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Bathymetric and Sediment Assessment in the Bishopville Prong of St. Martin River.

by

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EXECUTIVE SUMMARY

The Maryland Geological Survey (MGS) conducted hydrographic and sediment surveys of the Bishopville Prong. The purpose of this study, funded through Maryland Coastal Bays Program Implementation Grant, was to document existing environmental conditions of the Bishopville Prong. This information can be used to assessment of the environmental impact, particularly with sediment quality issues, from the proposed Bishopville Dam Removal project and provide a baseline for future monitoring efforts.

MGS conducted the hydrographic surveys in June, 2011, using differential global positioning service (DGPS) techniques and digital echosounding equipment. MGS also collected sub-bottom seismic profiles along with the sounding data. `Over thirty thousand discrete soundings were collected and used to generate a current bathymetric model of the Prong.

Concurrent with hydrographic surveys, MGS collected surficial sediment samples in Bishopville Prong and Pond. The sediments were analyzed for texture (sand, silt, clay contents), and thirty-seven element constituents, including total carbon (C), nitrogen (N), phosphorus (P), sulfur (S), arsenic (As), silver (Ag), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), manganese (Mn), lead (Pb), nickel (Ni), and zinc (Zn).

Results of chemical analyses of the Pond sediments are similar to those reported by in an earlier feasibility study of the Pond (KCI, 2002). Any discrepancies in results from the two studies are attributed to differences in sampling techniques and analytical methods, and variation in sample textures, which range from sand collected in the upper end of the pond to fine grained silty clay collected near the dam. Results from the MGS study confirm that the Pond contain high nutrient levels. C, N, and P contents were some of the highest observed in the coastal bays watershed. Pond sediments also contain S at levels higher than what would be expected in a fresh water environment. The amount of S is fairly consistent in sediments (~0.5 %) regardless of clay content, suggesting that S is in a stable mineral form. However, sediment samples collected in this study represent the top 5 cm of the sediment profile. Analyses of a sediment core collected in 2013 in the middle of the pond indicate that in some areas of the pond sediment deeper than 10 cm contain higher S levels. The source of S is thought to be from historic spills from a poultry processing plant within the Pond's watershed.

The Pond sediments also contain higher concentrations of several metals: Cd, Co, Ni, Pb and Zn, compared to sediment in Bishopville Prong and other Coastal Bay tributaries. All Bishopville Pond samples contained concentrations of As and Cd exceeding the Threshold Effects Level (TEL) value and over half the samples had concentrations of Cr, Cu, Ni, Pb, and Zn exceeding the TEL. Several samples (closer to the dam) contain Ni and Zn concentrations exceeding the Probable Effects Level (PEL).

Bishopville Prong can be divided into three segments, defined, in part, by geomorphology and hydrodynamic regime. These segments are useful in explaining the bathymetry and sediment data from this study. The upper 1500 m segment, immediately downstream of the

Bishopville dam, represents the narrowest portion of the Prong and encompasses the deepest portions of the Prong, with depths greater than 4 meters. The deep areas are probably from scour during high stream flow events. Sub-bottom data indicate that very little sediment is accumulating in this segment. Sediments collected in this segment ranged from coarser sand to sand-silt-clay to silty clays. However, the sediments collected in the segment contained the highest C, N, P and S contents measured for this project. N:C:P ratios suggest that the organic matter is from algae, mostly likely transported from the Pond.

The second segment of the prong, between N4253500 and N4251750, is generally wider and characterized by shallower depths (< 3 m). Sub-bottom data show accumulation of sediments along outside edge of stream meanders. Sediments in this segment range from sand in the up-stream portion to silty clays downstream. C, N, P and S contents in sediments in this segment are lower compared to upstream areas. When normalize to clay content, C, N, P and S gradually decrease in the downstream direction within this segment.

The mouth of the Prong represents the third segment. Here, the Prong broadens to 300 to 500 m wide before the confluence with the St. Martin River. Water depths increase slightly along this segment of the Prong. However, there is no distinct central channel. Sub-bottom data show what is interpreted to be thick layer (1 meter thick) of recently deposited sediments, the texture of which is predominately silty clay. C:N:P ratios approach those ratios reported in main stem of the coastal bays (Wells et al., 1994).

Data from this study provide a general characterization of the Bishopville Prong study area. This assessment may be use as a baseline for future assessments after the removal of Bishopville Dam, particularly if the removal results in major alteration of stream hydraulics.

INTRODUCTION

Background

The removal of Bishopville Dam is part of the Bishopville Integrated Watershed Restoration Project. The design of this restoration project includes several elements: the creation of a unique wetland and upland plant community to provide water quality attenuation for agricultural drainage; remediation of the Bishopville Pond which is a freshwater hyper-eutrophic body of water; and restoration of fish passage by removing the Bishopville Dam.

The Bishopville Pond and Dam are at the headwaters of Bishopville Prong which drains into the St. Martin River, considered one of the most nutrient enriched rivers in the Maryland Coastal Bays. However, the pond contains highly nutrient rich sediments, a legacy of historical spills form the Bishopville Processing Plant located within the watershed. Although the restoration project incorporates design to limit the downstream movement of these legacy sediments, there are no provisions for assessing or monitoring of physical impacts downstream from the restoration project during and post construction. The information presented in this study is intended to provide a pre-construction characterization of the stream channel and bottom sediments within the Bishopville Prong. This characterization will serve as a baseline for future monitoring.

Physical and Geological Setting

Bishopville Prong is one of two upstream tributaries to the St. Martin River; Shingle Landing Prong is the second tributary (Figure 1). St. Martin River is the major tributary, accounting for 62 % of the total drainage area for Isle of Wight and Assawoman Bays (Bartberger and Biggs, 1970; UM and CESI, 1993).

Bishopville Prong watershed drains approximately 10,817 acres (43.8 km2) (MDE, 2002). The watershed consists of two major subsystems: Carey Branch and Bunting Branch, the latter having headwaters in the Great Delmarva Cypress Swamp in Delaware. Both Carey Branch and Bunting Branch feed into Bishopville Pond. This 2-hectare shallow pond is impounded by Bishopville Dam, a structure that was originally built in the 1870's to provide power for mill operations. The dam was restructured in 1959 at which time the pond was created (Weisberg et al. 1985) . The Bishopville Dam is a physical barrier, separating the Pond from the tidally influenced Bishopville Prong.

The study area and vicinity overlie unconsolidated Coastal Plain sediments, the upper 60 meters of which are Cenozoic in age. The Bishopville Prong dissects several formations in the upper most Quaternary sequence. The youngest formation is the Ironshire Formation (Qi), which is exposed along a short reach of south shoreline at the mouth of Bishopville Prong (Figure 2). Consisting of pale yellow to white sand and gravelly sand and having a maximum thickness of 8 meters (25 ft), the Ironshire Formation is interpreted to be a barrier-back barrier sequence (Owens and Denny, 1978). The Ironshire Formation unconformably overlies the Omar Formation (Q_o) and Beaverdam Sand (T_b) within the study area.

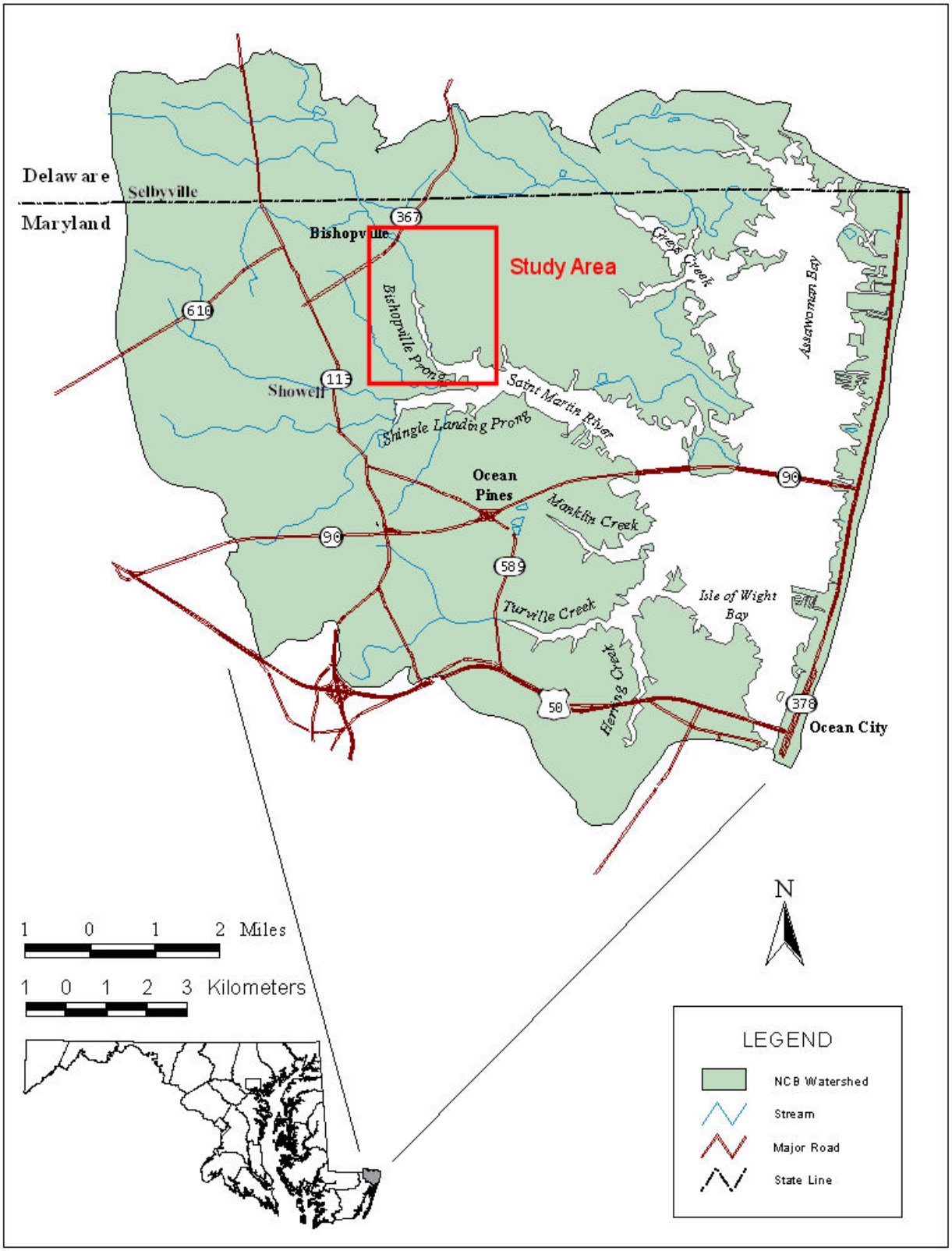
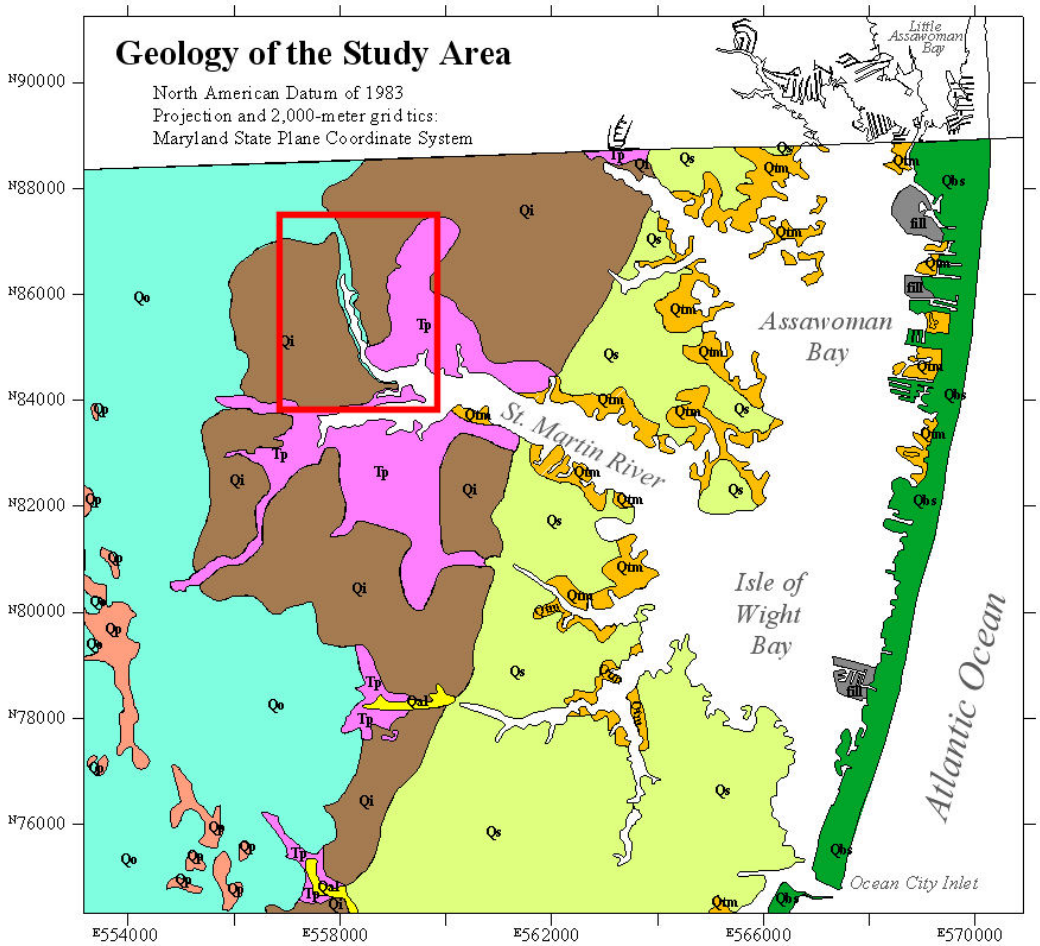
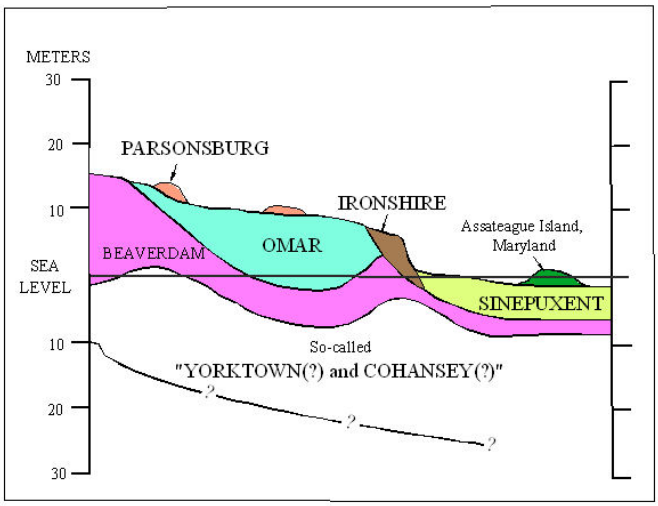


Figure 1. Location map of the Maryland northern most coastal bays, with the study area shown. Map modified from MDE, 2002.





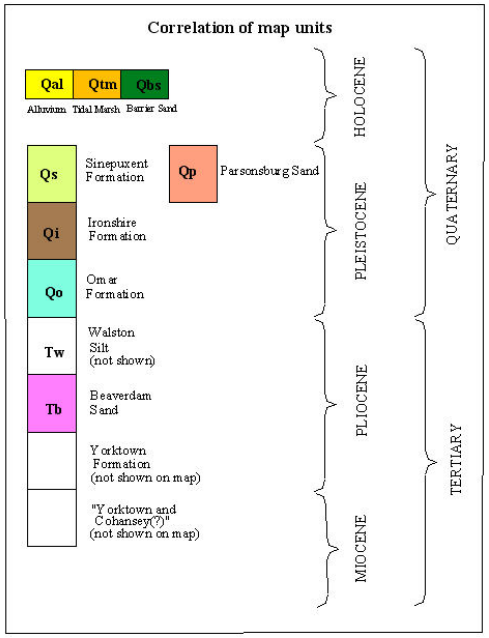


Figure 2. Geology of the study area (red box). The cross-section illustrates the general relationship of the geologic formations (modified from Ownes and Denny, 1978, 1979).

The Omar Formation, thought to be early Pleistocene in age, is exposed west of the Ironshire Formation and lies directly above the Beaverdam Sand. Within the study area, the Omar Formation, representing lagoonal/estuarine depositional sequence, consists of interstratified light colored sand and dark colored sand-silt-clay or silty clay. The formation is exposed along the banks of the Bishopville Prong.

Locally, the Beaverdam Sand, which is Pliocene (Tertiary) in age, is exposed along the mouth of Bishopville Prong and the upstream area of the St. Martin River. The exposed portion of the Beaverdam is characterized by extensively cross-stratified sand, interbedded with clay-silt laminae. Unweathered Beaverdam Sand sediments may be pale blue-green or white; weathered sediments are orange or reddish brown. Due to the abundance of silt, the Beaverdam Sand is more cohesive than the Ironshire Formation.

Previous Bathymetric and Sediment Surveys

In 2000, MGS conducted bathymetric surveys in the northern coastal bays, including portions of the mouth of Bishopville Prong adjacent to Piney Island (Figure 3) (Wells and Ortt, 2001). It is not known if any systematic bathymetric surveys have been previously collected in the upper portion of Bishopville Prong.

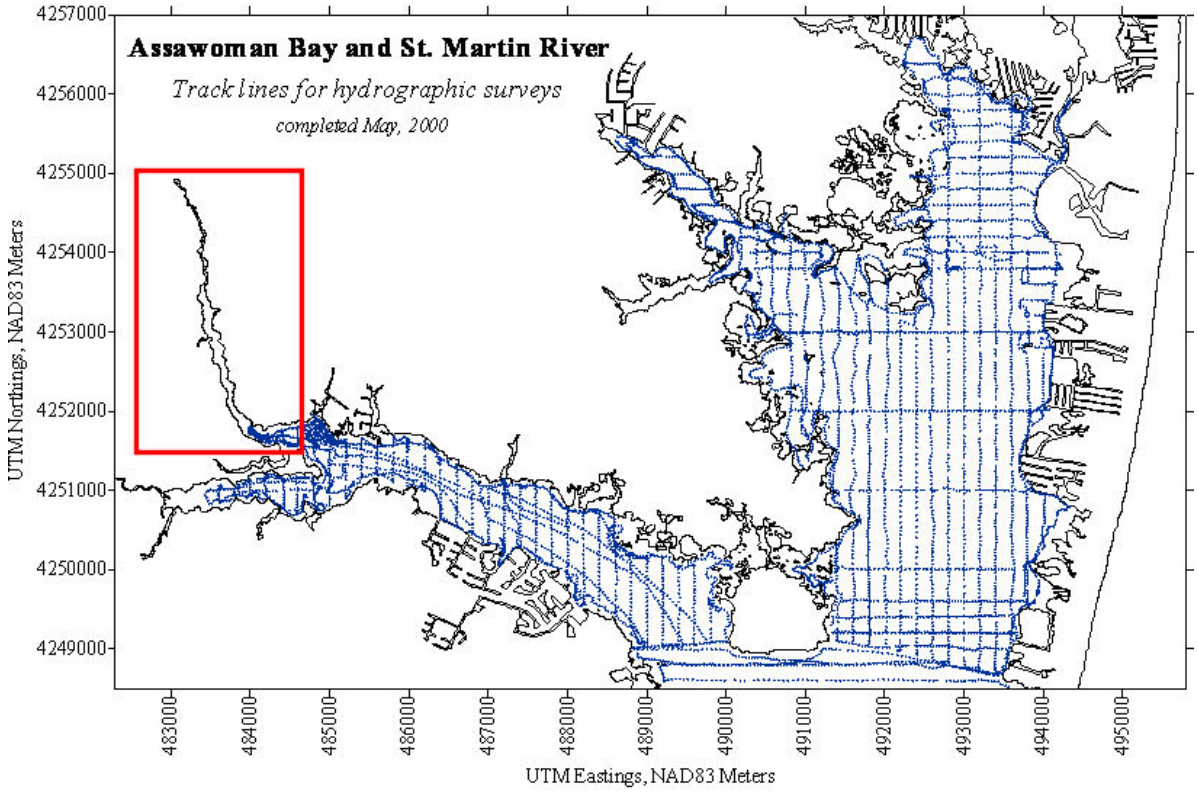


Figure 3. Track lines for hydrographic (bathymetric) surveys collected in 2000 by MGS (Wells and Ortt, 2001). Bishopville Prong study area is indicated by the red box.

