2017 MOBILE SEDIMENT CHARACTERIZATION REPORT

Penobscot River Phase III Engineering Study

Penobscot River, Maine

Prepared for:

United States District Court
District of Maine

Prepared by:

Amec Foster Wheeler Environment & Infrastructure, Inc.
511 Congress Street
Portland, ME 04101

Project No. 3616166052

Final

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EXECUTIVE SUMMARY

This report describes the results of a sediment characterization study of the Penobscot River Estuary (Estuary) conducted by Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) in 2017. This study was undertaken to better understand the size, location, seasonal movement and composition of the ‘mobile pool’, a term historically used to identify a potentially recurring source of mercury contamination to the system via the recycling of mercury-impacted sediment and wood waste. In 2016, Amec Foster Wheeler conducted a partial geophysical survey of the Estuary that used multiple technologies to map and characterize both suspended and bedded sediments in the Estuary. The 2016 Mobile Sediment Characterization (Amec Foster Wheeler 2017) was limited to select areas in the Estuary. The data collected in 2017 and presented in this report are intended to broaden the focus of the 2016 geophysical survey and to refine the assessment of the volume of sediment in the system potentially requiring remediation and/or impacting the rate of system recovery. A working hypothesis following the 2016 and 2017 field seasons and mobile sediment investigations is that mercury associated with mobile sediment and wood waste continues to redistribute between subtidal, intertidal, and marsh platform sediments in the Estuary. This report focuses on estimating the extent of mobile sediments within the project limits of the Estuary. The mercury content of mobile sediments is evaluated and discussed separately in the 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018a). Data from this report and the 2017 Intertidal and Subtidal Sediment Characterization Report (as well as other Amec Foster Wheeler reports) will be integrated as lines of evidence in support of remedial evaluation for the Estuary. The remedial evaluation is presented in the Alternatives Evaluation Report (Amec Foster Wheeler 2018b) and the Phase III Engineering Study Report (Amec Foster Wheeler 2018c).

This report presents the results of mobile sediment characterization conducted between July 2017 and September 2017. The objectives of this work were to:

- Map and estimate the volume and mass of bedded sediment and wood waste in the system;
- Estimate the mass of sediment and wood waste that appears to move in suspension with tidal cycles;
- Estimate the extent of sediment on intertidal flats that is potentially erodible; and
- Map areas of bedrock, boulders, or hardpan in which sediment and/or wood waste are absent.

The results of this characterization are as follows:

- There appears to be approximately 6.6 million cubic yards or 6.5 million tons ± 2.1 million (wet weight) of material in the system that can be characterized as a mix of bedded sediment and wood waste. Of this total volume, approximately 50% appears to be in accumulations greater than one foot thick;

- There appears to be approximately 40,000 tons ± 10,000 (wet weight) of low density, suspended sediment and wood waste in the system;

- Based on erosional indicator measurements, erosional features ranged from 0.2 feet – 6.6 feet wide and 0.1 foot – 1.0 foot deep; and

- Approximately 22 percent of the subtidal area between Bangor and the southern tip of Verona Island is bedrock/hardpan; approximately 14 percent to 20 percent of the intertidal area between Bangor and Cape Jellison is bedrock or boulders.

Dual-frequency sonar was used to identify and delineate mixtures of sediment and wood waste in suspension in the Estuary. Sub-bottom profiling was used to identify and delineate mixtures of sediment and wood waste on the estuary bed. For each geophysical survey method, coverage was completed along transects to evaluate spatial trends from Bangor to the southern tip of Verona Island.

From the dual-frequency survey, the dual-frequency separation ranged from 0 – 31 feet, with an overall average thickness for the whole study area of approximately 0.41 feet. The total suspended solids concentration (i.e., the concentration of sediment and wood waste in suspension) from material sampled from within this layer ranged between 0.15 – 1.7 grams per liter (g/L) (dry weight) or between 1.6 – 21.0 g/L (wet weight) based on calculations from field measurements. Mercury concentrations in suspended material ranged from 1,340 nanograms per gram (ng/g) to 1,820 ng/g for samples (n = 6) specific to the Orland River and Verona East reaches. The mercury concentration results presented here are restricted to a limited number of stations and should be extrapolated with caution for characterizing suspended sediment and wood waste from throughout the Orland River and Verona East reaches or overall for the Estuary. These data have been used to estimate the volume and chemical characteristics of material detected by the dual-frequency survey to assess the significance of this suspended material in remedial evaluation and design.

The material identified through sub-bottom profiling was determined to be substantially composed of bedded sediment and wood waste. The mixture of bedded sediment and wood waste appeared to range from 0 – 6 feet in thickness throughout the area surveyed and was on average 0.6 feet thick.

Wood waste is highly saturated, leading to significant differences in dry weight versus wet weight densities. Dry weight densities for samples of bedded sediment and wood waste ranged from 170 – 800 kilograms per cubic meter (kg/m^3). Wet weight densities for samples of bedded sediment and wood waste ranged from 900 – 1,330 kg/m^3. The difference in dry weight versus wet weight density has implications for remedial evaluation and design.

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ACRONYMS AND ABBREVIATIONS

%	Percent
Amec Foster Wheeler	Amec Foster Wheeler Environment & Infrastructure, Inc.
AOI	Area of Interest
Court	US District Court for the District of Maine
DEP	(Maine) Department of Environmental Protection
EGAD	(Maine) Environmental Geographic Analysis Database
g/L	grams per liter
GIS	Geographic Information Services
kg/m^3	kilograms per cubic meter
kHz	kilohertz
ng/g	nanograms per gram
PRMSP	Penobscot River Mercury Study Panel

1.0 INTRODUCTION

In January 2016, the US District Court for the District of Maine (the Court) selected Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) to conduct the Phase III Engineering Study for the Penobscot River Estuary (Estuary). The purpose of this study is to identify and evaluate potential remedial options for mercury impacts to Estuary. The area under remedial evaluation includes the main stem of the lower Penobscot River from the site of the former Veazie Dam (upstream) to Upper Penobscot Bay (at the mouth of the river), as well as Mendall Marsh and the Orland River (**Figure 1-1**).

This report presents the results of additional characterization of the Estuary conducted between July 2017 and September 2017. This characterization was undertaken to:

- Map and estimate the volume and mass of bedded sediment and wood waste in the system;
- Estimate the mass of sediment and wood waste that appears to move in suspension with tidal cycles;
- Estimate the extent of sediment on intertidal flats that is potentially erodible; and
- Map areas of bedrock, boulders, or hardpan in which sediment and/or wood waste are absent.

Work undertaken in 2017 and presented herein expands on the geophysical evaluation undertaken in 2016 and presented in the 2016 Mobile Sediment Characterization Report (Amec Foster Wheeler 2017). As compared to 2016 geophysical data, 2017 data expand both the spatial extent of mapping and the timing of sampling to allow comparison of spring freshet conditions (2016) versus late summer conditions (2017) in the Estuary. Where possible, the 2017 geophysical surveys overlapped survey lines completed in 2016. This overlap allowed for (limited) data comparison between the 2016 and 2017 surveys.

Regarding terminology, the term ‘mobile muds’ was defined in the Phase II Study based on the color of sediment samples. In this classification, ‘mobile’ material is identified as being brown in color and more oxidized than non-mobile (black) materials (Chapter 8; PRMSP 2013). In the Phase II Study, the term ‘mobile pool’ was used to define a recently deposited, light colored unconsolidated mud that is ‘remobilized and redistributed by changes in the hydrodynamic forcing conditions through the year’ (Chapter 7; PRMSP 2013). Amec Foster Wheeler geophysical surveys use non-visual, acoustical methods to identify materials (i.e., mineral sediment and/or wood waste) in the Penobscot system that have distinct physical properties. In terms of characterization, materials identified by geophysical methods may overlap with materials identified visually in the Phase II Study, but the techniques employed are sufficiently different that this overlap is not exact. For example, while material identified by dual-frequency mapping (presented in Section 2.1) is 'mobile' in the sense that the material is in suspension in the water column, this material is not an exact equivalent to material identified visually in the Phase II Study as 'mobile pool' material. Likewise, material identified by sub-bottom profiling (presented in Section 2.2) is located on the sediment bed, and is, in places, enriched in sediment and/or wood waste that may contribute material to a more 'mobile' fraction through erosion and/or the breakdown of wood waste into smaller particles that can redistribute in the system.

This Report is organized as follows:

- Section 1.0 - Introduction presents the purpose and organization of this report.
- Section 2.0 – Geophysics and Suspended Material Collection presents the scope and methods and summarizes geophysical and suspended material collection results (Work Order 4A–60 Task 1).
- Section 3.0 – Mass and Volume Estimations summarizes mass and volume estimates of suspended and bedded sediment and wood waste in the Estuary.
- Section 4.0 – Erosional Indicator Measurements summarizes the evaluation of the stability of potentially erodible sediments in intertidal and shallow subtidal zones (Work Order 4A-60 Task 2).
- Section 5.0 – Estimation of Bedrock, Boulder, or Hardpan Areal Extent identifies areas where bedrock, boulders or hardpan are present and would impede in-water construction work (Work Order 4A–60 Task 3).
- Section 6.0 – Summary of Findings presents current understanding of the distribution, characterization, volume and mass estimates for mobile sediments in the system.
- Section 7.0 – References provides references for documents cited in this report.

2.0 GEOPHYSICS AND SUSPENDED MATERIAL COLLECTION

Geophysical field work completed in July 2017 focused on geophysical surveys to further characterize the estuary bed beyond characterization completed in 2016. For these surveys, dual-frequency sonar and sub-bottom profiling were used to identify and delineate mixtures of potentially mobile sediment and wood waste in the system. Based on differences in acoustical properties between suspended material and bedded material, dual-frequency sonar was used to identify material in suspension, while sub-bottom profiling was used to identify material on the sediment bed. For each geophysical survey method, data were collected over survey transects from Bangor to the southern tip of Verona Island. Geophysical survey data were verified by ground-truth sampling of suspended particulate matter and bed sediment. Ground-truth sampling of suspended particulate matter is included in this report. Ground-truth sampling of bed sediment included grab sampling presented in this report as well as sediment coring conducted under a parallel field program and detailed in the 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018a). Geophysical survey details, supporting methods, calculations and summary findings are included in **Appendix A-1**.

During field surveys, dual-frequency data were processed daily to identify areas of interest (AOI) and water column depths for collection and identification of suspended material (discussed in Section 2.4). Where practical, samples of the suspended material (identified as a mix of mineral sediment and wood waste) were collected and analysed for total suspended solids (standard method 2540D), total mercury (adjusted method 7474-1631), and total organic carbon (Lloyd Khan method). Likewise, where practical, samples of bedded sediment were collected by ponar grab. Due to time restraints and site conditions, no suspended material collection occurred north of Frankfort Flats. Overall, based on visual observation of suspended material, samples were comprised of wood waste without other identifiable organic constituents (e.g., leaves, macroalgae).

Dual-frequency surveying were conducted daily on the flood or high tide to allow for consistent characterization of flow dynamics that influence the transport of suspended material (**Table 2-1**). Sub-bottom profile surveying of bedded sediment was conducted across the range of tidal conditions (e.g., ebb, low, flood, and high tides). Based on site understanding, it was assumed that while sediments detected by sub-bottom profiling are potentially mobile on seasonal and/or annual timescales, significant mobility of bedded sediment is not expected to occur on the timescale of daily (tidal) survey activities. Overall, geophysical surveys conducted by each of the two methods included approximately 248 transects and covered approximately 134 survey miles (**Table 2-1**).

