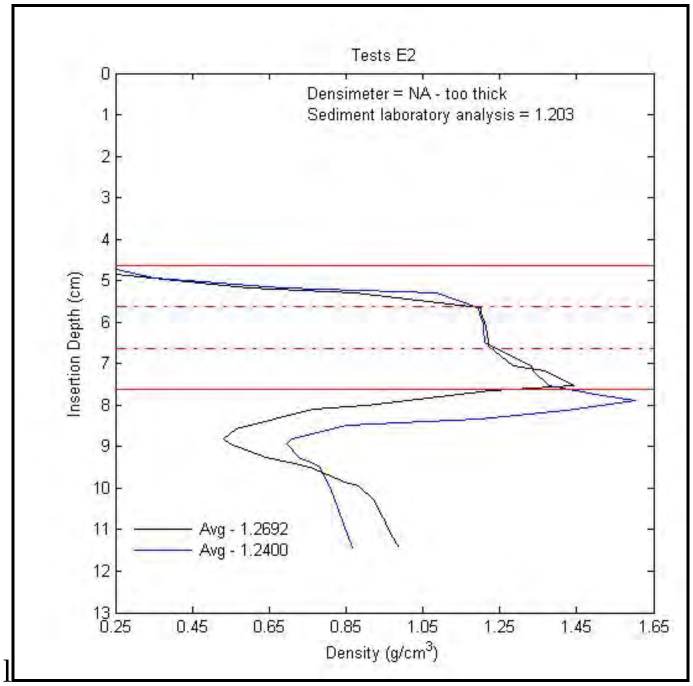

Figure 20. Results of Test E2, profile of 2-cm mud layer with no water on top.

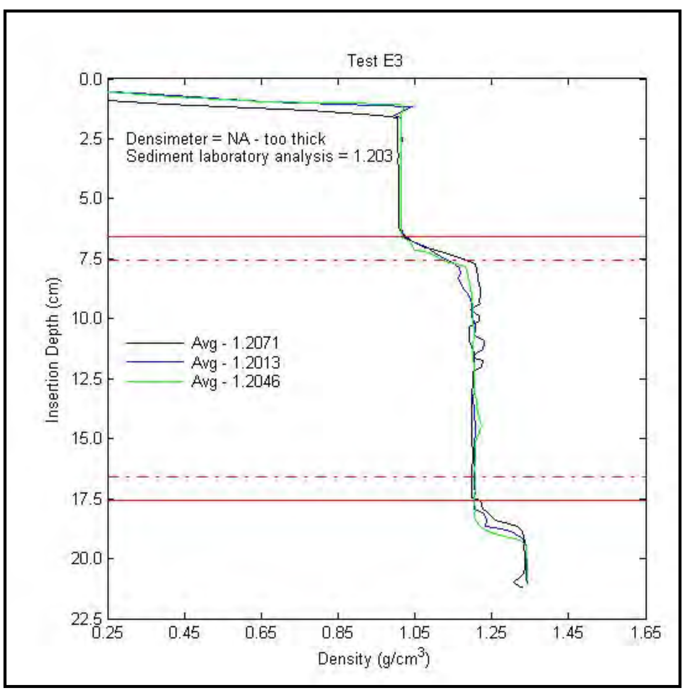

Figure 21. Results of Test E3, profile of 10-cm mud layer with 5.7-cm layer of water on top.

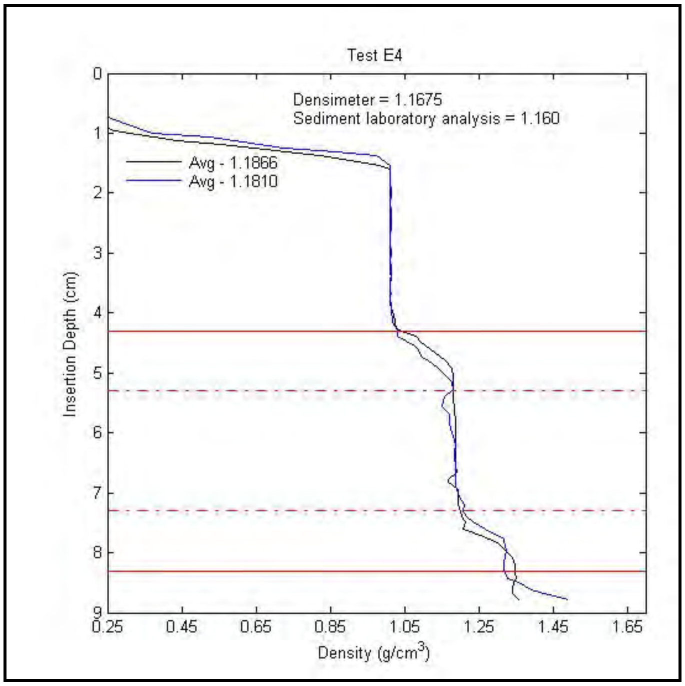

Figure 22. Results of Test E4, profile of 3-cm mud layer with 3.5-cm layer of water on top.

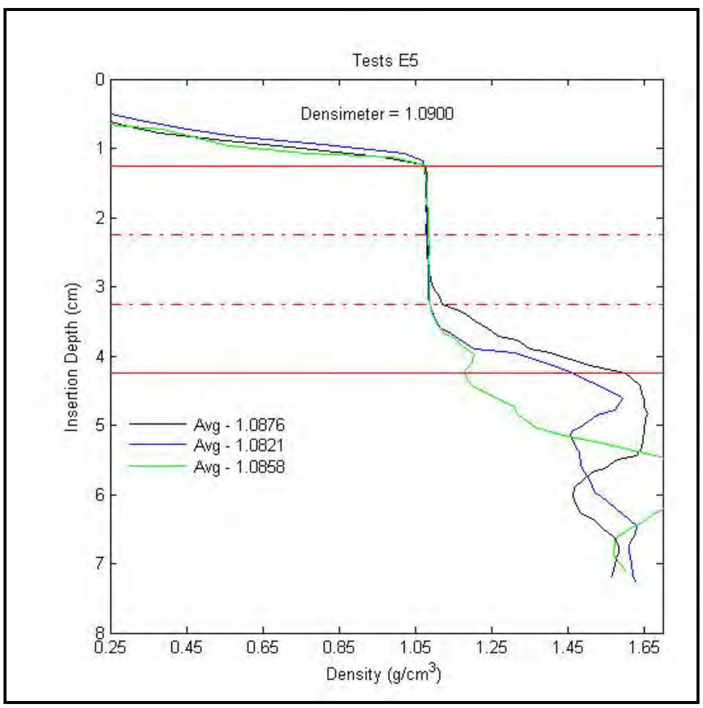

Figure 23. Results of Test E5, profile of 2-cm mud layer with no water on top.

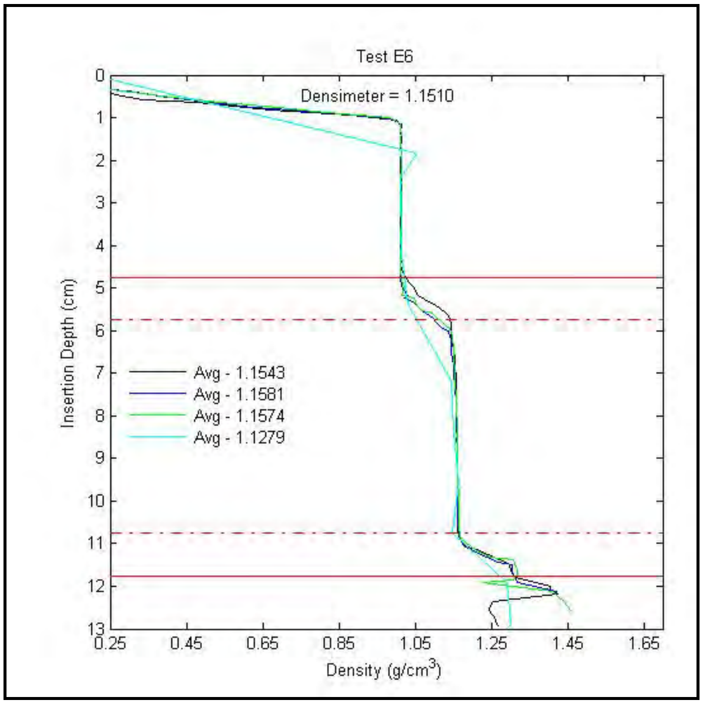

Figure 24. Results of Test E6, profile of 6-cm mud layer with no water on top.

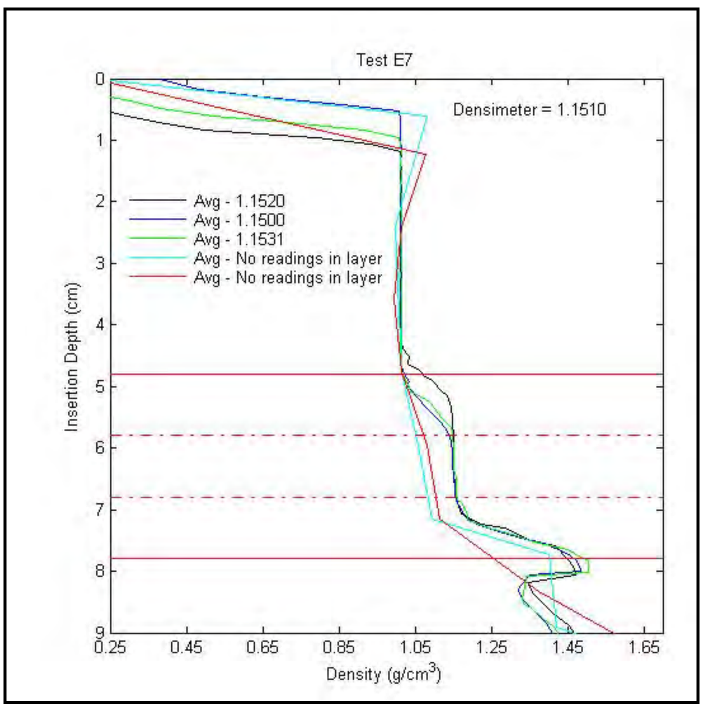

Figure 25. Results of Test E7, profile of 2-cm mud layer with 4-cm layer of water on top.