Most of the information on sediments in Maryland's coastal bays has come from studies conducted within the last 20 years. Between 1991 and 1995, the Maryland Geological Survey conducted an intensive sediment sampling in the Maryland coastal bays as part of the Maryland Coastal Bays Sediment Mapping Project (MCBSMP) (Wells and Conkwright, 1999). Over 900 surficial sediment samples were collected and analyzed for total carbon, nitrogen and phosphorus and seven metals (cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc). Several of the MCBSMP samples were collected in the mouth of Bishopville Prong.

In 1993, the Coastal Bays Joint Assessment (CBJA), led by the U.S. Environmental Protection Agency (EPA) as part of the Environmental Monitoring and Assessment Program (EMAP), collected water and sediment samples in an effort to characterize the Maryland and Delaware coastal bays (Chaillou and others, 1996). Because of budget constraints, CBJA analyzed sediment from 36 of the 200 sites sampled, and of those 36, only 16 were in Maryland's coastal bays. The sediments were analyzed for 15 elements, and 66 organic toxins.

In 1997, EPA collected water and sediment samples in four estuarine systems in the mid-Atlantic region as part of the Mid-Atlantic Integrated Assessment (MAIA) (EPA, 2002). Data for Maryland coastal bays included 16 samples taken in lower bays (Sinepuxent, Newport, and Chincoteague Bays) and did not include the northern bays (Assawoman and Isle of Wight Bays).

As part of the National Coastal Assessment (NCA), EPA collected sediments at 54 locations matching the water quality stations monitored for the Maryland Coastal Bays Program. The sediments were analyzed for water, mud (silt-clay), and total organic carbon content, metals, PAHs, PCBs, and pesticides. The NCA sampling was done several times between 2000 and 2006.

In the fall of 1998 and spring of 2001, sediment samples were collected in the St. Martin River and Prong for a Pfiesteria Study (DNR, unpublished data). The samples were analyzed for grain size, total N, C and P. Several sampling stations were in Bishopville Prong.

KCI Technologies, Inc. conducted a feasibility study of the Bishopville dam removal in 2001 (KCI, 2002). As part of the study, sediment samples were collected in Bishopville Pond and analyzed for the following: pesticides and polychlorinated biphenyls (PCBs), total Resource Conservation and Recovery Act (RCRA) metals, toxicity characteristic leaching procedure (TCLP) metals (if total metal concentrations were high), nitrate/nitrite, total Kjeldahl nitrogen, and total phosphorus.

Between December 2, 2010 and March 9, 2011, the National Park Service (NPS) collected sediment samples in the tidal tributaries to Maryland and Virginia coastal bays, including four samples from Bishopville Prong (Figure 4). The NPS collected the samples as part of a study looking at phosphorus in sediments (Wells et al, 2012). Using the analytical methods described in this report, MGS analyzed the NPS samples for the same textural and chemical constituent as the Bishopville Prong sediments. The results of the four sediment samples are included in the sediment data presented in this report. NPS data are referenced as the "coastal bays tributaries" throughout the discussion in this report.

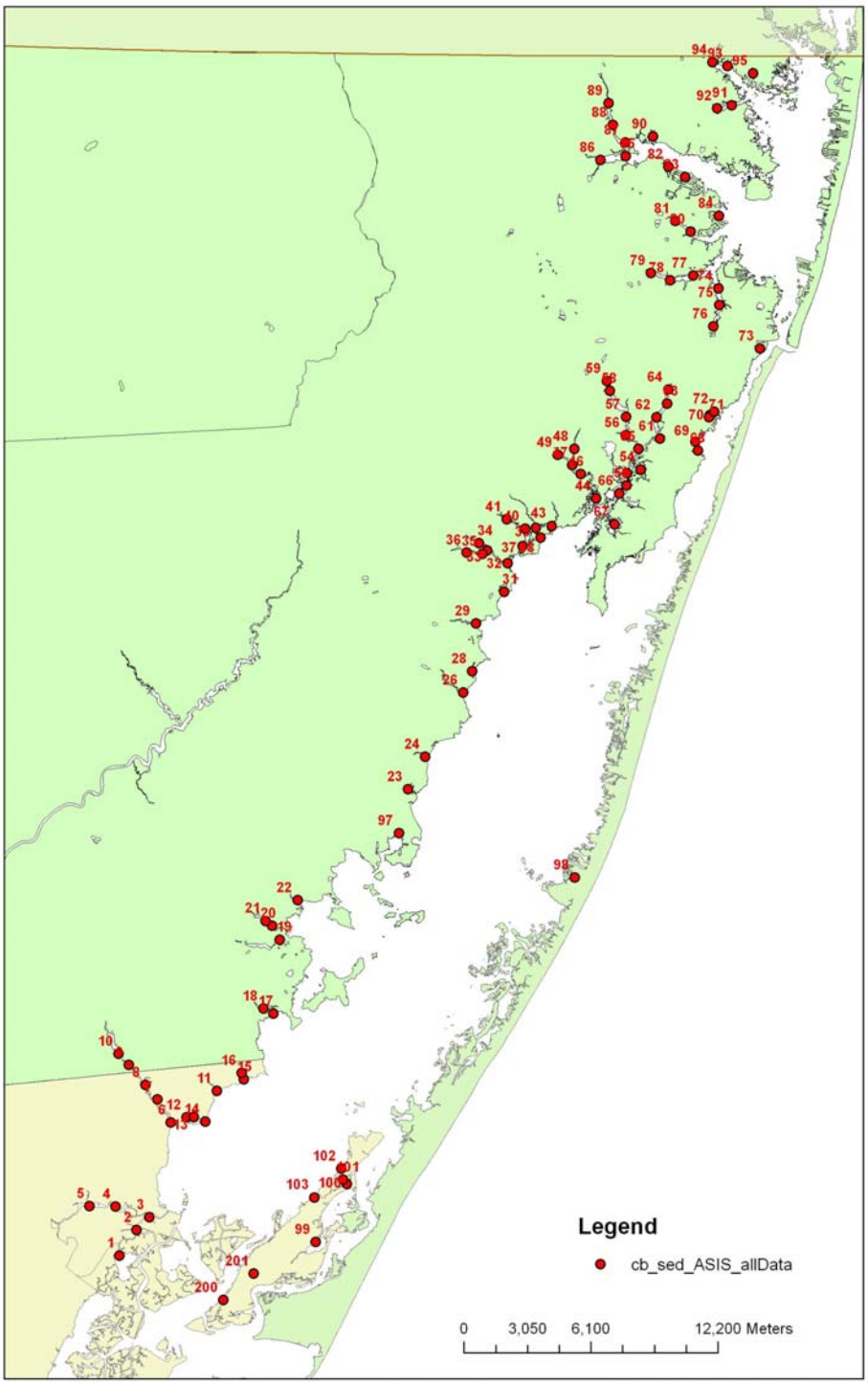


Figure 4. Locations of the NPS sediment samples collected in various tributaries feeding the coastal bays (Wells et al, 2012). Samples 87, 88, 89 and 90 were collected in Bishopville Prong area.

Study Objectives

The purpose of this study was to document existing (pre-construction) environmental conditions of the Bishopville Prong. This information can be used to assessment of the environmental impact, particularly with sediment quality issues, from the proposed Bishopville Dam Removal project and provide a baseline for future monitoring efforts. The objectives for this study are:

1. To document stream geometry of Bishopville Prong prior to construction phase of the Dam removal project.
2. To document the bottom sediment characteristics prior to construction.

This study included sediment analyses of Pond samples. Results were to supplement sediment data reported by KCI, Inc. (2002).

Study Approach

The study consisted of two main tasks, each to address the main objectives. The first task was accomplished through the measuring and modeling of the current bathymetry of the Prong. Hydrographic surveys were collected using digital echosounding equipment and differential global positioning system (DGPS) equipment. The data was collected as discrete x, y, z points and processed with Surfer®, a three-dimensional surface modeling software package, and various geographical information systems (GIS) to produce a modeled surface of the Bishopville Prong's bottom.

The second task was to characterize the bottom sediments in Bishopville Prong. This was accomplished through the collection surficial sediment grabs along the length of Bishopville Prong and Bishopville Pond, and analyzing the sediments for textural and chemical properties.

METHODS

Task 1: Bathymetry

Hydrographic Surveys

Hydrographic surveys of the study area were collected using a 17 ft Boston Whaler equipped with a 70 horsepower outboard engine. Track lines running perpendicular to the river channels were established for bathymetric surveying. These track lines were spaced 50 meters apart and extended from shoreline to shoreline. When possible, survey lines were navigated on UTM-NAD83 lines running either east-west or north-south. In upstream area where stream width was 50 meters or less, track lines were run in a zig-zag pattern. Tie-in lines were run perpendicular to the survey lines and along the axial channels of the Prong. Additionally, survey track lines were run along the perimeter, as close to the shoreline as possible and also, where necessary,

between the centerline and shoreline to assist in the surface modeling analysis. Survey track lines are shown in Figure 5. The hydrographic surveys were conducted in June 15 and 16, 2011, which corresponded to a spring tide (full moon phase).

Bathymetric data (soundings) were collected using a Thales Navigation (Ashtech) DGPS (model DG-16; L1 code and carrier with SBAS and differential beacon corrections; 5Hz Update rate) and a Knudsen 320B/P dual frequency echosounder with sounding frequencies of 200 KHz and 28 KHz. The 200 KHz frequency is used primarily to determine depth to sediment surface, whereas the lower frequency (28 KHz) is used to detect sub-bottom features such as buried channels (see Sub-Bottom Seismic Reflection Surveying method). The echosounder transducer is a KEL771 dual frequency transducer with a 200 KHz beam angle of 4 degrees and a 28 KHz beam angle of 29 degrees. The echosounder generated acoustic pulses for bottom recognition at a rate of 4 Hz. The pulse width was set to automatically change between 0.2 milliseconds (mS) and 0.8 mS depending on the depth of the water. The transmitted acoustic wave reflected off the density gradient separating the water column from the bottom sediment. The returned acoustic wave is received by the transducer, and the time separation between the sent and the returned wave is recorded. This time separation is directly proportional to distance. The intensity of the returned signal versus depth is recorded by the echosounder and displayed visually on a graph. After many repeated pulses the bay bottom becomes discernable as a horizontal black line, which follows the contours of the bottom. The sharpness and clarity of the line is a function of the strength and quality of the echo, and depends on many factors, including bottom characteristics (roughness, sediment type), pulse length, depth of the water, and the amount of ambient noise (other factors that interfere with the return signal such as air bubbles in water column, fish, changes in temperature and/or salinity). The strongest echo is identified by the Knudsen echosounder and displayed/recorded as a depth in meters.

The recordings were then filtered for points that were outside of the tracking gate window (2 meters) and integrated within the echosounder to produce an accurate measurement from the transducer to the water/sediment interface. At an average vessel speed of 4 knots, a depth sounding was collected approximately every 0.5 meters [1.6 feet] along the survey track-lines. This data along with the GPS location and positional latency are output as ASCII comma-delimited text files (kea files) and as binary data (keb files) for use by post-processing software; both sets of data are stored in a laptop computer. Navigation was provided through a Lowrance LCX-15MT interfaced to a Lowrance DGPS beacon receiver. DGPS differential corrections broadcast by the Nationwide Differential Global Positioning System (NDGPS) provided a real-time horizontal accuracy of +/- 1 meter [3.3 feet].

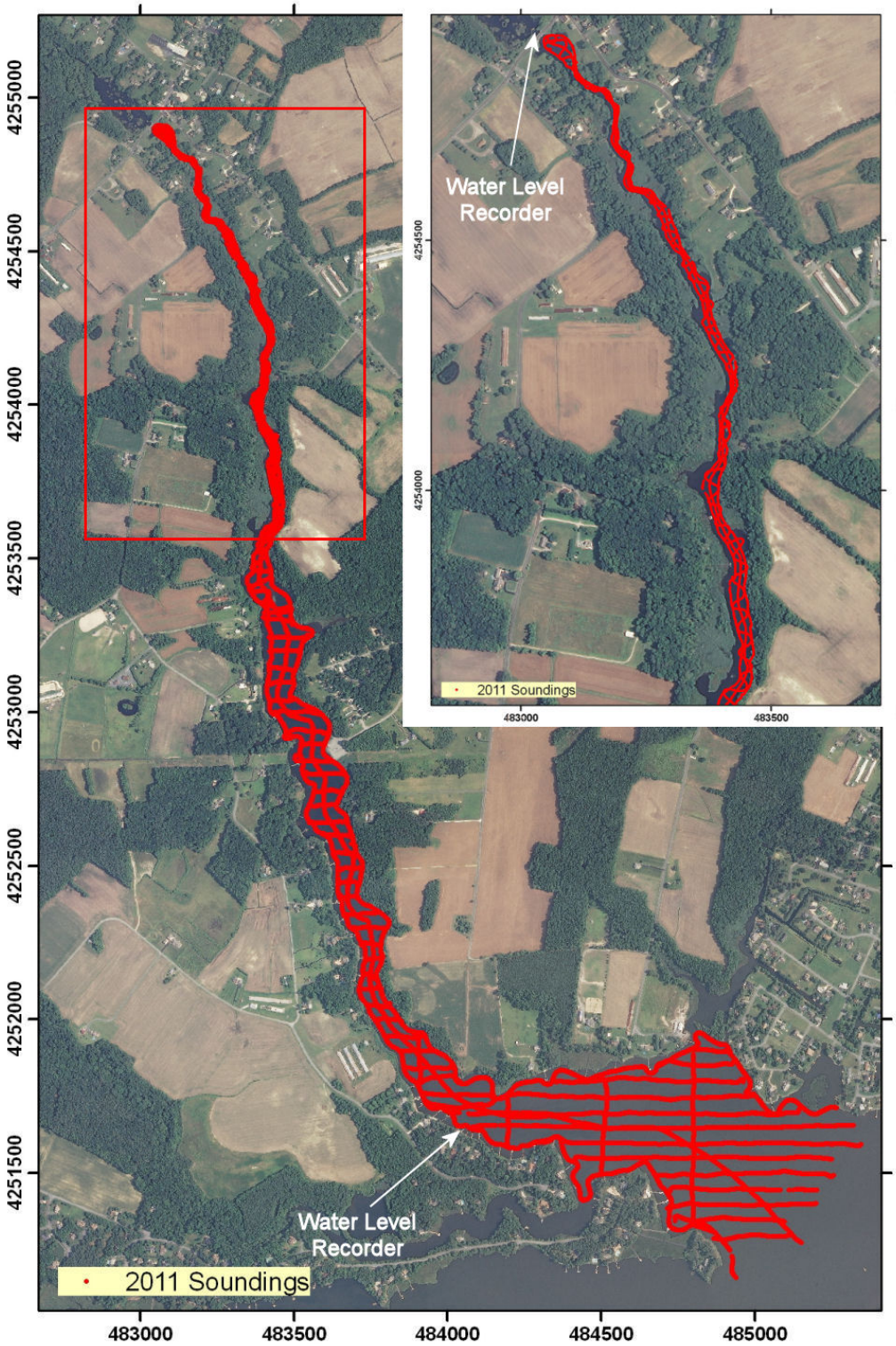


Figure 5. Track lines for bathymetric surveys collected in Bishopville Prong for this study. Also shown are the locations of the water level recorders.

Water Level Measurement and Tide Adjustment

The bathymetric data collected represented measurements based upon the distance between the surface of the water in Bishopville Prong and the top of the water-sediment interface. Due to tidal and wind fluctuations in the water level, the bathymetric data was adjusted to a known reference datum (NAVD88) using recorded water levels. Water level measurements were recorded at two locations: Bishopville Dam at the upstream extent, and at a private dock (Sansom Dock) near the mouth of Bishopville Prong (Figure 5). Location coordinates and elevation, in NAVD88, of each WLR were determined by DGPS. Details regarding the installations of the water level recorders and location surveys are presented in Appendix A.

The manufacturer calibrated the water level recorders prior to shipping. Calibrations were confirmed in the field prior to deployment and again at the end of the study. Both instruments met the field calibration check within 0.05 feet of the observed level on the gauge.

To account for the tide phase offset between the two water level locations, tidal corrections for each sounding were calculated using one of two methods. For depth soundings collected south of the southern WLR, tidal corrections were interpreted using data from that water level recorder. For depth soundings collected between the north and south WLR (*i.e.*, Bishopville Dam and Sansom Dock.), tidal corrections were calculated using a two-step process. 1.) Water levels from each recorder were interpolated for exact times soundings were collected. 2.) From the time-interpolated water levels, a water level for each sounding location was interpolated using a weighted factor based on the distance the sounding location was between two adjacent water level recorders. Distance was calculated using the northing coordinate for the sounding and the WLR.

Data Accuracy

The accuracy of the post-processed bathymetric data is ± 0.15 m (0.5 ft) + 1% of the water depth to NAVD88. The accuracy of the horizontal DGPS data is ±1.0 m (±3.3 ft).

Digitizing 2009 Shorelines

Bishopville Prong shorelines were interpreted from high resolution, natural color digital orthophotography taken during the Spring of 2009. The imagery was taken when the trees had leaves causing portions of the shoreline to be obscured. In the areas where the shoreline was obscured, the shoreline was digitized using 1989 Color Infrared imagery and/or adjusted to accommodate the plotted boat path of the hydrographic surveys collected for this study.

The digitized 2009 shoreline was converted to point data, and assigned an elevation of 0 m, NAV88, defining the shoreline boundary for the surface modeling (see next section).

Bathymetric Interpretation

Using Surfer software package, the bathymetric data of Bishopville Prong were gridded and modeled into a three dimensional surface. The combined data were then processed using Kriging method, to create a three-dimensional surface (bottom topography) model. A one-meter regularly spaced grid was then calculated by analyzing the depths on the surface model.

The Kriging method was used as it traditionally produced the best fit compared to the other surface modeling methods (see Appendix A: Bathymetric Modeling section for discussion) and a more natural elevation surface (*i.e.*, natural sloping stream channel, parallel to shoreline, etc.). . To further smooth the Kriging model surface, the sounding data were processed using a Gaussian moving average filter before gridding.

The one-meter grid was imported into ArcMap as a raster grid.

Sub-Bottom Seismic Reflection Surveys

Sub-Bottom seismic reflection surveys were conducted concurrent with the bathymetry survey using the Knudsen's low frequency of 28 KHz. The 28 KHz is ideal for identifying shallow and thin deposits as this frequency has penetration power while maintaining resolution due to its short wavelength. In other riverine and estuarine studies using this equipment, stratigraphic features (horizons) as deep as 25 meter below the sediment surface as well as sediment layers less than 10 centimeters thick have been visible in the 28 KHz record. The theoretical resolution (1/3 of a wavelength) of the acoustic profiling equipment operating at 28 KHz is 0.017 meters [0.6 inches].

The 28KHz signal can also be used to identify and verify the general type of bottom sediment (i.e. soft muddy bottom as opposed to hard sandy bottom).

Shoreline Videos

Videos of the entire shoreline of Bishopville Prong were collected concurrent with the perimeter hydrographic surveys using a Contour GPS video camera which records GPS-tagged videos. The videos were collected to provide visual conditions of the shoreline at the time of the hydrographic surveys. Details and playback instructions are provided in Appendix D.

Task 2: Sediment Assessment

Field Collection

MGS collected 26 sediment grab samples for this study. Nineteen samples were collected at sites along the mid-channel and at the mouth of the Prong (Figure 6). The remaining seven samples were collected in Bishopville Pond (Figure 6- Inset). The samples were collected to document the character of the of the bottom sediments.

Samples were collected on June, 2011. Locations of the sediment samples were documented using a Thales Navigation Promark 3 GPS receiver. Location coordinates were recorded in UTM, NAD83, meters. A 17-ft Boston Whaler was used to collect the samples in the Prong. Due to restricted access to Bishopville Pond, kayaks were used to collect the pond samples. However, the northern most area of the pond could not be reached because of extremely shallow water depths (< 1 foot, or 30 cm) and abundant subaquatic vegetation (SAV).