2.1 DUAL-FREQUENCY MAPPING

The dual-frequency technique was used to estimate the thickness of a layer of suspended material in the water column as determined by the magnitude of the dual-frequency separation. The dual-frequency separation represents the difference between two acoustical returns: a return detected at a 200 kilohertz [kHz] frequency and a return detected at a 33 kHz frequency. The 200 kHz return can be associated with a layer of low density suspended material; the 33 kHz return can be associated with the surface of soft bedded sediment. Overall for the 2017 survey, the dual-frequency separation ranged from 0 feet to 31 feet (**Figure 2-1**) and was most significant in the Orrington reach. In contrast, in 2016, the dual-frequency separation ranged from 0 feet to 22 feet and was most significant in the Frankfort Flats reach. The greater dual frequency separation recorded in 2017 may be due to seasonal effects; the 2016 survey was conducted under freshet (spring) conditions while the 2017 survey was conducted under lower flow conditions in the late summer and early fall. While the ability to compare 2016 and 2017 geophysical survey data is limited by the lower spatial coverage of the 2016 surveys, the Phase II Study also reported elevated suspended sediment concentrations in the Orrington reach during late summer (PRMSP 2013). For 2017 data, the overall average dual-frequency separation for the study area was approximately 0.41 feet. Data presented in **Figure 2-1** were created by kriging field survey data (included in **Appendix A-2.2**). Kriging is a geostatistical procedure that uses statistical relationships between data points to generate an estimated or smoothed data surface. Kriging is commonly used to evaluate spatial patterns in data by interpolating data values for locations in which data are not available. Detailed evaluation of the dual-frequency data is included in **Appendix A-1**.

2.2 SUB-BOTTOM MAPPING

Sub-bottom mapping uses acoustical methods to generate high-resolution (on the order of 0.5-1 foot) cross-sectional images of the sub-bottom of the estuary bed. With a sub-bottom profiler, transmitted sound pulses travel through the water column and sediment and are reflected back toward the surface when density differences in bedded material are encountered. **Figure 2-2** presents the results of the sub-bottom mapping of the first boundary or interface consistently encountered in surveying. This boundary – identified as 'Reflector 1' – defines the thickness of a surficial bedded material layer that ranges from 0 – 6 feet thick throughout the area surveyed and is, on average, 0.6 feet thick. For the sub-bottom mapping, data coverage extending into the intertidal zone occurred where possible, but was limited by the minimum water depth necessary for the survey equipment. Delineation of the survey limit boundary is presented on **Figure 2-2**. Additional evaluation and characterization of sediments within intertidal mudflats is discussed in Section 4.0. Data presented in **Figure 2-2** were created by kriging field survey data (included in **Appendix A-2.3)** as described in Section 2.1 (Dual-frequency Mapping). The material identified as 'Reflector 1' is characterized as a mixture of bedded sediment and wood waste. The field coring program under which Reflector 1 material was more fully characterized is detailed in the 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018a). Further discussion of bedded sediment and wood waste is included in the Alternatives Evaluation Report (Amec Foster Wheeler 2018b) and Phase III Engineering Study Report (Amec Foster Wheeler 2018c). Detailed evaluation of sub-bottom profiling data is included in **Appendix A-1**.

Evidence of localized mobility of the material identified through sub-bottom profiling was observed in the vicinity of Bucksport for a feature identified in the 2016 geophysical survey as the 'Bucksport Mill Pile' (**Appendix Figure A-2**). While this discrete feature appears to have moved upgradient in the deeper water channel in 2017 relative to its position in 2016, other deposits of Reflector 1 material characterized as bedded sediment and wood waste appear generally to be in consistent locations between 2016 and 2017. This suggestion of the general large-scale stability of these deposits is based on observations of surface deposits of bedded sediment and wood waste in Frankfort Flats, Bucksport and Verona East seen in both the 2016 and 2017 geophysical surveys.

Overall, the extent to which bedded deposits identified through sub-bottom profiling are mobile cannot be confirmed without further sampling/surveying, although it is likely that these accumulations are somewhat erodible and contribute material to suspension in the water column. The long-term stability of these bedded deposits was assessed through evaluation of mercury profiles in sediment cores collected from within the footprint of the deposits. Results of this evaluation are presented in the Alternative Evaluation Report (Amec Foster Wheeler 2018b).

2.3 COMPARATIVE EVALUATION OF DUAL-FREQUENCY AND SUB-BOTTOM DATA

Spatial relationships between dual-frequency and sub-bottom survey data are presented in **Figure 2-3** through **Figure 2-9**. For each figure, the phase of the tide and sub-bottom imagery are also presented. For the data presented in **Figure 2-3** through **Figure 2-9**, no consistent visual relationship is apparent between the results of the two survey methods.

Potential measurement overlap likely occurs between dual-frequency and sub-bottom survey data because of the continuity between the "base" of the water column and the "top" of the sediment bed. The extent of overlap between data generated by these two survey methods is relevant for estimating volumes and masses as well as for quantifying uncertainty in these estimations (discussed further below). Based on the known resolution of each survey method (i.e., 0.1 feet for dual-frequency and 0.5-1 feet for sub-bottom), the overlap in measurement between these survey methods is assumed to be 0.5 feet. Uncertainty associated with this overlap in measurement is assumed to be low.

2.4 SUSPENDED MATERIAL COLLECTION

Suspended material sampling was undertaken to evaluate the material identified in the 2016 and 2017 dual-frequency geophysical survey programs. The material identified by the dual-frequency survey appears to be in suspension and was not previously well characterized. Characterization of this material is important for evaluating its contribution to the volume of mobile material in the Estuary and the potential significance of this material as a remedial target. As such, sampling was undertaken to evaluate composition and concentration in suspension, as well as for analysis of total mercury in recovered samples.

For this sampling, the geophysical survey data were used to identify locations of significant dual-frequency separation between the 200 kHz and 33 kHz frequencies. After daily, partial processing of the dual-frequency data to identify areas with greatest dual-frequency separation, select locations were targeted for suspended material sampling. Sampling of the suspended material was completed at approximately the same tidal phase as the dual-frequency survey, although on a different day due to time and schedule constraints. Sampling results and observations are presented in **Figure 2-10**. As station locations targeted for suspended material sampling were based on partial (daily) data processing, not all locations in **Figure 2-10** are consistent with areas of greater dual-frequency separation as determined following full data processing (and presented in **Figure 2-1**).

A water quality sonde was used to evaluate temperature, salinity, and turbidity at each of the sampling locations. Elevated water column turbidity was detected at stations AOI-OR-1, AOI-20, AOI-21, and AOI-29 (**Figure 2-10**) at a distance of approximately 2 feet from the sediment surface. Maximum turbidity readings at these locations ranged from approximately 700 – 2,000 nephelometric turbidity units. Turbidity measurements sometimes varied significantly and abruptly with depth at individual sampling stations, suggesting that the suspended material being characterized was compositionally variable (versus representing material of a more uniform suspension) (**Appendix B**). Likewise, variability also existed between turbidity measurements as determined by the water quality sonde and direct measures of total suspended solid concentration (described further below). The variability between these two data sets suggests that the optical measure of suspended particulate material may capture variability in the composition of suspended material that includes wood waste.

For the characterization of total suspended solids, three methods were used to collect suspended material: a rigid pole and hose assembly; a weighted hose and pump assembly; and deployment of a near-bottom sampling net.

Initially, rigid aluminum poles were used to support a hose that was lowered to a target sampling depth. Once at the target sampling depth, suspended material was pumped to the deck of the survey vessel. This technique was limited in effectiveness at high flow velocity.

At each station where the weighted hose and pump assembly was employed, the hose was lowered simultaneous with the water quality sonde until the sonde registered elevated turbidity; at that water depth suspended material was pumped to a sieve stack on the deck of the vessel. Based on the pumping rate, time of deployment, and wet or dry weight of material captured in the sieve stack or directly from the hose, the concentration of total suspended solids was calculated. As determined from the wet weight measure of material recovered in the sieve stack, the wet weight for total suspended solid concentrations ranged from 1.6 grams per liter (g/L) to 21.0 g/L, with an average of 11.3 g/L; as determined from the dry weight of material recovered in the sieve stack, the dry weight for total suspended solids ranged from 0.15 g/L to 1.7 g/L and averaged 1.0 g/L (**Table 2-2**). Calculations used to determine total suspended solid concentrations are presented in **Appendix A-1**. Flow diagrams illustrating the process of evaluating total suspended solids are provided in **Table A-6** through **Table A-8**.

For stations AOI-20, AOI-21, and AOI-OR-1 (**Figure 2-10**), suspended material recovered via grab sampling was characterized by total organic carbon ranging from 28% to 40%, and mercury concentrations ranging from 1,340 nanograms per gram (ng/g) to 1,820 ng/g. For context, these concentrations of total mercury in suspended material are higher than concentrations in Orland River surface sediments reported in the 2017 Marsh Platform Sediment Characterization (Amec Foster Wheeler 2018d), as well as higher than concentrations in the majority of Verona East surface sediments reported in the 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018a).

The mercury concentration results presented here are restricted to a limited number of stations (n = 6) and should be extrapolated with caution for characterizing suspended sediment and wood waste from throughout the Orland River and Verona East reaches or overall for the Estuary. These data have been used to estimate the volume and chemical characteristics of material detected by the dual-frequency survey to assess the significance of this suspended material in remedial evaluation and design. Characterizing the mercury concentration of material in suspension is relevant to the working hypothesis that mercury associated with mobile sediment and wood waste continues to redistribute between subtidal, intertidal, and marsh platform sediments in the Estuary. The relationship between mercury concentrations in suspended sediment and wood waste and corresponding bedded material may provide information pertaining to the deposition/cycling of suspended materials in the Estuary. This relationship between bedded and suspended material is discussed in the Alternatives Evaluation Report (Amec Foster Wheeler 2018b).

Dual-frequency data from the Bucksport, Bucksport Thalweg, and Verona West reaches of the Estuary were ground-truthed with a stream bed sampling net. The sampling net (1 ft^2 opening; 500 micron mesh) was lowered on a weighted line to a depth approximately one foot above the sediment surface and left in place for a timed deployment. The concentration of total suspended solids calculated from the timed deployment was 0.1 - 0.2 g/L. At station AOI-25, deployment of the sampling net for 10 minutes resulted in the collection of approximately 6 gallons of wood waste. The wood waste was medium brown, uniform in composition, and visually similar to what was observed and reported in the 2016 Sediment Characterization Report (Amec Foster Wheeler 2017).

Further details on sampling methods and results are provided in **Appendix A-1;** water quality sonde data are provided in **Appendix B**. Field data records from sampling activities are included in **Appendix C-1** and a photographic log of sample collection is presented in **Appendix D-1**.

3.0 MASS AND VOLUME ESTIMATIONS

To estimate the mass and volume of the mixture of sediment and wood waste in the system, samples were analyzed for moisture content to allow calculation of both wet and dry weight densities. For these calculations, samples were selected to span a range of potential sediment compositions/mixtures from dominantly mineral sediment to dominantly wood waste. Wet weight and dry weight densities were calculated following the American Society for Testing and Materials (ASTM) method D7263 (ASTM 2009). **Table 3-1** presents the results of wet weight and dry weight density measurements. The samples included in **Table 3-1** were selected from sediment cores associated with the 2017 coring program as presented in the 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018a). Samples were selected from this coring program because material recovered in cores was confirmed as representing accumulations of bedded sediment and wood waste.

For these samples, wet weight densities ranged from approximately 900 – 1,330 kilograms per cubic meter (kg/m^3) and dry weight densities ranged from approximately 170 – 800 kg/m^3 (**Table 3-1**). The average calculated dry density (i.e., 566 kg/m^3) is consistent with the assumed dry density (500 kg/m^3) applied in the Phase II Study Report to estimate the mass of the 'mobile pool' (PRMSP 2013). As evident in **Table 3-1**, the moisture content of these samples exceeded 100%, and for samples identified as primarily wood waste, exceeded 800%. The moisture content presented here is reported with respect to dry weight and represents the weight of water as a percentage of the dry solid sample. Thus, a moisture content exceeding 800% indicates that wood waste can absorb an amount of water more than eight times its dry weight. Source data for moisture content and density calculations are provided in **Appendix C** of the 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018a).

Table 3-2 presents a summary of volume and mass estimates for sediment and wood waste mixtures assessed through the 2016 – 2017 dual-frequency and sub-bottom profiling surveys. Estimates presented in **Table 3-2** are specific to the time period and hydrodynamic conditions encountered during data collection and should be extrapolated with caution to other time periods, seasons, or hydrodynamic conditions in the Estuary. Supporting information for estimates presented in **Table 3-2** is included in **Appendix A-1**.