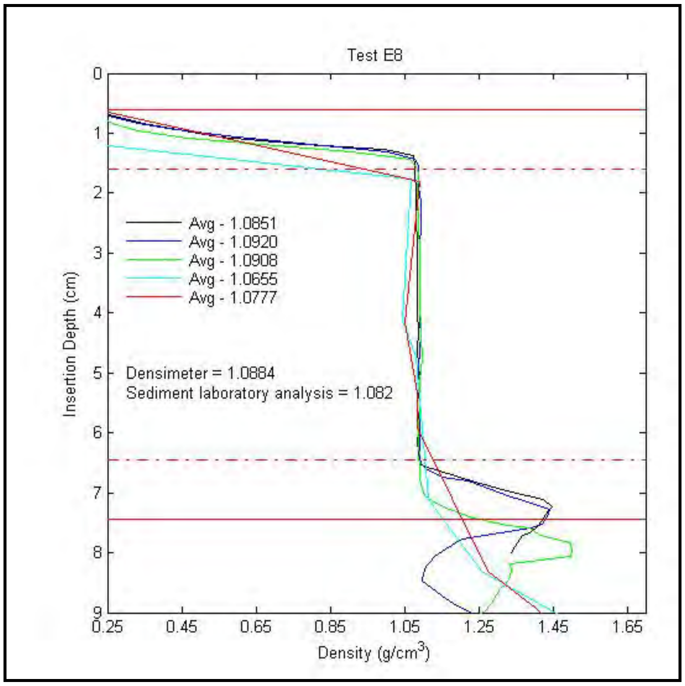

Figure 26. Results of Test E8, profile of 5.85-cm mud layer with no water on top.

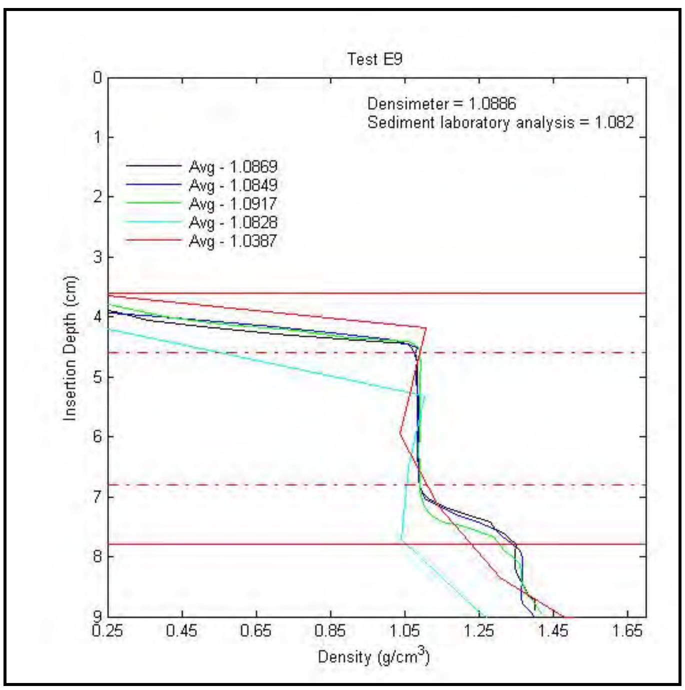

Figure 27. Results of Test E9, profile of 3-cm mud layer with no water on top.

To objectively evaluate the ability of the DRDP to measure the thicknesses of the mud layers, the following process was applied to the Type E test data.

Steps:

1. The gradients of the DRDP density readings were calculated at each data point in the profile as the difference between the density measured at that point, and the density measured at the data point nearest to being 0.25 cm further down in the profile.

2. From the gradients calculated in Step 1, the changes in the gradient at each point in the profile were calculated (starting from the top) as the value of the gradient at that point, minus the value of the gradient at the point that immediately preceded it.

3. Starting from the top of the profile, the point at which the first change in gradient exceeded 0.025 was marked as the start of the first layer. The value 0.025 was chosen by trial-and-error using the criteria that it identify the depths where the lines were plotted in Figures 19 through 27 at the locations where the DRDP sensor appeared to start to enter a layer of water, mud or kaolinite. For those tests that had no water on top of the mud layer, this point was marked as the point at which the DRDP entered the mud layer. In the cases where there was water on top of the mud layer, this point was taken as the point at which the DRDP entered the water, and the next point at which the change in the gradient exceeded 0.025 was marked as the point where the DRDP entered the mud layer.

4. After marking the start of the mud layer, the next point at which the change in gradient exceeded 0.025, and that was at least a distance of 0.75 times the thickness of the mud layer further down in the profile, was marked as the point the DRDP entered the kaolinite substrate.

5. The thickness of the mud layer was calculated as the difference between the point marked as that where the DRDP entered the mud layer and the point marked as that where the DRDP entered the kaolinite layer.

Of the 34 profiles through the mud layers made in the Type E tests, the above algorithm failed to detect the mud layer for only two profiles. Figure 28 is a histogram of the differences between the width of the mud layer measured using the algorithm, and the measured widths using a measuring tape. The mean of the differences is -0.34 cm and the standard deviation is 0.69 cm. A possible reason that the mean is a negative is that it was noted that the sensor was compressing the mud layer, to some degree, as it entered the mud. As it did this, it was noted that mud did not start covering the sensor face until some small vertical distance below the surrounding mud surface. Thus, the DRDP measured mud-layer thicknesses would be smaller than those measured with a measuring tape when the original mud layers for testing were prepared. It is also possible that the mud layers were not perfectly uniform in thickness leading to the slight differences in values.

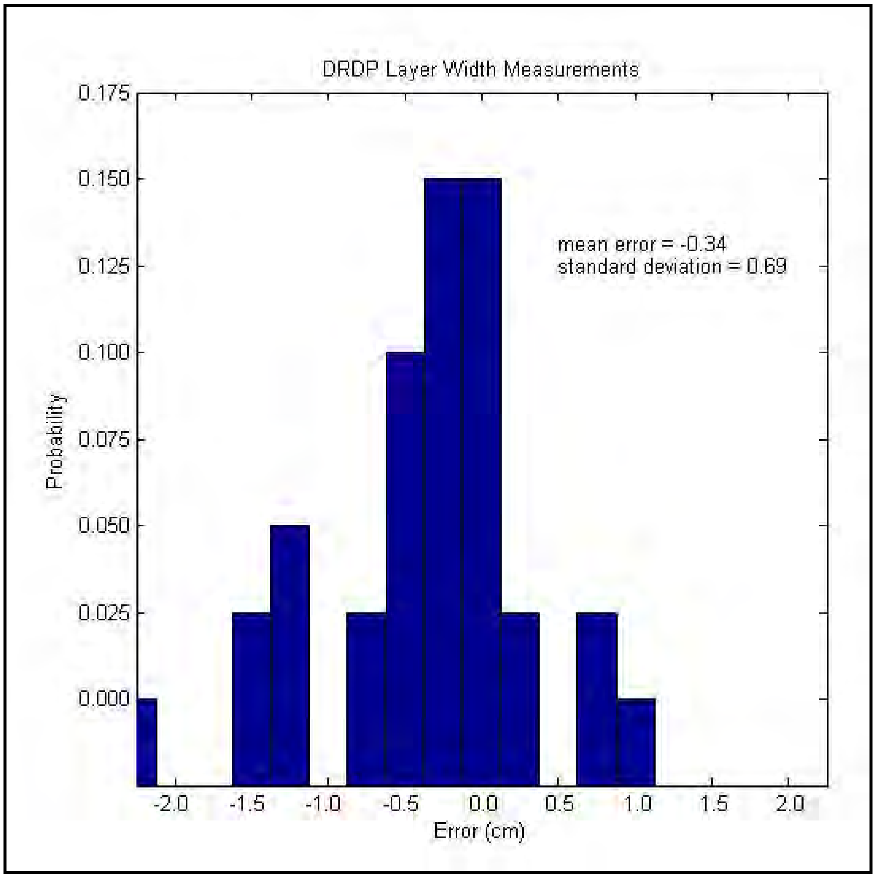

Figure 28. Histogram of the differences between the thicknessess of the mud layers using the test procedure, and the thicknessess measured with a measuring tape.

The average difference between the mean DRDP density readings in the mud layer and the densimeter readings, and between the mean DRDP density readings and the sediment laboratory density determinations for the mud sample from which the layer was made are shown in Table 6. The density differences shown in the table are in g/cm^3.

Table 6. Comparison of DRDP density measurements, densimeter measurements and sediment laboratory analyses for the Type E tests.

Test	DRDP Mean Density*		DRDP Mean Minus Densimeter Reading* Speed1/Speed2	DRDP Mean Minus Sediment Laboratory Sample Analysis* Speed 1/Speed 2
	Insertion Speed 1 1.27 or 0.63 cm/s	Insertion Speed 2 6.35 cm/s		
E1	1.2003	NA	NA-too dense	-0.003
E2	1.2546	NA	NA-too dense	0.049
E3	1.2043	NA	NA-too dense	0.000
E4	1.1838	NA	0.0163	0.023
E5	1.0852	NA	-0.0048	NA
E6	1.1566	1.1279	0.0056/-0.0231	NA
E7	1.1517	No readings when the DRDP sensor face was completely in mud	0.0007	NA
E8	1.0893	1.0716	0.0009/-0.0168	0.007/-0.011
E9	1.0878	1.0608	-0.0008/-0.0279	0.005/-0.022

* Values are in g/cm^3.

