Impacts of Environmental Muck Dredging 2015-2017
Moving Muck & Fluidized Mud & Tributary Bedload Measurements at Dredge Sites (Subtask 6)

Final Project Report to Brevard County Natural Resources Management Department
Funding provided by the Florida legislature as part of
DEP Grant Agreement No. S0714 – Brevard County Muck Dredging

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May, 2018

Cover: Top image pane shows sondes used to collect moving muck and fluidized mud and shown in Figures 6. Middle left image pane shows vertical sonde arrays as shown in Figure 7 in the report. The middle pane right shows bottom mounted sondes deployed as horizontal arrays. The lower image pane shows crucibles containing moving fluidized mud collected by sondes as shown to the right.

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Brevard County Natural Resources Management Department
2725 Judge Fran Jamieson Way, Building A, Room 219
Viera, Florida, 32940
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Table of Contents

List of Figures

Executive Summary

During this project moving fluid mud and muck samples were collected in Palm Bay and Turkey Creek from March, 2015 through March, 2017. Samples collected pre-dredging, during dredging and post dredging conditions are collected to help assess the environmental benefits of muck dredging. The goal was to determine if moving muck reduction occurred after dredging. If the moving fluidized mud is reduced after dredging, this is considered to be a positive benefit due to the environmental dredging. Bedload fluid mud and muck sampling occurred in Turkey Creek from August through November, 2016 in order to estimate the magnitude of moving fluidized mud that moved downstream within the bottom water layer. The efficacy or effects of dredging using the passive sondes indicates (1) after dredging, the average moving fluidized mud (g m^{-2} day^{-1}) decreased 55% when compared to pre-dredging conditions in the middle region of Palm Bay, (2) at the mouth of Palm Bay, pre-dredging versus post-dredging analysis suggests the maximum movement (g m^{-2} day^{-1}) of moving fluidized mud decreased by 45% after dredging and the average movement decreased by 3% after dredging, (3) the spatial variability of muck movement at stations TC1-TC6 decreased by 31% across the mouth of Palm Bay and (4) west of the railroad bridge in Turkey Creek, the post-dredging results indicated the maximum moving fluidized mud (g m^{-2} day^{-1}) decreased 57% compared to during dredging condition, but post-dredging mean fluid mud fluxes exceeded the pre-dredging condition. These results suggest a reduction of muck movement at the dredging site and downstream of the dredging site despite an increase in movement upstream of the project and the influence of Hurricane Matthew. The results near the bridge may have been influenced by the downstream fluid mud movement that occurred during Hurricane Matthew in the fall of 2016. Thus, there was a reduction of moving fluid mud and muck near the bottom after dredging, especially in the middle region of Palm Bay and at the mouth of Palm Bay. Extrapolation of data to the cross-sectional area at the upper Turkey Creek station suggests 55 +/- 7.7 metric tons of particulates (dry weight) moved downstream as bedload material within the lutocline from August 1 to November 12, 2016. Extrapolation to an annual basis suggests 195 +/ 28 metric tons of bedload moving fluidized mud is downstream. The calculated watershed loading rate (August-November 12, 2016) is estimated to be 7.5 +/- 1.1 kg km^{-}

^{2} inch rain^{-1}. Results suggest (a) a reduction of moving fluidized mud occurred due to dredging and (b) the source of this material enters Palm Bay during storm events. Comparison between data at the lutocline to the upper boundary layer water column indicated an increase from ~80 to over 500 times in Turkey creek using vertical sonde array measurements.

1. Moving Fluidized Mud Measurements in Palm Bay

1.1 Background

The goal was to collect data concerning the movement of moving fluidized mud (a) before dredging, (b) during dredging and (c) post dredging and to compare results to determine if there was a reduction in the quantity of the moving fluidized mud after dredging. The methods were developed during a USACE dredging project in the Indian River Lagoon (Maglio et al., 2016). The measurement protocol (Bostater and Rotkiske, 2015, 2016(b) uses passive sondes that collect mass flux density (g m^{-2} day^{-1}) or movement of moving fluidized mud within the lutocline at the bottom boundary layer (See Appendix 1 of this report). Sampling stations were located at the (a) mouth of Palm Bay (TC1-6), (b) the middle region of Palm Bay, and (c) in Turkey Creek west of a railroad bridge in Figure 1. See additional station details in Appendix 1.

Figure 1. Pre-dredge moving fluidized mud sample locations from March, 2015 to March 2017. Stations were selected using a stratified random sampling procedure in order to insure stations were located (**1**) west of the railroad bridge, (**2**) in the main bay of Turkey Creek and (**3**) near the mouth of Turkey Creek. Satellite image courtesy Digital Globe.

Sampling of the bedload moving fluidized mud flux is important because traditional water sampling methods do not account for bedload inputs of moving fluidized mud and colloidal aggregates (for more details consult the literature review in Bostater and Rotkiske, 2015) that move with internal waves in the moving lutocline (Bostater, 2016). Near bottom water grab sample devices underestimate total load of particulates entering lakes and estuaries because they do not include detailed sampling of particulates, flocs and aggregate material within the moving lutocline. Particulate matter in the lutocline is a major location and source of the material removed during waterway maintenance dredging projects (NAS, 1987).

1.2 Approach

The moving fluid mud and muck collected within the sondes shown on the cover of this report, has a water content > 75% by weight. It thus moves like a dense water fluid consisting of sand, silt, and clay particles with 80-90 % of the particles (by weight) passing through a number 04 sieve. This fluidized mud settles within ~5 hours (Bostater and Rotkiske, 2016(a)). The moving fluid mud is easily resuspended and moves horizontally due to disturbance from wind and waves (Bostater and Yang, 2014). It is not uncommon for the disturbed and resuspended matter to settle after forming flocs, estuarine snow, or colloidal aggregates (Bostater, 2016, Bostater and Rotkiske, 2015). The horizontal sondes are shown on the cover of this report, Figure 6 and in previous publications. The design, operation and engineering principal of operation and how they work is described in Bostater and Rotkiske, 2016(b), Bostater, Rotkiske, Oney and Obot, 2017. Additional detailed information concerning how the sondes are used and what the sondes collect has been described in Bostater and Rotkiske, 2016(a), 2016(b).

1.3 Results of Palm Bay Pre-dredging, Dredging and Post-dredging Sonde Sampling

From March, 2015 until March, 2017 sampling occurred in Palm Bay and Turkey Creek at stations described in the first year report (Bostater and Rotkiske, 2016(b)) and at stations shown in Figure 1. During dredging results are compared to pre-dredging and post-dredging measurements of moving fluidized mud in terms of fluxes (g m^{-2} day^{-1}) within and just above the bottom boundary layer. Stations across the mouth of Palm Bay (TC1-TC6) are indicated in Figure 1. Stations in Turkey Creek at the railroad bridge (TCB1-TCB3) are also indicated in Figure 1. The remaining stations were in the middle region of Palm Bay east of US1. Sampling (n=92) at stations near the mouth of Palm Bay are shown in the box plots in Figure 2. Box plots and interquartile ranges are used as described by Goic et al. 2013; Frigge et al. 1989; Iglewicz and Hoaglin, 1993. Box plots show statistical distributions of sample results (e.g. normal or non-normal distributions) and thus whether parametric or non-parametric tests should be applied. During dredging, total movement of fluid mud increased 3 to 4 times compared to the pre-dredging conditions at the mouth of Palm Bay.

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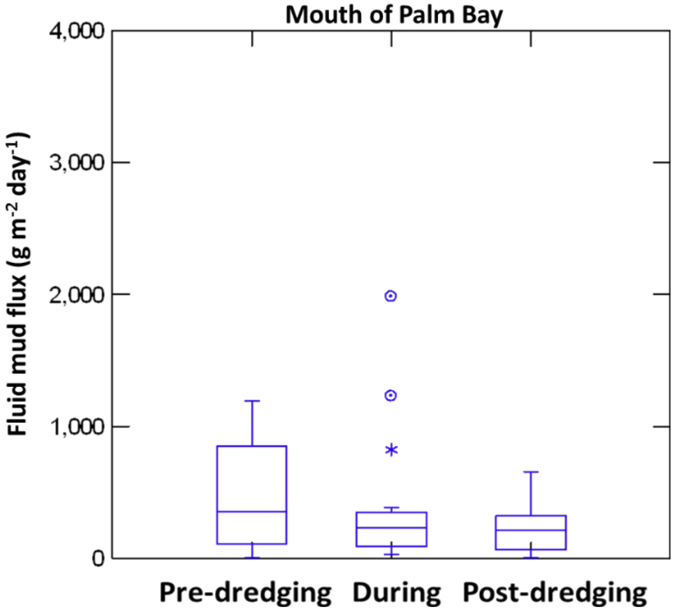

Figure 2. The pre-dredging, during dredging and post-dredging comparison of dry weight fluxes (g m^{-2} day^{-1}) of moving fluid muck at the mouth of Palm Bay. Collected samples (n=92) indicate that during dredging the fluid mud movement increased. After dredging, the average flux decreased by 3%, the spatial variability of the dry weight fluxes decreased by 31% (indicated by the standard deviation). The maximum movement of muck decreased 45% and is attributed to the efficacy of the dredging based upon the *in-situ* samples during the 3-year study period.