For material in suspension, the data underlying **Figure 2-1** were used as the basis for calculations. For this material, the area defined by the survey was multiplied by the interpolated dual-frequency separation layer thickness to determine an estimated volume of material. Based on this calculation, there is approximately 40,000 tons ± 10,000 (wet weight) of suspended material in the system. The resolution of the dual-frequency survey equipment (i.e., 0.1 feet) was used to quantify uncertainty around this estimated volume of material. This material sampled in the water column appears to be a mixture of sediment and wood waste and, overall, represents a small fraction of the mass of mixed sediment and wood waste in the Estuary (further discussion below).

For bedded material, the 2017 sub-bottom profiling survey identified an estimated 6.5 million tons ± 2.1 million tons (wet weight) of material characterized by the Reflector 1 return as a mixture of bedded sediment and wood waste. In terms of volume, this mass is equivalent to 6.6 million cubic yards of material. The data underlying **Figure 2-2** were used as the basis for these calculations. For this material, the area defined by the survey was multiplied by the interpolated sub-bottom layer thickness of Reflector 1 to determine the volume. This estimated volume potentially includes an overlap between survey methods of 0.5 feet (as described in Section 2.3) which corresponds to the uncertainty range estimate of 2.1 million tons. Approximately 50% of the material identified by Reflector 1 in the sub-bottom survey is found in accumulations greater than one foot thick.

4.0 EROSIONAL INDICATOR MEASUREMENTS

The objective of this task was to provide an estimated measurement of the dimensions of erosional rivulets in soft sediments in intertidal and shallow subtidal areas. Visual observations and measurements are summarized in **Appendix A-1**. Field data records for this task are included in **Appendix C-2**.

Table 4-1 presents a summary of erosional indicator measurements collected during a single point in time. For the areas surveyed, erosional features ranged from 0.2 feet to 6.6 feet wide and 0.1 feet to 1.0 foot deep. These measurements were recorded from September 23-27, 2017 during a period in which there had been no significant storm activity within the preceding month. Collection of the erosional measurements during a relatively stable weather period likely provides a conservative estimate of the extent to which intertidal sediments are erodible over annual conditions in the Estuary. The erosional features measured in this survey likely result from a combination of factors including coastal runoff and tidal action, both of which may be responsible for the resuspension and redistribution of sediment within intertidal and shallow subtidal areas.

On average, the upper 0.3 feet (9 cm) of the intertidal areas studied may be susceptible to erosion based on field measurements of rivulet depth. Applying the average depth measurement uniformly over the intertidal area in the Estuary, a volume of approximately 1.1 million cubic yards of soft sediment may be susceptible to erosion. This volume calculation likely overestimates the intertidal area susceptible to erosion and so may be biased high. Likewise, in application of the average erosional depth measurement to the calculation, there is the potential for bias resulting from an incomplete characterization of erosional depth system-wide. Further characterization of sediment stability in the intertidal zone is included in the Thin Interval Core Sampling Report (Amec Foster Wheeler 2018e), the Alternatives Evaluation Report (Amec Foster Wheeler 2018b) and the Phase III Engineering Study Report (2018c).

5.0 ESTIMATION OF BEDROCK, BOULDER, OR HARDPAN AREAL EXTENT

The objective of this task was to estimate the areal extent of bedrock, boulders and hardpan in the Estuary to support the evaluation of remedial alternatives. **Figure 5-1** presents the areas that have been interpreted as bedrock or hardpan in the subtidal zone, and as bedrock or boulder coverage in the intertidal zone. These areas either lack soft sediment and/or wood waste (i.e., bedrock or hardpan bottom) or represent locations in which the presence of boulders would limit the ability to remove soft sediment and/or wood waste if present. Details of the methods and analysis used for estimation of bedrock, boulder or hardpan areal extent in the subtidal and intertidal zones are included in **Appendix A-1**. Photographs taken during field surveys are included in **Appendix D-2**.

For subtidal areas, locations with exposed bedrock or an absence of soft sediment were identified based on the sub-bottom profiling data. Data from the Phase II Study grab sample sediment classifications (PRMSP 2013), MEDEP Environmental and Geographic Analysis Database sediment sample classifications as of 2017 (EGAD 2017), and Amec Foster Wheeler 2016 side-scan sonar bottom characterizations (Amec Foster Wheeler 2017) were used to confirm the characteristics of the 2017 subtidal exclusion areas. Areas dominated by bedrock or hardpan were generally observed in the main channel between Bangor and Frankfort Flats and in the Verona West reach (**Table 5-1**).

Intertidal areas were evaluated for the presence of bedrock or boulders using Geographic Information System (GIS) analysis and field-based observations and analyses (**Table 5-1**). For the GIS analysis, bedrock or boulder coverage was evaluated at a 1:1,000 scale using high-resolution National Oceanic and Atmospheric Administration low tide exposure aerial imagery.

Overall, approximately 22 percent of the subtidal zone between Bangor and South Verona Island was identified as bedrock or hardpan and between 14 percent and 20 percent of the intertidal zone between Bangor and Cape Jellison was classified as having bedrock or boulder coverage (**Table 5-1**). The intertidal zone of the Bucksport Thalweg and Verona West reaches appears to substantially lack soft sediment and/or wood waste. Bedrock or boulder coverage in these areas is 100% for Bucksport Thalweg and 50% for Verona West. The areal extent of subtidal and intertidal exclusion within each reach will be applied to the evaluation of remedial alternatives in the Alternatives Evaluation Report (Amec Foster Wheeler 2018b).

6.0 SUMMARY OF FINDINGS

The dual-frequency survey identified suspended material that was, on average, 0.41 foot thick throughout the surveyed area and reached 31 feet thick in the Orrington reach. For the material identified through the dual-frequency survey, the concentration of total suspended solids ranged from 0.15 g/L to 1.7 g/L (dry weight) or from 1.6 g/L to 21.0 g/L (wet weight). The total calculated mass of suspended material was approximately 40,000 tons ± 10,000 (wet weight) and grab samples of this material confirmed that it contained abundant wood waste. The total mercury concentration in samples (n = 6) of suspended material from the Orland River and Verona East reaches ranged from 1,340 ng/g to 1,820 ng/g. Understanding the mercury concentration of material in suspension is relevant to the working hypothesis that mercury associated with mobile sediment and wood waste continues to redistribute between subtidal, intertidal, and marsh platform sediments in the Estuary.

The sub-bottom profiling survey identified a layer of material (defined by Reflector 1) that ranged from 0 to 6 feet thick throughout the area surveyed and is, on average, 0.6 feet thick. Confirmation sampling of this material characterized it as a mixture of bedded sediment and wood waste. The total calculated volume of material identified by Reflector 1 was approximately 6.6 million cubic yards and the total calculated mass was approximately 6.5 million tons ± 2.1 million (wet weight). Approximately 50% of this material characterized as a mixture of bedded sediment and wood waste appears to be in accumulations greater than one foot thick.

The wet weight density of samples of sediment and wood waste ranged from 900-1,330 kg/m^3; the dry weight density ranged from 170-800 kg/m^3 (**Table 3-1**). Wood waste is highly saturated; both wet weight and dry weight densities should be considered during remedial evaluation and design.

While bedded deposits of sediment and wood waste may be generally stable on seasonal and/or annual timescales, there is evidence of mobility in the Bucksport Mill Pile, a bedded deposit that shifted in location between 2016 and 2017 (**Appendix Figure A-2).** Overall, the extent to which bedded deposits identified through sub-bottom profiling are mobile cannot be confirmed without further sampling/surveying, although it is likely that these accumulations of material are somewhat erodible and contribute material to suspension and transport in the water column.

Erosional features in the intertidal zone ranged from 0.2 feet to 6.6 feet wide and 0.1 foot to 1.0 foot deep. On average, the upper 0.3 feet (9 cm) of the intertidal area studied may be susceptible to erosion. Applying this average depth measurement uniformly over the intertidal zone system-wide suggests a total volume of approximately 1.1 million cubic yards of soft sediment may be susceptible to erosion. This volume calculation likely overestimates the intertidal area in the system and so may be biased high. Likewise, in application of the average erosional depth measurement to the calculation, there is the potential for bias resulting from an incomplete characterization of erosional depth system-wide. Erosional measurements were recorded during a period in which there had been no significant storm activity within the preceding month. Collection of the erosional measurements during a relatively stable weather period likely provides a conservative estimate of the extent to which intertidal sediments are erodible over annual conditions in the Estuary.

Based on the 2017 sub-bottom survey data, areas dominated by bedrock or hardpan were generally in the main channel between Bangor and Frankfort Flats and in the Verona West reach. Overall, approximately 22 percent of the subtidal zone between Bangor and South Verona Island is characterized as bedrock or hardpan. Based on a combination of GIS and visual observation, approximately 14 percent to 20 percent of the intertidal zone between Bangor and Cape Jellison can be classified as bedrock or boulder coverage.

Data from this report will be integrated with data from other Amec Foster Wheeler reports to develop lines of evidence in support of remedial evaluation for the Estuary. The remedial evaluation is presented in the Alternatives Evaluation Report (Amec Foster Wheeler 2018b) and the Phase III Engineering Study Report (Amec Foster Wheeler 2018c).

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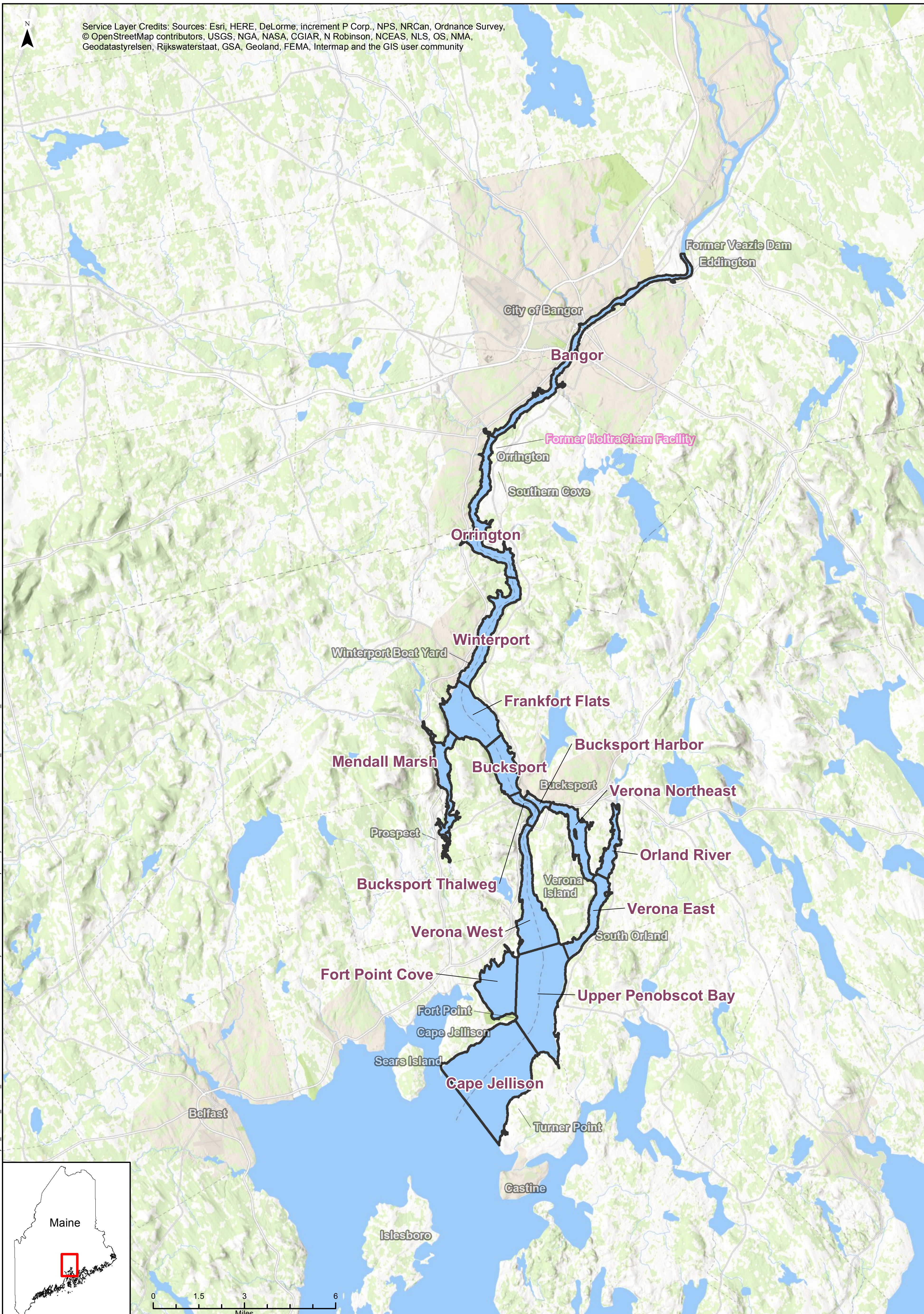
FIGURES