The average difference between the mean DRDP readings in comparison to the densimeter readings at the 1.27 or 0.63 cm/s insertion speeds is 0.0029 g/cm^3 with a standard deviation of 0.0023 g/cm^3. The average difference between the mean densities measured by the DRDP and the densities determined from the sediment laboratory analyses of the mud samples at the 1.27 or 0.63 cm/s insertion speeds is 0.013 g/cm^3 and the standard distribution is 0.019 g/cm^3. At a faster insertion speed of 6.35 cm/s, the average difference between the mean DRDP readings in comparison to the densimeter readings is 0.0223 g/cm^3. At the faster insertion speed 0f 6.35 cm/s, the average difference between the mean densities measured by the DRDP and the densities determined from the sediment laboratory analyses of the mud samples is -0.016 g/cm^3. The errors at the 6.35 cm/s insertion speed may have been significantly better if the DRDP had been able to output data at the normal 20 Hz rate. The Phase II sensor will not have the 8 Hz sampling rate limitation and is expected to sample at 20 Hz.

4.0 SUMMARY AND CONCLUSIONS

The DRDP is capable of delineating fluid mud layers of 2-cm thickness or greater, when it profiles these layers at an insertion speed of 1.27 cm/s or less. The average difference between the DRDP measured thicknesses and those measured with a measuring tape was -0.34 cm with a standard deviation of 0.69 cm. The negative mean for the differences is likely due to the DRDP depressing the fluid mud layer as is enters it. It may be possible to significantly reduce this by redesigning the DRDP housing (Phase II).

In comparison to the densimeter, the average difference between the DRDP density measurements (for Type A, Type D, and Type E tests at insertion speeds of 1.27 cm/s or less) and the densimeter readings is 0.0023 g/cm^3 with a standard deviation of 0.0063 g/cm^3 (n = 25). In comparison to the sediment laboratory sample analyses, the average difference between the DRDP density measurements (for Type D and Type E tests at insertion speeds of 1.27 cm/s or less) and the sample analyses is 0.0095 g/cm^3 with a standard deviation is 0.0156 g/cm^3 (n = 11). The average precision of the DRDP measurements during the evaluation was 0.0007 g/cm^3. For both comparisons, the average difference is positive. This difference can potentially be significantly reduced during instrument calibration.

The initial prototype of the DRDP was successful in delineating the mud layer thicknesses and in determining the density of each mud layer. The fastest profiling speed that would produce reasonable results may be higher when the DRDP operates at a sample output speed greater than the 8 Hz needed for this laboratory evaluation. The results of this evaluation will be incorporated into recommendations to modifying the Phase I prototype during Phase II and in the subsequent delivery of the final DRDP prototype.

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Appendix A: Quality Assurance Project Plan

QUALITY ASSURANCE PROJECT PLAN
FOR THE
DEVELOPMENT OF A DREDGING RESIDUALS DENSITY PROFILER (DRDP)

Prepared for:

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U.S. Environmental Protection Agency
National Exposure Research Laboratory
Las Vegas, Nevada

Prepared By:

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9 February 2009

Approved by:

Tim Welp	Date	Dr. Brian Schumacher	Date
ERDC Project Manager		EPA Project Officer	
Derek Wilson	Date	George Brilis	Date
ERDC Quality Assurance Coordinator		EPA Quality Assurance Manager (concurrence)	

Distribution List:

Individuals who will receive a copy of the QA Project Plan:

Brian Schumacher	**EPA**
George Brilis	**EPA**
Timothy Welp	**USACE**
Derek Wilson	**USACE**
Trap Puckette	**Evans Hamilton, Inc.**

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Project/Task Organization

Successful development of a dredging residual density profiler (DRDP) requires a qualified project team that effectively implements project and quality assurance plans. The project organization and responsible staff are presented and summarized in Figure 1.

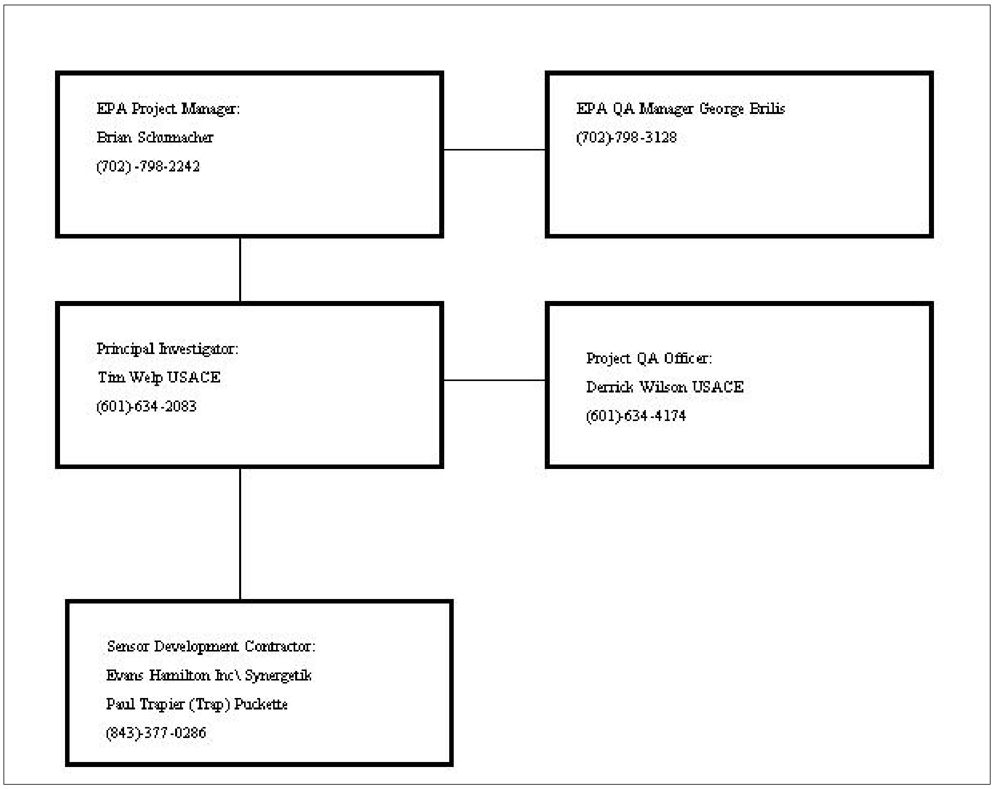

Figure 1. Also shows overall organization for this project.

U.S. Environmental Protection Agency (USEPA)

The U.S. Environmental Protection Agency (EPA) Project Officer, Dr. Brian Schumacher of the Environmental Sciences Division-Las Vegas (ESD-LV), is responsible for direction and oversight of this project. George Brilis, ESD-LV Quality Assurance (QA) Manager, will ensure that the project conforms to the quality standards set by EPA.

Engineer Research and Development Center (ERDC)

ERDC will provide comprehensive technical support for this development project. The project manager, Tim Welp, is responsible for tasks assigned to ERDC and for direct communication with all project participants. Mr. Welp is also responsible for ensuring that testing and quality assurance and quality control (QA/QC) requirements are met for the project and will prepare technical documents and coordinate technical communications with the EPA project officer. Mr. Welp also will review analytical data obtained during the demonstration and will be responsible for preparing the final report.

Mr. Welp’s responsibilities as project manager will include the following:

- Maintain communication with the EPA Project Officer.
- Develop the QAPP and other project deliverables in accordance with the project schedule.
- Manage staff and coordinate with the contractor.
- Provide required planning, cost, and schedule control.
- Maintain the project file and documentation of written records.
- Provide submittals to the project officer in a timely manner.

Derek Wilson is the ERDC QA Coordinator for this project and is responsible for reviewing and ensuring the quality of project deliverables. Additional responsibilities will include:

- Determining that the QAPP is prepared in accordance with quality assurance requirements.
- Provide assistance and guidance in developing and revising the QAPP.
- Review the quality of project documentation.
- Ensure deliverables meet the quality goals of the project.

Evans Hamilton Inc (EHI).

ERDC’s primary contractor for developing the DRDP will be EHI. Mr. Paul Trapier Puckette of EHI will provide contractual coordination and technical oversight on subcontractors involved in developing and testing the DRDP.

Grieser und Partners/Synergetik

Grieser und Partners/Synergetik will redesign the original ADMODUS measurement system, construct the DRDP prototype to improve spatial resolution, and assist in the laboratory and field trials.

Problem Definition/Background

Fluid mud is found in navigation projects on the northeast coast, along the southeast coast, and in several projects along the Gulf Coast. Dredging residuals, in the context of environmental dredging projects, can consist of unconsolidated, fine-grained, high water content suspensions that, while similar in composition to navigation project fluid muds, exist in thinner layers (10 cm thick as opposed to 1 m). No standardized method exists in the USACE to survey fluid mud. “When the upper sediment layer is not well consolidated, the three major depth measurement methods used in the Corps (sounding pole, lead line, and acoustic echo sounding) will generally not correlate with one another, or perhaps not even give consistent readings from one time to the next when the same type of instrument or technique is used” (USACE 2001). This measurement ambiguity has resulted in navigation dredging contract payment disputes and has hindered complete site characterizations of environmental dredging site sediment conditions.

The objective of this project is to improve the capability to accurately and precisely characterize environmental dredging projects where fluid mud/residual conditions occur. The ADMODUS fluid mud survey system was successfully demonstrated in the field (Gulfport, MS, navigation channel) and in the laboratory as part of a project to evaluate the systems accuracy, precision, and applicability to USACE surveying practices. The laboratory testing plan was designed to investigate the systems maximum spatial resolution for detecting and characterizing fluid mud layer thicknesses as it relates to surveying nautical depth applications. This work also set the baseline work for investigating the systems capacities for surveying dredging residual layers in environmental dredging applications that are usually thinner (e.g., 1 to 10 cm) than nautical depth applications (1 m plus).

As per Bridges et al. (2008)[1] “dredging residuals refer to contaminated sediment found at the post-dredging surface of the sediment profile, either within or adjacent to the dredging footprint.” After the initial consolidation period (i.e., within a period of several days to a few weeks, depending on sediment characteristics and site conditions), generated residuals (excluding sloughed materials) typically occur as a thin veneer (1 to 10 cm thick) of fine-grained material, with relatively low dry bulk density (ranging from approximately 0.2 to 0.5 g/cm^3). For comparison, the typical dry bulk density for fine-grained sediment is 0.5 to 0.9 g/cm^3.

