# ALTERNATIVES EVALUATION REPORT

## Penobscot River Phase III Engineering Study

## Penobscot River Estuary, Maine

*Prepared for:*

**United States District Court**
**District of Maine**

*Prepared by:*

**Amec Foster Wheeler Environment & Infrastructure, Inc.**
511 Congress Street, Suite 200
Portland, Maine 04101

Project No. 3616166052

**September 2018**

# ALTERNATIVES EVALUATION REPORT

## Penobscot River Phase III Engineering Study

## Penobscot River Estuary, Maine

*Prepared for:*

**United States District Court**
**District of Maine**

*Prepared by:*

**Amec Foster Wheeler Environment & Infrastructure, Inc.**
511 Congress Street, Suite 200
Portland, Maine 04101

Project No. 3616166052

**September 2018**

Nelson Walter, P.E.
Principal Project Manager

Eugene Shephard, P.E.
Associate Engineer

# EXECUTIVE SUMMARY

In January 2016, the United States District Court for the District of Maine (the Court) selected Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) to conduct the Penobscot River Phase III Engineering Study (Phase III Engineering Study), to identify and evaluate feasible, effective and cost-effective measures to remediate mercury in the Penobscot River Estuary (the Estuary). The geographic area to be addressed within the Phase III Engineering Study is described by the Court as "*the region from the site of the former Veazie Dam south to Upper Penobscot Bay, including Mendall Marsh and the Orland River."*

Beginning in 1967, a chlor-alkali facility located in Orrington, Maine released mercury into the Estuary. Releases of mercury at overall declining concentrations continued throughout facility operation and ceased with facility closure in 2000. In 2002, the Court ordered an independent scientific study, the Penobscot River Mercury Study, to assess the spatial distribution and impact of mercury discharge in the Penobscot River. As of 2017, two phases of the study have been completed: Phase I in 2008 (PRMSP 2008) and Phase II in 2013 (PRMSP 2013). The Phase I Report (PRMSP 2008) concluded that there was enough scientific evidence to conclude that the Penobscot River is contaminated with mercury to an extent that poses risks to some wildlife species, and possibly some limited risk for human consumers of fish and shellfish. The Penobscot River Mercury Study Panel recommended that the study proceed to a second phase (Phase II). The Phase II Study estimated that although the Estuary has recovered significantly since the period of peak mercury discharge, it will take over 100 years for mercury concentrations in Estuary sediment to decrease to a level consistent with regional background concentrations in sediment at the current rate of system recovery (PRMSP 2013). The slow rate of decline of mercury concentrations in the Estuary is attributable, in part, to the presence of a large pool of mercury-affected mobile sediment in the Estuary. This mobile sediment is retained in the Estuary by natural processes that result in the landward flow of both bottom water and associated sediment under the influence of tides. This large volume of contaminated sediment is referred to in the Phase II Study as "the mobile pool" (PRMSP 2013).

With these studies as background, and following additional sampling and analysis conducted by Amec Foster Wheeler in 2016–2017, this Alternatives Evaluation Report presents the results of the development, evaluation, and comparison of remedial alternatives that could be implemented to reduce ecological and human health risks resulting from the discharge and subsequent accumulation of mercury in the sediments and biota of the Estuary. Alternatives were developed, evaluated, and compared based on six evaluation criteria as established by the Court Order and the Phase III Engineering Study process. These criteria are: (1) viability of remedy; (2) whether the proposed solution has been successfully attempted previously or is innovative; (3) the likely cost of the solution; (4) the length of time to complete the recommendations; (5) the likely effectiveness of the solution; and (6) any potential environmental harm that may be caused by the proposed solution. The remedial strategy recommended as the result of the alternatives assessment presented in this report is presented in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

As a component of the evaluation process, bench-scale treatability studies were conducted to provide data for the development and evaluation of alternatives. Data generated from the bench-scale treatability studies were used to support selection of process options and technologies; refine engineering assumptions used as the basis for the detailed evaluation of alternatives; support cost estimation; and assess feasibility, limiting conditions and/or aspects of uncertainty associated with the implementing various remedial technologies. These studies included evaluation of: (1) the physical properties of sediments to determine whether physical separation techniques can be used to reduce the volume of sediment requiring treatment or removal; (2) the chemical properties of sediments, to assess the need for sediment treatment, removal, and containment, and subsequent material handling, dewatering, and water treatment or disposal requirements following removal (if applied); and (3) the toxicity of carbon-based amendments under consideration for application on marsh platforms.

Regarding the current site understanding and material transport in the Estuary, the processes that control the internal cycling of sediment within estuaries will significantly influence the recovery time of the system. For estuaries like the Penobscot River Estuary that have been historically impacted by chlor-alkali discharge, recovery times have been documented to vary from years to decades, depending on how recovery is defined. Modelling of 2017 geochronology data and calculation of apparent recovery half times for the Estuary suggest that the apparent natural recovery rate is slowing relative to what was calculated in 2009 during the Phase II Study. The term ‘apparent’ is used herein consistent with its use in the Phase II Study in which the calculation of recovery rates is dependent on data extrapolation and assumptions regarding temporal mixing and redistribution of mercury in the Estuary. Increasing apparent recovery half times calculated in 2017 relative to the apparent recovery half time calculated in 2009 indicate that the rate of change in sediment mercury profiles over the 21-year interval from 1996–2017 is decreasing relative to the rate of change in sediment mercury profiles over the 21-year interval from 1988–2009 used in the Phase II modeling. For cores collected in 2009 from locations defined as reflecting representative physical mixing and chemical attenuation within the Estuary (i.e., cores from locations in communication with the larger system), surface sediment concentrations in 2009 appeared to be converging toward 600–700 nanograms per gram (ng/g). For cores collected in 2017 from similarly defined locations, surface sediment total mercury concentrations do not appear to have changed significantly from this average, and in some reaches of the Estuary remain higher than 700 ng/g.

For data used in this report in the assessment of remedial alternatives, the general consistency in calculated average total mercury concentrations over much of the Estuary supports a hypothesis that the Estuary is achieving some level of homogenization or equilibrium redistribution of mobile mercury-affected sediment and wood waste. In attempting to evaluate or predict system-wide ecological recovery, the extent to which mobile sediments are a mixture of mineral sediment and wood waste—two distinct phases with differing particle sizes and densities, mercury concentrations, and transport properties—impacts the ability to accurately project recovery rates for the Estuary. Likewise, if sediment mercury concentrations in those portions of the system that are not in communication with the larger system are elevated relative to a homogeneously mixed concentration for other parts of the system, then changes to the hydrodynamic processes controlling sediment mixing or erosion (e.g., increases in wind/wave action, changes to flow regime) will also impact projections for system-wide recovery.

The remedial evaluation presented in this report includes the delineation of the Estuary into reaches and hydrodynamic zones, and calculation of area weighted average total mercury concentrations within each reach/zone unit. Calculation of area weighted average total mercury concentrations included all total mercury data in the project database from 2000–2017, with the exception of data for which either the analytical laboratory, the analytical method, or sampling details were unclear. Data were grouped into discrete depth increments using an interval participation weighted concentration approach. This approach allows for the integration of data from a project database that includes a range of sampling types (e.g., grab samples and sediment cores) that may have been collected for differing objectives and depth-sectioned at differing interval schemes (e.g., tenths of a foot versus centimeters).

Following identification of reach/zone units, calculation of interval participation weighted concentrations, and application of exclusion zones (including areas of exposed bedrock, boulders or hardpan, locations of archeological significance, and the footprint of the 2017 dredge removal in Southern Cove), an area weighted average total mercury concentration was calculated for each reach/zone unit. The identification of areas potentially warranting remedy was then based on the comparison of area weighted average concentrations of total mercury versus ecological and human health-based preliminary remediation goals (PRGs) developed based on total mercury concentrations in sediment. In addition to reach/zone units identified for a remedy based on area weighted average total mercury concentrations, proposed remedial scenarios also include the removal of surface deposits of mineral sediment and wood waste that are more than 3 feet thick with mercury concentrations generally higher than 1,000 ng/g. These surface deposits are found in the Frankfort Flats, Orland River and Verona East reaches of the Estuary.

As an overall strategy for the estimation of remedial volumes, remedial footprints have been developed with the goal of reducing the system-wide average sediment concentration of total mercury to either a PRG of 300 ng/g or 500 ng/g. Total mercury-based PRGs considered in this report for marsh platform, intertidal and subtidal sediments are applicable to all sediments within the bioactive zone for estuarine environments. The 300ng/g PRG is a sediment mercury concentration that is expected to meet the Maine Center for Disease Control and Prevention (MeCDC) 200 ng/g fish tissue action level in edible tissues; the 500 ng/g PRG is a sediment mercury concentration developed in the Phase III Study to be protective of ecological risk and the local consumer. The development of the 500 ng/g PRG for total mercury in sediment is summarized in this report and presented in the Risk Assessment and Preliminary Remediation Goal Development Report (Amec Foster Wheeler 2018b).

For subaqueous areas in the Estuary, including along the main channel, the eastern channel around Verona Island, the Orland River and in Mendall Marsh, proposed sediment removal would involve a minimum 6-inch dredge depth with a 6-inch over-dredge allowance, followed by backfill with clean similar substrate. For the marsh platform, remedy would entail the placement of a minimum 3-inch sand/silt cap. For both these scenarios, it is assumed that the mercury concentration in the clean backfill or cap material is approximately 20 ng/g, and that the emplaced concentration post-remedy will be 180 ng/g. This choice of post-remedy mercury concentration for either intertidal/subtidal areas that are dredged or the portion of marsh platforms that may be capped is based on the expectation that recontamination of the dredged area via sedimentation of mobile material will increase the concentration of mercury within the biological mixed depth by a concentration that reflects mixing of backfill material with residual mobile sediment in the system. In addition to these two scenarios described above, additional dredging is evaluated for: (1) areas in which there are sediment deposits enriched in wood waste and containing mercury concentrations at or greater than 1,000 ng/g and a thickness of over 3 feet of sediment (as described above); and (2) Southern Cove and the wider Orrington Reach, to target locations in the fringing marsh and/or intertidal area in which Amec Foster Wheeler 2017 sampling and prior Phase II sampling identified elevated mercury concentrations in locations outside of the 2017 dredge footprint in Southern Cove.

With this understanding of mercury distribution in the system, this report develops remedial alternatives that could be implemented to address potential risks to human consumers and ecological receptors throughout the Estuary. The process of developing remedial alternatives has included: (1) an initial screening of remedial technologies; (2) identification of technologies for which treatability studies (bench- and/or pilot-scale studies) are or would be needed to evaluate site-specific effectiveness; (3) identification of general response actions; (4) development of the list of potential remedial technologies consistent with general response actions; and (5) screening of potential remedial technology process options against the criteria of effectiveness, implementability, and relative cost.

Six remedial alternatives are retained and evaluated in this report:

- ***Alternative 1: Monitored Natural Recovery***, including institutional controls and long term (45-year) monitoring of sediment, surface water (including total suspended solids) and biota to assess progress toward system-wide ecological recovery;
- ***Alternative 2: Enhanced Monitored Natural Recovery***, effected through the addition of clean sediment to the system with the goal of reducing total mercury concentrations in mobile sediment throughout the intertidal and subtidal zones, as well as on marsh platforms where mobile sediment can deposit following inundation of the platform;
- ***Alternative 3: Dredging***, consisting of mechanical removal of either/both subaqueous sediment and fringing and pocket marsh soils, with dredged or excavated material to be either disposed of off-site or available for beneficial reuse;
- ***Alternative 4: Thin Layer Capping*** on the Mendall Marsh platform to reduce total mercury concentrations across the biological mixed depth on the platform;
- ***Alternative 5: Amendment Application***, consisting of addition of sediment amendments to the Mendall Marsh platform to reduce biological accumulation of methyl mercury from porewater on the marsh platform; and
- ***Alternative 6: Dredging in Intertidal and Subtidal Zones & Thin Layer Capping,*** a combination remedy for Mendall Marsh that includes thin layer capping on the marsh platform and dredging in the marsh intertidal and subtidal zones.

In addition to the six remedial alternatives evaluated in this report, adaptive management is retained as a remedial strategy. Adaptive management is a strategy for assessing progress toward the achievement of recovery targets through iterative monitoring, data evaluation, and alterations to the planned course of action if necessary to maintain progress toward recovery targets.

For all potential remedial alternatives including material addition (either sediment, cap material or amendments) or material removal (dredging or excavation), it is recommended that long term ecological recovery monitoring be included in the remedial alternative. Overall, it is recommended that the long term ecological recovery monitoring begin in the near future and be undertaken every three years for a period of 45 years. This interval would allow for iterative evaluation of monitoring data with respect to projected system recovery rates and confirmation of progress toward system-wide recovery. In the event that insufficient progress toward achieving the PRGs of 500 ng/g or 300 ng/g total mercury in sediment occurs during this timeframe, monitoring could be extended beyond 45 years. A summary of estimated costs associated with the components of each of the remedial alternatives is presented below.

| Remedial Alternative | Capital Cost | Operation & Maintenance Cost | Pilot Study Cost | Total Cost |
|---|---|---|---|---|
| **System Wide Alternatives** | | | | |
| Alternative 1: Monitored Natural Recovery | $0 | $16,540,000 | $0 | **$16,540,000** |
| Alternative 2: Enhanced Monitored Natural Recovery (500 ng/g PRG) | $307,570,000 | $18,300,000 | $10,000,000 | **$335,870,000** |
| Alternative 2: Enhanced Monitored Natural Recovery (300 ng/g PRG) | $965,580,000 | $21,620,000 | $10,000,000 | **$997,200,000** |
| **Main Channel of Penobscot River and Orland River Alternative** | | | | |
| Alternative 3: Dredging (500 ng/g PRG with Off-Site Disposal) | $1,713,820,000 | $12,460,000 | $0 | **$1,726,280,000** |
| Alternative 3: Dredging (500 ng/g PRG with Beneficial Reuse) | $1,295,320,000 | $12,460,000 | $0 | **$1,307,780,000** |
| Alternative 3: Dredging (300 ng/g PRG with Off-Site Disposal) | $5,544,190,000 | $15,780,000 | $0 | **$5,559,970,000** |
| Alternative 3: Dredging (300 ng/g PRG with Beneficial Reuse) | $4,388,280,000 | $15,780,000 | $0 | **$4,404,060,000** |
| **Mendall Marsh Alternatives** | | | | |
| Alternative 4: Thin Layer Capping | $52,640,000 | $5,910,000 | $7,500,000 | **$66,050,000** |
| Alternative 5: Amendment Application | $37,080,000 | $6,290,000 | $7,500,000 | **$50,870,000** |
| Alternative 6: Intertidal and Subtidal Dredging (Off-Site Disposal) | $174,050,000 | $11,250,000 | $0 | **$185,300,000** |
| Alternative 6: Intertidal and Subtidal Dredging (Beneficial Reuse) | $125,870,000 | $11,250,000 | $0 | **$137,120,000** |

Significant uncertainties remain regarding the implementability of enhanced MNR and amendment application. Pilot studies that focus on numerical modeling, particle tracking and pilot-scale material addition have been included in estimated costing for enhanced MNR. These studies would be needed to evaluate the potential viability of this remedial alternative, either on a system-wide scale or for discrete portions of the Estuary such as Orland River. For amendment addition (as for thin layer capping) on Mendall Marsh, two pilot-scale studies are included: an initial study to assess potential impacts of material placement on vegetation, followed by a larger-scale study (likely in subsequent years) to assess the effectiveness of the remedy at reducing tissue mercury concentrations in biota from within the footprint of the pilot study area. Pilot studies on the Mendall Marsh platform should be conducted on the scale of acres and encompass a range of marsh elevations and vegetation types.

## TABLE OF CONTENTS

## TABLES

## FIGURES

## APPENDICES

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| Amec Foster Wheeler | Amec Foster Wheeler Environment & Infrastructure, Inc. |
| BERA | Baseline Ecological Risk Assessment |
| CAD | confined aquatic disposal |
| cm | centimeters |
| Court | United States District Court for the District of Maine |
| CWA | Clean Water Act |
| cy | cubic yards |
| DMR | Department of Marine Resources |
| EPA | (US) Environmental Protection Agency |
| ESA | Endangered Species Act |
| Estuary | Penobscot River Estuary |
| ETM | estuarine turbidity maximum |
| GRA | general response action |
| HHRA | Human Health Risk Assessment |
| HoltraChem | HoltraChem Manufacturing Company, LLC |
| IPWC | interval participation weighted concentration |
| MeCDC | Maine Center for Disease Control and Prevention |
| MEDEP | Maine Department of Environmental Protection |
| mg/kg | milligrams per kilogram |
| mg/L | milligrams per liter |
| MLLW | mean lower low water |
| MNR | monitored natural recovery |
| NAVD88 | North American Vertical Datum of 1988 |
| ng/g | nanograms per gram |
| ng/L | nanograms per liter |
| NOAA | National Oceanic and Atmospheric Administration |
| O&M | operations and maintenance |
| Phase III Engineering Study | Penobscot River Phase III Engineering Study |
| ppt | parts per thousand |
| PRGs | preliminary remediation goals |
| PRMS | Penobscot River Mercury Study |
| PRMSP | Penobscot River Mercury Study Panel |
| RAO | remedial action objective |
| SMA | sediment management area |

| | |
|---|---|
| TOC | total organic carbon |
| USACE | U.S. Army Corps of Engineers |
| USC | United States Code |

# 1.0 INTRODUCTION

In January 2016, the United States District Court for the District of Maine (the Court) selected Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) to conduct the Penobscot River Phase III Engineering Study (Phase III Engineering Study) to identify and evaluate feasible, effective and cost-effective measures to remediate mercury contamination in the Penobscot River Estuary (the Estuary). The project area is shown on **Figure 1-1**. The geographic area to be addressed within the Phase III Engineering Study is described by the Court as follows: *"The evaluation will focus in particular on the region from the site of the former Veazie Dam south to Upper Penobscot Bay, including Mendall Marsh and the Orland River."*

The Court ordered the Phase III Engineering Study in order to *"…investigate the current status of mercury contamination in the Penobscot River and to propose potential solutions to mitigate the current harm to the people, biota, and environment of the Penobscot River estuary*." The Court mandated "…*an immediate, thorough, open, and independent identification and evaluation of potential active remedies to speed the recovery of the Penobscot River estuary from its present state of mercury contamination,*" and concluded that based on the results of previous Phase I and II investigative studies, the Phase III Engineering Study "*is essential in order to understand the range, practicality, and cost of potential solutions"* And to "*…develop cost-effective and effective remedies to clean up the remaining mercury in the Penobscot River*."

This Alternatives Evaluation Report presents the results of the development, evaluation, and comparison of remedial alternatives that could potentially be implemented to reduce risks posed to ecological receptors and humans by mercury contamination present in the Estuary. Alternatives were developed, evaluated, and compared based on the following six site-specific criteria which have been established based on the Court Order, the Phase III Engineering Study process and site specific considerations: (1) viability of remedy; (2) whether the proposed solution has been successfully attempted previously or is innovative; (3) the likely cost of the solution; (4) the length of time to complete the recommendations; (5) the likely effectiveness of the solution; and (6) potential environmental harm that may be caused by the proposed solution.

The components of the alternatives evaluation process consist of:

- Assembling select remedial technologies and process options retained for consideration in the Technology Screening Report (Amec Foster Wheeler 2017a) into alternatives applicable within specific reaches of the Estuary;
- Evaluating and comparing the alternatives based on engineering considerations and available data using the site-specific evaluation criteria; and
- Refining the alternatives based on the results of the Phase III Engineering Study field sampling and analysis programs, as well as bench-scale treatability studies.

In this process, each of the alternatives that are developed from assembly of the technologies and process options retained from the technology screening are subject to a detailed evaluation based on the evaluation criteria and are compared based on their ability to meet the criteria.

Concurrent with the alternatives evaluation process, bench-scale treatability studies were conducted to provide data in support of the development and evaluation of alternatives. These studies have included evaluation of:

- The physical properties of sediments to evaluate whether physical separation techniques or size classifications may be used to reduce the volume of sediment requiring treatment or removal;
- The chemical properties of sediments to assess the need for sediment treatment, removal, and containment, and subsequent material handling, dewatering and water treatment or disposal requirements for sediment removal; and
- The toxicity of carbon-based amendments under evaluation for application in marsh areas.

A Phase III Engineering Study Report (Amec Foster Wheeler 2018a) presents the remedial alternatives that are recommended as the result of the evaluation process presented in this report.

## 1.1 PURPOSE, SCOPE, AND OBJECTIVES

The evaluation of alternatives is based on interpretation of the results of the Phase II Study and the completed Phase III Engineering Study field and laboratory program, information presented in the Technology Screening Report (Amec Foster Wheeler 2017a), and the engineering basis and assumptions discussed in Section 5.0 of this report. The recommended remedial alternatives are presented in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

On September 2, 2015, the Court ordered that a thorough, open, and independent study be completed by a professional engineering firm to identify and evaluate potentially viable and cost-effective measures to remediate mercury present in the Estuary. The Court selected Amec Foster Wheeler to conduct a Phase III Engineering Study to evaluate remedial alternatives for the Estuary. The goal of remedy implementation as presented in the Phase III Engineering Study is to reduce ecological and human health risks resulting from the discharge and subsequent accumulation of mercury in sediments and biota in the Estuary.

Beginning in 1967, a chlor-alkali facility located in Orrington, Maine released mercury into the Estuary. Releases of mercury continued throughout facility operation at overall declining concentrations and ceased with facility closure in 2000. In 2000, Maine People's Alliance joined with the Natural Resources Defense Council to file a lawsuit against HoltraChem Manufacturing Company, LLC (HoltraChem) and Mallinckrodt Inc., based on evidence of elevated concentrations of total mercury and methyl mercury in sediment and biota. Methyl mercury is a form of mercury with increased biological toxicity that results from the bacterial transformation of inorganic mercury to a methylated form. The lawsuit was pursuant to the imminent and substantial endangerment provision of the Resource Conservation and Recovery Act. At the time the suit was filed in 2000, HoltraChem owned the chlor-alkali facility; Mallinckrodt Inc., with its affiliates and predecessors, owned the facility from 1967 to 1982.

In July 2002, the Court ruled in the plaintiffs' favor and ordered an independent scientific study, the Penobscot River Mercury Study (PRMS), to assess the spatial distribution and impact of mercury discharge in the Penobscot River. The Penobscot River Mercury Study Panel (PRMSP) was appointed to complete the PRMS. As of 2017, two phases of the PRMS were completed: Phase I in 2008 (PRMSP 2008) and Phase II in 2013 (PRMSP 2013).

Regarding these earlier phases of the PRMS, the Phase I Report (PRMSP 2008) concluded that there was enough scientific evidence to conclude that the Penobscot River is contaminated with mercury to an extent that poses risks to some wildlife species, and possibly some limited risk for human consumers of fish and shellfish. The PRMSP recommended that the study of the Penobscot River proceed to a second phase—the Phase II Study.

The Phase II Report (PRMSP 2013) concluded that:

- Inorganic mercury discharged from the HoltraChem plant remains present in high concentrations in sediments of the Penobscot River and Estuary. Inorganic mercury in Estuary sediment is being converted by bacteria into methyl mercury, an organic form of mercury that enters and persists in the bodies of animals that ingest it; methyl mercury biomagnifies in the food chain, meaning it becomes more concentrated as it passes from prey to predator.
- Total mercury concentrations in the Estuary are declining in some areas; although the Estuary has recovered significantly since the period of peak mercury discharge, it is estimated that at the current rate of recovery, it will take more than 100 years for mercury concentrations in Estuary sediment to decrease to a level consistent with regional background concentrations in sediment.
- The slow rate of decline of mercury concentrations in the Estuary is attributable, in part, to the presence of a large pool of mercury- affected mobile sediment in the Estuary. This mobile sediment is retained in the Estuary by natural processes that result in the landward flow of both bottom water and associated sediment under the influence of tides. This large pool of contaminated sediment is referred to in the Phase II Report as "the mobile pool."

Based on the Phase II Study conclusions and the potential for ongoing risks to Estuary ecology from biomagnification of methyl mercury, the PRMSP recommended that a remediation plan be developed to address contamination of Estuary sediments and risks to Estuary organisms. This remediation plan forms the basis of the Phase III Engineering Study. The Phase III Engineering Study is focused on developing recommendations regarding viable and cost-effective alternatives for Estuary remediation that should proceed to the design phase.

# 2.0 SUPPORTING INFORMATION

Section 2.0 summarizes supporting information used in the development of remedial alternatives. Supporting information includes a summary of background documents (Section 2.1); a list of technical memoranda and reports (Section 2.2); and a summary of bench-scale treatability studies conducted to support remedial evaluations (Section 2.3). Specifically, data generated from the bench-scale treatability studies were used to support selection of process options and technologies; refine engineering assumptions used as the basis for the detailed evaluation of alternatives; support cost estimations; and assess feasibility and/or aspects of uncertainty associated with the implementation of various remedial technologies.

## 2.1 BACKGROUND DOCUMENTATION

The Phase I and Phase II studies are summarized in Sections 2.1.1 (Phase I) and 2.2.2 (Phase II).

### 2.1.1 Phase I Study Summary

In July 2005, the PRMSP submitted A Study Plan for Evaluation of the Mercury Contamination of the Penobscot River/Estuary, Maine, with the overall objective of determining whether mercury concentrations in biota in the Penobscot River and Estuary were a concern, and whether remediation within the river or additional remediation at the HoltraChem facility was recommended.

Phase I sampling of water, sediments, benthic invertebrates, finfish, shellfish, birds and mammals was carried out in 2006–2007 to characterize mercury and methyl mercury concentrations and spatial patterns in the Penobscot River and Estuary. Four criteria were used to evaluate whether mercury concentrations in Estuary water, sediment, and biota were a concern, and whether the source of that mercury appeared to be the HoltraChem facility. These four criteria were:

1. Comparison of concentrations of mercury in the Penobscot system to available National Oceanic and Atmospheric Administration (NOAA), Maine Department of Environmental Protection (MEDEP), and U.S. Environmental Protection Agency (EPA) benchmarks for toxic effects on benthic organisms and human consumers;

2. Comparison of mercury concentrations in the Penobscot system to scientific literature on toxicological effects;

3. Assessment of geographical patterns of mercury distribution within the Penobscot system, especially in spatial relation to the HoltraChem facility; and

4. Comparison of mercury concentrations in the Penobscot system to concentrations in uncontaminated and contaminated sites.

The Phase I Report concluded that, based on available evidence, mercury present in the Penobscot River and Estuary posed risks to some wildlife species, as well as limited risks to human consumers of finfish and shellfish. The PRMSP recommended that a Phase II Study be undertaken to examine the dynamics of mercury cycling in the Penobscot River and Estuary, including estimation of the rate of natural attenuation of mercury in the system.

### 2.1.2 Phase II Study Summary

A Phase II Study Plan was submitted to and approved by the Court in July 2008. Primary objectives of the Phase II Study were to assess whether the process of natural attenuation could reduce concentrations of mercury in sediments in the Estuary to acceptable levels within a reasonable time frame, and to evaluate whether active remediation measures could feasibly accelerate recovery.

The Phase II Report (PRMSP 2013), submitted in April 2013, concluded that inorganic mercury discharged from the HoltraChem facility was present in sediments of the Penobscot River and Estuary, and that the mercury was being converted by bacteria into methyl mercury.

The Phase II Report noted that while total mercury concentrations were declining in some areas of the Estuary, at the current estimated rate of decline it would take more than 100 years (specifically, 106 to 390 years, depending on location and choice of recovery rate parameters) for mercury concentrations in sediment and biota to decrease to levels that no longer pose ecological risks. The Phase II Report attributed this slow rate of decline of mercury concentrations in the Estuary to the presence of a large pool of mercury-affected mobile sediment (estimated at 320,000 tons of sediment) that has been trapped in the upper Estuary by natural circulation dynamics. Based on ongoing ecological risks, the PRMSP recommended an evaluation of active remedies, if any, that could be implemented to shorten the duration of estimated recovery times and reduce mercury concentrations in sediments and biota in the Estuary.

## 2.2 TECHNICAL MEMORANDA AND REPORTS

Technical memoranda and reports prepared during the Phase III Study are listed below.

- Technology Screening Report (Amec Foster Wheeler 2017a)
- 2016 Biota Monitoring Report (Amec Foster Wheeler 2017b)
- 2016 Sediment and Surface Water Quality Monitoring Report (Amec Foster Wheeler 2017c)
- Summary of Biota-Sediment Accumulation Factor Evaluation Technical Memorandum (Amec Foster Wheeler 2017d)
- 2016 Mobile Sediment Characterization Report (Amec Foster Wheeler 2017e)

- Leachability Bench-Scale Testing Technical Memorandum (Amec Foster Wheeler 2017f)
- Penobscot River Risk Assessment and Preliminary Remediation Goal Development Report (Amec Foster Wheeler 2018b)
- 2017 Marsh Platform Sediment Characterization Report (Amec Foster Wheeler 2018c)
- Analysis of Lignin Oxidation Products in Sediments Technical Memorandum (Amec Foster Wheeler 2018d)
- Analytical Methods Comparison Technical Memorandum (Amec Foster Wheeler 2018e)
- Hydrodynamic Simulation Report (Amec Foster Wheeler 2018f)
- 2017 Sediment and Surface Water Quality Monitoring Report (Amec Foster Wheeler 2018g)
- 2017 Mobile Sediment Characterization Report (Amec Foster Wheeler 2018h)
- 2017 Intertidal and Subtidal Characterization Technical Memorandum (Amec Foster Wheeler 2018i)
- 2017 Biota Monitoring Report (Amec Foster Wheeler 2018j)
- 2018 Thin Interval Core Sampling Report (Amec Foster Wheeler 2018k)
- Amendment Plot Resampling Study Technical Memorandum (Amec Foster Wheeler 2018l)
- Risk Reduction Report (Amec Foster Wheeler 2018m)
- Communication and Community Involvement Plan Report (Amec Foster Wheeler 2018n)

Results and information obtained from activities undertaken in support of this engineering evaluation have provided the basis for refining current site understanding. A summary of results from these technical memoranda and reports are presented in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

## 2.3 BENCH-SCALE TREATABILITY STUDIES

As part of the Phase III Engineering Study, Amec Foster Wheeler conducted bench-scale treatability studies to provide site-specific data to evaluate the effectiveness, implementability, and cost of remedial technologies and processes that have been identified as potentially applicable in the Technology Screening Report (Amec Foster Wheeler 2017a).

Data gathered from treatability studies are used to support selection of process options and technologies in the development of remedial alternatives; refine engineering assumptions used as the basis for the detailed evaluation of alternatives; support cost estimations; and establish the feasibility of implementing the technologies in different ecological and/or hydrodynamic zones within the Estuary. The results of the bench-scale treatability studies are discussed in Sections 2.3.1 through 2.3.5.

### 2.3.1 Technical Memorandum Leachability Bench-Scale Testing

A bench-scale leachability study was undertaken in support of the remedial evaluation to assess the leachability of mercury and methyl mercury from sediment and mixtures of sediment and wood waste (Amec Foster Wheeler 2017f). This study also assessed whether salinity influences the leachability of mercury and methyl mercury from sediment and from mixtures of sediment and wood waste. Details of the study, including a summary technical memorandum, are provided **Appendix A**. A summary of the study is provided below.

- Bulk sediment samples were collected from three areas (Verona Northeast intertidal, Frankfort Flats/Bucksport intertidal, and Bucksport subtidal) for leachability testing. These locations were chosen to represent a range of organic carbon concentrations (two samples had organic carbon content between 5 and 10 percent and the third had organic carbon content of approximately 45 percent).
- Surface water samples were collected from two locations: near Fort Point at high tide for higher salinity conditions (24 parts per thousand [ppt]) and near Hampden at low tide for low salinity conditions (0 ppt).
- Testing included the following scenarios:
    - Scenario 1: Wood waste mixed with river water, shaken, settled, decanted and filtered; elutriate analyzed for total mercury and methyl mercury.
    - Scenario 2: Wood waste mixed with river water, shaken, settled, centrifuged and pressed; elutriate analyzed for total mercury and methyl mercury
- Results did not indicate rapid transfer of dissolved mercury from the particulate phase to the aqueous phase, even with aggressive sample agitation.
- Elutriate mercury concentrations were reported at concentrations below the Maine Freshwater Chronic Water Quality Criteria of 910 nanograms per liter (ng/L), suggesting that water treatment for mercury removal during sediment dewatering may not be needed prior to discharge.

### 2.3.2 Toxicity Study

A toxicity study was undertaken to evaluate potential impacts of activated carbon-based amendments on the survival, growth and/or mercury body burden of test organisms. Toxicity testing included an estuarine amphipod (*Leptocheirus plumulosus*) and a marine polychaete worm (*Nereis virens*) exposed to varying application rates (3, 5, and 10 percent dry weight) of amendments (activated carbon, SediMite™, and biochar) mixed with sediment collected from Mendall Marsh. The average total mercury concentration in the test sediment was 347.7 nanograms per gram (ng/g) (± 11.4 ng/g; n = 3). The average methyl mercury concentration in the test sediment was 9.7 ng/g (± 1.1 ng/g; n = 3). The location for test sediment collection was based on existing sediment mercury data for the south branch of Marsh River; sediment was collected from the upper intertidal zone. The endpoints evaluated for the amphipod included survival, growth (dry biomass and dry weight), and reproduction (juvenile production per organism and juvenile production per female) in 28-day tests. The endpoints evaluated for the polychaete worm included survival and body burden in a 28-day test.

Overall, the study findings show that adding SediMite™ at a rate of 3 percent achieved the best performance for nearly all endpoints measured based on mean survival, growth, and reproduction. The addition of activated carbon at either 5 percent or 10 percent generated results similar to the addition of 3 percent SediMite™. The addition of biochar resulted in reduced survival relative to the control across all application rates. The methyl mercury body burden in polychaetes for each treatment within the 28-day toxicity test did not show a difference relative to the control. The report provided by EnviroSystems, Inc., along with a summary of toxicity test results and body burden analysis are presented in **Appendix B.**

### 2.3.3 Technical Memorandum Dewatering Study

A dewatering study was undertaken to evaluate dewatering technologies for dredged sediments and wood waste. The study was conducted on composite samples of sediment and wood waste collected from the Estuary to evaluate mechanical technologies, geotextile fabric and gravity drainage technologies, and commonly available reagents and additives to increase the material percent solids and material density for potential disposal. The Penobscot River Dewatering Bench-Scale Study Report provided by KEMRON Environmental Services, Inc. is included as **Appendix C-1** and summarized in this section. Analytical results of samples submitted for analysis by Eurofins is provided in **Appendix C-2**.

Amec Foster Wheeler submitted bulk composite sediment and river water samples from Frankfort Flats/Bucksport and Verona North. These areas were chosen for the dewatering study because they represent prospective locations for dredging. KEMRON Environmental Services, Inc. combined equal quantities of the Frankfort Flats/Bucksport and Verona North sediment to create a composite sample (FFBU-VN-Composite) for the study. As collected, bulk sediment from Frankfort Flats/Bucksport contained approximately 60 percent wood waste; bulk sediment from Verona North contained approximately 25 percent wood waste. The composite sediment sample was classified as dark brown elastic silt. The composite sample was characterized with a total mercury concentration of 663 ng/g, 14 percent organic content and 37 percent solids content.

Water samples collected from both locations were also mixed in equal proportion to generate a composite water sample for the bench-scale testing.

***Polymer Testing:*** A sample of approximately 10 percent solids was generated to mimic a hydraulic slurry and was used to identify the most effective polymer and dosage for flocculation. Results indicated that a single application of Solve 137 at a dosage of 2.9 pounds per dry ton produced the best floc and water clarity.

***Mechanical Dewatering Evaluations:*** Mechanical dewatering evaluations were performed on four different material conditions:

- Raw hydraulic dredge: Bulk composite sediment slurried to approximately 10 percent solids.
- Bulk polymer treatment: Bulk composite sediment slurried to approximately 10 percent solids treated with a polymer (Solve 137) at a dosage of 2.9 pounds per dry ton.
- Bulk pre-screening: Bulk composite sediment slurried to approximately 10 percent solids screened with a #10 sieve.
- Bulk screening polymer treatment: Bulk composite sediment slurried to approximately 10 percent solids screened with a #10 sieve and treated with Solve 137 at a dosage of 2.9 pounds per dry ton.

Belt press testing was performed on the bulk polymer treatment and bulk screening polymer treatment material conditions. The results of testing indicated that both materials produce similar percent solids and pass the paint filter test. Both materials failed uniaxial compressive strength testing and showed no pocket penetrometer strength. Based on the study, belt filter press technology requires the use of polymer to create a material capable of belt dewatering. The resultant filter cake passed paint filter testing either with or without removal of wood waste from the material.

Centrifugation testing was performed on the four material conditions. After centrifuging, the raw hydraulic dredge and bulk pre-screening materials exhibited the lowest percent solids. The raw hydraulic dredge, bulk polymer treatment, and bulk screening polymer treatment materials passed the paint filter test while the bulk pre-screening material failed the paint filter test. All materials failed uniaxial compressive strength testing and showed no pocket penetrometer strength. Based on the study, centrifugation technology appears to provide multiple options for full scale treatment. Treatment involving centrifugation does not appear to require the use of polymer to create a material that passes paint filter testing; removal of wood waste is not required.

Filter press testing was performed on the four material conditions. Results of the filter press tests show that the raw hydraulic dredge and bulk pre-screening materials achieved higher percent solids compared to the bulk polymer treatment and bulk screening polymer treatment materials. Filter press tests were less effective with polymer treatment and the resultant filter cakes did not pass the paint filter test. When polymer was not used, filter press tests were more effective following removal of wood waste, although for the raw hydraulic dredge material, the filter cake passed the paint filter test even with wood waste present.

***Geotextile Fabric Testing:*** Rapid dewatering testing and geotube dewatering testing were performed on the bulk polymer treatment and bulk screening polymer treatment materials. After allowing 15 gallons of test slurry to drain for 24 hours, the materials passed the paint filter test. Percent solids for the bulk polymer treatment and bulk screening polymer treatment materials were 35.2 percent and 46.2 percent, respectively.  Neither material exhibited strength by uniaxial compressive strength testing or pocket penetrometer testing.

***Gravity Drainage Testing:*** Gravity drainage testing was conducted on the composited bulk sediment material at the "as received" moisture content to evaluate the reduction in moisture achieved by allowing the material to drain while stockpiled. After 24 hours of gravity draining, the percent solids increased from 36.1 percent to 39.7 percent. The material failed paint filter testing and did not exhibit strength by uniaxial compressive testing or pocket penetrometer testing. Gravity drainage does not appear to be an effective dewatering technology.

***Solidification Evaluations:*** Solidification testing was conducted using Type I Portland cement and lime kiln dust. Solidification testing evaluates improvements to the physical properties of site sediment, mainly passing the paint filter test and reducing free liquids in sediment while maintaining a soil-like consistency and minimizing the increase to treated material volume. For each solidification product, addition rates of 4, 8, 12, 16, and 20 percent were evaluated. Results indicate the adding Portland cement to sediment mixtures reduces free liquid more effectively than adding lime kiln dust. Portland cement mixtures passed paint filter testing after 24 hours of curing, whereas lime kiln dust mixtures failed paint filter testing after 24 hours of curing. Study results indicate that ex situ solidification of the mechanically dredged sediments with the addition of 4 percent Portland cement appears to achieve a material capable of being transported for disposal. Addition of 4 percent Portland cement resulted in an approximately 4 percent increase in material volume.

### 2.3.4 Technical Memorandum Cohesive Sediment Erosion Field Study

The United States Army Corps of Engineers (USACE) Coastal and Hydraulics Laboratory was contracted to conduct a sediment bed erosion study which included erosion testing for 15 cores collected from select reaches of the Estuary. The study used the USACE High Shear Stress flume

(SEDflume) designed for estimating erosion rates of sediments collected as cores and analyzed across the depth profile of each core. The USACE report presents the results of erosion testing for each core by sampling location along with the results for analysis of physical samples collected; the report is included as **Appendix D**.

In summary, fifteen 10-centimeter (cm) diameter cores were collected from throughout the Estuary. Cores were described in terms of length, condition of the core surface, biological activity, and visual evidence of sediment layering. SEDflume was used to evaluate critical shear stress for erosion as well as the erosion rate as a function of applied shear stress for multiple layers in a sediment core. For testing, cores were inserted into the testing section of SEDflume and advanced via a screw jack to remain flush with the bottom wall of the flume. Flow was directed over the core surface to generate shear stress on the sediment. Approximately 1 millimeter to 5 millimeters of sediment were eroded at each specified shear stress. Additionally, for each core, subsamples were taken at 3 centimeter (cm) to 5 cm intervals for measurement of sediment bulk physical properties. Subsamples were analyzed for bulk density and grain-size distribution.

Data generated from the SEDflume testing indicated that, with the exception of one core from Mendall Marsh (MM-MU6-SF-1), distinct sediment layers with varied erosional resistance could be identified in each core collected from the Estuary. Frequently, the boundary of erosional layers within cores was associated with zones of visible bioturbation. Other commonly observed markers of erosional layers included the surface layer (the upper 1 cm of sediment within each core), variations in sediment grain size, and changes in sediment bulk density. In general, it was found that erosion rates tended to decrease with depth in the core; however, instances of more easily erodible layers were observed at depth in some cores. Overall, critical shear stresses ranged from 0.11–1.21 pascal; for identified surface layers, the range of critical shear stress was 0.11–0.43 pascal.

### 2.3.5 Technical Memorandum Amendment Plot Resampling Study

The Smithsonian Environmental Research Center (SERC) conducted resampling of the amendment test plots initially established by SERC as a component of the Phase II Study (PRMSP 2013). As detailed in the Phase II Study, the establishment and monitoring of amendment test plots was designed to assess the effectiveness of amendments as a remediation strategy for mercury in Mendall Marsh. While four amendments (iron as $FeCl_2$, lime, activated carbon formulated as SediMite® and biochar) were initially applied in 2010, iron and lime were dropped from further evaluation in 2012 based on the results of interim sampling and analysis. The 2017 sampling focused on the test plots containing SediMite® and biochar. The overall objective of 2017 sampling was consistent with the Phase II objectives, namely evaluation of the effectiveness of SediMite® and biochar in reducing soil and porewater concentrations of total mercury and methyl mercury relative to concentrations in control plots with no amendment addition. The results of the 2017 resampling are presented in **Appendix E**.

Results of the 2017 resampling demonstrate that SediMite® and biochar applied in 2010 remain visible and measurable after 7 years in the field. Marsh accretion has buried the amendments to a current depth of 2-3 cm. Based on analytical measurement of soil carbon, the retention rate of SediMite® through 2017 was 127 ± 57% at the Central site and 90 ± 32% at the West site. For biochar, the retention rate was 62 ± 26% at the Central site and 29 ± 11% at the West site.

For depth-integrated porewater analyses (0-5 cm), the addition of both SediMite® and biochar decreased porewater concentrations of total mercury and methyl mercury relative to the control for the Central location but not the West location. Overall, throughout this study, SediMite® was more effective than biochar in reducing concentrations of porewater total mercury and methyl mercury.

For depth-integrated marsh soil analyses (0-3 cm), the addition of SediMite® appears to have minimal impact on concentrations of total mercury and methyl mercury in either the Central or West location. In contrast, the addition of biochar, while having no impact on the soil total mercury concentration in either the Central or West location, significantly increased the soil concentration of methyl mercury in both test locations. The increased concentration of soil-associated methyl mercury following the addition of biochar may result from the ability of biochar to sorb or bind methyl mercury and inhibit demethylation back to inorganic mercury.

Based on the review of these data, the use of amendment application as a component of site remedy for the Penobscot River Estuary has not been proven effective. It is currently not possible to evaluate whether the amendments, either applied as a stand-alone remedy or incorporated into a thin layer cap, would result in decreased biological update and trophic transfer of methyl mercury as there are only limited data on biota uptake of mercury with amendment addition. While SediMite® was more effective than biochar in reducing porewater concentrations of total mercury and methyl mercury over the study period (2010 – 2017), the impact of SediMite® addition was not equally apparent between the Central and West locations. Moreover, changes in soil redox conditions in 2017 relative to the earlier sampling period adds uncertainty to the evaluation of the long-term effectiveness of amendment addition by complicating interpretation of 2017 data relative to 2010 - 2012 data. For other sites, if biochar is to be evaluated as a potential amendment for reducing biological uptake of methyl mercury, the bioavailability of methyl mercury that sorbs to biochar, particularly as the amendment ages in the field, should be assessed.

# 3.0 CURRENT SITE UNDERSTANDING

This section presents the current site understanding and includes an overview of the Estuary, including division of the river into reaches to facilitate delineation and assessment of remedial alternatives (Section 3.1); a description of site geomorphology, including sediment transport dynamics and Estuary circulation (Section 3.2); an overview of historical human activities in the Penobscot River watershed (Section 3.3); a description of current activities that affect the Estuary (Section 3.4); a conceptual understanding of mercury fate and transport (Section 3.5); spatial distribution of mercury and methyl mercury by reach (Section 3.6); ecological exposure (Section 3.7); wood waste/wood products fate and transport (Section 3.8); and system recovery times (Section 3.9).

## 3.1 SITE OVERVIEW AND REACH DESIGNATIONS

The Penobscot River is the second largest river system in New England, draining a watershed of approximately 7470 square miles. The lower river is defined by the Penobscot River Estuary, which extends 22 miles from Bangor to the vicinity of Searsport, Maine. The surface area of the Estuary is approximately 35 square miles. The geographic area of the river addressed in the Phase III Engineering Study is described by the Court as "*the region from the site of the former Veazie Dam south to upper Penobscot Bay, including Mendall Marsh and the Orland River*" (**Figure 1-1**). The Estuary also includes reference stations from upgradient of the former Veazie Dam.

Tidal range in the Estuary can vary from 9.5 feet at neap tides to 16 feet at spring tides, with a tidal velocity that ranges from 2.3 feet per second during neap tides to 4.3 feet per second during spring tides (Geyer and Ralston 2018). Salinity within the Estuary ranges from 0 to 30 ppt depending on location and season, and the upgradient limit of tidal influence can exceed the upgradient limit of salt water incursion. Freshwater outflow from the Penobscot River varies seasonally from approximately 5,000 cubic feet per second during low flow conditions to 63,000 cubic feet per second during peak spring freshet, with an average annual discharge of 12,000 cubic feet per second (Geyer and Ralston 2018). During seasonal periods of high freshwater outflow, tidal inflow does not mix salt water throughout the water column; during these periods, stratification or layering is created in the water column, resulting in freshwater outflow predominating in surface waters and tidal (salt water) inflow being confined to the lower water column. Under these high river flow conditions, the extent of salt water incursion into the Estuary is restricted, and salinity may be 0 ppt north of Winterport (Geyer and Ralston 2018). During seasonal periods of lower freshwater outflow, tidal inflow may significantly mix salt water throughout the water column. This vertical mixing of salt water reduces stratification or layering of the water column and under these conditions, the tidal incursion may be evident as far upgradient as Bangor (Geyer and Ralston 2018). The impact of seasonal variations in stratification and salt water incursion on sediment transport dynamics is discussed in greater detail in Section 3.2.2.