Legend

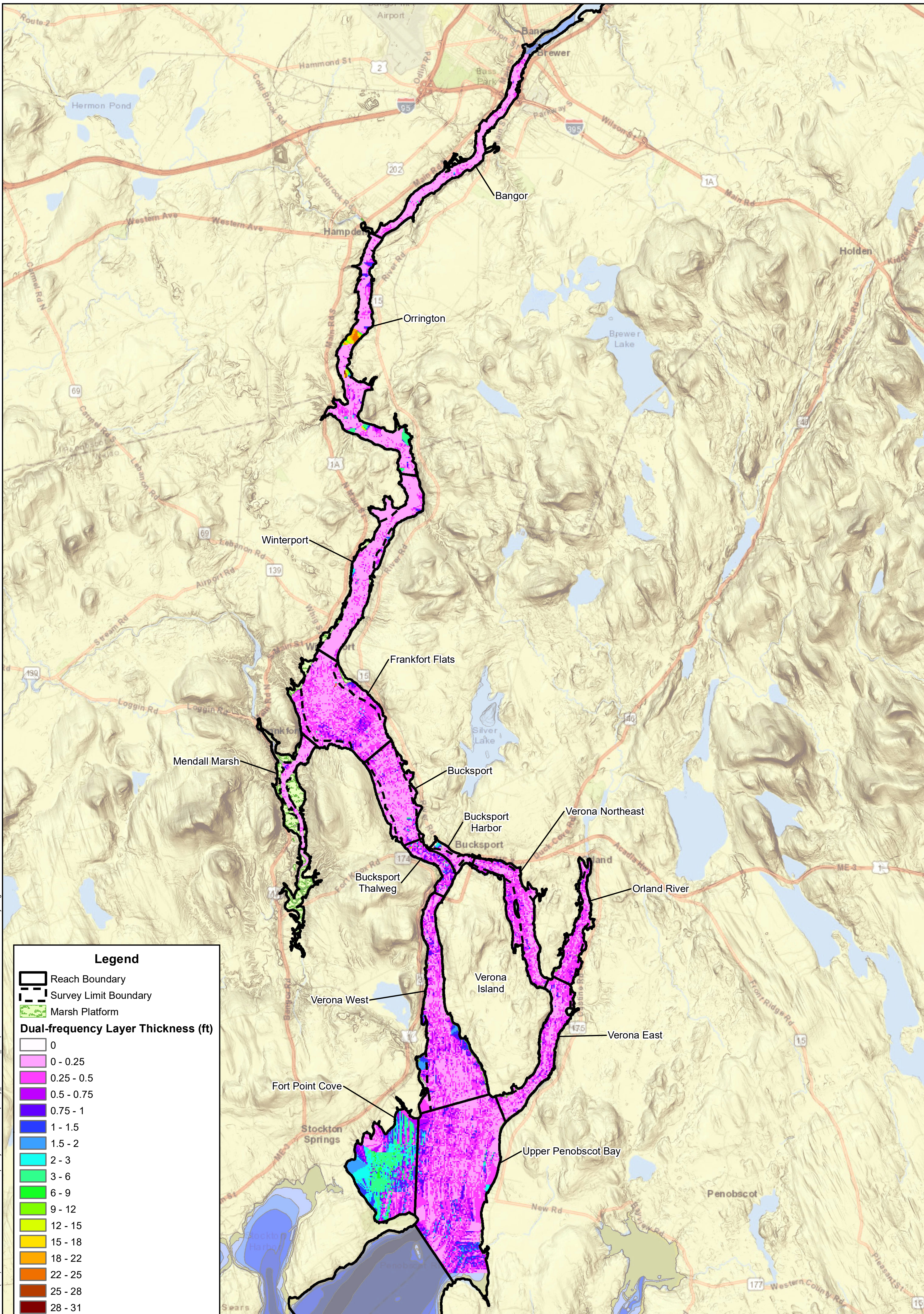
Boundary of River Reach

Project: 3616166052 | Prepared: ICD 12/8/2017 | Checked: BPW 12/8/2017

Figure 1-1
Site Location and River Reaches

2017 Mobile Sediment Characterization Report
Penobscot River Phase III Engineering Study

Document:P:\Projects\USDC- Penobscot GIS Control8 - AER WORKSPACE\WO-4A\WO-4A033\MXDs\Project_Location_11x17P_Index1.mxd 12/8/2017 11:27:27 AM ian.desjarlais PDF: \\PLD2-FS1\Project\Projects\USDC - Penobscot River\4.0_Deliverables\4.5_Databases\GIS\EXPORT_HUB\8 - AER WORKSPACE\WO-4A\WO-4A033\PDFs_BETA\vF



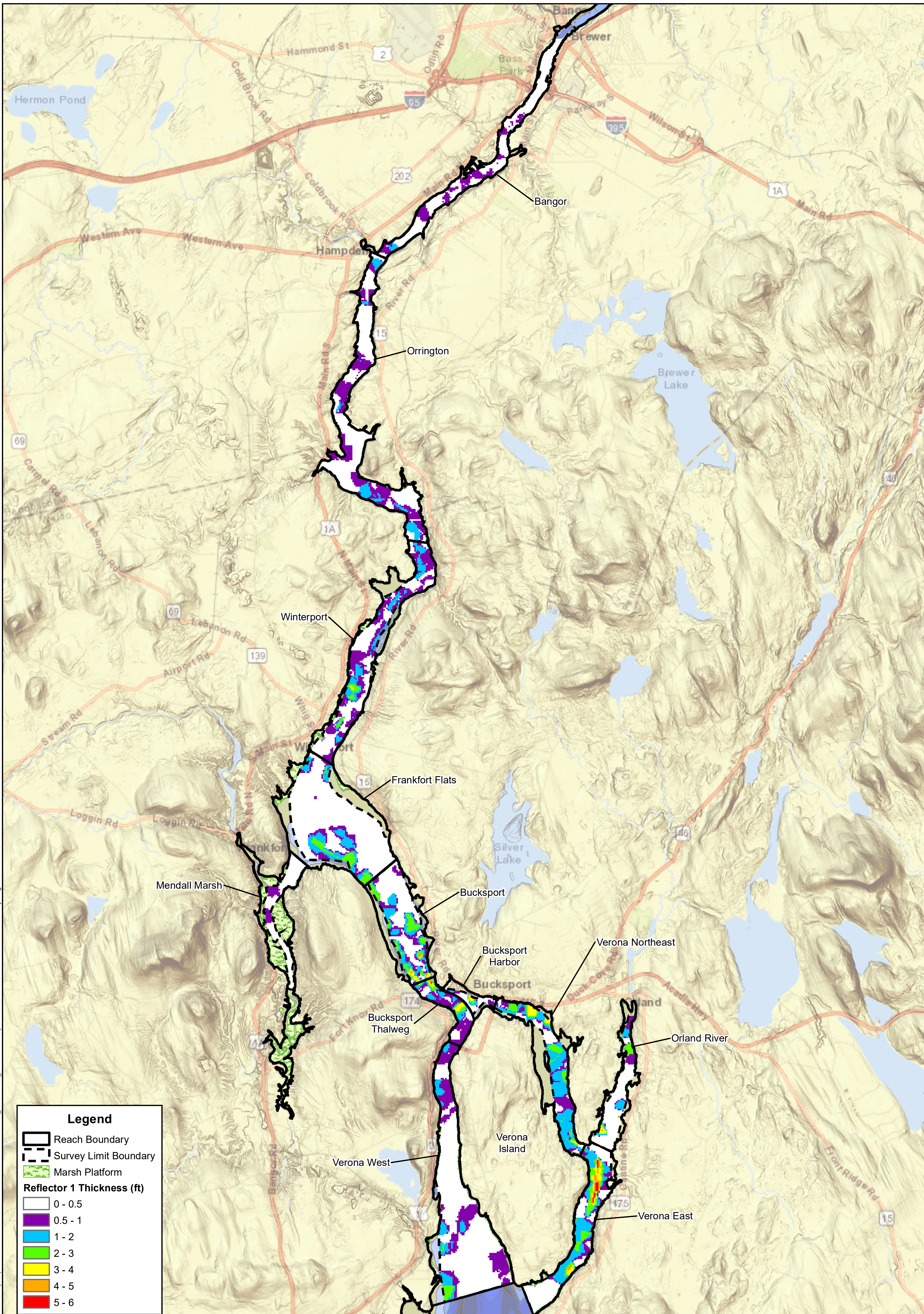
N
0 5,000 10,000 20,000
Feet
0 2.5 5 10
Kilometers

Figure 2-1
2017 Dual-frequency Layer Thickness - All Reaches

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052	Prepared/Date: 5/23/2018	Checked/Date: 5/23/2018	NAD83 State Plane Maine East, US Survey Feet

Document:P:\Comm-Ind\Projects\Clients M to S\Penobscot(GIS)\Work Order 4A-060\2017 Dual Frequency\2017 Dual Frequency_All Reaches_Interpolated.mxd 5/23/2018 10:35:17 AM david.young2



N

0 5,000 10,000 20,000
Feet
0 2.5 5 10
Kilometers

Figure 2-2
Mapped Thickness of Reflector 1 - All Reaches

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052	Prepared/Date: 5/23/2018	Checked/Date: 5/23/2018	NAD83 State Plane Maine East, US Survey Feet

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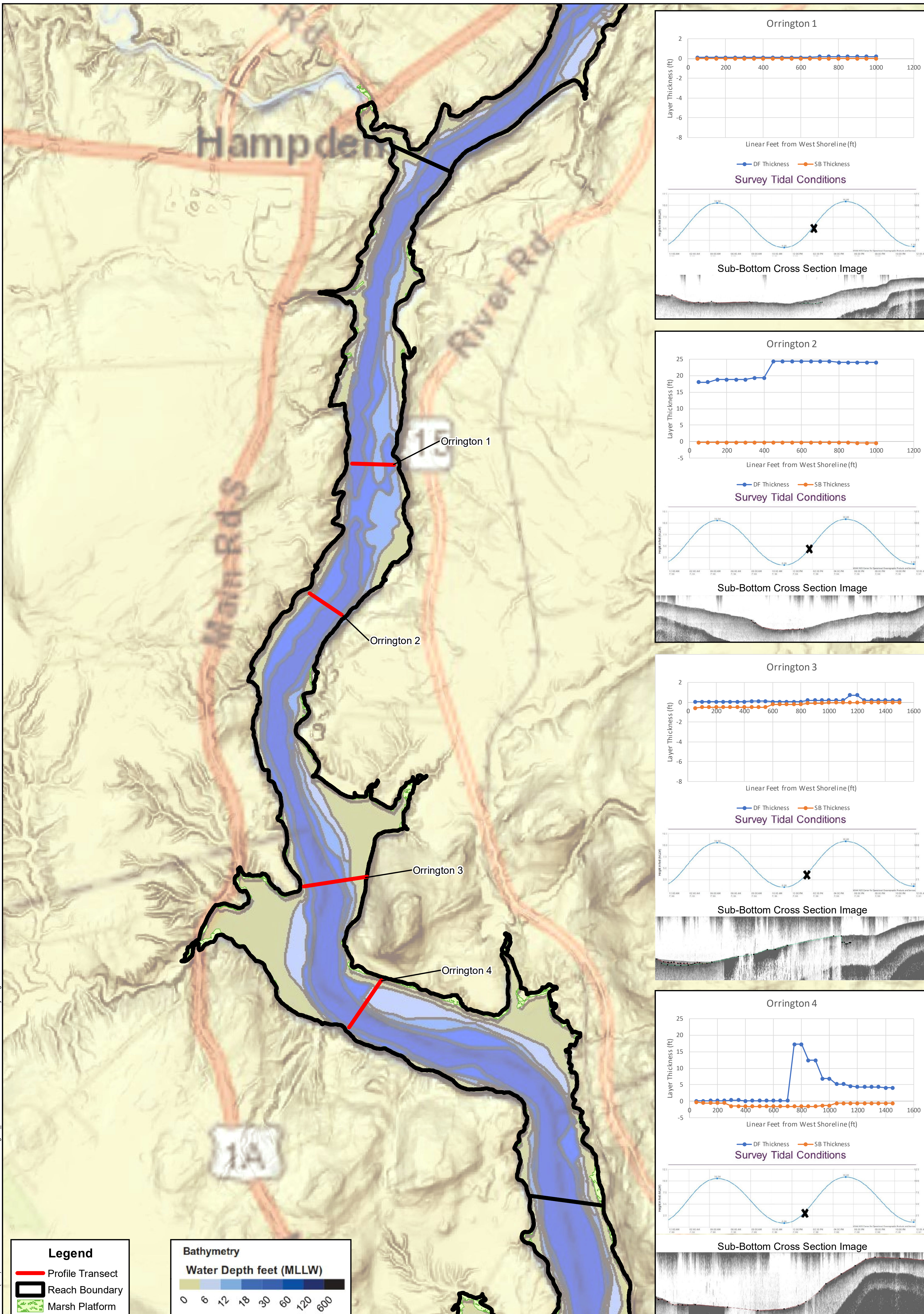