An EPA Interagency Agreement (IAG) was signed between the ERDC and EPA's Environmental Sciences Division (ESD) of the Office of Research and Development's National Exposure Research Laboratory to have ERDC modify the ADMODUS probe for use in characterizing dredge residuals for environmental dredge projects. Specifically, the system will be optimized to identify fluid mud (or "fluff") residuals (possibly down to a resolution of 1 cm) and facilitate sediment sampling efforts in conjunction with EPA's new Undisturbed Sediment Sampler (USS) designed for environmental dredging projects by the EPA's Characterization and Monitoring Branch (CMB).

In the environmental arena, it would be of great benefit to know *a priori* the exact locations and thicknesses of the fluff layers without having to actually sample the sediment and visually examining the collected sediment column. The sediment fluff layers (e.g., newly deposited sediments from an upstream dredging event) of thicknesses as thin as 1 cm are of interest to meet the needs identified in the National Research Council (NRC 2001)[2] report. The increased resolution of a modified ADMODUS probe will allow accurate characterization of the thinner layers of dredging residuals and enhance environmental dredging site characterization efforts.

[1]Bridges, T., S. Ells, D. Hayes, D. Mount, S. Nadeau, M. Palermo, C. Patmont, and P. Schroeder. 2008. The Four Rs of Environmental Dredging: Resuspension, Release, Residual, and Risk. Environmental Laboratory Technical Report ERDC/EL TR-08-4. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

[2]National Research Council. 2001. *A Risk-Management Strategy for PCB-Contaminated Sediments*. National Academy Press, Washington, D.C.

Project/Task Description

A questionnaire will be sent out to personnel involved in dredging residual-related activities to facilitate a requirements analysis to determine the needs that the DRDP system should meet (functional requirements) in order to measure density profiles (density vs. depth) in dredging residuals (also referred to as fluid mud).

This analysis will be the basis for establishing the following:

- The physical environment that the system should be able to function in.
- Systems measurement accuracies, precisions, and resolutions.

- Operational parameters (deployment characteristics, sampling frequencies, etc.).

Information developed from this analysis will be used to develop design specifications, cost estimations, and evaluate design/development trade offs.

An ERDC USACE delivery order contract will be established with EHI/Synergetik to design and develop the DRDP incorporating results from the systems requirements analyses and consideration of available funding. After assembly of the DRDP by the contractor, ERDC will receive the prototype and conduct laboratory tests to estimate its accuracy (measure of overall agreement of a sensor measurement to a known value), precision (measure of agreement among repeated measurements of the same property under substantially similar condition expressed generally in terms of the standard deviation), and vertical resolution. The results of these trials will be documented in an interim technical report. If performance is deemed successful, the contractor will construct the DRDP, and provide it to ERDC and tested and evaluated in a laboratory to estimate its respective dredging residual density measurement accuracy and resolution then it will be demonstrated in a marine environment to evaluate its ability to measure density profiles in field conditions. This quality assurance project plan (QAPP) defines quality assurance requirements for the laboratory testing of the DRDP prototype, and subsequent laboratory and field testing of the DRDP to demonstrate its robustness.

Prototype DRDP Laboratory Testing

Laboratory testing will include a series of tests performed in 10-gallon (38 L) buckets and 82-gallon (310) round and square columns with custom-designed sampling ports as shown respectively in Figures 2, 3, and 4. The containers will be filled with fluid mud collected from the Gulfport Navigation Ship channel, and water (also collected from the Gulfport Ship channel). Gulfport navigation channel sediment (from select reaches) is generally a fine grained cohesive sediment with an organic content of approximately 12 percent, and density profile (in the dredging template) ranging from 1.006 to 1.250 g/cm^3. Additional amounts of water will be subsequently added to vary densities ranging from approximately 1.010 to 1.300 g/cm^3 with one suspension density in between this span at approximately 1.150 g/cm^3. Thicknesses of these varying suspensions will be varied from approximately 0.5 m to 0.5 cm to evaluate DRDP vertical measurement resolution.

Figure 2. Ten-gallon (38 L) buckets for lab tests.

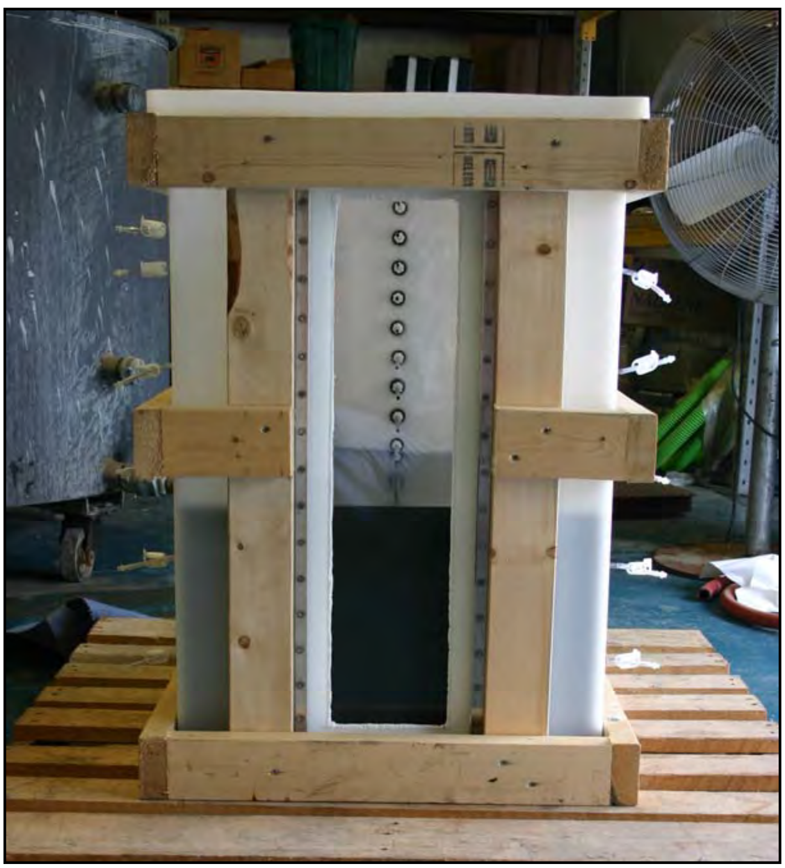

Figure 3. 82-gallon (310 L) capacity square sampling column for laboratory tests.

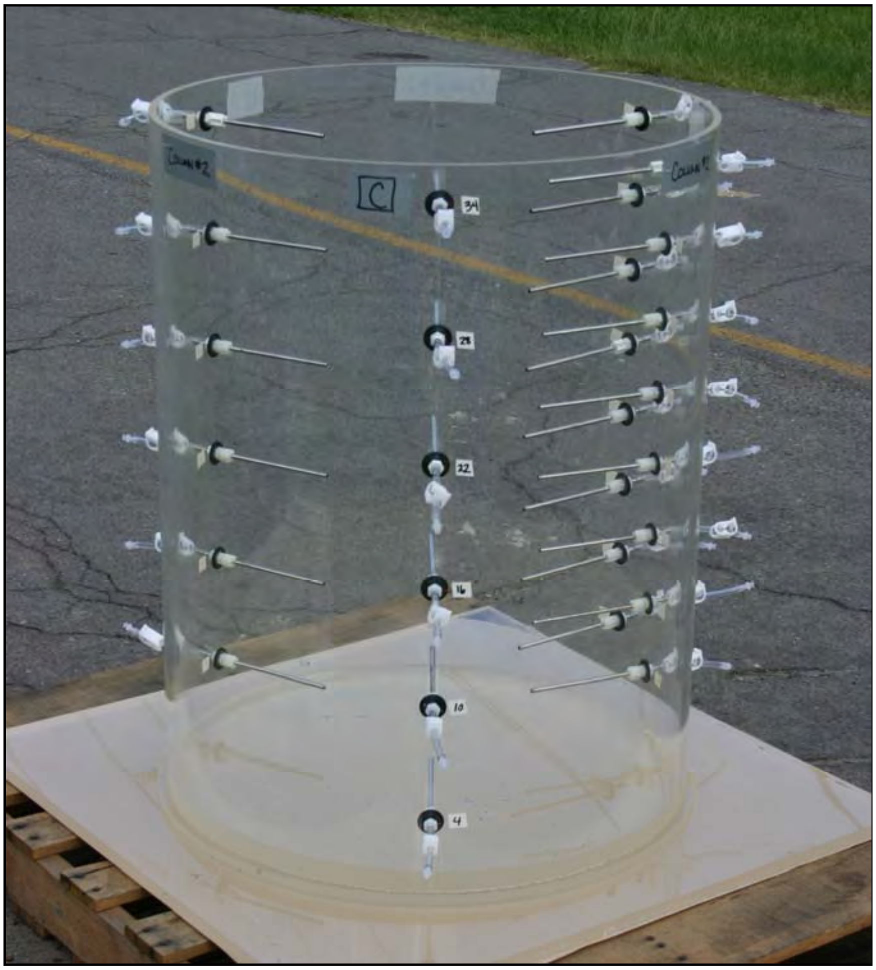

Figure 4. 82-gallon (310 L) capacity round sampling column for laboratory tests.

The prototype DRDP will be mounted on a rigid bracket on a sliding track suspended over the tanks. This custom-designed Sensor Insertion Device (SID, Figure 5) will be equipped with castors and moved from tank to tank each with a specific mud/fluid mud configuration. The SID will use an adjustable-speed programmable linear actuator (XLA-9 T35LS 500-ENC Specialty Motions, Inc.) to raise and lower the bracket on its track, thereby raising and lowering the instruments into and out of the tanks, and having the ability to control the rate of descent at the design recommended speed of 45 cm/sec.

Laboratory samples will be collected in one of two ways: with a syringe attached to a sampling port (ports shown in Figures 3 and 4), or with a syringe and a length of vinyl tubing attached to a rigid rod (Figure 6). The first method will utilize fixed sampling ports and the second method will be employed to take samples anywhere within the column.