This increase during dredging is consistent with previous results (Maglio et al., 2015) using the sonde sampling protocol and box plot analyses. Statistical analysis of station data near the mouth of Palm Bay (TC1-TC6) pre-dredging versus post-dredging suggests the maximum movement (g m^{-2} day^{-1}) of moving fluidized fluid mud decreased by 45% and spatial variability (standard deviation) of fluxes across the mouth of Palm Bay (g m^{-2} day^{-}1) decreased by 31%. The reduction in the average dry weight flux between pre-dredging conditions and post-dredging was near 3%. The efficacy or effect of dredging is estimated to have resulted in a 45% reduction in the maximum muck moving at or near the mouth of Palm Bay within the lutocline.

Figure 3 shows the sampling (n=64) results of the fluid mud measurements (right) from station data collected within the middle region of Palm Bay. During dredging the dry weight flux (g m^{-2} day^{-1}) of moving fluidized mud increased. After dredging, average moving fluidized mud decreased 55% when compared to pre-dredging conditions. This decrease is a measure of the efficacy of dredging or the effect of dredging on muck movement reduction (MMR) within the middle region of Palm Bay. Points above the box plots indicate inter-quartile range, location of sample distribution tails, inter-quartile ranges, and show flux measurements are not normally distributed. In this case, nonparametric statistical tests are needed to compare statistical differences between pre-dredging, during and post-dredging sample results. The pre-dredging, during dredging and post-dredging dry weight fluxes of moving fluidized mud west of the railroad bridge at Turkey Creek are shown in Figure 4. Sample results (n=33) indicate that during dredging the maximum levels of moving fluidized mud increased. The after dredging results indicate the maximum moving fluidized mud decreased 57% compared to during dredging conditions. The pre-dredging versus post-dredging comparison shown below indicates the moving fluidized mud flux did not return to pre-dredging levels west of the railroad bridge. Hurricane Matthew may have influenced the post dredging results at the sampling stations near the railroad bridge. The post dredging sampling at these stations occurred after the hurricane so that the post-dredging fluxes did not return to pre-dredging conditions.

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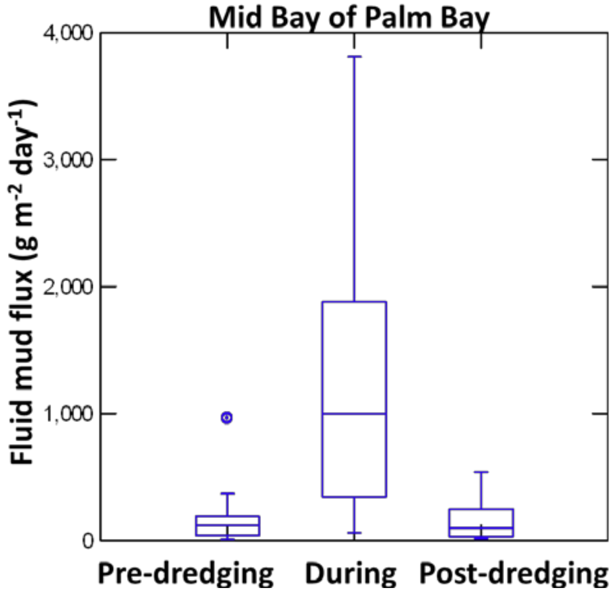

Figure 3. The pre-dredging, during dredging and post-dredging comparison of dry weight fluxes (g m^{-2} day^{-1}) of moving fluid muck in the middle region of Palm Bay. Samples (n=64) indicate that during dredging the maximum levels of moving fluid muck increased. After dredging results indicate the average moving fluid mud movement (g m^{-2} day^{-1}) decreased by 55% when compared to the pre-dredging conditions. This decrease is a measure of the efficacy of dredging or the effect that dredging resulted in a reduction in moving muck within the middle region of Palm Bay.

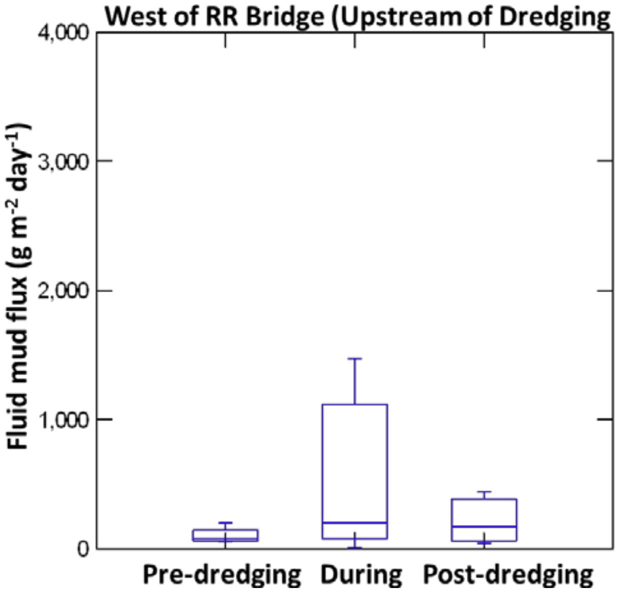

Figure 4.The pre-dredging, during dredging and post-dredging dry weight fluxes (g m^{-2} day^{-1}) of moving fluid muck comparison west of the railroad bridge at Turkey Creek. Samples (n=33) indicate that during dredging the maximum levels of moving fluid muck increased. After dredging results indicate the maximum fluid mud movement (g m^{-2} day^{-1}) decreased 57% compared to during dredging conditions. The pre-dredging versus post-dredging comparison shown above indicate the moving fluid mud fluxes exceeded pre-dredging magnitude near the railroad bridge and may have been influenced by bedload material moved downstream by Hurricane Matthew.

1.4 Summary of Pre-dredging, During & Post-Dredging Comparisons

Comparison between pre-dredging and post-dredging fluid mud movement can be used to infer the efficacy of environmental dredging. Reduction in the movement of fluidized mud is used as a surrogate indicator of a potential benefit of dredging because this fluid mud in the bottom boundary layer can easily be resuspended. The comparison of pre-dredging, during and post-dredging measurements of moving muck or fluid mud was made using box plots shown above. Box plots suggest the fluid mud movement measurement distributions are non-normal. Thus, nonparametric tests are applied to compare measurements. The nonparametric Kruskal-Wallis p test for analysis of variance indicated p-values <0.001 and indicates the station areas (mouth of Palm Bay, middle of Palm Bay, west of the railroad bridge) are statistically different with respect to the dry weight flux measurements (g m^{-2} day^{-1}). Applications of the nonparametric Kolmogorov-Smirnov two sample test probabilities were 0.001 or less indicates at this sampling area, pre-dredge, during and post-dredging flux distributions are statistically different from each other for each area. The Palm Bay station comparisons demonstrate that muck movement reduction (MMR) occurred at (a) the mouth of Palm Bay and (b) in the middle area of Palm Bay. This reduction, in the magnitude of the fluidized muck is related to the efficacy of the environmental dredging. The efficacy or effects of dredging using the passive sondes suggests the following: (1) after dredging, the average fluid mud movement (g m^{-2} day^{-1}) decreased 55% when compared to pre-dredging conditions in the middle region of Palm Bay, (2) at the mouth of Palm Bay, pre-dredging versus post-dredging analysis suggests the maximum movement (g m^{2} day^{-1}) of muck and fluid mud decreased by 45% and the average movement decreased by 3% after dredging, (3) the spatial variability of muck movement at stations TC1-TC6 decreased by 31% across the mouth of Palm Bay and (4) west of the railroad bridge in Turkey Creek, the post-dredging results indicated the maximum fluid mud movement (g m^{-2} day^{-1}) decreased 57% compared to during dredging condition, but post dredging mean fluid mud fluxes exceed the pre-dredging condition. This result could have been influenced by the downstream bedload fluid mud movement that occurred during the fall of 2016 that was influenced by Hurricane Matthew. Thus, there was a reduction of moving fluid mud and muck in the bottom waters after dredging, especially in the middle region of Palm Bay and at the mouth of Palm Bay.

2. Bedload sampling of moving fluidized mud in Turkey Creek

2.1 Background.

Sampling bedload movement of fluid mud and flux is important because traditional water sampling methods do not account for bedload inputs of fluid mud and muck and colloidal aggregates (for more details consult the literature review in Bostater and Rotkiske, 2015) that move with internal waves in the moving lutocline (Bostater, 2016). Near bottom water grab sample devices underestimate the total load of particulates entering lakes and estuaries because they do not include detailed sampling of particulates, flocs, and aggregate material within the moving lutocline. Particulate matter in the lutocline is a major location and source of the material removed during waterway maintenance dredging projects (NAS, 1987). In the NAS report (p. 32) R. Gibbs wrote “the major complicating factor in our present understanding of these processes is that when fine grained particles first encounter small amounts of seawater, they are attracted to each other to form aggregates and flocs”.