To characterize sections of the Estuary that may be distinct in terms of river flow, tidal influence, and/or the transport and deposition of mercury associated with sediment, Amec Foster Wheeler has delineated 15 Estuary reaches (**Figure 1-1**). Reach boundaries incorporate physical river features so that field personnel can recognize these features during sample collection efforts. For the 15 reaches delineated, the lateral landward extent of the reach boundary is the 14-foot North American Vertical Datum of 1988 (NAVD88) elevation contour.

## 3.2 SITE GEOMORPHOLOGY AND ESTUARINE CHARACTERIZATION

Regarding geomorphology (or shape), the upper Penobscot River Estuary is defined by a narrow channel (< 0.5 mile) that is generally bound by bedrock. The channel widens downgradient of Winterport in the vicinity of Frankfort Flats and then narrows again in the vicinity of Verona Island. The Estuary channel divides around Verona Island, with the main flow passing to the west of Verona Island; a secondary channel passes to the east of Verona Island where it is joined by the Orland River at Gross Point. South of Gross Point, the eastern channel narrows and, passing south of Verona Island, rejoins the western channel. South of Verona Island the single main channel enters the lower Estuary and widens considerably to more than a mile in width. The lower Estuary is defined by the broadening and deepening area from the southern tip of Verona Island south past Fort Point Cove, Cape Jellison, and Sears Island, and south to the upper extent of Penobscot Bay. The upper extent of Penobscot Bay (distinct from the reach named "Upper Penobscot Bay" on **Figure 1-1**) is generally defined by a line drawn from Belfast Bay on the west side of the upper bay across Turtle Head on Islesboro to Castine on the east side of the upper bay. Overall, the Estuary can be described as a drowned river channel carved and framed by glaciers.

### 3.2.1 Glacial History and Sediment Inputs

The glacial framing of the Penobscot River and Estuary has resulted in features including shoaled or shallow areas, such as in the vicinity of Frankfort Flats, as well as areas in which the bedrock has been scoured and incised. Water depth in the upper Estuary is generally less than 30 feet, increasing to more than 60 feet in the vicinity of Bucksport and in the main channel west of Verona Island. Water depth east of Verona Island and in the Orland River is generally consistent with water depth in the upper Estuary, and increases to more than 30 feet southeast of Verona Island, where the east and west channels converge.

Sediment inputs to the upper Estuary are derived from multiple sources, including transport from upgradient in the river, lateral transport into the Estuary from creeks or tributary streams (such as Marsh River), and landward transport from downgradient in the Estuary as the result of tidal action. Mass estimates of sediment input to the Estuary are on the order of 44,000 (metric) tons per year from sources upstream of the Estuary and 12,300 (metric) tons per year from lateral creeks and tributaries from within the Estuary, as discussed in Chapter 18 of the Phase II Report (PRMSP 2013). The mass of sediment annually transported into the Estuary from Upper Penobscot Bay is currently unknown.

### 3.2.2 Estuary Characterization

An estuary can be generally defined as a semi-enclosed coastal body of water that exists at the interface between an outflowing body of fresh water (i.e., a river) and an incursion of salt water (i.e., ocean tides). A more complete characterization of sediment transport in estuaries therefore requires understanding the processes regulating the potential for that transport. The dominant processes regulating transport described further in this section include tidal circulation and the impact of that circulation on the balance between burial/storage versus resuspension and redistribution of particulate matter. Particulate matter includes mineral sediment as well as organic particles that may originate from upgradient transport and/or from primary production (i.e., phytoplankton growth) within the Estuary. For the Penobscot River, organic particle transport into the Estuary includes an unknown volume of wood waste originating from upstream historical sawmill activities along the river (see Section 3.3.1.2). Chapter 18 of the Phase II Report estimated that the rate of new particle formation within the Penobscot River Estuary is approximately 12,500 (metric) tons per year (PRMSP 2013), with an uncertain fraction of this material being recycled in the water column versus depositing (either temporarily or as a component of stable storage) on the sediment bed. Stable storage results from the settling of particulate material to the Estuary bed where it may be ultimately buried by continued deposition. Resuspension refers to the re-entrainment of material into the water column as the result of natural (e.g., tidal action, storm events) or anthropogenic (i.e., vessel traffic, dredging activities) disturbances to the sediment bed.

#### *3.2.2.1 Tidal Volume/Circulation*

Estuaries can be generally described in terms of two features: (1) the balance between the magnitude of freshwater outflow and the tidal amplitude; and (2) the impact of that balance on the salinity profile of the water column. Geyer and Ralston (2018) describe the profile of the Penobscot River Estuary as a tidally forced salt wedge. A salt wedge is created when the magnitude of freshwater outflow is sufficient to stratify the water column and create a vertical gradient in water column salinity (**Figure 3-1**). This gradient is driven by the difference in density between fresh water (lower density) and salt water (higher density).

Although density gradients can be created by multiple factors, including water temperature and variations in suspended sediment concentrations, the principal driving mechanism for stratification in estuaries is the salinity gradient. In a salt wedge estuary, surface water flowing downgradient (i.e., flowing toward the coastal ocean) is fresh (salinity = 0 ppt) and bottom water flowing upgradient (i.e., moving up the estuary from the coastal ocean) reflects the salinity of the incoming tide. For the Penobscot River Estuary, Geyer and Ralston (2018) have documented that under high freshwater outflow conditions, such as occurs in the spring. a salinity greater than zero is measurable in the bottom water as far upgradient as Mendall Marsh on the incoming tide. During outgoing (ebb) tide in a salt wedge estuary, the structure of the salt wedge can collapse, resulting in a water column salinity profile that is more evenly mixed throughout the water column. Under these ebb tide conditions, the upgradient extent of salt water incursion will move back downgradient toward the mouth of the estuary. For the Penobscot River Estuary, under spring flow conditions, the ebb tide limit of salt water incursion can move downgradient from Mendall Marsh to the vicinity of Bucksport (Geyer and Ralston 2018).

During low flow (summer) conditions in a tidally stratified estuary, the decrease in the volume of freshwater outflow results both in an increased incursion of salt water further up the estuary and a general decrease in water column stratification as salt water is mixed farther up into the water column. For the Penobscot River Estuary, data collected during lower flow conditions have demonstrated measurable saline bottom water as far up as Orrington during the flood tide, and salinity remaining measurable in the vicinity of Winterport during ebb tide (Geyer and Ralston 2018). For the data presented in Geyer and Ralston (2018), although the water column was stratified and vertical profiles in salinity were measurable throughout the June (low flow) 2011 sampling cycle, the extent of stratification was not as significant as it was during high flow/flood tide conditions measured in the spring of that year.

The 2011 data presented by Geyer and Ralston (2018) highlight the balance between freshwater outflow and salt water inflow that characterize the dominant circulation within estuaries. Depending on the size and shape of an estuary, other mechanisms can contribute to circulation, although the overall impacts of these mechanisms may be less significant (such as residual circulation resulting from Coriolis forcing), localized (such as meanders or other variabilities in channel shape or depth), and/or episodic (such as wind-driven forcing during storm events). For the Penobscot River Estuary, localized cross-channel circulation occurs at Frankfort Flats because of the shape of channel meanders in this reach (Hegermiller 2011). This localized cross-channel circulation enhances sediment trapping in this area.

#### *3.2.2.2 Sediment Storage/Recirculation*

Estuaries tend to function as traps for sediment and suspended particulate matter due to a combination of factors, including a change in channel slope in an estuary relative to the slope in the upgradient river and the impact of tidal inflow on freshwater outflow. While some portion of the sediment in estuaries is in either periodic or continuous motion, the majority of sediment in estuaries is deposited on the sediment bed or (if present) within adjoining marshes, either within marsh channels or on marsh platforms. Sediment deposition on marsh platforms is the result of inundation of the platform; site-specific sediment accumulation rates on platforms vary as a function of factors including inundation frequency, vegetation (amount and type) and the presence of pannes or other topographic low spots. The rate at which sediment accumulates in estuaries can vary significantly as a function of background/natural factors and human activities. If an estuary is considered as an equilibrium profile that joins a riverine reach and the coastal ocean, the dominant process responsible for sediment storage in estuaries is the accommodation space created by sea level rise. That is, as sea level rises, underwater space is created in estuaries for the settling and storage of sediment. In a typical New England estuary like the Penobscot River Estuary, the accommodation space created by sea level rise allows for the deposition of approximately 2 millimeters of sediment per year as a background sedimentation rate, as detailed in Chapter 7 of the Phase II Report (PRMSP 2013). Within the Penobscot River Estuary, sediment accumulation rates vary from 0–2.5 cm per year (Santschi et al. 2017; Amec Foster Wheeler 2018k) depending on site-specific factors, including location on marsh platforms (near the edge versus in the interior) and hydrodynamic controls on potential deposition and accumulation in intertidal areas (**Figure 3-2**). The rate at which sediment accumulates in a location will influence both the spatial pattern and the site-specific inventory of particulate-associated contaminants such as mercury.

Sediment deposition can be enhanced or reduced by a range of human use activities that disturb the equilibrium profile in estuaries. Activities that can enhance sediment deposition include dredging and the placement of structures such as docks or groins that change localized circulation patterns in an estuary. Activities that can reduce sediment deposition include the placement of upgradient structures like dams that might limit sediment supply to an estuary or activities within an estuary—such as placement of bulkheads or other channelizing structures—that would limit or prevent sediment deposition and storage. Overall, historical dam construction on the Penobscot River was typically run-of-river and did not result in significant fine-grained sediment retention upgradient of the Estuary (see Section 3.3.1.3).

Following deposition, the resuspension of particulate matter from the sediment bed requires a disturbance of that bed. Disturbance can be localized (such as from the passage of a vessel) or more broadly distributed (such as from a storm surge), but in either scenario, the resuspension of bed sediment is the result of shear stress applied to the bed surface. Factors influencing the magnitude of the sediment bed response to the applied shear stress include: (1) the size and density of bed particles, with greater shear stress required to re-suspend larger and/or denser particles; and (2) the overall previous stability of the sediment bed, with a consolidated bed requiring greater shear stress to re-suspend particles than a bed enriched in unconsolidated or flocculant material.

Of importance for the question of mercury fate and transport (Section 3.5), this model of sediment retention and recirculation in estuaries suggests that for contaminants such as mercury associated with fine-grained sediment or low density organic matter, there is likely to be significant mixing and retention of contaminants *within* estuaries. The cycling and retention of fine-grained sediment or low-density organic matter within estuaries can therefore have the effect of homogenizing or blurring contaminant concentration gradients (either spatially or vertically) which may have implications for the ability to use the spatial distribution (either/both vertical or horizontal) of contaminants to assess fate and transport dynamics and/or system recovery rates for that estuary. Use of site data to assess system recovery rates for the Penobscot River Estuary is discussed in Section 3.9.

#### *3.2.2.3 Estuarine Turbidity Maximum*

In some scenarios and under specific conditions of freshwater outflow and tidal range, hydrodynamic circulation can create regions in an estuary in which a pool of mobile material is maintained continuously in suspension. This feature is described as an estuarine turbidity maximum (ETM) and defines a location, typically near the landward limit of salt water incursion, where the stratification and convergence of flow created by the interaction of fresh and salt water promotes the retention, accumulation, and recycling of fine-grained materials (**Figure 3-3**) (Geyer 1993). As its location relative to the limit of salt water incursion suggests, if an estuary has an identifiable ETM, the feature will move seasonally as changes in the volume of freshwater outflow influence the location of the salt wedge. The concentration of particulate matter in the ETM may also vary seasonally as the extent of water column stratification will influence the vertical expression of water column turbidity and the magnitude of freshwater discharge will influence the concentration of suspended particulate matter in the water column.

In general, for energetic salt wedge estuaries, sediment accumulation occurs predominantly in mud-dominated environments that fringe the main estuary channel (Yellen et al. 2017). As example, Yellen et al. (2017) observe that, for the Connecticut River, a combination of: (1) the presence of a pool of re-suspended/mobile fine grained particulate matter in an ETM that seasonally moves into the vicinity of an off-channel cove; (2) a salinity (density) gradient between saltier water in the main estuary channel and fresher water in that cove; and (3) vertical water column stratification within the cove that tends to limit localized sediment resuspension, create a dynamic in which embayments and off-channel coves can significantly retain particulate matter (**Figure 3-4**). Conceptually, this model of sediment accumulation has relevance for the Penobscot River Estuary in locations including Mendall Marsh and the Orland River, as well as for smaller embayments like Bald Hill Cove along the main Estuary channel.

### *3.2.2.4 Penobscot River Estuary/Mobile Pool*

Consistent with the general model of sediment transport dynamics in estuaries presented in Sections 3.2.2.2 and 3.2.2.3, the Phase II Report (2013) identified a pool of mobile sediment in the Estuary that appears to migrate upgradient and downgradient in response to variations in tidal range and freshwater discharge, and appears to concentrate in the vicinity of Mendall Marsh and the Orland River as the result of tidal movement and associated sediment trapping (**Figure 3-5**). As described in Geyer and Ralston (2018), tidal effects on the mobility of this sediment pool occur on the time scale of weeks (i.e., spring versus neap tides) to seasons (i.e., movement of the salt wedge as the result of seasonal variation in the magnitude of freshwater discharge), and are associated with two distinct, localized turbidity maxima within the Estuary—a more upgradient ETM located near the point of maximum salt water incursion, and a further downgradient ETM located at the point of ebb tide retreat (**Figure 3-6**). During high flow spring freshet conditions in the Penobscot River Estuary, the upgradient ETM moves into the vicinity of Frankfort Flats and Mendall Marsh and suspended particulate matter concentrations in this region can exceed 1,000 milligrams per liter (mg/L) in bottom water (Geyer and Ralston 2018). As context for evaluating this concentration of suspended particulate matter, Chapter 3 of the Phase II Report and the 2017 Sediment and Water Quality Monitoring Report documented that concentrations of suspended solids entering the Estuary from upgradient of the site of the former Veazie Dam range between from 0.5–23 mg/L (PRMSP 2013; Amec Foster Wheeler 2018g) and concentrations of suspended solids in the water column within the Estuary range from 5–50 mg/L (Amec Foster Wheeler 2017c) and non-detect to 1,710 mg/L (n = 973) with an average of 32 mg/L (PRMSP 2013).

During low flow conditions in the Estuary, these two turbidity features remain, although the increase in overall water column mixing that occurs during periods of lower freshwater outflow results in a decrease in the concentration of suspended particulate matter in the water column. As example, for the location in the Estuary in which the upgradient ETM was described during freshet conditions, suspended sediment concentrations decreased to < 200 mg/L during 2011 sampling (Geyer and Ralston 2018). During low flow conditions in the Estuary, a third localized ETM may also appear; during 2011 sampling, suspended sediment concentrations at the location of the third localized ETM reached 400 mg/L (Geyer and Ralston 2018). This third localized ETM appeared during late flood tide in the vicinity of Orrington (**Figure 3-5**). A 2017 geophysical survey conducted in the Estuary also documented an area of enhanced water column turbidity in the vicinity of Orrington (Amec Foster Wheeler 2018h). While the concentration of suspended particulate matter in that area could not be measured via geophysical survey techniques, the dual frequency separation indicated the presence of a region of elevated water column turbidity that exceeded 20 feet thick in at least one Orrington transect (Amec Foster Wheeler 2018h). Further discussion of the geophysical survey data is presented in Section 3.8.1.

The location and intensity of the ebb tide ETM is also important from the perspective of particulate transport and retention in the Penobscot River Estuary. Under both high flow and low flow conditions in 2011, elevated suspended sediment concentrations were documented near Bucksport in the location where the river channel deepens to greater than 60 feet (**Figure 3-5**). This bathymetric low spot appears associated with the retention and recycling of suspended sediment. Likewise, data presented in Chapter 7 of the Phase II Report (PRMSP 2013) suggest that sediment trapping occurs at least temporarily in the area southeast of Verona Island, and that near-bottom flow in this reach of the Estuary is typically in the landward direction. Geophysical survey data from this area collected by Amec Foster Wheeler in 2017 have identified a bedded deposit of mixed non-cohesive sediment and wood waste that is more than 6 feet thick near the convergence of the East Channel and Orland River (Amec Foster Wheeler 2018h). A sediment core collected from within this deposit (Station VE-05-01-E) contained concentrations of total mercury between 1,200 and 1,600 ng/g over 4 feet of the recovered core (Amec Foster Wheeler 2018i), further supporting the characterization of this area as a zone of physical mixing and at least temporary material trapping. Overall, for the area east of Verona Island, these characteristics suggest that sediment resuspension and cycling in this reach is influenced both by seasonal variations in the magnitude of freshwater discharge in the main Estuary channel (west of Verona Island) and by the relationship between the size/shape of the channel east of Verona Island and tidal forcing through this channel constriction.

Other locations in the Estuary with similar characteristics in terms of sediment mercury profiles and the composition of the sediment bed (i.e., a bedded mixture of non-cohesive sediment and wood waste) include stations in the upper Orland River (Station OR-T3-C3) and Frankfort Flats (Station FF-04-01). For both these locations, the bedded deposit is at least 3 feet thick and the mercury concentration profile is consistent and greater than 1000 ng/g throughout the deposit (Amec Foster Wheeler 2018i).

Relatedly, if an ETM facilitates the transport of fine-grained sediment or low density organic matter into off-channel coves, then these environments may play a key role in highlighting aspects of site variability that impact understanding of chemical fate and transport dynamics throughout the system. That is, an embayment that serves to focus sediment that is characterized by a spatially and temporally averaged contaminant concentration (such as would result from mixing and transport under the influence of the ETM) may preserve a chemical input and burial record that looks different than the record preserved in a location in which contaminant storage may more directly reflect a chemical discharge history without the significant resuspension, mixing, and redistribution that characterizes deposition in an ETM-influenced embayment.

In the Penobscot River Estuary, an example of an embayment in which sediment mixing and/or deposition may be influenced by the ETM is the embayment upgradient of Snub Point (Station

PBR-19). For this station, the mercury concentration profile from 2017 sampling shows a broadly defined mercury concentration peak (2,682 ng/g) at a depth of 17–18 cm, with mercury concentrations over the top 1 foot ranging from 1,300 ng/g (at 30–32 cm) to 1,164 ng/g (at 0–1 cm). Below a depth of 32 cm, mercury concentrations are consistently below 366 ng/g (Amec Foster Wheeler 2018k). The sediment accumulation rate calculated from the cesium radioisotope ($^{137}$Cs) profile for this location was 0.51 cm per year, with the cesium radioisotope, excess lead radioisotope ($^{210}Pb_{xs}$), and total mercury profiles each showing similarly broadly defined maxima over the top foot of the core and decreasing to low or background concentrations below this depth in the core. A core collected in approximately the same location in 2009 was characterized by a peak in mercury concentration (6,440 ng/g) at a depth of 50–55 cm and mercury concentrations that decreases slowly and inconsistently toward the surface, according to Chapter 5 of the Phase II Report (PRMSP 2013). The calculated sediment accumulation rate for this location in 2009 was 1.0 cm per year, and the rate for that coring program was elevated relative to the average sediment accumulation rate (0.56 cm per year) for cores (n = 24) characterizing the main Estuary channel (Santschi et al. 2017).

Overall, with respect to sediment mobility, sediment resuspension and mobilization in the Estuary occurs on the time scale of days (i.e., flood versus ebb tides), weeks (i.e., spring versus neap tides) and seasons (i.e., movement of the salt wedge as the result of seasonal variation in the magnitude of freshwater discharge), suggesting that material available for resuspension is bedded through at least a portion of these different cycles. The thickness (and therefore the volume) of these transiently bedded deposits can be estimated in a range of ways, including redox effects on sediment color (see Chapter 7 of the Phase II Report [PRMSP 2013] and Geyer and Ralston [2018]), ruler resistance measures of sediment consolidation (Amec Foster Wheeler 2017e and 2018k), measurements of critical shear stress for erosion (**Appendix D**), geophysical survey techniques (Amec Foster Wheeler 2017e), sediment chemical profiles (Amec Foster Wheeler 2018b and 2018k) and changes in sediment physical properties (Amec Foster Wheeler 2018b). For the Penobscot River Estuary, the combination of these approaches suggests an unconsolidated mobile sediment layer thickness of approximately 0.3 foot (3.6 inches) (**Table 3-1** and **Table 3-2**), depending on how this layer is defined and over what time scale it is considered mobile. The volume of this material is an important variable in modeling system recovery, because it contributes to the residence time of sediment (and mercury) in the system.

## 3.3 History of Human Activities in the Penobscot River and Estuary

A range of activities have played a role in shaping current conditions in the Estuary, including natural resource use, dredging in support of navigation or commerce, industrial activities including use of the chlor-alkali process for the manufacture of caustic soda and chlorine, the passage of federal and state legislation that affect water quality, removal of dams as a component of ecosystem restoration, and current (ongoing) remedial activities resulting from historical use of mercury within the Estuary.

## 3.3.1 Natural Resource Use

This section summarizes natural resources uses of fisheries, timber/lumber/pulp and paper, hydroelectric power, and quarrying.

### *3.3.1.1 Fisheries/Fish Species*

Historically, the Penobscot River and Estuary were home to 11 sea-run fish species: shortnose sturgeon (*Acipenser brevirostrum*), Atlantic sturgeon (*Acipenser oxyrinchus*), Atlantic salmon (*Salmo salar*), alewife (*Alosa pseudoharengus*), tomcod (*Microgadus tomcod*), American shad (*Alosa sapidissima*), blueback herring (*Alosa aestivalis*), sea-run brook trout (*Salvelinus fontinalis*), striped bass (*Morone saxatilis*), rainbow smelt (*Osmerus mordax*), sea lamprey (*Petromyzon marinus*) and American eel (*Anguilla rostrata*). As with many east coast rivers, historical activities include dam construction, overfishing, dredging and resultant impacts on benthic habitat, and industrial discharges, including logging and sawmill wastes. The resulting impacts on water quality have negatively affected the distribution and abundance of these fish in the Penobscot River and Estuary. Shortnose sturgeon, Atlantic sturgeon, and Atlantic salmon are currently protected under the Endangered Species Act (ESA).[1]

Shortnose sturgeon have been documented as foraging and wintering in the Estuary (Lachapelle 2013). Wintering is a behavior in which sturgeon cluster together and swim in place while orienting into the freshwater current. The upstream limit of sturgeon migration in rivers is generally defined by the location of the most downstream obstruction to fish passage, because sturgeon do not typically use fish ladders. Due to this limitation, prior to the removal of the Veazie and Great Works Dams (see Section 3.3.2), shortnose sturgeon were not able to reach historical spawning grounds in the Penobscot River (Wegener 2012). Following dam removal, it is expected that shortnose sturgeon will be able to access their historical range, including potential breeding grounds (Wegener 2012). It is currently estimated that around 1,000 shortnose sturgeon forage and winter in the Estuary. Tagged Penobscot shortnose sturgeon have been recorded as far away as the Kennebec River in Maine, a distance of approximately 100 miles.[2]

[1] http://www.regions.noaa.gov/north-atlantic/index.php/penobscot-river-watershed/ (accessed 8/31/17)
[2] https://www.greateratlantic.fisheries.noaa.gov/stories/2015/november/16_after_a_century__shortnose_sturgeon_return_to_historic_habitat.html (accessed 8/31/17)

Atlantic sturgeon are less well studied in the Penobscot River than shortnose sturgeon, but estimates suggest that there are currently >600 Atlantic sturgeon in the Gulf of Maine (Wippelhauser et al. 2017). An unknown number of Atlantic sturgeon spend at least a portion of the year foraging in the Penobscot River Estuary, with data from Wippelhauser et al. (2017) suggesting that the annually returning population of Atlantic sturgeon to the Penobscot River is approximately 40 fish. While tagged Atlantic sturgeon have been detected as far upriver as Bangor, they more typically forage in the reach between Winterport and Bucksport. Atlantic sturgeon tagged in the Penobscot River have been detected as far north as Minas Basin (Bay of Fundy) and as far south as the Hudson River (Altenritter et al. 2017).

In August 2017, NOAA designated the Penobscot River as critical habitat for the Atlantic sturgeon. Critical habitat is designated based on *"physical or biological features essential to the conservation of the listed entity (e.g., species, subspecies or DPS [Distinct Population Segment]) and which may require special management or protection."*[3] In the Penobscot River, the critical habitat unit for the Atlantic sturgeon extends from the Milford Dam (approximately 15 miles upriver from Bangor) to the mouth of the river in Penobscot Bay. Four additional critical habitat units are included in the overall Gulf of Maine Distinct Population Segment. These four units are in the lower Kennebec River, lower Androscoggin River to Merrymeeting Bay, lower Piscataqua River, and the lower Merrimack River. Overall, the total length of designated critical habitat within these five units is approximately 152 miles.

For Atlantic salmon, historical numbers suggest catches of >20,000 fish/year were common on the Penobscot River in the late 1800s, with catch numbers decreasing until the commercial fishery closed in the late 1940s. Fishermen caught 40 salmon in 1947, the final year in which commercial fishing was allowed in the Penobscot River (EPA 1980). Current estimates of Atlantic salmon in the Penobscot River suggest fewer than 1,000 individuals returning annually to the river.[4] Critical habitat for the Gulf of Maine Distinct Population Segment of Atlantic salmon includes remnant populations from the Kennebec River downstream of the former Edwards Dam site to the St. Croix River, also including the Penobscot River. It is estimated that 75 percent of the remaining adult Atlantic salmon in the United States are found in the Penobscot River (NMFS and USFWS 2005).

[3] https://www.greateratlantic.fisheries.noaa.gov/regs/2017/August/17criticalhabitatdpssatlanticsturgeonfria.pdf (accessed 11/9/17)
[4] http://www.maine.gov/dmr/science-research/searun/programs/trapcounts.html (accessed 8/31/17)

### *3.3.1.2 Lumber/Timber/Pulp and Paper*

Maine is one of the most heavily forested eastern states and historically hosted one of the largest wood products industries in the United States. The Penobscot River watershed has a long history of timber harvesting and sawmill production. Bangor, in the 1850s, was identified as the "Queen City" of lumber and served as the largest lumber exporting port in the world (Bloom 1971, Mower 2009). At that time, there were approximately 410 sawmills operating along the river, with 52 operating in the vicinity of Bangor (Bloom 1971). Wastes from sawmill operations, including sawdust, wood slabs, bark, and edgings, were disposed of directly into the river. Over 100 years later, the Penobscot River Estuary was still characterized by the presence of *"great islands and bogs of sawdust"* (Bloom 1971) in deposits reaching 22 feet thick and visible in the area of Frankfort Flats (Davies 1972) resulting from historical use and discharge practices. Direct discharge of wood waste into the Penobscot River was curtailed by the 1972 Clean Water Act (CWA) and ceased by the mid-1980s.

Pulp and paper production began on the Penobscot River in 1882, with early mills constructed along the lower river in Brewer, Howland, and Old Town, followed by the upper West Branch mills in Millinocket and East Millinocket (Mower 2009). Pulp and paper production expanded along the Penobscot River to ultimately include seven mills, including the mill in Bucksport. As of 2017, only a portion of the Bucksport mill was still operating. Prior to the construction of wastewater treatment facilities, including clarifiers and stabilization basins as required by the CWA, pulp and paper mills discharged effluent directly into the river. Pulp and paper mill effluent may have included mercury compounds historically used as slimicides or fungicides in mill operations.

### *3.3.1.3 Dam Construction/Hydroelectricity Generation*

Construction of dams on the Penobscot River, like other Maine rivers, was historically connected to flow control, log driving, and/or power generation for mills. Currently, there are 13 dams along the Penobscot River, with seven of those structures located on the West Branch of the river (Kleinschmidt 2015). Two additional dams located along the lower river were removed between 2013 and 2014 as a component of the Penobscot River Restoration Project (see Section 3.3.2). Not all dams remaining on the Penobscot River are power generating, as some structures on the West Branch serve flow and flood control purposes. Total hydroelectric power generation capacity on the Penobscot River is currently <200 megawatts (Kleinschmidt 2015). Overall, dam construction on the Penobscot River was typically run-of-river, meaning that power generation did not involve the creation of a reservoir or significant pondage upstream of the dam. One implication of run-of-river construction is that without an impoundment defined by quiescent conditions, fine-grained sediment storage upstream of the dams is generally minimal.

The presence of dams on the Penobscot River has resulted in historical and ongoing impacts on fisheries and fish habitat. Fish passage to spawning grounds is limited by the dams. Water quality and riparian and upland habitat are altered, with associated species impacts in these areas. Dams along the Penobscot River have also likely served to trap an unknown volume of logs and wood debris from historical upgradient timber/lumber works.

#### *3.3.1.4 Quarrying*

Historical quarrying activities along the lower Penobscot River have included granite, clay, and ice. Granite quarrying occurred principally at the Mount Waldo Granite formation in Frankfort, Maine, along the North Branch of Marsh River. Stone was quarried from a range of hills in the vicinity of Frankfort, including Mount Waldo, Mosquito Mountain, Mack Mountain, Heagan Mountain, and Treat Hill. The granite was cut and processed along Marsh River and then transported via the Penobscot River to cities along the east coast and the Great Lakes. Quarrying in Frankfort began in the early 1800s and lasted until the mid-1900s. Cut stone transport via the river ceased in the early 1900s, when rail replaced schooners and barges. Quarrying still occurs on Mosquito Mountain for local, small-scale processing and use. There are no data readily available on the impact of stone quarrying and cutting activities on sediment transport in Marsh River or the Penobscot River Estuary.

### 3.3.2 Dam Removal/River Restoration

The Penobscot River Restoration project[5] commenced with the signing of the Lower Penobscot River Settlement Accord in 2004 and the creation of the Penobscot Trust. In 2010, having reached financing goals and receiving the necessary state and federal permits, the Penobscot Trust purchased the Great Works (Bradley), Veazie, and Howland Dams. The Great Works Dam was removed in 2012 and the Veazie Dam in 2013. A fish bypass around the Howland Dam was completed in 2016. With the completion of the bypass, and the installation of a fish elevator at the Milford Dam, access to more than 1,000 miles of riverine and lacustrine habitat has been re-opened for native sea-run fish species on the Penobscot River.

Sediment sampling conducted in the impoundments upstream of the Great Works and Veazie Dams prior to dam removal indicated low sediment total mercury concentrations. Sediment total mercury concentrations at two locations within Great Works impoundment were 0.094 milligrams per kilogram (mg/kg) (equivalent to 94 ng/g) and 0.12 mg/kg (120 ng/g); sediment total mercury concentrations at two locations within the Veazie Dam impoundment were 0.042 mg/kg (42 ng/g) and 0.074 mg/kg (74 ng/g) (Kleinschmidt 2008). These four sediment samples were characterized as silty sands, with the impoundments upstream of each (former) dam being described as lacking

[5] http://www.penobscotriver.org/ (accessed 9/8/17)

in fine grained (<0.0625 millimeter) material. These data suggest both that chemical inputs from upgradient reaches of the Penobscot River are limited and, consistent with the conceptual understanding of these dams as run-of-river structures (Section 3.3.1.3), that historical (and current) impoundments on the river are not serving as significant depositional areas for fine-grained sediment or sediment-associated contaminants.

### 3.3.3 Navigation/Dredging

There are three federally-authorized channels and an anchorage within the Estuary. The channels are the Lawrence Cove Channel (historically dredged to 22 feet mean lower low water [MLLW]), the Frankfort Flats Channel (historically dredged to 22 feet MLLW), and the Bangor Harbor Channel (historically dredged to 14 feet MLLW); the anchorage is the Middle Ground Area in Bucksport Harbor, historically dredged to 16 feet MLLW. Of these locations, only the Lawrence Cove Channel has been dredged since the 1960s. USACE records indicate that Lawrence Cove Channel was dredged five times between 1960 and 1985, with a total dredge volume of ~ 300,000 cubic yards (cy). A 2008 USACE bathymetric survey of the Lawrence Cove Channel suggested that the cove had accumulated approximately 7 feet of sediment within the dredge footprint since the most recent dredge activity in 1984. If that sediment accumulation is considered as an annual average process rather than as the (more likely) rapid infilling of the dredge channel by mobile material, the accumulation rate since 1984 would be approximately 6 cm per year.

USACE records of where dredged material was disposed of in the Estuary are limited. Great Lakes Dredge & Dock Company, LLC, who served as the project engineer for the maintenance dredging of the Lawrence Cove Channel in the 1980s, indicated that mechanically dredged silts and wood waste were disposed of by open scow dump north of the Verona Island Bridge (Stan Ekren, personal communication). Mr. Ekren stated anecdotally that the area north of the Verona Island Bridge was a historical disposal site commonly used for disposal of dredged material. Relatedly, the 2010 USACE bathymetric survey data indicated the presence of sediment ridges or elevation changes oriented parallel to both the Frankfort Flats and Lawrence Cove navigational channels in 2010. The orientation of these bed features suggests that sidecast disposal of sediment dredged from the navigational channels also may have occurred.

### 3.3.4 Mercury Utilization in the Penobscot Estuary

As detailed in the Phase II Report (PRMSP 2013), mercury discharge to the Penobscot River was predominantly associated with the operation of a mercury cell chlor-alkali facility in Orrington, Maine from 1967 to 2000. The mercury cell chlor-alkali process employed mercury as a mobile cathode in an electrolytic cell that decomposed sodium chloride brine into caustic soda and chlorine. The Orrington facility produced chlorine for Maine's pulp and paper industry. Mercury released from the facility during the history of operation likely included atmospheric/volatile emissions, releases to soils and waste ponds on site, and discharge via the facility outfall into

Southern Cove in the Estuary. The amount of mercury released from the facility over time, as well as the relative magnitude of releases via these different pathways, is uncertain.

Regarding both atmospheric emissions and the potential for spills/release on site, it was estimated that during the early years of facility operation, approximately 90 pounds of mercury per day were lost from facility inventory through routes other than the facility outfall in Southern Cove (PRMSP 2013). Mass release to the Southern Cove outfall (initially) and to a brine sludge pond on site (post-1970), has been estimated at approximately 19 pounds per day, with an unspecified amount of this sludge being recycled back into the system for reuse. The Phase II Report calculated that from 6–12 metric tons (equivalent to approximately 7–13 U.S. [short] tons) of mercury were discharged through the facility outfall into Southern Cove during the initial years of facility operation.

As detailed in the Phase I Report (PRMSP 2008), a 2003 review of reported mercury releases from operational chlor-alkali facilities in the United States suggests that total mercury releases from the Orrington facility over its 33-year operating life were likely between 30 and 640 tons, or approximately 1–20 tons per year. This estimate of total mercury releases includes atmospheric/volatile emissions, release to soils and waste ponds on site, and discharge via the facility outfall into Southern Cove. The level of uncertainty in this estimate is typical of estimates from other mercury cell chlor-alkali facilities (PRMSP 2008).

Regarding the current distribution of mercury in Estuary sediment, the Phase II Report estimated 10.2 tons of mercury is present in the Estuary, with a large fraction of the total mass in the sediment of the outer Estuary south of Verona Island, where the majority of long term sediment deposition and accumulation in this system occurs (PRMSP 2013). This estimate of mercury storage is based on bedded sediment and may not include mercury that is associated with unconsolidated mobile sediment or mercury associated with bedded wood waste (see Section 3.8) that was not fully characterized or evaluated in the Phase II Report.

Current estimates of additional mercury storage in the Estuary include an additional 0.5 ton associated with mobile sediment and 2.3 tons associated with bedded deposits of mixed mineral sediment and wood waste. For mobile sediment, this estimate of additional mercury storage is based on an average unconsolidated layer thickness of 3.6 inches, a total depositional area (40.1 square kilometers) and a mass of mobile sediment (700,000 tons) as presented in Geyer and Ralston (2018) with the inclusion of Fort Point Cove, and an average total mercury concentration in mobile sediment of 760 ng/g. For bedded deposits of mixed mineral sediment and wood waste, this estimate is based on an approximate mass of 1,500,000 tons of mixed mineral sediment and bedded wood waste in deposits less than 1 foot thick plus an additional 450,000 tons of wood waste in discrete surface deposits greater than 3 feet thick (Amec Foster Wheeler 2017e), as discussed further in Section 5.0, and an average total mercury concentration in this material of 1,175 ng/g. The average total mercury concentration applied to the unconsolidated sediment is based on the evaluations presented in **Tables 3-2 and 3-3**. The average total mercury concentration applied to the bedded deposits of mixed mineral sediment and wood waste is not well constrained because of low sample density within the footprint of these deposits. Based on cores that were recovered from within the footprint of these discrete deposits during the Phase III sampling, the total mercury concentration in these locations can range from equivalent to the unconsolidated sediment (approximately 760 ng/g) to approximately twice that value (Amec Foster Wheeler 2018k). Considering this possible range of total mercury concentrations, an average total mercury concentration of 1,175 ng/g is used in the estimation of additional mercury mass associated with bedded deposits of mixed mineral sediment and wood waste. **Appendix F** contains a figure set that presents the Phase III 2017 sediment data used in the analyses and summaries presented in **Tables 3-2 and 3-3**. Further discussion of wood waste cycling in the Estuary, including the associated mercury content and implications regarding fate and transport, is presented in Section 3.8.

### 3.3.5 Passage of the Clean Water Act

Direct discharges to the lower river during the 1940s–1960s included municipal sewerage, waste from tanneries and textile facilities, lumber wastes (largely curtailed by the 1950s) and pulp and paper industry discharges from seven operating mills. Pulp and paper mill discharges included pulping liquors as well as fibers and paper coatings. In 1964, the Penobscot River received a Class D rating, with the State of Maine Water Improvement Commission reporting that dissolved oxygen concentration in the river were as low as zero for sections of the river during certain times of the year (EPA 1980). Following passage of the 1967 Maine Revised Standards, the Penobscot River was reclassified as a *potential* Class C waterway, suitable for water contact recreation (except swimming) and acceptable for municipal water supply following treatment and disinfection (EPA 1980), with the goal of achieving this designation by 1976.

Following passage of the CWA in 1972, water quality in the Penobscot River improved significantly as mills installed pollution controls for addressing organic wastes and suspended solids, and municipalities constructed sewage treatment plants. By 1977, the river met the state Class C water quality standard and dissolved oxygen concentrations had increased along the length of the river to 5 parts per million or more (the state water quality standard for Class C waters) (EPA 1980). Water quality continued to improve as the EPA and MEDEP issued discharge permits under the National Pollutant Discharge Elimination System to 26 industrial and municipal discharge operators along the river between 1978 and 1979, as well as widening their focus to include non-point source discharges from agriculture, private, and solid waste disposal activities. The lower Penobscot River is currently classified as a Class B river basin; the dissolved oxygen concentration of Class B waters must equal or exceed 7 parts per million.[6]

## 3.4 CURRENT REMEDIATION AND MONITORING ACTIVITIES IN THE PENOBSCOT RIVER AND ESTUARY

Recent active remediation in the Estuary focused primarily on sediment removal in Southern Cove. Current biological monitoring in the Estuary includes lobster, crab, mussels, and black ducks.

As detailed in the Corrective Measures Implementation Plan for Southern Cove (Anchor QEA and CDM Smith, Inc. 2017), a range of bathymetric, geotechnical, hydrodynamic, ecological, and geochemical data, including in situ characterization and characterization for material disposal following removal/dredging, were collected from 2015 to 2016. The overall design objectives for sediment removal in Southern Cove were to remove sediment where mercury concentrations exceed 2.2 mg/kg over a 0.25-acre area, as well as where specific locations (hot spots) of elevated mercury concentration were identified. Sediment dredged from Southern Cove can be characterized as solid, non-hazardous waste using the toxicity characteristic leaching procedure (Anchor QEA and CDM Smith, Inc. 2017).

Three sediment management areas (SMAs) were defined in the Southern Cove Corrective Measures Plan: SMA-1 (a nearshore area with a shallow dredge depth delineation); SMA-2 (a northern area in the cove characterized by elevated mercury concentrations and located adjacent to the historical facility wastewater discharge point); and SMA-3 (a southern area characterized by elevated mercury concentrations and adjacent to SMA-2). Proposed dredge depth delineations in SMA-2 ranged from 1 foot (in the outer cove) to 3 feet (adjacent to the historical wastewater outfall); the proposed dredge depth delineation in SMA-3 ranged from 1 foot to 1.5 feet throughout the SMA. Details regarding the implementation of the Corrective Measures Plan have not been provided to Amec Foster Wheeler, and so are not available for inclusion in this report.

In terms of biological monitoring, current and ongoing monitoring programs in the Estuary that involve tissue analysis for mercury include the Maine Department of Marine Resources (DMR) monitoring of mercury in lobster and crab tissue and the NOAA National Status and Trends

[6] http://legislature.maine.gov/statutes/38/title38sec465.html; "*[W]aters must be of such quality that they are suitable for the designated uses of drinking water supply after treatment; fishing; agriculture; recreation in and on the water; industrial process and cooling water supply; hydroelectric power generation, except as prohibited under Title 12, section 403; navigation; and as habitat for fish and other aquatic life. The habitat must be characterized as unimpaired.*" (accessed 9/5/17)

Mussel Watch program, with stations in Penobscot Bay and the Estuary. These monitoring programs are discussed further in Section 3.7.2.1 (including the spatial extent of the lobster closure areas resulting from Maine DMR monitoring) and 3.7.2.2. Maine Department of Inland Fisheries and Wildlife also conducts biological monitoring of black ducks in the Estuary, although monitoring does not include tissue analyses for mercury.

## 3.5 CONCEPTUAL FATE AND TRANSPORT

The conceptual understanding of mercury fate and transport in the Estuary described in this section includes an overview of mercury and methyl mercury chemistry, as well as mercury transformation, transport, and sequestration dynamics in the water column, in sediment, and on marsh platforms.

### 3.5.1 Contaminants of Concern

The principal contaminant of concern in this system is mercury. As described in Section 3.3.4, mercury was discharged into the Penobscot River as a component of brine waste from a mercury cell chlor-alkali facility in Orrington. The chlor-alkali process uses mercury in its elemental form ($Hg^0$). Discharge of mercury into the environment results in its oxidation to cationic mercury ($Hg^{2+}$), which sorbs to suspended particulate matter (e.g., fine grained mineral sediment, algal cells, other sources of organic matter) and settles with that particulate matter to the sediment bed. The majority of mercury remains in inorganic form in the sediment bed in estuaries, adsorbed to particles and/or ultimately stably buried in association with sulfide or selenide minerals.

Under a specific set of geochemical conditions, including the availability of dissolved sulfate and sufficient easily degradable organic matter to create oxygen-poor conditions in sediment porewater, a small fraction of the inorganic mercury in sediment is converted to methyl mercury (**Figure 3-7**). The conversion from inorganic mercury to methyl mercury occurs predominantly through the respiratory action of sulfate-reducing bacteria (Compeau and Bartha 1985) and occurs in the aqueous phase in porewater. If the depth increment in sediment in which this specific microbial process dominates bacterial activity is within the biologically active zone for prey species such as benthic invertebrates, the methylated mercury that is created can enter the food web. Transfer of methyl mercury from sediment or sediment porewater to biota can occur through either porewater exposure (aqueous phase) or via consumption of sediment organic matter to which methyl mercury has adsorbed (solid phase; deposit feeding). Because both inorganic mercury and methyl mercury are taken up in biological tissue and because methyl mercury is more slowly excreted from tissue than inorganic mercury, the transfer of mercury up the food chain through the consumption of prey species results both in an increased body burden of total mercury in consumer species, as well as an increased percentage of that total body burden that is in the form of methyl mercury (Morel et al. 1998).

Food web transfer of methyl mercury to higher trophic level consumers can also occur through the diffusion of methyl mercury from sediment porewater into overlying (surface) water. Through this transfer mechanism, methyl mercury may become available to water column species by direct exposure or via trophic transfer from phytoplankton to zooplankton to higher trophic level consumers. For fish species, in the absence of a direct source of water column discharge of mercury, such as originating from industrial wastewater, exposure to mercury results predominantly from consumption of prey species. Because of this variability in exposure routes for different organisms with different feeding strategies, the recovery rate for different species following remedy implementation can vary depending on factors such as trophic level (e.g., forage fish vs. predatory fish).

### 3.5.2 Methylation Dynamics

As described in Section 3.5.1, within sediment and under a specific set of geochemical conditions, a small fraction of the inorganic mercury can be converted to methyl mercury. Microbial methylation of inorganic mercury is dominated by the action of sulfate-reducing bacteria in a process that results from either the diffusive or facilitated uptake of inorganic mercury by microbial cells or the subsequent release of methyl mercury back into porewater (Schaefer et al. 2011). Once released into porewater, aqueous phase methyl mercury may sorb or partition to sediment solid phases (including sediment organic matter), be taken up by biota, be transported to surface water (or to porewater at different sediment depths) via advection or diffusion, and/or be demethylated back to inorganic mercury. The inorganic mercury generated via demethylation may, in turn, sorb to sediment or be incorporated into stable aqueous phase complexes with organic matter and dissolved sulfide (Graham et al. 2012).

Overall, the production and accumulation of methyl mercury occurs most readily in estuary and marine environments and under low oxygen (i.e., suboxic) conditions (Merritt and Amirbahman 2009; Cossa et al. 2014). For a specific location, however, the processes of methyl mercury production and accumulation (if it occurs) represent a dynamic equilibrium that is influenced by a range of environmental factors. On a mechanistic level, the relationship between methylation potential and the concentration of porewater and sediment-associated methyl mercury that has been measured will depend on both the site-specific turnover rate of methyl mercury and the extent to which the methyl mercury measured is the result of in situ production versus transport from other locations. If the turnover rate between methylation and demethylation favors net methyl mercury production, an elevated production rate can result in proportionately higher aqueous and solid phase methyl mercury concentrations (Drott et al. 2008). Because there are many variables that can influence both methylation rates and methyl mercury accumulation (in either porewater or sediment), it is important to recognize that methyl mercury production may be more or less strongly associated with its accumulation. Relevant variables include flow dynamics in the overlying water (Merritt and Amirbahman 2008), organic matter input and/or accumulation rates

(Lambertsson and Nilsson 2006), organic matter quality (Graham et al. 2012; Chiasson-Gould et al. 2014; Mazrui et al. 2016), the relationship between organic matter quality and sediment sampling location (e.g., position along a transect), the dominance of in situ production versus ex situ transport at that location (Mason and Lawrence 1999), and ambient variables that would influence microbial respiration rates (e.g., season, temperature).