Sediment samples were collected with a hand-operated LaMotte stainless-steel dredge which sampled a bottom surface area of 19 cm x 14 cm and a mean sediment depth of 5 cm. Upon collection, the samples were placed in Whirl-Pak™ bags and kept cool until delivery to the MGS laboratory where they were refrigerated at 4˚ C. until analyses.

Laboratory Analyses

Textural Analyses

All sediment samples were analyzed for water content, bulk density, and grain size (sand, silt, clay contents, as well as gravel, when present). Two homogeneous splits of each sample are processed, one for bulk property analyses and the other for grain-size characterization. Analyses were performed as soon as possible after sample collection, and all samples were refrigerated in sealed Whirl-Pak™ plastic bags prior to analysis.

Water content was calculated as the percentage of water weight to the weight of the wet sediment using equation 1.

$$\%Water = \frac{W_w}{W_t} * 100 \qquad \text{Equation 1}$$

where: W_w is the weight of water; and
W_t is the weight of wet sediment.

Water content was determined by weighing 20-30 g of sediment; the sediment was dried at 65°C, and then re-weighing the dried sediment. Dried sediments were saved for chemical analyses (see *Chemical Analyses* section).

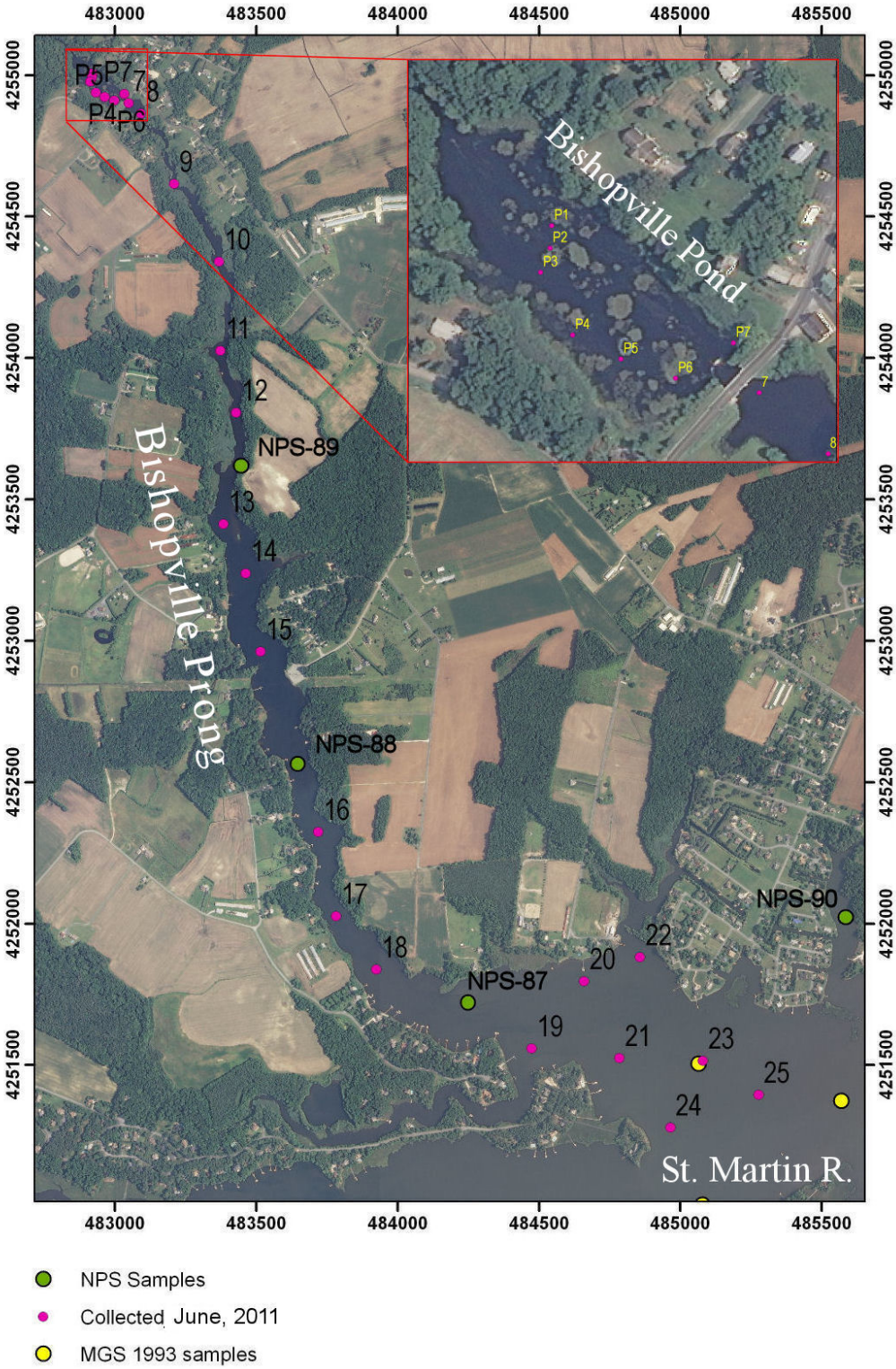


Figure 6. Locations of the sediment samples collected for this study. The samples include four collected by NPS between December, 2010 and March, 2011 (green circles). Two samples collected by MGS in 1993 (Wells and Conkwright, 1999) are shown (yellow circles).

Bulk density (ρ_B) is calculated from water content utilizing equation 2 by assuming an average grain density (ρ_s) of 2.72 g/cm^3 and saturation of voids with water of density ρ_w = 1.0 g/cm³. This method was adopted from the work of Bennett and Lambert (1971):

$$\rho_B = \frac{W_t}{W_d \ / \ 2.72 + W_w} \qquad \text{Equation 2}$$

where W_d is the weight of dry sediment.

Sand, silt and clay contents were determined using the textural analysis detailed in Kerhin et al., (1988). Grain size analysis consists of cleaning the samples in solutions of 10 percent hydrochloric acid and 6 or 15 percent hydrogen peroxide (determined by water content) with subsequent rinsing with deionized water. This process removed soluble salts, carbonates, and organic matter that could interfere with the dis-aggregation of the individual grains. The samples are then treated with a 0.26 percent solution of the dispersant sodium hexametaphosphate ($(NaPO_3)_6$) to ensure that individual grains did not re-aggregate during analysis.

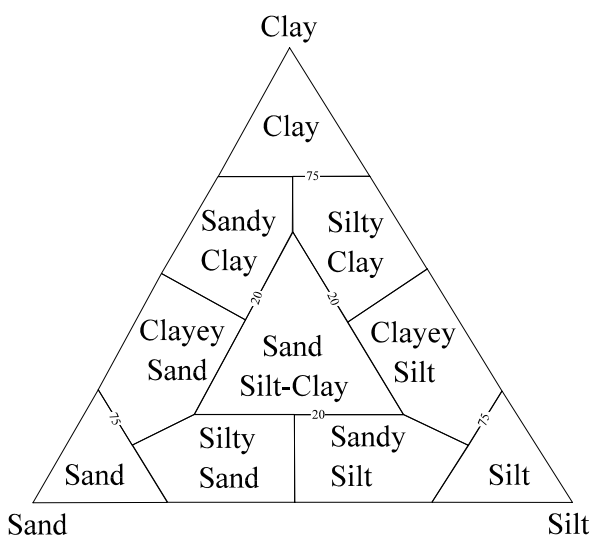


Figure 7. Shepard's (1954) classification of sediment types.

The separation of sand and silt-clay portions of the sample is accomplished by wet-sieving through a 4-phi mesh sieve (0.0625 mm, U.S. Standard Sieve #230). The sand fraction is dried and weighed. The finer silt and clay-sized particles are suspended in a 1000 ml cylinder in a solution of 0.26 percent sodium hexametaphosphate. The suspension is agitated and, at specified times thereafter; 20 ml pipette withdrawals are made (Carver, 1971; Folk, 1974). The rationale behind this process is that larger particles settle faster than smaller ones (Stoke's law). By calculating the settling velocities for different sized particles, times for withdrawal can be determined at which all particles of a specified size will have settled past the point of withdrawal. Sampling times are calculated to permit the determination of the amount of silt (4 phi) and clay sized (8 phi) particles in the suspension. Withdrawn samples are dried at 65°C and weighed. From these data the percentages by dry weight of sand, silt, and clay are calculated for each sample and classified according to Shepard's (1954) nomenclature (Figure 7). Results of textural analyses are presented in Appendix C (Table C-1).

Chemical Analyses

Sediments dried for water content determination were saved for elemental analyses. The dried sediments were pulverized in tungsten-carbide vials using a ball mill, then placed in Whirl-Pak™ bags and stored in a desiccator.

Nitrogen, Carbon and Sulfur Analysis

The sediments were analyzed for total nitrogen, carbon and sulfur (NCS using a Carlo Erba NA1500 analyzer. Untreated dried sediments were analyzed for total nitrogen, carbon and sulfur (NCS) contents. Approximately 10-15 mg of dried sediment was weighed into a tin capsule. The exact weight (to the nearest µg) of the sample was recorded. To ensure complete combustion during the analysis, 15-20 mg of vanadium pentoxide (V_2O_5) was added to the sediment. The tin capsule containing the sediment and vanadium pentoxide mixture was then crimped to seal and stored until analysis.

The sediment sample, contained in a tin capsule, was dropped into a combustion chamber where the sample was oxidized in pure oxygen. The resulting combustion gases (N, C, H, and S), along with pure helium used as a carrier gas, were passed through a reduction furnace to remove free oxygen and then through a sorption trap to remove water. Separation of the gas components was achieved by passing the gas mixture through a chromatographic column. A thermal conductivity detector was used to measure the relative concentrations of the gases.

The NA1500 Analyzer was configured for NCS analysis using the manufacturer's recommended settings. As a primary standard, Sulfanilamide was used. Blanks (tin capsules containing only vanadium pentoxide) were run at the beginning and end of sample set. Replicates of every fifth sample were run. As secondary standards, one or more standard reference materials (SRMs) were run every 8 to 10 samples. The SRMs used were National Institute of Standards and Technology (NIST) SRM #1646a - Estuarine Sediment; NIST SRM #2702 - Marine Sediment, and the National Research Council of Canada (NRCC) PACS-2 - Marine Sediment) Comparison of the results of SRMs to their certified values are presented in the QA/QC discussion in Appendix B. Results of the NCS analysis are presented in Appendix C (Table C-2)

Elemental Analysis

Two to three-gram splits of the dried sediments were shipped to Activation Laboratories, Ltd. (Actlabs) of Ancaster, Ontario, Canada, to be analyzed for 34 elements including total phosphorus (Table 1). Actlabs used a four-acid, “near total” digestion process, followed by analysis of the digestate by inductively coupled plasma emission spectroscopy (ICP-OES). The four-acid digestion employed perchloric ($HClO_4$), hydrochloric (HCl), nitric (HNO_3), and hydrofluoric (HF) acids. To insure proper QA/QC, SRMs and replicates were included run for every eight to 10 samples. SRM NIST #8704 and #2702 were included as double- blind samples

with the sediment samples shipped to Actlabs. The Actlabs' results of the analyses of the SRMs are listed in Appendix B. Elemental analysis results for the surficial samples are listed in Appendix C, Tables C-1 – C-3. It should be noted that the extraction method used in this study is a more vigorous digestion compared to EPA methods 3050B or 3051A, thus will result in higher recovery of most elements reported.

Table 1. Reporting units and (method) detection limits of the elements included in the Actlabs analyses.

Element Symbol	Element Name	Reporting unit	Detection Limit (Method)
P	Phosphorus	%	0.001
Cd	Cadmium	ppm (ug/g)	0.3
Cr	Chromium	ppm (ug/g)	1
Cu	Copper	ppm (ug/g)	1
Fe	Iron	%	0.01
Mn	Manganese	ppm (ug/g)	1
Ni	Nickel	ppm (ug/g)	1
Pb	Lead	ppm (ug/g)	3
Zn	Zinc	ppm (ug/g)	1
Ag	Silver	ppm (ug/g)	0.3
Al	Aluminum	%	0.01
As	Arsenic	ppm (ug/g)	3
Ba	Barium	ppm (ug/g)	7
Be	Beryllium	ppm (ug/g)	1
Bi	Bismuth	ppm (ug/g)	2
Ca	Calcium	%	0.01
Co	Cobalt	ppm (ug/g)	1
Ga	Gallium	ppm (ug/g)	1
K	Potassium	%	0.01
Li	Lithium	ppm (ug/g)	1
Mg	Magnesium	%	0.01
Mo	Molybdenum	ppm (ug/g)	1
Na	Sodium	%	0.01
S	Sulfur	%	0.01
Sb	Antimony	ppm (ug/g)	5
Sc	Scandium	ppm (ug/g)	4
Sr	Strontium	ppm (ug/g)	1
Te	Tellurium	ppm (ug/g)	2
Ti	Titanium	%	0.01
Tl	Thallium	ppm (ug/g)	5

Table 1. Reporting units and (method) detection limits of the elements included in the Actlabs analyses.			
Element Symbol	**Element Name**	**Reporting unit**	**Detection Limit (Method)**
U	Uranium	ppm (ug/g)	10
V	Vanadium	ppm (ug/g)	2
W	Tungsten	ppm (ug/g)	5
Y	Yttrium	ppm (ug/g)	1
Zr	Zirconium	ppm (ug/g)	5

RESULTS AND DISCUSSION

Bathymetric Results

The 2011 bathymetry for the Bishopville Prong is presented in Figure 8. The deepest portion of the Prong, with depths up to 4.7 m (15.3 ft), is in the large pool just downstream (approximately 150 meters) of the dam and the Rt. 367 bridge. The deep pool probably formed from toe scour below the dam during high flow events. Additional deep areas (> 3 m) are found along the upper 1500 m of the stream. This upper section of the stream represents the narrowest portion (< 50 m wide) of the Prong, and is characterized by multiple meanders. The greater depths, defining the thalweg, are usually found along the outside edge of the meanders or along the narrowest stretches of the stream. Approximately 1500 m downstream of the dam, the Prong widens abruptly, with stream widths between 100 t o150 m, and depths become more shallow (< 2 m). The thalweg along this section is still distinct in many areas. This change in the stream morphology corresponds to the general contact between the Ironshire Formation and the underling Omar formation, the latter being comparatively more resistant to stream cut. Approximately 3500 m downstream of the dam, where the longitudinal axis shifts from north-south direction to east-west, the Prong broadens to 300 to 500 m wide before the confluence with the St. Martin River. Water depths increase slightly along this segment of the Prong. However, there is no distinct central channel.

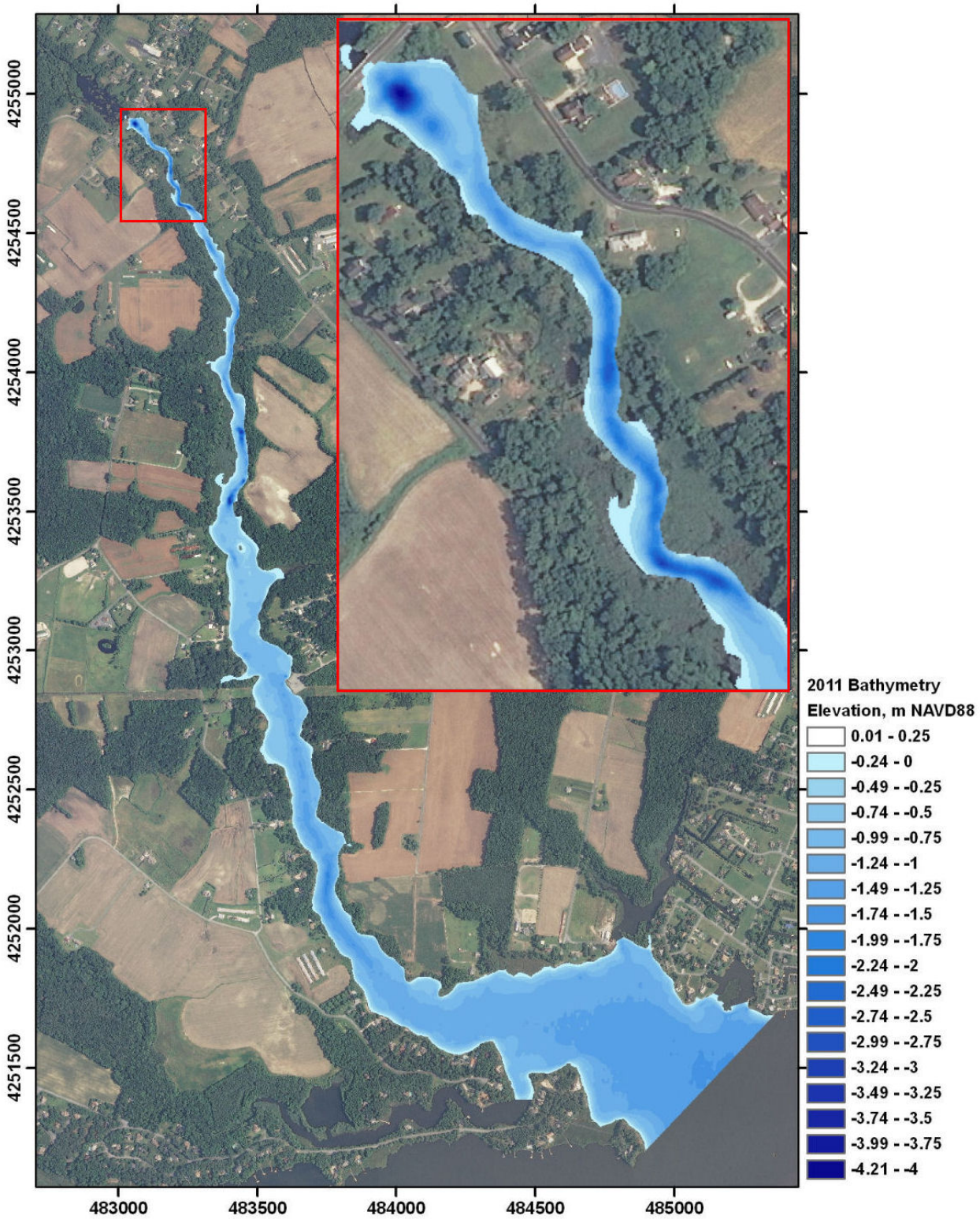


Figure 8. Bathymetry of Bishopville Prong. The bathymetry shown represents the bottom topographic model derived from the 5x Gaussian Kriging.

Comparison of 2011 Bathymetry to 2000 Bathymetry

The sounding data collected for this study were compared to those data collected in 2000. The area where the two bathymetric surveys overlapped is shown in Figure 9. The intersections (where track lines from both surveys cross) were visually identified and soundings used for comparison were selected based on (minimum) distance between the two points, and spatial distribution of the pairs. Between 2000 and 2011 changes in depths ranged from +0.04 m (indicating deposition) to -0.53 m (erosion). Based on 77 sounding pairs, the depths increased, on an average, by 0.20 m. The increase in depths may be attributed to a number of factors, including differences in accuracies of the 2000 and 2011 bathymetric data, local events such as dredging or weather related scouring, and local sea level rise. The last factor can account for an increase of 6 cm in depth since 2000 (based on local sea level rise rate of 5.47 mm/yr, NOAA, 2012).