amec foster wheeler

Notes:
DF = Dual-frequency
SB = Sub-bottom

N

0 1,000 2,000 4,000
Feet

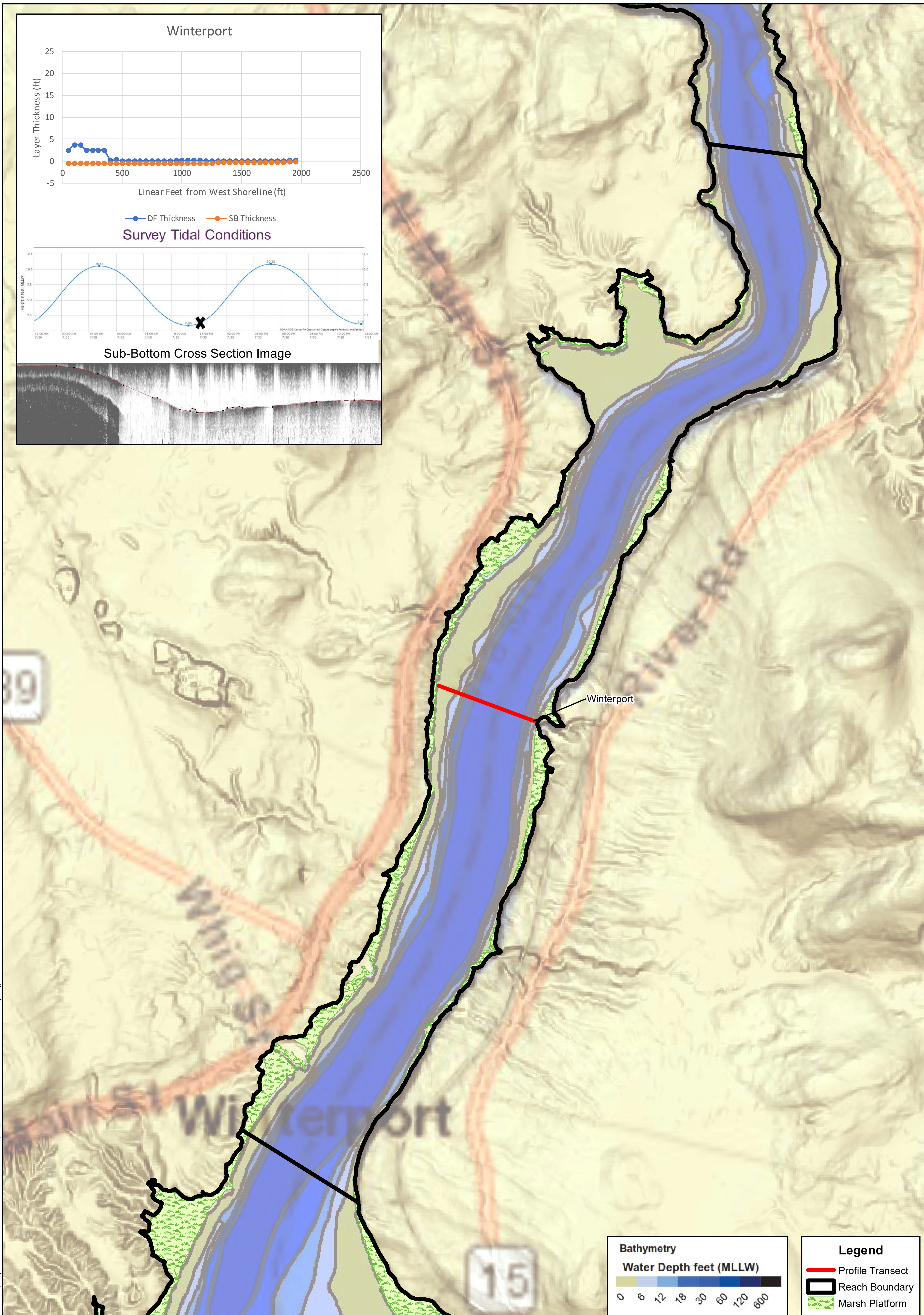
0 0.5 1 2
Kilometers

Figure 2-3
2017 Dual-frequency and Sub-bottom Profile Comparison - Orrington Reach

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052	Prepared/Date: 4/19/2018	Checked/Date: 4/19/2018	NAD83 State Plane Maine East, US Survey Feet

Document: P:\Comm-Ind\Projects\Clients M to S\Penobscot(GIS)\Work Order 4A-060\2017 DF & SB\2017 Orrington_Profiles.mxd 4/19/2018 8:23:00 AM david.young2



amec foster wheeler

Notes:
DF = Dual-frequency
SB = Sub-bottom

0 500 1,000 2,000 Feet

0 0.25 0.5 1 Kilometers

Figure 2-4

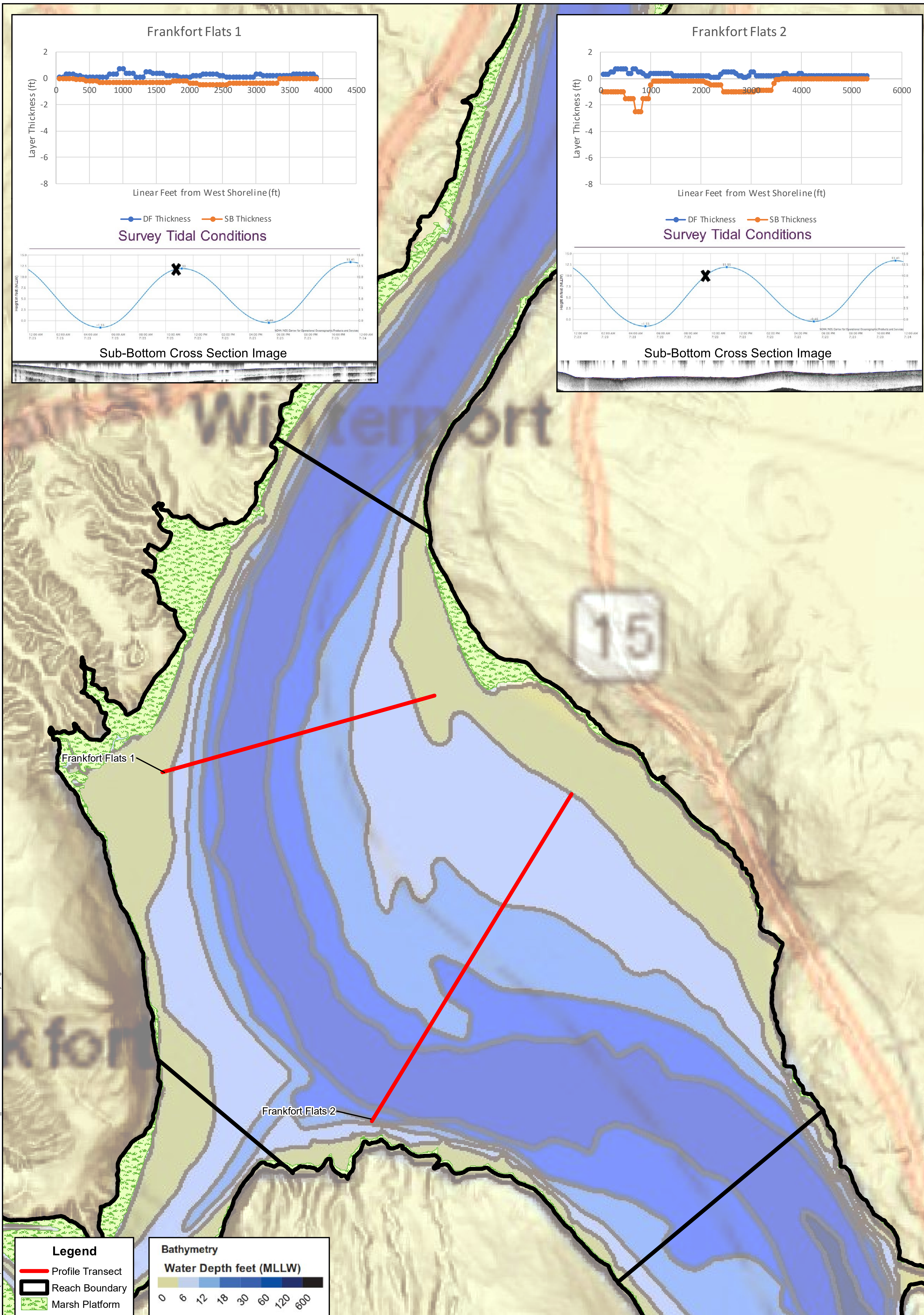
2017 Dual-frequency and Sub-bottom Profile Comparison - Winterport Reach

2017 Mobile Sediment Characterization

Penobscot River Phase III Engineering Study

Project: 3616166052	Prepared/Date: 4/19/2018	Checked/Date: 4/19/2018	NAD83 State Plane Maine East, US Survey Feet

Document: P:\Comm-Ind\Projects\Clients M to S\Penobscot(GIS)\Work Order 4A-060\2017 DF & SB\2017 Winterport_Profiles.mxd 4/19/2018 9:19:45 AM david.young2