Field and laboratory studies have established that the degree of bioturbation or physical mixing of the sediment by benthic infauna strongly influences the presence and persistence of chemical concentration gradients in both aqueous and sediment solid phases (Fisher and Matisoff 1981; D'Andrea et al. 2002; Kostka et al. 2002; Benoit et al. 2006). Because of the relationship between the biogeochemical environment and mercury methylation dynamics (see Section 3.5.1), significant bioturbation or physical mixing likely also alters in situ relationships between methyl mercury production and either/both aqueous phase concentrations and sediment accumulation. Likewise, while the concentration of inorganic mercury in a system may be generally correlated with methylation rates and/or methyl mercury accumulation (Merritt and Amirbahman 2009; Cossa et al. 2014) there can be considerable variability within these relationships, both within a site and across sites with similar sediment total mercury concentrations. For the Penobscot River Estuary, the depth and extent of sediment mixing likely varies across the Estuary. Within Mendall Marsh, analysis of the depth distribution of the radioisotope $^{7}$Be suggested a mixing depth of 3–4 cm (see Chapter 7 of the Phase II Report [PRMSP 2013]), although application of this mixing depth system-wide should be approached with caution in the absence of additional data.

For remedial investigations, the variability in the relationship between the total mercury loading at a site and the production and accumulation of methyl mercury highlights the necessity of exploring site-specific linkages (and uncertainties) between remedial decisions based on bulk sediment total mercury chemistry and the time frame for achieving methyl mercury-based ecological risk reduction goals.

From the context of biological exposure, the data presented in **Table 3-1** for mixing depth in Mendall Marsh are correct in the sense that they describe site-specific potential for mercury exposure in individual locations with specific biological and hydrodynamic conditions, but they also describe two potentially distinct exposure scenarios: the first, in which there may be evidence of sediment physical stability and only small-scale biological mixing, and the second, in which there is evidence of sediment physical mixing and an unknown association between the physical mixed depth and the potential for either biological exposure or sediment redistribution (which may ultimately result in exposure elsewhere in the system).

### 3.5.3 Water Column Transport and Sedimentation

Mercury transport in aquatic ecosystems can occur in the dissolved phase or in the particulate phase. Because of its association with organic matter, dissolved phase transport of mercury in oxygenated waters is typically in the form of complexes with dissolved organic matter. For this aqueous phase of mercury associated with dissolved organic matter, sedimentation of mercury can result from the flocculation and settling of dissolved organic matter. This mechanism, resulting most commonly from the increase in salinity of surface water in estuaries, is defined as salting out, and is responsible for the observed non-conservative behavior of dissolved organic matter, as well as associated mercury, in estuarine transects (Turner et al. 2001), including in the Penobscot River Estuary (PRMSP 2013; Amec Foster Wheeler 2017c).

Particulate phase transport of mercury in surface waters of an estuary may involve erosion and transport of watershed soils and sediments that contain mercury, or transport of mercury associated with organic particulates such as algal cells. Sorption of mercury onto mineral or organic surfaces or diffusion into algal cells can serve as mechanisms for transferring dissolved mercury to the particulate fraction (Pickhardt and Fisher 2007). Both inorganic mercury and, to a lesser extent, methyl mercury, have an affinity for sorption and, for systems at equilibrium, this affinity results in the majority of the mercury or methyl mercury that is present being associated with solids. Distribution coefficients—the ratio of the analyte concentration in the solid phase to the concentration in the aqueous phase—for total mercury commonly range from $10^3$–$10^5$, highlighting the extent to which mercury is associated with solid phases (Turner et al. 2001). Distribution coefficient values for methyl mercury range commonly from $10^3$–$10^4$ (including for the Penobscot River Estuary), are typically lower than for total mercury, but still suggest transport dominantly associated with solids (PRMSP 2013).

### 3.5.4 Internal Recycling through Estuary Circulation

As a result of the affinity of inorganic mercury and methyl mercury for solid phases such as algal cells and sediment, the hydrodynamic processes discussed in Section 3.2.2.2 that influence sediment transport and deposition in estuaries also influence the transport and deposition of mercury. That is, if fine-grained sediment and organic matter are retained in an estuary as the result of tidally-influenced circulation, then mercury associated with those particles is also retained. One principal implication of this retention is that the recovery rate of an estuary from historical mercury inputs may be controlled more by the (slow) loss rate of contaminated sediment from the estuary than by either the input rate of clean sediment from upgradient (i.e., recovery by solids dilution) or the transit time of river discharge.

A second implication of this retention is that the eventual in-estuary burial of contaminated sediment (if it occurs) may follow a prolonged period of sediment mobility and redistribution. For mercury associated with mineral sediment, estuary cycling, including recycling with an ETM, does not appear to be associated with significant desorption or repartitioning of mercury from the solids to the aqueous phase (Heyes et al. 2004; Gosnell et al. 2016). The implication of this general stability of sediment-associated mercury is that the process of sediment redistribution does not necessarily result in significant changes to the biological availability of the bulk of mercury associated with mineral sediment.

For mercury associated with wood waste mixed with mineral sediment, while desorption from wood particles may not be a significant loss mechanism during the resuspension and redistribution of wood waste, the abrading of wood particles into smaller size pieces may be associated with the transfer of mercury and/or methyl mercury into a solids fraction that does not readily resettle. Results of leachability tests conducted in 2017 on mercury-enriched wood waste samples suggest that wood waste does not readily leach mercury, but when centrifuged and pressed, low concentrations of mercury are measurable in suspension in unfiltered leachate samples, likely associated with wood fines (**Appendix A**). These results indicate that the mechanism of release mercury from wood waste is likely principally through degradation and/or breakdown of wood waste rather than through desorption of mercury into the aqueous phase. While the breakdown rate of wood waste is not well constrained in this Estuary (or other estuaries), Louchouarn et al. (1997) have observed that for sediment in the Lower St. Lawrence Estuary, the degradation rate of historical pulp and paper mill solid wastes is on the order of 2–5 percent of the residual mass per year. The cycling of wood waste in the Penobscot River Estuary is discussed in more detail in Section 3.8.1.

These factors highlight the multiple processes that influence estuary-specific recovery rates. For a specific estuary, modeling or estimating recovery requires understanding the balance between eventual mercury loss through stable sediment burial versus discharge from the estuary, a process balance which itself is a function of the size and shape of the estuary, flow hydrodynamics, sediment bed stability and the availability of clean sediment for dilution and burial. On a system-wide scale, estuary-specific recovery rates from mercury discharge can range from years (Bothner et al. 1980) to decades (Bloom et al. 2004; Santschi et al. 2017). A more detailed discussion of recovery rate models for the Penobscot River Estuary are presented in Section 3.9.

## 3.6 SPATIAL DISTRIBUTION OF MERCURY AND METHYL MERCURY BY REACH

This section presents a summary of the current understanding of the spatial distribution of mercury and methyl mercury in the Penobscot River Estuary. Data are presented by reach for surface water (Section 3.6.1) and sediment (Section 3.6.2).

### 3.6.1 Surface Water Data

Surface water data for total mercury and methyl mercury are summarized by reach in **Table 3-4**. **Table 3-4** does not include historical (pre-Phase III) data, because the historical aqueous data set includes a range of sampling types, including surface water, pore water, and discharge monitoring data, that are not well characterized or identified by sampling type and so may not be not directly comparable with Phase III field data.

For Phase III data collected in 2016, total mercury concentrations in surface water range from non-detect to 37.2 ng/L for sampling stations from throughout the Estuary. For Phase III data collected in 2017, total mercury concentrations in surface water range from 2.94 ng/L to 4.93 ng/L. The 2017 total mercury surface water data were collected in the Bangor reach.

For Phase III methyl mercury data collected in 2016, concentrations in surface water range from 0.029 ng/L to 0.617 ng/L for sampling stations from throughout the Estuary. For Phase III methyl mercury data collected in 2017, concentrations in surface water range from non-detect to 0.101 ng/L. The 2017 methyl mercury surface water data were collected in the Bangor reach.

### 3.6.2 Sediment Data

Total mercury and methyl mercury concentrations in sediment are summarized for historical (pre-Phase III; 2000 - 2012) and for Phase III (2016 – 2017) data by reach in **Tables 3-5 and 3-6**. These tables include data for both surface sediment (0–0.5 foot) and subsurface sediment (deeper than 0.5 foot). For each reach, the data range, mean values and the number of data points are presented. Concentrations in surface sediment (0–0.5 foot) for both historic (pre-Phase III) and Phase III data are presented in **Figures 3-8-1 through 3-8-16** for total mercury and in **Figures 3-9-1 through 3-9-16** for methyl mercury. Data summarized in **Tables 3-5 and 3-6** and presented **Figures 3-8-1 through 3-8-16** and **3-9-1 through 3-9-16** are as discrete data points. The summaries presented in these tables and figures include data collected by different methods (i.e., grab samples, sediment cores) across different environments (i.e., marshes, intertidal zone, subtidal zone) with different strategies for depth-sectioning/processing cores (where relevant).

For historical data (**Table 3-5**), total mercury concentrations in surface sediment (0–0.5 foot) range from 0.01 to 12,500 ng/g. Total mercury concentrations in subsurface sediment (> 0.5 foot) range from 0.03 ng/g to 73,300 ng/g.

Methyl mercury concentrations in historical surface sediment range from less than 0.001 ng/g to 98.4 ng/g. For subsurface sediments, historical methyl mercury data are limited to the Bangor and Orrington reaches. For these reaches, subsurface methyl mercury concentrations are below 0.04 ng/g.

For Phase III (2016–2017) data (**Table 3-6**), total mercury concentrations in surface sediment (0–0.5 foot) range from 0.08 ng/g to 100,200 ng/g. Total mercury concentrations in subsurface sediment (>0.5 foot) range from 1.71 ng/g to 5,570 ng/g.

For Phase III (2016–2017) data, methyl mercury concentrations in surface sediment (0 – 0.5 foot) range from less than 0.02 ng/g to 55.8 ng/g. Subsurface methyl mercury was not analyzed in Phase III.

**Appendix F** includes a figure set of Amec Foster Wheeler 2017 sediment data. Data included in the figures in this Appendix were generated as the result of multiple Amec Foster Wheeler field programs (Amec Foster Wheeler 2018c; 2018g; 2018i; 2018j; 2018k).

## 3.7 ECOLOGICAL EXPOSURE

This section presents a brief overview of mercury biomagnification in biota and describes the ecological exposure pathways for species of potential concern in the Estuary. Species of potential concern include lobster, blue mussel, forage and predatory fish, songbirds, and black ducks. Trending of tissue chemistry data for species of potential concern is discussed in Section 3.9.3.4. A more complete discussion of ecological exposure, trophic transfer, and species of potential concern for the Penobscot River Estuary can be found in the Amec Foster Wheeler 2017 Biota Monitoring Report (Amec Foster Wheeler 2018j) and the 2018 Risk Assessment and Preliminary Remediation Goal Development Report (Amec Foster Wheeler 2018b).

### 3.7.1 Biomagnification

Biomagnification is the uptake of a chemical from one trophic level to the next, where the concentration of the contaminant of concern is greater in each subsequent higher trophic level compared to the concentration in the previous lower trophic level. Biomagnification occurs through the dietary pathway of exposure; thus, the accumulation and magnification of the contaminant of concern depends on chemical concentrations in prey species consumed by the next higher trophic level consumer species. The potential for biomagnification is typically a concern for chemicals that are fat-soluble or protein binding (in the case of mercury), mobile in the environment, and persistent. For mercury, biomagnification principally involves the trophic transfer of methyl mercury, as this form is excreted more slowly from tissue than inorganic mercury (Tsui and Wang 2004; Dutton and Fisher 2011).

### 3.7.2 Species of Potential Concern and Exposure Pathways

Ecological species of potential concern were selected to represent specific positions on the food chain and thus multiple trophic levels. Terrestrial and aquatic species were selected to understand differences in the exposure pathways for each different species. Mid- and upper-trophic-level species were selected to understand biomagnification at different positions of the food chain. Using the example of an aquatic food chain, forage fish and predatory fish were investigated to understand how much of the mercury is magnified in the food chain via benthic invertebrates, then the forage fish, and then the predatory fish consuming lower trophic level organisms. Tissue concentrations of total mercury and methyl mercury for species described in Sections 3.7.2.1

through 3.2.7.6 are presented in the 2016 Biota Monitoring Report (Amec Foster Wheeler 2017b) and 2017 Biota Monitoring Report (Amec Foster Wheeler 2018j).

### *3.7.2.1 Lobster*

Lobsters (*Homarus americanus*) are a predatory benthic invertebrate that are restricted to saltwater habitat and broadly inhabit Penobscot Bay. Lobsters have a strong preference for rock crab but consume a variety of prey species including fish, crustaceans and their molted exoskeletons (including other lobsters), mollusks, and polychaetes. Additional prey items known to be consumed infrequently by lobsters are plant matter, detritus, and other aquatic invertebrates such as sponges, gastropods, echinoderms, and tunicates.

Lobsters are commonly consumed by humans and are a potential source of human exposure to mercury in the lower Estuary. In 2014, Maine DMR designated a lobster fishing closure area in part of Upper Penobscot Bay in response to elevated mercury concentrations in lobster tissue. The closure area was north (riverward) from a line drawn from Fort Point to Wilson Point. Following further evaluation of lobster tissue mercury concentrations in 2014 and 2015, the Maine DMR expanded the closure area southward in 2016 to a line from Squaw Point to Perkins Point (MeCDC 2016).

### *3.7.2.2 Other Shellfish*

Other shellfish of concern are blue mussels (*Mytilus edulis*). Shellfish are typically exposed to mercury in surface water and sediment via direct contact or via filtering of food particles from the water column. Blue mussels are commonly monitored along the East Coast of the United States,[7] including in the Penobscot Bay region, allowing comparison of tissue mercury concentrations in blue mussels from the Penobscot River Estuary and Penobscot Bay versus tissue mercury concentrations in blue mussels from other locations.

### *3.7.2.3 Forage Fish*

Forage fish inhabit riverine and estuarine habitats, as well as wetland habitats such as the pocket and fringe marshes along the Estuary main channel, the Orland River, and Mendall Marsh. The mummichog (*Fundulus heteroclitus*) is a benthopelagic mid-trophic level receptor that consumes benthic and terrestrial invertebrates, predominantly insects. Rainbow smelt (*Osmerus mordax*) is another mid-trophic level receptor, but is a nerito-pelagic (occurs midwater, but in shallow areas

[7] https://data.noaa.gov/dataset/national-status-and-trends-mussel-watch-program

where it is also associated with the bottom) schooling species that feeds predominantly on shrimp and other forage fish.

#### *3.7.2.4 Predatory Fish*

Predatory fish are upper trophic level fish that consume benthic and terrestrial invertebrates, forage fish, and crustaceans. Predatory fish inhabit riverine and estuarine habitats and can be found throughout the Penobscot River system. Atlantic tomcod (*Microgadus tomcod*) is an anadromous demersal (bottom associated) species that feeds predominantly on crustaceans, particularly shrimp, but also feeds on worms and forage fish. The American eel (*Anguilla rostrata*) is a demersal catadromous species, primarily feeding on benthic invertebrates, including insects, worms, and shrimp, but also consuming forage fish.

#### *3.7.2.5 Songbirds*

Marsh songbirds are mid- to upper-trophic-level terrestrial species that feed on insects, spiders and seeds. Mercury exposure for songbirds is principally through consumption of prey species. These birds, including Nelson’s sparrow (*Ammodramus nelsoni*) and red-winged blackbird (*Agelaius phoeniceus*), forage and breed in marsh and wetlands habitats along the river and in Mendall Marsh. Prey species/food sources include spiders, insects, and seeds. Songbirds typically arrive at the Estuary in the spring (March for red-winged blackbirds and late May for Nelson’s sparrows) and depart in late summer or early fall.

#### *3.7.2.6 American Black Duck*

The American black duck (*Anas rubripes*) is a mid-trophic level species that forages and overwinters in aquatic habitats including small coves and shallow water/intertidal areas. Black ducks migrate south from Canada and typically arrive in the Estuary in September/October. American black ducks represent a species that serves as a potential route for human exposure to mercury. Humans hunt ducks in November and December and consume the tissue.

## 3.8 WOOD WASTE/WOOD PRODUCTS FATE AND TRANSPORT

This section describes the contemporary impact of the historical wood processing industry on the Estuary. Impacts of the historical wood processing industry include the spatial distribution of residual wood deposits, as well as the role that wood waste plays in the fate and transport of mercury in this system. Impacts of wood waste on mercury fate and transport include impacts of wood waste on mercury methylation dynamics and the transport of methyl mercury associated with wood waste.

### 3.8.1 Contemporary Cycling of Wood Waste

Sub-bottom profiling surveys generated as a component of the 2016–2017 site characterizations and presented in the 2016 and 2017 Mobile Sediment Characterization Reports (Amec Foster Wheeler 2017e and 2018h) suggest that there may be as much as 3,000,000 tons (dry weight) of material on the Estuary sediment bed that appears as a mixture of wood waste and mineral sediment. Approximately half of this material is in deposits more than 1 foot thick, with some deposits reaching 6 feet in thickness. This material appears to be distributed throughout the system, with specific, identifiable deposits of varying thickness in the vicinity of Snub Point, Winterport, Frankfort Flats, upgradient of Bucksport, in the Orland River, and in the Verona East channel (Amec Foster Wheeler 2018h). These deposits are likely somewhat mobile, may occur in locations in which material is at least temporarily (seasonally) trapped, and may contribute material to the mix of sediment and wood waste that moves in suspension in the water column. The Amec Foster Wheeler 2016 field program also documented sediment samples visibly enriched with wood waste in Orrington, Frankfort Flats, Bucksport, Verona Northeast, Verona East and Orland River (Amec Foster Wheeler 2017e). Evidence of annual 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." Between the 2016 and 2017 geophysical surveys, this feature appears to have moved upgradient into the deeper water channel near Bucksport relative to its position in 2016 (Amec Foster Wheeler 2018h). Comparative mapping of the position of the Bucksport Mill Pile is presented in **Figure A-2** (**Appendix A**).

Regarding wood waste that moves in suspension (in contrast to the 3,000,000 tons [dry weight] of bedded material discussed in the previous paragraph), the 2016 Mobile Sediment Characterization Report described the recovery of modified eel traps full of wood waste from deployments in the vicinity of Frankfort Flats and Verona East (Amec Foster Wheeler 2017e). Likewise, a streambed sampling net deployed in the vicinity of the Lawrence Cove Channel in September 2017 was recovered containing wood waste (Amec Foster Wheeler 2018h). Wood particles recovered through both these sampling efforts are described as medium brown in color and uniform in composition. Particles are somewhat blocky in shape, clearly identifiable as wood and approximately 1/8–1/16 inch in size. These descriptive data are supported by visual observations of suspended material by Amec Foster Wheeler staff during deployment of an underwater camera, and reports of an equipment tripod being temporarily buried by a moving wave of material (W. Rockwell Geyer, personal communication). Combining the results of the near-bed suspended sediment sampling (average total suspended solids concentration of 1.0 grams per liter) and the geophysical survey data suggests on the order of 4,000 tons (dry weight) or 41,000 tons (wet weight) of low density wood waste and mineral sediment in suspension in the Estuary (Amec Foster Wheeler 2018h). This mass of material captured in suspension is a fraction of the mass of mineral sediment and wood waste identified through the sub-bottom profiling survey.

Corroboration of a mass of material in suspension is available from the 2016 and 2017 geophysical survey data in which, for some areas of the Estuary, the dual frequency separation is greater than the depth to hardpan/bedrock defined by sub-bottom profiling. One possible explanation for this variability between results for different geophysical survey techniques is that the dual frequency separation is detecting material transported in suspension. Extrapolation and averaging of the dual frequency separation across the Estuary suggests an average thickness of this material of 1 foot, roughly consistent with what was observed from the stream bed sampling net deployment.

If the material identified through the dual frequency survey is the same material recovered in modified eel traps and by the stream bed sampling net, a small fraction of the bedded wood waste that is a component of the mix of wood waste and mineral sediment identified by the sub-bottom profiling survey is moving in suspension. This material may have ecological impacts on benthic habitat, as well as serving as a mobile pool of wood waste that may be transported to more stable depositional areas, such as onto the Mendall Marsh platform, during high tides. Under this scenario, bedded wood waste could serve as a significant ongoing source of wood-enriched fines in suspension. Preliminary assessment of lignin oxidation products in Estuary sediments (n = 6) suggests that the organic carbon in unconsolidated surface sediments does contain a significant component of wood waste (**Appendix G**), although the transport and degradation rate of this material in the Estuary is not well constrained. Louchouarn et al. (1997) observed that for sediment in the Lower St. Lawrence Estuary, for example, the degradation rate of historical pulp and paper mill solid wastes is on the order of 2–5 percent of the residual mass per year.

### 3.8.2 Mercury and Wood Waste

Regarding mercury methylation dynamics, it is not currently clear whether wood waste provides enhanced potential habitat for methylating microbes or enhanced sorption of methylated mercury. As detailed in Chapter 8 of the Phase II Report (PRMSP 2013), and by Amec Foster Wheeler (2017e and 2018e), sampling of wood waste suggests that wood waste contain elevated concentrations of total mercury and methyl mercury on a dry weight basis relative to concentrations in either bulk mineral sediment or the fraction of a bulk sediment sample passing through a #40 sieve. A #40 sieve will retain sand-sized particles approximately 0.42 millimeter in diameter or larger. For wood waste sampled as a discrete particulate class or for sediment samples sieved to remove wood waste, the average concentration of total mercury in the wood waste fraction can be as much as 50 percent higher than the concentration of total mercury in unsieved or bulk sediment sample (PRMSP 2013; Amec Foster Wheeler 2018e).

The physical manipulation of wood waste samples appears to release some mercury, both to a very small extent in the dissolved (filtered) phase and, to a more significant (although still small) extent, after the physical manipulation of wood waste samples and/or the centrifugation and pressing of wood-enriched suspensions. These results are presented in the 2016 Mobile Sediment Characterization Report (Amec Foster Wheeler 2017e) and in **Appendix A**. These observations of elevated mercury concentration in wood waste samples suggest that the resuspension, movement, deposition, and breakdown of wood waste may contribute to the variability in surface sediment mercury concentrations in the Estuary through the transport of mercury associated with wood particles and wood fines/fibers. Transport of wood waste enriched in mercury and/or methyl mercury onto the marsh platform may provide an additional exposure route for mercury and/or methyl mercury for organisms feeding on the platform. Because the breakdown rate of wood particles is slow in aqueous environments (Louchouarn et al. 1997), the dominant mechanisms for removal of this fines/low density wood-rich material from the Estuary may be a combination of transport into environments such as Mendall Marsh, where degradation by fungi may occur, and discharge from the Estuary into Penobscot Bay at a slow, but non-zero rate.

Based on Amec Foster Wheeler current site understanding, of the approximately 1,500,000 tons [dry weight] of material on the Estuary bed that appears as a mixture of bedded wood waste and mineral sediment in deposits greater than 1 foot thick (i.e., 50 percent of the total mass of material discussed in Section 3.3.4.2), approximately 70 percent of this mixture is characterized by mercury concentrations above 500 ng/g (Amec Foster Wheeler 2018i). That is, there is approximately 1,000,000 tons [dry weight] of mixed mineral sediment and wood waste in deposits greater than 1 foot thick with total mercury concentrations above 500 ng/g. The ongoing erosion of these wood-enriched deposits may serve as an ongoing source of mercury to depositional areas, including marsh platforms. Accumulations of bedded wood waste and mineral sediment that may be slowing system recovery are consistent with the hypothesis presented in Chapter 18 of the Phase II Report (PRMSP 2013) that there may be "*additional sediment zones in non-depositional areas that are contaminated and interacting with the mobile bed;"* the presence of this material can explain discrepancies between previously calculated rates of sediment turnover versus previously modeled rates of decreasing mercury concentration and system recovery in the Estuary.

## 3.9 SYSTEM RECOVERY TIME

This section reviews the concept of system recovery, including what is meant by the term recovery, whether the focus of recovery is physical or ecological, and the impact of key system dynamics—including the nature of Estuary circulation and the impact of legacy wood waste—on defining a recovery time for the Estuary. This section also reviews lines of evidence for evaluating the Estuary recovery rate, including the evaluation of vertical trends in sediment chemical concentrations, a mixing model that assesses the potential for diluting chemically impacted sediment with cleaner sediments, spatial (lateral) trends in sediment chemistry, and trends in biota tissue chemistry.

### 3.9.1 Mechanisms of System Recovery

In the context of remedial engineering, recovery can be defined as allowing system conditions to evolve toward the achievement of stated engineering and/or ecological objectives. Objectives can be defined in terms of changes to sediment chemical concentrations or in terms of ecological goals, such as improving habitat quality or reducing tissue concentrations of contaminants of concern in receptors of interest. Recovery either implicitly or explicitly includes a time component, as, for example, with projecting a time frame for ecological recovery following completion of sediment remediation.

Physical recovery of chemically-impacted systems can be achieved through a variety of strategies, including sediment removal (i.e., dredging), in situ burial of contaminated sediment (isolation capping), dilution/mixing of contaminated sediment with cleaner material (thin layer capping), and reliance on natural processes such as dispersion, chemical precipitation, and/or chemical breakdown (for organic contaminants) to reduce chemical concentrations in surface sediment. Importantly, for remedial design focused on physical recovery, sediment clean up targets may be defined as a function of costs, limitations on the practicality of achieving lower concentration targets, and/or the desire to accomplish mass removal goals, such as with hot spot removals in locations with significantly elevated but laterally constrained chemical distributions.

In contrast, remedial design focused on ecological recovery explicitly addresses the recovery of receptors of interest. Overall ecological recovery objectives can include improvements to habitat quality, declines in chemical concentrations in biota (such as tissue and blood concentrations), or changes to behavioural dynamics, either at the organism level or population level. The focus for biota can be on direct exposure through contact, such as with surface water or sediment, or exposure through food web transfer via consumption of prey species.

### 3.9.2 Factors Affecting Recovery Time

Processes that control the internal cycling of sediment in an estuary will significantly influence the recovery time of the system. Processes influencing recovery time include the timing and extent of historical chemical discharge, the magnitude of tidal circulation, the availability of clean sediment for burial, and the impact of tidal circulation on the presence, seasonal movement, and sediment redistribution potential of an ETM or bedded deposits. For estuaries historically impacted by chlor-alkali discharge, recovery times have been documented to vary from years (Bothner et al. 1980) to decades (Bloom et al. 2004; Merritt et al. 2009; Santschi et al. 2017), depending on how recovery is defined.

The presence of wood waste in the Penobscot River Estuary can impact system recovery time in various ways. Amec Foster Wheeler data on the concentration of mercury in wood waste suggest that total mercury and methyl mercury concentrations in wood waste are elevated overall relative to concentrations in mineral sediment. This elevated concentration, coupled with the lower density of wood waste relative to mineral sediment, and a poorly constrained understanding of its mobility (on seasonal, annual, or decadal time scales) suggests that the resuspension/transport/recycling of wood waste within the system may not follow modelling predictions for transport/recycling of mineral sediment.

These impacts on system recovery time are a function of the volume of wood waste potentially present in the system, the concentration of mercury in that material, and the impact of system hydrodynamics on the mobility of this material. As noted in Section 3.8.2, the breakdown rate of wood waste in aqueous environments is sufficiently slow that material may cycle for decades, contributing to mercury remobilization and redistribution within the Estuary before it is removed from the system through burial or transport out of the Estuary.

### 3.9.3 Proposed Recovery Time – Lines of Evidence

There are multiple lines of evidence that can be integrated to evaluate potential recovery scenarios for the Estuary. Relevant lines of evidence include numerical modeling applied to data collected from sediment cores, evaluation of recovery rates through sediment mixing models, and analysis of temporal trends in sediment chemistry and biotic tissue concentrations. This section reviews the existing data on these relevant lines of evidence. The Phase III Engineering Report (Amec Foster Wheeler, 2018a) presents an assessment of recovery times for the Estuary that incorporates Amec Foster Wheeler 2016–2017 data for recommended remedial alternatives.

#### *3.9.3.1 Apparent Half-Time Modeling – Sediment Cores*

Apparent half-time recovery modeling as applied to the Estuary has focused on sediment cores collected in 2009 (PRMSP 2013) and in 2017 (Amec Foster Wheeler 2018k). The term ‘apparent’ is used herein consistent with its use in the Phase II Study in which the calculation of recovery rates is dependent on data extrapolation and assumptions regarding temporal mixing and redistribution of mercury in the Estuary. For the cores collected in 2009, mercury concentration profiles were evaluated over two intervals: a rapid recovery interval defined as 1967–1988, and a slower recovery interval defined as 1988–2009. For the slower recovery interval, an apparent recovery rate was calculated by fitting an exponential curve to the concentration profile under the assumption that mixing chemically-affected sediment with sediment having lower mercury concentrations has yielded exponentially decreasing concentrations of mercury over the interval from 1988–2009. Assuming an exponential fit to the data, an apparent recovery half-time (i.e., the time required for the concentration of mercury to decrease by 50 percent relative to the concentration in 1988, the beginning of the slower recovery interval), was then calculated, with the goal of evaluating the rate at which surface sediment concentrations could be predicted to decrease toward stated concentration targets of 0, 100, and 400 ng/g. These concentration targets were chosen by the Phase II Study based on an asymptotic model fit to a zero concentration (0 ng/g), an estimate of regional background mercury concentration (100 ng/g), and a recommendation made for the protection of wildlife and human health (400 ng/g) (PRMSP 2013).

For the cores collected in 2017, the same model was applied with a few initial modifications: (1) the slower recovery interval was considered either to be 1988–2017 (i.e., with the same start year as for the 2009 study and including 29 years) or to be 1996–2017 (i.e., with the same interval length of 21 years as for the 2009 study) and (2) only the 0 ng/g and the 400 ng/g recovery targets were applied (Amec Foster Wheeler 2018k). Based on preliminary review and the similarity of modeling results for either the 21-year or the 29-year interval as evaluated by Dr. Kevin Yeager, only the 21-year interval was carried through the apparent recovery rate modeling exercise.

For the 2009 cores, application of the apparent recovery rate modeling strategy to cores recovered from throughout the Estuary resulted in average (mean) recovery half times of 22 years for cores collected from Mendall Marsh; 31 years for cores collected along the main stem of the Estuary channel; 69 years for cores collected from Orland River; and 120 years for cores collected from Fort Point Cove and the outer Estuary (PRMSP 2013; Santschi et al. 2017).

As summarized in the 2017 Thin Interval Core Sampling Report (Amec Foster Wheeler 2018k), looking specifically at the 21 stations that were sampled in both 2009 and again 2017, calculated apparent mercury recovery half times show that natural recovery is slowing in the Penobscot River system. For apparent mercury recovery half times calculated assuming $Hg_{(\infty)}$ = 0 ng/g, nine of 11 stations (82 percent) for which recovery half times could be calculated showed increasing half times relative to rates calculated for 2009 data applying the same asymptotic concentration of 0 ng/g; for apparent mercury half times calculated assuming $Hg_{(\infty)}$ = 400 ng/g, eight of 10 stations (80 percent) showed increasing half times for recovery relative to 2009 rates modeled by applying the same Hg(∞) = 400 ng/g concentration . Increasing apparent recovery half times result from incrementally decreasing changes in sediment mercury concentration in surface intervals of cores over a consistent 21-year interval. Thus, for a station sampled in both 2009 and 2017, an increasing recovery half time calculated in 2017 relative to the recovery half time calculated in 2009 suggests that the rate of change in the mercury profile over the 21-year interval from 1996–2017 is decreasing relative to the rate of change in the mercury profile over the 21-year interval from 1988–2009 used in the Phase II modeling.

While the apparent half time to recovery model presented here allows for curve-fitting of current and historical sediment data to reflect sediment mixing processes over time, the extrapolation of this approach to future recovery should be approached with caution. In evaluation of Penobscot River Estuary sediment mercury data, Santschi et al. (2017) characterized the system as being defined by three intervals: a release phase characterized by mercury inputs to the Estuary, a redistribution phase characterized by the equilibration or homogenization of surface sediment mercury concentrations throughout the Estuary via mixing processes, and a recovery phase characterized by the continued decrease of surface sediment mercury concentrations from the equilibration concentration toward a desired concentration target. For cores collected in 2009 from locations defined as reflecting representative physical mixing and chemical attenuation within the Estuary (i.e., cores described as being from locations in communication with the larger system), surface sediment concentrations in 2009 appeared to be converging toward 600–700 ng/g (Santschi et al. 2017). As shown in **Table 3-5** for Phase III data collected in 2016-2017, surface sediment total mercury concentrations in the main channel of the Estuary do not appear to have changed significantly from this average, and in some reaches remain higher than 700 ng/g.

The general consistency in average total mercury concentrations in surface sediment over much of the Estuary supports the concept that the Estuary is achieving some level of homogenization or equilibrium redistribution of mercury-affected sediment and wood waste. If this approach toward homogenization accurately reflects system dynamics, then in the absence of sediment removal by engineered means, the process of continued natural recovery via declining surface sediment mercury concentration will be driven more specifically by the input rate of clean sediment from upgradient (assuming mixing of that clean upgradient sediment within the Estuary) than by the combination of clean sediment input and mixing/redistribution within the system. The relative size of these two pools of material (i.e., sediment from upgradient sources versus mobile/re-suspended sediment from within the Estuary) is currently not well constrained and is discussed further in the evaluation of box models (Section 3.9.3.2). Likewise, if mercury concentrations in those portions of the system that are not in communication with the larger system are elevated relative to a homogeneously mixed concentration in mobile sediment, then changes to the hydrodynamic processes controlling sediment mixing or erosion (e.g., increases in wind/wave action, changes to flow regime) have the potential to re-entrain sediments into suspension that would be a continuing source of mercury that further slows projected system-wide recovery rates.

#### *3.9.3.2 Box Models*

Box model approaches to evaluating system recovery have focused on estimating the turnover time of sediment in the system. Box model estimates for the Estuary have observed that based on the annual mass of sediment entering the Estuary from upgradient (40,000–50,000 tons) and the estimated mass of mobile sediment within the upper Estuary (320,000 tons; defined by the Phase II Study as the "mobile pool"), the turnover time of mobile sediment should be on the order of <10 years (PRMSP 2013). That this time scale does not appear to correspond to the time scale for mercury recovery in the Estuary suggests that: (1) the mass of mobile material in the Estuary has been underestimated (i.e., that the mass of material in the system that mixes with new sediment from upgradient is larger than 320,000 tons); (2) new sediment entering the Estuary annually from upgradient passes through the system without mixing with mobile sediment within the Estuary; and/or (3) there are additional sources of mercury within the Estuary that are contributing to the delay in the system recovery rate relative to what would be expected simply based on the turnover time of sediment defined as 'mobile' in the system.

To assess the scenario that the mass of the "mobile pool" has been underestimated, Geyer and Ralston (2018) estimated that by entraining an additional 10–15 percent of solids from the consolidated sediment bed, a mixing model recovery rate can be generated that roughly matches the apparent half-time recovery model estimate for Mendall Marsh. That is, the Geyer and Ralston (2018) model predicts that by increasing the volume of mobile sediment by 10–15 percent through inclusion of re-suspended bed sediment, the modeled mercury concentration in that mobile sediment will decrease exponentially over an estimated 25 years, an interval similar to the average modeled apparent recovery half-time for Mendall Marsh (mean half time = 22 years) (Santschi et al. 2017). This box model assumes that the concentration of mercury in mobile sediment is more homogeneous than the concentration of mercury in bed sediment and that the mass of mobile material in the system is in steady-state on a yearly time scale (i.e., on an annual basis there is approximately as much particulate matter leaving the Estuary as entering the Estuary from upgradient sources).

One implication of the convergence in time scales between the apparent recovery half-time model for Mendall Marsh and the box model recovery estimate for the whole Estuary as presented in Geyer and Ralston (2018) is that the mercury distribution and recovery rate in off-channel areas such as Mendall Marsh (and Orland River) is therefore influenced by the redistribution of mercury-affected sediment and wood waste from within the remainder of the Estuary. This implication is important in that it: (1) highlights the role that Estuary processes, including the ETM and variability in sediment transport and deposition rates in off-channel areas, play in slowing the turnover rate of sediment and wood waste throughout the Estuary; and (2) introduces uncertainty to predictions regarding the rate at which inputs of clean sediment to the Estuary will result in continued declines in surface sediment mercury concentrations within the Estuary. For example, if the system-wide average thickness of unconsolidated sediment is approximately 9 cm (**Tables 3-1 and 3-2**) and the thickness of the mixed sediment and wood waste is an additional 15–20 cm (**Table 3-1**), then the mass of the material that could be defined as "mobile" (i.e., the material captured by the Reflector 1 return in the sub-bottom profiling data; Amec Foster Wheeler 2017e) may be closer to 1,950,000 tons (dry weight) versus the 320,000 tons defined by the 5-cm thick (on average) redox color change in bed sediment evaluated by Geyer and Ralston (2018). That data presented in the 2017 Thin Interval Core Sampling Report (Amec Foster Wheeler 2018k) suggest that apparent system-wide recovery rates have effectively stalled relative to apparent system-wide recovery rates modeled in 2009, supports the idea that the volume of material recycling within the system is likely larger than Phase II box model estimates, even including the 10–15 percent of re-suspended bed sediment that Geyer and Ralston (2018) have modeled as an addition to what they define as the mobile pool. Of importance from the vantage of evaluating system recovery is that neither the volume of 'mobile' sediment in the Estuary nor the calculated or apparent recovery rates for this system are well constrained. Likewise, while the term 'mobile pool' as introduced in the Phase II Study is intended to describe sediment that may mix and redistribute on a time-scale that creates visible redox boundaries in the sediment bed (i.e., material described in the Phase II Study as "a recently deposited, light colored unconsolidated mud"), multiple lines of evidence suggest that additional volumes or higher concentrations of sediment and/or wood waste may be serving to slow system-wide recovery rates in the Estuary through resuspension/erosion, transport and mixing on seasonal, annual or decadal time scales.

In considering system recovery, an additional implication of the box model assumptions discussed above is that re-deposition of mobile sediment within the Estuary (either in off-channel areas or as the result of dredging) or removal/release of this material from the Estuary will occur at a mercury concentration that is equivalent to the homogeneous mixed concentration in the mobile pool. While this statement is generally true and the mercury and total organic carbon (TOC) content of unconsolidated sediments appears statistical similar in different parts of the system (i.e., Mendall Marsh, the main channel, and the East Channel including Orland River) (**Table 3-2**), the extent to which the mobile pool is a mixture of mineral sediment and wood waste—two distinct phases with differing particle sizes and densities, mercury concentrations, and transport properties—will influence the extent to which box models are useful tools for projecting recovery rates for the Estuary. Box model scenarios for evaluating system recovery rates are presented in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

#### *3.9.3.3 Sediment Spatial and Temporal Trends*

System recovery rates also can be assessed through the evaluation of spatial trends in surface sediment chemistry. For the Estuary, evaluation of sediment spatial trends includes evaluation of data presented in the Phase II Report (PRMSP 2013) as well as 2016 Amec Foster Wheeler data evaluated for continuing changes in sediment chemistry over time. Sediment trends analysis presented here are included in the Phase II Report (PRMSP 2013) and the 2017 Sediment and Surface Water Monitoring Report (Amec Foster Wheeler 2018g).

The Phase II Report (PRMSP 2013) concluded that for sampling conducted between 2006 and 2012, total mercury concentrations in surface sediments were generally unchanged. When analyzed by sediment class (subtidal, intertidal, wetland high elevation, wetland medium elevation, wetland low elevation, and wetland mudflats), there were significant trends over time only for intertidal and wetland mudflat sites. For one out of the seven intertidal sites evaluated, there was a significant increase in total mercury concentration over the interval 2006–2012, while for two out of six wetland mudflat sites, there was a significant decrease in total mercury concentration.

Sediment concentrations were also generally consistent for methyl mercury over this same time interval, although with a greater degree of variability than for total mercury concentrations. Site-specific factors including sediment organic matter content, sediment grain size distribution, and availability of dissolved oxygen and sulfate influence in situ methyl mercury production and consequently influence temporal and spatial trends in methyl mercury distribution (Merritt and Amirbahman 2009). Overall, the spatial and temporal distribution of sediment methyl mercury concentrations for 2006–2012 typically reflects the distribution of total mercury concentrations (PRMSP 2013).

Amec Foster Wheeler sampling in 2016 concluded that, overall, when 2016 data were integrated with the Phase II data, no consistent temporal trends were evident for either total mercury or methyl mercury concentrations in sediment (Amec Foster Wheeler 2017c). The absence of temporal trends in decreasing sediment mercury concentrations is consistent with observations discussed in Section 3.9.3.1 regarding the system reaching or having reached a level of equilibrium redistribution of mercury-affected sediment. The inclusion of 2017 data does not change this conclusion overall. With the inclusion of 2017 data, while there is some evidence of decreasing concentrations of mercury and/or methyl mercury over time, particularly when data are normalized to the organic carbon content of samples, these results were apparent at only six out of 37 stations, with five of the six in Mendall Marsh, and were not consistently apparent across reaches (Amec Foster Wheeler 2018g). If the temporal trend analysis is correct, it supports the suggestion of an overall spatial equilibration of surface sediment chemistry occurring in the system and slow or minimal recovery.

#### *3.9.3.4 Biota Trends*

System recovery rates also can be assessed through the evaluation of trends in biota tissue chemistry. For the Estuary, evaluation of tissue trends includes evaluation of data presented in the Phase II Report (PRMSP 2013) as well as 2016–2017 Amec Foster Wheeler data evaluated for continuing changes in tissue chemistry over time (Amec Foster Wheeler 2018b; 2018m).

The Phase II Report (PRMSP 2013) concluded that for sampling conducted between 2006 and 2012, there were no significant overall temporal trends in tissue mercury chemistry for biota species, including fish (American eels, tomcod, rainbow smelt, winter flounder), lobster, and birds (Nelson's sparrow, song sparrow, swamp sparrow, red-winged blackbird, Virginia rail). For blue mussels, tissue concentrations declined at study sites in the upper Estuary, but not at study sites in the lower Estuary below Fort Point. For mummichogs, double-crested cormorants, American black ducks and bats, sampling limitations precluded the ability to assess trends in tissue chemistry.

In terms of spatial trends, the Phase II Report (PRMSP 2013) concluded that tissue concentrations of mercury generally declined with distance from the HoltraChem facility for most fish species (American eels, tomcod, rainbow smelt, winter flounder), lobster, mussels, and double-crested cormorants. For birds, the highest tissue mercury concentrations in marsh birds (Nelson's sparrow, song sparrow, swamp sparrow, red-winged blackbird, Virginia rail and American black duck) were found in Mendall Marsh, likely reflecting the proximity of the marsh to the HoltraChem facility. One caveat to this conclusion presented in the Phase II Report is that birds were sampled at a limited number of sampling locations, primarily focused in the Mendall Marsh area.

Amec Foster Wheeler sampling in 2016 concluded that, overall, when 2016 data were integrated with the Phase II data, fish showed more significant declines in tissue mercury concentration than songbirds (Amec Foster Wheeler 2017b). Overall, 2016 songbird results were similar to what was found in the Phase II Report. For aquatic biota, (lobster, blue mussel, rainbow smelt, eel, tomcod, and mummichog) tissue mercury concentrations in the Estuary are either generally decreasing (0.5 to 9 percent annually) or not changing. For bird species at two sampling locations (south of Verona Island and Mendall Marsh Southeast) and for blue mussels at one location (ES-FP), mercury concentrations appear to be increasing over time.

Geographically, biota collected in the areas of Mendall Marsh and south of Verona Island tend to have higher tissue mercury concentrations than biota collected in other parts of the Estuary. For many species (tomcod, smelt, lobster, and polychaetes), mercury concentrations continue to show decreases with distance downstream from the HoltraChem facility. Blue mussel and mummichog showed no strong spatial patterns of mercury concentrations within the Estuary (Amec Foster Wheeler 2017b). In terms of trophic level, low trophic level and terrestrial mid-trophic level species (one shellfish, two songbird species, and one waterfowl species) tend to show limited or no change in tissue mercury concentrations through time; whereas upper trophic level species (four fish and one shellfish species) show greater reduction in mercury tissue concentrations than either low trophic level or terrestrial mid-trophic level species.

With the inclusion of 2017 data (Amec Foster Wheeler 2018j), Amec Foster Wheeler concluded that overall, mercury concentrations in aquatic biota (lobster, blue mussel, rainbow smelt, eel, tomcod, and mummichog) in the Estuary are generally decreasing (0.2 to 6.5 percent annual decline), indicating either the potential for some natural recovery or that tissue concentrations are not changing. Blue mussels at two locations and red-winged blackbirds at most locations had increasing mercury concentrations (0.4 to 2.2 percent annual increase). Aquatic low trophic level species (one shellfish species) and terrestrial mid-trophic level species (two songbird species) tended to show limited or no change in concentrations through time. Upper trophic level species (four fish and one shellfish species) showed more reduction through time in mercury concentrations than aquatic low trophic level or terrestrial mid-trophic level species. Results from 2017 biota monitoring also indicated that biota collected in the areas of Mendall Marsh and south of Verona Island tended to have higher mercury concentrations than biota in other parts of the Estuary. This tendency toward higher tissue concentrations in the areas of Mendall Marsh and south Verona Island depended on the species analyzed. For many species, mercury concentrations decreased with distance downstream, consistent with results presented in the Phase II Study Report (PRMSP 2013).

# 4.0 APPLICABLE FEDERAL AND STATE STATUTES, REGULATIONS, AND PROGRAMS

Remedial alternatives that are under consideration to remediate mercury-contaminated sediments in the Penobscot River and Estuary would be subject to a variety of federal and state statutes, regulations, and permits (applicable requirements). Local reviews, permits, and/or approvals may also be required depending on the location and nature of the activities.

Applicable requirements fall into three general categories:

- Action-Specific Requirements: Triggered when taking remedial action or implementing an active remedy (e.g., dredging of sediments). Consist of technology- or activity-based requirements or limitations on performance, design and controls of remedial actions, or restrictions on activities (e.g., permit requirements for dredging or filling activities).
- Location-Specific Requirements: Triggered when the location where a remedial action would be taken is regulated (e.g., in an area identified as an essential fish habitat). Consist of requirements for how activities will be conducted because they are in special locations (e.g., wetlands, floodplains, essential or critical habitats, coastal areas), or establishing siting parameters for facilities based on their proximity to special locations.
- Chemical-Specific Requirements: Triggered when chemicals are present at regulated concentrations e.g., mercury in dewatering fluids from dredging operations). Consist of health- or risk-based numerical values limiting the amount or concentration of a chemical that may be found in, or discharged to, the environment (e.g., ambient surface water quality criteria).