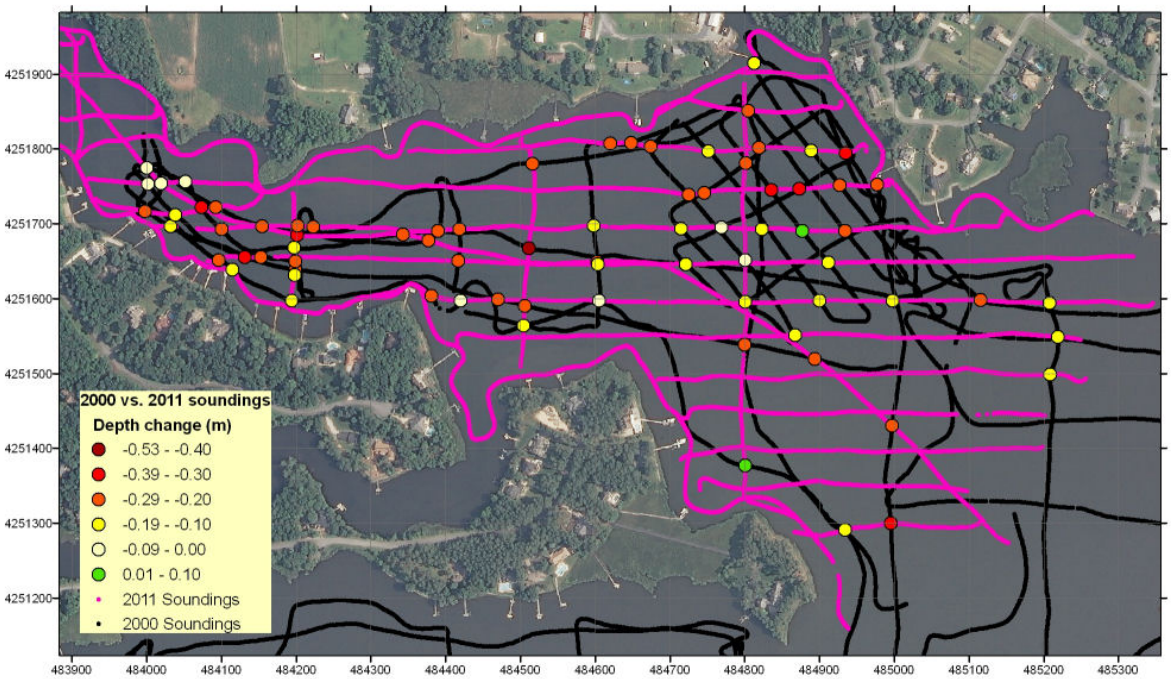


Figure 9. Map showing the track lines for the hydrographic surveys collected in 2000 and 2011 (this study), and locations of points used for depth comparisons. The comparison points are color coded based on the amount of depth change between 2000 and 2011.

Sub-Bottom Seismic Reflection Results

Sub-bottom Seismic Reflection (28 kHz) records (echograms) are useful in identifying areas of scour/erosion and sediment accumulation, and in distinguishing hard bottom from soft bottom.

No discernible sediment layers could be identified in records from the upper 1500 m of the stream. This section of the Prong is narrow and comparatively deep, mostly likely as a result of repeated scouring during high flow events. The bottom within this upper segment of the Prong shows up as a strong return (*i.e.*, dense, narrow band) from both the 200KHz and the 28Khz signal indicating relatively hard bottom, either consisting of sandy sediments and/or low water content.

Most sub-bottom records collected south of Northing 4253100 revealed some subsurface structures. Examples of sub-bottom structures are presented in Figures 10 and 11. In Figure 10, a cross-section line (N4253000) which shows a cross section of Bishopville Prong where present day depths are less than a meter (NAV88). The wide bottom track (~20 cm range in depth readings) in the 200 KHz record suggests that the bottom is soft, watery sediments which tend to attenuate the reflective acoustic signal. The 28 KHz record reveals an earlier channel bottom, with a thalweg depth of 1.5 meters, on the east side of the stream. The present day channel is offset to the west from the earlier channel. The layer of sediments on top of the earlier bottom represents more recent deposits.

Figure 11 features the records from a east-west survey line (N4251700) transecting the mouth of Bishopville Prong. The 200 KHz record indicates that the present day bottom becomes slightly firmer going east. The 28 KHz record reveals a sub-bottom horizon, most likely representing a historical stream bed, or the interface between fluvial and estuarine sediments. Up to a meter of what is interpreted to be more recent sediment has accumulated on top of the sub-bottom horizon.

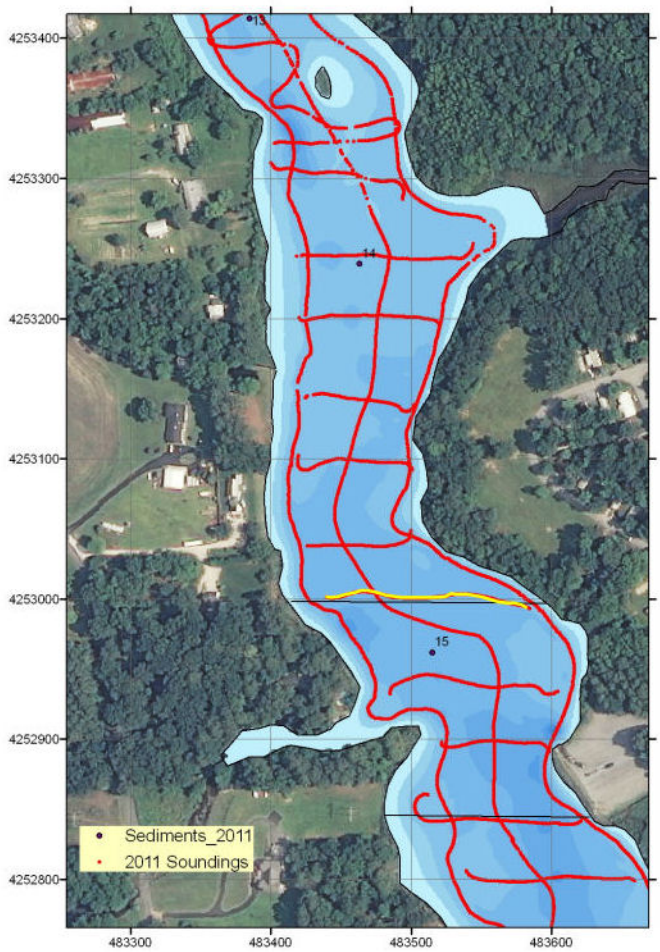
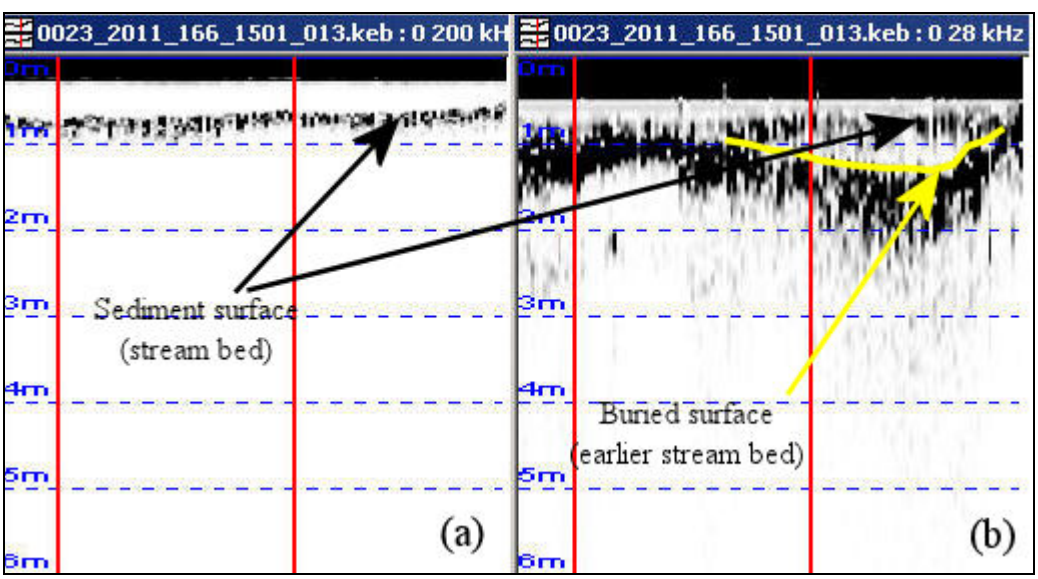


Figure 10. Location of cross-section of survey line at N253000 (line runs from west to east) is shown in map (yellow line) to the left. Both 200 KHz (a) and 28 kHz records (b) are presented below. The 200 KHz echogram shows the present sediment bottom of the Prong. The depth sounding data are based on this record. In the 28 KHz record, a buried surface, representing an earlier stream bottom, is shown (yellow annotation). The area between the present surface and the historic bottom represents accumulated sediments.



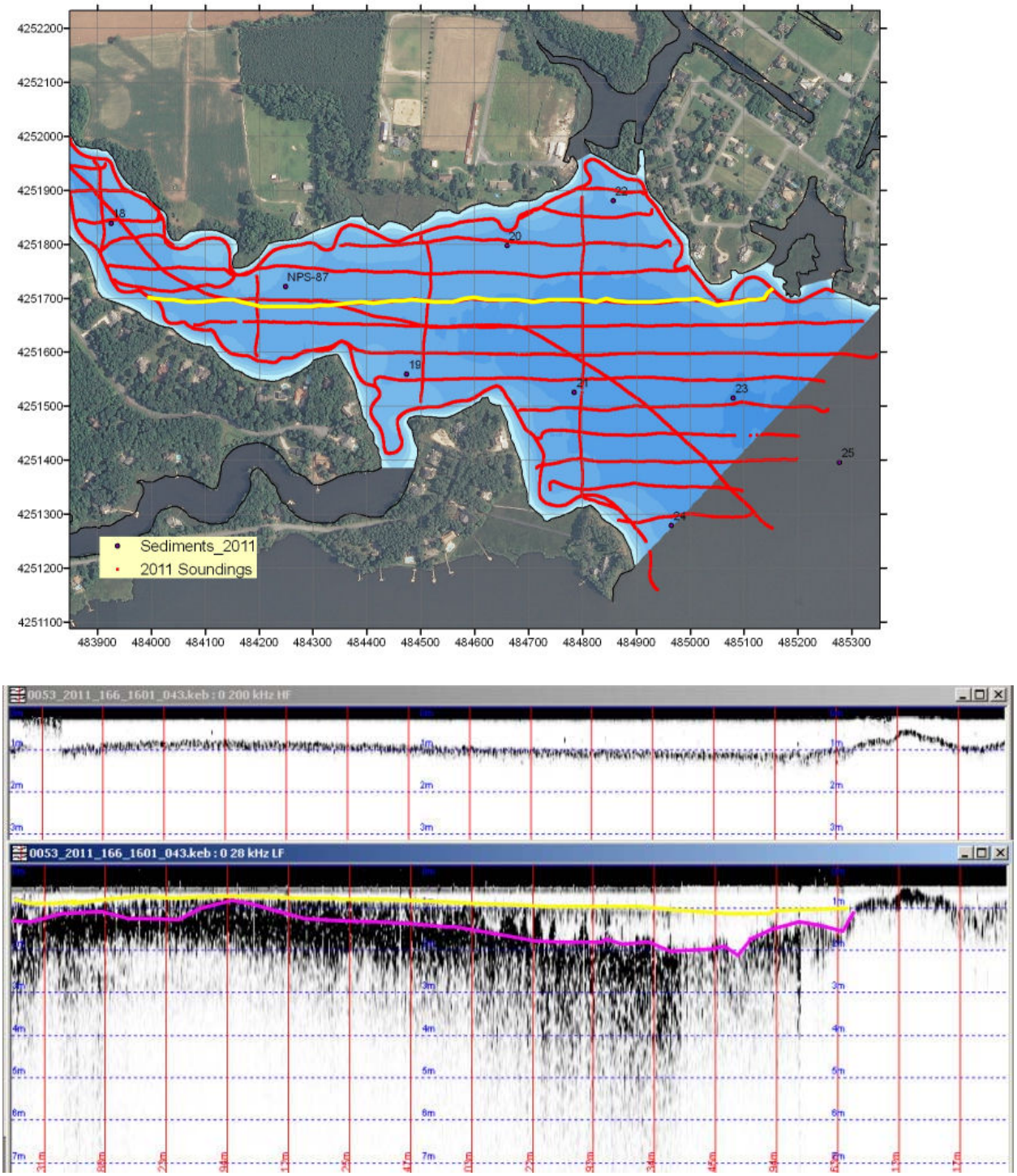


Figure 11. Map showing the location of survey line N4251700, which runs west to east across the mouth of the Prong (upper panel), and the 200 KHz and 28 KHz echograms for the line (lower panel). The 28 KHz echogram reveals a buried surface (pink annotated line) and thick layer (up to 1 meter) of sediment on top. The current sediment surface is indicated in yellow.

Sediment Characterization

Texture

Based on textural analyses of the 30 surficial sediment samples (representing the top 10 cm of the sediment column), sediments in the Bishopville Pond and Prong range from coarse sand to fine grained silty clay, the latter being the most often collected (e.g., representing 33% of the samples collected). One sample, #8, contained significant gravel (12%). This sample was collected along the edge of the large pool just downstream of the dam. Clay content in sediment is very important because nutrients and many metals are often associated with the clay fraction.

The distribution of the sediment types is controlled by stream hydraulic regime. The distribution of the Pond sediments follow the expected pattern, with the coarser sediments found in the deltaic headwater area and become finer downstream, with silty clay found near the dam. Just below the dam, sediments collected are coarse sand and sand silt clay. These types reflect a bottom environment where the finer fraction has been winnowed out by periods of high stream flow, leaving a lag deposit. This pattern is supported by the bathymetry and sub-bottom data which indicate a harder bottom and very little accumulation. Further downstream but within the narrowest part of the Prong, sediments ranged from sand to silty clays, reflecting the coarse grained sediment deposited on point bars and fine grained sediment accumulating in deeper edge pools of a meandering stream

Sand size sediment (sample #s 13 and 14) was collected just below the point where the Prong widens abruptly (~N4253600). During high flow events, flow velocities decrease significantly at this point, and the coarser bed load is dropped along the reach where the steam becomes wider. Sediment gradually becomes finer downstream. Sediment deposition becomes more evident in the sub-bottom records, starting at this point. At the mouth of the Prong where the stream flows into the St. Martin River, silty clays are found, the texture of which is more characteristic of estuarine, back-bay sediments. Silty clay is the most common sediment type collected within the study area.

Chemistry

Table 2 presents the summary statistics for total N, C, S and P contents of the sediments collected in the study area. The Bishopville Pond sediments are listed separate from the sediments collected in the Prong because of the basic chemical differences between estuarine-marine and fresh water sediment environments. These differences affect the geochemical behavior and cycling of N, C, P and S, as well as other elements, such as Fe, Mn, As, Ni and Zn. These differences are evident in comparison with the Bishopville Prong and other coastal bay tributaries sediments.

Total carbon in both the Pond and Prong sediments represent some of the highest contents measured in the coastal bays tributaries. The highest value, 20.2% C, was measured in a clayey silt (Sample #11) collected in upper segment of the Prong, and is considered an anomaly (Figure 12). Correlation analysis of data reveal significant associations between carbon content and clay

for both the Prong sediments (r = 0.78; exclusive of sample #11), and Pond sediments (r=0.92). Compared to sediments in the main portions of the coastal bays, the Prong sediments contain amounts of carbon above what is expected based on clay content (Wells and Conkwight, 1999; Wazniak, el al., 2004). However, carbon contents are comparable to contents measured in sediments from other coastal bays tributaries. The carbon is attributed to either excessive plant debris (such as peat from eroding marshes) or anthropogenic loading, contributing to algae blooms. Observations while collecting the samples in the Pond noted the presence of thick algal mats on the Pond surface and sediment bottom.

Table 2. Summary statistics for elemental nutrients and sulfur content of the sediment samples collected for this study. Sediments are grouped according to freshwater (Bishopville Pond) and marine (Bishopville Prong- tidal reach) environments.

Bishopville Prong samples				
	N (%)	C (%)	S (%)	P (%)
Average	0.465	6.033	2.207	0.067
Std Dev	0.309	4.289	1.237	0.047
min	0.044	0.641	0.174	0.007
max	1.322	20.225	4.154	0.218
n	23	23	23	23
Pond samples				
	N (%)	C (%)	S (%)	P (%)
Average	0.527	8.163	0.435	0.155
Std Dev	0.275	3.765	0.219	0.092
min	0.021	0.390	0.000	0.003
max	0.827	11.746	0.637	0.287
n	7	7	7	7

Total N, when plotted in terms of clay content, show very similar relationships and distributions compared to carbon. N shows a significant correlation with clay content (r = 0.81 for Prong, exclusive of #11 and r = 0.97 for Pond sediments). The highest N values: 1.3%, 0.93 % and 0.92%, correspond to Sample #s 11, 7 and 12, respectively, collected in the upstream most areas of the Prong. N contents measured in the rest of the Prong samples are comparable to contents measured in sediments from other coastal bays tributaries. Pond sediments contain slightly higher N contents. N values reported in this study are higher than those reported by Gascoyne Labs, Inc. (KCI, 2002) (Table 3); the difference being attributed to different analytical methods. Based on mass ratio C to N, a significant portion of the total C and N in the Pond and upstream area of the Prong may be attributed to algae blooms. C:N:P ratios for samples P4 through P7, and # 7 are similar to the C:N:P of dried algae (Table 4).

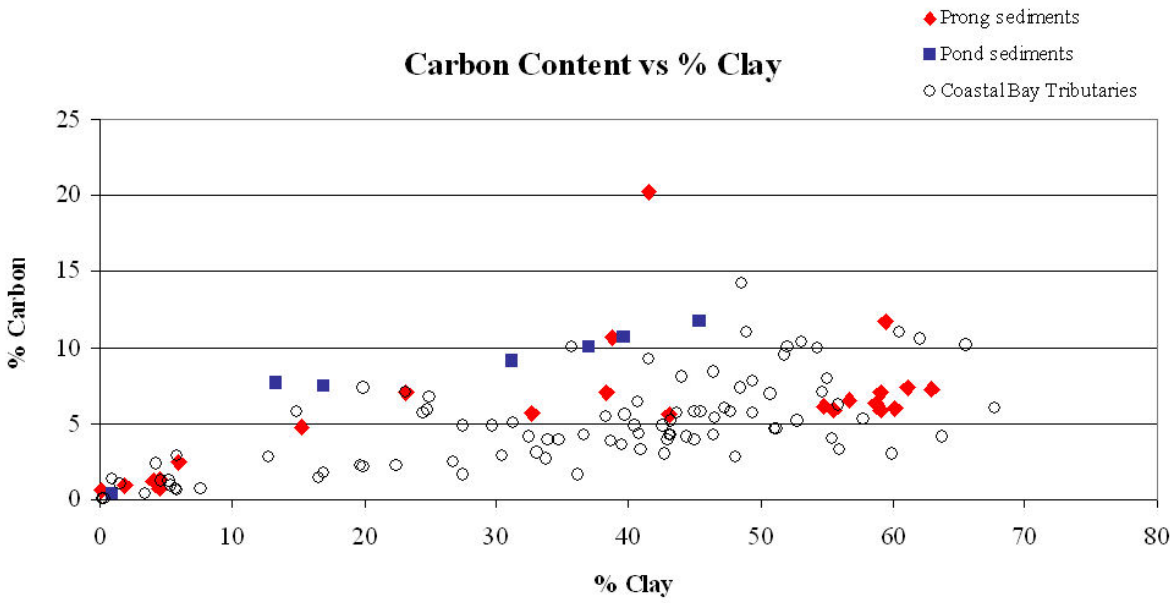


Figure 12 . Plot of total C as a function of clay content for Bishopville Pond (blue) and Prong (red) sediments. For comparison, sediments collected by NPS in other coastal bay tributaries (Wells et al, 2012) are included in the plot (open circles).

Table 3. Result of Bishopville pond sediments analyzed by Gascoyne Labs, Inc. (KCI, 2002). Note that mg/Kg = ppm. N was determined using Kjeldahl digestion.