The American Society of Civil Engineers (ASCE) Task Force on sedimentation presented a review of methods and results related to bedload and near bottom sediment sampling with reference to hydraulic and sedimentation engineering (Vanoni, 1975). It is clear from previous research that bedload sediment inputs in streams and tributaries increase exponentially near the bed or bottom boundary layer and the bottom suspended load was shown to be over 500 times greater than the suspended particulate load in overlying water columns (Vanoni, 1975). This magnitude of bedload flux increase has recently been found to be well over 450 times in the open water of the Indian River Lagoon system (Bostater, Yang and Rotkiske, 2018) using a vertical array of 6 sondes. Existing methods for sampling bedload in rivers and streams are used to measure sand, pebbles and coarse particulate movement and not fine fluid muds or muck. The International Standards Organization (ISO) bedload material sampling subcommittee on sediment transport published ISO Standard Number 4364 for open channel bed material sampling (ISO, 2000). In their report, methods were described that applied to sampling these coarse bedload materials. One method was however presented that essentially is an open horizontal pipe sampler for sampling all particle sizes moving as bedload sediment material. The sondes used in the collection of the moving bedload material in this study resembles an ISO method in concept, since it is a round sampler with a circular opening. Methods applicable to sampling fine grain bedload and bottom boundary layer material were reviewed in Bostater and Rotkiske, 2015. This review indicated the limitations of other sampling techniques (including optical and acoustic) for quantitative sampling of moving fluid mud and muck. The sampling devices shown in Bostater and Yang, 2014, and reported in Bostater and Rotkiske, 2015, 2016(a,b); Bostater, Rotkiske and Oney, 2016; Bostater Rotkiske, Oney and Obot, 2017 are the only reported devices that directly measure the physical movement and horizontal mass flux of moving fluid mud and muck. The sondes used in this study overcome sampling problems described by Bianchi, 2007, since the method samples the movement of fine mud and muck movement in bottom water over both space and time - for extended time periods.

2.2 Approach

The approach developed for bedload measurements utilized sonde arrays (Bostater, Rotkiske, Oney, et al. 2017; Bostater, Yang, Rotkiske, 2017). The sampling devices resemble the sondes shown in Bostater and Yang, 2014. The sondes were developed using computer aided design (CAD) techniques and 3D printing of the devices shown on the cover of this report and below. The 3D printer passive flux traps or sondes can be printed with acrylonitrile butadiene styrene (ABS) plastic filaments or made from polyvinyl chloride. The approach follows the techniques described in Maglio et al., 2016 and overcomes other sampling strategy limitations as outlined by Bianchi, 2007. Horizontal and vertical sonde arrays were deployed from 12 hours to well over one month at the location shown in Figure 5. Eight sondes were deployed in a vertical array in order to measure the moving fluid bedload within the bottom boundary layer (moving lutocline) above the consolidated bottom sediments. The consolidated bottom layer depth below the mean water surface was determined using a sludge judge.

Results from the vertical array deployments provide information to develop the necessary Cauchy type boundary conditions used in modeling the vertical structure of horizontally moving fluid mud (Bostater, Rotkiske, Oney, 2016, Bostater, Rotkiske, Oney and Obot, 2017) as well as the boundary conditions used to model the underwater light field described in Bostater, Ma, McNally, Gimond and Lamb (1995).

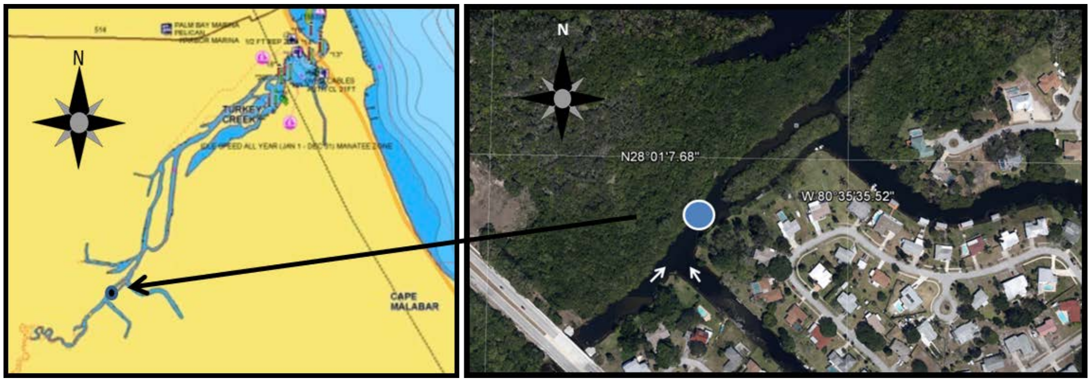

Figure 5. Location of bedload vertical array deployments in Turkey Creek, Florida used to estimate the downstream moving fluid mud bedload fluxes and watershed loading rates above the sampling location (N 28^{O}1.5’ 0.99”, W 80^{O}35’40.87”).

During the deployments at the location shown above, acoustic imaging was conducted using the technique described by Bostater and Rotkiske, 2015 and Bostater, 2017. Seven array deployments were conducted from August to November 12, 2016 in Turkey Creek, Florida. The downstream bedload material fluxes were sampled during base flow conditions and high flow water conditions. High flow downstream material fluxes (dry weight) were collected during Hurricane Matthew. Figures 6 and 7 show the horizontal and vertical sondes used. Figure 7 (left and middle image) shows a vertical array of eight sondes deployed in the field and before deployment in the lab. For further details consult Bostater, Rotkiske, Oney and Obot, 2017.

Figure 6.Fluid mud sondes created using 3-D printers based upon computer aided designs originally described in Bostater and Yang, 2014. From Bostater, Rotkiske, Oney and Obot, 2017, and shown on the cover of this report.

Figure 7. Vertical array of eight horizontal flux sondes in the field (left). The left and the center image shows the array of sondes in the field and lab. Field deployments were conducted August 1 to November 12, 2016. The right image shows the horizontal flux sondes located in a horizontal array (4.5 x 2 m). From Bostater, Rotkiske, Oney and Obot, 2017. Also see the cover of this report for images.

2.3 Turkey Creek Bedload Measurement Results

Results demonstrate the ability of vertical sonde arrays to measure the vertical structure of moving downstream horizontal particulate fluxes or and movement of fluid mud and muck within and above the moving lutocline as shown below. The definition of moving fluid mud captured by the sondes was reported in Bostater, 2016(b) and Bostater and Rotkiske, 2016. The material has also been described by Teeter et al., 1992 and more recently by McAnally et al., 2007. Results obtained from similar horizontal and vertical sediment traps or sondes are used in estimating rate constants used in modeling sediment and nutrient fluxes (Di Toro, 2001). An extensive review of techniques and methods previously used to sample muck and fluid mud pointed out the limitations of the previous techniques (Bostater and Rotkiske, 2015). The principle of operation and sampling moving fluid mud using the passive sondes is based upon perturbation theory concerning estimating mass flux density (Q) by direct measurement of a time and space averaged mass flux density ($\overline{\overline{CU}}$) where U is velocity and C is concentration. This directly measured quantity Q (measured by the sondes over a deployment period) is composed of an instantaneous flux (CU) that is typically obtained from grab samples. The sondes also capture the turbulent flux ($C'U'$) that is not sampled with grab water samplers. They also measure the secondary flux ($C''U''$) that occurs due to the presence of wave-like structures of mass flux (See Eq. 1). These wavelike structures of mass flux are not sampled via grab sampling techniques that measure a nearly instantaneous point in time and space. This flux is known to exist and can be observed through acoustic imaging showing internal waves of nephelometric particulate fluxes as shown by Bourgault et al. (2014) as well as Bostater and Rotkiske, (2015), where:

$$Q = \overline{\overline{CU}} = CU + C'U' + C''U'' \quad . \tag{1}$$

In addition, the horizontal flux sondes are scalable in size and can be placed in vertical or horizontal arrays as suggested by Rotkiske and Bostater (2016).

The Turkey Creek vertical measurements of the downstream moving fluid mud show an exponential relationship with, the greatest downstream flux at or near the lutocline - at the water bottom. Comparison between data at the lutocline to the upper boundary layer water column indicated an increase from ~80 to over 500 times as shown below in Figure 8, consistent with previous data described in Vanoni, 1975; Bostater and Rotkiske, 2015; Mehta, Lee and Li, 1994. This has also been verified in the open waters of the Indian River lagoon during 2017 by Bostater, Yang, and Rotkiske (2018) where bedload movement or fluxes were 450 times the water surface column fluxes based upon replicate array deployments.

The results in Figure 8 also demonstrate the sondes estimate the horizontal downstream movement or fluxes of fluid mud - fine particulate matter as a function of the water column depth in Turkey Creek. The results can be used in 3D water quality modeling or modeled using fundamental transport theory for 1D flow using solutions to advective-dispersive differential equations described in Bostater, Rotkiske, Oney and Obot, 2017.

Results of Turkey Creek horizontal downstream fluxes have been provided to Gary Zarillo at FIT for use in sediment and water quality modeling.