Figure 5. Sensor insertion Device (SID) with linear actuator.

Figure 6. Rod and tube sampling apparatus.

The sampling ports were constructed by drilling holes through the side of the columns and a 12 in. (30 cm) stainless steel tube with a 0.18 in. (0.5 cm) ID was inserted using a bulkhead style compression fitting. The rods extend approximately 8 in. (20 cm) into the container. On the exterior end of the rod, a small piece of vinyl tubing with a tubing clamp and female luer lock fitting was attached. When sampling, a male luer lock syringe will be attached to the female fitting on the end of the sampling port and the plastic tubing clamp will be opened. Approximately 30 cc of material will be purged from each port before filling the sampling syringe with a sample volume of 60 cc. A clean, dry syringe will be used to sample each port. When a sample is needed from a location for which there was no sampling port, the syringe and tube method will be used (10 gallon (38 L) bucket tests). This will consist of a rigid rod attached to a piece of vinyl tubing with a female luer lock fitting on one end. The rod/tubing will be inserted to a specified depth, approximately 30 cc of material purged, and a sample drawn with a luer lock syringe (sample volume of 60 cc). The sampling tube will be cleaned and dried between individual samples.

Fluid mud residuals will be collected with these two sampling setups. Samples will be collected from as close to the DRDP sensor as possible. These sediment samples will be analyzed using ASTM D854-06 Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer to calculate specific gravity of soil solids and bulk wet density. The precision for (within) laboratory testing in calculating solids specific gravity for single operator results between 5 replicates, as defined by the standard deviation equation and supplementary equations for mean and variance below) is estimated to be: one standard deviation = 0.009 specific gravity units.

Mean

$$\bar{x} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Where *n* is defined as the number of values.

Variance

$$s^2 = \frac{\sum_{i=1}^{n} (x_1 - \bar{x})^2}{n-1}$$

Standard Deviation is the positive square root of the variance.

To express variation as a fraction of the mean, the measure of relative variation, the relative standard deviation (RSD) (or coefficient of variation (CV)) [as calculated by dividing the standard deviation by the mean and multiplying by 100 to express as a percentage] for the 5 replicates is estimated to be <5 percent.

Laboratory-measured residual sample values (collected as near to the DRDP as practical) will be compared to the DRDP-determined values.

Absolute and relative errors as defined by:

$E_{abs} = \rho_{DRDP} - \rho_{lab}$

$E_{rel} = E_{abs/}\ \rho_{lab}$

where

E_{abs} = Absolute error between instrument and laboratory-measured sample densities (g/cc).

E_{rel} = Relative error between instrument and laboratory-measured sample densities (g/cc).

ρ_{DRDP} = Density measured by Dredging Residual Density Profiler (g/cc).

ρ_{Lab} = Density measured by laboratory-measured sample (g/cc).

will be calculated and analyzed by descriptive statistic methods, such as scatter plots, histograms, and box plots, to describe accuracy and precision measurement capabilities of the DRDP.

The fluid mud organic content of will be determined using the ASTM Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils (D 2974-07A). A composite sampling protocol will consist of homogenizing the fluid mud in two 55 gallon (208 L) drums with a paddle stirrer and scooping a 1 L sample of material from the surface of each drum. In turn, these samples will be stirred and a 60 cm^3 sample scooped from this composite and subsequently analyzed. As per ASTM D 2974-071, this test's precision is not presented "due to the nature of the soil materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program." Regarding test bias, "There is no accepted reference value for this test method; therefore, bias cannot be determined." A total of three composites (one taken at the beginning, one at the mid point, and one near the end of the testing period) will be tested in triplicate and respective means and 95 percent confidence intervals calculated.

DRDP Laboratory and Field Testing

The final DRDP design will be evaluated in the lab as well as in the field. The lab testing will consist of the same protocols as proscribed for the prototype DRDP testing.

Field testing will be conducted in the Gulfport MS Navigation channel. The DRDP will be deployed at three different locations (locations will be selected by determining presence of fluid mud present in the channel) to measure depth versus density profiles. A ball valve sampler (BVS) (Figure 7) will be attached to the DRDP (to minimize spatial variability) to collect fluid mud samples within the fluid mud strata. The BVS consists of four sample containers mounted on a bar and separated by 1 ft (30 cm) spans. This assembly is heavily weighed at one end. Each 200 ml sample container has an open/close mechanism on it that can be activated pneumatically by a line from an air compressor on the boat. To collect a sample, the bar with the sample containers (attached to the DRDP) will be lowered to a specified depth. A depth pressure sensor (vented to the atmosphere) attached to the bar will provide measurements of the systems vertical position in the water column. During lowering, the sample containers are closed. Upon reaching the specified depth, the open/close mechanisms on the sample jar are activated and the containers opened. The air in the containers escapes and the surrounding fluid mud fills the containers. After approximately 30 sec, the open/close mechanism is deactivated allowing the bottles to close. The entire system is then recovered and the samples removed from each sample container and placed into plastic sample bottles. To verify the both the DRDP and BVS depth sensors' accuracies (BVS depth sensor is plus/minus 0.1 percent of the depth range) an engineering tape will be fastened to the ball valve sampler and lowered down to the channel bottom and the deck unit-reported values will be compared to measurements read from the tape at the waters surface.

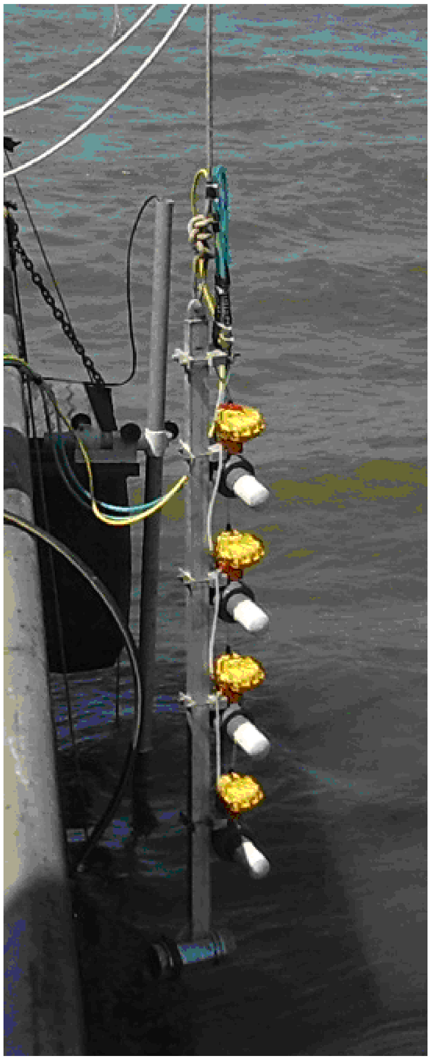

Figure 7. Ball valve sampler (BVS).

EPA National Geospatial Data Policy (NGDP)

Whenever practical, and applicable this project shall adhere to the National Geospatial Data Policy (NGDP) which establishes principles, responsibilities, and requirements for collecting and managing geospatial data used by Federal environmental programs and projects within the jurisdiction of the U.S. Environmental Protection Agency (EPA 2006). This Policy also establishes the requirement of collecting and managing geospatial metadata describing the Agency's geospatial assets to underscore EPA's commitment to data sharing, promoting secondary data use, and supporting the National Spatial Data Infrastructure (NSDI).

A minimum of three profiles (collecting density profiles from DRDP and four BVS-collected sediment samples each) will be collected at each location. The BVS-collected fluid mud samples will be analyzed in the same manner (with the same estimated testing precision) as previously described for the DRDP prototype laboratory testing phase to determine specific gravity and organic content (ASTM D854-06 and ASTM D2974-071).

The laboratory-measured fluid mud sample values (collected by the BVS as near to the DRDP as practical) will be compared to the DRDP-determined values. By calculating absolute and relative errors as defined by:

$E_{abs} = \rho_{DRDP} - \rho_{bv}$

$E_{rel} = E_{abs} / \rho_{bv}$

where

E_{abs} = Absolute error between instrument and laboratory-measured sample densities (g/cm^3).

E_{rel} = Relative error between instrument and laboratory-measured sample densities collected by ball valve sampler (g/cm^3).

ρ_{DRDP} = Density measured by Dredging Residual Density Profiler (g/cm^3).

ρ_{bv} = Density measured by laboratory-measured sample collected by the ball valve sampler (g/cm^3).

will be calculated and analyzed by descriptive statistic methods such as scatter plots, histograms, and box plots, to describe accuracy and precision measurement capabilities of the DRDP.

Quality Control Checks

To verify precision of the soil specific gravity test (ASTM D854-06, Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer) results, 5 replicates will be tested and analyzed for every 20 samples collected and tested. Replicate variance will be expressed as a measure of relative variation by calculating the relative standard deviation (RSD) (or coefficient of variation (CV)) as calculated by dividing the standard deviation by the mean and multiplying by 100 to express as a percentage (previously explained and defined in Prototype DRDP Laboratory Testing section). The RSD of the 5 replicates is estimated to be <5 percent. If this variance is exceeded, both the threshold variance value of 5 percent and the laboratory testing procedure will be investigated and the QC issue will be resolved to the mutual satisfaction of both the EPA and ERDC project managers' satisfaction.

Regarding the precision and bias of the fluid mud organic content values determined by the ASTM Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils (D 2974-07A) as previously referenced in ASTM D 2974-071, "due to the nature of the soil materials tested by this test method. It is either not feasible or too costly at this time to have ten or more laboratories participate in a round-robin testing program." Regarding test bias, "There is no accepted reference value for this test method, therefore, bias cannot be determined." A total of three composites will be taken (one at the beginning, one at the mid point, and one near the end of the laboratory trials will be tested in triplicate and respective means and 95 percent confidence intervals calculated).

In the field tests, to verify the BVS depth sensors reported accuracy of +/- 0.1 percent of the depth range, an engineering tape will be fastened to the ball valve sampler and lowered down to the channel bottom and the deck unit-reported values will be compared (at 10 ft (3 m) intervals) to measurements read from the tape at the waters surface. If the reported depth value exceeds this specified accuracy (as compared to the measurement tape), the depth sensor will be replaced and retested, or the engineering tape will be manually read and values recorded.