Potentially applicable federal and state requirements were preliminarily identified in the Technology Screening Report (Amec Foster Wheeler 2017a) for the range of remedial technologies that were evaluated for remediation of mercury in sediments in the Penobscot River and Estuary.

As part of evaluation of the remedial alternatives under the following site-specific criteria, the list of potentially applicable requirements was refined to identify just those that are applicable to the implementation of the remedial alternatives identified in Section 7.0.

Sections 4.1 and 4.2 summarize anticipated applicable federal and State of Maine requirements that would be triggered by implementation of the remedial alternatives under consideration; identify restrictions or limitations on the implementation of the remedial alternatives; and describe how the requirement would be complied with during implementation of the alternatives.

## 4.1 APPLICABLE FEDERAL REQUIREMENTS

**Table 4-1** identifies the anticipated applicable federal requirements that would be triggered by implementation of the remedial alternatives under consideration, and describes the anticipated processes, permits, reviews, and regulatory agency interactions that would be required to be followed prior to and during implementation of remedial alternatives.

## 4.2 APPLICABLE STATE REQUIREMENTS

**Table 4-2** identifies the anticipated state requirements that would be triggered by implementation of the remedial alternatives under consideration, and describes the anticipated processes, permits, reviews, and regulatory agency interactions that would be required to be followed prior to and during implementation of remedial alternatives.

## 4.3 PERMITTING AND REGULATORY LIMITATIONS

Implementation of active remedies within the Estuary will require multiple environmental permits to conduct work. Lead regulatory agencies for the permitting will be the USACE for federal permits and the MEDEP for state permits. Local permits and approvals may also be required from certain townships. The permitting process will involve extensive coordination with state and federal agencies as well as local municipalities and will include public participation as part of the permit review process. MEDEP and USACE noted in discussions conducted during preparation of this Report that a permitting timeframe of between 2 years and 10 years could be expected for a project of this magnitude, with the longer timeframe accounting for permitting of a new disposal facility (if required).

Sections 4.3.1 through 4.3.3 describe the federal, state and local permits needed to implement the remedies evaluated in this Report. Section 5.5 includes discussion of a process for the permit application effort. Evaluation of the permitting process is also included in Section 8.0 for each of the alternatives presented. It should be noted that during the permitting process a permit application may be denied by the permitting authority. Denial by a permitting authority may require revision and resubmittal of the application which would delay implementation of the work, or the denial may require that restrictive conditions be incorporated into the approach to conduct the work such that implementation under the conditions proposed is either more expensive or more difficult to implement. In some cases, the additional restrictive permit conditions may make the implementation of that remedial approach no longer feasible.

### 4.3.1 Federal Permitting

The USACE regulates activities under the federal CWA, the Rivers and Harbors Act of 1899, and the Marine Protection, Research, and Sanctuaries Act. In general, activities affecting jurisdictional waters of the US (waters and wetlands) are regulated under the CWA and require a permit. A federal CWA 404 permit from the USACE to dredge and fill waters of the US can be issued under the General Permit for the State of Maine or as an Individual Permit. Under the Maine General Permit, a Category 1 or Category 2 permit can be issued for smaller projects that affect fewer than 3 acres of waters of the US. There are also many conditions that must be met to permit a project under the Maine General Permit. Due to the size, location, and complexity of this project, permitting under the General Permit was not considered, because several of the conditions for a General Permit cannot be met. Therefore, an Individual 404 Permit would be required.

An Individual Permit requires additional information and evaluation of potential impacts to the environment. It also requires the USACE to seek input from other federal agencies, including EPA, the US Fish and Wildlife Service, and NOAA's National Marine Fisheries Service.

Under federal permitting, the presence of historic artifacts as well the interests and rights of Native American Tribes also need to be considered when implementing an active remedy. Formal public input is also typical during the federal permitting process via public informational meetings. Although public meetings are not always needed, they are likely for a project of this magnitude and local interest.

**Table 4-3** describes federal and state applicable requirements and summarizes permits that are anticipated to be required for the project, along with pertinent requirements that need to be considered during project permitting and implementation.

Because portions of the Estuary are within federally-authorized channels that considered to be part of an ongoing USACE civil works project that includes maintaining the river for ship passage and navigation, the project is subject to review by the Secretary of the Army, as authorized under Section 14 of the Rivers and Harbors Act of 1899 and United States Code (U.S.C.) Section 408. The Secretary of the Army can grant permission for a proposed alteration (i.e., remedial activities) if they meet the criteria established for approval under 33 U.S.C. Section 408. CWA Section 404 and 401 permit application review can occur concurrent with the 33 U.S.C. Section 408 review; however, it is expected that 33 U.S.C. Section 408 review may add additional permitting time to the project.

In addition to a CWA 404 Individual Permit, the project also requires a CWA 401 Certification to accompany the CWA 404 Individual Permit. The CWA 401 Certification covers water quality components of the CWA 404 permit project but is issued by the State of Maine. A National Pollution Elimination Discharge Permit under Section 402 of the CWA is expected to be required for placement of amendments.

There are three species listed under the federal ESA that are known to occur in the Penobscot Estuary: the shortnose sturgeon, the Atlantic sturgeon, and the Atlantic salmon. Because these species could be injured during the project implementation, Incidental Take Permits for species should be obtained from National Marine Fisheries Service in advance of the work. Additional species may be identified during the permitting process.

### 4.3.2 State Permitting

State permitting will involve meeting the requirements of both the Natural Resources Protection Act and the Site Location of Development Law. The Natural Resources Protection Act has three tiers of permitting, depending on the size of proposed impacts to wetlands, water bodies, or other regulated areas. The most complex tier, an Individual Permit, will be needed for this project due to the size of the impacts proposed to wetlands.

The Site Location of Development Law is a comprehensive permitting process reserved for major projects. The process considers proposed impacts of the project to various resources, including wildlife, aquifers, air, surface water bodies and wetlands; visual, noise, and traffic impacts; and benefits to the community. The process also requires a stormwater management plan for the project components, developed using the Maine Stormwater Rules. Maine is a “designated” state by EPA, with an approved stormwater program and programmatic permits, which makes MEDEP the lead agency on stormwater-related issues and permits; thus, the federal CWA 401 Certification is administered by the State of Maine.

Any disposal areas for excavated or dredged materials will require permitting under the Maine Solid Waste Rules, as shown on **Table 4-3**. Transportation of certain materials will also fall under the Maine Hazardous Waste, Septage, and Solid Waste Management Act.

Beneficial reuse of the dredged material appears feasible in accordance with Maine Solid Waste Management Rules, which will require permitting and state approval (MEDEP 2012).

Permanent structures placed in the river as part of the project may require a Submerged Land Lease from the State of Maine.

Like the federal ESA, Maine has an ESA with an associated list of state-listed threatened and endangered species. Incidental Take Permits may be required from the State for species that may be accidentally taken during implementation of the remedies.

Like the USACE, the MEDEP will call on experts from within MEDEP as well as other state agencies to review the Site Location of Development Law and Natural Resources Protection Act permit applications for the project. Other state agencies that will likely be involved in reviewing the state applications include:

- Maine Department of Inland Fisheries and Wildlife;

- Maine DMR; and

- Maine Department of Agriculture, Conservation, and Forestry (Submerged Lands Program).

### 4.3.3 Local Municipal Permitting

Local permitting for on-shore facilities will be required and will likely include towns along the river. Components of the project requiring local permitting include the proposed sediment handling facility and the long-term material placement area(s).

# 5.0 BASIS OF REMEDIATION AND ENGINEERING ASSUMPTIONS

Section 5.0 discusses data usability, the basis of the remediation, and the engineering assumptions used in the development of the remedial alternatives.

## 5.1 PREVIOUS REMEDIAL ACTIONS CONDUCTED

Pursuant to a separate remedial effort undertaken by Mallinckrodt and overseen by MEDEP to address contamination at the former chlor-alkali manufacturing facility location (which was not part of the current effort), remediation of the buildings, landfills, soil areas, groundwater and a small area of the Southern Cove sediments has been or is in the process of being remediated. Southern Cove sediments in areas with an average concentration greater than 2.2 mg/kg were removed in 2017, using mechanical excavation and dredging techniques.

## 5.2 DATA USABILITY AND SOURCE OF UNCERTAINTY

To characterize sections of the Estuary that may be distinct in terms of river flow, tidal influence, and/or the transport and deposition of mercury-affected sediment, Amec Foster Wheeler has delineated 15 Estuary reaches (**Figure 1-1; Table 5-1**). Reach boundaries incorporated physical river features so that field personnel could recognize these features during sample collection efforts. For Mendall Marsh, the boundary of the reach is defined as the upgradient extent of the north and south branches of Marsh River as defined in **Table 5-1**. For Fort Point Cove, a single reach boundary is defined for the eastern side of the cove, with the remaining perimeter of the cove being dry land. For the 15 reaches delineated for the Estuary, the lateral landward extent of the reach boundary is the 14-foot MLLW (8 feet NAVD88) elevation contour that corresponds with the highest annual tide.

Reaches have been subdivided into zones to provide additional characterization with respect to types of environments and potential constraints on remediation equipment access (**Table 5-2**). Zones are based on either bathymetric location (as defined by digitized NOAA navigation chart 13309) or discrete physical features such as historically dredged navigational channels, the presence of wood waste deposits (the "Pile") identified through the 2016 geophysical survey program (Amec Foster Wheeler 2017a) or areas that are dominantly sub-aerially exposed (Mendall Marsh) and not well delineated on a NOAA navigational chart.

### 5.2.1 Hydrodynamic Zones

To further support evaluation of the data during alternatives development, the zones listed in **Table 5-2** were further divided into hydrodynamic regimes within each reach (**Figures 5-1-1 through 5-1-16**). The goal of this division was to facilitate evaluation of sediment mercury data in terms of the dominant mechanism (flow regime) likely influencing the spatial distribution of those data. The choice of hydrodynamic regime was based on preliminary geospatial analysis of the data, which highlighted the likely impact of flow regime on grain size distribution (and, relatedly, mercury distribution) across intertidal, subtidal, and thalweg zones. The hydrodynamic zones chosen for the evaluation of sediment mercury distributions are as follows:

- ***Marsh Zone:*** The marsh zone refers to the generally flat, vegetated marsh surface that is at or just above the mean high water level and is inundated regularly by high tides (minimally during neap tides and more substantially during spring tides). For evaluation of remedial alternatives, the upper elevation boundary of the marsh zone is identified by the 14-foot MLLW elevation contour that defines the lateral boundary of the Estuary.

- ***Intertidal Zone:*** The intertidal zone refers to the portion of the system that is located between the mean high water and mean low water levels and is alternately submerged and exposed during the tidal cycle. During low tide, the entire sediment surface of the intertidal zone is exposed, while at high tide the area is completely submerged.

- ***Subtidal Zone:*** The subtidal zone refers to areas in the main channel of the Estuary and separate side channels (e.g., Mendall Marsh, the Orland River, and lesser tributaries) that are always submerged below MLLW. Some of these areas are relatively shallow with average depths ranging from 1 to 5 feet below MLLW; the majority of these areas have average depths ranging from approximately 20 to 30 feet below MLLW; and portions of the river channels are much deeper, with average depths ranging from 50 to 80 feet below MLLW, and in the Verona Narrows reaching 90 feet below MLLW.

- ***Thalweg/Main Channel Zone:*** The thalweg/main channel zone refers to areas defined by the greatest bathymetric contour within each reach. Because of both the overall longitudinal elevation drop and variability in channel depth along the Estuary channel, the thalweg is not defined by a consistent bathymetric contour. The thalweg zone is not present in Mendall Marsh.

To allow for further spatial refinement of the data for areal averaging, both the intertidal and subtidal zones were further divided into eastern and western portions of those zones. Thus, for a hypothetical river reach (n = 15), the reach could contain as many as seven hydrodynamic zones: west side marsh, west side intertidal, west side subtidal, thalweg/main channel, east side subtidal, east side intertidal, and east side marsh. In locations in which an intermediary hydrodynamic zone is absent (such as in Mendall Marsh, where there was no thalweg/main channel zone), the adjacent west side subtidal and east side subtidal zones were combined into a single subtidal zone. Likewise, in Mendall Marsh, in the upper marsh where there is no subtidal zone, the west side intertidal and east side intertidal are combined into a single intertidal zone. This refinement of hydrodynamic boundaries also occurred in the Upper Penobscot Bay Reach, in which the permanently submerged portion of the reach was considered a single integrated subtidal zone.

Based on a preliminary assessment of the distribution of total mercury in sediment in Mendall Marsh, the similarity between area averaged concentrations of total mercury on the marsh east platform versus marsh west platform, and consideration of the dominant mechanism likely responsible for transport of mercury onto the marsh platform (i.e., the frequency and extent of inundation of the platform), hydrodynamic zones in Mendall Marsh were further refined as a function of elevation. For this assessment, the Mendall Marsh platform was subdivided based on NAVD88 elevation breakpoints of 2.0, 5.8, 7.0, and 7.5 feet. The subdivision of Mendall Marsh as defined by elevation breakpoints was based on the spatial distribution of total mercury data on the marsh platform and the evaluation of whether an elevation breakpoint could be identified associated with a decrease in total mercury concentration moving inland across the platform. The basis for this delineation of Mendall Marsh is presented in **Appendix H**. The delineation described here and presented in **Appendix H** was carried forward in the evaluation of remedial alternatives for Mendall Marsh.

### 5.2.2 Area Weighted Average Concentration Approach

Identification of Estuary areas potentially warranting remedy was based on a comparison of area weighted average concentrations of total mercury versus ecological and human health-based preliminary remediation goals (PRGs). Calculation of the PRGs for total mercury in sediment is presented in the Penobscot River Risk Assessment and Preliminary Remediation Goal Development Report (Amec Foster Wheeler 2018b)

#### *5.2.2.1 Data Sources*

For the calculation of area weighted average concentrations of total mercury to be used in the development of remedial alternatives, all mercury data in the project database from 2000–2017 were included, with the exception of data points for which either the analytical laboratory or the analytical method were unclear, or for which sampling details (e.g., uncertain sampling location, undefined sampling depth increments) could not be confirmed. As detailed in **Appendix I**, when these basic exclusions are applied, data from 906 field sample locations were available for the calculation of area weighted averages. In terms of overall sampling station density, for the upper Estuary (defined as the portion of the study area upstream of the southern tip of Verona Island), the current (2018) sampling station density is approximately one station per 12 acres. For the lower Estuary (defined as the portion of the study area downstream of the southern tip of Verona Island), the current (2018) sampling station density is approximately one station per 99 acres.

The area unit used in the calculation of area weighted average concentrations is defined by a combination of a reach and a hydrodynamic zone. For each reach/hydrodynamic zone, a preliminary area weighted average concentration was calculated for each of the following depth intervals:

- 0–0.5 foot;
- 0.5–1.0 foot;

- 1.0–2.0 feet;
- 2.0–3.0 feet;
- >3.0 feet

In evaluating remedial options for Mendall Marsh, area weighted average mercury concentrations were also generated for the 0–0.25 foot depth interval to allow evaluation of the effectiveness of thin layer cap placement for achieving marsh platform PRGs. Details regarding the number of sample points within each depth interval are presented in **Appendix I**.

#### *5.2.2.2 Interval Participation Weighted Concentration*

To integrate the useable data into the depth increments defined in Section 5.2.2.1, an interval participation weighted concentration (IPWC) was calculated for each depth increment. This technique allows for the integration of data from a project database that can include a range of sampling types (e.g., grab samples and sediment cores) that may have been collected for differing objectives and depth sectioned at differing interval schemes (e.g., tenths of feet versus centimeter scales). In brief, for this technique, a depth interval (such as 0–0.5 foot) is identified and a weighted concentration is calculated for the data points/field locations for which there are data within or spanning that depth interval. Once interval-specific contributing weights are calculated and assigned, then for each interval, the total weights from samples in the interval are summed and the weighted concentrations are calculated in proportion to each sample's contribution to the total standard interval weight. For incomplete intervals, such as when a sectioned core does not reach the base of a defined IPWC interval, concentrations in the missing depth increments were assumed to be equal to the calculated weighted average concentration for that interval. Further discussion of IPWCs is included in **Appendix I**.

#### *5.2.2.3 Calculating Bootstrap Means*

Following identification of reach/hydrodynamic zone units and calculation of IPWCs, a bootstrap mean total mercury concentration was calculated for each reach/hydrodynamic zone. Based on the geospatial distribution of existing data, and the overall weak spatial correlation structure observed in the geospatial statistical variograms (as discussed in **Appendix I**), it was concluded that for the existing data set and remedy-focused evaluation, traditional statistics would be a more appropriate method for estimating total mercury concentrations in each reach/hydrodynamic zone than geospatial statistical approaches such as kriging. Because traditional statistical methods assume that sample points are independent from each other, relationships based on distance between samples or the direction of interpolation are not accounted for in the areal averaging of data. Potential constraints on the use of traditional statistical methods for areal averaging of data include the loss of small-scale variations in elevated chemical concentrations (i.e. loss of hot spots in averaging), as well as the impact of averaging on either under-estimating higher concentrations or over-estimating lower concentrations. That this constraint can also be applied to geospatial statistical approaches, such as kriging, highlights the importance of evaluating both known data and interpolated values when evaluating remedial alternatives.

Bootstrapping is a resampling method that estimates statistical parameters (e.g. mean, variance, confidence intervals, etc.) by continually resampling the sample population. Bootstrapping is advantageous in cases where it is difficult to define the statistical parameters of a sample population and/or there are too few samples available to adequately assess statistical parameters. To calculate a bootstrap mean, each sample falling within a predefined area (i.e., a hydrodynamic unit) undergoes a procedure called "resampling with replacement," meaning each sample has a random and equal chance for selection during each bootstrap resampling iteration. Each resample event generates a mini-population of the greater sample population and each resampling event, or mini-population, produces slightly different sample statistics. The results from multiple resampling iterations converge around a general statistical parameterization that is reported for interpretation.

For the Estuary data, bootstrap resampling was conducted in proportion to the original number of samples with analytical results in each hydrodynamic zone, and 1,000 resampling iterations were performed for each zone. Bootstrapping is a non-parametric method, meaning it makes no assumptions about the underlying distribution of the sample data set. The primary assumption, however, is the sample data set provides an adequate approximation of the underlying statistical or "true" population. This assumption can be challenged or violated in cases where a reach/hydrodynamic zone contains too few samples for analysis. As with any statistical presentation of spatial data, lack of sufficient data creates a source of uncertainty in interpreting area weighted average concentrations.

Bootstrap means and associated statistical parameters calculated for each of the IPWC depth intervals for each reach/hydrodynamic zone are presented in **Tables 5-3 through 5-8.** For those reach/hydrodynamic zone units (n = 5) for which no field data are available, an estimated bootstrap mean was assigned to the unit based on the bootstrap mean calculated for the nearest relevant hydrodynamic unit. For example, no data are available for the intertidal area on the west side of the Verona West reach. A bootstrap mean value of 92.2 ng/g was assigned to this unit based on the bootstrap mean of 92.2 ng/g calculated for the intertidal area on the east side of the Verona West reach (for which there was only a single field data point). Because field data include a combination of grab samples and cores of different lengths, the number of data points per reach/hydrodynamic zone decreases with depth interval. For depths greater than 0.5 foot (i.e., for subsurface intervals), the number of data points used in the calculation of bootstrap means decreases with each subsequent interval from 0.5–1.0 foot downward to the interval deeper than 3 feet.

**Figures 5-2-1 through 5-2-16** present the bootstrap mean total mercury concentrations for the 0-0.5 foot depth increment for each reach in the Estuary. Station locations for data used in the bootstrap mean calculations are included on these figures. Further details regarding the bootstrap mean technique are presented in **Appendix I**.

#### *5.2.2.4 Applying Exclusion Areas*

As calculated, the bootstrap means apply to the entire area defined for each reach/hydrodynamic zone. However, it is only a portion of the area encompassed by each reach/hydrodynamic zone that is characterized by the presence of fine-grained sediment and/or wood waste. Other areas, including locations with exposed bedrock, ledge, or hardpan bottom, are not likely to accumulate the fine-grained materials that could be associated with potentially elevated mercury concentrations. Based on this understanding of mercury fate and transport dynamics, estimates of the percentage of each reach area that could be characterized as bedrock/hardpan in the subtidal zone or ledge/boulder field in the intertidal zone were made. Excluding these areas from area weighted average footprints has the effect of appropriately decreasing the areal extent and therefore decreasing the volume of sediment potentially requiring active remediation. Importantly, these exclusion areas represent locations in which sampling has not occurred (or at least has not been successful), so removing the area from the reach/hydrodynamic zone does not remove sampling stations from the station data used to generate the bootstrap means and thus does not affect the area weighted average total mercury concentration calculated for that reach/ hydrodynamic zone.

Exclusions also include locations where identified historic shipwrecks or archeological sites would limit the ability to engage in in-water work. Information on exclusion areas was provided by Maine Historic Preservation and is included on **Figure 5-3**. Exclusions for shipwrecks or archeological sites may occur in areas in which sampling has occurred. Because the footprint of the exclusion areas is small, the bootstrap means were not re-calculated for those reach/hydrodynamic zones in which shipwreck or archeological exclusion areas occur.

For subtidal areas, locations with exposed bedrock or an absence of soft sediment were identified based on sub-bottom profiling data from the 2017 Mobile Sediment Characterization Report (Amec Foster Wheeler 2018h). These data were used in conjunction with additional data sources including the Phase II grab sample sediment classifications (PRMSP 2013), MEDEP Environmental and Geographic Analysis Database sediment sample classifications from 2017, and 2016 side-scan sonar bottom characterizations (Amec Foster Wheeler 2017a). 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 5-9**). Estimated subtidal exclusion areas for each reach were applied to relevant reach/hydrodynamic zones.

For intertidal areas, field estimates of boulder or bedrock outcrop/ledge were made in a low draft vessel in 2017 during Amec Foster Wheeler field sampling, with the goal of assessing 10 percent of each relevant reach/hydrodynamic zone. Field estimates were made during low tide conditions and along randomly chosen 100-foot stretches of shoreline for each reach. A Geographic Information System was used to view low tide aerial imagery at between 1:1500 and 1:2000 scale to establish a footprint around visible boulders, exposed bedrock ledge, and rocky shoreline. An arithmetic-based evaluation was performed using the planimetric areas of the digitized polygons to define the percentage composition (by area) of exposed rocks in each study reach. The landward limit of the Geographic Information System evaluation was the US Geological Survey hydrologic break line defining the shoreline. This low tide aerial imagery review was completed to support the visual field observations (**Table 5-9**). Estimated intertidal exclusion areas for each reach were applied to relevant reach/hydrodynamic zones**.**

In addition to the bedrock/boulder/hardpan exclusion areas, other areas also were excluded from the areal footprint used to calculate the bootstrap mean prior to calculation. These areas included the dredging footprint of the 2017 removal in Southern Cove (Anchor QEA and CDM Smith, Inc. 2017) and locations identified through the 2017 geophysical survey as representing deposits or accumulations of mixed mineral sediment and wood waste more than 3 feet thick. These locations were cored during either the 2017 subtidal and intertidal characterization field program (Amec Foster Wheeler 2018i) or the 2017 thin interval core sampling field program (Amec Foster Wheeler 2018k) and confirmed to contain 3+ feet of mixed mineral sediment and wood waste with mercury concentrations generally greater than 1,000 ng/g throughout the surface deposit layers. Because these areas represent known remedial targets with consistently elevated total mercury concentration throughout the deposits, the areal footprint plus the associated mercury core location were removed from the aerial footprint prior to calculation so as not to skew depth interval-specific bootstrap mean values. Deposits of mineral sediment and wood waste more than 3 feet thick with mercury concentrations generally above 1,000 ng/g were removed from Frankfort Flats, Orland River, and Verona East reaches. These three deposits contain approximately 960,000 cy of material.

## 5.3 REMEDIAL ACTION OBJECTIVES AND PRELIMINARY REMEDIATION GOALS

This section describes the development of narrative (i.e., non-numerical) remedial action objectives (RAOs) for the site. RAOs are developed to protect human health and the environment and provide the foundation upon which preliminary numerical remediation goals, cleanup levels, and remediation alternatives can be developed. The RAOs pertain to the specific exposure pathways and receptors that were evaluated in the human health and ecological risk assessments, and for which potential unacceptable risks were identified in the Risk Assessment (Amec Foster Wheeler 2018b).

RAOs are the basis for developing numerical PRGs, the target endpoint contaminant concentrations that are believed sufficient to protect human health and the environment based on available site information (EPA 1997). In addition to ensuring that human and ecological receptors are protected, RAOs take into account applicable federal and state statutes, regulations, and programs.

### 5.3.1 Current and Future Receptors of Concern and Exposure Pathways

**Figure 5-4** presents a simplified graphical depiction of a generalized food web chain that includes ecological and human receptors. The food web identifies processes such as mercury methylation, demethylation, settling, resuspension, diffusion, and other biochemical and physical processes, which contribute to the bioavailability of mercury, allowing it to be absorbed and bioaccumulate within the food chain in ecological species and human consumers. This section discusses current and hypothetical future ecological and human receptors and potentially complete exposure pathways for mercury in the Penobscot River.

#### *5.3.1.1 Human Receptors and Exposure Pathways*

Potential exposure pathways are those mechanisms by which an exposed receptor may come in contact with impacted environmental media at or originating from the Penobscot River. For human receptors, the primary possible exposure pathway under current and hypothetical future conditions is the consumption of locally harvested biota from the Penobscot River and the Estuary.

A conceptual exposure model outlining the complete exposure pathways evaluated in the 2018 HHRA for human receptors is presented in **Figure 5-5**. Further details regarding consumption rates for local consumers are presented in the Penobscot River Risk Assessment and Preliminary Remediation Goal Development Report (Amec Foster Wheeler 2018b).

Exposures to total mercury and methyl mercury were quantified to characterize risk from the consumption of local biota for adult and younger child local consumers. Local consumers are defined as those individuals with a portion of their diet consisting of finfish (represented by rainbow smelt, Atlantic tomcod, and American eel), lobster, shellfish (represented by blue mussels and soft-shell clams), and duck (represented by the black duck).

Regarding subsistence consumers, discussions with the Maine Centers for Disease Control (MeCDC) have indicated that the State of Maine does not consider a non-indigenous subsistence consumer in the development of the fish tissue action level (Amec Foster Wheeler 2018b). Furthermore, MeCDC considers that the developed fish tissue action level is protective of sensitive subpopulations, and as such the evaluation of a non-indigenous subsistence consumer is not necessary.

The biota consumption scenarios included in the Human Health Risk Assessment (HHRA) assumed the ingestion of finfish (catadromous[8] and anadromous[9] fish), lobster, other shellfish (e.g., clams and mussels), and duck by local consumers. For each receptor type, age-specific consumption rates were derived for adults and younger children (1–7 years of age). Children of less than one year of age (i.e., infants) were not evaluated, as they are unlikely to consume the evaluated biota as part of their normal infant diet.

For this alternatives evaluation, risks associated with ingestion of biota by local consumers are based on the results of the HHRA. For the local consumer, the biota that have the potential to result in adverse risk levels are the American eel and the black duck. Shellfish other than lobster were not identified as being a source of potentially adverse impact for the local consumer in the HHRA and are not evaluated as part of this alternatives evaluation.

#### *5.3.1.2 Ecological Receptors and Exposure Pathways*

Ecological receptor exposure to mercury in the Penobscot River varies depending on the species because of diverse life cycle characteristics, diet, and habitat. Ecological receptors may be exposed via incidental ingestion, direct contact, and/or the food web. Mercury biomagnifies in the food web, resulting in greater exposure to higher trophic level organisms. Potential ecological exposure pathways are summarized in **Figures 5-6 and 5-7**. **Figure 5-6** presents the ecological conceptual exposure model, which includes aquatic, wetland-dependent, and piscivorous receptors evaluated in the 2018 Baseline Ecological Risk Assessment (BERA) for the Penobscot River (Amec Foster Wheeler, 2018b). The food web model presented in **Figure 5-7** illustrates the various ecological trophic levels at the site.

Twelve species— four finfish (i.e., rainbow smelt, mummichog, Atlantic tomcod and American eel), two aquatic invertebrates (i.e., blue mussel and American lobster), five birds (i.e., Nelson's sparrow, red-winged blackbird, American black duck, bald eagle, and belted kingfisher), and one mammal (i.e., mink)—were selected as surrogates for ecological receptors of various trophic levels and feeding guilds that are present at the site. These species were selected based on current and future potential exposure to mercury. Receptors were evaluated from either direct

[8] Catadromous fish migrate from freshwater to the sea to spawn (American eel).
[9] Anadromous fish migrate upriver from the sea to spawn (Atlantic tomcod and rainbow smelt).

contact to surface water, food web exposure, and/or body burden (i.e., tissue accumulation) from food web exposure.

Ecological receptors included in this alternatives evaluation are only those biota with potential adverse risk based on the results of the BERA. The BERA indicated a potential for adverse risk to marsh songbirds (i.e., Nelson's sparrow and red-winged blackbird) due to exposure to mercury in the Penobscot River. Ecological receptors that were identified as not adversely impacted through exposure to mercury in the BERA are not included in this alternatives evaluation.

### 5.3.2 Remedial Action Objectives

Consistent with the direction from the Court to evaluate risk reduction that may be achieved by remedial alternatives, the RAOs will be linked to measurable indicators of risk reduction, including reduced exposure of humans to elevated mercury in biota food products (e.g., lobsters, shellfish, fish, and ducks) and declines in key biota mercury concentrations. Long term monitoring of the food web will be the method by which biota mercury concentration decline is documented.

Based on decisions by the Court, including the requirement for the Phase III Engineering Contractor to *"investigate the current status of mercury contamination in the Penobscot River and to propose potential solutions to mitigate the current harm to the people, biota, and environment of the Penobscot River estuary,"* and to *"submit a written report, recommending to the Court a remediation plan or plans that would be effective and cost-justified, or explaining why there is no viable remedy to pursue,"* utilizing the work completed by the PRMSP and our assessment of studies performed, the following RAOs were developed:

- Protect humans who consume Penobscot Estuary edible biota from exposure to elevated mercury concentrations that exceed protective levels; and
- Protect aquatic ecological receptors from exposure to mercury concentrations in sediment that exceed protective levels for local populations.

These RAOs are as based on the development and implementation of PRGs as described below in Section 5.3.3. Sediment-based PRGs have been developed based on both the HHRA and the BERA, as presented in the Penobscot River Risk Assessment and Preliminary Remediation Goal Development Report (Amec Foster Wheeler 2018b).

### 5.3.3 Preliminary Remediation Goals

Two sets of PRGs were initially proposed for evaluation in this Alternatives Evaluation Report, as determined from the Penobscot River Risk Assessment and Preliminary Remediation Goal

Development Report (Amec Foster Wheeler 2018b). These PRGs are protective of both ecological and human receptors.

- Total mercury: 300 ng/g to 500 ng/g for the marsh platform, intertidal, and subtidal sediments.
- Methyl mercury: 8 ng/g to 10 ng/g for the marsh platform, intertidal, and subtidal sediments.

The proposed sediment PRGs are applicable to all sediments within the bioactive zone for estuarine environments. The mercury sediment 300ng/g PRG is a concentration that is expected to meet the MeCDC 200 ng/g fish tissue action level in edible tissues while the mercury sediment 500 ng/g PRG was developed in the risk assessment to be protective of ecological risk and the local consumer.

While PRGs were developed and presented for both total mercury and methyl mercury in the Risk Assessment and Preliminary Remediation Goal Development Report (Amec Foster Wheeler 2018b), the evaluation of remedial alternatives presented in Sections 6.0 through 8.0 of this report focuses on the PRGs for total mercury. Reductions in total mercury concentrations should result in reduced methyl mercury concentrations and a decreased potential for biological uptake and trophic transfer of methyl mercury, because the rate at which mercury is methylated is related to (although not necessarily directly proportional to) the concentration of total mercury present in sediment (Cossa et. al. 2014). Methyl mercury data are included in this Alternatives Evaluation Report as a screening tool for prioritizing (if necessary) remedial decisions between reach/zones with potentially similar (and/or low) area weighted average concentrations of total mercury but different (and/or elevated) concentrations of methyl mercury. Following on this approach, evaluation of methyl mercury data is on a station-specific basis (**Figures 3-9-1** through **3-9-16**) and area weighted average concentrations of methyl mercury are not calculated.

## 5.4 ENGINEERING ASSUMPTIONS

Assumptions made in the calculation of area weighted average total mercury concentrations for use in the evaluation of remedial alternatives include:

- For the Bangor reach, the area upstream of the Route 395 bridge was not included in evaluation of active remediation (**Figure 5-1-1**). This exclusion is based on water access limitations north (upstream) of the bridge.
- Fort Point Cove and Upper Penobscot Bay are included in the evaluation of remedial alternatives for the main channel to allow evaluation of sediment volumes and costs associated with dredging remedies for the Estuary. While area weighted average concentrations were calculated for these most downgradient reaches of the Estuary, and these reaches are included in the evaluation of remedial actions required to achieve PRGs for total mercury in sediment, Amec Foster Wheeler is not recommending active remediation downstream of the southern tip of Verona Island. Instead, it is expected that active remediation in the upper Estuary will translate, with time, to decreased

surface sediment concentrations of total mercury and methyl mercury in the reaches downstream of the southern tip of Verona Island through the transport of sediment with lower total mercury concentrations from the upper Estuary into the lower Estuary.

- Areas within a reach that were identified as bedrock, hardpan, ledge or boulder were delineated and removed from the relevant reach/hydrodynamic zone areal calculation (see **Section 5.2.2.4**).

- Data applied to the calculations of remedial volumes included all useable total mercury data in the project database from 2000–2017, except for data points for which the analytical laboratory or the analytical method was unclear, or based on sampling details (e.g., uncertain sampling location, undefined sampling depth increment).

- The calculation of remedial volumes assumed generally a 1-foot dredge depth with backfill (with backfill selected to meet site-specific stability gradation requirements for the Estuary; to be evaluated during pre-engineering design); the 1-foot dredge depth accounts for the targeted removal of the biological mix depth [0-0.5 feet] and includes an allowance of 0.5 feet for over-dredging during implementation; remedial volumes for locations in which surface deposits of mixed mineral sediment and wood waste have been identified assume a dredge depth based on the known (or estimated) thickness of the deposit as defined by the mercury distribution in sediment cores from within those deposits.

- The mercury concentration of backfill material was assumed to be 20 ng/g. Once placed as backfill, a mercury concentration of 180 ng/g was used to calculate the post-remedy area weighted average concentration assuming that some of the mobile sediments may partially re-contaminate the newly placed clean material over time.

- The concentration of 180 ng/g applied as the post-remedy concentration is an estimate based on the assumptions that: (1) with an average system-wide sedimentation rate of approximately 0.5 cm per year (Amec Foster Wheeler 2018k) and a mobile sediment total mercury concentration of 730 ng/g, in 10 years the weighted average total mercury concentration within the biological mixed depth in areas that have been dredged and backfilled would be approximately 140 ng/g; and (2) the average concentration of total mercury on particulate matter entering the system from upgradient sources is 220 ng/g.

- An environmental work window from July 15 through November 30 was assumed for in-water work.

## 5.5 LOGISTICS OF PERMITTING

As presented in Section 4.3, implementation of active remedies within the Estuary will require multiple environmental permits to conduct work. Lead regulatory agencies for the permitting will be the USACE for federal permits and the MEDEP for state permits. Local permits and approvals may also be required from certain townships. Coordination of access with individual property owners along the Estuary will also need to be accomplished during the permitting process.

Due to the magnitude of this project and the volume of information, preparing and reviewing a single permit application covering the 30-plus miles of the Estuary will constitute a significant effort. To make the federal and state permitting more efficient and manageable, discussion with the USACE and MEDEP on July 13, 2017 (during preparation of this Alternatives Evaluation Report), coalesced around an approach that included completing a series of applications for work within specific management units or river reaches that will allow a for more manageable production and review.

To accomplish this, a Permitting Work Plan would be created as part of the design phase for the remediation. The plan would contain background information required for both the federal and state permits applications, including a project description, a purpose and need statement, and an alternatives analysis as required by federal and state permit applications. The plan will include a list of properties abutting the Estuary and may include a compensation statement as needed. A discussion of technical and financial capacity will be included as well as a description of the remedial technologies that will be employed during the project. Details of where the work will be conducted and specific conditions for the work, dictated by location, will not be discussed in the plan but included in the subsequent permit applications.

After the Permitting Work Plan is complete, a series of permit applications will be made, staggered several months apart. This will allow the applications to be more manageable for completion and review. Management units or river reaches may be grouped together into a single permit application based on the type of technology being used (e.g., hydraulic dredging, thin layer capping, etc.) and/or by location/proximity. Having the background information germane to the project presented in the plan should streamline permit applications, so preparers can focus on the specific details of the remedial activities and remediation areas covered by the permit application.

It is anticipated that work packages would be developed to logically group remedial areas identified, and that the associated permit applications will be appropriate for the project and keep the content of any one application at a manageable level. If applications are made and reviewed on a staggered schedule, it is anticipated that the duration of permitting could be two to four years for the whole project. Permit applications submitted early in the process should be approved within six months to a year, at which point work mobilization can begin.

## 5.6 PHYSICAL LIMITATIONS

There are characteristics of the Penobscot River and Estuary that will affect the construction work conditions and must be considered in the evaluation of technologies and alternatives for remediating mercury in sediments (PRMSP 2013). The following factors were considered in the development and evaluation of potential remedial alternatives:

- ***Varied Depth of Channels:*** The subtidal channels are both access ways and potential locations for removal actions. Channel depths vary throughout the different reaches of the Penobscot River and Estuary; therefore, depending on the location of remedial operations in the river, construction equipment would need to be selected to match water depths. Because of the different depths, a variety of equipment may be needed to address remedial activities. For example, a barge with a loaded draft of 12 feet cannot access Mendall Marsh, Orland River, portions of the Bucksport Harbor, or nearshore subtidal areas of other reaches, because the channels are too shallow, but could access the East Channel, Frankfort Flats, and the northwestern portion of the channel near Bucksport. Likewise, a barge-mounted long reach excavator could extend and conduct dredging work in portions of the river upstream of Winterport, where depths are similar to southeastern Bucksport and eastern Fort Point Cove (30 to 40 feet) but may not have sufficient reach for portions of Bucksport Harbor and Odom's Ledge (50 to 60 feet). Barge-mounted cranes would be needed for dredging in the Narrows (west of Verona Island) and the southern portion of Bucksport, which have the deepest waters from 70 to upwards of 90 feet.

- ***Speed of Currents:*** The currents affect construction means and methods as well as environmental considerations. From a construction fleet perspective, the rate of the flood and ebb currents with a virtually non-existent period of calm between will increase vessel horsepower requirements, fuel consumption, tow/push restrictions, and increased anchoring and spudding. From an environmental perspective, the dispersion of re-suspended sediment and the creation of dredging residuals will need to be addressed. Dredging equipment that may not be commonly considered may be more appropriate, depending on its ability to meet performance objectives for both construction production and environmental restrictions (e.g., dustpan dredge or a jetted hydraulic dredge).

- ***Tidal Fluctuation:*** Tidal fluctuations (~14 feet) affect construction means and methods as well as access to nearshore work zones (e.g., intertidal zones and vegetated marshes accessed from water). Sequencing of intertidal applications or excavations must account for working in exposed and inundated conditions, which can affect production rates, dispersion of sediments, and contact time between equipment and mobilized sediments, as well as the choice of equipment. Regarding access, tidal fluctuation can help (by providing water depth conditions to float equipment in and out of work sites) and hinder (by requiring equipment capable of working when beached).

- ***Seasonal Conditions and Environmental Windows:*** With the typical regionally-accepted in-water construction work being performed during the winter months to minimize impacts on protected species, the presence of ice sheets, frozen equipment, and snow/ice on vessel decks require accommodations and affect construction production rates and access. Likewise, selecting admixtures that can be dispersed during the warmer months may be preferred to other winter-season dependent methods.

- ***Bottom Type:*** Over the 30+ river miles, there are a number of bottom types and conditions that affect construction methods. Thin layers (inches) of softer sediments underlain by hard-packed sands require different methods than thick layers (feet) of softer sediment underlain by bedrock. In the intertidal zones, thick layers of soft sediments intermixed and underlain by gravel, cobbles, and boulders make some construction equipment impractical.

- ***Obstructions and Debris:*** With centuries of logging, shipwrecks, and a history of waste disposal, obstructions and debris are expected to be interlaid with the sediments. Obstructions and debris foul construction equipment causing production delays. Removal of debris will generally increase the potential for sediment and contaminant resuspension and transport.

- ***Contaminated Sediment Layer Thickness:*** The precision of floating construction equipment will likely be reduced due to the tidal and current conditions of the Penobscot River, making it infeasible to remediate very thin layers of surficial sediment in deeper or open waters of the Estuary (such as in the thalweg). For open water areas, the accuracy of active work depths will most likely be measured in feet rather than inches. For remediation conducted along protected shorelines or in coves, it is likely that the active work depths can be measured at sub-foot accuracy.

- ***Length of River Potentially Requiring Remediation and Associated Large Quantity of Contaminated Sediments:*** In-water construction requires landside support, which can include vessel access, refueling, material barge loading, transfer/unloading with dewatering followed by truck or rail loading, and upland sediment treatment and disposal areas. Under any hydraulic pumping technology scenario with a slurry, dewatering cells may be needed landside. Depending on the location of remediation activities, with multiple work zones, multiple dewatering and sediment handling landside facilities may be required.

- ***Land Ownership and Access Agreements for Land above Mean Low Water:*** Individual land owner selection or approval of remedial action measures/technology to be applied to his/her shoreline may affect product and means/methods selection.

- ***Size of Marshes:*** While the Mendall Marsh reach is approximately 779 acres, including the marsh platform and associated intertidal and subtidal zones, there are multiple smaller, distinct pocket and fringe marshes distributed throughout the Estuary. The combined area of these pocket and fringe marsh platforms and associated intertidal zones is greater than the platform area in Mendall Marsh, although the ecological benefit associated with remediation of individual pocket and fringe marshes is less quantifiable.

- ***Wood Waste:*** Amec Foster Wheeler currently estimates that approximately 3,000,000 tons (dry weight) of material on the Estuary sediment bed appears as a mixture of wood waste and mineral sediment. Approximately half of this material is in deposits more than 1 foot thick, with some deposits reaching 6 feet in thickness. This material appears to be distributed throughout the system, with specific, identifiable deposits of varying thickness in the vicinity of Snub Point, Winterport, at Frankfort Flats, upgradient of Bucksport, in the Orland River, and in the Verona East channel, (Amec Foster Wheeler 2017e). These deposits are likely somewhat mobile, may occur in locations in which material is at least temporarily (seasonally) trapped, and may contribute material to the mix of sediment and wood waste that moves in suspension in the water column. Requirements for remediation of these deposits, including the current spatial distribution and mobility of this material, as well as technical constraints on how and where to recover this material (i.e., dredging specific deposits and/or the creation of sediment traps to improve material recovery) are being evaluated.

## 5.7 ESTIMATION OF VOLUMES

As an overall strategy for the estimation of remedial volumes, remedial footprints have been developed with the goal of reducing the system-wide average sediment concentration of total mercury to PRGs developed to be protective of both ecological and human receptors. This strategy applies both the low end PRG for total mercury (300 ng/g) and the high end PRG for total mercury (500 ng/g) in evaluation and estimation of remedial footprints. For subaqueous areas in the Estuary, including along the main channel, the east channel around Verona Island, the Orland River, and in Mendall Marsh, sediment removal will involve a minimum 6-inch dredge depth with a 6-inch over-dredge allowance, followed by backfill with clean, similar substrate. For the marsh platform, remedy will entail the placement of a minimum 3-inch sand/silt cap. For both these scenarios, it is assumed that the mercury concentration in the clean backfill or cap material is approximately 20 ng/g, and that the emplaced concentration post-remedy will be 180 ng/g. This choice of post-remedy mercury concentration for either intertidal/subtidal areas that are dredged or the portion of marsh platforms that may be capped is based on the assumption that recontamination of sediments via mobile material will increase the concentration of mercury within the biological mixed depth by a concentration that reflects mixing of cap material (at 20 ng/g total mercury) with residual mobile sediment in the system.

Thus, calculation of estimated remedial volumes for areas excavated for dredging for either a 500 ng/g or a 300 ng/g PRG will be based on the areal extent of reach/hydrodynamic zones receiving the remedy and an assumed dredge depth of 1 foot. For platform areas receiving a sand/silt cap, calculation of remedial volumes will be based on the areal extent of the marsh platform receiving the cap and an assumed minimum cap thickness of 3 inches.

In addition to these two scenarios, additional dredging is being evaluated:

- In areas in which there are sediment deposits enriched in wood waste and containing mercury concentrations at or above 1,000 ng/g and a thickness of over 3 feet of sediment; and
- In Southern Cove and/or the wider Orrington Reach, to target locations in the fringing marsh and/or intertidal area in which Amec Foster Wheeler 2017 and Phase II sampling identified elevated mercury concentrations in locations outside of the 2017 dredge footprint in Southern Cove.

Regarding the surface deposits, these locations are being evaluated for dredging based on: (1) the deposits appearing on the geophysical survey as identifiable targets above bathymetric grade (Amec Foster Wheeler 2018h); and (2) for the three larger of the deposits identified, consistently elevated mercury concentrations in cores recovered from within the footprint of the deposits (Amec Foster Wheeler 2018i). As presented in the 2017 Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler 2018i), this volume of mixed mineral sediment and wood waste accounts for approximately 1/3 of the overall volume of mixed mineral sediment and wood waste identified through the geophysical survey. These surface deposits may also represent locations in the Estuary in which sediment and wood waste reaccumulate at a sufficient rate to create natural sediment traps.

For both of these additional scenarios, remedial volumes are being estimated based on the areal footprint of the feature (i.e., the identified deposit or the portion of the Southern Cove and/or wider Orrington Reach fringing marsh and intertidal area) and the thickness of the deposit plus an additional proposed 1-foot over-dredge. The calculation of estimated remedial volumes for potential remedies is presented in **Tables 5-10 through 5-15.** These tables include estimated remedial volumes for the main channel, the east channel around Verona Island including Orland River, and Mendall Marsh, for both the 500 ng/g and the 300 ng/g PRGs, as well as a volume for the sediment deposits enriched in wood waste and containing mercury concentrations at or above 1,000 ng/g. The proposed remediation areas are shown on **Figures 5-8-1 through 5-8-16**. The selection of the proposed remediation areas was based on the goal of reducing the area weighted average total mercury concentration to below the target PRGs. This strategy entailed the selection of the reach/hydrodynamic zones with the highest pre-remedy bootstrap mean total mercury concentration for active remedy and included specific evaluation of reach/hydrodynamic zones of ecological importance in both marsh and intertidal areas and the identification, where possible, of contiguous reach/hydrodynamic zones in which selection for proposed remediation would improve operational efficiencies. For Mendall Marsh, the precise location of the recommended thin layer cap would be determined following pilot testing during pre-design.