	Water	N	P	Ag	As	Hg	Cd	Cr	Pb	Se
	%	%	%	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg	mg/Kg
Average	52.3	0.318	0.23	0.29	3.36	0.16	0.60	10.4	35.0	0.55
Std Dev	15.9	0.170	0.15	0.29	1.84	0.07	0.50	5.6	32.4	0.17
min	25.0	0.082	0.04	0.04	0.64	0.05	0.03	3.1	2.9	0.25
max	73.0	0.680	0.56	1.20	7.50	0.32	2.00	24.0	160.0	0.99
n (> dl)	23	22	22	19	20	20	22	23	23	21
TEL*					5.9	0.174	0.6	37.3	35	
n>TEL					2	6	10	0	11	
PEL*					17	0.486	3.5	90	91.3	
n>PEL					0	0	0	0	1	

Table 4. Comparison of mass ratios of C, N, and P observed in organic material from several sources and in sediment samples from fresh and marine environments in Maryland.			
	C:N	**C:P**	**N:P**
Global forest litter (McGroddy et al., 2004)	57.3	1166.1	20.4
Global forest foliage (McGroddy et al., 2004)	37.1	470.0	12.7
Dried marsh plant (Wells et al., 2002)	32.3	711.2	21.7
Marsh sediments (Wells et al., 2002)	18.1	243.6	13
Bishopville Pond (This study)	**16.4**	**67.0**	**4.0**
Coastal Bays Tributaries (Wells et al., 2012)	*13.7*	*98.8*	*7.1*
New Germany Lake (Ortt et al., 2010)	13.5	109.2	8.1
Dried algae (Wetzel, 1983)	13.3	40.0	3.0
Bishopville Prong (This study)	**13.0**	**90.1**	**6.9**
Deep Creek Lake (Wells and Ortt, 2011)	12.9	87.5	6.5
Rocky Gorge Reservoir (Wells et al., 2007)	12.5	31.2	2.5
Triadelphia Reservoir (Wells et al., 2007)	11.1	29.2	2.6
Loch Raven Reservoir (Ortt et al., 1999)	10.1	19.9	2.0
Coastal Bays bottom sediments (Wells el al., 1994)	7.0	65.1	9.3
Plankton (Redfield et al., 1963)	5.7	41	7.2

P values reported in this study for the Pond samples are lower than those reported by Gascoyne Labs, the difference attributed to different analytical methods and sampling methods. In this study, P correlates very well with clay content of the Pond samples ($R^2 = 0.97$). Overall, the Pond sediments contain twice the P than the Prong sediments (Figure 13). Marine sediments generally have a lower P-binding capacity than freshwater sediments, the difference due to higher availability of S in marine environment. Concentrations of P in the Bishopville Prong sediments are comparable to concentrations reported for other coastal bays tributaries. The higher P values correspond to fine-grained sediments collected from the upstream area of the Prong (samples 7, 11, and 12).

The Pond sediments contain some sulfur, the source of which is thought to be from historic spills from several poultry processing plants within the Pond's watershed. The spills contained sulfuric acid, which was used to strip chicken and vegetable oils for reprocessing into feed grade products (MDE, 2005).. The amount of S is fairly consistent in sediments (~0.5 %) regardless of clay content (Figure 14), suggesting that S is in a stable mineral form. However, sediment samples collected in this study represent the top 5 cm of the sediment profile. The more volatile forms of sulfur have cycled out of the surface Pond sediments, but may be preserved in deeper sediments.

To obtain data on sediments at depth, three cores were collected in June, 2013. The cores were collected along the longitudal axis of the Pond (Figure E-1). The cores, ranging from 39 to 62 cm in length, were subsampled at top, middle and bottom and samples were analyzed for

textural properties and NCS. The cores collected toward the head of the pond and near the dam yielded S levels at depth comparable to the surficial samples; S value ranged from 0.03% to 0.42%. The core collected in the deeper, middle area of the Pond yielded sediment containing as much as 1.05% sulfur (at 42-62 cm sediment depth) (Table E-2 in Appendix E).

Given both carbon and clay contents of the Prong sediments, sulfur contents are twice the levels expected, particularly when compared to other coastal bays tributaries (Figure 14). Sulfur levels are the highest just below the dam and decrease slightly going downstream. The high sulfur in the Prong is thought to be a legacy of the historic spills from the Bishopville Processing Plant.

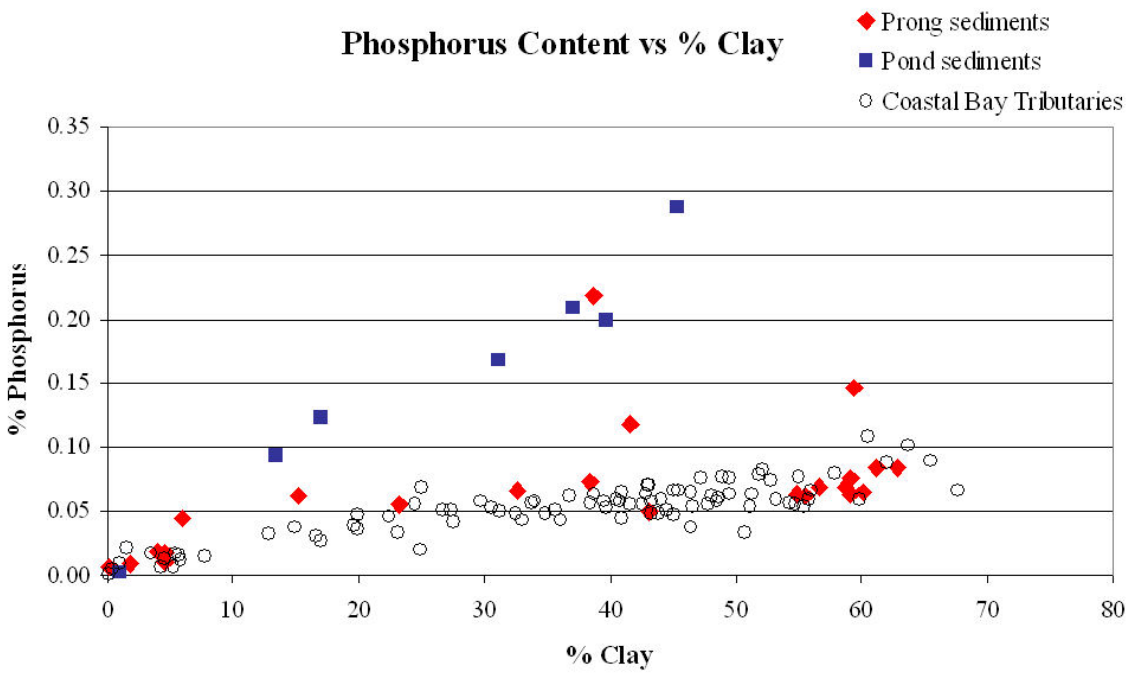


Figure 13. Plot of total P as a function of clay content for Bishopville Pond (blue) and Prong (red) sediments. For comparison, sediments collected by NPS in other coastal bay tributaries (Wells et al, 2012) are included in the plot (open circles).

Tables 5 and 6 list summary statistics for the specific metals in the Bishopville Pond and Prong, and other coastal bays tributaries. While concentrations of most metals are similar for the Prong and tributary sediments, the Pond sediments contain twice the amount of Cd, Co, and Zn and approximately 1.5 the amount of Ni and Pb as sediments from Bishopville Prong and other Coastal Bays tributaries. Figures 15 and 16 present plots of the concentrations of these metals as a function of the clay content in the sediment. Co, Pb, Ni and Zn are strongly correlated with clay content of the sediments; Cd shows a weaker correlation. However, in all plots, the Pond samples are distinct from the other sediment sets. While this disparity is attributed, in part, to the different geochemical behavior of these metals in fresh versus marine environments, a portion of the metal concentration may be a result of historic processing plant spills containing sulfuric

acid. Some of the more soluble metal may have been mobilized and eventually ended up in the Pond sediments.

For reference, benchmark levels taken from the NOAA Screening Quick Reference Tables (SQuiRTs) (Buchman, 2008) for some of the metals are included in Tables 5 and 6. However, the sediment samples in this study were subjected to an extraction method that was more vigorous than the methods recommended in the NOAA tables. The concentrations for some metals reported in this study may be higher than those reported if using the EPA methods. More than half of the Bishopville Prong sediments samples contain concentrations of Cu, Ni and Zn above the Effects Range-Low (ERL) benchmark. All metal concentrations are below the Effects Range Median (ERM) benchmark level.

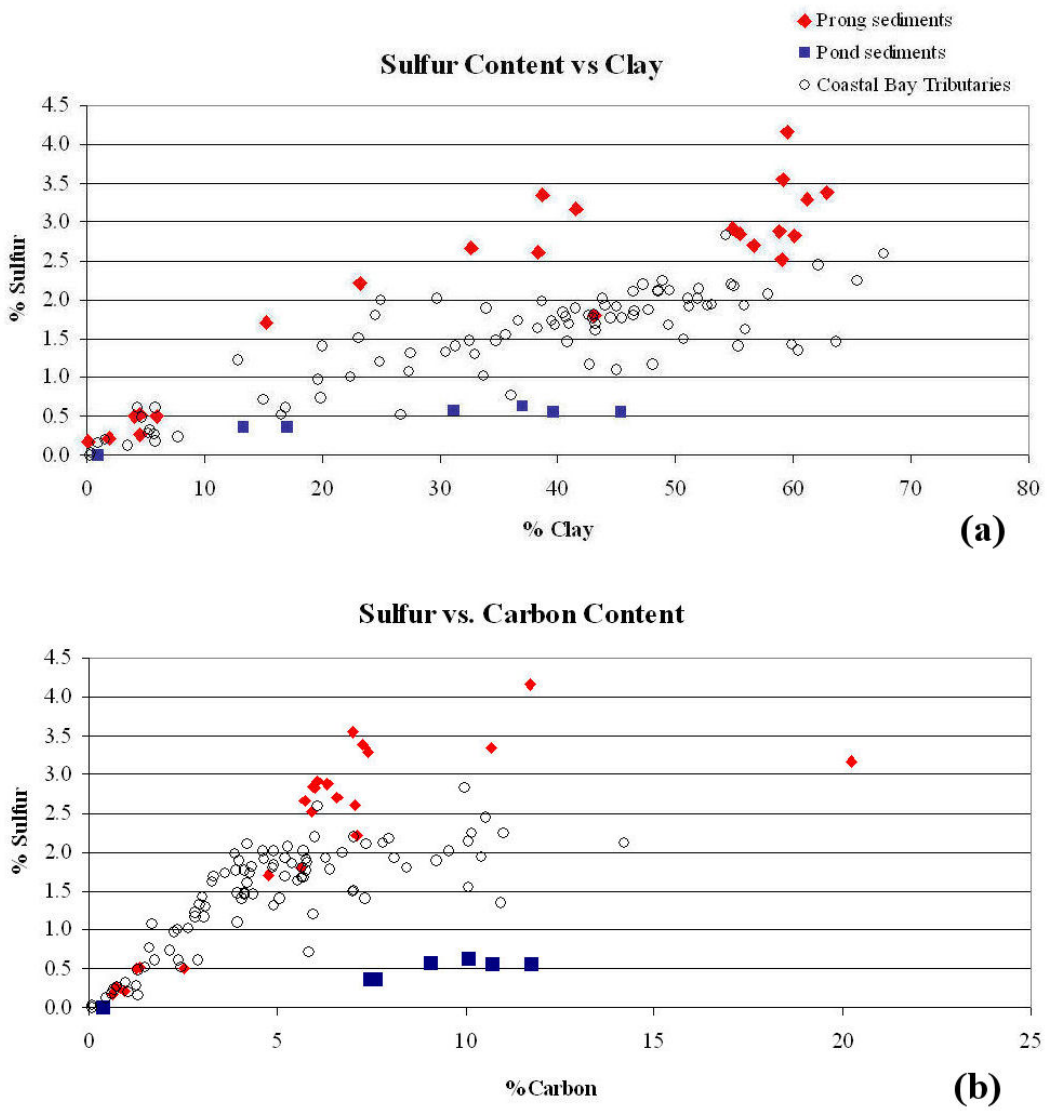


Figure 14. Plots showing relationships between S, C and Clay contents. Samples include Bishopville Pond (blue) and Prong (red) sediments. For comparison, sediments collected by NPS in other coastal bay tributaries (Wells et al, 2012) are included in the plot (open circles).

Table 5. Summary statistics for select metal concentrations in sediments collected for this study. Sediments are grouped according to freshwater (Bishopville Pond) and marine (Bishopville Prong- tidal reach) environments. Included for reference are the Effects Range Low (ERL), Effects Range Median (ERM), Threshold Effects Level (TEL) and Probable Effects Level (PEL) benchmark levels from Buchman (2008).

Bishopville Prong Samples										
	Ag (ppm)	As (ppm)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
Average	1	9	0.8	39	28	2.66	210	21	26	172
Std Dev	0	5	0.2	20	16	1.34	91	12	11	88
min	0	4	0.4	5	3	0.18	29	2	6	12
max	1	26	1.3	88	66	4.02	334	35	42	290
n (> dl)	20	18	17	23	23	23	23	23	23	23
ERL	1	8.2	1.2	81	34			20.9	46.7	150
n>ERL	2	8	1	1	**12**			**13**	0	**16**
ERM	3.7	70	9.6	370	270			51.6	218	410
n>ERM	0	0	0	0	0			0	0	0
Pond Samples										
	Ag (ppm)	As (ppm)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
Average	0.3	7.2	2.2	36.4	28.6	1.6	274.4	28.3	38.7	375.8
Std Dev		1.3	0.6	15.5	14.2	0.7	140.2	13.1	17.6	183.9
min	0.3	6.0	1.5	7.0	1.0	0.1	23.0	3.0	4.0	14.0
max	0.3	9.0	2.9	51.0	41.0	2.3	440.0	40.0	56.0	527.0
n (> dl)	1	5	6	7	7	7	7	7	7	7
TEL*		5.9	0.6	37.3	35.7			18	35	123
n>TEL		**5**	**6**	**4**	**4**			**6**	**4**	**6**
PEL		17	3.5	90	197			36	91.3	315
n>PEL		0	0	0	0			**3**	0	**4**

Threshold Effects Level (TEL) and Probable Effects Level (PEL) benchmark values are used for the freshwater Pond samples; there are no published ERLs/ERMs for fresh water sediments. While TEL/:PEL benchmark values are similar to ERLs/ERMs, they are generally lower for freshwater sediments compared to marine sediments. All Bishopville Pond samples contained concentrations of As and Cd exceeding the TEL value and over half the samples had concentrations of Cr, Cu, Ni, Pb, and Zn exceeding the TEL. Several samples (closer to the dam) contain Ni and Zn concentrations exceedeng the Probable Effects Level (PEL). These areas represent the concentrations above which adverse effects are likely. For concentrations that fall below the PEL but above the TEL adverse effects to benthic organisms are uncertain. The only threshold values listed for Co are Lowest Effects Limit (LEL) for freshwater sediments and

Apparent Effects Thrshold (AET) for marine sediments (Buchmand, 2008). The LEL and AET values for Co are 50 ppm and 10 ppm, respectively. No Pond samples contained Co concentrations exceeding the LEL, and 14 Prong samples exceeded the AET.

Table 6. Summary statistics for select metal concentrations in sediments collected for other coastal bays tributaries (Wells et al., 2012). Included for reference are the ERLs/ERMs benchmark levels.

	Ag (ppm)	As (ppm)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
Average	0.5	10.1	0.5	50.7	21.2	2.59	274.6	21.6	20.8	115.0
Std Dev	0.22	4.26	0.20	16.50	17.24	0.94	74.14	7.89	8.12	52.72
min	0.3	4	0.3	11	2	0.23	93	1	7	8
max	1.7	25	1.1	83	133	3.91	407	34	57	311
n (> dl)	69	77	37	91	90			91	90	91
ERL	1	8.2	1.2	81	34			20.9	46.7	150
n>ERL	2	44	0	1	8			62	1	18
ERM	3.7	70	9.6	370	270			51.6	218	410
n>ERM	0	0	0	0	0			0	0	0

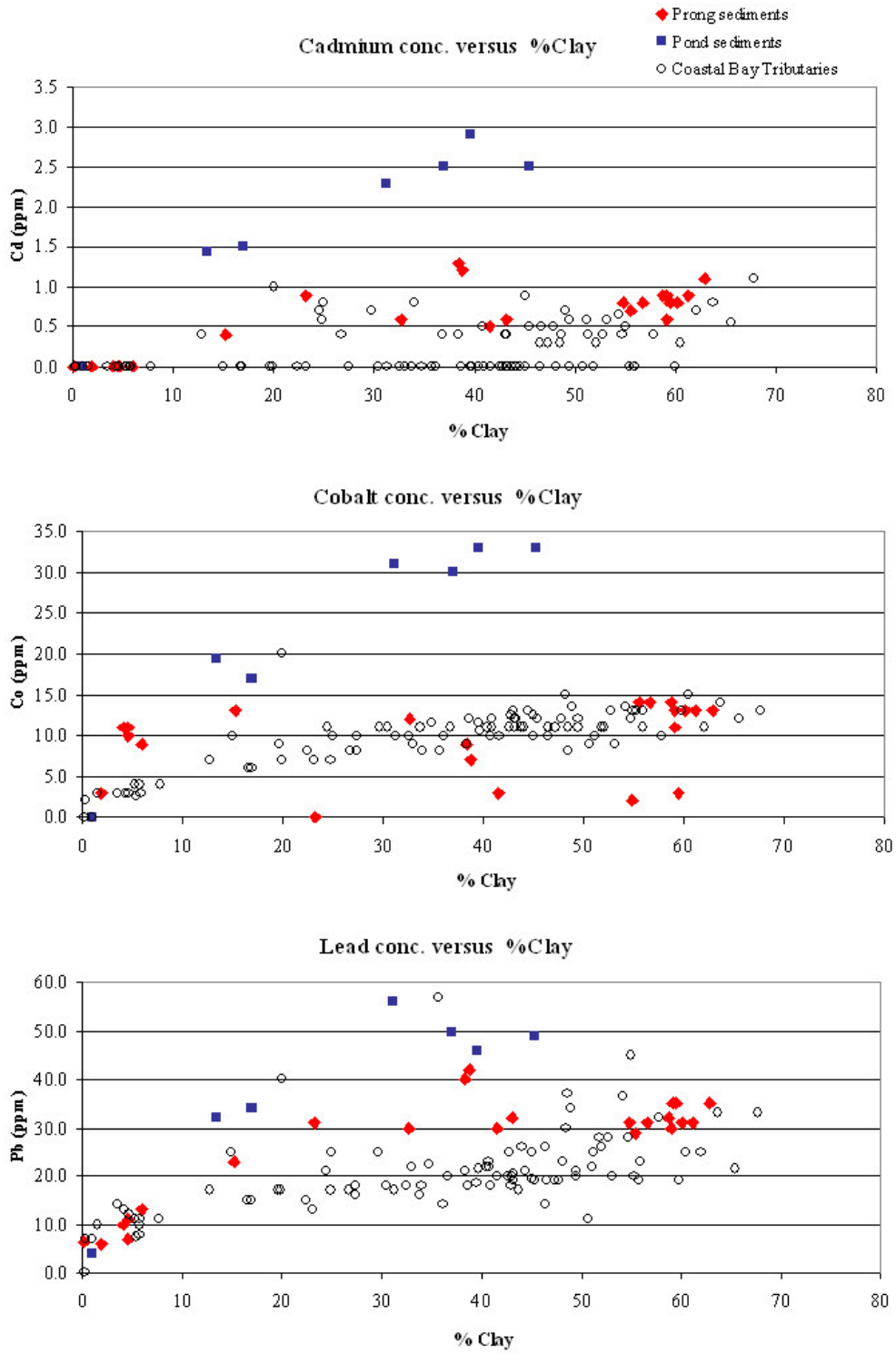


Figure 15. Plots showing relationship between Cd, Co, and Pb and clay contents. Samples include Bishopville Pond (blue) and Prong (red) sediments. For comparison, sediments collected by NPS in other coastal bay tributaries (Wells et al, 2012) are included in the plot (open circles).