Notes:
DF = Dual-frequency
SB = Sub-bottom

0 500 1,000 2,000 Feet

0 0.25 0.5 1 Kilometers

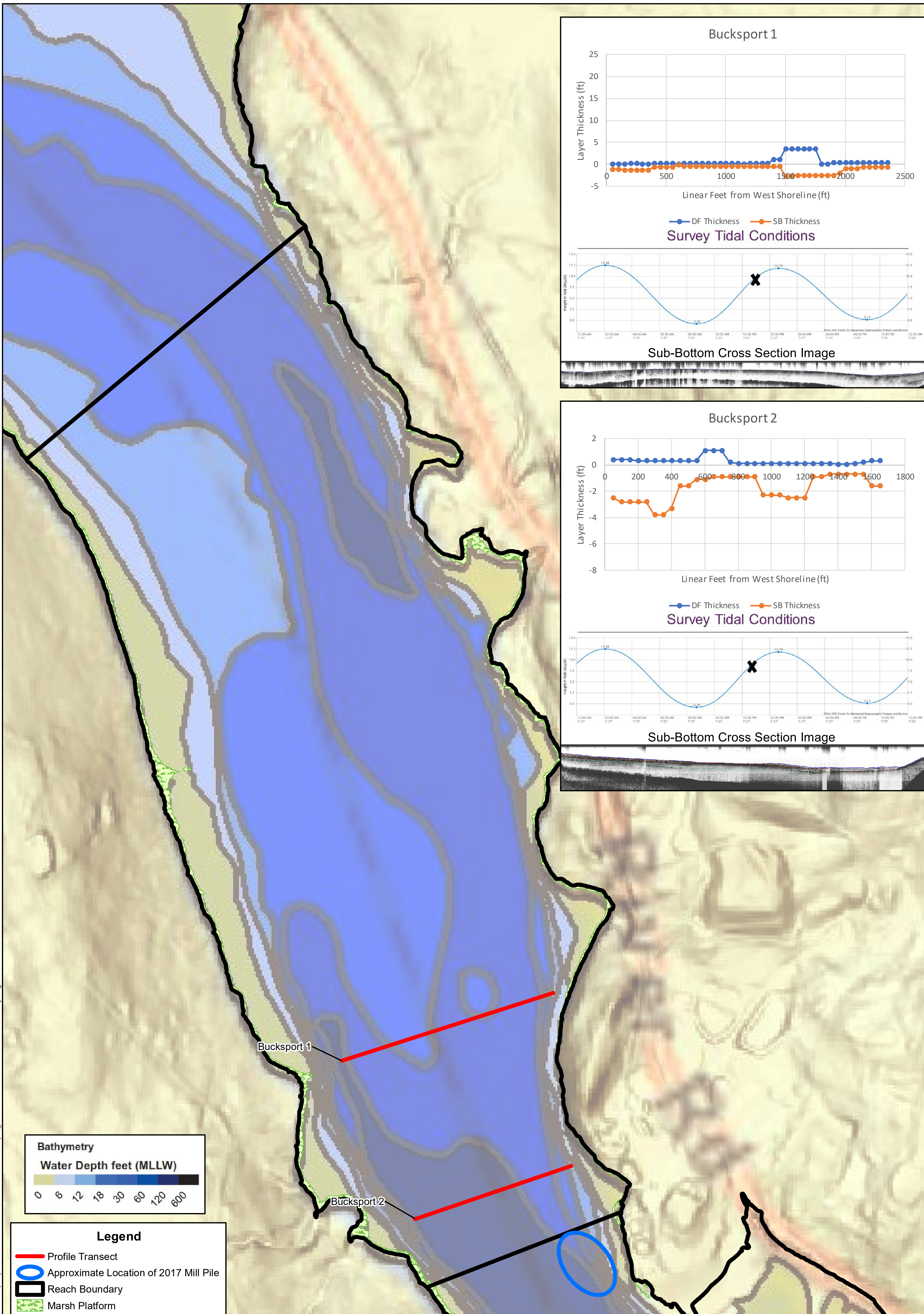
amec foster wheeler

Figure 2-5
2017 Dual-frequency and Sub-bottom Profile Comparison - Frankfort Flats Reach

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052 | Prepared/Date: 4/19/2018 | Checked/Date: 4/19/2018 | NAD83 State Plane Maine East, US Survey Feet

Document:P:\Comm-Ind\Projects\Clients M to S\Penobscot(GIS)\Work Order 4A-060\2017 DF & SB\2017 Frankfort Flats_Profiles.mxd 4/19/2018 9:02:22 AM david.young2



Notes:
DF = Dual-frequency
SB = Sub-bottom

0 500 1,000 2,000 Feet

0 0.25 0.5 1 Kilometers

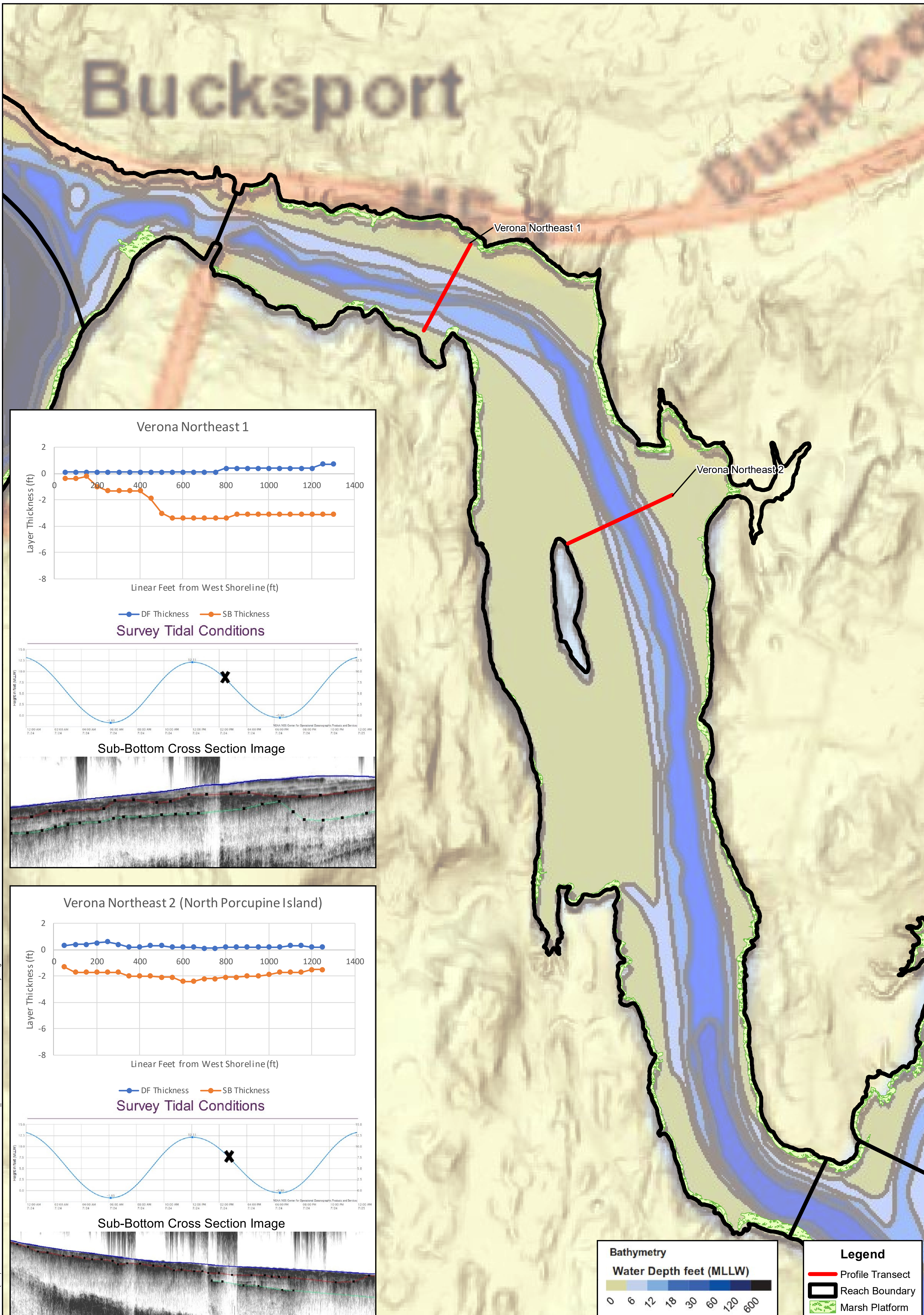
Figure 2-6

2017 Dual-frequency and Sub-bottom Profile Comparison - Bucksport Reach

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052 | Prepared/Date: 4/19/2018 | Checked/Date: 4/19/2018 | NAD83 State Plane Maine East, US Survey Feet

Document: P:\Comm-Ind\Projects\Clients M to S\Penobscot(GIS)\Work Order 4A-060\2017 DF & SB\2017 Bucksport_Profiles.mxd 4/19/2018 9:03:23 AM david.young2



amec foster wheeler

Notes:
DF = Dual-frequency
SB = Sub-bottom

0 500 1,000 2,000 Feet

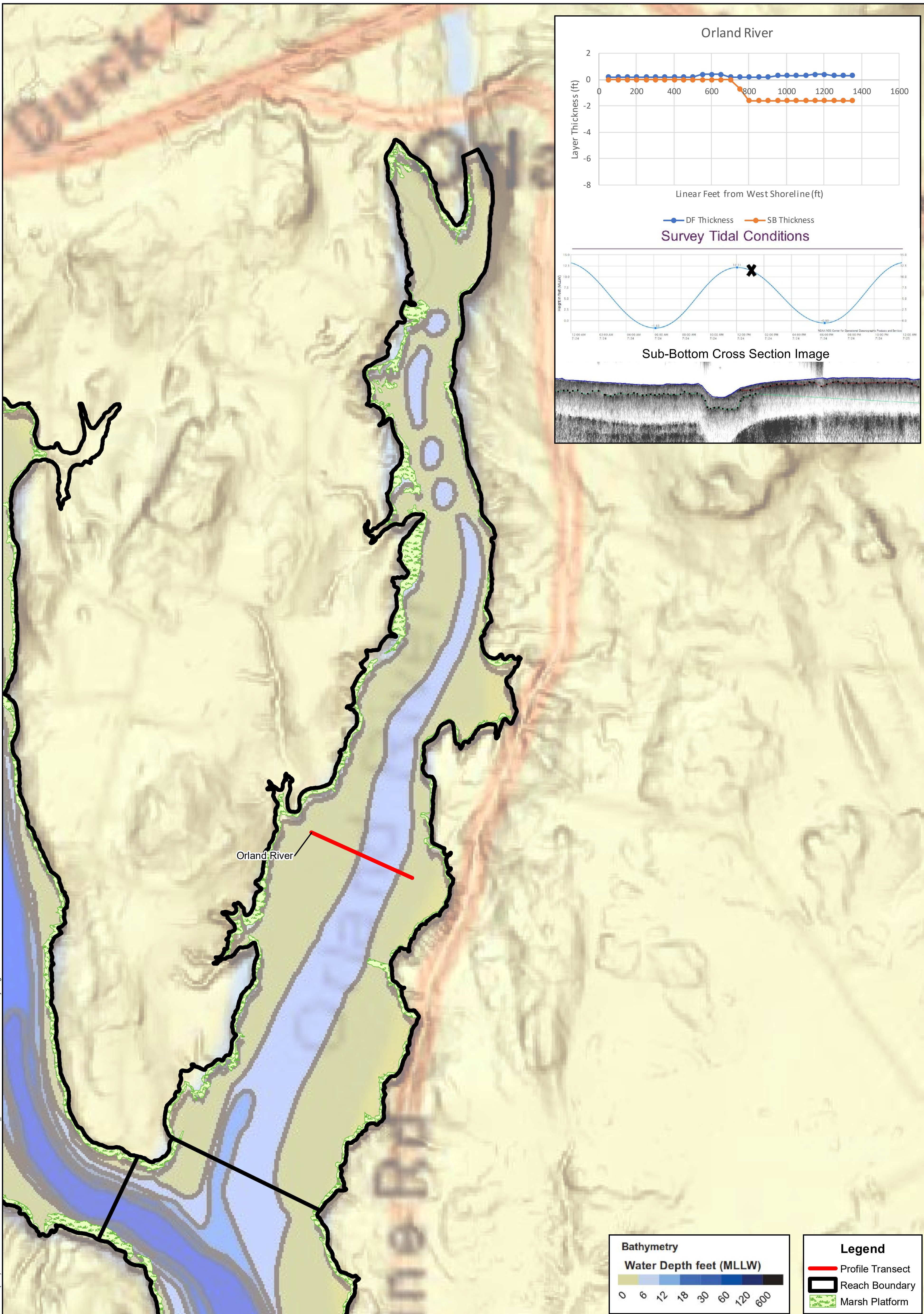
0 0.25 0.5 1 Kilometers

Figure 2-7
2017 Dual-frequency and Sub-bottom Profile Comparison - Verona Northeast Reach

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052	Prepared/Date: 4/19/2018	Checked/Date: 4/19/2018	NAD83 State Plane Maine East, US Survey Feet

Document: P:\Comm-Ind\Projects\Clients M to S\Penobscot(GIS)\Work Order 4A-060\2017 DF & SB\2017 Verona Northeast_Profiles.mxd 4/19/2018 9:14:06 AM david.young2



Notes:
DF = Dual-frequency
SB = Sub-bottom

0 500 1,000 2,000
Feet
0 0.25 0.5 1
Kilometers

Figure 2-8
2017 Dual-frequency and Sub-bottom Profile Comparison - Orland River Reach

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052	Prepared/Date: 4/19/2018	Checked/Date: 4/19/2018	NAD83 State Plane Maine East, US Survey Feet