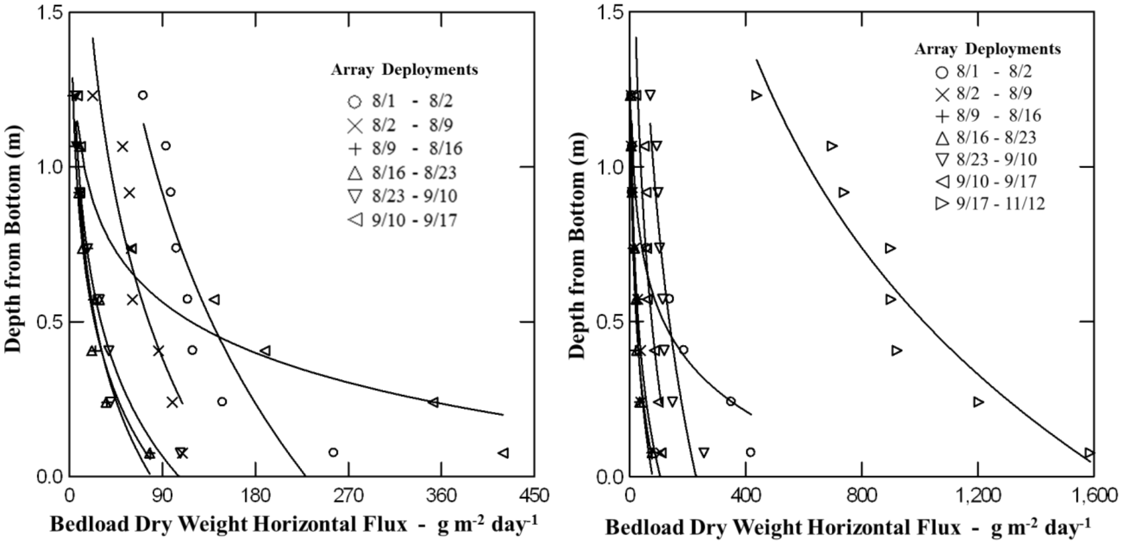

Figure 8. Fluid mud dry weight downstream horizontal flux (g m^{-2} day^{-1}) profiles obtained from downstream sonde array deployments from August through September 17, 2016 (left) and vertical array profiles results from sonde deployments from all deployments through November 12, 2016 (right). The influence of Hurricane Matthew caused an increase from 400 to 1600 g m^{-2} day^{-1} in the movement of particulates within the lutocline at the water bottom at z=0 for the September 17 through November 12, 2016 deployment periods. From Bostater, Rotkiske, Oney and Obot, 2017.

Analyses performed by Bostater and Rotkiske, 2016(b) provide information concerning the precision of horizontal mass flux estimates using the sondes located in the lutocline. Triplicate deployments resulted in the coefficient of variation ranging from 0.13 to 0.15. The measurement error of these results is expected to be approximately 14 percent using the estimation procedures recommended by the US Environmental Protection Agency (EPA, 1984).

Extrapolation of data to the cross-sectional area of the Turkey Creek station suggests 55 +/- 7.7 metric tons of particulates (dry weight) moved downstream as bedload material within the lutocline from August 1 to November 12, 2016. Extrapolation to an annual basis suggests 195 +/- 27.8 metric tons of bedload fluid mud and muck moves downstream within the moving lutocline and bottom water column.

Calculation of the loading rates utilized data (shown in Figure 4) makes use of the stream cross-sectional area (m^2) at the location shown in Figure 5, knowledge of the watershed drainage area (km^2) above the location and total daily rainfall in inches (based upon the nearby Melbourne, Florida airport rain gauge). The calculated loading rate (August-November 12, 2016) is thus estimated to be 7.5 +/- 1.1 kg km^{-2} inch $rain^{-1}$. These bedload moving fluidized mud loading rates can be used in modeling scenarios regarding actual muck inputs to the Indian River Lagoon. Note these bedload estimates of muck and fluid mud cannot be obtained from suspended sediment or turbidity measurements from water samples. These loading rates were provided for use in water quality and sediment modeling.

2.4 Summary of Bedload Sampling of Moving Fluidized Mud in Turkey Creek

The fluid mud and muck bedload loading rates described above can be used in related water quality model scenarios of Indian River Lagoon. The vertical profiles of horizontal fluxes shown in Figure 8 can be used to develop model input estimates of bottom bedload material as a function of model layers in sediment transport modeling. The profiles follow the solution of theoretical models based upon advective diffusive partial differential equations (see Bostater, et al., 2017).

The results shown in Figure 8 demonstrate the ability of sonde arrays to measure the vertical structure of horizontal particulate fluxes or movement of fluid mud and muck within approximately 1 m from the consolidated mud bottom. The sondes measure moving fluidized mud described by Teeter, et al. (1992) and more recently by McAnally, et al. (2007). The sondes measure this moving muck and fluid mud using perturbation theory discussed above and the laboratory methods and calculations of mass flux density described in Appendix 1 below. Results obtained from horizontal sondes are used in estimating rate constants used in modeling sediment and nutrient fluxes (Di Toro, 2001). An extensive review of techniques and methods previously used to sample muck and fluid mud pointed out the limitations of other methods (Bostater and Rotkiske, 2015).

The bedload sampling using the vertical array of sondes (see Figure 7) has allowed the estimation of the mass flux density of boundary layer moving fluidized mud to be nearly approximately 100 to 450 times greater than upper water column fluxes during non-hurricane conditions. During the Hurricane Matthew sampling period, the bottom moving fluidized mud in the bottom boundary layer reached over 1200 times the upper water column transport.

More recent research using the sonde array method and protocol within Indian River Lagoon and Banana River to be 500 times greater in the bottom boundary layer compared to upper water column during small wind driven small gravity wave conditions (Bostater, Yang and Rotkiske, 2018; Bostater, Rotkiske and Oney, 2018.

3.0 References

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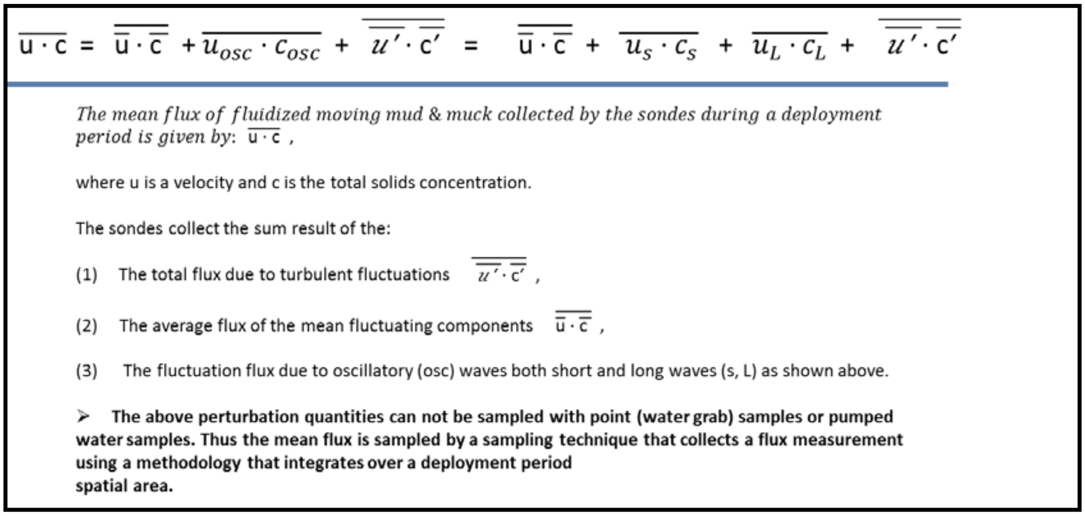
Appendix: Quality Assurance Plan

A. Project Purpose and intended use of data

The statement of work provided to Brevard County contains information on the purpose and intended use of the data collected in Task 6. In general, the purpose of Task 6 is to (a) continue collection of research data to assess the movement of fluid mud and muck at dredge sites before, during and post dredging; (b) measure bedload movement of muck and fluidized mud in tributaries. The scope of work described the probes and sondes to be deployed in order to assess measure muck movement reduction (MMR) during the pre-dredge, during dredging, and post dredging sampling in order to assess the benefits of environmental dredging. Efficacy of the dredging can be inferred by analysis of sonde data in terms of total non-directional flux density (mass per unit area per unit time) – fluid mud and muck movement. Bedload measurements in Turkey Creek will also be provided for water quality and sediment modeling.

B. Brief historical overview and literature search

Bostater and Yang, 2014; Bostater and Rotkiske, 2015; Maglio et al., 2016; Bostater and Rotkiske, 2016 and Rotkiske and Bostater, 2016 previously described the sondes (vertical & horizontal). They reviewed existing and historical aquatic methods that might be considered for indirect (surrogate) and direct measurements of fluid mud movement in terms of mass flux density (mass per unit are per unit time). The scientific methods and approaches reported in Bostater and Rotkiske, 2015, presented and compared (1) different operating principles of over 20 different specific samplers, probes and sensor systems applicable to sampling of fluid mud and bottom sediment characteristics, (2) the methodologies were compared as being optical, acoustical or direct and (3) the benefit and limitations of the various methods (particularly bedload type samplers). Only cylindrical sediment traps were noted as being capable of measuring vertical flux density, and that these were used around the world in different configurations by researchers. Horizontal bedload traps or samplers are commonly designed for collecting large grain sizes of bedload material and shown in Vanoni, 1975. The review also indicated no *direct* methods had been developed and reported in the open scientific literature for horizontal and directional fluid mud movements. Vanoni reported bedload values of suspended particulates in the bottom boundary layer reach values of over 500 times the water column values. Only one technique that incorporated directional measurement method has been published in the form of a US patent (Anderson, 1992) but the patent did not address or mention the ability to measure time and spatially averaged horizontal *fluxes* of particulates using the invention. A cylindrical bedload sampler has been documented in ISO standard 4360 (ISO, 1977) and is essentially a horizontal cylindrical can that at the bottom of a stream bed. Figure 1.1 below summarizes the theoretical operational basis and field sampling approach of the mass conserving sondes that are similar in concept to the ISO reported bedload sampler.



$$\overline{u \cdot c} = \overline{\overline{u} \cdot \overline{c}} + \overline{u_{osc} \cdot c_{osc}} + \overline{\overline{u'} \cdot \overline{c'}} = \overline{\overline{u} \cdot \overline{c}} + \overline{u_S \cdot c_S} + \overline{u_L \cdot c_L} + \overline{\overline{u'} \cdot \overline{c'}}$$

The mean flux of fluidized moving mud & muck collected by the sondes during a deployment period is given by: $\overline{u \cdot c}$,

where u is a velocity and c is the total solids concentration.