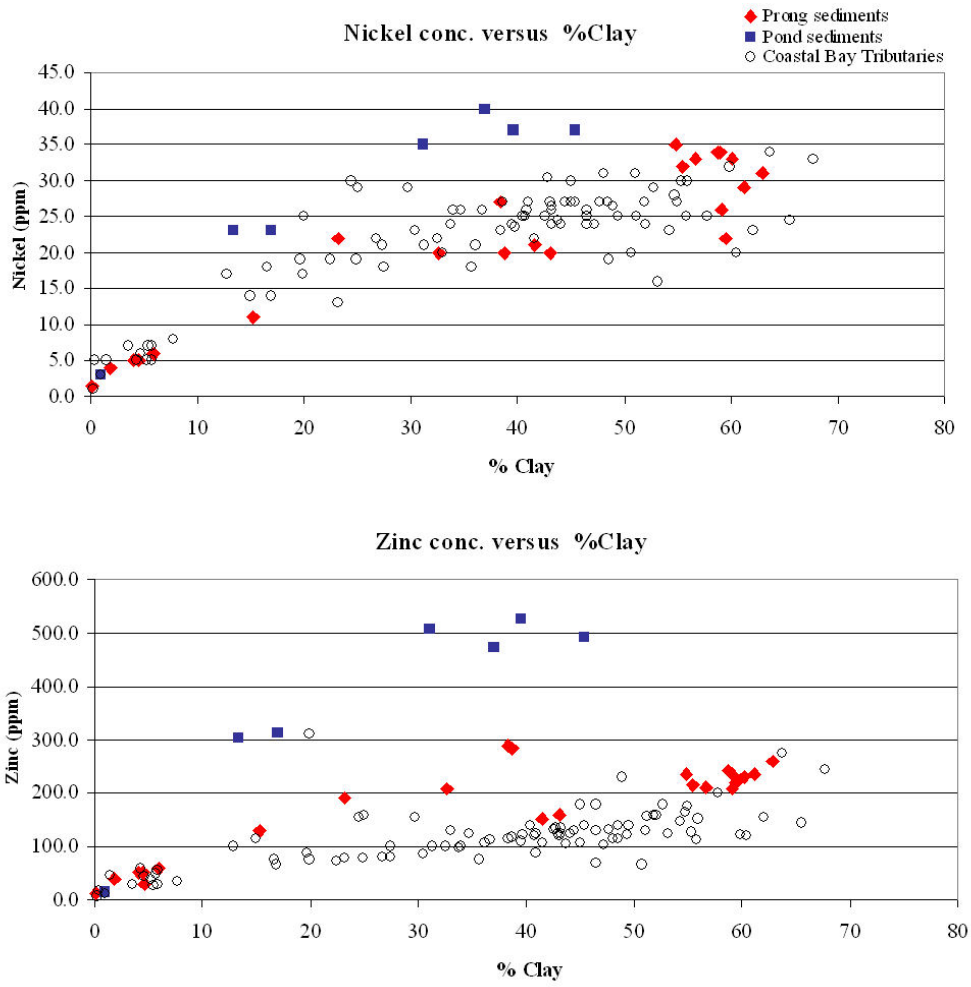


Figure 16. Plots showing relationship between Ni and Zn and clay contents. Samples include Bishopville Pond (blue) and Prong (red) sediments. For comparison, sediments collected by NPS in other coastal bay tributaries (Wells et al, 2012) are included in the plot (open circles).

SUMMARY AND CONCLUSION

Results of chemical analyses of the Pond sediments are similar to those reported by Gascoyne Labs, Inc. (KCI, 2002) for those chemical constituents measured in both studies. Any discrepancies in results from the two studies are attributed to differences in sampling techniques and analytical methods, and variation in sample textures, which range from sand collected in the upper end of the pond to fine grained silty clay collected near the dam. Results from the MGS study confirm that the Pond contain high nutrient levels. C, N and P contents were some of the highest observed in the coastal bays watershed. Pond sediments also contain S at levels higher than what would be expected in a fresh water environment. However, the S concentrations are lower than what was found in some of the Prong sediments, which contained some of the highest sulfur contents found the coastal bays. The source of S is thought to be from historic spills from chicken processing plants within the watershed.

The Pond sediments contain twice the amount of Cd, Co, and Zn and approximately 1.5 the amount of Ni and Pb compared to Bishopville Prong and other Coastal Bays tributary sediments. While this disparity is contributed, in part, to the different geochemical behavior of these metals in fresh versus marine environments, a portion of the metal concentrations may also be a result of leaching effect from historic processing plant spills containing sulfuric acid.

Bishopville Prong can be divided into three segments, defined, in part, by geomorphology and hydrodynamic regime (maximum energy levels). These segments are useful in explaining the bathymetry and sediment data from this study. The upper 1500 m segment, immediately downstream of the Bishopville dam, represents the narrowest portion of the Prong and encompasses the deepest portions of the Prong, with depths greater than 4 meters. The deep areas are probably from scour during high stream flow events. Subbottom data indicate that very little sediment is accumulating in this segment. Sediments collected in this segment ranged from coarser sand to sand-silt-clay to silty clays. However, the sediments collected in the segment contained the highest C, N, P and S contents measured for this project. N:C:P ratios suggest that the organic matter is from algae, mostly likely transported from the Pond.

The second segment of the prong, between N4253500 and N4251750, is generally wider and characterized by shallower depths (< 3 m). Subbottom data show accumulation of sediments along outside edge of stream meanders. Sediments in this segment range from sand in the up-stream portion to silty clays downstream. C, N, P and S contents in sediments in this segment are lower compared to upstream areas. When normalize to clay content, C, N, P and S gradually decrease in the downstream direction within this segment. This segment represents a transitional reach.

The mouth of the Prong represents the third segment. Here, the Prong broadens to 300 to 500 m wide before the confluence with the St. Martin River. Water depths increase slightly along this segment of the Prong. However, there is no distinct central channel. Subbottom data show what is interpreted to be thick layer (1 meter thick) of recently deposited sediments, the texture of which is predominately silty clay. C:N:P ratios approach those ratios reported in main stem of the coastal bays (Wells et al., 1994).

Data from this study provide a general characterization of the Bishopville Prong study area. This assessment may be use as a baseline for future assessments after the removal of Bishopville Dam, particularly if the removal results in major alteration of stream hydraulics.

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REFERENCES

Bartberger, C.E., and Biggs, R.B., 1970, Sedimentation in Chincoteague Bay: in Natural Resources Institute, University of Maryland, Oct. 1970, Assateague ecological studies, Part I: Environmental threats, Contribution #446, Chesapeake Biological Lab, Solomons, Md., 426 pp.

Bennett, R.H., and Lambert, D.V., 1971, Rapid and reliable technique for determining unit weight and porosity of deep-sea sediments: Marine Geology, v. 11, p. 201-207.

Buchman, M.F., 2008, NOAA Screening Quick Reference Tables, NOAA OR&R Report 08-1, Seattle, WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Adm., 34 pages.

Carver, R.E., 1971, *Procedures in Sedimentary Petrology*, Wiley-Interscience, New York, 653 pp.

Challiou, J.C., Weisberg, F.W., Kutz, F.W., DeMoss, T.E., Mangiaracina, L., Magnien, R., Eskin, R., Maxted, J., Price, K., and Summers, J.K., 1996, Assessment of the ecological condition of the Delaware and Maryland coastal bays, U.S. Environmental Protection Agency, National Human and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, FL., EPA/620/R-96/004

In-Situ, Inc., 2007, Level Troll operator's manual: Level Troll 300, 500, 700 and BaroTroll, Rev. .04, March 2007, In-Situ, Inc., Fort Collins, CO.

KCI Technologies, Inc., 2002, Bishopville Dam Fish Passage Feasibility Study and Preliminary Investigation Design Report, prepared for Maryland State Highway Administration, KCI Job # 01-99071C1.

Kerhin, R.T., Halka, J.P., Wells, D.V., Hennessee, E.L., Blakeslee, P.J., Zoltan, N., and Cuthbertson, R.H., 1988, The surficial sediments of Chesapeake Bay, Maryland: physical characteristics and sediment budget: Maryland Geological Survey RI 48, 82 p., 8 plates.

Maryland Department of the Environment (MDE), 2005, Former Bishop Processing Site Bishopville, Maryland 21872, Fact Sheet issued May 24, 2005, Waste Management Administration, Environmental Restoration & Redevelopment Program. Downloaded from http://www.mde.state.md.us/assets/document/brownfields/Bishop_Processing.pdf on 2/25/2011

Maryland Department of the Environment (MDE), 2002, Total maximum daily load of nitrogen and phosphorus for five tidal tributaries in the northern coastal bays system, Worchester County, Maryland. Submitted to Watershed Protection Division, U.S. EPA, District III, Dec. 2001.

Maryland Department of Natural Resources (DNR), 1998, **swsub8** - Maryland's Sub-Watershed, statewide digital watershed file, found at: http://dnrweb.dnr.state.md.us/gis/data/data.asp, Annapolis, Maryland.

McGroddy, M.E., Daufresne, T., and Hedin, L.O., 2004, Scaling of C:N:P stoichiometry in forests worldwide: implications of terrestrial Redfield-type ratios. Ecology, vol. 85, p. 2390-2401.

National Oceanic and Atmospheric Administration (NOAA), 2012, Tides and Currents Sea Levels Online interactive map: http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml

Ortt, Jr., R.A., Kerhin, R.T., Wells, D.V., and Cornwell, J., 1999, Bathymetric Survey and Sedimentation Analysis of Loch Raven and Prettyboy Reservoirs: Maryland Geological Survey, Coastal and Estuarine Geology Program, File Report 99-04, 89 p.

Ortt, Jr., R. and Wells D. V., 2010, Sedimentation analysis of New Germany Lake: Baltimore, Md., Maryland Geological Survey, Coastal and Estuarine Geology File Report No. 10-02, 81 p.

Owens, J.P., and Denny, C.S., 1978, Geologic Map of Worcester County, scale 1:62,500; Maryland Geological Survey, color county geologic map with text.

Owens, J.P., and Denny, C.S., 1979, Upper Cenozoic deposits of the Central Delmarva Peninsula, Maryland and Delaware: U.S. Geol. Survey. Prof. Paper 1067-A, 28 p.

Pejrup, M., 1988, The triangular diagram used for classification of estuarine sediments: a new approach: *in* de Boer, P.L., van Gelder, A., and Nio, S.D., eds., Tide-Influenced Sedimentary Environments and Facies, Dordrecht,Holland, D. Reidel Publishing Co., p. 289-300

Redfield, A.C., Ketchum, B.H., and Richards, F.A., 1963, The influence of organisms on the composition of sea-water, in Hill, M.N. (ed.), The Sea, Volume 2, The Composition of Seawater, Comparative and Descriptive Oceanography: London, Interscience, p. 26-77.

Shepard, F.P., 1954, Nomenclature based on sand-silt-clay ratios: Jour. Sed. Petrology, vol. 24, p. 151-158.

University of Md. (UM), and Coastal Environmental Services, Inc. (CESI), 1993, Maryland's coastal bays: an assessment of aquatic ecosystems, pollutant loadings, and management options: submitted to Maryland Dept. of the Environment, Chesapeake Bay and Special Projects Branch, Baltimore, Md.

U.S. Environmental Protection Agency (EPA), 2002, Mid-Atlantic Integrated Asessment (MAIA) Estuaries 1997-98: Summary Report, EPA/620/R-02/003, 115 p.

U.S Department of the Interior (USDI), 1998, Guidelines for interpretation of the biological effects of selected constituents in biota, water, and sediment: Zinc, National Irrigation Water Quality Program Information Report #3, Nov. 1998, p. 185-198.

Wazniak, C.E. and Hall, M.R. (eds), 2004, Maryland S Coastal Bays Ecosystem Health Assessment 2004, DNR-12-1202-0009, Maryland Department of Natural Resources, Tidewater Ecosystem Assessment, Annapolis, Md.

Wells, D.V., Conkwright, R.D., and Park, J., 1994, Geochemistry and geophysical framework of the shallow sediments of Assawoman Bay and Isle of Wight Bay in Maryland: Maryland Geological Survey, Coastal and Estuarine Geology Program Open File Report No. 15, Baltimore, Md., 125 pp.

Wells, D.V, and Conkwright, R., 1999, The Maryland Coastal Bays Sediment Mapping Project - Physical and chemical characteristics of the shallow sediments: Synthesis Report and Atlas, Md. Dept. of Natural Resources, Maryland Geological Survey, Coastal & Estuarine Geology Program File Report 99-5, *HTML*-format on CD-ROM.

Wells, D.V., and Ortt, R.A., 2001, Bathymetric Survey of Assawoman Bay, St. Martin River, Sinepuxent Bay and Newport Bay. Md. Dept. of Natural Resources, Maryland Geological Survey, Coastal & Estuarine Geology Program File Report 01-2, PDF-format on CD-ROM.

Wells, D.V., Hennessee, E.L., and Hill, J.M., 2002, Shoreline Erosion as a Source of Sediments and Nutrients, Northern Coastal Bays, Maryland. Maryland Geological Survey, Coastal and Estuarine Geology Program, File Report 02-05.

Wells. D.V, Hill, J., Ortt, Jr., R. and Van Ryswick, S., 2007, Sediment Mapping and Sediment Oxygen Demand of Triadelphia and Rocky Gorge Reservoirs. Coastal and Estuarine Geology Program, FR 07-02, 47 p.

Wells, D.V., and Ortt, R.A., 2011, Deep Creek Lake Sediment Study: Physical and Chemical Characteristics of Lake Sediments. Md. Dept. of Natural Resources, Maryland Geological Survey, Coastal and Environmental Geosciences Program File Report 11-05, 46 p.

Wells, D.V., Sylvia, E. and Kurtz, N., 2012, Analyses of Sediments from the Estuarine Waters of Assateague Island National Seashore, MD and VA. Maryland Geological Survey, Coastal and Environmental Geosciences Program File Report 12-03, draft report submitted to National Park Service, Assateague Island National Seashore in fulfillment of Contract #NPS PMIS 162239.

Weisberg, S.B., Rose,K.A., Clevenger, B.S. and Smith, J.O. 1985. Inventory of Maryland Dams and Assessment of Hydropower Resources. Power Plant Siting, Annapolis

Wetzel, R.G., 1983, *Limnology*, 2nd Edition. Saunders College Publishing, NY.

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APPENDIX A
Bathymetry- Processing and Quality Assurance/Quality Control

1. Hydrographic Surveying

Surveying was halted during times when GPS horizontal accuracy was affected. The GPS is set to stop determining positions if any of the following conditions are met:

1. Number of useable satellites falls below 5.
2. PDOP value exceeds 6.
3. Differential correction updates are older than 30 seconds.
4. Carrier lock is lost on the satellites.

Additionally an elevation mask of 15 degrees was set to filter out satellites that were low on the horizon and which could insert errors into the position solution. Any sounding that was tagged with a GPS position that was greater than 350 milliseconds old was deleted from the dataset.

The sounding data was verified through multiple techniques. During collection, a minimum and a maximum depth were provided to assist in the selection of the bottom. Various filters are used internally of the echosounder to accurately track the bottom. Occasionally, the echosounder would lose bottom lock, and it would track a multiple (echo), sub aquatic vegetation, or water column noise. When feasible, these data errors were determined through visual observation and filtered from the dataset.

Following the adjustments to depth and the removal of poor quality horizontal and vertical data, the data was further analyzed at the intersection of the tie-in lines. Tie-in lines were run perpendicularly to the established transects. These intersections were visually identified and the surrounding data was analyzed for consistency and accuracy. Forty-eight intersections were visually identified and compared. The processed depths at the intersection points were within, on average, 0.06 m +/- 0.06 m. However, the differences at 60% of the observed intersection points exceeded the accuracy standard of +/- 0.03 m (0.1 feet) plus one percent of the water depth.

Equipment Calibration

Calibration of the equipment was conducted during the data collection process. The GPS equipment conducts a self-test every day, and it was field checked against known horizontal control points. An annual accuracy validation is performed on the GPS.

Usually the calibration of the echosounder is checked by comparing observed depth values with actual depths over the maximum range of depths (*i.e.,* depths > 15 to 20 m). Regression analysis is preformed on the observed versus actual depth to obtain the following calibration equation:

$$y = mx + b$$

where x is the observed (recorded) depth, and

y is the actual depth; and

m is the correction factor for the speed of sound

b is the transducer offset

Due to the limited working depths (*i.e*, < 2 meters) and extremely soft bottom encountered in the Bishopville Study area, calibration depths were not collected during the survey. In very shallow working depths, realistic depth observations versus recorded depth observations have more error than any possible change in the slope of the calibration curve. Therefore, only the keel offset was used in adjusting the sounding depths. Essentially, m was fixed at 1 in the above equation. In other study areas where depths exceed 50 feet (15 m), m typically ranges from 0.998 to 1.002. The b, keel offset (0.24 m), was measured in the field and also compared to various other MGS surveys conducted on the Whaler.

The recorded depths were adjusted for keel offset and an adjustment made for tidal offsets based on water level data from two recorders, located at north and south extents of the study (see section on **Water Level Recording and Adjustments**).

2. Water Level Recordings and Adjustments

The Troll 500 water level recorder (WLR), manufactured by In-Situ, Inc. were used for this study. The WLRs are designed for long-term monitoring and record level/pressure and temperature data. Sensors and data loggers are contained in a single, sealed unit. The recorder uses a vented pressure sensor, 15 psi (0 to 11 m range). The vent to the atmosphere minimized offsets caused by barometric changes. The reported accuracy of the Level Troll 500 level sensor is +/-0.1% full scale, -5 to 50° C (In-Situ, Inc., 2007).

To minimize noise from wave activity, the sensor was mounted in a "stilling well" which consisted of a 5-foot length of 4 inch PVC pipe. The sensor was affixed to the inside wall of the pipe. The level of the sensor and a second level corresponding to 48 inches (1.22 m) above the sensor were marked on the outside of the pipe. The top and bottom of the PVC pipe were capped. To allow slow passage of water between the inside and outside of the pipe, four 1/8" holes were drilled through the PVC wall near the bottom of the pipe. The PVC pipe was securely mounted to a piling, with the bottom of the pipe positioned on or near the river bottom.

The manufacturer calibrated the water level recorders prior to shipping. Calibrations were confirmed in the field prior to deployment and again at the end of the study. Both instruments met the field calibration check within 0.05 feet of the observed level on the gauge.

Two water level recorders were installed for this project. One WLR was installed at the Bishopville dam, next to the U.S. Geological Survey stream gauge (Figure A-1) and concrete abutment to MD Rt. 367 bridge (Figure A-2). The second WLR was installed at the southern extent of the study area, on a private dock (Figure A-3).

Elevations of the WLR sensors were determined using GPS (Ashtech Promark 3 GPS receiver). The GPS system was set up at temporary benchmark (TBM) near each WLR and surveyed for approximately an hour. The GPS data were post processed using Ashtech GNSS Solution software, obtaining the location (UTM, NAD83) and elevation (Orthometric height or NAVD88) of the TBMs. Elevations of the WLR sensors were then determined from TBM using standard leveling methods. Elevation data for both WLRs are presented in Table A-1.

Continuous water level readings were collected between June 14 and 16, 2011. A graph of the tidal data collected from both WLR is presented in Figure A-4. The data capture three tidal cycles and show that tide within the entire Prong is semi-diurnal. For reference, the tidal data from the NOAA Tide Station # 837-0283 for the same time period are plotted in the graph. This time period corresponded to the spring tide (full moon) when tide range would be at a maximum. Field observations at the time the hydrographic surveys were collected noted that water levels were "higher than normal", allowing access by the survey boat to portions of the study area which would be too shallow under normal conditions. Time offset for high and low tide at the Bishopville Dam and NOAA Tide Station in Isle of Wight averaged 2 hr 29 min and 2 hr 55 min, respectively. The tide range (MHHW - MLLW) during this two-day period was calculated to be 0.47 m (1.55 ft) and 0.45 m (1.48 ft) at Bishopville Dam and Sansom Dock, respectively. Mean tide level at the Bishopville dam was 0.02 m (0.06 ft) NAVD88.

Figure A-1 (left). Location of the WLR at Bishopville Dam. The WLR was mounting on sheet piling adjacent to the NE abutment to the MD Rt. 367 Bridge.

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Figure A-2 (right). GPS system was used to determine elevation of the WLRs. In the photograph, GPS was set up on a guard rail piling next to NE abutment of the MD Rt. 367 Bridge.

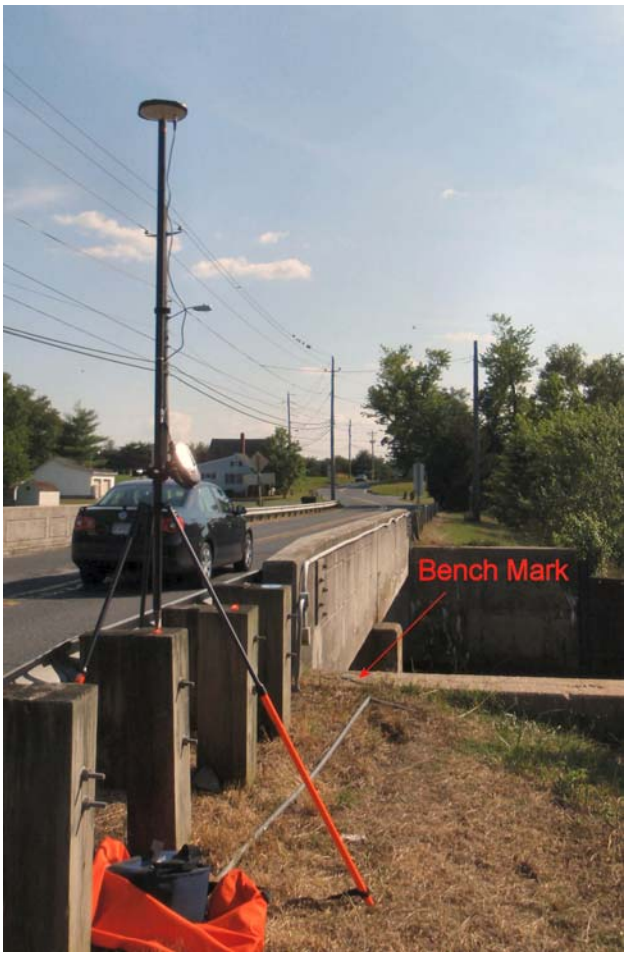

Figure A-3. Frame capture from shoreline video viewed in StoryTeller ®, showing the location of the southern WLR, which was installed on a private dock. The map inset in the upper right corner shows the location of the frame (white circle). See **Methods** in report for discussion on the video documentation of the shoreline.