Schedule

The preliminary schedule is presented next. Specific schedules will depend upon funding, personnel availability, contractual requirements, and DRDP design/development parameters determined from the systems requirement analysis.

Activity	Date (MM/DD/YY)		Deliverable	Deliverable Due Date
	Anticipated Date of Initiation	Anticipated Date of Completion		
Conduct requirements analysis	11/1/08	12/30/08	Requirements analysis	
Scope of Work /Award Delivery Order Contract	1/1/09	1/30/09		
Develop and test DRDP prototype in laboratory	2/1/09	8 /1/09	DRDP prototype and preliminary test report	
Develop and test final DRDP in laboratory and field.	8/2/09	4/30/10	DRDP	
Technical Report	4/30//10	7/31/10	Technical Report	

Reports to Management

Quarterly status reports will be delivered to the EPA Project Manager (Brian Schumacher) to inform management of project status. If something occurs that could significantly affect the quality of the data, the USACE Principal Investigator (Tim Welp) will notify the EPA Project Manager to seek resolution and advice on how to proceed.

Data Management

Data generated during the laboratory and field sampling portion of this project will be input to a data management system based on Microsoft Excel. The system will be customized for this project to optimize the efficiency and functionality.

The data management system will be used to store all relevant project data such as sample locations and depths, sample-specific principal parameter settings, sample collection and analysis times, analytical results for field samples, laboratory and QC sample results. Hand entered data will be checked by someone not responsible for the manual data input to verify accuracy.

The data management system will facilitate export of the investigation results to a variety of statistical software programs for analysis.

Data Validation

The laboratory data will be reviewed for compliance with the applicable method and the quality of the data reported. The following summarizes the areas of data validation:

- Data completeness
- Calibrations
- Replicates
- Field QC samples

Each data set will be validated to identify biases inherent to the data and determine its usefulness. Data validation flags will be applied to those sample results that fall outside of specified tolerance limits and, therefore, do not meet the data quality requirements of the project. Data validation flags will indicate if results are considered anomalous, estimated, or rejected. Only rejected data are considered unusable; however, other qualified data may require further verification.

Reports

ERDC will prepare a preliminary report documenting results from the prototype DRDP laboratory testing phase. A detailed report will be prepared that documents the complete investigation's activities and findings, summarizes the conclusions, and provides recommendations for applying the results of this investigation. Recommendations for additional research will be provided as warranted. The detailed report will be prepared in the format specified in the *EPA Handbook for Preparing Office of Research and Development Reports* (EPA 1995).

References

U.S. Army Corps of Engineers. 2001. Hydrographic Surveying. Engineer Manual EM 1110-2-1003.

U.S. Environmental Protection Agency. 2006. U.S. Environmental Protection Agency, CIO Policy Transmittal 05-022, Classification No. 2121, Policy Title: *EPA National Geospatial Data Policy*, http://www.epa.gov/glnpo/fund/ngdp.pdf, 24 August 2005 (cited 15 September 2006).

U.S. Environmental Protection Agency. 1995. *Handbook for Preparing Office of Research and Development Report, 3rd Edition.* EPA600/K-95/002. Cincinnati, OH: Office of Research and Development, National Risk Management Research Laboratory.

Appendix B: Pycnometer Volume Calibration

Procedure:

1. Go to SedLab_sheets directory, Sprdshts, PYCNOVOL for a spreadsheet example to use in determining the volume of a pycnometer. Copy and paste the spreadsheet to another file.

2. Inspect all pycnometers to be calibrated for cracks or chips. If there are any cracks or chips in the glass or glass stopper, discard pycnometer. Each pycnometer and stopper has a matching number etched on them, so if either is cracked discard both.

3. Make sure pycnometers are clean and dry. Remove all fingerprints from inside and outside pycnometer and stopper by using Kimwipes.

4. Handle a pycnometer with a Kimwipe or exam glove and get tare weight using a small balance. Record weight in the Tare column on the spreadsheet.

5. Remove pycnometer from balance, remove the stopper, and fill pycnometer with room temperature distilled water up to the bottom of the pycnometer neck. Insert stopper. Use a 10 cc syringe with hypodermic needle filled with room temperature distilled water to finish filling pycnometer and stopper with water until a small amount of water pushes out of stopper opening. Kimwipe water from stopper and any external water on the pycnometer. Inspect pycnometer and stopper for air bubbles (all air must be removed). If air is present, try tapping on pycnometer to remove air. If tapping doesn't work, insert hypodermic needle again and try short quick squirts of distilled water to remove air. Again, remove any external water and fingerprints. Place filled pycnometer on balance and record weight in the Wt. bottle + water column on the spreadsheet.

6. This can be done before or after weighing pycnometers. Place a thermometer in the distilled water used in filling pycnometer(s) and record temperature in the Temp. C column on the spreadsheet. The water temperature will correspond to a value on the Density of Water chart (on the wall behind computer). Record the value (rounded to the third decimal) in the Dens. Water column on the spreadsheet. Example: 22.2°C = 0.998.

7. After the Tare wt., Wt. pycno + water and Density of water have been recorded on the spreadsheet the water wt. and the pycnometer volume will be generated automatically by formulas on the spreadsheet.

8. Do this procedure three times on each pycnometer. Calculate the average of the three pycnometer volumes obtained. The averaged volume then will used in the calculation of bulk density of a sediment sample.

Bulk Density Analysis-Pycnometer Method

Using pycnometers to determine the bulk density of sediment has shown to be the most accurate method.

Before starting this procedure:

1. Clean and inspect pycnometers. If glass is cracked or glass stopper is chipped do not use.

2. Pycnometers and stoppers all have numbers etched on them. Make sure pycnometers and stoppers match.

3. Periodically, the pycnometers volumes need to be checked. Procedure for doing this can be found in SedLab_sheets directory, Sprdshts, Pycnovol file. The pycnometer volume is used in the equation to determine the bulk density.

4. Sediment samples and distilled water should be at room temperature.

5. Create or open directory and create file in Excel.

    a. Spreadsheet is in SedLab_sheets directory, Sprdshts, BDENSITY.

    b. Enter sample information, pycnometer numbers, and pycnometer volumes on the spreadsheet.

Procedure:

1. First clean pycnometers and stoppers inside and outside using Kimwipes to remove fingerprints, dust, water, etc.

2. Weigh each stoppered pycnometer on microbalance (small scales) and record under Tare wt. column on the spreadsheet. **Note: Whichever balance was used to get Tare wts. use that balance for remaining weights**.

3. Thoroughly mix sediment sample then carefully spoon sample into pycnometer until it's about one-half full. Kimwipe away any sample that is on the lip or inside neck of pycnometer and insert stopper.

4. Wipe fingerprints, etc., from outside of pycnometer, weigh and record in Wt. bottle + sediment column on the spreadsheet.

5. Fill a 250 ml beaker with distilled water, insert a thermometer for several minutes and record temperature in Temp. C column on the spreadsheet. Look at Density of Water chart, find density (probably 0.998) in relation to temperature, and record in the Density of water column on the spreadsheet.

6. Filling the pycnometer:

   a. Remove stopper.

   b. Using squirt bottle slowly fill pycnometer with distilled water until water level is at bottom of pycnometer neck.

   c. Inspect sediment and be sure there are no imbedded air bubbles. If there is, use a needle to gently remove them.

   d. Insert stopper.

   e. Attach a hypodermic needle to a 10 cc syringe and fill syringe with distilled water from beaker mentioned in 5 above.

   f. Insert needle into stopper opening down to just below stopper bottom and slowly fill remaining area in pycnometer and stopper until a small amount of water seeps from stopper opening. Wipe off excess water.

   g. Inspect for any trapped air bubbles in pycnometer and stopper. **All air bubbles must be removed**! If air bubble is noticed, try tapping on pycnometer or a short quick jet from the syringe may work. If all else fails remove stopper and refill.

7. Kimwipe off water, fingerprints, etc. from pycnometer and stopper. Weigh and record in Wt. bottle + sed. + water column of spreadsheet.

8. Formula in the sediment density column of spreadsheet will generate the bulk density.

9. Empty pycnometers and wash with soap and warm water. If sample residue stain is noticed inside the pycnometer, use a test tube brush to remove residue. Rinse pycnometers with distilled water and either place the pycnometers upside down into a sieve and place into the oven (60°-80°C) and allow to dry ~30 min or use Kimwipes to remove water inside and out of pycnometer. Also, canned air can be used to blow and dry water from inside the pycnometer and stopper. NOTE: If the pycnometers have been oven dried they need time to cool down before reuse (~30 min).

10. Normally pycnometers not in use are placed in a desiccator and set on a counter top where they aren't bothered or jostled.