The sondes collect the sum result of the:

(1) The total flux due to turbulent fluctuations $\overline{\overline{u'} \cdot \overline{c'}}$,

(2) The average flux of the mean fluctuating components $\overline{u} \cdot \overline{c}$,

(3) The fluctuation flux due to oscillatory (osc) waves both short and long waves (s, L) as shown above.

➢ **The above perturbation quantities can not be sampled with point (water grab) samples or pumped water samples. Thus the mean flux is sampled by a sampling technique that collects a flux measurement using a methodology that integrates over a deployment period spatial area.**

Figure 1.1 Operation of the sondes or probes is based upon perturbation theory that indicates the sondes automatically perform a time and spatial averaging collection method to collect moving fluidized mud. The method allows one to capture particulate matter fluctuations where turbulence, water wave effects, variations in flux fluctuations due to mean river flow, fluctuating concentrations and velocities dominate instantaneous measurement systems in use today (from Bostater & Rotkiske, 2016).

Instantaneous water sample sampling (grab samples) or pumped samples cannot capture the variability of fluxes of substances in waters nor can grab sample results or pumped samples be used to calculate the conservation of mass in time and space that the sondes capture and which point sampling techniques cannot estimate. Maglio, et al., 2016 reported on the use and results to estimate muck movement reduction in Florida waters during a recent dredging project using the sondes and methods proposed for and accepted for use in this project. This research and the sonde operational theory follow the recommendations of the American Society of Civil Engineers (ASCE), Task Committee on Management of Fluid Mud, 2007 concerning the need to develop methods to measure fluid mud using temporal and spatial averaging techniques. No prior US EPA standard method or American Society of Testing and Materials (ASTM) is known to exist concerning direct or indirect (surrogate) horizontal fluid mud movement or flux density (mass L^{-2} T^{-1}) in aquatic systems.

C. Statement of anticipated results of the research project

The intended use of the data collected in this research is to help assess the benefits of muck dredging in the Indian River Lagoon as part of needed environmental remediation due to impacts of muck on the water quality and biotic populations in the Indian River Lagoon. The expected outcome of the research is to document through research data the reduction in the amount of moving fluid mud and muck after dredging has been completed. The concept of muck movement reduction (MMR) was recently developed for a dredging project in the Sebastian Inlet region and Intracoastal Waterway near Wabasso, Florida. The research demonstrated the ability of the sondes to document muck movement reduction at coastal waterway transects where research monitoring occurred during 2015 (Weaver et al., 2015; Maglio et al., 2016; Bostater and Rotkiske, 2015). Similar to the above referenced dredging project, this research task makes use of stratified random sampling for selection of stations and transects where sonde deployments occur. In addition, stratified random sampling is used to determine when sampling will occur during a selected day. Use of stratified random sampling design for *in-situ* sampling is intended to remove bias in results that could be attributed to sampling in time and space or locations.

D. Description of work to be conducted, including the types of analyses to be performed to monitor the effectiveness of the research

Field Sampling:

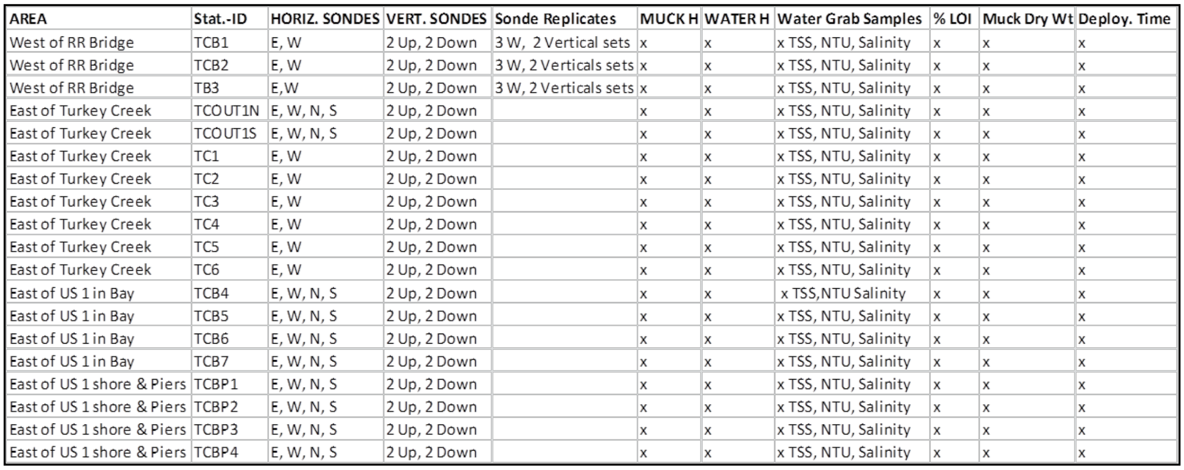
- *Sampling Plan Design and Rationale*

The *in-situ* station sampling design rationale makes use of a stratified random sampling of locations that allows the (1) use of sondes located along transects, (2) stations in the vicinity of shorelines and (3) stations outside the bay (west of the mouth of the bay and upstream of the railroad bridge). This approach allows for the analysis of pre-dredge, during dredging, and post dredging sonde measurements of fluid mud movement in terms of - mass per unit area per unit time.

- *Location of each sampling point for the project and link each point to the sampling methods, analysis, indicators, populations to be measured or investigated and frequency.*

The map Figure 1.2 shows the location of each sampling point. At each location deployments of the sondes are made. At each location 2 or 4 horizontal directional sondes are deployed. Two along the transect at the mouth of the Turkey Creek measuring inflow and outflow (east-west directions) and two at the 3 stations west of the railroad bridge in Turkey Creek for measuring upstream and downstream (east-west directions). Horizontal sondes deployments at all other stations were in the North, South, East, and West orientation.

Table 1.1 Description of dredge site sample locations and samples proposed for 2016.



AREA	Stat.-ID	HORIZ. SONDES	VERT. SONDES	Sonde Replicates	MUCK H	WATER H	Water Grab Samples	% LOI	Muck Dry Wt	Deploy. Time
West of RR Bridge	TCB1	E, W	2 Up, 2 Down	3 W, 2 Vertical sets	x	x	x TSS, NTU, Salinity	x	x	x
West of RR Bridge	TCB2	E, W	2 Up, 2 Down	3 W, 2 Verticals sets	x	x	x TSS, NTU, Salinity	x	x	x
West of RR Bridge	TB3	E,W	2 Up, 2 Down	3 W, 2 Verticals sets	x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TCOUT1N	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TCOUT1S	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TC1	E, W	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TC2	E, W	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TC3	E, W	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TC4	E, W	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TC5	E, W	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of Turkey Creek	TC6	E, W	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of US 1 in Bay	TCB4	E, W, N, S	2 Up, 2 Down		x	x	x TSS,NTU Salinity	x	x	x
East of US 1 in Bay	TCB5	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of US 1 in Bay	TCB6	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of US 1 in Bay	TCB7	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of US 1 shore & Piers	TCBP1	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of US 1 shore & Piers	TCBP2	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of US 1 shore & Piers	TCBP3	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x
East of US 1 shore & Piers	TCBP4	E, W, N, S	2 Up, 2 Down		x	x	x TSS, NTU, Salinity	x	x	x

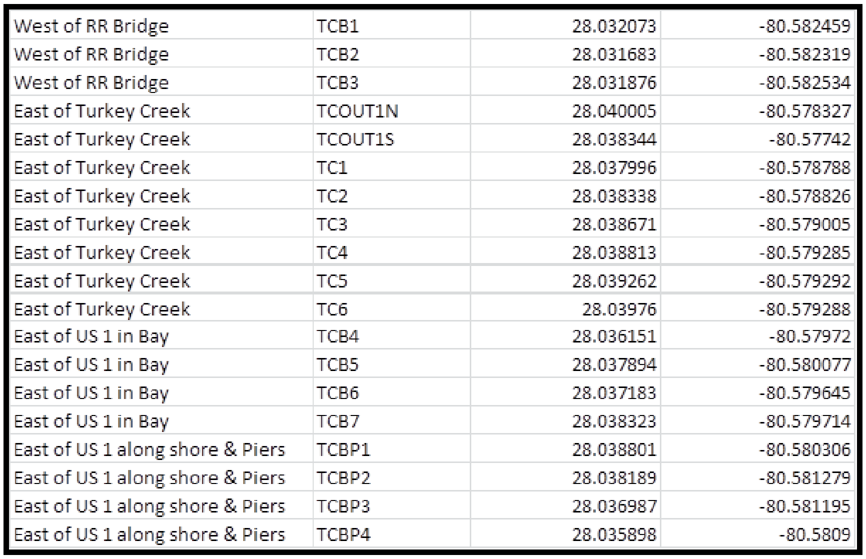
All of the above stations were selected as being relevant to the purpose and intent of the project. The key parameters necessary to estimate muck movement reduction project goal are derived from the deployment of the vertical sondes and horizontal sondes. Key parameters essential for calculation of direction fluxes (mass m^{-2} t^{-1}) of fluid mud & muck passively moving into each directional horizontal or vertical sonde (depositional, resuspended matter are: (1) deployment time (HH.MM), (2) dry weight (grams), (3) calculation of % loss on ignition (estimation of organic content of the fluid mud and after ignition in a muffle furnace).