# 6.0 ALTERNATIVE DEVELOPMENT APPROACH

This section presents the approach followed to develop remedial technologies (described in Section 5.0) into remedial alternatives to reduce human and ecological exposure to total mercury in Estuary sediments.

An initial screening of remedial technologies was conducted based on available data from the Phase I and Phase II Studies as a first step in the Phase III Engineering Study, and the results were presented in the Technology Screening Report (Amec Foster Wheeler 2017a).

The initial remedial technology screening process documented in the Technology Screening Report included identification of technologies for which treatability studies (bench- and/or pilot-scale studies) would need to be performed to evaluate site-specific effectiveness. The need for treatability studies and requirement for progression from bench-scale to small field-scale to large-scale pilot testing depends on many factors, including whether a given technology has been demonstrated and proven effective for remediation of mercury in sediments, site conditions, the expected time frame and costs associated with conducting the study, uncertainties related to full-scale implementation, permitting requirements, and balancing the benefits of advancing a promising technology with the potential for environmental harm resulting from a lack of field-scale application data from other similar locations.

Engineering assumptions presented in the Technology Screening Report that were used as the basis for identifying and screening remedial technologies were re-evaluated and refined based on the additional data obtained from field efforts and bench-scale treatability studies conducted as part of the Phase III Engineering Study. The remedial technologies were further evaluated for applicability within the remedial environments (marshes, intertidal, and subtidal zones) and for the associated estimated extent (spatially and with depth) of sediment that contains total mercury at concentrations that exceed target total mercury PRGs.

The process used to identify and screen technologies included the following steps:

- First, general response actions (GRAs) were identified. GRAs are broad categories of remedial actions that can be used to attain RAOs by reducing contaminant concentrations in sediment below a PRG, preventing receptor exposure to contaminated sediments, or monitoring the natural attenuation of contaminant concentrations.
- Second, a list of potential remedial technologies consistent with the range of each GRA was developed based on experience with similar studies, site media, and contaminant-driven considerations. The demonstrated performance or proven effectiveness of each technology for site contaminants and conditions (mercury in sediments) was considered during technology identification.

- Third, the resulting list of potential remedial technology process options was screened against effectiveness, implementability, and relative cost criteria with a focus on retaining those technologies and process options applicable to mercury in sediments and with consideration of the physical characteristics in each of the reaches and zones where target PRGs are exceeded.

Potential GRAs for the Penobscot River and Estuary were identified in the Technology Screening Report (Amec Foster Wheeler 2017a); remedial technologies within each of the GRAs were identified based on a review of engineering experience, literature, vendor information, and past performance data. Sections 6.1 through 6.11 (below) present further screening of relevant remedial technologies. Screening is based on applicability and effectiveness for remediation of sediments that contain total mercury concentrations that exceed the PRGs in marshes, intertidal and/or subtidal zones, as well as whether technologies could be combined into alternatives that would achieve the RAOs identified in Section 5.3.2. The following chart summarizes the GRAs and associated remedial technologies that are retained for further consideration based on the technology screening presented in the Technology Screening Report (Amec Foster Wheeler 2017a).

| General Response Action | Remedial Technology |
|---|---|
| Institutional Controls | Administrative Restrictions |
| Natural Recovery | Monitored Natural Recovery<br>Enhanced Monitored Natural Recovery |
| Monitoring | Long Term Monitoring |
| Containment | Thin Layer Capping<br>In Situ Capping<br>In Situ Capping with Amendments |
| Removal | Hydraulic Dredging<br>Mechanical Dredging<br>Excavation<br>Excavation Support<br>Sediment Trapping and Removal |
| Ex Situ Treatment | Physical Treatment<br>Wastewater Treatment |
| In Situ Treatment | Chemical Additives<br>Injection, Placement, Mixing, and Broadcasting of Chemical Additives<br>Water Column Treatment<br>Phytoremediation<br>Solidification |
| Hydrodynamic Manipulation | Engineering Controls<br>Physical Controls<br>Hydrodynamic Controls<br>Channel Manipulation |
| Disposal | On-Site Disposal<br>On-Site & Off-Site Beneficial Reuse<br>Off-Site Disposal |
| Habitat Restoration | Physical Restoration |
| Adaptive Management | Adaptive Management |

Sections 6.1 through 6.11 present the updated screening of technologies for each GRA based on the results of the Phase III Engineering Study. The assembly of technologies into remedial alternatives and descriptions of the remedial technologies that are retained as components of remedial alternatives are presented in Section 7.0.

## 6.1 INSTITUTIONAL CONTROLS

Institutional controls are administrative controls designed to reduce human exposure to contaminated media. Potentially applicable institutional controls include educational programs, warning signs, consumption advisories, access restrictions, fishery closures, property controls, and waterway use restrictions.

Institutional controls that are retained as components in the development of remedial alternatives for local consumers include educational programs, warning signs, consumption advisories, and fishery closures.

Educational programs, warning signs, consumption advisories, and fishery closures are retained as adjuncts to other technologies in the development of alternatives because: (1) they can be effective communication tools for local consumers; and (2) they function as an efficient means to update or maintain existing programs to educate the public on exposure to contaminants via consumption. Access restrictions may be implemented temporarily while remediation is taking place and during restoration activities to protect the public and to avoid interference with remediation efforts. These programs would need to be updated to advise consumers on biota consumption limitations to reduce exposure to unacceptable mercury concentrations in biota. These institutional controls would not be effective as a stand-alone technology to prevent exposures, although they would be relatively easy to implement and maintain from an administrative perspective as an adjunct to other technologies until biota tissue concentrations decrease to acceptable levels for safe consumption. Ongoing maintenance of institutional controls would require coordination with state and local authorities and ongoing monitoring and updates to advisories and closures. Institutional controls have a low relative cost in the short term to implement and in the long term to update and maintain.

Institutional controls such as property controls and long-term access and waterway restrictions were eliminated from further consideration because they would be more difficult to implement and may not increase the effectiveness of existing controls or provide additional mitigation of exposure for human consumers.

Although institutional controls would not actively remediate sediment characterized by total mercury concentrations in exceedance of PRGs, implementation and maintenance of institutional controls as a component of remedial alternatives would be effective at preventing and limiting exposures to human consumers in the short term until biota tissue concentrations decrease to acceptable levels for safe consumption. Institutional controls are relatively easy to implement and maintain because public education programs, warning signs, consumption advisories, and fishery closures are already in place and/or readily implemented. Institutional controls could be maintained and/or expanded based on monitoring and evaluation of mercury concentration trends in sediment and/or biota. Institutional controls have a low relative cost compared to other remedial technologies.

## 6.2 NATURAL RECOVERY

Natural recovery relies on naturally occurring processes such as dispersion, deposition and the mixing (physical or biological) of existing surface sediment with cleaner sediment entering the system from upgradient sources. These processes associated with natural recovery reduce concentrations of mercury in surface sediment to achieve the PRGs.

Potentially applicable natural recovery technologies include monitored natural recovery (MNR) and enhanced MNR. MNR includes long term monitoring of mercury concentrations in sediments and biota as a stand-alone remedial technology; enhanced MNR can include the addition or placement of clean sediment to accelerate reductions in total mercury concentrations in surface sediments. Both MNR and enhanced MNR include the long-term monitoring of mercury concentrations in sediment and biota tissue. For both approaches to natural recovery, monitoring data are evaluated over time to confirm trends and progress toward achievement of PRGs and to update (as required) institutional controls such as educational programs, consumption advisories, and fishery closures.

Based on available data, the spatial consistency of surface sediment total mercury concentration observed in much of the Estuary supports a hypothesis that some level of homogenous redistribution of mercury-impacted sediment is occurring within the Estuary. In the absence of sediment removal through engineered remedy, the process of continued natural recovery via declining surface sediment mercury concentrations in the Estuary will therefore be driven largely by the input rate of clean sediment into the Estuary.

MNR and enhanced MNR are retained in the development of remedial alternatives in combination with institutional controls for local consumers to achieve RAOs in the long term.

Although MNR would not actively remediate sediments characterized by total mercury concentrations that exceed the PRG, implementation of a long-term monitoring program would be effective to evaluate natural recovery processes as a remedial alternative. MNR would be easy to implement and maintain from an administrative perspective because existing monitoring programs are in place, could be continued, and are expected to have low relative costs over the period of predicted recovery (on the order of decades) to meet the PRG. Recommendations for the development of a long-term monitoring program to build on existing monitoring data are presented in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

Enhanced MNR would include an active remediation component through addition or placement of clean material into the Estuary. Permitting and pre-design activities to support clean material addition or placement such as hydrodynamic modeling, particle tracking, materials testing, and evaluation of placement methods would be necessary to refine engineering assumptions. Depending on the scale at which enhanced MNR would be implemented (i.e., implemented for a portion of the system versus system-wide), costs would be expected to be moderate to significant.

## 6.3 MONITORING

Monitoring in support of remedial evaluation could include: (1) short term placement monitoring, such as during or immediately following capping or dredging; (2) post-placement monitoring, such as to evaluate the intermediate-term (i.e., 10 years) stability of an emplaced cap; and (3) long term ecological recovery monitoring to evaluate the effectiveness of an overall site remedy. Based on the predicted recovery times for the Estuary, long term ecological recovery monitoring could reasonably include a monitoring period of 45 years to evaluate progress toward the recovery goal.

For both placement and post-placement monitoring, the frequency, extent and density of sampling stations (e.g.., number of samples per acre), the analytes measured (e.g., total mercury, methyl mercury, organic carbon content), and the evaluation of the data would be tailored to the implemented remedy.

For long term ecological recovery monitoring, specific details regarding monitoring objectives and the frequency of monitoring would be evaluated and specified in a long-term monitoring work plan that would take into account the remedial action(s) taken. This evaluation would likely include statistical analysis of sampling density for biota and sediment, refinement of the evaluation of sampling period, and assessment of whether additional fate and transport modeling is required for recovery rate characterization.

Overall, monitoring would have a low relative cost over the period of predicted recovery to meet the PRGs.

## 6.4 CONTAINMENT

Containment consists of restricting movement of contaminated media and/or creating a barrier between contaminated sediments and biota and human consumers.

Potentially applicable containment technologies identified include: (1) in situ isolation capping through placement and maintenance of a layer of materials such as clean sediment, either with or without chemical additives such as amendments; (2) armoring, such as placement of rip rap over areas prone to erosion in which sediment contains mercury concentrations that exceed PRGs; and (3) thin layer capping through placement of a thin layer of material on marsh platforms or in subaqueous environment in locations where total mercury concentrations exceed PRGs. Thin layer capping is considered separately from isolation capping in that a thin layer cap can work by the biological or physical mixing of cap material with underlying sediment to decrease total contaminant concentrations integrated across the biological mixed depth.

In situ isolation capping in the intertidal and/or subtidal zones was initially evaluated for areas such as the Orland River where it would be difficult to remove impacted sediment. Results of the evaluation suggested that a cap could be designed and constructed to withstand current velocities in this system, although episodic storm events would likely erode capping materials over the long term unless the isolation cap was armored with a coarser grain size material than the native sediment. Based on the likely impacts to habitat from armoring and the challenge of maintaining chemical isolation in an environment in which recontamination of the armored cap surface would continue for as long as total mercury concentrations in mobile sediment exceed the PRGs, in situ isolation capping is eliminated from further consideration.

Sediment trapping would only be applicable for collection of sediment in depositional areas. Portable sediment traps were investigated as a potential remedial technology based on the accumulation of wood waste in sampling equipment (eel traps) assessed during Phase III field efforts. Based on the estimated volume of wood waste in the system compared to the volume of material in a trap that could be lifted onto a vessel (less than 20 cy), use of portable sediment traps is not feasible and sediment trapping via the construction of portable sediment traps is eliminated from further consideration. Likewise, while the presence of historical groins and former dredged channels in the Estuary have served as areas of enhanced sediment accumulation, the distribution of mercury in the sediments in these locations (with more elevated concentrations stably buried at depth) may not warrant dredging. Thus, dredging to create a sediment trap in locations of historical sediment in-fill is eliminated from further consideration. Sediment trapping is retained in consideration of dredging the surface deposits as noted in Section 5.7; these surface deposits may represent remedial targets in locations in the Estuary in which sediment and wood waste accumulate at a sufficient rate to create natural sediment traps. Dredging of surface deposits is discussed further in Section 8.0 of this Report and in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

Thin layer capping on marsh platforms through placement of clean cap material would be effective in reducing surface sediment/soil mercury concentrations and resultant biota exposures.

Permitting would be required to place a thin layer cap on the marsh platforms. Although capping would not remove sediment containing mercury at concentrations that exceed the PRGs, thin layer cap placement and maintenance would be effective at reducing the total mercury concentration integrated over the biological mixed depth to which biota are directly exposed. Thin layer capping could assist in achieving the PRGs in areas where active remediation through sediment/soil removal is not implementable due to ecological, physical or constructability constraints. Thin layer capping would be moderately difficult to implement due to access restrictions and permitting constraints and, depending on the size of the cap, would have a moderate relative cost compared to other remedial technologies. Thin layer capping is retained for further consideration as a remedial alternative for marsh platforms. The evaluation of thin layer caps carried forward is focused specifically on the Mendall Marsh platform. Thin layer capping could be expanded to other marshes in the Estuary, although evaluation of thin layer capping for individual pocket and fringe marshes requires additional evaluation of marsh geomorphology (i.e., shape and slope), as well as assessment of the ecological benefit of cap placement for appropriate receptors in these smaller marshes. Pilot testing of thin layer capping on marsh platforms is recommended (discussed further in Section 8.0); results of pilot testing on Mendall Marsh are relevant for assessing the effectiveness of thin layer capping on other marsh platforms in the Estuary.

## 6.5 REMOVAL

Removal consists of physical excavation or dredging of contaminated sediment.

Potentially applicable removal technologies identified include hydraulic dredging, mechanical dredging, and excavation of sediments that contain mercury at concentrations that exceed the PRGs. Controls would be required for removal technologies to reduce impacts on water quality and marine biota and would include various types of resuspension controls and fish exclusion barriers.

Hydraulic and mechanical dredging are proven, effective methods for removal of subtidal and submerged intertidal sediments and are retained in the development of remedial alternatives. Permitting would be required, and in-water work would be performed in phases within the allowable in-water work periods (annual environmental window assumed to be July 15 through November 30 with 112 working days per year) negotiated with regulatory agencies. Hydraulic and mechanical dredging are retained for further consideration for removal of subtidal sediment.

Excavation is not applicable to the subtidal and submerged intertidal sediments. Excavation is applicable for removal of exposed intertidal and marsh sediments. Excavation is retained for further consideration for exposed intertidal and marsh sediments.

## 6.6 EX SITU TREATMENT

Ex situ treatment consists of landside treatment of sediment that has been removed and requires dewatering and/or stabilization prior to disposal to meet applicable regulations.

Potentially applicable ex situ treatment technologies identified include physical treatment and wastewater treatment.

As part of the Phase III Engineering Study, treatability studies were conducted to refine engineering assumptions regarding full-scale remedial alternatives. As a component of the treatability studies, a dewatering bench-scale study was conducted to evaluate the need for treatment of dredged sediments and dewatering fluids (Section 2.3.3). The study evaluated the effectiveness of dewatering of sediment to support evaluation of dredging as a component of a full-scale remedial alternative(s); generated data to estimate the volume of dewatered sediments; and assessed whether sediments would require stabilization prior to disposal. The dewatering bench-scale study also evaluated whether the wood waste component of dredged sediments would require an alternative dewatering process (e.g., addition of flocculants and/or physical removal), and whether dewatering fluids would need to be treated to meet potential discharge standards prior to discharge back into the river.

The results of the dewatering bench-scale study (Section 2.3.3) indicate that dredged sediment and dredged sediment mixed with wood waste could be effectively dewatered and stabilized for transportation and off-site disposal and/or beneficial reuse using standard dewatering and stabilization methods. Dewatering and stabilization are retained for further consideration.

## 6.7 IN SITU TREATMENT

In situ treatment consists of in-place treatment of sediments containing mercury at concentrations that exceed the PRGs for total mercury in sediment.

Potentially applicable in situ treatment technologies identified include injection, broadcasting or in-place mixing of chemical additives (amendments), water column treatment, phytoremediation, and solidification.

To evaluate the effectiveness of amendments in reducing concentrations of mercury and methyl mercury in sediment porewater, amendments were applied to Mendall Marsh in test plots during the Phase II Study. Amendments tested included biochar, SediMite™, lime, and iron (Chapter 19; PRMSP 2013). As a component of the treatability study program conducted as part of the Phase III Engineering Study, the Phase II amendment test plots were resampled, and a bench-scale study was conducted to evaluate the potential toxicity of carbon-based amendments. While results of the toxicity testing indicated that application of SediMite at a rate of 3 percent and application of activated carbon at a rate of either 5 percent or 10 percent achieved satisfactory results in terms of survival, growth, and reproduction of test organisms, the amendment test plot data are inconclusive as to whether amendments, either applied as a stand-alone remedy or incorporated into a thin layer cap, result in decreased biological update and trophic transfer of methyl mercury. For the test plot sites, while SediMite® appeared more effective than biochar in reducing porewater concentrations of total mercury and methyl mercury over the study period (2010 – 2017), the impact of SediMite® addition was not equally apparent between the two test plot locations and changes in soil redox conditions in 2017 relative to the earlier sampling period complicated interpretation of 2017 data relative to 2010 – 2012 data.

The addition of amendments, either applied as a stand-alone remedy or as a component of a thin layer cap, is retained for further evaluation. Additional demonstration of the ability of amendments to decrease biological uptake and trophic transfer of methyl mercury is required for full evaluation of this remedial approach.

Chemical additives other than carbon-based amendments identified as potentially applicable in the Technology Screening Report (Amec Foster Wheeler 2017a), as well as the other in situ treatment technologies, are eliminated from consideration based on difficulties in full-scale application and/or unproven effectiveness at reducing biological uptake of methyl mercury.

## 6.8 HYDRODYNAMIC MANIPULATION

Hydrodynamic manipulation consists of changing or controlling the flow of surface water, including physical changes to the river channel, with the goal of limiting or directing sediment resuspension, transport and/or deposition. Potentially applicable hydrodynamic manipulation technologies identified in the Technology Screening Report (Amec Foster Wheeler 2017a) include engineering controls (e.g., physical barriers such as berms, groins, baffles, etc.), hydrodynamic controls (e.g., salt front manipulation), and channel manipulation (e.g., dam removal).

Due to the potential ecological impacts of altering Estuary hydrodynamics, associated permitting difficulties, and physical limitations associated with in-water construction (Section 5.6), hydrodynamic manipulation would be difficult to implement. Moreover, the potential impacts of hydrodynamic manipulation on the transport and mixing of mobile sediments within the Estuary, including the impact of manipulation on Estuary flushing rates, are highly uncertain and would require thorough analysis. Hydrodynamic manipulation is not retained for further evaluation.

## 6.9 DISPOSAL

Disposal consists of placing dredged sediment containing mercury in either an off-site permitted landfill facility or in an on-site permitted confined aquatic disposal (CAD) cell, or beneficial reuse of the sediment off-site as fill material. Potentially applicable disposal technologies identified include on-site disposal; off-site beneficial reuse; and off-site disposal.

On-site disposal of sediment in a CAD cell was eliminated from consideration because: (1) the low density of the wood waste in the dredged material would likely prevent reliable placement in a CAD cell; (2) public opposition to in-water disposal in Penobscot Bay is expected; and (3) it would be difficult to implement this approach on a full-scale basis. Regarding wood waste, the low density of this material would likely complicate both placement of the material in the CAD cell and secure capping of the CAD cell.

To refine assumptions regarding requirements for off-site reuse or disposal of dredged sediment, sediment samples were collected from Frankfort Flats, Bucksport, and Verona North. For these samples, preliminary waste characterization profiles were developed based on disposal facility acceptance criteria. Results of the preliminary waste characterization are presented in **Table 6-1 (a-c)** and are compared to: (1) anticipated landfill acceptance criteria; (2) MEDEP Chapter 418 Beneficial Use of Solid Waste Screening Levels; (3) MEDEP Remedial Action Guidelines; and (4) NOAA Ecotox Effects Range Low and Probable Effects Level Thresholds. These comparisons indicate that, overall, dredged sediments: (1) would meet primary landfill acceptance criteria for off-site disposal; and (2) with the exception of arsenic and naphthalene, would meet Maine beneficial reuse criteria. While arsenic and naphthalene are anticipated to be associated with anthropogenic background conditions, a background investigation and statistical evaluation of dredge sediment may be required to obtain regulatory approval for reuse.

In a meeting between Amec Foster Wheeler and the MEDEP Commissioner and management staff on January 23, 2018, MEDEP indicated that beneficial reuse of dredged sediment meeting the State of Maine Solid Waste Management Rules for Beneficial Use would be considered. Off-site beneficial reuse would have a lower relative cost than off-site disposal in a permitted landfill facility and would be a more sustainable option. Constructability reviews and MEDEP communication indicate that there are no local landfills in Maine with sufficient available capacity to accept the volume of sediments estimated for removal. MEDEP has also indicated that it would be difficult to obtain permits for the construction of new landfills in Maine, thus beneficial reuse or out-of-state transportation and disposal would likely be required.

Off-site beneficial reuse and off-site disposal in a permitted landfill facility are proven, effective disposal technologies that could be implemented on a full-scale basis and are retained for further evaluation as a component of the remedial alternatives assembled in Section 7.0.

## 6.10 HABITAT RESTORATION

Habitat restoration consists of mitigation and management of impacts to habitat from remediation, including removal and/or in situ treatment. Habitat restoration may include restoring sediments/soils to pre-remediation elevations for excavation and dredging remedies, and re-establishing vegetation where disturbed.

Habitat restoration is retained and included in combination with remedies in which vegetation and/or terrain are disturbed by remedy implementation.

## 6.11 ADAPTIVE MANAGEMENT

Adaptive management is a strategy for assessing progress toward the achievement of recovery targets through iterative monitoring, data evaluation, and alterations to the planned course of action if necessary to maintain progress toward those targets. The goal of adaptive management is to improve the overall remedial outcome while reducing uncertainty in the effectiveness of remedy implementation. As a strategy, adaptive management should be applied during all phases of remedy design and implementation.

Adaptive management is retained as a component of all remedial alternatives.

# 7.0 ALTERNATIVE DEVELOPMENT AND ASSEMBLY OF REMEDIAL ALTERNATIVES

This section presents the assembly, development, and descriptions of remedial alternatives that could be implemented to remediate sediments characterized by mercury concentrations that exceed the PRGs. Remedial alternatives are developed by grouping the remedial technologies retained from the further technology screening presented in Section 6.0. Remedial alternatives are developed for subaqueous hydrodynamic zones (i.e., intertidal, subtidal, and thalweg/main channel) as well as for the Mendall Marsh platform.

Section 7.1 presents the assembly of remedial technologies and descriptions of the common elements in technologies that can be developed into remedial alternatives. Section 7.2 describes the remedial alternatives. A remedial alternative as presented in Section 7.2 can describe either a site-wide strategy (such as the potential for Estuary-wide dredging), or a strategy specific to a hydrodynamic zone (such as thin layer capping on a marsh platform). Evaluation of the remedial alternatives described in Section 7.2 with respect to six site-specific evaluation criteria for the Estuary is presented in Section 8.0.

For the remedial alternatives identified in Section 7.2, additional pre-design studies and/or pilot-testing of components of these remedies are recommended. This recommendation is based on a range of factors, including the need for additional sampling to improve the delineation of potential dredge footprints, the need to identify or constrain material application rates for cap placement, and additional data needs to support the advancement of currently plot-scale evaluations to pilot- or field-scale assessment (as appropriate for different remedial alternatives presented in Section 7.2). Thus, additional pre-design studies and/or pilot tests are needed to establish design parameters; evaluate implementability and long-term effectiveness of specific remedial technologies; refine engineering assumptions incorporated into the alternatives development and evaluation; and refine production rates and other assumptions incorporated into the cost evaluations. A pre-design investigation phase is incorporated into each of the active remedial alternatives and should include collection of additional data (as warranted) to delineate bounds of remedial action, as well as any additional studies and testing required to facilitate engineering design. As examples, as noted in Section 5.2.2.1 (Data Sources), for the upper Estuary (defined as the portion of the study area upstream of the southern tip of Verona Island), the current (2018) sampling station density is approximately one station per 12 acres. While this sampling station density is sufficient for the broad-scale identification of areas potentially warranting a dredge remedy, additional delineation, including specific further delineation of the surface deposits of sediment and wood waste, should be included in the pre-design investigation. Likewise, while thin layer capping of Mendall Marsh would serve to reduce sediment total mercury concentrations across the biological mixed depth, details of cap placement (including material application rate) should be evaluated by pilot testing prior to field-scale implementation of this remedial alternative.

## 7.1 ALTERNATIVE DEVELOPMENT

Remedial technologies that are retained for development into remedial alternatives are summarized in the chart below. For each remedial technology included in the table, the applicable zone (i.e., marsh, intertidal or subtidal) is indicated.

| Remedial Technology | Applicable Zone |
|---|---|
| Institutional Controls<br>Long Term Monitoring<br>Monitored Natural Recovery<br>Enhanced Monitored Natural Recovery | Marsh, Intertidal, Subtidal |
| Hydraulic Dredging<br>Mechanical Dredging<br>Dewatering<br>Stabilization<br>Off-Site Disposal<br>Off-Site Beneficial Reuse | Marsh, Intertidal, Subtidal |
| Thin Layer Capping | Marsh |
| Chemical Additives / Amendment Application | Marsh |

Remedial alternatives developed from these remedial technologies are summarized below and in **Table 7-1**.

### 7.1.1 Monitored Natural Recovery Alternative

MNR would rely on a combination of monitoring and institutional controls in both the short and long term to achieve RAOs. As a stand-alone remedy, MNR consists of: (1) continuing to monitor sediment, biota and surface water at existing station locations; (2) evaluating monitoring data with respect to identified success metrics for system recovery (such as sediment mercury concentrations decreasing to below PRGs and/or biota tissue concentrations decreasing to levels that no longer pose risks to biota or consumers); and (3) implementing, updating, and maintaining existing institutional controls (public education, consumption advisories, and fishery closures) in coordination with MEDEP as necessary based on monitoring data. Effectiveness of MNR as a remedy would be determined based on the results of a monitoring program developed to evaluate declining surface sediment total mercury concentrations over time, as well as biota recovery. With predicted recovery times on the order of decades to meet the PRGs, implementation of MNR requires an adaptive management approach in that data collected during the recovery interval are used to refine the model and/or predictions upon which the initial recovery rate prediction was based. Evaluation of the current system monitoring program and recommendations for refinements or changes to that program in support of long term monitoring for MNR are presented in the Phase III Engineering Study Report (Amec Foster Wheeler, 2018a). Examples of refinements or changes to the current system monitoring program could include additional monitoring stations to improve sampling density and/or changes to the frequency of monitoring to more cost-effectively evaluate long term trends in sediment total mercury or biota methyl mercury concentrations.

### 7.1.2 Enhanced Monitored Natural Recovery Alternative

Enhanced MNR would improve the rate of system recovery through the addition of clean sediment to the system. Clean sediment would mix with existing sediment to reduce the concentration of total mercury within mobile sediments, thereby ultimately reducing biological exposure through reducing total mercury concentrations across the biological mixed depth in sediments. Enhanced MNR as evaluated here was suggested as a potential remedial alternative by the Phase II Study Panel (PRMSP 2013) and could theoretically be applied to the whole system or to portions of the system in which hydrodynamics would serve to enhance the dispersion and mixing of clean sediment. This approach to enhanced MNR is distinct from how enhanced MNR (or EMNR) is more commonly defined, in which MNR and system recovery are facilitated through the direct placement of a thin layer cap to reduce biological exposure through in situ mixing and dilution.

As with MNR, enhanced MNR would rely on long term monitoring and use of institutional controls to achieve RAOs. Enhanced MNR could be applied in either/both the intertidal and subtidal zones depending on placement strategy (i.e., clean material added to the water column or placed in discrete piles or windrows for hydrodynamic dispersion). While not placed directly on marsh platforms, clean sediment added to the intertidal or subtidal zone through enhanced MNR would ultimately also redistribute to the platforms. Effectiveness of enhanced MNR would be determined based on the results of a monitoring program developed to evaluate decreasing surface sediment total mercury concentrations over time, as well as confirm biota recovery. With predicted system recovery times on the order of decades to meet PRGs, periodic evaluation of the effectiveness of enhanced MNR would be required to determine whether material added through enhanced MNR is mixing with existing mobile sediment in the system and resulting in the decrease in total mercury concentrations across the biological mixed depth in sediment.

### 7.1.3 Dredging Alternative

Dredging of the subaqueous zone could be performed using either hydraulic or mechanical methods. Excavation of marsh platforms could be performed via mechanical removal. For costing, it was assumed that mechanical dredging would be conducted in subaqueous zones. Results of the dewatering bench-scale study indicated that stabilization of dredged material with Portland cement to a high solids content (approximately 40 percent; similar to mechanically dredged sediment), was the most favorable treatment regime. Final determination of dredge and backfill methods would be evaluated further as part of pre-design activities.

Dredging and mechanical removal are assumed to remove the top 1 foot of sediment. A 1-foot removal depth targets removal of the top 6 inches of sediment (the biologically active zone), with an additional 6 inches assumed for construction tolerance. The dredged area would be backfilled with 1 foot of clean material, with material grain size to be evaluated during pre-design. Dredged sediments would be dewatered and stabilized at a landside processing facility prior to off-site transportation and beneficial reuse as fill material or disposal at a landfill facility. Dredging would also rely on monitoring and institutional controls in both the short and long term to achieve RAOs.

Dredging, backfilling, dewatering, stabilization, and off-site beneficial reuse or disposal at a landfill facility in combination with monitoring and institutional controls are assembled into a dredging alternative for the main channel of the Estuary and the Orland River. For the main channel of the Estuary and the Orland River, the dredging alternative includes excavation and replacement of marshes as well as dredging portions of the intertidal, subtidal, and thalweg/main channel hydrodynamic zones. Due to the size and ecological sensitivity of Mendall Marsh, excavation and replacement of Mendall Marsh are not included as an alternative. Dredging of the intertidal areas in the Marsh River is considered as a component of the remedial strategy for Mendall Marsh when the target PRG cannot be met using MNR, enhanced MNR, or the placement of a thin layer cap or amendments on the marsh platform (Section 7.1.4 and 7.1.5).

Post-placement monitoring for the dredging alternative would focus on evaluation of area weighted average total mercury concentrations relative to PRGs, both within the dredge footprint and within the hydrodynamic zone in which dredging and backfill were conducted (in the event that the dredge footprint is smaller than the hydrodynamic zone). Effectiveness of the dredge alternative would be determined based on the results of long term monitoring of sediment and biota.

### 7.1.4 Thin Layer Capping Alternative

The thin layer capping alternative would be applicable for marsh platforms where concentrations of mercury exceed the PRGs and ecologically sensitive habitat is present. The broadcasting of clean material onto the marsh platform to form a 3-inch thin layer cap would immediately reduce the area weighted average concentration of total mercury across the biologically active zone to below the 500 ng/g PRG. The intention with thin layer capping is to enhance the system recovery rate through dilution of the total mercury concentration over an integrated 6-inch depth rather than isolating or sequestering mercury in the underlying native marsh soil. In the long term, the placement of a thin layer cap would reduce the recovery time frame for species feeding on marsh platforms. Thin layer capping would rely on monitoring and institutional controls in both the short and long term to achieve RAOs.

While thin layer caps could potentially be placed on marsh platforms throughout the Estuary, the alternative evaluated through the remainder of this Report focuses on Mendall Marsh. Evaluation of thin layer caps for specific pocket and fringe marshes in the Estuary will require additional evaluation of marsh geomorphology (i.e., shape and slope), as well as assessment of the ecological benefit of cap placement for appropriate receptors in these smaller marsh areas. For Mendall Marsh, because lower elevations on the marsh platform are generally characterized by higher concentrations of total mercury than higher elevations on the marsh platform (as discussed in Section 5.2.1 and presented in **Appendix H**), application of the thin layer cap principally targets platform areas below the 7.5-foot elevation contour (as determined from NAVD88). In addition to these lower elevation areas, approximately 20 percent of the marsh platform at elevations above the 7.5-foot contour would also be capped to meet the 500 ng/g PRG for total mercury. Overall, the total area to be capped under this scenario is approximately 50 percent of the marsh platform in Mendall Marsh.

For Mendall Marsh, thin layer capping of the marsh platform would not achieve the 300 ng/g PRG, regardless of the cap area footprint. To achieve the 300 ng/g PRG for total mercury in Mendall Marsh, dredging of the intertidal and subtidal zones of Mendall Marsh is also required.

Based on the potential for erosion of cap material, as well as recontamination of the cap surface from mobile sediment depositing on the marsh platform, long term monitoring of the effectiveness of this remedy is warranted. Monitoring would focus on evaluation of whether additional cap material is required to maintain depth-integrated and area-averaged concentrations of total mercury below the PRG, as well as to evaluate whether additional remedial measures might be warranted as part of an adaptive management approach to accelerate marsh recovery.

### 7.1.5 Amendment Alternative

The amendment alternative would apply to marsh platforms where concentrations of mercury exceed the PRG in ecologically sensitive habitat. Broadcasting of amendments onto the marsh platform would provide a layer of carbon enrichment that would reduce biological uptake of methyl mercury in the short term and would reduce recovery time frames in the long term by increasing the rate of biological recovery in the marsh. Application of amendments would also rely on monitoring and institutional controls in both the short and long term to achieve RAOs. As described for thin layer capping, the amendment alternative evaluated through the remainder of this Report focuses on Mendall Marsh. Evaluation of amendment addition for specific pocket and fringe marshes in the Estuary will require additional evaluation of marsh geomorphology (i.e., shape and slope), as well as assessment of the ecological benefit of amendment addition for appropriate receptors in these smaller marsh areas. Amendment application for Mendall Marsh assumed application over the entire marsh platform at elevations between the 2-foot and 9-foot contours (as described in Section 5.2.1).

Based on the overall results of bench-scale treatability studies, it is assumed for costing purposes that SediMite™ would be broadcast at a rate of 3 percent activated carbon addition to achieve placement of the amendment over Mendall Marsh.

Post-placement monitoring would focus on confirming the presence of amendments in marsh soils. Additionally, long term monitoring would be conducted to evaluate the effectiveness of amendment addition in biota recovery. Continued evaluation of the presence and concentration of amendments in marsh soil is warranted to determine whether placement of additional amendment is needed and/or whether the introduction of additional remedial measures might be warranted as part of an adaptive management approach to accelerate marsh recovery.

## 7.2 ALTERNATIVE DESCRIPTIONS

Remedial alternatives described in this section are: (1) system-wide alternatives; (2) alternatives focused on the main channel of the Estuary and Orland River; and (3) alternatives focused on Mendall Marsh.

### 7.2.1 System-Wide Alternatives

System-wide remedial alternatives consist of:

- Alternative 1: Monitored Natural Recovery
- Alternative 2: Enhanced Monitored Natural Recovery

#### *7.2.1.1 Alternative 1: Monitored Natural Recovery*

Existing institutional controls (consumption advisories, fishery closures, and public education programs) would be maintained and updated/expanded if necessary based on the results of iterative long-term monitoring. Monitoring would focus on system recovery as determined by decreasing concentrations of total mercury in Estuary sediment and decreasing concentrations of methyl mercury in biota tissue.

As a first step in implementation of MNR, monitoring objectives and the extent to which the current annual monitoring program is adequate should be evaluated. This evaluation should include statistical analysis of sampling density, refinement of the evaluation of sampling period, and assessment of whether additional fate and transport modeling is required for system characterization. The overall monitoring program would include analysis of total mercury and methyl mercury in sediment and biota, as well as (likely) the development/refinement of a sediment transport model for the Estuary.

For costing purposes, it is assumed that for MNR, monitoring and reporting would be conducted every three years for 45 years; iterative evaluation of the effectiveness of MNR at reducing sediment mercury concentrations relative to PRGs and continued biological recovery would be conducted every 10 years. The evaluation would focus on MNR progress toward interim recovery targets to determine whether additional remedial measures are warranted to accelerate system recovery. The 45-year time frame applied in conceptual evaluation and costing is a reasonable estimate for an MNR-focused long-term monitoring framework because it is likely to capture trends in system recovery that are not well resolved in evaluation of data from the 5–10 year interval between Phase II sampling and Amec Foster Wheeler Phase III sampling (Amec Foster Wheeler 2018g and 2018j). Based on the iterative evaluation of data collected during this monitoring program, this 45-year time frame may be adjusted.

***Cost***

Costs associated with MNR, including implementation of the monitoring part of the remedy and development and implementation of institutional controls are estimated at approximately $16,540,000 as summarized in **Table 7-2.** Cost details are included in **Appendix J**.

#### *7.2.1.2 Alternative 2: Enhanced Monitored Natural Recovery*

Enhanced monitored natural recovery would be implemented through addition of clean sediments in the intertidal and subtidal zones. Addition of clean sediment would likely be achieved through placement of discrete piles or windrows of material for hydrodynamic dispersion. The assumption with enhanced MNR as described here is that clean sediment added to the system would mix with mobile sediments to achieve reduction in mobile sediment total mercury concentrations through dilution. To estimate the volume of clean sediments required to achieve the PRGs system-wide through dilution of native sediment with clean sediment addition, it is assumed that sufficient clean sediment with a mercury concentration of 20 ng/g is added to reduce the concentration of mercury in mobile sediments to below either 500 ng/g or 300 ng/g. Following this approach, an estimated volume of 3,900,000 cubic yards of clean sediment is required to achieve the 500 ng/g PRG; an estimated volume of 10,700,000 cubic yards of clean sediment is required to achieve the 300 ng/g PRG.

This calculation assumes a mass of mobile sediment (including wood waste) in the system of approximately 5,700,000 cy as calculated from an unconsolidated sediment thickness of 3.6 inches (see Section 3.2.2.4), an area extent of the Estuary adapted from Geyer and Ralston (2018) to include Fort Point Cove and the inclusion of surface deposits of wood waste and mineral sediment at least 3 feet thick. The average total mercury concentrations applied to the unconsolidated sediment in this calculation is 760 ng/g; the average total mercury concentration applied to the surface deposits is 1,176 ng/g (**Tables 3-2, 3-3, and 5-15**).

For costing purposes, it is assumed that clean sediment would be placed in phases of work conducted annually during the environmental window (assumed to be July 15 through November 30 with 112 working days per year) over a period of years to achieve placement of the volume of material required. Numerical modeling, particle tracking studies and pilot testing of material addition would be required to determine the time frame over which material added to the system would mix with mobile surface sediment to achieve the PRGs.

Implementation of enhanced MNR includes construction of a staging and stockpile area, mobilization of equipment for sediment placement and mobilization of equipment for the transfer of sediment from a clean borrow source to the distribution barges. For costing purposes, it is assumed a clean borrow source would be identified within Maine. Distribution methods for enhanced MNR could include hydraulic washing of sediment from a barge; aerial, surface, or underwater discharge from a swinging cable arm bucket; use of a split hull hopper barge; or underwater discharge to subtidal areas using Tremie tubes. The placement method will be further assessed during pilot-scale and/or pre-design studies.

Bathymetric surveys and post-placement monitoring would be used to confirm the volume and areal extent of the clean sediment placement. Selection criteria for appropriate clean sediments will include grain size considerations, material organic content and the potential for using clean native sediment from other portions of the Estuary or from regional sources. An appropriate grain size would balance habitat considerations with the limiting grain size required for bed stability.

Post-placement monitoring of clean sediment as a component of enhanced MNR will include a geophysical survey conducted every three years for 10 years to evaluate the rate and extent of sediment redistribution. Post-placement monitoring will be, followed by long term system recovery monitoring every three years for 45 years. Long term recovery monitoring will include both sediment and biota; sediment monitoring will likely include ongoing analysis of total mercury, methyl mercury and TOC or organic content; biota analysis will include total mercury and methyl mercury in appropriate species. Long term monitoring for ecological recovery could begin during the interval in which post-placement monitoring is occurring. Institutional controls would be implemented as described above until PRGs are met. As described for MNR, the 45-year time period for long term monitoring is selected as the base time period for evaluation purposes. Implementation of enhanced MNR would reduce the recovery time period relative to the recovery time period following implementation of the MNR remedy. Specific reductions in the system-wide recovery time period following implementation of enhanced MNR are uncertain, as numerical modeling, particle tracking studies and pilot testing of material addition in a portion of the estuary would be required prior to full scale implementation of this remedial alternative.

***Cost***

Costs associated with numerical modeling, particle tracking, addition of clean sediments (both on the pilot scale and [if undertaken] for full implementation), implementation of institutional controls, post-placement monitoring over 10 years, and establishment and implementation of a long term monitoring program for a period of 45 years are estimated at approximately $335,870,000 to achieve the 500 ng/g PRG and $997,200,000 to achieve the 300 ng/g PRG (**Table 7-2**). The cost differences for the two PRGs result from differences in material quantities and number of mobilization/placement events required. Cost details are included in **Appendix J**.

### 7.2.2 Main Channel of Penobscot River and Orland River Alternative

Reaches identified for remediation in the main channel of the Estuary are shown in **Figures 5-8-1** through **5-8-12**; the Orland River is shown in **Figures 5-8-15** and **5-8-16**. For these areas, the remedial alternative developed to achieve the 500 ng/g and 300 ng/g PRGs is:

- Alternative 3: Dredging

#### *7.2.2.1 Alternative 3: Dredging*

Shallow water and deep water dredging would require construction of near shore landside offloading/material management areas. Potential offloading/material management areas are shown on **Figures 7-1 through 7-3.** For costing purposes, it is assumed that offloading/material management areas could be constructed on the 73-acre parcel at Frankfort Flats (**Figure 7-2**) and the 9.8-acre former Northeast Coal site (**Figure 7-3**), where sediment staging, stockpiling, and processing could occur. Inclusion of these areas is conceptual and does not reflect discussion with landowners regarding availability.

Work in support of this remedial alternative would include mobilization of multiple mechanical dredges and shallow draft barges, operation of a floating water clarification system and a crane for offloading sediments, and pug mills for processing and stabilizing screened sediments prior to transportation and off-site reuse or disposal. The offloading/material management areas would be used for sediment offloading, dewatering, solidification/stabilization, stockpiling, and load out of sediment to the off-site beneficial reuse and/or disposal facilities.

Prior to dredging, debris identification surveys and removal operations would be conducted in the main channel of the Estuary and the Orland River. The debris removal survey would consist of a side scan sonar survey for the sediment surface and a sub-bottom profiling survey with a magnetometer to identify buried debris. Debris identified via the surveys would be removed using barge-mounted excavator(s) and shallow draft barges.

***Dredging, Dewatering, and Stabilization***

For costing and feasibility evaluation purposes, this remedial alternative assumes mechanical dredging, dewatering via stabilization with Portland cement, and disposal by local beneficial reuse or out-of-state disposal. Other dredge/dewatering/disposal options could be selected during the design process following further evaluation. Several dredging, dewatering and disposal options are available.

*Dredging*

Following debris removal, the top 1 foot of sediment (6-inch dredge with a 6-inch construction allowance) would be mechanically dredged and replaced with 1 foot of clean backfill material.

For shallow water dredging in intertidal zones, sediments could be dredged using barge-mounted precision excavators with level-cut sealed environmental clamshell buckets. The mechanical dredges would be outfitted with Real Time Kinematic and Differential Global Positioning Systems that use a series of inclinometers and rotation sensors for precise location and monitoring of the dredge bucket that can remove sediments at close to in situ percent solid concentrations. Typical shallow draft barges would draft 2 to 3 feet; therefore, tides and water elevations would be monitored to schedule dredging and backfilling operations during hours of the day when water depth exceeds 3 feet to minimize downtime. The production of a mechanical dredge is generally defined by the capacity of the bucket, the average grab of each bucket, the dig-swing-empty-reposition cycle time of the excavator (cycle time), and the anticipated downtime associated with repositioning of the dredge barge to each of the sediment removal locations. Mechanical systems described herein are assumed to have an average production rate of approximately 3,150 cy per day based on a 12-hour work day, assuming five dredges are operating concurrently outfitted with a 10-cy bucket, each bucket contains 60 percent sediment, a 2-minute cycle time, and 25 percent efficiency operating six days per week during the environmental work window. Dredged material would be loaded onto three shallow draft barges dedicated to the dredge; backfill materials would be offloaded from dedicated barges and placed within the dredge footprint. Sump basins would be installed in the corners of each barge to facilitate dewatering prior to offloading. Typical dredged sediment volume capacities for shallow draft barges range from 100 to 500 cy depending on the size of the barge; several smaller capacity barges (100 cy) can also be connected to create a larger capacity barge (500 cy).

For deep water dredging in subtidal zones, sediment could be dredged using barge mounted cranes coupled with level-cut sealed environmental clamshell buckets. The mechanical dredges would be outfitted with Real Time Kinematic and Differential Global Positioning Systems that use a series inclinometers and rotation sensors for precise location and monitoring of the dredge bucket. This method of dredging would provide a high degree of accuracy and precision while removing sediments at close to in situ percent solid concentrations. The deep-water dredge would be conducted in areas with greater than 20 feet of water, thus there would be little tidal downtime. For this reason, dredging would have minimal downtime associated with the tides. Each mechanical system described above would have an average production of approximately 2,800 cy per day based on a 12-hour work day, assuming two dredges are operating concurrently outfitted with a 10-cy bucket, each bucket contains 70 percent sediment, a 2.5-minute cycle time, and 70 percent efficiency operating six days per week during the environmental work window. Dredged material would be loaded into one of three large capacity sediment scows dedicated to the dredge. Sump basins would be installed in the corners of each scow to facilitate dewatering prior to offloading. Typical dredged sediment volume capacities for large scows range from 1,000 to 2,500 cy.