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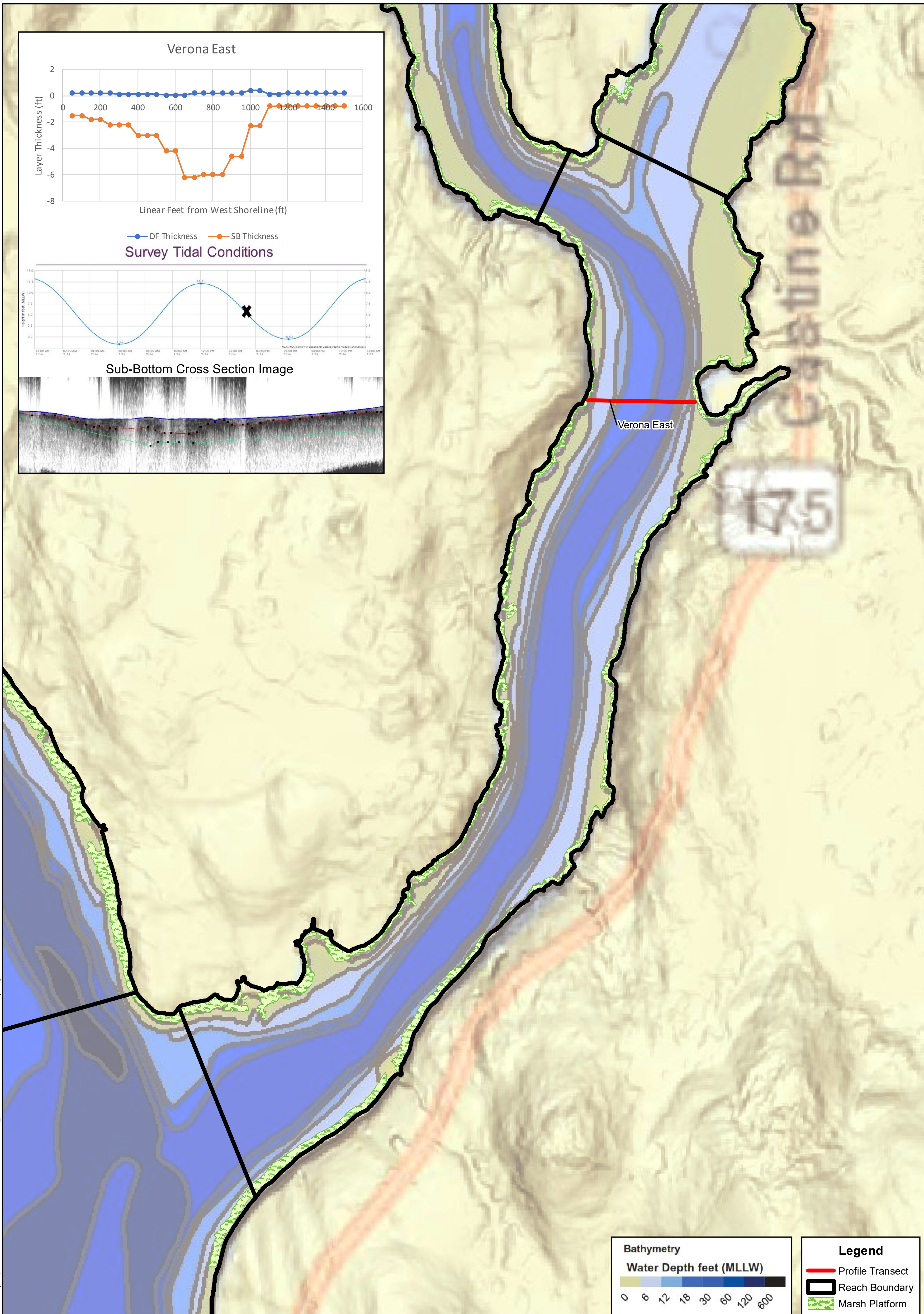

Notes:
DF = Dual-frequency
SB = Sub-bottom

N

0 500 1,000 2,000
Feet

0 0.25 0.5 1
Kilometers

Figure 2-9
2017 Dual-frequency and Sub-bottom Profile Comparison - Verona East Reach

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

amec foster wheeler

Project: 3616166052	Prepared/Date: 4/19/2018	Checked/Date: 4/19/2018	NAD83 State Plane Maine East, US Survey Feet

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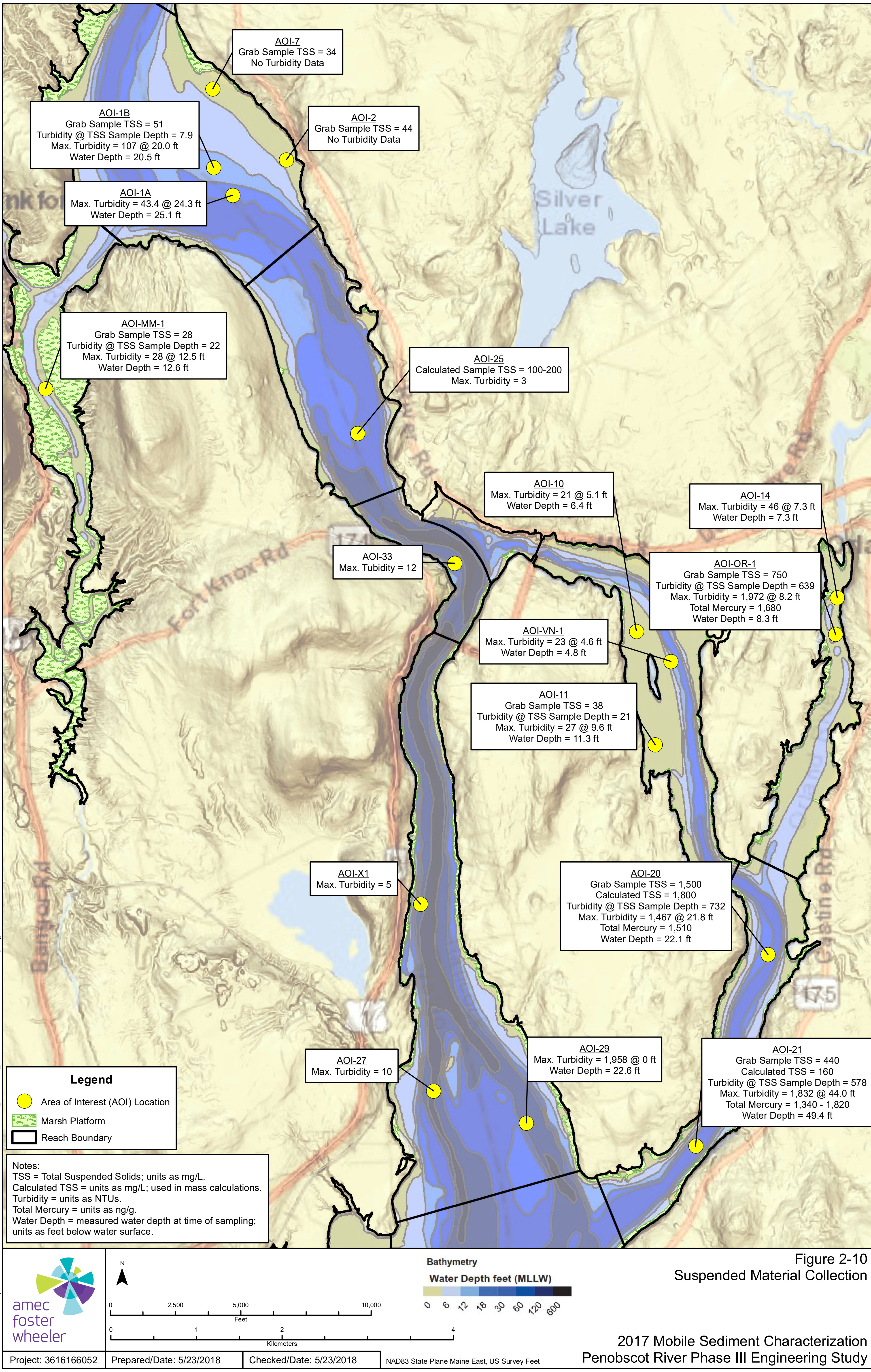

Figure 2-10
Suspended Material Collection

amec foster wheeler

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052 | Prepared/Date: 5/23/2018 | Checked/Date: 5/23/2018 | NAD83 State Plane Maine East, US Survey Feet

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amec foster wheeler

N

0 2,500 5,000 10,000
Feet

0 1 2 4
Kilometers

Bathymetry

Water Depth feet (MLLW)

0 6 12 18 30 60 120 600

Figure 5-1
Interpreted Areas of Bedrock, Boulders and Hardpan

2017 Mobile Sediment Characterization
Penobscot River Phase III Engineering Study

Project: 3616166052	Prepared/Date: 5/7/2018	Checked/Date: 5/7/2018	NAD83 State Plane Maine East, US Survey Feet

TABLES

TABLE 2-1

DUAL-FREQUENCY SURVEY CONDITIONS
Penobscot River Phase III Engineering Study
Penobscot River Estuary, Maine

Reach	Date of Data Collection	Tide Cycle during Data Collection	Number of Transects	Transect Miles (approximate)	Wind Conditions (knots)	Wave Conditions (feet)
Bangor	7/30/2017	Late Flood/High Tide	24	8	0-5	0-1
Orrington	7/30/2017	Flood Tide	26	12	0-5	0-1
Winterport	7/30/2017	Flood Tide	21	11	0-5	0-1
Frankfort Flats	7/23/2017	Late Flood/High Tide	14	15	5-10	0-2
Mendall Marsh	7/27/2017	High Tide	22	3.5	5-10	0-1
Bucksport	7/27/2017	Late Flood/High Tide	19	15	5-10	0-1
Bucksport Thalweg	7/28/2017	Flood Tide	14	4	0-5	0-1
Bucksport Harbor	7/28/2017	Late Flood/High Tide	8	2.5	0-5	0-1
Verona Northeast	7/24/2017	High/Ebb Tide	23	8	0-5	0-1
Orland River	7/24/2017	High Tide	17	5	0-5	0-1
Verona East	7/24/2017	High/Ebb Tide	20	10	0-5	0-1
Verona West	7/27/2017	Flood Tide	23	17	5-10	0-1
Upper Penobscot Bay	7/31/2017	High/Ebb Tide	11	17	0-5	0-1
Fort Point Cove	7/31/2017	High/Ebb Tide	6	6	0-5	0-1
Total			**248**	**134**	**0-10**	**0-2**

Prepared by: DRY 1/9/2018
Checked by: KAM 1/9/2018

TABLE 2-2

TOTAL SUSPENDED SOLID CONCENTRATION RESULTS SUMMARY[1,2]
Penobscot River Phase III Engineering Study
Penobscot River Estuary, Maine