Appendix C: Sediment Laboratory Total Organic Content and Grain-size Analyses Results

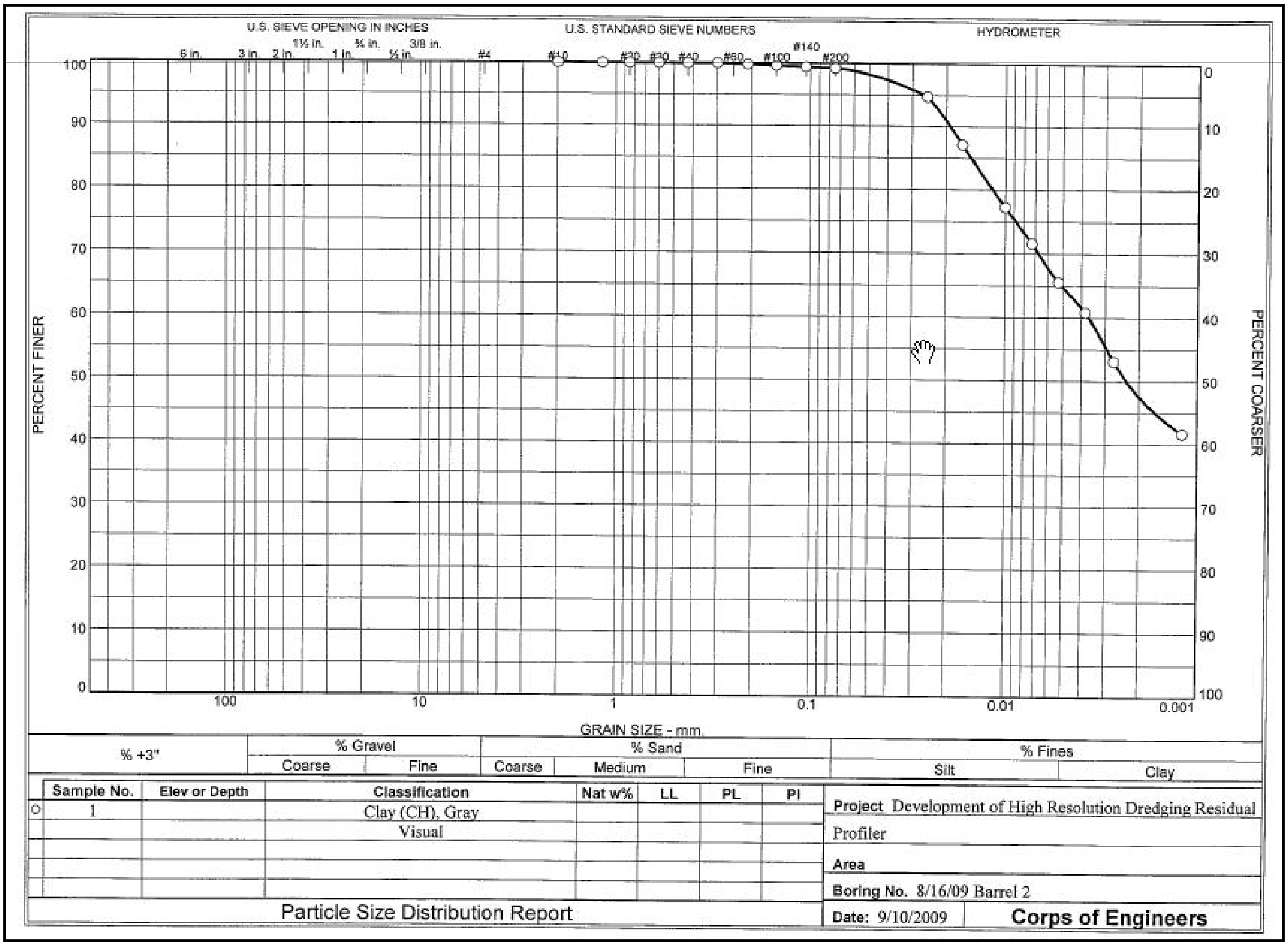

Figure C1. Plot of the grain size distribution for Barrel 2, Sample 1.

GRAIN SIZE DISTRIBUTION TEST DATA

9/10/2009

Project: Development of High Resolution Dredging Residual Profiler
Location: 8/16/09 Barrel 2
Sample Number: 1
Material Description: Clay (CH), Gray
Visual

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
50.10	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.10	99.8
			#100	0.20	99.6
			#140	0.30	99.4
			#200	0.40	99.2

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =50.1
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.8
Meniscus correction only = -0.1
Specific gravity of solids = 2.70 est.
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.5	1.0345	1.0299	0.0132	34.5	7.2	0.0250	94.7
5.00	21.5	1.0321	1.0275	0.0132	32.1	7.8	0.0165	87.1
15.00	21.5	1.0290	1.0244	0.0132	29.0	8.6	0.0100	77.3
30.00	21.5	1.0272	1.0226	0.0132	27.2	9.1	0.0073	71.6
60.00	21.5	1.0253	1.0207	0.0132	25.3	9.6	0.0053	65.6
120.00	21.5	1.0238	1.0192	0.0132	23.8	10.0	0.0038	60.8
250.00	22.0	1.0213	1.0168	0.0131	21.3	10.7	0.0027	53.1
1440.00	20.5	1.0179	1.0131	0.0134	17.8	11.6	0.0012	41.7

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.8	34.5	64.7	99.2

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
				0.0023	0.0037	0.0116	0.0149	0.0190	0.0261

Figure C2. Grain size distribution test data for Barrel 2, Sample 1.

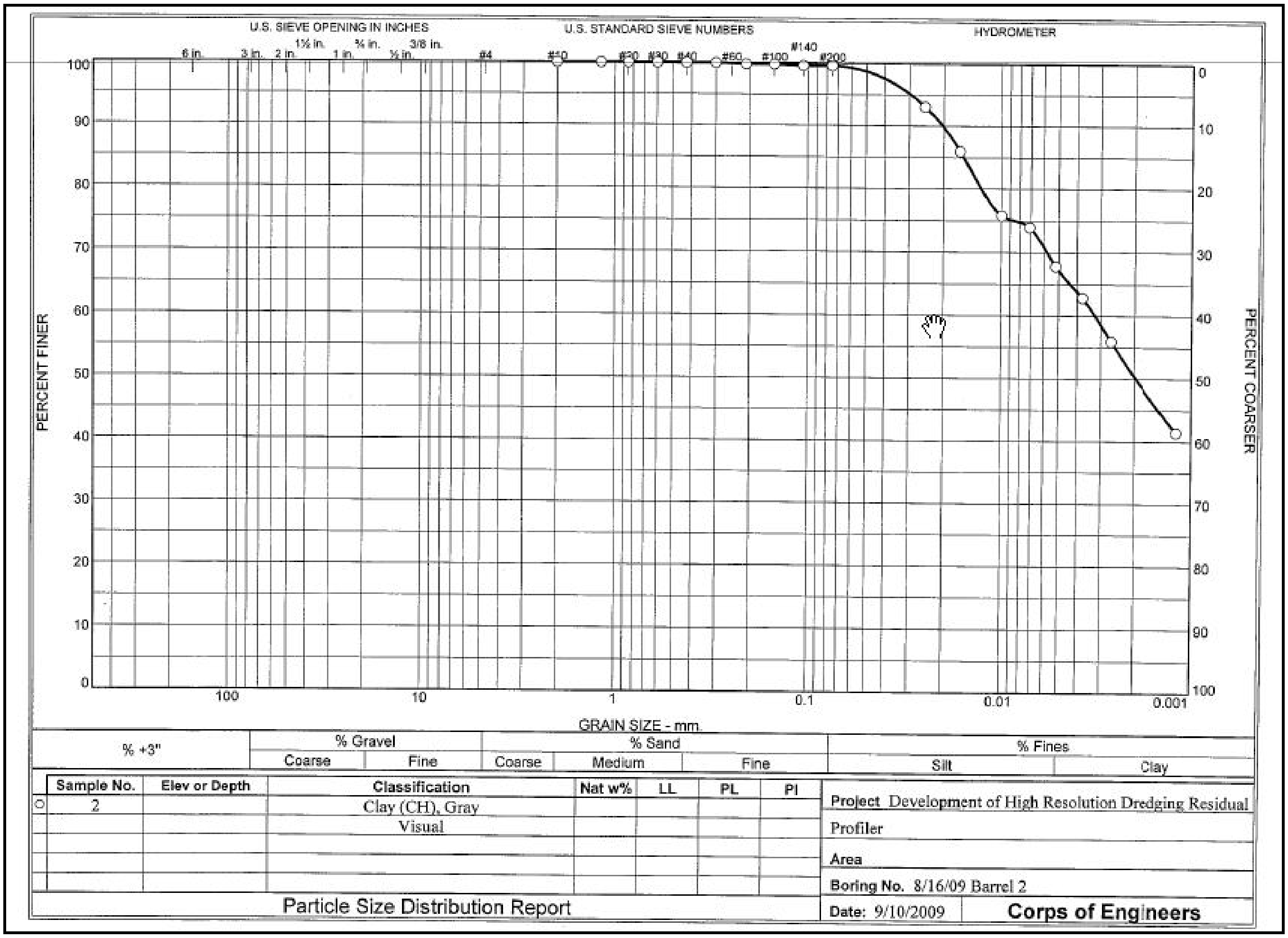

Figure C3. Plot of the grain size distribution for Barrel 2, Sample 2.

GRAIN SIZE DISTRIBUTION TEST DATA

9/10/2009

Project: Development of High Resolution Dredging Residual Profiler
Location: 8/16/09 Barrel 2
Sample Number: 2
Material Description: Clay (CH), Gray
Visual

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
51.50	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.10	99.8
			#100	0.10	99.8
			#140	0.20	99.6
			#200	0.20	99.6

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =51.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.8
Meniscus correction only = -0.1
Specific gravity of solids = 2.70 est.
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.5	1.0348	1.0302	0.0132	34.8	7.1	0.0249	93.1
5.00	21.5	1.0325	1.0279	0.0132	32.5	7.7	0.0164	86.0
15.00	21.5	1.0292	1.0246	0.0132	29.2	8.6	0.0100	75.8
30.00	21.5	1.0286	1.0240	0.0132	28.6	8.7	0.0071	73.9
60.00	21.5	1.0266	1.0220	0.0132	26.6	9.3	0.0052	67.8
120.00	21.5	1.0250	1.0204	0.0132	25.0	9.7	0.0038	62.8
250.00	22.5	1.0226	1.0181	0.0130	22.6	10.3	0.0027	55.9
1440.00	20.5	1.0182	1.0134	0.0134	18.2	11.5	0.0012	41.4

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	32.5	67.1	99.6

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
				0.0020	0.0032	0.0127	0.0157	0.0202	0.0294

Figure C4. Grain size distribution test data for Barrel 2, Sample 2.