All other parameters collected are provided as ancillary background information such as depths and water grab samples (salinity, NTU, TSS). Water grab sample results at each station are not used in the calculation of moving fluid mud & muck fluxes. As noted above either 2 or 4 horizontal sondes are deployed and one set of four vertical sondes are deployed at each station. The deployment design allows the estimation of muck movement reduction as reported in Maglio, et al., 2016 using the methods for direct measurement of fluid mud & muck flux in Bostater & Rotkiske, 2015.

- *Map of the sampling point locations*

The Table below gives the general area, station ID name and latitude longitude information. Stations are relevant for calculation of moving fluid mud flux at the following areas: (1) just west of the railroad bridge, (2) with the bay (east of US 1), and (3) at or near the mouth of Palm Bay.

Table 1.2 Palm Bay sampling station locations (latitude longitude decimal degrees), station ID and region.



West of RR Bridge	TCB1	28.032073	-80.582459
West of RR Bridge	TCB2	28.031683	-80.582319
West of RR Bridge	TCB3	28.031876	-80.582534
East of Turkey Creek	TCOUT1N	28.040005	-80.578327
East of Turkey Creek	TCOUT1S	28.038344	-80.57742
East of Turkey Creek	TC1	28.037996	-80.578788
East of Turkey Creek	TC2	28.038338	-80.578826
East of Turkey Creek	TC3	28.038671	-80.579005
East of Turkey Creek	TC4	28.038813	-80.579285
East of Turkey Creek	TC5	28.039262	-80.579292
East of Turkey Creek	TC6	28.03976	-80.579288
East of US 1 in Bay	TCB4	28.036151	-80.57972
East of US 1 in Bay	TCB5	28.037894	-80.580077
East of US 1 in Bay	TCB6	28.037183	-80.579645
East of US 1 in Bay	TCB7	28.038323	-80.579714
East of US 1 along shore & Piers	TCBP1	28.038801	-80.580306
East of US 1 along shore & Piers	TCBP2	28.038189	-80.581279
East of US 1 along shore & Piers	TCBP3	28.036987	-80.581195
East of US 1 along shore & Piers	TCBP4	28.035898	-80.5809

Figure 1.2 Map of dredge site stations for Task 4 and as described in the above table.

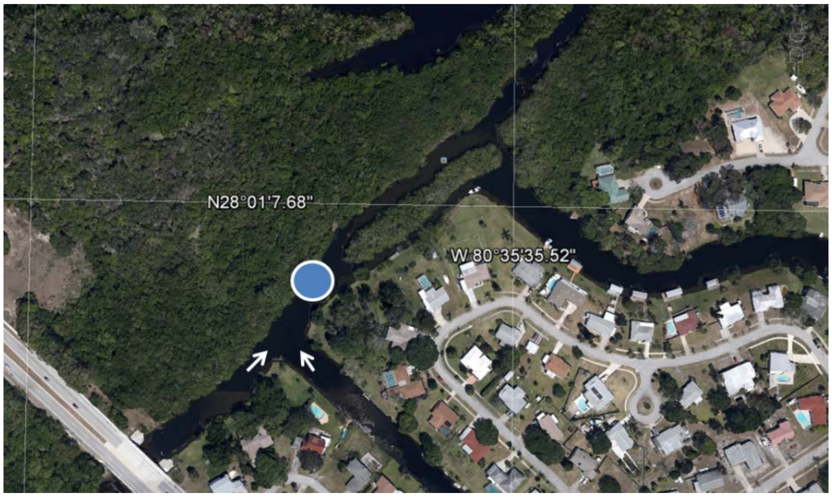
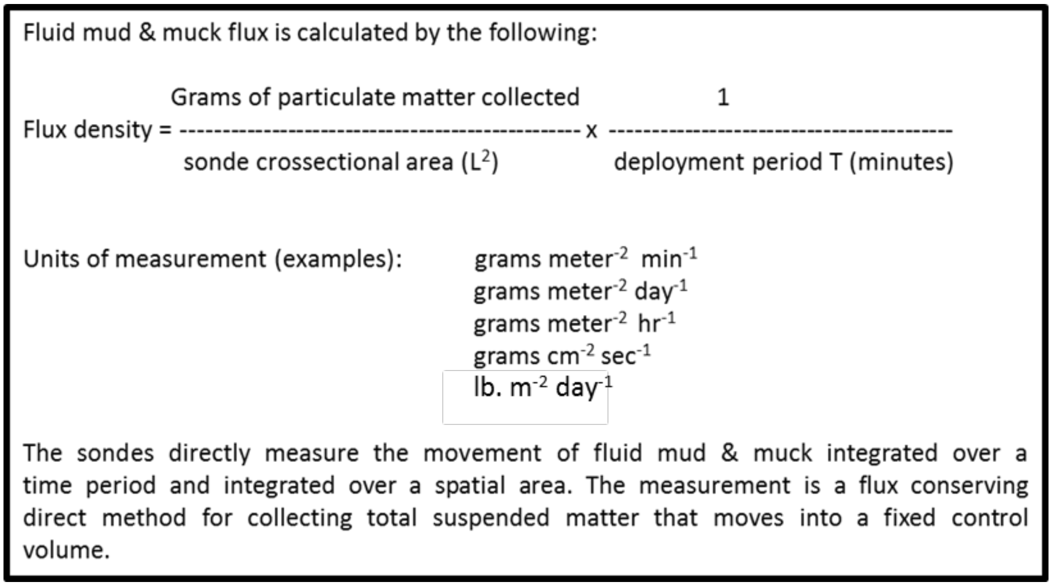


Figure 1.3. Location of the Turkey Creek bedload sampling station. This location was selected as the most upstream location but downward of the confluence of the braided stream after Port Malabar Blvd.,(N 28^{o} 1.5' 0.99", W 80^{o} 35' 40.87").). The arrows show the direction of water flow at the confluence at the confluence of two upland streams (image courtesy Google Earth).

Laboratory Analysis

- Previously published references concerning the sondes, field and laboratory analyses are provided in Bostater and Rotkiske, 2015 and Weaver, et al., 2015. Images of the sondes are published in Bostater and Yang, 2014. Data derived from the devices are independent of any time dependent calibration or standards. The volumes of the sondes are essential the same. The cross-sectional sonde openings (areas) are fixed and identical and only vary depending upon whether the sonde is a vertical or horizontal type. Pre-deployment requires capping as the sonde enters the water. After they are attached to the bottom, caps are removed. A cap is reinserted before sonde retrieval. This insures no mud enters the sonde during the deployment and recovery process.

- Calculations for estimating the moving fluid mud flux after laboratory analyses are complete is described in Figure 1.4 below. The instruments and methodology is described in Bostater and Yang, 2014; Bostater and Rotkiske, 2015 and Weaver et al., 2015.



Fluid mud & muck flux is calculated by the following:

$$\text{Flux density} = \frac{\text{Grams of particulate matter collected}}{\text{sonde crossectional area } (L^2)} \times \frac{1}{\text{deployment period T (minutes)}}$$

Units of measurement (examples):

$\text{grams meter}^{-2}\ \text{min}^{-1}$

$\text{grams meter}^{-2}\ \text{day}^{-1}$

$\text{grams meter}^{-2}\ \text{hr}^{-1}$

$\text{grams cm}^{-2}\ \text{sec}^{-1}$

$\text{lb. m}^{-2}\ \text{day}^{-1}$

The sondes directly measure the movement of fluid mud & muck integrated over a time period and integrated over a spatial area. The measurement is a flux conserving direct method for collecting total suspended matter that moves into a fixed control volume.

Figure 1.4 Method for calculating the moving fluid mud flux density for the horizontal and vertical sondes. The cross-sectional area for the vertical sondes is 20.261 cm^2 and the cross-sectional area for the horizontal sondes is 81.073 cm^2 (based upon ANSI approved NEIKO Model 01412A Digital Caliper, 0.02 mm Accuracy, 0.01 Digital Resolution).