Reach	Location	Lab Sample ID	Date	Time	Sample Method	Sample Depth above Mudline (feet)	Measured Water Depth (feet)[3]	Water Depth of Maximum Turbidity (feet)	Maximum Turbidity (NTU)	Turbidity @ TSS Sample Depth (NTU)	Discrete Grab TSS from Hose (mg/L)[4]	Time-Integrated Grab TSS (mg/L)[5]	Time-Integrated Calculated TSS (mg/L)[6]	Total Mercury (ng/g)[7]
Frankfort Flats	AOI-1A	No Lab Sample Collected	7/28/2017	10:15	Hose, Pump, and Sonde	2	25.1	24.3	43	-	-	-	-	-
	AOI-1B	AOI_1B_072817_SS_N15	7/28/2017	17:40	Hose, Pump, and Sonde	1.5	20.5	20.0	107	7.9	51[9]	-	-	-
	AOI-2	AOI_2_072417_SS_N21	7/24/2017	12:24	Rigid Poles	2.1	10.1	-	-	-	44[9]	-	-	-
	AOI-7	AOI_7_072417_SS_N10	7/24/2017	13:55	Rigid Poles	1	6.4	-	-	-	34[9]	-	-	-
Mendall Marsh	AOI-MM-1	AOI_MM_1_072817_SS_N15	7/28/2017	16:20	Hose, Pump, and Sonde	1.5	12.6	12.5	28	22	28[9]	-	-	-
Bucksport	AOI-25	No Lab Sample Collected	9/19/2017	13:30	Sonde and Net Deployment	2	31	31	3	-	-	-	100-200	-
Bucksport Thalweg	AOI-33	No Lab Sample Collected	9/19/2017	12:30	Sonde and Net Deployment	2	78	78	12	-	-	-	-	-
Verona Northeast	AOI-VN-1	No Lab Sample Collected	7/29/2017	10:15	Hose, Pump, and Sonde	1.5	4.8	4.6	23	-	-	-	-	-
	AOI-10	No Lab Sample Collected	7/25/2017	10:00	Hose, Pump, and Sonde	1.5	6.4	5.1	21	-	-	-	-	-
	AOI-11	AOI_11_072517_SS_N08	7/25/2017	11:55	Hose, Pump, and Sonde	0.8	11.3	9.6	27	21	38[9]	-	-	-
Orland River	AOI-OR-1	AOI_1_OR_072917_SS_N08_R1	7/29/2017	13:50	Hose, Pump, and Sonde	0.8	8.3	8.2	1,972	639	160	-	-	-
		AOI_1_OR_072917_SS_N08_R2									750	-	-	-
		AOI_1_OR_072917_SS_N08_R3									710	-	-	-
		AOI_1_OR_080117_SS_N08	8/1/2017	10:40							-	-	-	1,680
	AOI-14	No Lab Sample Collected	7/25/2017	13:55	Hose, Pump, and Sonde	1.5	7.3	7.3	46	-	-	-	-	-
Verona East	AOI-20	AOI20_P200_10082017_SW_R1	10/8/2017	18:20	Hose, Pump, and Sonde	0.8	22.1	21.8	1,467	732	-	480	1,700	-
		AOI20_P200_10082017_SW_R2									-	470		-
		AOI20_P200_10082017_SW_R3									-	480		-
		VE_AOI20_072517_SS_N20	7/25/2017	19:00		2					800	-	-	-
		AOI_20_072517_SS_N08_R1	7/25/2017	16:00		0.8					1,500	-	-	-
		AOI_20_072517_SS_N08_R2									1,500	-	-	-
		AOI_20_072517_SS_N08_R3									1,300	-	-	-
		AOI_20_072517_SS_N08	8/1/2017	10:30							-	-	-	1,510
	AOI-21	AOI21_P200_10102017_SW_R1	10/10/2017	12:10	Hose, Pump, and Sonde	0.6	49.4	44.0	1,832	578	-	53	160	-
		AOI21_P200_10102017_SW_R2									-	54		-
		AOI21_P200_10102017_SW_R3									-	77		-
		AOI_21_072617_SS_N06	7/26/2017	15:45							440	-	-	-
		AOI_21_080117_SS_N06_DUP	8/1/2017	10:50							-	-	-	1,340
		AOI_21_080117_SS_N06_R1									-	-	-	1,820
		AOI_21_080117_SS_N06_R2									-	-	-	1,520
		AOI_21_080117_SS_N06_R3									-	-	-	1,780
Verona West	AOI-X1	No Lab Sample Collected	9/19/2017	11:30	Sonde and Net Deployment	2	84	84	5	-	-	-	-	-
	AOI-27	No Lab Sample Collected	9/19/2017	10:10	Sonde and Net Deployment	2	86	86	10	-	-	-	-	-
	AOI-29	No Lab Sample Collected	7/29/2017	12:00	Hose, Pump, and Sonde	1.5	22.6	0[8]	1,958[8]	-	-	-	-	-

Prepared by: DRY 1/9/2018
Checked by: KAM 1/9/2018

Notes:
1. Sample collection was completed during the sample tidal phase as the dual-frequency survey, unless noted otherwise.
2. Laboratory methods = Grab TSS (standard method 2540D) and total mercury (adjusted method 7474-1631).
3. Measured water depth at time of sampling.
4. Samples were collected directly from the sample hose into laboratory provided containers.
5. Grab samples represent material passing the #200 sieve.
6. Calculated TSS is the sum of material retained on and passing the #200 sieve and averages from AOI-20 and AOI-21 were used in mass calculations.
7. Samples collected from material retained on #200 sieve.
8. Potential anomaly due to instrumental error.
9. Sample not collected within the dual-frequency related suspended material layer.

Abbreviations:
- = Not analyzed
mg/L = milligrams per liter
ng/g = nanograms per gram
NTU = nephelometric turbidity units
TSS = Total Suspended Solids

TABLE 3-1

BEDDED MATERIAL DENSITY SUMMARY
Penobscot River Phase III Engineering Study
Penobscot River Estuary, Maine

Reach	Core Location	Sediment Type	Sample Depth (inches)	Moisture Content (%)[1]	Wet Density (kg/m^3)[2]	Dry Density (kg/m^3)[2]
Orrington	ON-18-01	Silt with Wood Fines	0-4	141	1,229	722
Winterport	WP-06-02	Silt with Wood Fines	4-8	220	1,099	523
Frankfort Flats	FF-08-02	Mixture of Silt & Wood Waste	8-12	142	1,193	697
Bucksport	BU-02-01	Mixture of Silt & Wood Waste	0-4	189	1,321	679
Verona Northeast	VN-02-03	Mixture of Silt & Wood Waste	4-8	145	1,331	772
Verona East	VE-10-01	Mixture of Silt & Wood Waste	0-4	115	1,229	782
	VE-05-01	Wood Waste	10-14	888	929	171
		Wood Waste	14-18	893	1,021	184
Average				**342**	**1,167**	**566**

Notes:

1. Reported with respect to dry basis, which represents the weight of water as a percentage of the completely dry solid.

2. Source data = Appendix C in 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018a).

Prepared by: DRY 1/9/2018
Checked by: KAM 1/9/2018

Abbreviations:

% = Percent

kg/m^3 = kilograms per cubic meter

TABLE 3-2

VOLUME AND MASS ESTIMATE SUMMARY[1,2,3,4,5]
Penobscot River Phase III Engineering Study
Penobscot River Estuary, Maine

System Component	Sub-Component	Total Area (ft^2)	Total Volume (ft^3)	Total Volume (yds^3)	Total Volume (m^3)	Approximate Total Mass (Tons; Wet Weight Average)[6]	Approximate Total Mass (Tons; Dry Weight Average)[6]
Dual-frequency Suspended Sediment and Wood Waste	Total	299,630,000	122,710,000	NA[7]	NA[7]	40,000[(8)]	4,000[(8)]
	Uncertainty of Total[9]	NA	31,980,000	NA[7]	NA[7]	10,000[(8)]	1,000[(8)]
Sub-bottom Sediment and Wood Waste	Less than 1.0 Foot Thickness in System	238,090,000	91,790,000	3,400,000	2,600,000	3,340,000	1,620,000
	Greater than 1.0 Foot Thickness in System	61,540,000	85,590,000	3,170,000	2,420,000	3,120,000	1,510,000
	Total	299,630,000	177,380,000	6,570,000	5,020,000	6,460,000	3,130,000
	Uncertainty of Total[10]	NA	57,820,000	2,140,000	1,640,000	2,110,000	1,020,000

Notes:
1. For sub-bottom estimates, the equation density = mass/volume was used to calculate mass.
2. For dual-frequency estimates, mass was calculated using the following equation: mass (grams) = volume (liters) * average total suspended solid concentration (g/L).
3. Ton units refer to the US standard.
4. Estimates represent specific time period and conditions during sampling activities and caution should be used when extrapolating to other time periods with different seasonal or hydrodynamic conditions.
5. Approximated values are presented, rounded to the nearest 10,000 where applicable, and are recommended for use.
6. Mass average density source = Table 3-1.
7. Calculation only for bedded material only.
8. Total suspended solids concentration source = Appendix Table A-2.
9. Quantifies resolution uncertainty of survey equipment (i.e., 0.1 feet).
10. Quantifies overlap detection uncertainty between survey methods (i.e., 0.5 feet).

Prepared by: DRY 1/9/2018
Checked by: KAM 1/9/2018

Abbreviations:
ft^2 = square feet
ft^3 = cubic feet
m^3 = cubic meters
NA = Not Applicable
yds^3 = cubic yards

TABLE 4-1

EROSIONAL INDICATOR MEASUREMENTS SUMMARY[1,2,3]
Penobscot River Phase III Engineering Study
Penobscot River Estuary, Maine

Reach	Rivulet ID	X Coordinate	Y Coordinate	Width (feet)	Depth (feet)
Mendall Marsh	MM-RV-1	889872.15	337329.89	2.0	0.2
	MM-RV-2	889845.40	337135.51	0.9	0.1
	MM-RV-3	889855.97	336924.67	0.3	0.1
	MM-RV-4	889869.26	336806.34	0.8	0.4
	MM-RV-5	889877.38	336780.03	0.5	0.2
	MM-RV-6	889411.09	338067.62	1.3	0.2
	MM-RV-7	889368.75	337985.47	2.3	0.4
	MM-RV-8	889335.78	337873.60	2.9	0.3
	MM-RV-9	889301.27	337774.22	0.8	0.2
	MM-RV-10	889288.87	337742.49	1.5	0.2
	MM-RV-11	891912.28	326502.44	0.4	0.1
	Reach Average			**1.2**	**0.2**
Orrington	ON-RV-1	899636.44	394479.00	0.6	0.2
	ON-RV-2	899636.44	394479.00	0.2	0.2
	ON-RV-3	899636.44	394479.00	0.2	0.6
	ON-RV-4	900456.52	371295.47	0.6	0.6
	ON-RV-5	901638.69	369181.60	0.6	0.2
	ON-RV-6	896165.40	380308.39	2.3	0.4
	ON-RV-7	901088.12	372650.48	0.6	1.0
	ON-RV-8	897231.28	385745.96	0.6	0.2
	ON-RV-9	NA	NA	0.6	0.2
	ON-RV-10	898162.35	383609.48	1.0	0.2
	ON-RV-11	896323.91	380857.25	0.6	0.6
	Reach Average			**0.7**	**0.4**
Bucksport	BU-RV-1	899342.79	336273.53	1.8	0.3
	BU-RV-2	899326.54	336283.13	1.1	0.2
	BU-RV-3	899291.96	336325.13	1.3	0.2
	BU-RV-4	900307.17	334358.94	1.8	0.2
	BU-RV-5	899210.09	336418.22	3.3	0.6
	BU-RV-6	NA	NA	0.2	0.2
	BU-RV-7	899697.76	335338.11	0.3	0.1
	BU-RV-8	899680.18	335414.86	0.3	0.1
	BU-RV-9	899650.30	335554.54	0.4	0.2
	Reach Average			**1.2**	**0.2**
Verona Northeast	VN-RV-1	909556.94	328634.20	6.6	0.7
	VN-RV-2	910661.12	329157.66	3.3	0.3
	VN-RV-3	910768.19	329135.48	0.2	0.2
	VN-RV-4	911362.46	329070.80	0.4	0.2
	Reach Average			**2.6**	**0.3**

Notes:

1. Coordinates are displayed in Maine East State Plane North American Datum of 1983 (NAD83) with units in US survey feet.

2. Coordinates were collected at the waterline of each location where measurements were recorded.

3. Measurements were completed from September 23-27, 2017.

Prepared by: DRY 1/9/2018
Checked by: KAM 1/9/2018

Abbreviations:
NA = Not Available

TABLE 5-1

BEDROCK, BOULDER AND HARDPAN COVERAGE SUMMARY
Penobscot River Phase III Engineering Study
Penobscot River Estuary, Maine

Reach	Subtidal Zone	Intertidal Zone	
	Total Bedrock/Hardpan Coverage (%)	Total Bedrock/Boulder Coverage (%)	
		GIS Based	Field Based
Bangor	17[1]	31	27
Orrington	22	13	7
Winterport	36	10	5
Frankfort Flats	7	10	8
Mendall Marsh	0	2	5
Bucksport	10	31	13
Bucksport Thalweg	70	[100][2]	24
Bucksport Harbor	0	32	10
Verona West	44	[50][2]	30
Verona Northeast	0	6	6
Orland River	0	5	5
Verona East	0	26	25
Fort Point Cove	NA[2]	46	24
Upper Penobscot Bay	NA[2]	8	35
Cape Jellison	NA[2]	45	16
Average	**22**	**20**	**14**

Notes:

1. Only subtidal area below Oak Street bridge in Bangor evaluated due to low bridge.
2. Not included in calculation of overall reach averages.

Prepared by: DRY 1/9/2018
Checked by: KAM 1/9/2018

Abbreviations:
% = Percent
NA = Not Available