Barges or scows loaded to capacity would be transported to the offloading/material management area using a push boat. The offloading/material management areas would be constructed in locations where adequate draft is available across the tidal range. The barge or scow would be docked against a series of dolphin piles adjacent to a floating water clarification system. The water clarification system would be used to decant the barge or scow and remove freestanding water by pumping through a clarification system for discharge back into the river. Once freestanding water is decanted, the barge or scow would be offloaded using a large crane(s) (e.g., a 300-ton lattice crawler crane or equivalent) positioned in the offloading/material management area. The crane(s) would swing over a drip apron to capture and collect any dredge material or liquids that may be lost during offloading. Material captured by the drip apron would be collected and transferred to the offloading/material management area for treatment and disposal. Water generated from the offloading/material management areas would be collected and pumped to the floating water clarification system for treatment and discharge back into the estuary. Cranes would offload the sediment directly into a hopper for initial screening of oversized debris (greater than 4 inches); oversized debris would be stockpiled and handled separately from dewatered sediments.

For costing purposes, it is assumed that dredging would be conducted in several phases of work during annual environmental work windows to achieve the PRGs. For the main channel of the Estuary and the Orland River, work durations are estimated at 22 years to meet the 500 ng/g PRG, and 58 years to meet the 300 ng/g PRG.

*Dewatering and Stabilization*

Sediment would be loaded from stockpiles into a pug mill, where it would be stabilized to increase the unconfined compressive strength by mixing with Portland cement at an assumed 4 percent application rate (**Appendix C**). Results of the dewatering study (**Appendix C**) indicate that material stabilized with 4 percent addition of Portland cement will pass the paint filter test for transportation and off-site disposal. As part of pre-design activities, additional treatability testing will be required.

Dewatered and stabilized sediment would be stockpiled and cured prior to loading into haul trucks to be transported for off-site reuse or disposal. Dump trailers used for transport are loaded to approximately 32 tons per truck. It is assumed that at least 132 trucks trips per day would be required for the duration of the work, assuming that all dredged, dewatered and stabilized sediment was loaded out during the environmental window for in-water work. Dredged sediments that could not be loaded out during the environmental window for in-water work (due to limits on truckloads or slower than expected curing times, as examples) would be stockpiled and covered to be loaded out throughout the remainder of the year.

***Off-Site Beneficial Reuse or Disposal of Dredged Sediments***

For the purposes of preparing cost estimates, two off-site options were assumed for stabilized sediments: beneficial reuse off site and disposal at an out-of-state permitted landfill facility. For beneficial reuse, sediment could potentially be used as fill at historical gravel pit locations, fill for road construction, or agriculturally. For landfill disposal, potential out-of-state landfill facilities include Clean Harbors (New Hampshire); Waste Management (New Hampshire); Clean Earth (New Jersey); and ESMI (New York).

***Monitoring***

For costing purposes, it is assumed that post-implementation monitoring would be conducted every three years for 10 years. Monitoring would focus on evaluation of sediment mercury concentrations relative to PRGs. Sediment sampling as a component of post-dredge monitoring would likely occur at a sampling density of approximately one sample (short core) per 5 acres of remediated area. Sampling would focus on total mercury with the goal of confirming that the area weighted average concentration of total mercury within the biologically active zone (0–0.5 foot) within the dredge area footprint(s) remains below the relevant PRG.

Additionally, long term post-remedy monitoring is assumed to be conducted every three years for 45 years. Long term recovery monitoring would include both sediment and biota; sediment monitoring would include ongoing analysis of total mercury, methyl mercury, and TOC or organic content; biota analysis would include total mercury and methyl mercury in appropriate species. Long term monitoring for ecological recovery could begin during the interval in which post-dredge monitoring is occurring. While it is generally expected that implementation of a dredge remedy will reduce the overall system recovery time relative to the recovery time period following implementation of either the MNR or enhanced MNR remedy, uncertainty in background system recovery rates (as described in Section 3.9.3 – Proposed Recovery Time), limit the ability to better quantify the impact of dredging on system recovery. That is, while long term monitoring is recommended for 45 years and it is assumed that sufficient progress toward the PRGs would be achieved over this interval to confirm whether MNR is functioning as a viable remedy, it is also possible that the PRGs are not reached in 45 years. In this case, a direct comparison of: (1) a dredge-based recovery rate, in which the rate is controlled by the duration of dredge operations but environmental impacts of dredge operations in the Estuary might take an additional number of years; and (2) MNR, in which recovery is a function of the ongoing rate of burial and/or loss of material as the result of resuspension, mixing, transport and erosion, are not necessarily directly comparable. Institutional controls would be implemented as described above until biota recovery criteria are met.

***Cost***

Costs associated with dredging and off-site beneficial reuse, confirmatory sampling during and following dredging, and establishment and implementation of the long term monitoring program for a period of 45 years are estimated at approximately $1,307,780,000 to achieve the 500 ng/g PRG and approximately $4,404,060,000 to achieve the 300 ng/g PRG for total mercury (**Table 7-2**). The difference in cost between the two estimations presented here is a function of differences in the quantity of material dredged, the quantity of backfill required, and removal and placement costs associated with meeting the different PRGs. Cost details are included in **Appendix J**.

Costs associated with dredging and off-site disposal, confirmatory sampling during and following dredging, and establishment and implementation of the long term monitoring program for a period of 45 years are estimated to range from approximately $1,726,280,000 to achieve the 500 ng/g PRG and approximately $5,559,970,000 to achieve the 300 ng/g PRG for total mercury (**Table 7-2**). Cost details are included in **Appendix J**.

### 7.2.3 Mendall Marsh Alternatives

Areas identified for remediation in Mendall Marsh are shown on **Figures 5-8-13 and 5-8-14.** Remedial alternatives that were developed to reduce area weighted average concentration of total mercury to achieve the 500 ng/g and 300 ng/g total mercury PRGs for Mendall Marsh consist of:

- <u>Alternative 4</u>: Thin Layer Capping
- <u>Alternative 5</u>: Amendment Application
- <u>Alternative 6</u>: Dredging in Intertidal Zones & Thin Layer Capping

For all Mendall Marsh remedial alternatives, the ability to assess recovery times to reach the PRGs for the marsh will depend on whether the marsh remedy is integrated with remedies for the wider Estuary. Because some sediment transport into Mendall Marsh from the main Estuary channel does occur, the extent to which a marsh-specific remedy will shorten the ecological recovery time for marsh biota will depend on the extent to which mobile sediment is a source of recontamination for the marsh platform following placement of a thin layer cap or addition of amendments.

#### *7.2.3.1 Alternative 4: Thin Layer Capping*

A thin layer cap would be placed on the Mendall Marsh platform by broadcasting a minimum 3-inch layer of clean sediment on top of the existing marsh surface. The estimated volume of clean sediment that would be placed as a thin layer cap on the Mendall Marsh platform to achieve the 500 ng/g PRG is approximately 191,000 cy. As proposed, the remedial alternative for Mendall Marsh for both the 500 ng/g and 300 ng/g PRGs includes placement of a thin layer cap over approximately 50 percent of the marsh platform. The area covered by the proposed thin layer cap would include 100 percent of the marsh platform in elevation zones between 2.0–7.5 feet (i.e., Elev 1, Elev 2, and Elev 3 on **Figure 5-8-13** and **Figure 5-8-14**), and approximately 20 percent of the marsh platform in the elevation zone above 7.5 feet (Elev 4). The remainder of the marsh platform (as well as the marsh intertidal and subtidal zones) that is not covered by the thin layer cap would remain at the calculated pre-remedy bootstrap mean concentration presented in **Tables 5-14 and 5-15**.

Two pilot-scale tests are recommended prior to implementation of this remedy: an initial test to assess potential impacts of cap material placement on vegetation, followed by a larger-scale test (likely in subsequent years) to evaluate the stability of the cap, and to assess the effectiveness of capping to reduce tissue mercury concentrations in biota from within the footprint of the pilot test area. It is expected that the pilot tests would be conducted on the scale of acres and that pilot test plots would encompass a range of marsh elevations and vegetation types.

Thin layer capping in these areas includes construction of an offloading/material management area, and mobilization of capping equipment, slurry boxes, and a hydraulic pipeline for transfer of the cap material to the capping barges. It is anticipated that the offloading/material management area for this alternative would be constructed on the 9.8-acre former Northeast Coal site shown on **Figure 7-3**. This location would be prepared and used for cap material staging, stockpiling, and transfer via slurry.

Following construction of infrastructure and mobilization of equipment, the cap material would be loaded into a hopper and conveyed to a slurry box. The dry cap material would be mixed with sufficient water to slurry and transport the material at maximum practical and steady-state density to the cap area through a 12-inch floating/submersible hydraulic pipeline. The pipeline would transfer the material to thin layer capping equipment specialized for broadcast capping. (i.e., broadcast capping). The specialized equipment would transfer and place the slurried cap material in a thin layer by broadcasting the material over a known area at known volumes based on the percent solids of the slurry. Cap material placement would be monitored in real time using sediment push cores to verify the thickness of material placement over time. Although broadcast capping systems generally draft less than 2 feet, the remedial contractor would be required to closely monitor tides and schedule thin layer capping operations to minimize downtime.

The production of thin layer capping systems is generally governed by the hydraulic material transfer rate typically defined by the diameter of the pump, the pump discharge velocity, the maximum percent solids targeted, and the anticipated downtime associated with repositioning of equipment to access application locations. The hydraulic system described above would have an average production of approximately 440 cy per day based on a 12-hour work day, assuming a

12-inch discharge pipeline, 3,500 gallons per minute flow rate, 60 percent solids, and 70 percent efficiency operating six days per week during the environmental work window.

***Monitoring***

Post-placement monitoring of the thin layer cap will include a baseline evaluation of cap material thickness (minimum of 3 inches) and three sampling events over 10 years with the goal of confirming that the area weighted average concentration of total mercury within the biological mixed depth (0–0.5 foot) on the marsh platform remains below the relevant PRG. Short core sampling will occur at a rate of approximately one station per capped acre (for full implementation) and will include analysis of both total mercury and methyl mercury.

Long term recovery monitoring will include both marsh soil/sediment and biota; soil/sediment monitoring will likely include ongoing analysis of total mercury, methyl mercury and TOC or organic content; biota analysis will include total mercury and methyl mercury in appropriate receptors. Long term monitoring for ecological recovery could begin during the interval in which post-placement cap monitoring is occurring. Institutional controls for black duck consumption would be implemented until the recovery criteria are met.

***Cost***

Costs associated with placement of a thin layer cap on the Mendall Marsh platform also include implementation of institutional controls and establishment of the long term monitoring program for a period of 45 years. Overall cost to achieve the 500 ng/g PRG on the Mendall Marsh platform are estimated at approximately $66,050,000 (**Table 7-2**) and assume a single placement of cap material. Cost details are included in **Appendix J.**

### *7.2.3.2 Alternative 5: Amendment Application*

Application of amendments on the marsh platforms includes construction of an offloading/material management area, mobilization of specialized broadcast trucks (i.e., low ground pressure vehicles with dump truck-like spreaders), multiple shallow draft material barges, a mechanical conveyor for loading amendment to material barges, and a barge mounted crane and mechanical conveyor for loading cap material to the broadcast trucks. It is anticipated that the offloading/material management area will be constructed on the 9.8-acre former Northeast Coal site (**Figure 7-3**). The location will be prepared and used for material staging, stockpiling, and loading.

Two pilot-scale tests are recommended prior to implementation of this remedy: an initial test to assess potential impacts of amendment addition on vegetation, followed by a larger-scale test (in subsequent years) to assess the effectiveness of amendments at reducing tissue mercury concentrations in biota, as well as the potential need for amendment re-application. It is expected that the pilot tests would be conducted on the scale of acres and that pilot test plots would encompass a range of marsh elevations and vegetation types.

Following construction of infrastructure and mobilization of equipment, amendment material will be delivered and stockpiled at the offloading/material management. The material will be loaded into a hopper and funneled to a mechanical conveyor. The conveyor will transfer the material 150–200 feet from the offloading/material management to the material barges that will be moored against dolphin piles. The material barges will be pushed to the amendment areas and moored alongside a cap material transfer barge consisting of a barge-mounted crane and material conveyor with 150–200 feet of reach. The cap material will be loaded into a hopper and funneled to the barge-mounted mechanical conveyor. The conveyor will transfer the cap material and load the back of open top track mounted low ground pressure trucks with broadcast spreaders installed on the dump body. The track-mounted broadcast spreaders will navigate over the marsh area and broadcast the amendment material to the area. The average production of this application is calculated by the equipment speed, width of coverage per pass, and the anticipated downtime associated with loading and capacity. It is estimated that each broadcast truck will cover 325,200 square feet per day based on a 12-hour day, with one pass (1 mile per hour, 20 feet of coverage/pass, 25 percent efficiency) operating six days per week during the environmental work window.

Based on current understanding of the effectiveness of amendments at reducing porewater concentrations of methyl mercury on the Mendall Marsh platform, it is expected that amendment reapplication will be necessary to maintain effectiveness.

***Monitoring***

Post-placement monitoring of amendment addition will include a baseline evaluation of application rate (with the goal of achieving a 3 percent addition to baseline organic carbon content of marsh soil) and three sampling events over 10 years with the goal of confirming the continued presence of amendment material. Short core sampling in support of this objective will occur at a rate of approximately one station per amended area and will focus on organic carbon content with measurement via a chemical oxidation method recommended for analysis of activated carbon (Grossman and Ghosh 2009).

Long term recovery monitoring will include both marsh platform soil/sediment and biota; soil/sediment monitoring will likely include ongoing analysis of total mercury, methyl mercury, and TOC or organic content; biota analysis will include total mercury and methyl mercury in appropriate receptors. Long term monitoring for ecological recovery could begin during the interval in which post-placement amendment monitoring is occurring. Institutional controls for black duck consumption would be implemented until the recovery criteria for black duck tissue are met.

***Cost***

Costs associated with application of amendments, implementing institutional controls, and establishing the long term monitoring program for a period of 45 years are estimated to be approximately $50,870,000 (**Table 7-2**). Costing for application of amendments assumes a single application. Cost details are included in **Appendix J**.

#### *7.2.3.3 Alternative 6: Dredging in Intertidal and Subtidal Zones & Thin Layer Capping*

To achieve the 300 ng/g PRG for Mendall Marsh while limiting impacts to biota in ecologically sensitive habitat, a combination of shallow water dredging in the marsh intertidal and subtidal zones and thin layer capping on the marsh platform would be implemented. Components of this alternative are discussed in Sections 7.2.2.1 and 7.2.3.1.

***Monitoring***

Post-placement sampling will include three sampling intervals over 10 years with the goal of confirming that backfill sediment placed after dredging remains in place. Sampling will occur as short cores at a rate of approximately one station per 5 acres of dredged/backfilled area. Sampling will focus on total mercury with the goal of confirming that the area weighted average concentration of total mercury within the biologically active zone (0–0.5 foot) within the dredge area footprint(s) remains below the relevant PRG.

Post-placement monitoring of the thin layer cap will include a baseline evaluation of cap material thickness (minimum of 3 inches) and three sampling events over 10 years with the goal of confirming that the area weighted average concentration of total mercury within the biologically active zone (0–0.5 foot) on the marsh platform remains below the relevant PRG. Short core sampling will occur at a rate of approximately one station per capped acre and include analysis for total mercury and methyl mercury.

Long term recovery monitoring will include both sediment and biota; sediment monitoring will likely include ongoing analysis of total mercury, methyl mercury and TOC or organic content; biota analysis will include total mercury and methyl mercury in appropriate species. Long term monitoring for ecological recovery could begin during the interval in which post-dredge monitoring is occurring. Institutional controls would be implemented as described above until the PRG and biota recovery criteria are met.

***Cost***

Costs associated with dredging, confirmatory sampling during and following dredging, and establishment and implementation of the long term monitoring program for a period of 45 years are estimated to range from approximately $137,120,000 (off-site beneficial reuse) to $185,300,000 (off-site disposal) (**Table 7-2**). Cost details are included in **Appendix J**.

Costs associated with placement of the thin layer cap to achieve the 500 ng/g PRG, implementation of institutional controls and establishment of the long term monitoring program for a period of 45 years are estimated to be approximately $66,050,000 (**Table 7-2**). Cost details are included in **Appendix J.**

The total cost for this alternative, including both dredging in intertidal zones and thin layer capping on the marsh platform, ranges from approximately $203,170,000 (off-site beneficial reuse for dredge materials) to $251,350,000 (off-site disposal for dredge materials).

# 8.0 EVALUATION OF REMEDIAL ALTERNATIVES

This section evaluates the remedial alternatives defined in Section 7.0 based on their ability to meet six evaluation criteria and associated sub-criteria, which were established based on the Court Order, the Phase III Engineering Study process, and site-specific considerations:

1) Viability of remedy
   - Ability to construct and/or operate the remedial alternative
   - Applicable regulations, coordination with agencies, and permits and approvals needed
   - Community acceptance
2) Whether the proposed solution has been successfully attempted previously or is innovative
   - Where the solution has been successfully implemented in the past
   - Status of the technology/innovation status/reliability
3) The likely cost of the solution
   - Capital costs
   - Operations and maintenance (O&M) costs
4) The length of time to complete the recommendations
   - Time to implement the remedy
   - Time until remedial action objectives are achieved
5) The likely effectiveness of the solution
   - Reduction in amount of/concentration of mercury/methyl mercury available in the Estuary/available to receptors after remediation
   - Reduction of risk to people
   - Reduction of risk to biota
   - Permanence of the remedy/remedy effectiveness
6) Any potential environmental harm that may be caused by the proposed solution
   - Adverse environmental impacts from remediation
   - Short and long term impacts to the community
   - Short term impact to workers
   - Sustainability/green remediation factors

Community acceptance as evaluated under Criteria 1 (Viability of Remedy) is as based on preliminary conversations with stakeholders including municipalities adjacent to the river, the Penobscot Indian Nation, resources users (including those impacted by the harvesting closures) and other interested parties. As detailed in the Communication and Community Involvement Plan (Amec Foster Wheeler 2018n), it is recommended that more a thorough and detailed presentation of remedial alternatives be conducted for communities and interested parties in the area of the Estuary and lower river, and that that presentation include opportunities for community feedback.

Regarding sustainability/green remediation factors as considered under the Court criteria, the US EPA defines green remediation as '*the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprints of cleanup actions*' (EPA 2010). Sustainability includes both green remediation and the wider economic and social components of a site remediation that may impact local individuals and communities (EPA 2010). In the context of the Estuary, sustainability/green remediation is considered within the framework of potential environmental harms associated with the remedial alternatives evaluated in this Report.

The detailed evaluation of the remedial alternatives based on their ability to achieve the evaluation criteria is presented below.

## 8.1 SYSTEM WIDE ALTERNATIVES

System-wide remedial alternatives consist of:

- Alternative 1: Monitored Natural Recovery, and
- Alternative 2: Enhanced Monitored Natural Recovery.

### 8.1.1 Alternative 1: Monitored Natural Recovery

MNR is an in-place sediment management approach that relies on natural recovery processes to transform, immobilize, or isolate contaminants such that contaminant concentrations and/or bioavailability in sediment are reduced to levels that achieve acceptable risk reduction within a defined period of time. MNR assumes source control has been achieved or that sources are sufficiently minimized so that slow rates of recovery are not outpaced by ongoing releases.

Based on available data, the overall general consistency of total mercury concentrations in surface sediment throughout the Estuary supports the hypothesis that some level of homogeneous re-distribution of mercury-impacted sediment is occurring within the Estuary. The principal source of mercury release to the Estuary from the HoltraChem facility ceased decades ago. During and following the period of release from the facility, mercury has been redistributed throughout the Estuary and into upper Penobscot Bay. The redistribution of mercury in the Estuary and upper Bay has been driven by estuary circulation in which there is both downgradient freshwater discharge from the river and upgradient tidal return from the bay. The magnitude of tidal return into the Estuary, coupled with the geomorphology (shape) of the Estuary, has resulted in the retention of a significant mass of mobile, mercury-impacted sediment that is slowing the rate of natural system recovery.

Based on evaluation of both Phase II and Phase III data, concentrations of mercury in sediment and biota tissue are only very slowly declining and it is expected that it will take on the order of decades to meet the PRGs through MNR.

An MNR alternative would include continued monitoring and iterative evaluation of monitoring data with respect to projected system recovery rates. Monitoring would include total mercury concentrations in sediment to evaluate progress toward the PRGs and methyl mercury concentrations in biota tissue to evaluate progress toward ecological recovery.

***(1) Viability of remedy***

*Ability to construct and/or operate the remedial alternative*

MNR is viable from a constructability perspective because it is not an active remedy from this perspective. Continued monitoring, assessment of concentration trends and recovery predictions, and updates to institutional controls would be easy to implement and maintain. For long term ecological recovery monitoring, details regarding monitoring objectives and the assessment of whether current (annual) monitoring is adequate in scope and extent require re-evaluation. This evaluation should include statistical analysis of sampling density for biota and sediment, refinement of the evaluation of sampling period, and assessment of whether additional fate and transport modeling is required for recovery rate characterization.

*Applicable regulations, coordination with agencies, and permits and approvals needed*

Implementation of MNR primarily consists of continued coordination with state agencies regarding the collection of monitoring data and evaluation of the need for maintaining, removing, or expanding institutional controls (advisories, closures, signage, education programs) based on concentrations of mercury in biota. Permits are not anticipated to be needed for implementation of MNR because no active in-water remediation work would be performed, and approvals would be obtained through the process of consulting with federal and state agencies during implementation.

*Community acceptance*

Community acceptance of MNR is anticipated to be mixed. Individuals and groups who depend on the river and its resources for livelihood or pleasure may support MNR as this remedial alternative would not have impact on their current usage. For example, some lobstermen indicated concern with active remedies that may cause mercury contaminated sediments to move into Penobscot Bay and result in additional lobster and crab fishing closure areas. For other individuals and groups that have the same dependence on the river and its resources, they may not support MNR because ecological recovery would be perceived as slow and advisories and closures would not be lifted in the short term. Effective and ongoing communication about the benefits and challenges as well as the timeframe of MNR would help to better inform the river community.

***(2) Whether the proposed solution has been successfully attempted previously or is innovative***

*Where the solution has been successfully implemented in the past*

MNR has been implemented at other contaminated sediment sites in recent years (EPA 2005, 2014, and 2017). Current practices and industry standards for selection of MNR as a remedial alternatives are for sites where: (1) contaminant concentrations are demonstrated to be declining solely through natural recovery processes in the system; or (2) active remediation to achieve ecological remedial goals has either been conducted and MNR is being used to confirm ongoing declines in residual contaminant concentrations, or active remediation could not be conducted due to either site-specific constraints (physical or constructability), or the scope and/or cost of the remedial effort was impractically large to implement using standard practices.

*Status of the technology/innovation status/reliability*

MNR is a technology that is gaining acceptance in the industry and regulatory community as a low-impact long term remedial approach for remediation of contaminated sediments under the types of site conditions described above.

***(3) The likely cost of the solution***

*Capital costs*

There are no initial outlays in capital costs for implementation of MNR.

*O&M costs*

Long term O&M costs for conducting the existing Phase III Engineering Study monitoring program every three years for 45 years to assess progress toward (1) sediment recovery relative to PRGs and (2) ecological recovery in biota are estimated at approximately $16,540,000 over 45 years. An additional 10 years of monitoring data will likely be required (beyond the 10-year period of Phase II and Phase III monitoring data currently available) to evaluate the likelihood of system recovery and refine predictions for the system recovery rate by MNR. Costs estimated here for MNR would be higher if an interval significantly longer than 45 years is required for evaluation of system recovery.

*Total costs*

The total estimated cost for MNR over a period of 45 years is approximately $16,540,000 for both the 500 ng/g and 300 ng/g PRG scenarios.

***(4) The length of time to complete the recommendations***

*Time to implement the remedy*

Planning for and establishing the monitoring program and coordinating with state agencies on updates to institutional controls could be implemented within a year.

*Time until remedial action objectives are achieved*

With the existing data for the Estuary, recovery periods to achieve RAOs protective of consumers and biota cannot be predicted with certainty and are reasonably on the order of decades. The MNR alternative would implement or develop (if necessary) an iterative monitoring program that would both evaluate progress toward system recovery and refine understanding of the projected system recovery rate. That monitoring program would include sediment, surface water, and biota sampling, and would focus on recovery targets based on total mercury and/or methyl mercury concentrations (as appropriate) in sediment, surface water (including total suspended solids) and biota.

***(5) The likely effectiveness of the solution***

*Reduction in amount of/concentration of mercury/methyl mercury available in the Penobscot System/available to receptors after remediation*

There would be no reductions in concentrations of mercury or methyl mercury available to receptors in the short term under MNR. Recovery under MNR is expected to take decades.

*Reduction of risk to people*

There would be little to no reduction of risk to people in the short term. Risk reduction would be assessed through long term monitoring. Institutional controls would be maintained and expanded, if necessary, based on biota monitoring, to continue to mitigate risks to consumers until biota tissue concentrations decline to safe levels for consumption.

*Reduction of risk to biota*

With predicted recovery times on the order of decades to meet the PRGs, there would be little to no reduction of risk to biota in the short term under MNR. Risk reduction would be assessed through long term biota recovery monitoring.

*Permanence of the remedy/remedy effectiveness*

MNR would not be an effective remedy in the short term because it does not include active remediation of mercury at concentrations that exceed the PRGs and so is not directly protective of consumers and biota. MNR would be effective in the short term in continuing to mitigate risks to consumers via maintenance of institutional controls that warn, advise and educate people on the risks associated with consumption of biota.

***(6) Any potential environmental harm that may be caused by the proposed solution***

*Adverse environmental impacts from remediation*

There would be no adverse environmental impacts from remediation under MNR because no remedial activities would be conducted.

*Short and long term impacts to the community*

There would be no short or long term impacts to the community from remediation under MNR because no remedial activities would be conducted.

*Short term impact to workers*

There would be no short or long term impacts to workers from remediation under MNR because no remedial activities would be conducted. Ongoing monitoring activities undertaken as components of MNR would be conducted by workers in accordance with contractor health and safety program requirements.

*Sustainability/green remediation factors*

MNR would not employ active sustainable or green remediation technologies in the short term since it would not actively remediate contaminated sediments. In the long term, it could be a sustainable approach to system recovery.

### 8.1.2 Alternative 2: Enhanced Monitored Natural Recovery

Enhanced MNR would improve the rate of system recovery through the addition of clean sediment to the system. Clean sediment would mix with existing sediment to reduce the concentration of total mercury within mobile sediments, thereby ultimately reducing biological exposure through reducing total mercury concentrations across the biological mixed depth in sediments. Enhanced MNR as evaluated here was suggested as a potential remedial alternative by the Phase II Study Panel (PRMSP 2013) and could theoretically be applied to the whole system or to portions of the system in which hydrodynamics would serve to enhance the dispersion and mixing of clean sediment. This approach to enhanced MNR is distinct from how enhanced MNR (or EMNR) is more commonly defined, in which MNR and system recovery are facilitated through the direct placement of a thin layer cap to reduce biological exposure through in situ mixing and dilution. As presented in Section 7.2.1.2, application of system-wide enhanced MNR through the addition of clean sediment would require an estimated 3,900,000 cy of clean sediment to reach the 500 ng/g PRG for total mercury in sediment and an estimated 10,700,000 cy of clean sediment to reach the 300 ng/g PRG for total mercury in sediment. After addition of clean sediment (which should be undertaken only after modeling/particle tracking and pilot testing of this remedial approach), long term monitoring should include both sediment and biota. Sediment monitoring would evaluate progress toward achieving the PRGs; biota monitoring would evaluate progress toward ecological recovery.

***(1) Viability of remedy***

*Ability to construct and/or operate the remedial alternative*

Enhanced MNR would require a potentially significant level of effort to procure and place large quantities of clean sediment to achieve the goal of lowering the total mercury concentration in mobile sediments in the Estuary. Significant uncertainties remain regarding the size, mixing rate and impact of mobile sediments on the rate of system recovery, all of which may have impacts on the viability of this approach to remedy. Likewise, viability of the remedy may be significantly affected by the method of sediment addition (i.e. addition to the water column, placement as discrete piles or windrows on the sediment bed). Bathymetric surveys, hydrodynamic modeling, and additional sediment characterization would be required during pre-design activities to improve understanding of sediment transport and to assess the extent to which it is possible to determine whether material added to the Estuary for this purpose would mix and deposit in targeted areas in predictable ways.

After placement of clean sediment, continuation of monitoring, revisions to recovery rate predictions (if warranted) and updates to institutional controls (when appropriate) could be implemented and maintained.

*Applicable regulations, coordination with agencies, and permits and approvals needed*

Addition of clean sediment under enhanced MNR would require extensive coordination with agencies and permitting to meet applicable requirements for performing in-water work. Because introduction of substantial quantities of additional sediment would result in increased water column turbidity and could change bathymetry, significant permitting challenges may exist for this remedial approach. It is anticipated that the duration of permitting could be on the order of two to four years during the pre-construction phase of remedy implementation, although, based on potential impacts to aquatic habit, permitting of this remedial alternative may not be possible. Permitting would require consultation with regulatory agencies on meeting a range of applicable requirements during implementation, with a primary focus on mitigating potential impacts to protected species and habitats and maintaining navigational elevations.

Implementation of enhanced MNR would require on-going coordination with state agencies regarding evaluation of the need for maintaining, removing or expanding institutional controls (advisories, closures, education programs) based on mercury concentrations in biota. Approvals for implementation of enhanced MNR would be obtained through consultation with federal and state agencies during pre-design and pilot testing, as well as during field-scale effort if results of pilot-testing indicate this alternative could be implemented either system-wide or for a portion of the Estuary.

*Community acceptance*

Community acceptance of enhanced MNR is anticipated to be favorable if modeling/particle tracking and pilot testing indicate that this alternative could be implemented on a field scale. At the current level of certainty for this remedial alternative, community acceptance may be low based on the unproven status of this approach to remedy. For individuals and groups who depend on the river and its resources for livelihood or pleasure, they may perceive the improvement in recovery over a relatively short period of time as a benefit, although some individuals and groups would experience a short-term disturbance to use in specific areas during the addition of clean sediment. Effective and ongoing communication about the benefits and challenges of this approach to remedy as well as the timeframe of enhanced MNR implementation would help to better inform the river community.

***(2) Whether the proposed solution has been successfully attempted previously or is innovative***

*Where the solution has been successfully implemented in the past*

Enhanced MNR through the addition of clean sediment and reliance on hydrodynamics to drive dispersion and mixing has not been implemented at other contaminated sediment sites on the scale being evaluated here. It is a new, unproven technology.

*Status of the technology/innovation status/reliability*

Enhanced MNR through the addition of clean sediment and reliance on hydrodynamics to drive dispersion and mixing has not been implemented at other contaminated sediment sites on the scale being evaluated here. It is a new, unproven technology.

*Capital costs*

Capital costs associated with enhanced MNR are estimated at approximately $307,570,000 for addition of clean sediment to achieve the 500 ng/g PRG, and $965,580,000 for addition of clean sediment to achieve the 300 ng/g PRG.

*O&M costs*

Long term O&M costs associated with enhanced MNR include post-implementation monitoring every three years for 10 years to evaluate the rate and extent of sediment mixing and redistribution, followed by long term system recovery monitoring at the same 3-year interval for the remainder of the 45-year long term monitoring period. The total estimated cost for enhanced MNR monitoring over 45 years is approximately $18,300,000 to achieve the 500 ng/g PRG and

$21,620,000 to achieve the 300 ng/g PRG. Costs do not include reapplication of clean sediment as part of the O&M.

*Total costs*

The total estimated cost for enhanced MNR is $335,870,000 to achieve the 500 ng/g PRG and $997,200,000 to achieve the 300 ng/g PRG. A pilot study has been included in these estimated costs for enhanced MNR; numerical modeling, particle tracking and pilot-scale testing would be needed to evaluate the potential viability of this remedial alternative, either on a system-wide scale or for discrete portions of the Estuary such as Orland River.

***(4) The length of time to complete the recommendations***

*Time to implement the remedy*

Addition of clean sediment, planning for and establishment of the monitoring program and coordination with state agencies on updates to institutional controls could be implemented within one year to achieve the 500 ng/g PRG, and four years to achieve the 300 ng/g PRG.

*Time until remedial action objectives are achieved*

With the existing data for the Estuary, recovery periods to achieve RAOs protective of consumers and biota cannot be predicted with certainty. Implementation of the remedy would be expected to reduce the concentration of mercury in mobile sediments in the Estuary within a few years, although transport modeling and pilot testing are required to define a more precise dispersion and mixing interval. Because mobile sediment ultimately contributes to deposition on marsh platforms, reducing the concentration of mercury in mobile sediments will ultimately result in decreasing mercury concentrations in the biological mixed depth (0–6 inches) on marsh platforms, although the timeframe for marsh platform recovery is also uncertain.

This alternative includes long term monitoring as part of an adaptive management approach to remediation. Development and implementation of an iterative monitoring program would focus on both evaluating progress toward system recovery and refining understanding of the projected system recovery rate following remedy implementation. It is expected that the monitoring program would include sediment, surface water, and biota sampling, and would focus on recovery targets based on total mercury and/or methyl mercury concentrations (as appropriate) in sediment, surface water (including total suspended solids) and biota.

Results of the monitoring program would be used to estimate the time required to achieve RAOs.

***(5) The likely effectiveness of the solution***

*Reduction in amount of/concentration of mercury/methyl mercury available in the Penobscot System/available to receptors after remediation*

Enhanced MNR through addition of clean sediment to dilute mercury concentrations in mobile sediment in the Estuary is an unproven technology. With respect to reducing sediment mercury concentrations below the PRG, this remedial alternative requires further assessment through pilot testing implementation in a portion of the estuary before potential effectiveness can be evaluated.

*Reduction of risk to people*

There would be little to no reduction of risk to people in the short term. If effective, enhanced MNR would result in risk reduction in the long term by reducing mercury concentrations in the food web and therefore ultimately reducing risks to people from consumption of biota; long term risk reduction would be assessed through the long term ecological recovery monitoring program. Institutional controls (warn, advise and educate people on the risks associated with consumption of biota at certain rates) would be maintained and expanded if necessary based on biota monitoring to continue to mitigate risks to consumers in the short and long term.

*Reduction of risk to biota*

There would be little to no reduction of risk to biota in the short term. Enhanced MNR would result in risk reduction for biota in the long term by reducing mercury concentrations in mobile sediment throughout the Estuary, thereby ultimately reducing food web exposure to methylated mercury, although the rate and extent of this risk reduction is uncertain Because it would take some years for cleaner (i.e., mixed and diluted) mobile sediment to deposit on marsh platforms, risk reduction to song birds and ducks would generally be expected to take longer than risk reduction to fish and shellfish, although relationships between total mercury concentration, mercury methylation rate, and methyl mercury transfer into the food web are likely sufficiently different on the marsh platform versus in subaqueous zones that relative recovery rates are not quantified in this general evaluation. Risk reduction would be assessed through long term biota recovery monitoring.

*Permanence of the remedy/remedy effectiveness*

Enhanced MNR would be expected to be a permanent, effective remedy since it would reduce mercury concentrations in mobile sediment throughout the Estuary, thereby reducing food web exposure. The potential effectiveness of enhanced MNR should be further assessed through pilot testing implementation in a portion of the estuary before the permanence of the remedy can be evaluated. Successful application of enhanced MNR assumes the mercury concentrations in mobile sediment are permanently reduced through addition of clean sediment. If erosional events occur, however, buried sediment with higher mercury concentrations could become mobilized and would result in increased mobile sediment mercury concentrations. Under this scenario, additional clean sediment would be required to maintain the effectiveness of the enhanced MNR remedy. If post-implementation monitoring indicated that sediment mercury concentrations were increasing over time, the need for reapplication of clean sediments or employment of other remedial strategies would be evaluated under an adaptive management approach.

***(6) Any potential environmental harm that may be caused by the proposed solution***

*Adverse environmental impacts from remediation*

Potential adverse environmental impacts in the short term from addition of clean sediments under enhanced MNR would include water column turbidity during direct addition or resuspension if added material was placed on the sediment bed. If sediment addition results in increased water column turbidity, there may be impacts on protected species and habitats. Placement of clean sediments for enhanced MNR could also affect bathymetry with resultant potential impacts on navigational channels in the Estuary. In the long term, impacts to biota would be reduced. The extent of risk reduction achieved through enhanced MNR would be assessed through long term biota recovery monitoring.

*Short and long term impacts to the community*

Short term impacts to the community from addition of clean sediment under enhanced MNR may include increased vehicular traffic on roads, and increased vessel traffic on the water. Short term impacts would be mitigated through compliance with applicable requirements during implementation. If successful, long term impacts would include reductions in recovery time frames.

*Short term impact to workers*

Short term impacts to workers from addition of clean sediment under enhanced MNR and ongoing monitoring activities would be mitigated by conducting these activities in accordance with contractor health and safety program requirements to mitigate risks during implementation. No significant impacts to workers from clean sediment addition are expected.

*Sustainability/green remediation factors*

If pilot testing confirms that this approach to system remedy is viable, enhanced MNR could serve as a sustainable approach to accelerating system recovery. Implementation of enhanced MNR would be a lower impact approach to remedy in the Estuary than dredging/excavation, although the integrated environmental impacts of sourcing, transporting and distributing the clean borrow material are currently unquantified and the time frame over which the application of enhanced MNR would result in successful remedy are uncertain.

## 8.2 MAIN CHANNEL OF PENOBSCOT RIVER AND ORLAND RIVER ALTERNATIVES

The remedial alternative that was developed to reduce area weighted average concentrations of mercury in surface sediment in the main channel of the Estuary and the Orland River is:

- Alternative 3: Dredging

### 8.2.1 Alternative 3: Dredging

Dredging is an active remedial approach that removes mercury contaminated sediment to achieve a permanent risk reduction within a short time period. Dredging contaminated sediment and backfilling with clean sediment would reduce the area weighted average concentration of total mercury within the dredge footprint to below the PRG. The dredging alternative includes pocket and fringe marshes along the main Estuary channel with the exception of Mendall Marsh. Dredging in Mendall Marsh is not necessary to meet the 500 ng/g PRG but would be required to meet the 300 ng/g PRG. Proposed dredge areas are shown on **Figures 5-8-1 through 5-8-16**.

Dredging in the main channel of the Estuary and in Orland River to meet target PRGs of either 500 ng/g or 300 ng/g total mercury would include removing:

- Surface deposits of wood waste and mineral sediment:

– 500 ng/g and 300 ng/g PRG: estimated dredge volume 950,000 cy

- Main channel of Penobscot River Estuary:

– 500 ng/g PRG: estimated dredge 1,700,000 cy of surface sediments (6-inch dredge with 6-inch over-dredge) and backfill with 12 inches clean sediment (containing 20 ng/g mercury)

– 300 ng/g PRG: estimated dredge 9,800,000 cy of surface sediments (6-inch dredge with 6-inch over-dredge) and backfill with 12 inches clean sediment (containing 20 ng/g mercury)

- Orland River, Verona East and Northeast Channels:

– 500 ng/g and 300 ng/g PRG: dredge 1,800,000 cy of surface sediments (6-inch dredge with 6-inch over-dredge) and backfill with 12 inches clean sediment (containing 20 ng/g mercury)

A total of 4,450,000 cy of dredged sediments (500 ng/g PRG) or 12,550,000 cy of dredged sediments (300 ng/g PRG) would be dewatered, stabilized, and transported off site. This material would be beneficially reused or disposed of at a permitted non-hazardous waste landfill facility.

Post-removal monitoring would be conducted every three years for 10 years to confirm that concentrations of mercury in surface sediment meet the relevant PRG. Long term monitoring would include monitoring of sediment total mercury concentrations to achieve the relevant PRG and monitoring of total mercury and methyl mercury in biota to evaluate progress toward ecological recovery.

***(1) Viability of remedy***

*Ability to construct and/or operate the remedial alternative*

Dredging would require a high level of effort to prepare permits and obtain regulatory approvals, construct landside offloading/material management areas, procure large quantities of backfill (clean sediment), mobilize equipment, dredge and backfill large quantities of sediments, dewater and stabilize dredged sediments, and transport stabilized sediments to off-site beneficial reuse or landfill facilities. In addition, access agreements with landowners would be required for privately owned intertidal and marsh areas identified for remedy.

A pre-construction period of five years is estimated to prepare permits and obtain regulatory approvals, construct landside offloading/material management areas, procure backfill and equipment, and establish access agreements.

Due to time constraints for conducting in-water work within the annual environmental window (assumed to be July 15 through November 30, with 112 working days per year), production rates during daily workable tidal conditions, and limitations on daily capacity for sediment processing, transportation, and off-site reuse or landfill facilities, it is estimated that it would require approximately 22 years to achieve the 500 ng/g PRG, and 58 years to achieve the 300 ng/g PRG. Work durations for dredging are based on a 12-hour work day; duration would be reduced by 50 percent if 24-hour operational hours were assumed. Work durations would also be reduced if the annual environmental window is extended.

*Applicable regulations, coordination with agencies, and permits and approvals needed*

Dredging, backfilling, dewatering, stabilization, and off-site transportation and beneficial reuse or disposal at a landfill facility would require extensive coordination with agencies and permitting to meet applicable requirements for performing in-water work. It is anticipated that the duration of permitting would be on the order of two to four years. Permitting would require consultation with regulatory agencies; the primary focus would be on mitigating potential impacts to protected species and habitats and maintaining navigational elevations.

*Community acceptance*

Community acceptance of dredging will largely depend on where and when it occurs and the involvement of those individuals and groups that may be directly impacted by the dredging activities. Recognizing that dredging would permanently remove contaminated sediments and reduce recovery times may be perceived for some as a benefit; whereas for others, concerns regarding re-distribution of impacted materials downstream into Penobscot Bay and significant alteration of the environment may result in perceptions that do not favor dredging. There has been identified concern regarding the potential for remedial activities to inadvertently result in expanded lobster and crab fishing closure areas. For example, some lobstermen indicated concern with active remedies that may cause mercury contaminated sediments to move into Penobscot Bay and result in additional closures. The associated disruptions to the use of the river and its resources as well as land-based activities (such as increased vehicular traffic and disposal of sediments) may also limit community acceptance. Information regarding monitoring during work activities as well as long-term monitoring could help to address some of the concerns that might be raised by individuals and groups.

***(2) Whether the proposed solution has been successfully attempted previously or is innovative***

*Where the solution has been successfully implemented in the past*

Dredging has been implemented at many contaminated sediment sites; it has been applied as a remedial strategy for decades using proven, conventional, and/or specialized equipment, and readily available construction methods. There could be limitations on equipment availability at the time that sediment removal activities would be implemented, in which case production rates would be constrained.

*Status of the technology/innovation status/reliability*

Dredging, backfilling, dewatering, stabilizing, and off-site transportation and beneficial reuse or landfill disposal of dredged sediments are all proven, reliable technologies that have been commonly implemented at many contaminated sediment sites for decades. These technologies use proven, conventional, and/or specialized equipment, and readily available construction methods.

***(3) The likely cost of the solution***

*Capital costs*

Capital costs associated with dredging are estimated as follows:

- PRG 500 ng/g off-site beneficial reuse: $1,295,320,000
- PRG 500 ng/g off-site disposal: $1,713,820,000
- PRG 300 ng/g off-site beneficial reuse: $4,388,280,000
- PRG 300 ng/g off-site disposal: $5,544,190,000

*O&M costs*

Long term O&M costs associated with the dredging alternative include post-placement sampling and long term monitoring. Post-placement sampling would include three sampling intervals over

10 years with the goal of confirming that backfill sediment has remained in place. Long term monitoring would include total mercury concentrations in sediment and total mercury and methyl mercury in biota to evaluate progress toward ecological recovery. The total estimated O&M costs are approximately $12,460,000 for the 500 ng/g PRG scenario and $15,780,000 for the 300 ng/g PRG scenario.

*Total costs*

The total estimated cost for dredging to achieve the 500 ng/g PRG is approximately $1,307,780,000 for off-site beneficial reuse and $1,726,280,000 for off-site disposal.

The total estimated cost for dredging to achieve the 300 ng/g PRG is approximately $4,404,060,000 for off-site beneficial reuse and $5,559,970,000 for landfill disposal.

Cost estimates are presented in **Appendix J.** O&M costs are summarized in **Table 7-2**.

***(4) The length of time to complete the recommendations***

*Time to implement the remedy*

The time to implement the dredging remedy is estimated at approximately 27 years (five years pre-construction and 22 years construction) for the 500 ng/g scenario, and 63 years (five years pre-construction and 58 years construction) for the 300 ng/g scenario. Post-dredge monitoring would be conducted for 10 years for both the 500 ng/g and 300 ng/g PRG scenarios. Work durations for dredging are based on a 12-hour work day and would be reduced by half if 24-hour operational hours were used. Work durations would also be reduced if the annual environmental window (assumed to be July 15 through November 30, with 112 working days per year) is extended.

*Time until remedial action objectives are achieved*

For the main channel of the Estuary, the PRG would be reached when dredging was completed. This alternative would implement an iterative monitoring program that would both evaluate progress toward system recovery and refine understanding of the projected system recovery rate post-remedy. It is expected that the monitoring program would include sediment, surface water, and biota sampling, and would focus on recovery targets based on total mercury and/or methyl mercury concentrations (as appropriate) in sediment, surface water (including total suspended solids), and biota. Results of the monitoring program would be used to estimate the time required to achieve RAOs.

***(5) The likely effectiveness of the solution***

*Reduction in amount of/concentration of mercury/methyl mercury available in the Penobscot System/available to receptors after remediation*

Dredging would be effective in both the short and long term because it would achieve permanent reductions in sediment mercury concentrations and would achieve the relevant PRG upon completion of removal activities.

*Reduction of risk to people*

Dredging and backfilling with clean sediments would reduce the sediment mercury concentration incrementally over the duration of dredging and would result in risk reduction over the long term. Long term risk reduction would include reducing mercury uptake and transfer through the food web, as well as reducing risks to humans from consumption of biota. Long term risk reduction would be assessed through a long term monitoring program. Institutional controls (warn, advise and educate people on the risks associated with consumption of biota at certain rates) would be maintained and expanded, if necessary, based on biota monitoring over time with the goal of continuing to mitigate risks to consumers in the short and long term.

*Reduction of risk to biota*

There would be short and long term reduction in risks to biota through removal of contaminated sediments. Implementation of this remedy alone (without an accompanying remedy for Mendall Marsh) is not expected to reduce risks for song birds in the short term. Risk reduction for biota in Mendall Marsh would occur over the long term because of declining mercury concentrations in the mobile sediments that are transported into the marsh and deposited in both the intertidal zone and on the marsh platform.

*Permanence of the remedy/remedy effectiveness*

Dredging and backfilling with clean sediment that has been appropriately graded to prevent erosion would be a permanent, effective remedy because there would be immediate reductions in mercury concentrations in surface sediments. Effectiveness of the remedy would be confirmed through post-removal sediment monitoring to confirm achievement of the relevant PRG.