At each station horizontal probes (up to 4 directions) and four vertical probes (2 measuring settling and 2 measuring upwelling or suspension are deployed at stations for ≈12-40 hours. In order to assess the muck movement, results are reported in terms of a mass flux (e.g. mg m^{-2} yr^{-1}) dry weight (following drying at 105^{o}C. The laboratory analysis of probe deployments also result in an estimate of % loss of ignition (LOI) based upon drying the total particulate matter captured in the sondes at 105^{o}C (Equatherm Environmental Oven) followed by placement of the material in a furnace (Thermodyne SYBRON Type 4800 furnace) at 550^o C) as described in Standard Methods For Examination of Water & Wastewater, 1980. Water grab samples are analyzed in the lab for conductivity, temperature and salinity using a calibrated YSI Model 33 (daily calibrated using LaMotte salinity standards). Total water suspended solids are filtered using Millipore nucleopore MF filters with nominal 0.45 micron pore size membrane filters followed by drying in a desiccator using the methods recommended in Standard Methods, 1980; EPA, 1983 and Grasshoff et al., 1976. These results are not needed to calculate fluxes and are collected as background data useful interpretation and modeling.

Water and total solids (fluid mud) are transferred from sondes by pouring from the horizontal sondes into 1 gallon plastic containers with marked lids with station ID, and material is transferred (within 1-2 hours from collection) to the lab for settling and processing. Water is removed in 24 hours and material settled again in the laboratory for 12 hours. Settled sample residue is rinsed and settled again for 12 hrs. Rinsing with deionized water removes dissolved salts that would influence weight of the particulate matter captured. Sample preservation is not practical according to EPA 1983, method 160.3 (Total Residue, STORET NO. 00500) and Greenberg, et al., 1980 (Standard Methods for Analysis of Water & Wastewater, 14th ed.). Settled fluid mud that has been placed into a pre-weighed porcelain evaporating dish is decanted using a vacuum tube and/or a syringe or similar device and volume and weight recorded for wet weight measurement and volume.

All distilled and deionized water used in the decanting process derived from a Barnstead F-Stream III glass still following by carbon activated filtering.

Filter pads are dried in a desiccator using Drierite desiccant, 8 mesh size (CAS 7778-18-9 and CAS7646-79-9) for 48 hours.

The sonde residue wet volume and wet weights are measured using an open balance, Olhaus Pioneer and Sartorius M prove model with 0.001 g digital scale). Scales are calibrated between measurements and at the beginning of daily use. Scale calibrations make use of TROEMNER calibration standards that follow ISO/IEC standard 17025 and ASTM class 4 standards for balance calibration standards (Certification No. 872685A).

Sonde wet density (mg ml^{-1}) is also calculated and recorded and is an ancillary measurement. Porcelain evaporating dishes are heated at 103-105^{o} C until water is removed (one hour or more). Dried residue is weighed and dry weight total residue (mg) recorded for each sample. Dry weight flux (g m^{-2} $time^{-1}$) is calculated based upon sonde deployment time and cross-sectional area of the sonde. Dried residue within in an evaporating dish is placed in a muffle furnace at 550^{o} C +/- 50^{o} C for one hour. Evaporating dish is then immediately covered, cooled to just above room temperature and weighed and recorded as oven weight for calculation of % loss on ignition (% LOI) using the same balances in order to provide an estimate of organic matter of the fluid mud flux collected in a sonde. Linear relations between % LOI and nutrients in the particulate matter (TPN, TPN, and TPC) are then calculated as proposed by Di Toro, 2001 using the relations obtained by Trefry (personal communication, 2015). Sonde nutrient fluxes are then calculated using % LOI and the dry weight for each sonde sample. Additional information concerning the relevant procedures are prescribed in Standard Methods for the Examination of Water & Wastewater (Greenberg, et al., 1980), Method 208A, ASTM D1888-1978, ASTM D1069-66, ASTM D509-13 (standard test methods for particulate, nonfilterable solids or residue in water). Triplicate horizontal and duplicate vertical sonde deployments have provided estimates of precision of % LOI and sonde dry weight fluxes and analyzed per guidance from EPA, 1984.

The passive sonde *in-situ* fluid mud flux measurements are a direct measurement technique. A review of direct and indirect fluid mud movement and flux methods is reported in Bostater and Rotkiske, 2015. No other direct method has been reported in any published literature for analysis of field based moving fluid mud, muck or particulate matter flux collected within a moving lutocline. No correction factors are thus used to correct for laboratory or field measurement bias.

E. Quality Control and Measures (per EPA, 1984)

Accuracy and precision of methods were examined during the study of the push pole measurements of station muck measurements using the push pole or sludge judge technique and the sondes fluid mass flux density. The figure below indicates muck depth changes at stations. During October, three closely space stations east of the railroad bridge in Turkey Creek, yielded measurements (n=6) the mean was 0.765 m, a range of 1.33 m, a standard deviation ± 0.481 m, and a coefficient of variation (CV) of 0.628. The precision (the closeness of data values to each other) estimated as relative standard deviation (standard deviation/mean x 100%) for the October transect (stations TCB1-3) muck depth data is thus 63%. Previous work (Weaver, et al., 2015) shows similar results for muck depth precision using a push pole or sludge judge (1.5 inch diameter clear PVC pipe) and similar replicate sampling technique.

EPA (1984) suggests the use of the sample coefficient of variation (CV – an index of precision and reliability of a measurement system (see Liu, 2012) as a method to address precision of physical measurements. EPA suggested (1984) data quality variability documentation is the purpose of a quality assessment program when considering physical measurement methods and the capability of a measurement system. Boxplots are used to help identify potential outliers (Frigge, Hoaglin and Iglewicz, 1989; Goic et al., 2013; Iglewicz and Hoaglin, 1993).

Figure 1.5 shown below and the results above make use of *collocated samples* (multiple measurements at a point in space and time) and replicates (duplicates and triplicates). Measurements are made immediately before and after sonde deployments for precision evaluation using the sludge judge (push pole method) method as described above.

Precision and reliability estimates based upon triplicate deployments at stations TCB1, TCB2 and TCB3 are shown in the Tables .3 through Table 1.5 below. Organic matter content in terms of % loss on ignition results precision results were 0.05 to 0.09 (coefficient f variation) at 2 stations for horizontal sonde flux triplicate results at stations TCB1 and TCB2 as shown in Table 1.3. The % loss on ignition (ash weight or organic matter) suggests good reproducibility between stations and a pooled coefficient of variability of 0.136 or 13.6 %. The % LOI and sonde flux measurements used to calculate the flux of carbon, nitrogen and phosphorus in the moving fluid mud collected within the sondes are described in the first year report for Task 6.

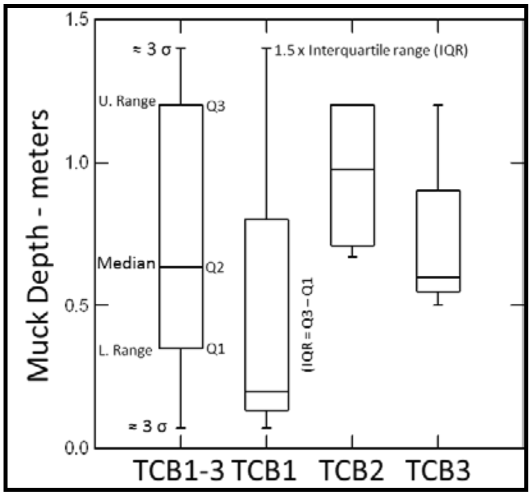
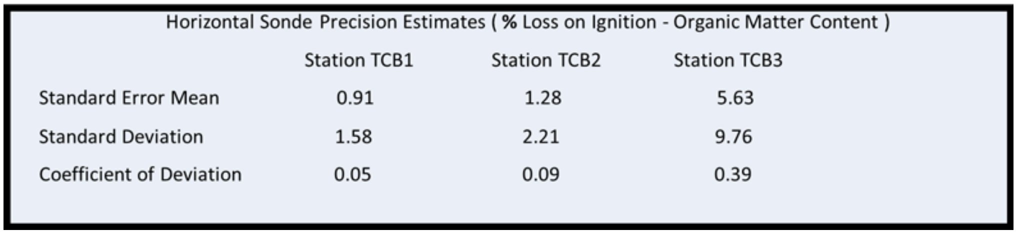


Figure 1.5 Muck depth (m) variability at stations TCB1 thru TCB3 during April and October Deployments. Total observations n=12 (n=4 at each station). The October pooled mean precision using the coefficient of variation (CV x 100) was 89% using the sludge judge or push pole technique. This measure of reliability is considered typical of this method for measuring muck depth.

Table 1.4 shows results from triplicate deployments at two stations with a pooled (average) variation of coefficient of 0.195 (19.5 %) for total particulate nitrogen. Similar quality control analyses were applied to the total dry weight horizontal and vertical sonde fluxes results from the two stations where triplicate deployments were made and is shown in Table 1.5 and Table 1.6 below.

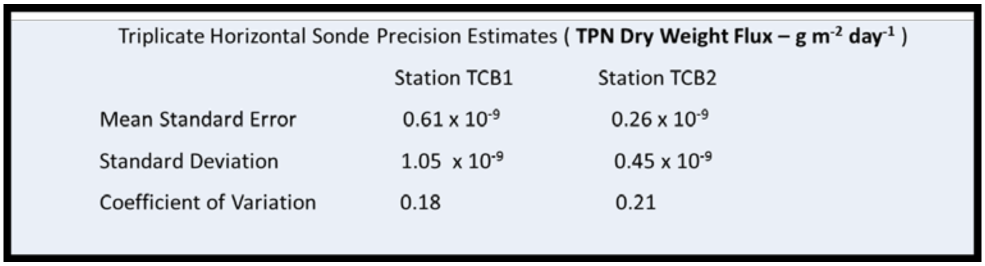
Table 1.3 Triplicate deployment results at three stations for % loss of ignition (% organic matter) within sonde moving fluid mud.