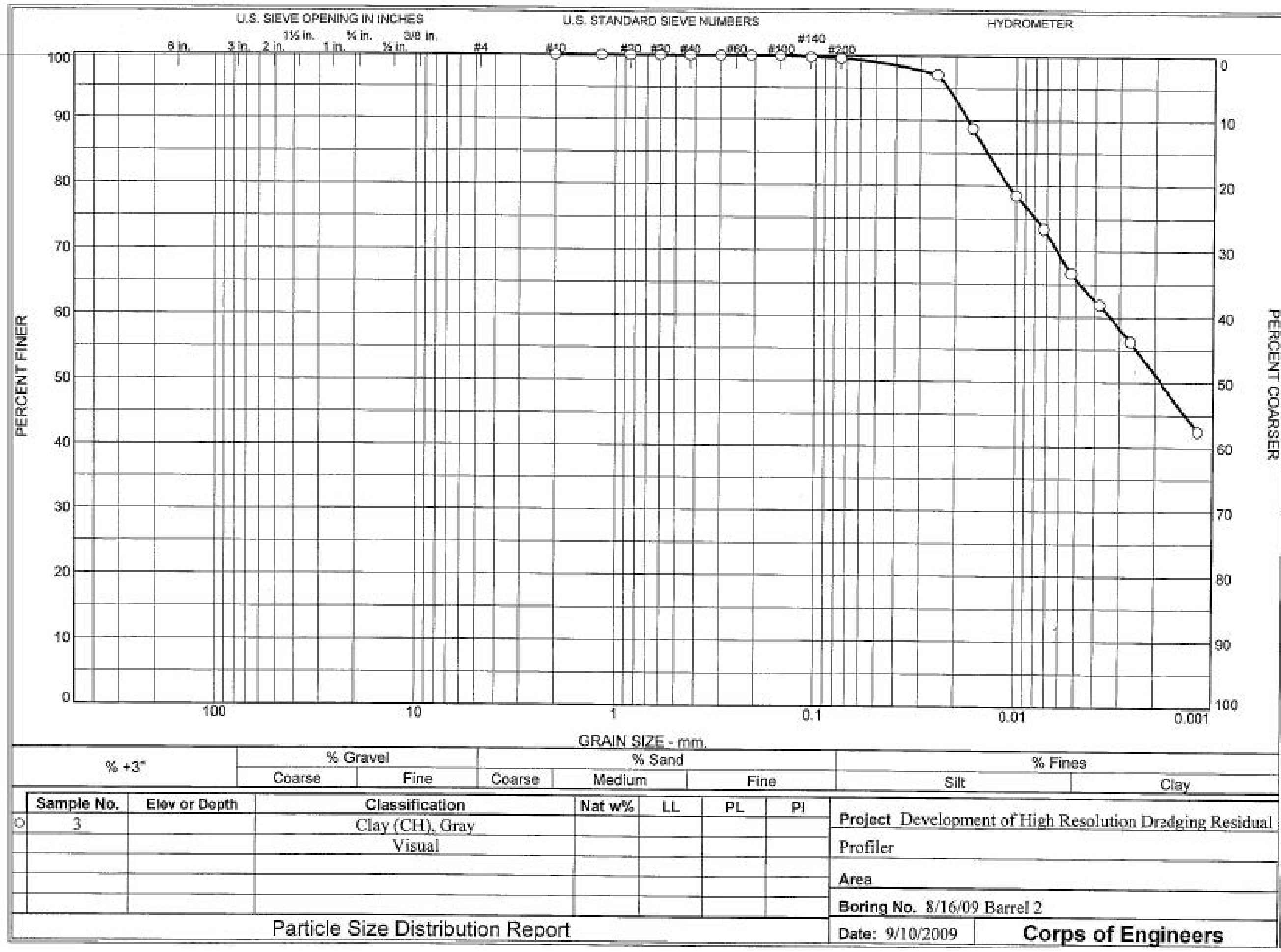

Figure C5. Plot of the grain size distribution for Barrel 2, Sample 3.

GRAIN SIZE DISTRIBUTION TEST DATA

9/10/2009

Project: Development of High Resolution Dredging Residual Profiler
Location: 8/16/09 Barrel 2
Sample Number: 3
Material Description: Clay (CH), Gray
Visual

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
49.50	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.10	99.8
			#200	0.20	99.6

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =49.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.8
Meniscus correction only = -0.1
Specific gravity of solids = 2.70 est.
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.5	1.0349	1.0303	0.0132	34.9	7.1	0.0248	97.1
5.00	21.5	1.0323	1.0277	0.0132	32.3	7.8	0.0164	88.8
15.00	21.5	1.0291	1.0245	0.0132	29.1	8.6	0.0100	78.5
30.00	21.5	1.0275	1.0229	0.0132	27.5	9.0	0.0072	73.4
60.00	21.5	1.0254	1.0208	0.0132	25.3	9.6	0.0053	66.7
120.00	21.5	1.0239	1.0193	0.0132	23.8	10.0	0.0038	61.9
250.00	22.5	1.0220	1.0175	0.0130	22.0	10.5	0.0027	56.2
1440.00	20.5	1.0180	1.0132	0.0134	18.0	11.5	0.0012	42.5

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	33.9	65.7	99.6

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
				0.0019	0.0034	0.0109	0.0139	0.0173	0.0219

Figure C6. Grain size distribution test data for Barrel 2, Sample 3.

DATA SHEET FOR ORGANIC CONTENT (ASTM D2974-07A)

PROJECT	Development of High Resolution Dredging Residual Profiler	FILE NO.	MD3309
		CLIENT	Tim Welp
REMARKS	Sheet 1 of 2	DATE	9/15/2009

	Boring	Barrel 1	Barrel 1	Barrel 1		
	Sample No.	1	2	3		
	Depth or Elevation	8/13/09	8/13/09	8/13/09		
	Tare No.	2	3	4		
Weight in grams	Tare + Soil (dried at 110°)	24.3	24.6	27.2		
	Soil (dried at 110°)	14.8	15.0	14.4		
	Tare + Soil (dried at 440°)	23.6	23.9	26.6		
	Soil (dried at 440°)	14.1	14.3	13.8		
	Tare Weight	9.5	9.6	12.8		
	Organic Content (wt.)					
	Organic Content (%)	4.7	4.7	4.2		
	Boring	Barrel 2	Barrel 2	Barrel 2		
	Sample No.	1	2	3		
	Depth or Elevation	8/14/09	8/14/09	8/14/09		
	Tare No.	7	11	12		
Weight in grams	Tare + Soil (dried at 110°)	25.6	27.6	25.9		
	Soil (dried at 110°)	14.9	14.9	15.3		
	Tare + Soil (dried at 440°)	24.9	26.9	25.2		
	Soil (dried at 440°)	14.2	14.2	14.6		
	Tare Weight	10.7	12.7	10.6		
	Organic Content (wt.)					
	Organic Content (%)	4.7	4.7	4.6		
	Boring	Barrel 1	Barrel 1	Barrel 1		
	Sample No.	1	2	3		
	Depth or Elevation	8/16/09	8/16/09	8/16/09		
	Tare No.	17	19	20		
Weight in grams	Tare + Soil (dried at 110°)	24.9	27.2	26.3		
	Soil (dried at 110°)	15.7	14.2	13.8		
	Tare + Soil (dried at 440°)	24.2	26.8	25.8		
	Soil (dried at 440°)	15.0	13.8	13.3		
	Tare Weight	9.2	13.0	12.5		
	Organic Content (wt.)					
	Organic Content (%)	4.5	2.8	3.6		

$$\% \text{ Organic} = \frac{(\text{Wt. of Soil Dried at } 110^\circ - \text{Wt. Soil Dried at } 440^\circ)}{\text{Wt. of Soil Dried at } 110^\circ} \times 100$$

Technician	COMPUTED BY:	CHECKED BY:

Figure C7. Results of the organic content analyses.

DATA SHEET FOR ORGANIC CONTENT (ASTM D2974-07A)

PROJECT: Development of High Resolution Dredging Residual Profiler	FILE NO. MD3309	
	CLIENT: Tim Welp	
REMARKS: Sheet 2 of 2	DATE	

		Barrel 2	Barrel 2	Barrel 2		
	Boring	Barrel 2	Barrel 2	Barrel 2		
	Sample No.	1	2	3		
	Depth or Elevation	8/16/09	8/16/09	8/16/09		
	Tare No.	21	22	31		
Weight in grams	Tare + Soil (dried at 110°)	28.1	24.6	25.0		
	Soil (dried at 110°)	15.0	13.4	15.8		
	Tare + Soil (dried at 440°)	27.3	24.0	24.2		
	Soil (dried at 440°)	14.2	12.8	15.0		
	Tare Weight	13.1	11.2	9.2		
	Organic Content (wt.)					
	Organic Content (%)	5.3	4.5	5.1		
	Boring	Barrel 1	Barrel 1	Barrel 1		
	Sample No.	1	2	3		
	Depth or Elevation	8/19/09	8/19/09	8/19/09		
	Tare No.	33.0	34.0	36.0		
Weight in grams	Tare + Soil (dried at 110°)	26.1	29.4	25.9		
	Soil (dried at 110°)	14.4	14.8	14.9		
	Tare + Soil (dried at 440°)	25.4	28.6	25.2		
	Soil (dried at 440°)	13.7	14.0	14.2		
	Tare Weight	11.7	14.6	11.0		
	Organic Content (wt.)					
	Organic Content (%)	4.9	5.4	4.7		
	Boring	Barrel 2	Barrel 2	Barrel 2		
	Sample No.	1	2	3		
	Depth or Elevation	8/19/09	8/19/09	8/19/09		
	Tare No.	37	38	39		
Weight in grams	Tare + Soil (dried at 110°)	29.6	27.5	26.9		
	Soil (dried at 110°)	15.6	15.5	14.5		
	Tare + Soil (dried at 440°)	29.1	26.9	26.5		
	Soil (dried at 440°)	15.1	14.9	14.1		
	Tare Weight	14.0	12.0	12.4		
	Organic Content (wt.)					
	Organic Content (%)	3.2	3.9	2.8		

$$\% \text{ Organic} = \frac{\text{Wt. of Soil Dried at } 110^\circ - \text{Wt. Soil Dried at } 440^\circ}{\text{Wt. of Soil Dried at } 110^\circ} \times 100$$

Technician | COMPUTED BY: | CHECKED BY:

Figure C8. Results of the organic content analyses.

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