If post-remedy monitoring indicates that sediment mercury concentrations are increasing or exceed the PRGs, the need for additional sediment removal or employment of other remedial strategies would be evaluated under an adaptive management approach.

***(6) Any potential environmental harm that may be caused by the proposed solution***

*Adverse environmental impacts from remediation*

Potential adverse environmental impacts in the short term from dredging would include resuspension of sediment in the Estuary while the dredge and backfill operation are in progress.

Impacts from sediment resuspension would be minimized through best management practices and would require coordination with agencies and permitting to meet applicable requirements for in-water work. The primary focus of minimizing resuspension and associated impacts would be on mitigating potential impacts to protected species/habitats as well as maintaining navigational elevations. In the long term, because the concentration of mercury in surface sediment would be reduced following dredging, impacts to the environment (biota and the food web) would be mitigated. Risk reduction as the result of dredging would be assessed through long term biota recovery monitoring.

*Short and long term impacts to the community*

Short and long term impacts to the community during dredging would be significant. Impacts would include increased use of local roads during construction and development of offloading/material management areas, disruptions to use of the waterway or resources in the reaches where in-water work is being conducted, increased vessel traffic on the water, and increased vehicular traffic to transport dredged material from the offloading/material management areas to areas identified for beneficial reuse or disposal. Dredging would be conducted during the environmental window in summer and fall and associated noise and disturbance may affect local tourism. In addition, much of the intertidal areas that could require dredging to achieve the PRGs are believed to be privately owned and approvals would be required from property owners prior to dredging. Notices to the community of the local construction schedules, as well as implementation and long term management of waterway access and roadway traffic management plans, would serve to minimize disruptions to some degree; however, due to the long time frame associated with implementation of the dredging alternative there would be long term impacts to the community. Dredge and backfill activities would involve numerous vessels and could impact navigation in the Estuary during on-water work.

*Short term impact to workers*

Short term impacts to workers from dredging and the associated activities would be mitigated by conducting activities in accordance with the contractor health and safety program requirements to mitigate risks during implementation.

*Sustainability/green remediation factors*

Dredging with off-site disposal and backfilling with off-site materials would not employ sustainable, green remediation technologies since large volumes of contaminated sediments would be removed and would require dewatering, stabilization, and off-site transportation for beneficial reuse or disposal at a landfill. If clean backfill materials could be procured from a location within the project area (such as Frankfort Flats) instead of from more distant borrow sources, the dredging alternative could be viewed as a more sustainable approach. For the east subtidal zone in Frankfort Flats, while the area weighted average concentration of total mercury is ~ 360 ng/g in the top 0 – 0.5 foot of sediment, the area weighted average concentration of total mercury at a depth greater than 0.5 feet may be < 100 ng/g to a depth greater than 3 feet, based on available core data. Additional coring in this reach/zone is warranted to confirm the overall low concentration of mercury in this area as determined in a small number of cores (n = 2) collected during the Phase III Study. If dredged sediments could be beneficially reused as fill for gravel pit closures or as road construction material, it would be a more sustainable, green remediation technology than off-site disposal in a landfill.

## 8.3 MENDALL MARSH ALTERNATIVES

Remedial alternatives developed to address mercury in surface sediment in Mendall Marsh consist of:

- Alternative 4: Thin Layer Capping
- Alternative 5: Amendment Application
- Alternative 6: Dredging in Intertidal Zones & Thin Layer Capping

### 8.3.1 Alternative 4: Thin Layer Capping

Thin layer capping is an in situ sediment management approach that relies on placement of clean sediment to reduce the concentration of mercury in the bioactive zone by the mixing of clean cap material and underlying native sediment. Placement of a thin layer cap on the marsh platform would reduce mercury concentrations in the bioactive zone, thereby reducing ecological exposure. Because the rate at which mercury is methylated is generally related to the total concentration of mercury present in marsh sediment, thin layer capping may result in reduced methylation rates and a decreased potential for biological update and trophic transfer of methyl mercury.

Two pilot-scale tests are recommended prior to implementation of this remedy: an initial test to assess potential impacts of cap material placement on vegetation, followed by a larger-scale test (likely in subsequent years) to evaluate the stability of the cap, and to assess the effectiveness of capping to reduce tissue mercury concentrations in biota from within the footprint of the pilot test area. It is expected that the pilot tests would be conducted on the scale of acres and that pilot test plots would encompass a range of marsh elevations and vegetation types. Details regarding the pilot tests, including engineering specifications, material specifications (i.e., sourcing, chemical characteristics and particle size limitations), timing of material placement relative to the growing season on the marsh, pilot study design and success metrics for evaluating ecological effectiveness of the thin layer cap will be developed during the pre-design phase of remedy.

Implementation of thin layer capping in Mendall Marsh assumes placement of 3 inches of clean sediment over the marsh platform, predominantly in elevation zones of between approximately 2 feet and 7.5 feet to achieve an area weighted average total mercury concentration of 500 ng/g in the bioactive zone. This elevation interval (2 feet to 7.5 feet) was selected based on the distribution of available mercury data and the conceptual understanding that mercury transport onto the marsh platform is a function of inundation extent (and therefore frequency). To place a thin layer cap on Mendall Marsh, approximately 191,000 cy of clean sediment would be placed in a 3-inch layer over approximately 50 percent of the marsh platform.

After placement of the thin layer cap, monitoring would be conducted to evaluate mercury concentrations on the marsh platform and progress toward ecological recovery in marsh biota. The thin layer cap alternative is designed to reduce the total mercury concentration on the marsh platform to below the 500 ng/g PRG. The remedial strategy evaluated for Mendall Marsh to lower total mercury concentration to below the 300 ng/g PRG would require excavation in the intertidal and subtidal zones. This alternative is discussed in Section 8.3.3

Thin layer capping of the marsh platform in Mendall Marsh would be evaluated for its ability to meet the specific evaluation criteria below. Thin layer capping could potentially be applied in other pocket and fringe marshes in the Estuary.

***(1) Viability of remedy***

*Ability to construct and/or operate the remedial alternative*

Thin layer capping would require a moderate to potentially significant level of effort to prepare permits and obtain regulatory approvals and to procure and place the cap material. Information obtained from pilot testing of cap material placement would be used in the development of a full-scale design.

Monitoring for cap material stability and ecological recovery following full-scale implementation would be viable, as would maintenance and updates (when appropriate) to institutional controls.

*Applicable regulations, coordination with agencies, and permits and approvals needed*

Placement of a thin layer cap would require extensive coordination with agencies and permitting to meet applicable requirements for performing work in the marsh. It is anticipated that permitting could require two to four years during the pre-construction phase of remedy implementation. It is anticipated that permitting would require consultation with regulatory agencies to meet a range of applicable requirements during remedy implementation.

*Community acceptance*

Mendall Marsh is perceived as high value environment that offers opportunities for wildlife viewing and enjoyment. Activities, such as thin layer capping, are anticipated to have favorable community acceptance because the exposure pathways that exceed the PRG would be reduced in a relatively short timeframe. Some individuals or groups may identify a concern with thin layer capping because cap material placement could result in short term disruptions to recreational use of the marsh. As well, some may identify concerns related to change to marsh ecosystem and the ability for the marsh to recover. Information regarding pilot testing, placement and monitoring during work activities as well as long-term monitoring could help to address some of the concerns that might be raised by individuals and groups.

*Where the solution has been successfully implemented in the past*

Thin layer capping is a proven technology that has been implemented at other sediment sites to enhance site-specific natural recovery processes (Merritt et al., 2011). Application of thin layers of sediment to marsh platforms has been more typically applied to address marsh disturbance or marsh platform subsidence resulting from a lack of natural sedimentation (e.g., Slocum et al. 2005; Stagg and Mendelssohn 2011). Thus, application of a thin layer cap to Mendall Marsh to reduce biological exposure to methylated mercury on the marsh platform is somewhat innovative.

*Status of the technology/innovation status/reliability*

Thin layer capping is gaining acceptance in both the industry and regulatory community as a low impact remedy for contaminated sediment sites.

***(3) The likely cost of the solution***

*Capital costs*

Capital costs associated with thin layer capping to achieve the PRGs on the Mendall Marsh platform are estimated at approximately $52,640,000.

*O&M costs*

O&M costs associated with the thin layer capping alternative include post-placement monitoring of sediment every three years for 10 years to evaluate the in-place stability of cap material, followed by long term ecological recovery monitoring. The total estimated cost for monitoring over a period of 45 years assumed for costing purposes for thin layer capping in Mendall Marsh is approximately $5,910,000. Costs do not include reapplication of the thin layer cap as part of the O&M.

*Pilot study costs*

Two pilot-scale tests are recommended prior to implementation of this remedy: an initial test to assess potential impacts of cap material placement on vegetation, followed by a larger-scale test (likely in subsequent years) to evaluate the stability of the cap, and to assess the effectiveness of capping to reduce tissue mercury concentrations in biota from within the footprint of the pilot test area. It is expected that the pilot tests would be conducted on the scale of acres and that pilot test plots would encompass a range of marsh elevations and vegetation types. Pilot tests will cost approximately $7,500,000.

*Total costs*

The total estimated cost for thin layer capping of Mendall Marsh is approximately $66,050,000. Cost estimates are presented in **Appendix J** and O&M costs are summarized in **Table 7-2**.

***(4) The length of time to complete the recommendations***

*Time to implement the remedy*

Pilot tests and associated monitoring is expected to take five to seven years.

The time to implement the thin layer cap at full-scale is estimated at approximately seven years (five years pre-construction and two years construction) after completion of pilot testing. Post-placement monitoring would be conducted for 10 years. Work durations for cap material placement are based on a 12-hour work day and would be reduced by half if 24-hour operational hours were used. To the extent that cap material placement requires an in-water work component for material transport, work durations would also be reduced if the annual environmental window (assumed to be July 15 through November 30, with 112 working days per year) is expanded.

*Time until remedial action objectives are achieved*

The placement of a thin layer cap will result in the immediate reduction in the area weighted average total mercury concentration on the marsh platform to below the 500 ng/g PRG. Biota recovery following thin layer cap placement would be monitored through a long term ecological recovery monitoring plan.

The program would develop and implement an iterative long term monitoring program that would both evaluate progress toward system recovery and refine understanding of the projected post-remedy system recovery rate for Mendall Marsh. It is expected that the monitoring program would include sediment and biota sampling and would focus on recovery targets based on total mercury and/or methyl mercury concentrations (as appropriate) in sediment and biota. It is expected that recontamination of the cap surface will occur based on material transport, inundation and sedimentation from the main channel. One principal objective of long term monitoring in Mendall Marsh will therefore be the ongoing evaluation of changes to the total mercury concentration integrated across the biological mixed depth on the marsh platform. Results of the monitoring program would be used to estimate the time required to achieve RAOs for Mendall Marsh.

***(5) The likely effectiveness of the solution***

*Reduction in amount of/concentration of mercury/methyl mercury available in the Penobscot System/available to receptors after remediation*

Thin layer capping is likely to be effective in the short term because there would be an immediate reduction in the total mercury concentration in the biological mixed zone following placement of the thin layer cap.

*Reduction of risk to people*

There would be little to no reduction of risk to people in the short term. Thin layer capping would result in risk reduction in the long term by reducing mercury concentrations in the food web (specifically, some reduction in black duck tissue mercury concentrations) and risks to people from consumption of biota, with long term risk reduction being assessed through long term monitoring. Institutional controls (warn, advise and educate people on the risks associated with consumption of biota at certain rates) would be maintained and expanded, if necessary, based on biota monitoring to mitigate risks to consumers in the short and long term.

*Reduction of risk to biota*

There would be reduction in risks to biota (song birds) on the marsh platform through the reduction in total mercury concentration within the biological mixed zone following thin layer cap placement. Because the rate at which mercury is methylated is related to the total concentration of mercury present in marsh sediment, it is expected that thin layer capping would result in reduced methylation rates and a decreased potential for biological update and trophic transfer of methyl mercury. Risk reduction to acceptable levels in biota may not be achieved without an active remedy in the intertidal areas (Section 8.3.3), however, because a portion of the food source for both song birds and black ducks is within the intertidal areas. Risk reduction would be assessed through long term ecological recovery monitoring.

*Permanence of the remedy/remedy effectiveness*

Thin layer capping may be a permanent, effective remedy because there would be reductions in total mercury concentrations in surface sediments which would result in reduced biological exposure to mercury on the marsh platform. Pilot testing of this alternative is recommended to confirm that cap material placement does not result in negative impacts to marsh ecological function. The long term effectiveness of thin layer capping in Mendall Marsh will be influenced by remedial decisions for the main channel because of the potential for recontamination of the marsh platform through transport and deposition of mobile sediment from the main channel. While the performance life of the cap can be estimated as a function of recontamination rate (i.e., as a function of inundation/sedimentation from mobile sediment with an estimated total mercury concentration), design constraints on the physical stability of cap material which could impact long term remedy effectiveness require further evaluation.

***(6) Any potential environmental harm that may be caused by the proposed solution***

*Adverse environmental impacts from remediation*

Potential adverse environmental impacts in the short term from placement of a thin layer cap of clean sediments would be minimized through coordination with agencies and permitting to meet applicable requirements for performing work on the marsh platform. Environmental impacts of cap material placement could include impacts to protected species/habitats through both the material application rate and the impact of cap material addition on marsh platform elevations. Pilot studies are recommended to assess the impact of cap material placement on marsh biota and vegetation prior to full scale implementation of this remedy.

*Short and long term impacts to the community*

Short term impacts to the community from placement of a thin layer cap of clean sediments on the marsh platform are expected to be minimal and would be mitigated through compliance with applicable requirements during implementation. Long term impacts would be assessed through post-placement monitoring.

*Short term impact to workers*

Short term impacts to workers from placement of a thin layer cap and ongoing monitoring activities would be mitigated by conducting the work in accordance with the contractor health and safety program requirements.

*Sustainability/green remediation factors*

Thin layer capping would employ sustainable, green remediation technologies in the short term, because placement of clean sediments does not disturb contaminated sediments or require handling, processing, or disposal technologies. In the long term, thin layer capping would be a sustainable approach to enhancing system recovery in Mendall Marsh.

### 8.3.2 Alternative 5: Amendment Application

Amendment application is an in-place sediment management approach that relies on the broadcasting of amendments onto the marsh platform. Application of amendments is designed to enhance sorption of methyl mercury to carbon substrate so that biological transfer of methyl mercury from sediment porewater into organisms is reduced.

Two pilot-scale tests are recommended prior to implementation of this remedy: an initial test to assess potential impacts of amendment application on marsh vegetation, followed by a larger-scale test (likely in subsequent years) to assess the effectiveness of amendment addition at reducing mercury concentrations in biota tissue from within the footprint of the pilot test area. The larger scale pilot study should be designed to encompass a larger area of the marsh that encompasses a range of marsh elevations and vegetation types to allow evaluation of influences that can affect mercury methylation rates, such as the extent and frequency of inundation. The larger scale pilot study also should incorporate biota sampling to evaluate uptake of methyl mercury within the pilot study area.

Amendment application at Mendall Marsh assumes broadcast placement of SediMite™, a carbon-based amendment, over the Mendall Marsh platform across the elevation range of 2 feet to 9 feet above mean sea level. Thus, for this remedy, approximately 9,000 cy of SediMite™ would be applied over approximately 470 acres. While amendment addition is evaluated here for Mendall Marsh, amendments could theoretically also be applied to the pocket and fringe marshes in the Estuary.

After placement of the amendments, monitoring would include assessment of the persistence and burial rate of amendment carbon and evaluation of the effectiveness of amendment addition at reducing biota tissue concentrations of methyl mercury.

***(1) Viability of remedy***

*Ability to construct and/or operate the remedial alternative*

Application of amendments would require a moderate to potentially significant level of effort to prepare permits and obtain regulatory approvals, and to procure and apply the amendments onto the marsh. Additional pilot-scale testing is recommended to evaluate the effectiveness of the remedial technology, as well as any potential negative impacts to plants and biota from amendment application. Pilot-scale testing of the amendments is needed to assess the effectiveness of the technique, including the potential necessity for amendment re-application. As noted in Section 2.3.5 (Technical Memorandum Amendment Test Plot Resampling Study) and Section 6.7 (In Situ Treatment), test plot studies of amendment application to Mendall Marsh are inconclusive as to whether amendments, either applied as a stand-alone remedy or incorporated into a thin layer cap, result in decreased biological update and trophic transfer of methyl mercury.

After placement of the amendment, continued monitoring, evaluation of concentration trends and recovery predictions, and updates to institutional controls would be implemented and maintained.

*Applicable regulations, coordination with agencies, and permits and approvals needed*

Placement of amendments would require extensive coordination with agencies and permitting to meet applicable requirements for performing work in the marsh. It is anticipated that the duration of permitting could be on the order of two to four years during the pre-construction phase of remedy implementation and would require consultation with regulatory agencies. It is anticipated that the primary focus of consultations with regulatory agencies would be on mitigating potential impacts to protected species and habitats from amendment application.

*Community acceptance*

As previously identified, Mendall Marsh is perceived as high value environment that offers opportunities for wildlife viewing and enjoyment. Similar to thin layer capping, it is anticipated that an amendment application to Mendall Marsh would be perceived as favorable due to the relatively rapid decrease in potential mercury exposure for biota on the marsh platform. Some individuals or groups may identify a concern with the application of an amendment due to short term disruptions to recreational use of the marsh. As well, some may identify concerns related to the use of innovative or unproven technologies, and how they may change the marsh ecosystem and the ability for the marsh to recover. Information regarding pilot testing, placement and monitoring during work activities as well as long-term monitoring could help to address some of the concerns that might be raised by individuals and groups.

***(2) Whether the proposed solution has been successfully attempted previously or is innovative***

*Where the solution has been successfully implemented in the past*

Amendments have been applied at other contaminated sediment sites in recent years, as detailed in Chapter 19 of the Phase II Report (PRMSP 2013), although not always with a focus on mercury remediation, as well as applied to small scale test plots in Mendall Marsh as part of the Phase II Study. Based on the limited availability of data demonstrating field-scale effectiveness of this technique at reducing biological update and trophic transfer of mercury or methyl mercury, a pilot-scale study is recommended prior to full scale implementation. Test plot studies of amendment application to Mendall Marsh are inconclusive as to whether amendments, either applied as a stand-alone remedy or incorporated into a thin layer cap, result in decreased biological update and trophic transfer of methyl mercury.

*Status of the technology/innovation status/reliability*

Amendments are a new, innovative technology that is gaining acceptance in the industry and regulatory community as low-impact remedial strategy for some contaminants in some locations. Application of amendments requires further testing, including pilot-scale as well as field-scale application for evaluation of effectiveness at reducing biological uptake of methyl mercury. There are currently no data available for evaluating the long term effectiveness of amendment addition for mercury-impacted sites.

***(3) The likely cost of the solution***

*Capital costs*

Capital costs associated with amendment application are estimated at approximately $37,080,000 for Mendall Marsh. Capital costs assume a single amendment application rate.

*O&M costs*

Long term O&M costs associated with the amendment application alternative include post-placement monitoring of amendments every three years for 10 years to evaluate mercury sediment concentrations, the depth of the black carbon layer, and biota recovery, followed by long term system recovery monitoring. The total estimated cost for monitoring over a period of 45 years assumed for costing purposes for amendment addition to Mendall Marsh is approximately $6,290,000. Costs do not include amendment reapplication as part of O&M.

*Pilot test costs*

Two pilot-scale tests are recommended prior to implementation of this remedy: an initial test to assess potential impacts of amendment application on marsh vegetation, followed by a larger-scale test (likely in subsequent years) to assess the effectiveness of amendment addition at reducing mercury concentrations in biota tissue from within the footprint of the pilot test area. Pilot scale tests will cost approximately $7,500,000.

*Total costs*

The total estimated cost for placement of amendments followed by 10 years of monitoring is approximately $50,870,000. Cost estimates are presented in **Appendix J** and O&M costs are summarized in **Table 7-2**.

***(4) The length of time to complete the recommendations***

*Time to implement the remedy*

Pilot tests and associated monitoring is expected to take five to seven years.

The time to implement the amendment application at full-scale is estimated at approximately six years (five years pre-construction and one year for construction) after completion of pilot testing. Post-placement monitoring would be conducted for 10 years. Work durations for amendment addition are based on a 12-hour work day and would be reduced by half if 24-hour operational hours were used. To the extent that amendment application requires an in-water work component for material transport, work durations would also be reduced if the annual environmental window (assumed to be July 15 through November 30, with 112 working days per year) is expanded.

*Time until remedial action objectives are achieved*

Recovery periods to achieve RAOs that would be protective of consumers and biota cannot be predicted with certainty.

The program would develop and implement an iterative long term monitoring program that would both evaluate progress toward system recovery and refine understanding of the projected post-remedy system recovery rate for Mendall Marsh. It is expected that the monitoring program would focus on recovery targets based on total mercury and/or methyl mercury concentrations in biota.

Results of the monitoring program would be used to estimate the time required to achieve RAOs.

***(5) The likely effectiveness of the solution***

*Reduction in amount of/concentration of mercury/methyl mercury available in the Penobscot System/available to receptors after remediation*

Amendment application effectiveness would need to be further assessed during pilot-scale studies. Test plot studies of amendment application to Mendall Marsh are inconclusive as to whether amendments, either applied as a stand-alone remedy or incorporated into a thin layer cap, result in decreased biological update and trophic transfer of methyl mercury.

*Reduction of risk to people*

There would be little to no reduction of risk to people in the short term. If pilot studies indicate that amendment application is an effective treatment technology, long term risk would be reduced by reducing mercury concentrations in the food web, as well as risks to people from consumption of biota. Long term risk reduction would be assessed through a long term monitoring program. Institutional controls (warn, advise and educate people on the risks associated with consumption of biota) would be maintained and expanded if necessary, based on long term biota monitoring, to continue to mitigate risks to consumers in the short and long term.

*Reduction of risk to biota*

If pilot studies indicate amendment application is an effective treatment technology and amendments are applied successfully on the field scale, application could result in lowered risks to biota through the effectiveness of amendments at reducing biological uptake and trophic transfer of mercury or methyl mercury. Risk reduction to acceptable levels in biota may not be achieved without an active remedy in the intertidal areas of the marsh, because a portion of the food source for both song birds and black ducks originated in the intertidal areas. Risk reduction would be assessed through long term biota recovery monitoring. Further discussion of remedy in the intertidal area of Mendall Marsh is presented in Section 8.3.3.

*Permanence of the remedy/remedy effectiveness*

It is unknown whether application of amendments would be a permanent, effective remedy to reduce risks to biota. Effectiveness would need to be further assessed in pilot-scale studies during pre-design activities. The long term effectiveness of amendment addition would also be influenced by remedial decisions for the main channel because of the potential for recontamination of the marsh platform through transport and deposition of mobile sediment from the main channel. Test plot studies of amendment application to Mendall Marsh are inconclusive as to whether amendments, either applied as a stand-alone remedy or incorporated into a thin layer cap, result in decreased biological update and trophic transfer of methyl mercury.

***(6) Any potential environmental harm that may be caused by the proposed solution***

*Adverse environmental impacts from remediation*

Potential adverse environmental impacts include potential negative impacts to plant and animal species on the marsh resulting from amendment application. The potential for these impacts from placement of amendments would be evaluated during pilot studies. Coordination with agencies and permitting to meet applicable requirements for performing work on the marsh platform, with a primary focus on mitigating potential impacts to protected species and habitats, would also be required. Risk reduction would be assessed through the long term ecological recovery monitoring program.

*Short and long term impacts to the community*

Short term impacts to the community from amendment application on the marsh platform would be mitigated through compliance with applicable requirements during implementation. Long term impacts would be assessed through post-placement monitoring.

*Short term impact to workers*

Short and long term impacts to workers from placement of amendments and ongoing monitoring activities would be mitigated by conducting the work in accordance with the contractor health and safety program requirements.

*Sustainability/green remediation factors*

Amendment application would employ sustainable, green remediation technologies in the short term because placement of amendments would not disturb contaminated sediments and so would not require handling, processing, or disposal technologies. In the long term, amendment addition could be a sustainable approach to enhancing ecological recovery within the bioactive zone on marsh platforms.

### 8.3.3 Alternative 6: Dredging in Intertidal and Subtidal Zones & Thin Layer Capping

This alternative includes dredging of sediments in the intertidal and subtidal zones of Mendall Marsh along with thin layer capping on the marsh platform to meet a PRG of 300 ng/g total mercury for Mendall Marsh. In the intertidal and subtidal zones of Mendall Marsh, this alternative would entail dredging 530,000 cy of sediments (the top 6 inches of the surface sediments and 6 inches of over-dredge) and backfilling with clean sediment. Dredged sediments would be dewatered, stabilized, and transported off site and either beneficially reused or disposed of at a permitted non-hazardous waste landfill facility. Post-removal monitoring would be conducted every three years for 10 years to confirm that the area weighted average total mercury concentration in the dredged area remains below the PRG.

For the marsh platform, a thin layer cap would be placed over approximately 240 acres, with a total volume of cap material (clean sediment) of approximately 191,000 cy. Post-placement monitoring of the cap thickness would be conducted every three years for 10 years.

Proposed areas for sediment dredging and marsh platform thin layer capping are shown on **Figures 5-8-13 and 5-8-14**.

The evaluation of this alternative against the six evaluation criteria are generally the same as for Alternatives 3 and 4 (see Sections 8.2.1 and 8.3.1), with the exception of the community acceptance aspect of Criterion 1, costs (Criterion 3), and the length of time to complete the recommendations (Criterion 4).

Regarding community acceptance (Criterion 1), Mendall Marsh is perceived as high value environment that offers opportunities for wildlife viewing and enjoyment. As described in Section 8.2.1 (Alternative 3: Dredging), community acceptance of dredging will largely depend on where and when it occurs and the involvement of those individuals and groups that may be directly impacted by the dredging activities. Recognizing that dredging would permanently remove contaminated sediments and reduce recovery times may be perceived for some as a benefit; whereas for others, concerns regarding, in this case, impacts to Mendall Marsh may result in perceptions that do not favor dredging. The associated disruptions to the use and/or enjoyment of the marsh and its resources may limit community acceptance to dredging within Mendall Marsh.

With respect to the capping component of this alternative, as described in Section 8.3.1 (Alternative 4: Thin Layer Capping), thin layer capping is anticipated to have favorable community acceptance because the exposure pathways that exceed the PRG would be reduced in a relatively short timeframe. Some individuals or groups may identify a concern with thin layer capping because cap material placement could result in short term disruptions to recreational use of the marsh. As well, some may identify concerns related to change to marsh ecosystem and the ability for the marsh to recover.

***(3) The likely cost of the solution***

*<u>Capital costs</u>*

Capital costs associated with dredging are estimated as follows:

- PRG 300 ng/g off-site beneficial reuse: $125,870,000
- PRG 300 ng/g off-site disposal: $174,050,000

Capital costs associated with thin layer capping on the Mendall Marsh platform are estimated at approximately $52,640,000.

*O&M costs*

Long term O&M costs associated with the dredging include post-placement sampling with three sampling intervals over 10 years with the goal of confirming that backfill sediment remains in place, as well as long term recovery monitoring of both sediment and biota. The total estimated cost for O&M costs are approximately $11,250,000.

Long term O&M costs associated with the thin layer capping alternative include post-placement monitoring of sediment every three years for 10 years to evaluate cap material stability and the rate and extent of cap recontamination, followed by long term system recovery monitoring. The total estimated cost for monitoring over a period of 45 years for thin layer capping in Mendall Marsh is approximately $5,910,000. Costs do not include reapplication of cap material as part of the O&M.

As with costs discussed for thin layer capping (Alternative 4), two pilot-scale tests are recommended prior to implementation of this remedy: an initial test to assess potential impacts of cap material placement on vegetation, followed by a larger-scale test (likely in subsequent years) to evaluate the stability of the cap, and to assess the effectiveness of capping to reduce tissue mercury concentrations in biota from within the footprint of the pilot test area. It is expected that the pilot tests would be conducted on the scale of acres and that pilot test plots would encompass a range of marsh elevations and vegetation types. Pilot scale tests will cost approximately $7,500,000.

*Total costs*

The total estimated cost for dredging to achieve the 300 ng/g PRG is approximately $137,120,000 (dredge with off-site beneficial reuse) to $185,300,000 (dredge with off-site disposal). The cost for the thin layer capping component of this remedy is presented separately. Cost estimates are presented in **Appendix J** and O&M costs are summarized in **Table 7-2**. The total integrated cost for this alternative, including both dredging in intertidal zones and thin layer capping on the marsh platform, ranges from approximately $203,170,000 (dredging with off-site beneficial reuse for dredge materials and thin layer capping on the marsh platform) to $251,350,000 (dredging with off-site disposal for dredge materials and thin layer capping on the marsh platform).

Regarding the length of time to complete the recommendations (Criterion 4), it is estimated that dredging within the intertidal zone in Mendall Marsh would take two years of construction. The time to implement the thin layer cap at full-scale is estimated at approximately seven years (five years pre-construction and two years construction) after completion of pilot testing. Pilot testing of the thin layer cap is estimated to take five to seven years. Dredging activities in the intertidal zone in Mendall Marsh should be completed prior to placement of the thin layer cap.

## 8.4 DISCUSSION OF REMEDIAL ALTERNATIVES

This section summarizes the remedial alternatives that were developed and evaluated for the Penobscot River Estuary—either on a system-wide basis or for specific reaches – and discusses the rationale for combining different alternatives or portions of alternatives to achieve system-wide reductions in risks to consumers and biota. Recommendations on how remedial alternatives could be implemented as stand-alone remedies and/or considered as partial remedies (e.g., limited dredge footprints, material-specific dredge targets) that could improve the system-wide recovery rate relative to the rate considered under MNR are presented in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

### 8.4.1 Summary of Remedial Alternatives

The overall strategy for developing remedial alternatives for the Estuary focused on the goal of reducing area weighted average concentrations of total mercury in sediments to PRGs of either 500 ng/g or 300 ng/g. This strategy was applied to either the whole system or to portions of the system such as Mendall Marsh. As noted in Section 6.4 (Containment), evaluation of remedial alternatives for Mendall Marsh – including thin layer capping and application of amendments – assumes that technologies applied to the Mendall Marsh platform could be expanded to other marshes in the Estuary, although development of remedial alternatives for individual pocket and fringe marshes would require additional evaluation of marsh geomorphology (i.e., shape and slope), as well as assessment of the ecological benefit of cap placement for appropriate receptors in these smaller marsh areas. The specific PRGs considered in this alternatives evaluation were developed to meet the RAOs and be protective of both ecological and human receptors. A range of remedial alternatives were developed along a spectrum of remedial approaches that range from innovative to proven in terms of documented ability to reduce both ecological risks and (relatedly) projected time frames for system recovery. Based on an evaluation of available sediment data and delineation of reaches and hydrodynamic zones in the Estuary, it was determined that some remedial alternatives could be applied on a system-wide basis, while others were likely most effective for specific reaches/locations such as Mendall Marsh.

The proposed remediation areas in each reach are shown on **Figures 5-8-1 through 5-8-16**. Proposed remediation areas and associated material volumes are presented in **Tables 5-10 through 5-15**. Calculation of the proposed remediation areas was as based on a goal of reducing area weighted average concentrations of total mercury to below the respective PRGs for that remedial scenario. For each scenario evaluated, this strategy entailed the ordering of reach/hydrodynamic zones by pre-remedy bootstrap mean total mercury concentration, with specific focus on prioritizing (as possible) reach/hydrodynamic zones of ecological importance in marshes and intertidal areas.

Remedial alternatives that are: (1) implementable from a constructability perspective; (2) could achieve one or both of the PRGs and (3) could be developed and implemented on either a reach-specific or system-wide basis are as follows:

- MNR:
  - MNR would be constructible on a system-wide basis.
  - Implementation of MNR would be effective in achieving both the 500 ng/g and 300 ng/g PRGs.
- Enhanced MNR:
  - Enhanced MNR through addition of clean sediment would be constructible on a system-wide basis.
  - Enhanced MNR through addition of clean sediment would be directly implementable in the intertidal and subtidal zones; material addition through enhanced MNR would ultimately reduce mercury concentrations on marsh platforms by reducing mercury concentrations in sediment that is transported onto marsh platforms during platform inundation.
  - Implementation of enhanced MNR could be effective in achieving both the 500 ng/g and 300 ng/g PRG scenarios in the intertidal and subtidal zones.
- Dredging:
  - Dredging would be constructible in marsh, intertidal, and subtidal zones of certain reaches where sediment could be accessed using conventional equipment; dredging would not be constructible in other reaches or portions of reaches (such as the thalweg) with significant flow velocity or water depth.
  - Dredging could be applied both in the main channel of the Estuary and the Orland River.
  - Dredging would be effective in achieving both the 500 ng/g and 300 ng/g PRG scenarios.
  - The dredging evaluation included pocket and fringe marshes along the Estuary main channel, and, in combination with thin layer capping, the intertidal and subtidal zones in Mendall Marsh.
- Thin Layer Capping:
  - Thin layer capping would be constructible on marsh platforms.
  - Implementation of thin layer capping on the marsh platform would be effective in achieving the 500 ng/g PRG scenario for Mendall Marsh. To achieve the 300

ng/g PRG for Mendall Marsh, dredging in the intertidal and subtidal zones would be required as well as thin layer capping on the marsh platform.

– The evaluation of thin layer capping was specific to Mendall Marsh, although could be considered for other marsh areas in the Estuary.

- Amendment Application:

– Amendment application would be constructible on marsh platforms.

– Implementation of amendment application would not be effective in achieving the 500 ng/g PRG and 300 ng/g PRG scenarios because amendments do not reduce the concentration of total mercury in sediment; addition of amendments could be effective in reducing the bioavailability of methyl mercury in marsh platform porewater, thereby reducing risks to biota.

– Evaluation of amendment application was specific to Mendall Marsh, although could be considered for other marsh areas in the Estuary.

Six remedial alternatives have been developed and evaluated in this Report:

- Alternative 1: Monitored Natural Recovery
- Alternative 2: Enhanced Monitored Natural Recovery
- Alternative 3: Dredging
- Alternative 4: Thin Layer Capping in Mendall Marsh
- Alternative 5: Amendment Application in Mendall Marsh
- Alternative 6: Dredging in Intertidal and Subtidal Zones & Thin Layer Capping in Mendall Marsh

These six alternatives could be implemented as stand-alone remedies or for specific reaches of the system, or portions of different alternatives could be combined to achieve system-wide reduction in the area weighted average concentration of total mercury in sediments.

### 8.4.2 Rationale for Implementation of Remedial Alternatives

This section summarizes the rationale for applying a flexible, integrated approach to combining the different remedial alternatives or portions of alternatives to achieve system-wide reductions in risks to consumers and biota.

***Alternative 1: Monitored Natural Recovery***

- MNR would be implementable as a stand-alone system-wide remedial alternative.
- MNR and institutional controls could be implemented either in combination with other active remedy alternatives or as a stand-alone remedial alternative; application of MNR would be appropriate for the main channel of the Estuary, the Orland River, and Mendall Marsh.

***Alternative 2: Enhanced Monitored Natural Recovery***

- Enhanced MNR through addition of clean sediment could be implementable as a stand-alone system-wide remedial alternative or could be implemented in portions of the system.
- Enhanced MNR could improve the ecological recovery timeframe in pocket and fringe marshes along the main channel of the Estuary, as well as in Mendall Marsh through the eventual redistribution of cleaner mobile sediment into the marshes and onto the marsh platforms during inundation.

***Alternative 3: Dredging***

- Dredging would be implementable as a stand-alone remedial alternative for both the main channel of the Estuary and the Orland River.
- Dredging could be implemented in conjunction with marsh platform alternatives such as thin layer capping or amendment addition.
- Dredging could be implemented to address smaller footprint and/or specific areas of elevated mercury concentration targeted for accelerating system recovery.

***Alternative 4: Thin Layer Capping***

- Thin layer capping would be implementable as a stand-alone remedial alternative for the marsh platform in Mendall Marsh.
- Thin layer capping could be implemented as a remedy for other marsh areas in the Estuary, or in combination with the dredging alternative for the main channel of the Estuary and the Orland River.

***Alternative 5: Amendment Application***

- Amendment application would be implementable as a stand-alone remedial alternative for the marsh platform in Mendall Marsh.
- Amendment application could be implemented as a remedy for other marsh areas in the Estuary, or in combination with the dredging alternative for the main channel of the Estuary and the Orland River.
- Amendment application could be implemented in combination with the thin layer capping alternative for the marsh platform in Mendall Marsh.

***Alternative 6: Dredging in Intertidal and Subtidal Zones & Thin Layer Capping***

- Dredging in the intertidal and subtidal zones of Mendall Marsh and thin layer capping on the marsh platform would be implementable as a stand-alone remedial alternative.
- Enhanced MNR (addition of clean sediments) could be applied in Mendall Marsh as a post-remediation adjunct to dredging and backfilling in the intertidal and subtidal zones.
- Amendment application could be combined with thin layer capping as a remedial alternative for the Mendall Marsh platform.

Recommendations on how the remedial alternatives could be implemented as stand-alone remedies or in combinations for specific reaches or remedial scenarios are presented in the Phase III Engineering Study Report (Amec Foster Wheeler 2018a).

# 9.0 REFERENCES

Altenritter, M.N., G.B. Zydlewski, M.T. Kinnison, and G.S. Wippelhauser. 2017. Atlantic Sturgeon Use of the Penobscot River and Marine Movements within and beyond the Gulf of Maine. Marine *and Coastal Fisheries* 9(1): 216–230.

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler). 2017a. Technology Screening Report, Penobscot River Phase III Engineering Study, Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2017b. 2016 Biota Monitoring Report. Penobscot River Phase III Engineering Study, Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2017c. 2016 Sediment and Water Quality Monitoring Report, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Amec Foster Wheeler. 2017d. BSAF Calculations, Summary of Biota-Sediment Accumulation Factor Evaluation, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Amec Foster Wheeler. 2017e. 2016 Mobile Sediment Characterization Report, Penobscot River Phase III Engineering Study, Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2017f. Leachability Bench-Scale Testing Technical Memorandum, Penobscot River Phase III Engineering Study, Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2018a. Phase III Engineering Study Report. Penobscot River Phase III Engineering Study. Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2018b. Penobscot River Risk Assessment and Preliminary Remediation Goal Development, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Amec Foster Wheeler. 2018c. 2017 Marsh Platform Sediment Characterization, Penobscot River Phase III Engineering Study, Penobscot River Estuary, Maine

Amec Foster Wheeler. 2018d. Analysis of Lignin Oxidation Products in Sediments Technical Memorandum, Phase III Engineering Study. Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2018e. 2017 Analytical Methods Comparison Technical Memorandum, Phase III Engineering Study. Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2018f. Hydrodynamic Simulation Report, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Amec Foster Wheeler. 2018g. 2017 Sediment and Water Quality Monitoring Report, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Amec Foster Wheeler 2018h. 2017 Mobile Sediment Characterization Report, Phase III Engineering Study, Penobscot River Estuary, Maine. January. Amec Foster Wheeler.

2018i. 2017 Intertidal and Subtidal Sediment Characterization Report, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Amec Foster Wheeler. 2018j. 2017 Biota Monitoring Report. Penobscot River Phase III Engineering Study. Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2018k. Thin Interval Core Sampling Report, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Amec Foster Wheeler. 2018l. Amendment Test Plot Resampling Study Technical Memorandum, Phase III Engineering Study. Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2018m. Risk Reduction Report. Penobscot River Phase III Engineering Study. Penobscot River Estuary, Maine.

Amec Foster Wheeler. 2018n. Communication and Community Involvement Plan, Penobscot River Phase III Engineering Study, Penobscot River, Maine.

Anchor QEA and CDM Smith, Inc. 2017. Corrective Measures Implementation Plan, Southern Cove Orrington Remediation Site, Orrington, Maine. May.

Benoit, J.M., D.H. Shull, P. Robinson, and L.R. Ucran. 2006. Infaunal burrow densities and sediment monomethyl mercury distributions in Boston Harbor, Massachusetts. *Marine Chemistry* 102: 124–133.

Bloom, C. 1971. The Penobscot River: A Study of Pollution Abatement Programs and Restoration Progress. Unpublished M.S. Thesis – Pulp and Paper Technology. University of Maine, Orono, ME.

Bloom, N.S., L.M. Moretto, and P. Ugo. 2004. A Comparison of the Speciation and Fate of Mercury in Two Contaminated Coastal Marine Ecosystems: The Venice Lagoon (Italy) and Lavaca Bay (Texas). *Limnology and Oceanography* 49(2): 367–375.

Bothner, M., R.A. Jahnke, M.L. Peterson, and R. Carpenter. 1980. Rate of Mercury Loss from Contaminated Estuarine Sediments. *Geochimica et Cosmochimica Acta* 44: 273–285.

Chiasson-Gould, S.A., J.M. Blais, and A.J. Poulain. 2014. Dissolved Organic Matter Kinetically Controls Mercury Bioavailability to Bacteria. *Environmental Science and Technology* 48: 3153–3161.

Compeau, G.C. and R. Bartha. 1985. Sulfate-Reducing Bacteria: Principal Methylators of Mercury in Anoxic Estuarine Sediment. *Applied and Environmental Microbiology* 50: 498–502.

Cossa, D., C. Garnier, R. Buscail, F. Elbaz-Poulichet, N. Mikac, N. Patel-Sorrentino, E. Tessier, S. Rigaud, V. Lenoble, and C. Gobeil. 2014. A Michaelis–Menten type Equation for Describing Methylmercury Dependence on Inorganic Mercury in Aquatic Sediments. *Biogeochemistry* 119: 35–43.

Davies, R. 1972. The History of the Penobscot River: Its Use and Abuse. Unpublished M.S. Thesis – History. University of Maine. Orono, ME.

D'Andrea, A.F., R.C. Aller, and G.R. Lopez. 2002. Organic Matter Flux and Reactivity on a South Carolina Sandflat: The Impacts of Porewater Advection and Macrobiological Structures. *Limnology and Oceanography* 47:1056– 070.

Drott, A., L. Lambertsson, E. Bjorn, U. Skyllberg. 2008. Do Potential Methylation Rates Reflect Accumulated Methyl Mercury in Contaminated Sediments? *Environmental Science and Technology* 42: 153–158.

Dutton, J. and N.S. Fisher. 2011. Bioaccumulation of As, Cd, Cr, Hg(II) and MeHg in Killifish (*Fundulus heteroclitus*) from Amphipod and Worm Prey. *The Science of the Total Environment* 409: 3438–3447.

Ekren, Stan. 2017. Director of Business Development, Rivers & Lakes Division at Great Lakes Dredge & Dock Company, LLC. Telephone conversation with Corry Platt, Senior Consultant, Amec Foster Wheeler. March 24.

EPA – see United States Environmental Protection Agency

Fisher, J.B., and G. Matisoff. 1981. High Resolution Vertical Profiles of pH in Recent Sediments. *Hydrobiology* 79: 277–284.

Geyer, W. Rockwell. 2017. Senior Scientist, Woods Hole Oceanographic Institution. Telephone communication with Corry Platt, Senior Consultant, and Nelson Walter, Program Manager, Amec Foster Wheeler. Multiple dates.

Geyer, W.R. 1993. The importance of suppression of turbulence by stratification on the estuarine turbidity maximum. *Estuaries and Coasts 16*(1): 113-125.

Geyer, W.R. and D.K. Ralston. 2018. A Mobile Pool of Contaminated Sediment in the Penobscot Estuary, Maine, USA. *Science of the Total Environment*. 612: 694–707.

Gosnell, K., P. Balcom, V. Ortiz, B. DiMento, A. Schartup, R. Greene, and R. Mason. 2016. Season Cycling and Transport of Mercury and Methylmercury in the Turbidity Maximum of the Delaware Estuary. *Aquatic Geochemistry* 22: 313–336.

Graham, A.M., G.R. Aiken, and C.C. Gilmour. 2012. Dissolved Organic Matter Enhances Microbial Mercury Methylation Under Sulfidic Conditions. *Environmental Science and Technology* 46: 2715−2723.

Grossman, A. and U. Ghosh. 2009. Measurement of Activated Carbon and Other Black Carbons in Sediments. *Chemosphere* 75: 469-475.

Hegermiller, C. 2011. Fine Sediment Trapping in the Penobscot River Estuary. Unpublished B.S. Thesis – Earth and Environmental Sciences. Boston College.

Heyes, A., C. Miller, and R. Mason. 2004. Mercury and methylmercury in Hudson River sediment: impact of tidal resuspension on partitioning and methylation. *Marine Chemistry* 90: 127–145.

Kleinschmidt. 2008. Penobscot River Restoration Trust Preliminary Draft Multi-Project Environmental Assessment: Veazie Project, FERC NO. 2403; Great Works Project, FERC NO. 2312; Howland Project, FERC NO. 2721. May.

Kleinschmidt. 2015. Maine Hydropower Study. Prepared for Maine Governor's Energy Office, Augusta, Maine.

Kostka, J.E., B. Gribsholt, E. Petrie, D. Dalton, H. Skelton, and E. Kristensen. 2002. The rates and pathways of carbon oxidation in bioturbed saltmarsh sediments. *Limnology and Oceanography* 47: 230–240.

Lachapelle, K. 2013. Wintering Shortnose Sturgeon (*Acipenser brevirostrum*) and Their Habitat in the Penobscot River, Maine. Unpublished M.S. Thesis – Ecology and Environmental Sciences. University of Maine, Orono, Maine.

Lambertsson, L., and M. Nilsson. 2006. Organic material: the primary control on mercury methylation and ambient methyl mercury concentrations in estuarine sediments. *Environmental Science and Technology* 40: 1822–1829.

Louchouarn, P., M. Lucotte, R. Canuel, J.-P. Gagne, and L.-F. Richard. 1997. Sources and early diagenesis of lignin and bulk organic matter in the sediments of the Lower St. Lawrence Estuary and the Saguenay Fjord. *Marine Chemistry* 58: 3–26.

Maine Center for Disease Control and Prevention (MeCDC). 2016. Penobscot River Estuary Lobster and Rock Crab Mercury Study; 2014 Sample Period Data Report. May.

Maine Department of Environmental Protection (MEDEP). 2012. Maine Solid Waste Management Rules. Chapter 418: Beneficial Use of Solid Wastes. February.

Mason, R.P., and A.L. Lawrence. 1999. Concentration, distribution and bioavailability of mercury and methylmercury in sediments of Baltimore Harbor and Chesapeake Bay, Maryland, USA. *Environmental Toxicology and Chemistry* 18: 2438–2447.

Mazrui, N.M., S. Jonsson, S. Thota, J. Zhao, and R.P. Mason. 2016. Enhanced availability of mercury bound to dissolved organic matter for methylation in marine sediments. *Geochimica et, Cosmochimica Acta* 194: 153–162.