Horizontal Sonde Precision Estimates (**%** Loss on Ignition - Organic Matter Content)

	Station TCB1	Station TCB2	Station TCB3
Standard Error Mean	0.91	1.28	5.63
Standard Deviation	1.58	2.21	9.76
Coefficient of Deviation	0.05	0.09	0.39

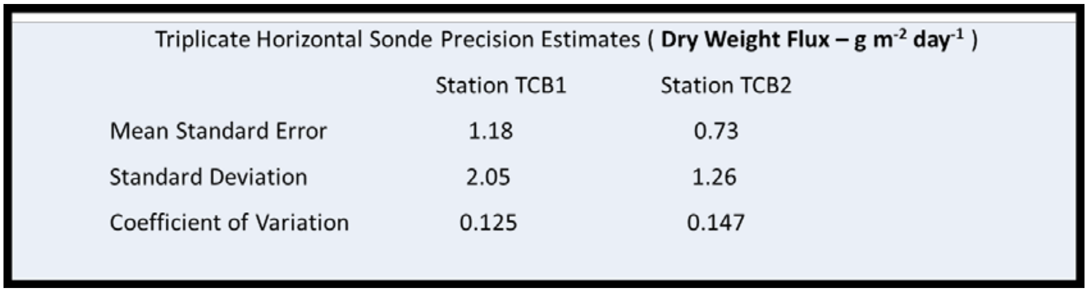
Table 1.4 Triplicate deployment results from two stations for moving horizontal sonde fluid mud flux measurements in g m $^{-2}$ day^{-1}of total organic particulate nitrogen.



Triplicate Horizontal Sonde Precision Estimates (**TPN Dry Weight Flux – g m^{-2} day^{-1}**)

	Station TCB1	Station TCB2
Mean Standard Error	0.61 x 10^{-9}	0.26 x 10^{-9}
Standard Deviation	1.05 x 10^{-9}	0.45 x 10^{-9}
Coefficient of Variation	0.18	0.21

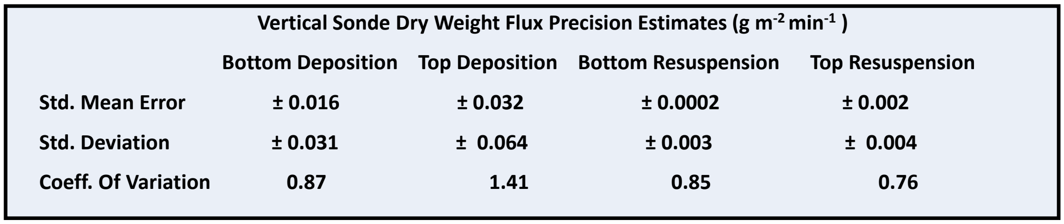
Table 1.5 Triplicate deployment results from two stations for horizontal sonde moving fluid mud flux dry weight measurements in g m $^{-2}$ day^{-1}.



Triplicate Horizontal Sonde Precision Estimates (**Dry Weight Flux – g m^{-2} day^{-1}**)

	Station TCB1	Station TCB2
Mean Standard Error	1.18	0.73
Standard Deviation	2.05	1.26
Coefficient of Variation	0.125	0.147

Table 1.6 Pooled station duplicate deployment results (TCB1 and TCB2) for vertical sonde particulate flux precision estimates.



Vertical Sonde Dry Weight Flux Precision Estimates (g m^{-2} min^{-1})

	Bottom Deposition	**Top Deposition**	**Bottom Resuspension**	**Top Resuspension**
Std. Mean Error	**± 0.016**	**± 0.032**	**± 0.0002**	**± 0.002**
Std. Deviation	**± 0.031**	**± 0.064**	**± 0.003**	**± 0.004**
Coeff. Of Variation	**0.87**	**1.41**	**0.85**	**0.76**

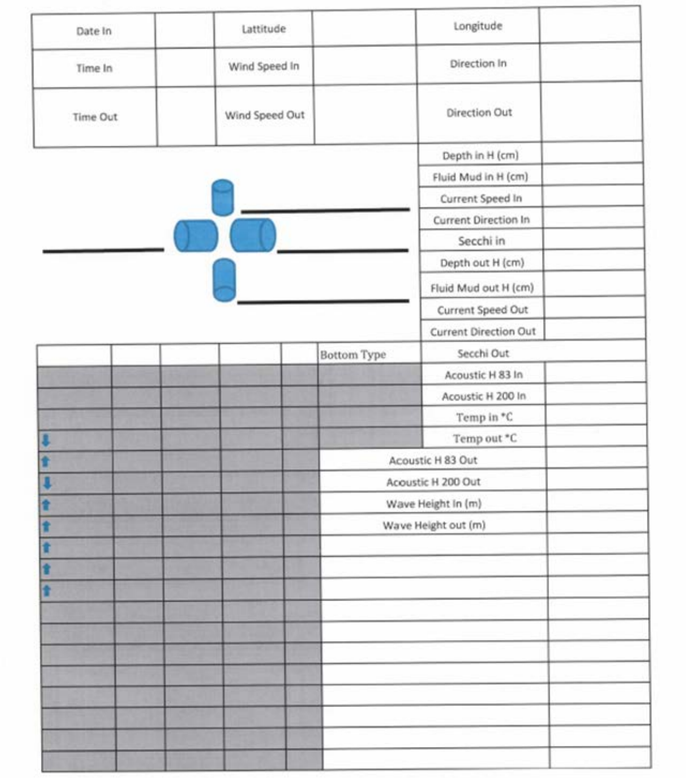
Table 1.6 shows quality control results in terms of precision estimates for vertical sonde measurements of depositional and resuspended total particulate matter collected at stations TCB1 and TCB2. Total samples (n=4) collected for each of the top and bottom sondes indicate lower precision. These results support prior research suggesting vertical probes, traps and sonde methods result in less reliable estimates of settling and resuspension of particulate matter (Di Toro, 2001).

Quality control estimates obtained from duplicate and triplicate sonde deployments as described above are the only known information available for any indirect or direct method related to measurements of moving fluid mud or muck flux density. Evaluation of the above suggests similar procedures need to be conducted at other stations within the sampling design being used in order to help insure quality indicators are available for Task 4 sonde data.

Subtask 6 endpoint analyses - data analysis products and interpretation will be based on the documentation of muck movement reduction (MMR) as presented in Figure 1.2 and as reported in Bostater and Rotkiske, 2015, 2016; Weaver et al., 2015, and Maglio et al., 2016.

F. Documentation and Records

Field sampling documentation utilizes field data sheets used to document sampling dates and ancillary data collected at each station. The form used is shown in Figure 4.5.6 and was specifically designed and used in a prior dredging research study where the sondes were deployed and is being used in this research. Station positions were determined using WAAS grade differential GPS receivers. Sheets are placed within a special aluminum page holding notebook in the field to help insure log sheets remain dry in the event of rain and during use. All field records are stored in the Environmental Optics & Remote Sensing Lab, Building 407, on the FIT Campus. All sample records are locked and only available to the PI and working lab and field assistants. Detailed results from sample analyses brought into the lab are recorded in bound notebooks. Selected information is recorded with different weights and volumes necessary for parameter calculations and tracked through the sample processing and data entry process until stored with original field data sheets. Any field or lab deviation or anomaly is recorded on the field sheets and in the bound notebooks and initialized by the PI. Sample bottles and containers are marked in the field as to station ID using waterproof pens/markers on the caps of the containers.



Date In		Lattitude		Longitude	
Time In		Wind Speed In		Direction In	
Time Out		Wind Speed Out		Direction Out	

Depth in H (cm)	
Fluid Mud in H (cm)	
Current Speed In	
Current Direction In	
Secchi in	
Depth out H (cm)	
Fluid Mud out H (cm)	
Current Speed Out	
Current Direction Out	
Secchi Out	
Acoustic H 83 In	
Acoustic H 200 In	
Temp in °C	
Temp out °C	
Acoustic H 83 Out	
Acoustic H 200 Out	
Wave Height In (m)	
Wave Height out (m)	

Bottom Type

Figure 1.6 Example of a field sampling log sheet used to record sonde deployments at each station and any field related information.

Field data are entered into a Microsoft Excel spreadsheet and calculations performed within the project sheets. The spreadsheet is copied and stored on multiple computers and digital storage devices to insure no loss of information may occur due to computer software or hardware problems. Data backups occur monthly. Data analysis is performed using SYSTAT statistical software, ArcGIS geographical information system software, and ENVI image processing software. Monthly reports and quarterly reports utilize the above software. MS Word and PowerPoint are used to produce reports. Data entry is verified from data sheets and lab notebooks.

G. Training Required For The Project

To date the Principal Investigator has personally trained assistants in the proper deployment of the sondes and their recovery, with special attention given to the insertion and removal of caps in the horizontal sondes to insure no fluid mud or muck enters the sondes during the deployment and retrieval process in the field.