Table A-1. Survey data for Water Level Recorders.

Bishopville Dam site, Level Survey 6/14/2011

Geoid09, Ortho height (NAVD88)	Height	Pt.	Mid-Stadia (ft)	Elevation, NAVD88		Comments	UTM/NAD83 CORS96, UTM Zone 18, m	
				feet	meters		Easting	Northing
12.38	13.48	#1	1.10			Nail on top of 3rd guard rail post, from end of north end of Bridge	483048.7	4254920
		#2	1.20	12.28	3.74	Nail on top of 2nd guard rail post, from end of Bridge		
		#3	3.73	9.75	2.97	BM on north end abutment of Bridge		
		#4	11.63	1.85	0.56	4-ft nail of WLR stilling well		
95%=0.13				-2.15	-0.66	WLR sensor		

Sansom Dock, Level Survey 6/14/2011

Geoid09, Ortho height (NAVD88)	Height	Pt.	Difference (ft)	Elevation, NAVD88		Comments	UTM/NAD83 CORS96, UTM Zone 18, m	
				feet	meters		Easting	Northing
2.35	2.35	#1	0			Nail on top of dock, over stilling well for WLR	484061.71	4251645
		#2	1.36	0.99	0.30	4-ft nail of WLR stilling well, directly measured from top of dock		
95% = 0.17				-3.01	-0.92	WLR sensor		

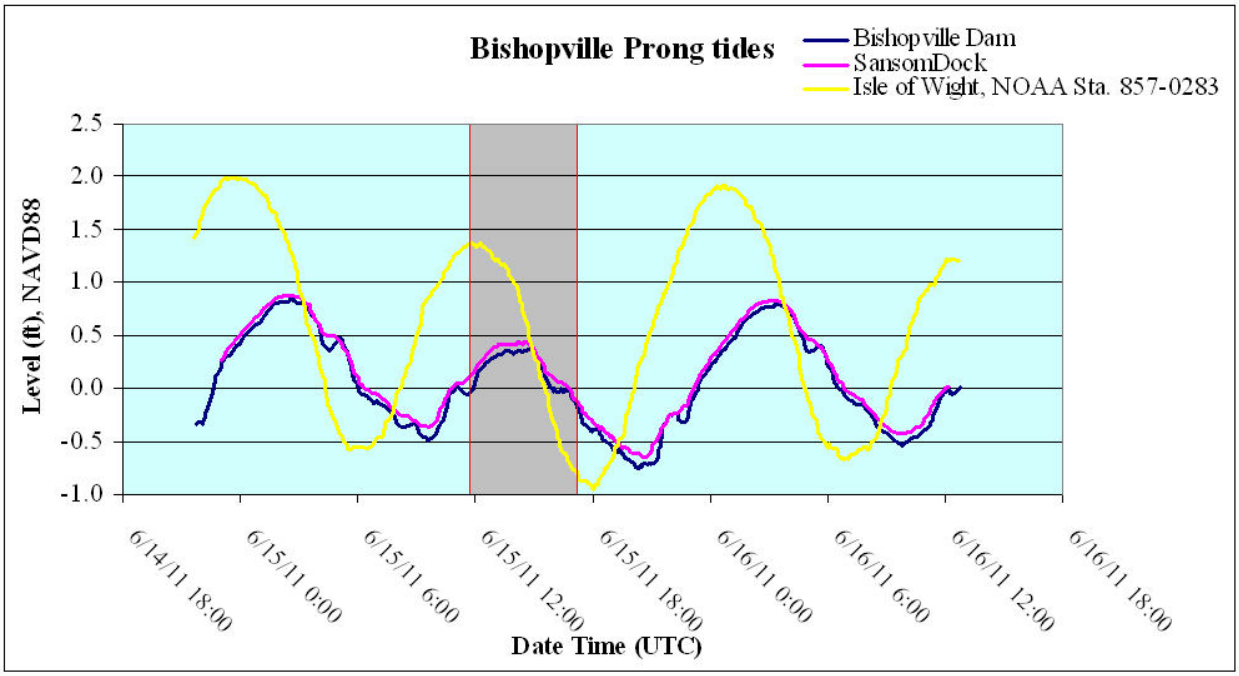

Figure A-4. Water levels collected for this study. For reference, the water levels at NOAA Tide Station #837-0283 , located in Isle of Wight Bay, is shown. The grey window shows the time period during which the hydrographic surveys were conducted.

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3. Bathymetric Modeling

Bathymetric data were interpreted with the Surfer software package. In Surfer, the raw data were processed using four methods: 1) Triangulated Irregular Network (TIN); 2) Kriging; 3) Minimum Curvature; and, 4) Inverse, to create a three-dimensional surface (bottom topography) model. A one-meter regularly spaced grid was then calculated by analyzing the depths on the surface model. The resulting grids were compared visually. Based on the degree of smoothness and overall 'noise' of the gridded rasters, the Kriging method produces the most natural surface.

A second Kriging model was created by applying a 5x Gaussian running average filter to further smooth the model surface. The validity of the models (Kriging-not smoothed and Kriging with smoothing) was analyzed by calculating residuals from the original data points against the modeled surface. After the models were generated, the original data set was compared to each. The amount that the actual raw data differed from the model at the data point's location is the residual for that data point. Residuals were calculated at all measured data points and a root mean square error analysis was performed on these residuals (Table A-5).

Table A-2 . Residual Root-Mean-Square (RMS) Analysis of computed surfaces from kriging, comparing smooth and non-smoothing averaging of sounding data.		
Surface	**Kriging Method**	**Residual RMS (meters)**
	No smoothing	0.0299
	5x Gaussian smoothed	0.0704

APPENDIX B
Sediment Analyses Quality Assurance/Quality Control

1. Textural Analysis

Although the techniques used to determine grain size are based on traditional analytical methods developed for the sedimentology lab, some analytical error is inherent to the techniques. For example, results can be affected by level of technician skill and/or changes in laboratory conditions (such as sudden temperature changes). Furthermore, there is no standard reference material available that includes the broad range of particle sizes and shapes contained in natural sediment. To maximize consistency of textural analysis, several "checks" are used to monitor results. The calculated sand, silt, clay, (and gravel) percentages are checked against 1) sample field descriptions; 2) calculated water contents; and 3) calculated weight loss of sample during cleaning process. These comparisons are made to determine if the size components match the visual description of the sample and/or fall within an expected range of values for water content and weight loss. Any discrepancy is "flagged"and the results are further reviewed to determine if re-analysis is warranted. In addition, new technicians analyze, as their first samples, a suite of randomly selected samples that have been analyzed previously (by an experience technician) and the results are compared.

The criteria for each of the internal checks are as follows:

1) Calculated sand, silt, clay, (and gravel) percentages and Shepard's classification of the sediments are compared to the visual description (both field description and lab description). This criteria is fairly straightforward. If the results indicate an entirely different sample than what was described when collected, then the sample is re-analyzed.

2) Percentages are compared to calculated water contents. Table lists the expected ranges of water content for each sediment type. Mean and ranges are based on sediments collected in Isle of Wight and Assawoman Bays.

3) Sample loss (% dry weight) during cleaning is calculated for each sample. The calculated water content, which usually is measured immediately after the sample is collected, is used to determine weight loss. If the sediment dried out, even slightly, before it was sub-sampled for textural analysis, then the amount of weight loss would be under estimated, and, in some instances, negative. The degree of weight loss during the cleaning process is related to sediment type (grain size) as well as the organic content of the sediment. Organic rich, fine grained sediments (*i.e.*, silty clay and clayey silt) may lose up to 30% dry weight during the cleaning process. Sand, which is fairly clean, usually yields the smallest weight loss, and often shows a negative weight loss due to error inherent to water content determinations. Table B-1 lists the ranges of weight loss percentages for each group of sediments. Mean and ranges are based on sediments collected in Isle of Wight and Assawoman Bays in 1993 for the MCBSMP.

Table B-1. Mean and range of water contents and calculated weight loss after cleaning for each sediment type (Shepard's Classification) based on sediments collected in Isle of Wight and Assawoman Bays (Wells and others, 1994). Means are rounded to nearest whole percentage. Range values are based on standard deviation from the mean.

Sediment Type	Water content (% wet weight)		Weight loss (% dry weight)	
	Mean	Range	Mean	Range
SAND	22	17 - 27	1	-4 - 6
SILTY SAND	39	31 - 47	7	2 - 12
CLAYEY SAND	47	41 - 53	3	0 -6
SANDY SILT	48	42 - 54	13	5 - 21
CLAYEY SILT	60	53 - 67	20	13 - 27
SILTY CLAY	70	67 - 73	28	23 - 33
SAND SILT CLAY	56	49 - 63	13	2 - 24

2. Nitrogen, Carbon and Sulfur Analysis

As part of the QA/QC protocol, SRMs (NIST SRM #1646 - Estuarine Sediment; NIST SRM #2704 – Marine Sediment; and NRCC SRM PACS-2 - Marine Sediment) were used as secondary standards. An SRM was run every 6 to 7 samples (unknowns). Table presents the comparisons of the MGS results and the certified values for total carbon, nitrogen and sulfur contents for the NIST standard. There is excellent agreement between the NIST values and MGS's results. Recoveries with this method generally are 90% or greater based on the certified values. Detection limit for this method is 0.001% for nitrogen, carbon and sulfur.

Table B-2. Results of nitrogen, carbon, and sulfur analyses of the standard reference materials (SRMs) compared to the certified or known values. MGS values were obtained by averaging the results of all SRM analyses run during this study.

Element	CRC SRM PACS-2			NIST SRM 1646a- Estuarine Sediments		
	NIST Values [1]	MGS Results	% Recovery	NIST Values [2]	MGS Results	% Recovery
Total Nitrogen (% dry weight)	0.27 +/- 0.021	0.259 +/- 0.001	95.9	0.059 +/-0.008	0.058 +/-0.001	98.2
Carbon (% dry weight)	3.30 +/- 0.02	3.204 +/- 0.07	97.08	0.587 +/-0.040	0.573 +/-0.001	95.5
Sulfur (% dry weight)	1.29 +/- 0.13	1.276 +/- 0.164	98.9	0.352 +/- 0.004	0.336 +/-0.009	95.4

[1] For SRM PACS-2, the value for sulfur is certified values reported by CRC; nitrogen and carbon values were obtained from repeated analyses in-house and by Actlabs

[2] For NIST 1646a, the value for sulfur is certified by NIST. The values for nitrogen and carbon were obtained from repeated analyses in-house and by other laboratories (Haake Buchler Labs and U.S. Dept. of Agriculture).

3. Elemental Analysis

Table B-3. Quality Assurance / Quality Control Values from elemental analysis by Actlabs. Results of analyses of Standard Reference Material (NIST SRM #8704 - Buffalo River Sediment) submitted as blind unknowns with the surficial samples. Also given are the method detection limits for each element reported by Actlabs.

			NIST Certified Values		**Actlabs Results**		
Element	**Units**	**Detection Limit**	**Conc.**	**Standard Deviation**	**Mean Conc.**	**Standard Deviation**	**% Recovery**
S	%	0.01			0.34	0.0	
P	%	0.001			0.084	0.0	
Cd	ppm	0.3	2.94	0.29	2.70	0.1	91.8
Cr	ppm	1	121.9	3.8	111.3	2.1	91.3
Cu	ppm	1			85	8.2	
Fe	%	0.01	3.97	0.1	4.02	0.1	101.3
Mn	ppm	1	544	21	531	13.9	97.6
Ni	ppm	1	42.9	3.7	46	2.6	107.2
Pb	ppm	3	150	17	127.7	2.1	85.1
Zn	ppm	1	408	15	354	8.9	86.8
Ag	ppm	0.3			0.57	0.1	
Al	%	0.01	6.1	0.18	3.8	0.0	62.5
As	ppm	3	17		15	3.0	88.2
Ba	ppm	7	413	13	380	12.9	91.9
Be	ppm	1			2	0.0	
Bi	ppm	2					

Table B-3. Quality Assurance / Quality Control Values from elemental analysis by Actlabs. Results of analyses of Standard Reference Material (NIST SRM #8704 - Buffalo River Sediment) submitted as blind unknowns with the surficial samples. Also given are the method detection limits for each element reported by Actlabs.

			NIST Certified Values		Actlabs Results		
Element	**Units**	**Detection Limit**	**Conc.**	**Standard Deviation**	**Mean Conc.**	**Standard Deviation**	**% Recovery**
Ca	%	0.01	2.641	0.083	2.807	0.1	106.3
Co	ppm	1	13.57	0.43	13.67	0.6	100.7
Ga	ppm	1			19	1.2	
K	%	0.01	2.001	0.041	1.43	0.1	71.5
Li	ppm	1			40	1.0	
Mg	%	0.01	1.2	0.018	1.14	0.0	95.0
Mo	ppm	1			2.0	0.0	
Na	%	0.01	0.553	0.015	0.553	0.0	100.1
Sb	ppm	5	3.07	0.32			
Sc	ppm	4	11.26	0.19	12	0.0	106.6
Sr	ppm	1			122.3	2.3	
Te	ppm	2			3	1.4	
Ti	%	0.01	0.457	0.02	0.41	0.0	90.4
Tl	ppm	5					
U	ppm	10	3.09	0.13			
V	ppm	2	94.6	4	84	6.1	88.8
W	ppm	5					
Y	ppm	1			23	0.0	
Zr	ppm	5			149	5.6	

Table B-4. Quality Assurance / Quality Control Values from elemental analysis by Actlabs. Results of analysis of Standard Reference Material (NIST SRM #2702 – Marine Sediment: Baltimore Harbor) submitted as blind unknown with the surficial samples. Also given are the method detection limits for each element reported by Actlabs.

			NIST Certified Values		Actlabs Results	
Element	**Units**	**Detection Limit**	**Conc.**	**Standard Deviation**	**Conc.**	**% Recovery**
S	%	0.01	2		1.00	92.7
P	%	0.001	0	0.007	0	78.0
Cd	ppm	0.3	1	0.0	0.6	73.4
Cr	ppm	1	352	22	281	79.8
Cu	ppm	1	117.7	5.6	111	94.3
Fe	%	0.01	7.91	0.24	7.44	94.1
Mn	ppm	1	1757	58	1560	88.8
Ni	ppm	1	75.4	1.5	79	104.8
Pb	ppm	3	132.8	1.1	108.0	81.3
Zn	ppm	1	485.3	4.2	432	89.0
Ag	ppm	0.3			1.2	
Al	%	0.01	8.41	0.22	4.81	57.2
As	ppm	3	45.3	1.8	41	90.5
Ba	ppm	7	397.4	3.2	346	87.1
Be	ppm	1	3		3	
Bi	ppm	2			4	
Ca	%	0.01	0	0.0	0.4	105.0
Co	ppm	1	27.76	0.58	29	104.5
Ga	ppm	1	24.3	1.9	25	
K	%	0.01			1.56	
Li	ppm	1			67	
Mg	%	0.01	0.99	0.074	0.88	88.9
Mo	ppm	1	10.8	1.6	8.0	74.1
Na	%	0.01	0.681	0.02	0.63	92.5
Sb	ppm	5	5.6	0.24	10	178.6
Sc	ppm	4	25.9	1.1	24	92.7
Sr	ppm	1	119.7	3	104	86.9
Te	ppm	2			7	
Ti	%	0.01	1	0.08	1	93.9
Tl	ppm	5	1	0.006	< 5	
U	ppm	10	10		< 10	

Table B-4. Quality Assurance / Quality Control Values from elemental analysis by Actlabs. Results of analysis of Standard Reference Material (NIST SRM #2702 – Marine Sediment: Baltimore Harbor) submitted as blind unknown with the surficial samples. Also given are the method detection limits for each element reported by Actlabs.

			NIST Certified Values		**Actlabs Results**	
Element	**Units**	**Detection Limit**	**Conc.**	**Standard Deviation**	**Conc.**	**% Recovery**
V	ppm	2	357.6	9.2	336	94.0
W	ppm	5			10	
Y	ppm	1			32	
Zr	ppm	5			268	

APPENDIX C
Sediment Data

Table C-1. Location and physical properties data for the surficial sediment samples collected in Bishopville Prong. Samples with Station IDs beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs preceded with "NPS" were samples collected by the National Park Service for another study (Wells, et al., 2012).

Station ID	NAD88, meters		Date Collected	Physical Properties						Sediment Classification	
	Northing	Easting		Water Content (%)	Bulk Density (g/cm^3)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Shepard (1954)	Pejrup (1988)
P1	4255007	482921	6/15/2011	22.59	1.96	0.00	97.95	1.04	1.00	Sand	A,III
P2	4254993	482920	6/15/2011	63.94	1.30	0.00	64.11	22.52	13.36	Silty-Sand	B,III
P3	4254978	482914	6/15/2011	62.68	1.31	0.00	53.57	29.45	16.98	Silty-Sand	B,III
P4	4254939	482934	6/15/2011	69.52	1.24	0.00	10.78	52.23	36.99	Clayey-Silt	C,III
P5	4254924	482964	6/15/2011	81.46	1.13	0.00	6.53	53.85	39.62	Clayey-Silt	D,III
P6	4254912	482998	6/15/2011	82.61	1.12	0.00	2.47	52.16	45.36	Clayey-Silt	D,III
P7	4254934	483034	6/15/2011	78.95	1.15	0.00	35.05	33.81	31.14	Sand-Silt-Clay	C,III
7	4254903	483050	6/16/2011	90.75	1.06	0.00	21.08	40.17	38.75	Sand-Silt-Clay	C,III
8	4254865	483093	6/16/2011	39.05	1.63	11.62	83.74	2.78	1.86	Sand	A,III
9	4254616	483210	6/16/2011	67.04	1.26	0.00	70.88	13.88	15.24	Clayey-Sand	B,II
10	4254342	483369	6/16/2011	40.32	1.61	0.00	87.99	6.07	5.95	Sand	B,III
11	4254027	483374	6/16/2011	86.26	1.10	0.00	12.99	45.47	41.54	Clayey-Silt	C,III
12	4253807	483429	6/16/2011	86.49	1.09	0.00	7.09	33.44	59.48	Silty-Clay	D,II
13	4253414	483385	6/16/2011	39.25	1.62	0.00	91.28	4.20	4.52	Sand	A,II
14	4253239	483463	6/16/2011	32.12	1.75	0.00	92.74	3.18	4.07	Sand	A,II
15	4252962	483515	6/16/2011	69.59	1.24	0.00	47.93	19.40	32.67	Clayey-Sand	C,II
16	4252325	483720	6/16/2011	75.38	1.18	0.00	9.12	31.76	59.12	Silty-Clay	D,II

Table C-1. Location and physical properties data for the surficial sediment samples collected in Bishopville Prong. Samples with Station IDs beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs preceded with "NPS" were samples collected by the National Park Service for another study (Wells, et al., 2012).

Station ID	NAD88, meters		Date Collected	Physical Properties						Sediment Classification	
	Northing	Easting		Water Content (%)	Bulk Density (g/cm^3)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Shepard (1954)	Pejrup (1988)
17	4252027	483783	6/16/2011	78.76	1.16	0.00	4.09	34.72	61.19	Silty-Clay	D,II
18	4251839	483925	6/16/2011	77.13	1.17	0.00	3.16	33.95	62.89	Silty-Clay	D,II
19	4251559	484474	6/16/2011	73.30	1.20	0.00	11.33	33.17	55.51	Silty-Clay	C,II
20	4251797	484660	6/16/2011	74.53	1.19	0.00	4.65	36.58	58.77	Silty-Clay	D,II
21	4251525	484785	6/16/2011	73.28	1.20	0.00	3.23	36.61	60.17	Silty-Clay	D,II
22	4251881	484857	6/16/2011	73.76	1.20	0.00	11.15	34.02	54.84	Silty-Clay	C,II
23	4251515	485080	6/16/2011	73.63	1.20	0.00	6.06	37.26	56.68	Silty-Clay	D,II
24	4251279	484965	6/16/2011	25.95	1.88	0.00	92.61	2.81	4.58	Sand	A,II
25	4251396	485277	6/16/2011	70.54	1.23	0.00	3.87	37.06	59.08	Silty-Clay	D,II
NPS-87	4251721	484249	1/27/2011	67.18	1.26	0.00	59.10	17.69	23.21	Clayey-Sand	B,II
NPS-88	4252564	483647	1/27/2011	79.60	1.15	0.00	22.71	38.91	38.38	Sand-Silt-Clay	C,III
NPS-89	4253619	483446	1/27/2011	22.48	1.96	0.00	98.55	1.30	0.14	Sand	A,IV
NPS-90	4252022	485585	1/27/2011	77.78	1.16	0.00	12.80	44.08	43.13	Clayey-Silt	C,III

Table C-2. Nutrient elements and primary metals of interest for the surficial sediment samples collected in Bishopville Prong. Samples with Station ID beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs beginning with "NPS" were samples collected by the National Park Service for another study (Wells, et al., 2012). Values proceeded by ">" indicate that concentration was below detection limit of the method. Detection limits for all chemical parameters are listed in Table 1.

Station ID	N (%)	C (%)	S (%)	P (%)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
P1	0.021	0.390	0.000	0.003	< 0.3	7	1	0.12	23	3	4	14
P2	0.417	7.641	0.361	0.093	1.45	29.5	22	1.425	224.5	23	32	304.5
P3	0.392	7.481	0.368	0.124	1.5	30	24	1.3	207	23	34	313
P4	0.636	10.072	0.637	0.209	2.5	51	37	1.97	287	40	50	472
P5	0.754	10.730	0.551	0.200	2.9	48	37	2.11	401	37	46	527
P6	0.827	11.746	0.555	0.287	2.5	47	38	2.32	440	37	49	492
P7	0.642	9.084	0.571	0.168	2.3	42	41	1.87	338	35	56	508
7	0.934	10.673	3.354	0.218	1.2	36	35	3.59	163	20	42	284
8	0.073	0.928	0.220	0.010	< 0.3	15	4	0.56	111	4	6	39
9	0.332	4.751	1.704	0.063	0.4	26	17	1.72	208	11	23	130
10	0.173	2.515	0.500	0.045	< 0.3	15	14	0.66	67	6	13	59
11	1.322	20.225	3.168	0.118	0.5	25	17	2.65	78	21	30	151
12	0.925	11.713	4.154	0.147	0.8	31	33	3.85	139	22	35	221
13	0.105	1.325	0.529	0.018	< 0.3	22	7	1	168	5	11	52
14	0.100	1.255	0.509	0.019	< 0.3	18.5	7	0.895	148.5	5	10	51.5
15	0.454	5.730	2.664	0.066	0.6	32	30	2.67	185	20	30	207
16	0.546	7.009	3.538	0.076	0.9	50	38	3.36	253	26	35	236
17	0.622	7.403	3.298	0.084	0.9	51	39	3.48	248	29	31	235
18	0.586	7.259	3.384	0.084	1.1	35	44	3.72	245	31	35	260
19	0.505	5.944	2.851	0.063	0.7	46	37	3.8	292	32	29	216

Table C-2. Nutrient elements and primary metals of interest for the surficial sediment samples collected in Bishopville Prong. Samples with Station ID beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs beginning with "NPS" were samples collected by the National Park Service for another study (Wells, et al., 2012). Values proceeded by ">" indicate that concentration was below detection limit of the method. Detection limits for all chemical parameters are listed in Table 1.

Station ID	N (%)	C (%)	S (%)	P (%)	Cd (ppm)	Cr (ppm)	Cu (ppm)	Fe (%)	Mn (ppm)	Ni (ppm)	Pb (ppm)	Zn (ppm)
20	0.532	6.312	2.877	0.070	0.9	66	44.5	3.95	307	34	32	241.5
21	0.490	5.992	2.820	0.065	0.8	62	40	3.93	334	33	31	231
22	0.504	6.075	2.912	0.064	0.8	88	66	4.02	313	35	31	234
23	0.507	6.570	2.709	0.069	0.8	50	36	3.89	313	33	31	211
24	0.064	0.719	0.271	0.011	< 0.3	25	4	0.75	124	5	7	30
25	0.467	5.922	2.513	0.064	0.6	46	35	3.97	331	34	30	208
NPS-87	0.369	7.104	2.218	0.056	0.9	38	26	2.6	232	22	31	192
NPS-88	0.561	7.062	2.602	0.073	1.3	49	41	3.26	278	27	40	290
NPS-89	0.044	0.641	0.174	0.007	< 0.3	4.5	3	0.18	29	1.5	6.5	12
NPS-90	0.476	5.627	1.799	0.050	0.6	59	36	2.56	266	20	32	160

Table C-3. Ancillary elements for the surficial sediment samples collected in Bishopville Prong. Samples with Station ID beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs beginning with "NPS" were samples collected by the National Park Service for another study (Wells, *et al.,* 2012). Values proceeded by ">" indicate that concentration was below detection limit of the method. Detection limits for all chemical parameters are listed in Table 1.

Station ID	Ag (ppm)	Al (%)	As (ppm)	Ba (ppm)	Be (ppm)	Bi (ppm)	Ca (%)	Co (ppm)	Ga (ppm)	K (%)	Li (ppm)	Mg (%)	Mo (ppm)
P1	< 0.3	0.55	< 3	259	< 1	< 2	0.07	< 1	2	0.64	4	0.03	< 1
P2	< 0.3	2.705	< 3	649.5	2	< 2	0.545	19.5	11	1.375	15	0.16	< 1
P3	< 0.3	2.7	6	659	2	< 2	0.53	17	11	1.39	15	0.15	< 1
P4	0.3	3.69	7	646	3	< 2	0.68	30	16	1.27	26	0.29	< 1
P5	< 0.3	3.65	8	638	3	< 2	0.69	33	16	1.19	27	0.29	< 1
P6	< 0.3	3.38	9	622	3	< 2	0.66	33	16	1	27	0.29	1
P7	< 0.3	3.15	6	631	3	< 2	0.64	31	13	1.08	23	0.26	< 1
7	< 0.3	2.31	26	121	2	< 2	0.72	13	12	0.96	30	0.9	17
8	< 0.3	0.61	< 3	194	< 1	< 2	0.17	2	3	0.53	6	0.13	< 1
9	1.1	1.66	8	321	1	< 2	0.33	7	7	0.97	18	0.29	6
10	0.5	1.2	6	346	< 1	< 2	0.21	3	5	0.93	11	0.15	2
11	0.5	1.88	12	158	2	< 2	0.7	13	10	0.77	25	0.79	4
12	0.3	2.62	8	104	2	< 2	0.61	9	12	0.97	39	0.81	11
13	1.3	1.27	< 3	407	< 1	2	0.2	3	5	1.06	12	0.13	3
14	0.9	1.045	< 3	346	< 1	< 2	0.175	3	5	0.89	10.5	0.12	1.5
15	0.7	2.75	5	130	2	< 2	0.42	10	12	1.24	37	0.57	10
16	0.8	4.55	12	285	2	< 2	0.56	11	15	1.41	52	0.89	7
17	0.4	3.41	11	224	2	< 2	0.55	12	16	1.36	51	0.88	5
18	0.5	3.81	4	157	2	< 2	0.57	13	16	1.45	54	0.9	5
19	0.6	3.77	11	66	2	< 2	0.58	13	19	0.81	53	0.94	7

Table C-3. Ancillary elements for the surficial sediment samples collected in Bishopville Prong. Samples with Station ID beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs beginning with "NPS" were samples collected by the National Park Service for another study (Wells, *et al.*, 2012). Values proceeded by ">" indicate that concentration was below detection limit of the method. Detection limits for all chemical parameters are listed in Table 1.

Station ID	Ag (ppm)	Al (%)	As (ppm)	Ba (ppm)	Be (ppm)	Bi (ppm)	Ca (%)	Co (ppm)	Ga (ppm)	K (%)	Li (ppm)	Mg (%)	Mo (ppm)
20	0.45	4.06	7	120.5	2	< 2	0.65	13	18	0.835	57	1.015	6
21	0.5	4.07	10	184	2	< 2	0.68	14	19	1.14	57	1.04	6
22	0.5	4.18	7	112	2	< 2	0.66	14	18	1.68	53	1	6
23	0.5	4.03	7	274	2	< 2	0.71	13	22	1.64	53	1.01	4
24	1	1.12	< 3	302	< 1	< 2	0.19	2	5	0.83	11	0.14	< 1
25	0.5	4.08	10	175	2	< 2	0.76	14	19	1.07	56	1.07	5
NPS-87	0.7	2.94	8	71	2	< 2	0.59	11	14	1.44	32	0.59	7
NPS-88	0.3	3.46	6	74	2	< 2	0.5	11	17	1.24	49	0.72	8
NPS-89	< 0.3	0.655	< 3	260	< 1	< 2	0.06	< 1	2.5	0.635	5	0.025	< 1
NPS-90	0.4	3.03	9	249	2	< 2	0.48	9	17	1.29	49	0.77	6

Table C-3 (cont.). Ancillary elements for the surficial sediment samples collected in Bishopville Prong. Samples with Station ID beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs beginning with "NPS" were samples collected by the National Park Service for another study (Wells, *et al.,* 2012). Values proceeded by ">" indicate that concentration was below detection limit of the method. Detection limits for all chemical parameters are listed in Table .

Station ID	Na (%)	S (%)	Sb (ppm)	Sc (ppm)	Sr (ppm)	Te (ppm)	Ti (%)	Tl (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Zr (ppm)
P1	0.12	0.01	< 5	< 4	44	< 2	0.07	< 5	< 10	4	< 5	14	70
P2	0.465	0.26	< 5	4.5	117.5	< 2	0.245	< 5	< 10	41	< 5	29.5	60.5
P3	0.47	0.28	< 5	4	120	< 2	0.2	< 5	< 10	38	< 5	28	33
P4	0.39	0.48	< 5	8	106	< 2	0.22	< 5	< 10	61	6	41	54
P5	0.37	0.38	< 5	8	100	< 2	0.2	< 5	< 10	63	6	39	15
P6	0.31	0.45	< 5	8	100	7	0.29	< 5	< 10	71	< 5	37	121
P7	0.33	0.46	< 5	7	103	< 2	0.17	< 5	< 10	57	6	39	79
7	4.55	3.1	< 5	6	134	4	0.29	< 5	20	55	< 5	29	36
8	0.37	0.19	< 5	< 4	43	2	0.22	< 5	< 10	13	< 5	23	120
9	1.11	1.42	< 5	< 4	121	8	0.49	< 5	< 10	35	< 5	28	429
10	0.58	0.42	< 5	< 4	83	< 2	0.2	< 5	< 10	16	< 5	17	214
11	3.05	2.82	< 5	4	121	9	0.26	< 5	10	39	< 5	30	153
12	3.3	3.6	< 5	6	116	< 2	0.29	< 5	10	55	< 5	28	151
13	0.67	0.5	< 5	< 4	109	6	0.55	< 5	< 10	22	< 5	27	514
14	0.54	0.47	< 5	< 4	77.5	5.5	0.45	< 5	< 10	20	< 5	19.5	377.5
15	1.98	2.39	< 5	6	105	3	0.36	< 5	< 10	50	< 5	29	274
16	2.52	2.95	< 5	11	135	< 2	0.36	< 5	< 10	64	< 5	43	165
17	2.68	2.68	< 5	9	107	< 2	0.36	< 5	< 10	68	< 5	28	147
18	2.58	2.92	< 5	10	117	2	0.41	< 5	< 10	71	< 5	31	157
19	2.64	2.85	< 5	10	117	3	0.42	< 5	< 10	75	< 5	29	169

Table C-3 (cont.). Ancillary elements for the surficial sediment samples collected in Bishopville Prong. Samples with Station ID beginning with "P" were collected in Bishopville Pond above the dam; Stations IDs beginning with "NPS" were samples collected by the National Park Service for another study (Wells, *et al.,* 2012). Values proceeded by ">" indicate that concentration was below detection limit of the method. Detection limits for all chemical parameters are listed in Table .

Station ID	Na (%)	S (%)	Sb (ppm)	Sc (ppm)	Sr (ppm)	Te (ppm)	Ti (%)	Tl (ppm)	U (ppm)	V (ppm)	W (ppm)	Y (ppm)	Zr (ppm)
20	2.77	2.92	< 5	11	123.5	< 2	0.42	< 5	< 10	80.5	< 5	29	138.5
21	2.81	2.83	< 5	11	123	3	0.41	< 5	< 10	82	< 5	30	163
22	2.79	2.76	< 5	11	132	2	0.38	< 5	10	80	< 5	32	180
23	2.72	2.66	< 5	11	133	< 2	0.4	< 5	< 10	81	< 5	31	167
24	0.54	0.26	< 5	< 4	70	4	0.35	< 5	< 10	18	< 5	18	338
25	2.81	2.54	< 5	12	132	3	0.43	< 5	< 10	86	< 5	30	167
NPS-87	2.18	2.38	< 5	6	162	4	0.37	< 5	< 10	50	< 5	31	292
NPS-88	2.53	2.82	< 5	8	120	4	0.42	< 5	< 10	68	6	38	149
NPS-89	0.21	0.105	< 5	< 4	53	< 2	0.05	< 5	< 10	4	< 5	2.5	< 5
NPS-90	2.58	1.78	< 5	7	96	4	0.41	< 5	< 10	68	< 5	18	220

APPENDIX D
Flash Drive Contents and Repository

The datasets collected, interpolated, and analyzed in this report are too large to be included in printed format. The digital datasets are archived on an USB flash drive. MGS also maintains a set of these data.

Maryland Geological Survey
2300 Saint Paul Street
Baltimore, MD 21218
(410)554-5500
http://www.mgs.md.gov

Contents of flash drive:

The datasets contained on the USB flash drive are listed below. Descriptions of the datasets, as well as special instructions for viewing specific file formats, are detailed in Table D-1 and in *ReadMe.doc* found in the **\Common\BishopvilleProngStudy** folder on the flash drive.

Table D-1. Listing of dataset associated with this study and transferred on flash drive.

Folder	Content Descriptions
Report	Adobe Portable Document Format (PDF) of this report
Data	X, Y, Z Soundings in ASCII format
	Spreadsheets containing results of textural and chemical analyses of sediment samples
ArcMap	Geodatabase, shapefiles, rasters, etc. in ESRI format (ArcGIS 9.3.1)
SonarWeb	HTML Index to KEB files and viewing in HTML format
Contour Video	Contour video files for Bishopville Prong Shoreline

Knudsen Data- Subbottom seismic records

Open the file Index.html located in the **SonarWeb** folder to access the SonarWeb Index page for viewing the subbottom seismic records collected in Bishopville Prong for this project:

To view the raw (KEB) files, you will have to install the SounderSuite PostSurvey Playback and Printing Program: 'PostSurveySetupV1.60.exe', located in the same folder as this document.

Contour Video

Video may be viewed with any video viewer software. However, to take advantage of the GPS tagged viewing, download Stoyteller ® software from the following Contour website: http://contour.com/software/storyteller and follow instructions for installing. You will be asked to register the software; you do not have to include serial number for the Contour camera. StoryTeller requires that QuickTime 7 be running on your computer.

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APPENDIX E
Bishopville Pond Cores

In June 2013, Roman Jesien collected three sediment cores in Bishopville Pond. The purpose of the cores was to provide additional chemical data on sediments below the pond sediment surface. The cores were collected by manually pushing the core liner (7.1 cm ID aluminum irrigation tubing, or 6.5 cm ID plastic tubing) into the sediment surface to refusal and then extracting the liner containing the sediment plug, and capping the ends of the liner. The locations of the cores are shown in Figure E-1. The cores were given to the Maryland Geological Survey for analyses.

The cores were opened on June 14, 2013, described, photographed and sampled at specific intervals (i.e., top, middle, bottom of core). The core samples were analyzed for textural properties and total nitrogen, carbon and sulfur. The analyses were done using the same methods described in the **Methods** section of this report.

Core logs and results of the sediment analyses are presented in Tables E-1 through E-3. Results are included in discussion in the main report.

Figure E-1. Location of cores collected in Bishopville Pond in June, 2013.

Table E-1. Description and texture and NCS data for Core collected at the head (Upper) of Bishopville Pond.

Date collected: June 11, 2013 | **Coordinates: 38˚ 26.58288' N 75˚ 11.75016'** | **Core length: 53 cm**

Photograph	Core Interval (cm)	Color*	Description	Sample interval (cm)	% H_2O	% Gravel	% Sand	%Silt	%Clay	Nitrogen (%)	Carbon (%)	Sulfur (%)
	0-1	5YR 2/1	Watery floc	0-10	53.00	0.00	71.60	18.97	9.43	0.223	3.966	0.202
	1-5	5YR 3/2	Watery mud									
	5-17	5YR 3/2	Watery, silty mud with sand, and some plant material									
	17-25	10YR 2/2	Dry clayey mud; very 'blocky'									
				20-30	54.70	0.00	6.68	55.12	38.20	0.651	9.113	0.422
	25-35.5	10YR2/2	More watery, clayey mud with plant roots									
	35.5-53	10YR 2/2	Drier clayey mud, roots; petroleum odor	40-50	36.83	0.00	14.47	41.88	43.65	0.787	11.083	0.310

* from Munsell Color Standard, GSA, 1991

Table E-2. Description and texture and NCS data for core collected at mid section of Bishopville Pond**.**

Date collected: 6/11/2013	**Coordinates: 38˚ 26.56596’ N 75˚ 11.70006’**									**Core length: 62 cm**		
Photograph	**Core Interval (cm)**	**Color***	**Description**	**Sample Interval (cm)**	**% H_2O**	**% Gravel**	**% Sand**	**%Silt**	**%Clay**	**Nitrogen (%)**	**Carbon (%)**	**Sulfur (%)**
	0-2	5YR 2/1	Floc; watery silty mud	0-10	70.69	0.00	63.06	22.70	14.25	0.461	7.628	0.268
	2-3	10YR 6/2	Sand layer									
	3-23	5YR 2/2	Watery, silty clay with lots of root and plant material									
	23-45	5YR 2/1	Drier, peaty mud	23-33	64.98	0.00	11.32	48.33	40.36	0.571	8.857	0.652
	45-62	5YR 2/1	Peat with clayey mud, some sand stringers	49-59	68.59	0.00	13.22	41.79	45.00	0.850	12.989	1.054

* from Munsell Color Standard, GSA, 1991

Table E-3. Description and texture and NCS data for core collected in Bishopville Pond near the Dam.

Date collected: 6/11/2013	**Coordinates: 38˚ 26.54802' N 75˚ 11.66988'**	**Core length: 39 cm**

Photograph	**Core Interval (cm)**	**Color***	**Description**	**Sample Interval (cm)**	**% H_2O**	**% Gravel**	**% Sand**	**%Silt**	**%Clay**	**Nitrogen (%)**	**Carbon (%)**	**Sulfur (%)**
	0-1	N1	Watery, organic floc	0-19	34.95	1.41	59.07	27.05	12.47	0.178	3.767	0.082
	1-19	N2 ↓ 5YR 2/1	Silty, very fine sand with lots of organics									
	19-24	5YR 2/2	Sandier (less silts)	19-24	22.32	0.00	79.40	14.31	6.29	0.070	1.578	0.027
	24-39	5Y 2/1	Dry, compact, slightly sand, silty clay; large tuberous root at bottom	24-36	41.09	0.00	52.63	26.18	21.19	0.245	4.230	0.116

* from Munsell Color Standard, GSA, 1991