Merritt, K.A. and A. Amirbahman. 2008. Methylmercury cycling in estuarine sediment porewaters (Penobscot River estuary Maine, USA). *Limnology and Oceanography* 53: 1064–1075.

MeCDC – see Maine Center for Disease Control and Prevention

MEDEP – Maine Department of Environmental Protection

Merritt, K.A. and A. Amirbahman. 2009. Mercury and methylation dynamics in estuarine and coastal marine environments – A critical review. *Earth Science Reviews* 96: 54–66.

Merritt, K., J. Conder, V. Magar, V.J. Kirtay, and D.B. Chadwick. 2009. Enhanced Monitored Natural Recovery (EMNR) Case Studies Review. *Technical Report* 1983. SPAWAR Systems Center Pacific.

Morel, F.M.M., A.M.L. Kraepiel, and M. Amyot. 1998. The Chemical Cycle and Bioaccumulation of Mercury. *Annual Review of Ecology, Evolution and Systematics* 29: 543–566.

Mower, B. 2009. Effects of Pulp and Paper Mill Discharges on Fish Populations in Three Maine Rivers. Unpublished PhD Thesis – Biological Sciences. University of Maine, Orono, Maine.

National Marine Fisheries Service and U.S. Fish and Wildlife Service (NMFS and USFWS). 2005. Recovery Plan for the Gulf of Maine Distinct Population Segment of Atlantic Salmon (*Salmo salar*).

Pickhardt, P.C. and N.S. Fisher. 2007. Accumulation of Inorganic and Methylmercury by Freshwater Phytoplankton in Two Contrasting Water Bodies. *Environmental Science and Technology* 41: 125–131.

Penobscot River Mercury Study Panel (PRMSP). 2008. Penobscot River Mercury Study – Phase 1 of the Study: 2006–2007. January.

PRMSP. 2013. Penobscot River Mercury Study Final Report: Mercury Contamination of the Penobscot River Estuary: Current Situation, Remediation Targets, and Possible Remediation Procedures. April.

Santschi, P.H., K.M. Yeager, K.A. Schwehr, and K.J. Schindler. 2017. Estimates of recovery of the Penobscot River and estuarine system from mercury contamination in the 1960s. *Science of the Total Environment* 596–597: 351–359.

Schaefer, J.K., S.S. Rocks, W. Zheng, L. Liang, B. Gu, and F.M.M. Morel. 2011. Active transport, substrate specificity, and methylation of Hg(II) in anaerobic bacteria. *PNAS* 108(21): 8714–8719.

Slocum, M.G., Mendelssohn, I.A., and N.L. Kuhn. 2005. Effects of Sediment Slurry Enrichment on Salt Marsh Rehabilitation: Plant and Soil Responses over Seven Years. *Estuaries*. 28 (4): 519-528.

Stagg, C.L. and I.A. Mendelssohn. 2011. Controls on resilience and stability in a sediment-subsidized salt marsh. *Ecological Applications*. 21(5):1731-1744.

Turner, A., G.E. Millward, and S.M. Roux. 2001. Sediment-Water Partitioning of Inorganic Mercury in Estuaries. *Environmental Science and Technology* 35: 4648–4654.

Tsui, M.T. and W.X. Wang. 2004. Uptake and Elimination Routes of Inorganic Mercury and Methylmercury in Daphnia magna. *Environmental Science and Technology* 38: 808–816.

United States Environmental Protection Agency (EPA). 1980. A Water Quality Success Story – Penobscot River Maine. Office of Water Regulations and Standards.

EPA. 1997. Ecological Risk Assessment Guidance for Superfund: Process for Defining and Conducting Ecological Risk Assessments. EPA 540-R-97-006. Office of Solid Waste and Emergency Response. July.

EPA. 2005. Contaminated Sediment Remediation Guidance for Hazardous Waste Sites. EPA/540/R-05-02. Office of Solid Waste and Emergency Response (OSWER) Directive 9355.0-85. December.

EPA. 2010. Superfund Green Remediation Strategy. Office of Solid Waste and Emergency Response. September.

EPA. 2014. Technical Resource Document on Monitored Natural Recovery. EPA/600/R-14/083. April.

EPA. 2017. Remediating Contaminated Sediments Sites – Clarification of Several Key Remedial Investigation/Feasibility Study and Risk Management Recommendations, and Updated Contaminated Sediment Technical Advisory Group Operating Procedures, Office of Land and Emergency Management, Directive No. 9200.1-130. January.

Wegener, M.T. 2012. Reproduction of Shortnose Sturgeon in the Gulf of Maine: a modeling and acoustic telemetry assessment. Unpublished M.S. Thesis – School of Marine Science. University of Maine, Orono, Maine.

Wippelhauser, G.S., J. Sulikowski, G.B. Zydlewski, M.A. Altenritter, M. Kieffer, and M.T. Kinnison. 2017. Movements of Atlantic Sturgeon of the Gulf of Maine Inside and Outside of the Geographically Defined Distinct Population Segment. *Marine and Coastal Fisheries* 9(1): 93–107.

Yellen, B., J.D. Woodruff, D.K. Ralston, D.G. MacDonald, and D.S. Jones. 2017. Salt wedge dynamics lead to enhanced sediment trapping within side embayments in high-energy estuaries. *Journal of Geophysical Research: Oceans* 122: 2226–2242.

# TABLES

**TABLE 3-1**

**EVALUATION OF SEDIMENT STABILITY AND MIXING DEPTH[1]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| | | Unconsolidated Sediments[2] | | | | | | | | | Mixed Sediments[3] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SedFlume Erosional Depth[4] | | Average Depth of Erosional Rivulets[5] | | Ruler Resistance Depth "Intact Sediment Surface" | | Color Above Intact Sediment Surface | Color Below Intact Sediment Surface | Source | Layer Thickness | |
| Reach | Zone | (ft) | (cm) | (ft) | (cm) | (ft) | (cm) | Munsell Code | | Station ID | (ft) | (cm) |
| **System Average** | | **0.3** | **8** | **0.4** | **11** | **0.3** | **8** | **NA** | **NA** | **NA** | **0.7** | **20** |
| Bangor | Intertidal | NA | NA | NA | NA | 0.7 | 20 | 10YR7/1 | 10YR7/1 | PBR-04 | NA | NA |
| | Subtidal | NA | NA | NA | NA | 0.7 | 20 | 10YR5/3 | 10YR5/3 | PBR-10 | 0.7 | 20 |
| | **Average** | **NA** | **NA** | **NA** | **NA** | **0.7** | **20** | **NA** | **NA** | **NA** | **0.7** | **20** |
| Orrington | Intertidal | 0.3 | 8 | 0.4 | 12 | 0.6 | 18 | 10YR4/1 | 10YR4/1 | PBR-18 | 0.7 | 20 |
| | | | | | | 0.2 | 7 | 10YR5/6 | 10YR5/6 | PBR-19 | 0.5 | 16 |
| | | | | | | 1.1 | 33 | 10YR3/2 | 10YR3/2 | ON-10-01 | 0.7 | 21 |
| | Subtidal | 0.3 | 10 | NA | NA | 0.3 | 8 | 10YR6/4 | 10YR6/4 | PBR-20 | 0.2 | 6 |
| | | | | | | 0.3 | 10 | 10YR4/2 | 10YR4/2 | ON-18-02 | 2.0 | 60 |
| | | | | | | 0.1 | 3 | NA | 10YR6/1 | ON-19-01 | NA | NA |
| | ***Average*** | ***0.3*** | ***9*** | ***0.4*** | ***12*** | ***0.4*** | ***13*** | ***NA*** | ***NA*** | ***NA*** | ***0.8*** | ***25*** |
| Winterport | Intertidal | NA | NA | NA | NA | 0.3 | 8 | 5Y2.5/1 | 5Y2.5/1 | WP-02-01 | 0.3 | 8 |
| | Subtidal | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | ***Average*** | ***NA*** | ***NA*** | ***NA*** | ***NA*** | ***0.3*** | ***8*** | ***NA*** | ***NA*** | ***NA*** | ***0.3*** | ***8*** |
| Frankfort Flats | Intertidal | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | Subtidal | 0.1 | 4 | NA | NA | 0.1 | 2 | 10YR5/3 | 10YR5/3 | PBR-26 | 0.2 | 7 |
| | | | | | | 0.3 | 9 | 10YR6/1 | 10YR2/1 | FF-06-01 | NA | NA |
| | **Average** | **0.1** | **4** | **NA** | **NA** | **0.2** | **6** | **NA** | **NA** | **NA** | **0.2** | **7** |
| Mendall Marsh | Intertidal | NA | NA | 0.3 | 9 | 0.2 | 6 | 5Y2/1 | 5Y2/1 | MM-04-01 | 0.7 | 21 |
| | | | | | | 0.3 | 8 | 5Y3/1 | 5Y3/1 | MM-T1-C2 | 0.8 | 24 |
| | | | | | | 0.2 | 6 | 10YR7/1 | 10YR6/2 | MM-T2-C4 | NA | NA |
| | | | | | | 0.2 | 6 | 2.5Y5/3 | 2.5Y6/2 | MM-T2-C6 | 1.8 | 55 |
| | | | | | | 0.3 | 8 | NA | NA | MM-T3-C2 | 0.4 | 11 |
| | | | | | | 0.1 | 3 | 10YR2/1 | 10YR2/1 | MM-T4-C2 | 0.2 | 5 |
| | Subtidal | 0.2 | 6 | NA | NA | 0.3 | 9 | NA | NA | MM-T2-C5 | 0.1 | 3 |
| | **Average** | **0.2** | **6** | **0.3** | **9** | **0.2** | **7** | **NA** | **NA** | **NA** | **0.7** | **20** |
| Bucksport | Intertidal | NA | NA | 0.3 | 9 | 0.2 | 6 | 5Y4/3 | 5Y4/3 | BU-08-01 | 0.5 | 15 |
| | Subtidal | 0.3 | 10 | NA | NA | 0.5 | 15 | 2.5Y6/2 | 2.5Y6/3 | BU-05-01 | 0.5 | 15 |
| | | | | | | 0.1 | 4 | NA | NA | BU-09-01 | 0.5 | 15 |
| | | | | | | 0.3 | 10 | 10YR6/4 | 10YR6/4 | BU-10-01 | 2.0 | 60 |
| | **Average** | **0.3** | **10** | **0.3** | **9** | **0.3** | **9** | **NA** | **NA** | **NA** | **0.9** | **26** |
| Bucksport Harbor | Intertidal | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | Subtidal | NA | NA | NA | NA | 0.3 | 9 | 5Y5/2 | 5Y5/2 | BH-03-01 | 1.0 | 30 |
| | **Average** | **NA** | **NA** | **NA** | **NA** | **0.3** | **9** | **NA** | **NA** | **NA** | **1.0** | **30** |
| Verona Northeast | Intertidal | 0.2 | 6 | 0.5 | 15 | 0.1 | 4 | 10YR4/2 | 10YR4/2 | VN-01-01 | 0.5 | 15 |
| | | | | | | 0.5 | 15 | 10YR4/1 | 10YR4/1 | VN-02-01 | 0.5 | 15 |
| | | | | | | 0.4 | 11 | 10YR4/1 | 10YR4/1 | VN-02-03 | NA | NA |
| | | | | | | 0.2 | 6 | 10YR3/1 | 10YR3/1 | VN-02-04 | NA | NA |
| | | | | | | 0.2 | 5 | 10YR3/1 | 10YR4/1 | VN-03-01 | 0.7 | 21 |
| | | | | | | 0.2 | 6 | NA | 10YR3/2 | VN-08-01 | 0.7 | 21 |
| | | | | | | 0.2 | 7 | 5Y4/2 | 5Y4/2 | VN-MU3-GC-1 | 1.0 | 32 |
| | Subtidal | 0.2 | 7 | NA | NA | 0.1 | 3 | 10YR4/1 | 10YR4/1 | VN-04-02 | NA | NA |
| | | | | | | 0.4 | 13 | 5Y4/1 | 5Y4/1 | VN-05-01 | NA | NA |
| | **Average** | **0.2** | **7** | **0.5** | **15** | **0.3** | **8** | **NA** | **NA** | **NA** | **0.7** | **21** |
| Orland River | Intertidal | 0.2 | 6 | NA | NA | 0.2 | 6 | 10YR4/2 | 10YR2/1 | OR-T1-C1 | 0.6 | 19 |
| | | | | | | 0.2 | 5 | 10YR5/2 | 10YR5/2 | OR-T1-C2 | 0.8 | 24 |
| | | | | | | 0.1 | 3 | 10YR6/3 | 10YR4/1 | OR-T1-C3 | 1.0 | 30 |
| | | | | | | 0.2 | 5 | 10YR6/3 | 10YR4/1 | OR-T1-C5 | 0.5 | 16 |
| | | | | | | 0.1 | 4 | 5Y3/2 | 5Y3/2 | OR-T2-C2 | 0.8 | 24 |
| | | | | | | 0.5 | 15 | 10YR6/3 | 10YR4/1 | OR-T2-C4 | 0.6 | 18 |
| | | | | | | 0.2 | 7 | 10YR4/2 | 10YR4/1 | OR-T2-C5 | 1.0 | 32 |
| | | | | | | 0.1 | 3 | 10YR3/2 | 10YR3/2 | OR-T3-C1 | 0.1 | 4 |
| | | | | | | 0.2 | 6 | 5Y4/1 | 5Y4/1 | OR-T3-C4 | 0.4 | 12 |
| | | | | | | 0.2 | 5 | 10YR3/2 | 10YR3/2 | OR-T3-C5 | 0.7 | 20 |
| | Subtidal | 0.3 | 10 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | **Average** | **0.3** | **8** | **NA** | **NA** | **0.2** | **6** | **NA** | **NA** | **NA** | **0.7** | **20** |
| Verona East | Intertidal | 0.1 | 4 | NA | NA | 0.3 | 10 | 2.5Y3/1 | 10YR2/2 | VE-09-01 | 0.5 | 15 |
| | | | | | | 0.2 | 5 | 10YR2/1 | 10YR2/1 | VE-10-01 | 0.5 | 15 |
| | | | | | | 0.1 | 3 | NA | 10Y/4 | VE-MU4-GC-1 | 0.1 | 3 |
| | Subtidal | 0.3 | 10 | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | **Average** | **0.2** | **7** | **NA** | **NA** | **0.2** | **6** | **NA** | **NA** | **NA** | **0.4** | **11** |
| Verona West | Intertidal | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | Subtidal | 0.3 | 9 | NA | NA | 0.2 | 5 | NA | 10Y/2.5 | VW-14-01 | 1.0 | 30 |
| | **Average** | **0.3** | **9** | **NA** | **NA** | **0.2** | **5** | **NA** | **NA** | **NA** | **1.0** | **30** |
| Fort Point Cove | Intertidal | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| | Subtidal | NA | NA | NA | NA | 0.1 | 4 | 10YR4/1 | 10YR4/1 | ES-01 | 0.2 | 7 |
| | | | | | | 0.4 | 13 | 10YR6/3 | 10YR6/2 | ES-17 | 0.7 | 20 |
| | | | | | | 0.4 | 11 | 10YR6/1 | 10YR6/1 | ES-20 | 0.3 | 9 |
| | **Average** | **NA** | **NA** | **NA** | **NA** | **0.3** | **9** | **NA** | **NA** | **NA** | **0.4** | **12** |

Prepared by: ESS 3/1/18
Checked by: KC 3/7/18

Notes:

1. Gray highlighted cells signify a change in sediment color between sediments above intact sediment surface and sediments below intact sediment surface.
2. Sediments above the intact sediment surface.
3. Sediments representative of homogenous total mercury concentrations with respect to total solids and lithology.
4. SEDflume erosional depths were determined from the US Army Corps of Engineers report found in Appendix D.
5. From the 2017 Mobile Sediment Characterization Report (Amec Foster Wheeler 2017h).

Abbreviations:

cm = centimeters
ft = feet
NA = not available

# TABLE 3-2

## EVALUATION OF MIXING DEPTH AND DISTRIBUTION FOR UNCONSOLIDATED SEDIMENT CORES[1]
## Penobscot River Phase III Engineering Study
## Penobscot River Estuary, Maine

| Interval | Mercury (ng/g) | | | | | | Total Organic Carbon (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Minimum | Mean | Median | Maximum | Significance[2] | N | Minimum | Mean | Median | Maximum | Significance[2] |
| 1 (0–0.1 feet) | 72 | 35.1 | 732 | 714 | 1,730 | a | 72 | 0.726 | 5.78 | 5.72 | 13.8 | a |
| 2 (0.1–0.3 feet) | 72 | 35.8 | 726 | 738 | 2,110 | a | 72 | 1.67 | 5.80 | 5.99 | 18.6 | a |
| 3 (0.3–0.5 feet) | 72 | 27.1 | 758 | 831 | 1,460 | a,b | 72 | 0.0250 | 5.70 | 5.86 | 10.8 | a |
| 4 (0.5–1.0 feet) | 63 | 18.6 | 942 | 972 | 3,210 | b | 62 | 1.30 | 6.42 | 6.42 | 15.4 | a |

| Unit[3] | Mercury (ng/g) | | | | | | Total Organic Carbon (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Minimum | Mean | Median | Maximum | Significance[2] | N | Minimum | Mean | Median | Maximum | Significance[2] |
| East Verona Island and Orland River | 48 | 112 | 783 | 763 | 1,730 | a | 48 | 1.57 | 5.66 | 5.59 | 9.83 | a |
| Main Channel | 78 | 35.1 | 716 | 714 | 2,110 | a | 78 | 1.81 | 5.91 | 5.97 | 18.6 | a |
| Mendall Marsh | 18 | 60.0 | 642 | 729 | 840 | a | 18 | 0.726 | 5.60 | 6.38 | 8.05 | a |

Notes:
1. Includes unconsolidated cores from Amec Foster Wheeler 2017b, 2017c, 2018g, 2018i, and 2018k.
2. Different letters indicate medians are significantly different ($\alpha = 0.05$); same letters indicate medians are not significantly different ($\alpha = 0.05$).
3. Statistical evaluation includes Intervals 1 and 2 of unconsolidated cores

Abbreviations:
% = percent
N = number of samples
ng/g = nanograms per gram

Prepared by: LSV 2/19/18
Checked by: KC 3/7/18

# TABLE 3-3

## SYSTEM-WIDE SEDIMENT MERCURY CHARACTERIZATION
## Penobscot River Phase III Engineering Study
## Penobscot River Estuary, Maine

| Layer Properties | | Total Mercury | | N Value | |
|---|---|---|---|---|---|
| **Layer Type** | **Layer Classification** | **Average Mercury Concentration (ng/g)** | **Standard Deviation (ng/g)** | **Number of Stations** | **Number of Samples** |
| Unconsolidated | Mobile Sediments[1,2] | 794 | 289 | 44 | 69 |
| Consolidated | Mixed Sediments - Mercury Based[1,2] | 787 | 408 | 69 | 793 |
| | Mixed Sediments - Modeled Geochronology (Original)[2,3] | 629 | 560 | 30 | 627 |
| | Mixed Sediments - Modeled Geochronology (Adjusted)[2,4] | 868 | 318 | 25 | 297 |
| Bedded Deposits of Mixed Mineral Sediment and Wood Waste[5] | Mixed Sediments[1,2] | 1,175 | 367 | 9 | 121 |

Notes:

1. Intertidal and Subtidal Sediment Characterization Report (Amec Foster Wheeler, 2018i)
2. Thin Interval Core Sampling Report (Amec Foster Wheeler, 2018k)
3. Corresponds with Table 1 presented in *Supplemental Spatial Analysis of Sedimentary Mercury (Hg) Distribution in the Lower Penobscot River Basin, ME - Informing System-Wide Remedial Design and Implementation* (Amec Foster Wheeler (2018k; Appendix C)).
4. Modeled geochronology data adjusted to reflect total mercury profile and lithology.
5. Determined from 2017 Mobile Sediment Characterization Report (Amec Foster Wheeler 2018h).

Mobile Sediments = Sediments above the intact sediment surface.

Mixed Sediments = Sediments representative of homogenous total mercury concentrations.

Prepared by: DRY 2/26/2018
Checked by: KMC 2/26/2018
Modified by: RMB 8/28/2018

Abbreviation:

ng/g = nanograms per gram

## TABLE 3-4

## MERCURY AND METHYL MERCURY SURFACE WATER DATA BY REACH
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Dates[1] | Mercury | | | Methyl Mercury | | |
|---|---|---|---|---|---|---|---|
| | | Result Range (ng/L) | Average[2] Result | Number of Hits/Total Results | Result Range (ng/L) | Average Result | Detected Values/Total Analyses |
| Bangor | 2016 | 0.96 - 2.18 | 1.61 | 3/6 | 0.078 - 0.205 | 0.13 | 5/6 |
| Bangor | 2017 | 2.94 - 4.93 | 3.82 | 9/9 | 0.074 - 0.101 | 0.09 | 6/9 |
| Orrington | 2016 | 1.99 - 37.2 | 11.3 | 6/6 | 0.12 - 0.617 | 0.28 | 6/6 |
| Winterport | 2016 | 3.31 - 34.9 | 11.2 | 6/6 | 0.062 - 0.423 | 0.22 | 5/6 |
| Frankfort Flats | Historical | NA | NA | NA | NA | NA | NA |
| Mendall Marsh | Historical | NA | NA | NA | NA | NA | NA |
| Bucksport | 2016 | 2.5 - 8.05 | 4.65 | 6/8 | 0.029 - 0.132 | 0.08 | 5/6 |
| Verona Northeast | 2016 | 0.32 - 0.32 | 0.32 | 1/3 | NA | NA | 0/0 |
| Orland River | 2016 | ND | ND | 0/2 | NA | NA | 0/0 |
| Verona East | 2016 | 2.3 - 9.14 | 5.33 | 6/7 | 0.036 - 0.155 | 0.10 | 4/6 |
| Verona West | 2016 | 1.72 - 21 | 7.76 | 5/6 | 0.043 - 0.345 | 0.20 | 3/6 |
| Fort Point Cove | Historical | NA | NA | NA | NA | NA | NA |
| Upper Penobscot Bay | 2016 | 1.44 - 1.87 | 1.65 | 5/6 | 0.035 - 0.04 | 0.04 | 2/6 |

Notes:

1. 2016 data from Amec Foster Wheeler (2017c); 2017 data from Amec Foster Wheeler (2018g); historical data are pre-Phase III (no current data are available for these reaches).
2. Average as mean values calculated from detected values.

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18
Modified by: RMB 8/28/18

Abbreviations:

NA = no data available
ND = non detect
ng/L = nanograms per liter

## TABLE 3-5

## HISTORICAL MERCURY AND METHYL MERCURY SEDIMENT DATA BY REACH
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Dates[1] | Sample Depth[2] | Mercury | | | Methyl Mercury | | |
|---|---|---|---|---|---|---|---|---|
| | | | Result Range (ng/g) | Average[3] Result | Number of Results | Result Range (ng/g) | Average[3] Result | Number of Results |
| Bangor | Historical | Surface | 0.04 - 2700 | 545 | 625 | 0.0007 - 5.29 | 1.15 | 75 |
| | | Subsurface | 0.21 - 4260 | 602 | 332 | 0.00088 - 0.00639 | - | 11 |
| Orrington | Historical | Surface | 0.01 - 12500 | 1100 | 521 | 0.00024 - 58.5 | 6.45 | 80 |
| | | Subsurface | 0.025 - 73300 | 2100 | 221 | 0.00006 - 0.0437 | 0.01 | 21 |
| Winterport | Historical | Surface | 62.3 - 1840 | 720 | 70 | 3.91 - 3.91 | 3.91 | 1 |
| | | Subsurface | 22.4 - 1580 | 508 | 50 | - | - | - |
| Frankfort Flats | Historical | Surface | 0.13 - 2670 | 676 | 266 | 0.00121 - 61.5 | 13.6 | 45 |
| | | Subsurface | 2.86 - 1100 | 53.9 | 98 | - | - | - |
| Mendall Marsh | Historical | Surface | 10 - 3200 | 695 | 597 | 1.12 - 98.4 | 24.7 | 261 |
| | | Subsurface | 13.9 - 6310 | 950 | 334 | - | - | - |
| Bucksport | Historical | Surface | 104 - 1340 | 663 | 16 | - | - | - |
| Bucksport Thalweg | Historical | Surface | 16.3 - 1750 | 849 | 9 | - | - | - |
| Bucksport Harbor | Historical | Surface | 361 - 782 | 645 | 16 | - | - | - |
| | | Subsurface | 49.1 - 8810 | 784 | 25 | - | - | - |
| Verona Northeast | Historical | Surface | 57.6 - 3150 | 937 | 221 | 3.02 - 27.7 | 10.5 | 16 |
| | | Subsurface | 13.7 - 3390 | 867 | 65 | - | - | - |
| Orland River | Historical | Surface | 39 - 2640 | 1082 | 195 | 0.19 - 19.6 | 7.15 | 13 |
| | | Subsurface | 10.8 - 4650 | 679 | 155 | - | - | - |
| Verona East | Historical | Surface | 18.6 - 2310 | 663 | 134 | 1.54 - 18.9 | 8.14 | 21 |
| | | Subsurface | 5.42 - 4510 | 720 | 50 | - | - | - |
| Verona West | Historical | Surface | 0.23 - 3470 | 637 | 81 | 0.00459 - 2.61 | 0.66 | 4 |
| | | Subsurface | 5.74 - 4240 | 567 | 75 | - | - | - |
| Fort Point Cove | Historical | Surface | 0.09 - 2090 | 630 | 160 | 0.00169 - 31.7 | 8.17 | 20 |
| | | Subsurface | 16.2 - 2710 | 803 | 110 | - | - | - |
| Upper Penobscot Bay | Historical | Surface | 14.7 - 1860 | 368 | 164 | 0.015 - 16.1 | 4.92 | 19 |
| | | Subsurface | 3.77 - 1380 | 251 | 46 | - | - | - |
| Cape Jellison | Historical | Surface | 12.3 - 934 | 510 | 48 | - | - | - |
| | | Subsurface | 4.53 - 959 | 253 | 75 | - | - | - |

1. Historical refers to pre-Phase III, 2000-2012.
2. Surface depth is 0–0.5 foot; Subsurface depth is greater than 0.5 foot.
3. Average as mean values.

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18

Abbreviations:
- = no data available
ng/g = nanograms per gram

## TABLE 3-6

### PHASE III MERCURY AND METHYL MERCURY SEDIMENT DATA BY REACH
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| | | | Mercury | | | Methyl Mercury | | |
|---|---|---|---|---|---|---|---|---|
| Reach | Dates | Sample Depth[1] | Result Range (ng/g) | Average[2] Result | Number of Results | Result Range (ng/g) | Average[2] Result | Number of Results |
| Veazie | Phase III | Surface | 11.4 - 109 | 43.8 | 11 | 0.02 - 3.68 | 1.34 | 9 |
| | | Subsurface | 15.1 - 15.1 | 15.1 | 1 | - | - | - |
| Bangor | Phase III | Surface | 1.4 - 1793 | 523 | 40 | 1.08 - 31.7 | 8.03 | 8 |
| | | Subsurface | 1.71 - 3270 | 624 | 41 | - | - | - |
| Orrington | Phase III | Surface | 10.5 - 100200 | 2700 | 128 | 0.232 - 37.4 | 9.22 | 32 |
| | | Subsurface | 7.46 - 2880 | 780 | 122 | - | - | - |
| Winterport | Phase III | Surface | 33.2 - 1150 | 690 | 34 | 1.1 - 37.5 | 15.2 | 19 |
| | | Subsurface | 13.5 - 3770 | 741 | 22 | - | - | - |
| Frankfort Flats | Phase III | Surface | 14.7 - 3480 | 569 | 100 | 2.2 - 50.7 | 13.9 | 30 |
| | | Subsurface | 8.1 - 3890 | 265 | 128 | - | - | - |
| Mendall Marsh | Phase III | Surface | 4.64 - 3820 | 645 | 674 | 0.067 - 51.8 | 9.33 | 109 |
| | | Subsurface | 1.97 - 5570 | 572 | 827 | - | - | - |
| Bucksport | Phase III | Surface | 82 - 3590 | 837 | 44 | 2.7 - 16 | 8.37 | 5 |
| | | Subsurface | 15.7 - 2870 | 838 | 56 | - | - | - |
| Bucksport Thalweg | Phase III | Surface | 539 - 706 | 600 | 3 | 3.4 - 4 | 3.70 | 2 |
| | | Subsurface | 478 - 478 | 478 | 1 | - | - | - |
| Bucksport Harbor | Phase III | Surface | 134 - 806 | 474 | 8 | 15.6 - 21.1 | 18.4 | 2 |
| | | Subsurface | 338 - 1820 | 781 | 11 | - | - | - |
| Verona Northeast | Phase III | Surface | 0.08 - 2380 | 797 | 114 | 1.4 - 55.8 | 11.3 | 30 |
| | | Subsurface | 13.8 - 2570 | 525 | 168 | - | - | - |
| Orland River | Phase III | Surface | 20.2 - 2310 | 851 | 327 | 1.9 - 30.6 | 10.9 | 30 |
| | | Subsurface | 12.4 - 5260 | 886 | 441 | - | - | - |
| Verona East | Phase III | Surface | 51.2 - 1620 | 605 | 65 | 1.11 - 39.5 | 12.0 | 25 |
| | | Subsurface | 4.43 - 1850 | 587 | 71 | - | - | - |
| Verona West | Phase III | Surface | 33.5 - 1140 | 330 | 31 | 0.533 - 14.5 | 4.27 | 16 |
| | | Subsurface | 9.68 - 813 | 98.1 | 30 | - | - | - |
| Fort Point Cove | Phase III | Surface | 1.42 - 1620 | 684 | 64 | 0.7 - 12.3 | 3.56 | 11 |
| | | Subsurface | 9.76 - 1200 | 343 | 83 | - | - | - |
| Upper Penobscot Bay | Phase III | Surface | 129 - 935 | 523 | 49 | 2.3 - 9.38 | 6.22 | 6 |
| | | Subsurface | 10.1 - 3190 | 696 | 73 | - | - | - |
| Cape Jellison | Phase III | Surface | 27.2 - 765 | 433 | 14 | 0.244 - 13.2 | 3.24 | 14 |

Notes:
1. Surface depth is 0–0.5 foot; Subsurface depth is greater than 0.5 foot.
2. Average as mean values.

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18

Abbreviations:
- = no data available
ng/g = nanograms per gram

**TABLE 4-1**

**APPLICABLE FEDERAL REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| Clean Water Act 33 U.S.C. §1251 et seq. | Section 404 | USACE permit required when dredging, filling, or construction of structures in navigable waters of the US | Obtain USACE Individual Permit | USACE Individual 404 Permit required for dredging, filling, or construction of structures in navigable waters | USACE Individual 404 Permit would be obtained for dredging, capping in navigable waters |
| | Section 401 | WQC required when dredging/filling waters of the US in conjunction with USACE Individual 404 Permit | Obtain WQC from MEDEP or State of Maine LUPC, depending on location of discharge in conjunction with USACE Individual Permit | In Maine, the WQC is issued either by the MEDEP or LUPC as an individual certificate or as part of a state permit such as a MEDEP Natural Resources Protection Act Permit or LUPC Development Permit, if applicable | WQC would be obtained in conjunction with USACE Individual 404 Permit for dredging, capping, amendment application in surface waters |
| | Section 402 | National Pollutant Discharge Elimination System Permit required for any pollutant discharge to waters of the US | Obtain Maine Pollutant Discharge Elimination System Permit in lieu of equivalent Federal National Pollutant Discharge Elimination System Permit | Maine Pollutant Discharge Elimination System Permit administered by MEDEP under Maine Pollutant Discharge Elimination System Program | Maine Pollutant Discharge Elimination System Permit would be obtained for application of amendments in surface waters |
| | Section 404 | USACE General Permit public interest review required for proposed actions that include discharge of dredged or fill materials into waters of the US | Obtain General Permit public interest review as part of USACE Individual Permit | State of Maine General Permit evaluation required under authority of USACE New England District for conditions that do not meet Category 1 or 2 and require a USACE Individual 404 Permit, including public notice and a public comment period | USACE Individual 404 Permit would be obtained for dredging, capping in surface waters |

**TABLE 4-1**

**APPLICABLE FEDERAL REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| Rivers and Harbors Appropriation Act of 1899 (33 U.S.C. §401, 403, 408) | Section 10 | Provides authority for USACE to regulate activities in, over, or under navigable waters of the US, including any activity that could affect the navigable capacity of such waters, including excavation, fill or alteration of the course, location, or capacity of such waters | Obtain approval of planned activities under USACE Individual Permit | USACE Individual Permit required for any planned activities in navigable waters, including methods and means that would be employed to maintain navigable bottom elevations | USACE Individual Permit would be obtained for dredging, capping in navigable waters that includes plans for maintaining navigable bottom elevations |
| | Section 9 | Provides authority for US Coast Guard to regulate activities that could affect bridges, dams, and other structures in navigable waters of the US | Obtain approval of planned activities under USACE Individual Permit in consultation with US Coast Guard for any planned activities that could affect bridges, dams, or other structures in navigable waters | USACE Individual Permit required for any planned activities in navigable waters, including methods and means that would be employed to prevent any impacts to bridges, dams, and other structures | USACE Individual Permit would be obtained for dredging, capping in navigable waters that includes plans for preventing any impacts to bridges, dams, and other structures |
| | Section 14 | Provides authority for USACE to regulate any activities that could affect civil works projects controlled by USACE, such as sea walls, bulkheads, flood walls, etc. | Obtain approval of planned activities under USACE Individual Permit | USACE Individual Permit required for any planned activities that could impact civil works projects controlled by USACE, including methods and means that would be employed to prevent any impacts to civil works projects | USACE Individual Permit would be obtained for dredging, capping in navigable waters that includes plans for preventing any impacts to civil works projects controlled by USACE |
| Marine Protection, Research and Sanctuaries Act (33 U.S.C §1401 et seq.) | Section 103 | Disposal of dredged materials in the ocean waters of the US | Obtain USACE Individual Permit that includes any plans for disposal of dredged materials in ocean waters | USACE Individual Permit required for disposal of dredged materials in ocean waters | USACE Individual Permit would be obtained for any planned disposal of dredged materials in ocean waters |

**TABLE 4-1**

**APPLICABLE FEDERAL REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| National Historic Preservation Act (16 U.S.C. §470) | Section 106 | Evaluation of potential impacts to historic and cultural resources from planned activities | Consult with SHPO and THPO prior to undertaking any action, including issuing permits, which may have an effect on properties listed on, or eligible for listing on the National Register of Historic Places | Consultation with SHPO and THPO is through Maine Historic Preservation Commission (the SHPO) for activities occurring within or adjacent to surface waters, or support activities on nearby lands that have the potential to affect listed properties or properties eligible for listing | SHPO would be consulted on locations of historic and cultural resources in conjunction with obtaining USACE Individual Permit for dredging, capping in surface waters and landside materials handling, transportation, storage, and disposal of dredged materials |
| Magnuson-Stevens Fisheries Consultation and Management Act | NA | Governing law for marine fisheries management in US federal waters implemented by NOAA Fisheries to achieve sustainable fisheries management, including establishment of EFH to protect critical habitats that managed fish species require to spawn, breed, feed or mature | Obtain approval of planned activities under USACE Individual Permit in consultation with NOAA Fisheries for any planned activities that have the potential to affect EFH | Obtain USACE Individual Permit in consultation with NOAA Fisheries representing other federal agencies including NMFS, USFWS, and EPA | NOAA Fisheries would be consulted on locations and seasonal restrictions for dredging, capping in EFH in conjunction with obtaining USACE Individual Permit |
| Endangered Species Act of 1973 (16 U.S.C. §1531 et seq.) | Section 7 | Establishes conservation program for threatened and endangered plants and animals and their habitats implemented by NOAA Fisheries and USFWS to ensure planned activities are unlikely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of designated critical habitat | Obtain approval of planned activities under USACE Individual Permit in consultation with NOAA Fisheries and USFWS for any planned activities that have the potential to effect listed species or impact designated critical habitat | Obtain USACE Individual Permit in consultation with NOAA Fisheries representing other Federal agencies including NMFS, USFWS, and EPA | NOAA Fisheries would be consulted on locations and seasonal restrictions for dredging, capping in areas where listed species are present or in designated critical habitat in conjunction with obtaining USACE Individual Permit |

**TABLE 4-1**

**APPLICABLE FEDERAL REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| Endangered Species Act of 1973 (16 U.S.C. §1531 et seq.)<br><br>(continued) | Section 10 | Establishes conservation program for threatened and endangered plants and animals and their habitats implemented by NOAA Fisheries and USFWS to ensure any planned activities do not result in the incidental "taking" of any listed species of endangered fish or wildlife, but provides for permitting of “takes” incidental to otherwise lawful activities | Obtain approval of planned activities under USACE Individual Permit in consultation with NOAA Fisheries and USFWS for any planned activities that have the potential to result in the incidental “take” of any listed species | Obtain USACE Individual Permit in consultation with NOAA Fisheries representing USFWS to determine if a “take permit” would be necessary for any planned activities in areas where listed species may be present | NOAA Fisheries would be consulted on locations and seasonal restrictions for dredging, capping in areas where listed species may be present and an incidental “take” may occur in conjunction with obtaining USACE Individual Permit |
| Fish and Wildlife Coordination Act (16 U.S.C. §661-666c) | NA | Prior to modification of any body of water by or approved by a federal agency, NOAA Fisheries, USFWS, and appropriate State agencies exercising administration over the wildlife resources of the affected state must be consulted | Obtain approval of planned activities under USACE Individual Permit in consultation with NOAA Fisheries and USFWS for any planned activities that have the potential to impact state wildlife resources | Obtain USACE Individual Permit in consultation with NOAA Fisheries representing USFWS and MEDEP for any planned activities in areas where there is a potential to affect wildlife resources | NOAA Fisheries and MEDEP would be consulted on locations and seasonal restrictions for dredging, capping in areas where is a potential to impact State of Maine wildlife resources |
| Marine Mammal Protection Act (16 U.S.C. Chapter 31) | Section 101 | Establishes conservation program for marine mammals and their habitats implemented by NOAA Fisheries and USFWS to ensure any planned activities do not result in the incidental "taking" of any species, but provides for permitting of “takes” incidental to otherwise lawful activities | Obtain approval of planned activities under USACE Individual Permit in consultation with NOAA Fisheries for any planned activities that have the potential to result in the incidental “take” of marine mammal species | Obtain USACE Individual Permit in consultation with NOAA Fisheries to determine if a “take permit” would be necessary for any planned activities in areas where marine mammal species may be present | NOAA Fisheries would be consulted on locations and seasonal restrictions for dredging, capping in areas where marine mammal species may be present and an incidental “take” may occur in conjunction with obtaining USACE Individual Permit |

## TABLE 4-1

## APPLICABLE FEDERAL REQUIREMENTS
## Penobscot River Phase III Engineering Study
## Penobscot River Estuary, Maine

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| Marine Mammal Protection Act (16 U.S.C. Chapter 31)<br><br>(continued) | Section 104 | NOAA Fisheries Service can issue permits for "takes" in support of a limited number of activities, including scientific research, education, and incidental takes during fishing or biota sampling/monitoring activities | Obtain approval of planned activities under USACE Individual Permit in consultation with NOAA Fisheries for any planned activities that have the potential to result in the incidental "take" of marine mammal species | Obtain USACE Individual Permit in consultation with NOAA Fisheries to determine if a "take permit" would be necessary for any planned activities in areas where marine mammal species may be present | NOAA Fisheries would be consulted on locations and seasonal restrictions for dredging, capping in areas where marine mammal species may be present and an incidental "take" may occur in conjunction with obtaining USACE Individual Permit |
| Migratory Bird Treaty Act (16 U.S.C. §703 et seq.) | NA | Establishes conservation program implemented by USFWS that makes it illegal to take, possess, sell, purchase or in any other manner trade any migratory bird or the parts, nests or eggs of such birds except under the terms of a permit issued by the USFWS for incidental take during biota sampling/monitoring activities | Obtain approval of planned activities under USACE Individual Permit in consultation with USFWS for any planned activities that have the potential to result in impacts to migratory birds or their habitats | Obtain USACE Individual Permit in consultation with USFWS to determine if "take permit" would be necessary for any planned activities in areas where migratory birds or their habitats may be present | USFWS would be consulted on locations and seasonal restrictions for dredging, capping, amendment application in areas where migratory birds or their habitats may be present and an incidental "take" may occur in conjunction with obtaining USACE Individual Permit |
| Coastal Zone Management Act of 1972 (16 U.S.C. §1451 et seq.) | 307 | Provides for the management of the nation's coastal resources and establishes the framework whereby coastal states are empowered to develop and implement controls on development and resource use and restoration within coastal areas | Coastal Zone Management Consistency Determination required for enforceable policies of the federally-approved Maine Coastal Program, and if a MEDEP Natural Resources Protection Act Permit is determined to be necessary | Administered by the State of Maine Department of Agriculture, Conservation, and Forestry, which coordinates and provides a point of contact for federal consistency review | A Coastal Zone Management Consistency Determination would be obtained in consultation with State of Maine Department of Agriculture, Conservation, and Forestry in conjunction with USACE Individual Permit for dredging, capping, amendment application in coastal areas identified in the Maine Coastal Program |

**TABLE 4-1**

**APPLICABLE FEDERAL REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| National Environmental Policy Act | NA | Requires federal agencies to systematically assess the environmental impacts of their proposed actions and to consider alternative, more environmentally protective ways to accomplish their mission | Consultation with federal agencies will be undertaken for any permits required for implementation of remedial alternatives, and the permits will be evaluated in accordance with that agency's National Environmental Policy Act requirements and provide for consultation with, and input from other agencies and the public | If determined to be necessary by the federal agencies, the National Environmental Policy Act also provides for application of a categorical exclusion for categories of actions that have been determined not to have the potential for significant effects | Federal agencies would be consulted and USACE Individual Permit would be obtained for dredging, capping in navigable waters to assess environmental impacts |
| Resource Conservation and Recovery Act | Subtitle D | Establishes disposal requirements for all non-hazardous solid waste generated from remediation activities. Waste materials (other than materials to be beneficially reused) will need to be disposed of at facilities properly permitted by the State under the Resource Conservation and Recovery Act | Conduct waste characterization profiles for dredged sediments prior to off-site beneficial reuse or disposal at a non-hazardous waste landfill facility | Administered by the State of Maine for beneficial reuse or landfill disposal within the state, and by other states if landfill disposal occurs out of state; concentrations of mercury and other chemicals in sediments are non-hazardous | Waste characterization profiling would be performed for dredged sediments prior to off-site beneficial reuse or disposal at a non-hazardous waste landfill facility |

Abbreviations:
EFH = essential fish habitat
EPA = (United States) Environmental Protection Agency
LUPC = Land Use Planning Commission
MEDEP = Maine Department of Environmental Protection
NA = not applicable
NMFS = National Marine Fisheries Service
NOAA Fisheries = National Oceanic Atmospheric Administration Fisheries Service
SHPO = State Historic Preservation Office
THPO = Tribal Historic Preservation Office
US = United States
USACE = United States Army Corps of Engineers
U.S.C. = United States Code
USFWS = United States Fish and Wildlife Service
WQC = Water Quality Certification

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18

# TABLE 4-2

## APPLICABLE STATE REQUIREMENTS
## Penobscot River Phase III Engineering Study
## Penobscot River Estuary, Maine

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| MEDEP Rules – AWQC | Rule 06-096 Chapter 584 | The AWQC established by this rule are applicable to all surface waters of the State, and are intended to prevent the occurrence of toxic pollutants in toxic amounts as prohibited by both the federal Clean Water Act and State law and protect aquatic life and human health | Total mercury concentration AWQC identified under MRSA, Title 38, Sections 420 (1-B) and 413(11) include:<br>(1) Ambient water quality criteria for aquatic life:<br>(a) Freshwater acute: 1.7 µg/L;<br>(b) Freshwater chronic: 0.91 µg/L;<br>(c) Saltwater acute: 2.1 µg/L; and<br>(d) Saltwater chronic: 1.1 µg/L<br>(2) Fish tissue residue criterion for human health: 0.2 mg/kg in the edible portion of fish. | AWQC for total mercury are used to define waste discharge limits under MEDEP waste discharge permits administered by MEDEP | MEDEP waste discharge permit that includes AWQC/waste discharge limits for total mercury would be obtained in conjunction with USACE Individual Permit for dredging, capping, or amendment application in waters of the State of Maine |
| MEDEP Rules – Waste Discharge Permits | Chapters 520–525 | Waste discharge program includes requirements for discharges to waters of the State of Maine | Obtain MEDEP waste discharge permit for discharges to waters of the State of Maine in conjunction with USACE Individual Permit | MEDEP waste discharge permit administered by MEDEP | MEDEP waste discharge permit would be obtained in conjunction with USACE Individual Permit for dredging, capping, or amendment application in waters of the State of Maine |
| MEDEP Rules – Waste Discharge Permits | Chapter 521 | WQC required when discharging to waters of the State of Maine | Obtain WQC from MEDEP or LUPC, depending on location of discharge in conjunction with USACE Individual Permit | In Maine, the WQC is issued either by the MEDEP or LUPC as an individual certificate or as part of a state permit such as an NRPA Permit or LUPC Development Permit, if applicable | WQC would be obtained in conjunction with USACE Individual Permit for dredging, capping, or amendment application in surface waters |

**TABLE 4-2**

**APPLICABLE STATE REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| MEDEP Rules – Waste Discharge Permits and MRSA (Title 38) | Chapters 520-525, 528, 529 & MRSA §§ 413, et. seq. | MEPDES Permit required for any pollutant discharge to waters of the State of Maine in lieu of Waste Discharge License under MRSA | Obtain MEPDES Permit in lieu of equivalent Federal National Pollutant Discharge Elimination Act Permit and MRSA Waste Discharge License | MEPDES Permit administered by MEDEP under MEPDES Program | MEPDES Permit would be obtained in conjunction with USACE Individual Permit for dredging, capping, or application of amendments in waters of the State of Maine |
| MEDEP Rules – Waste Discharge Permits | Chapters 528 and 529 | State of Maine General Permit authorizing the discharge of certain pollutants to waters of the State to cover multiple individual discharge sources and locations that all have the same type of discharges and that involve situations where MEDEP determines there is a relatively low risk for significant environmental impact | Obtain General Permit as part of USACE Individual Permit | State of Maine General Permit evaluation required under authority of USACE New England District for conditions that do not meet Category 1 or 2 and require a USACE Individual Permit, including public notice and a public comment period | State of Maine General Permit would be obtained in conjunction with USACE Individual Permit for dredging, capping, or application of amendments in waters of the State of Maine |
| Maine Natural Resources Protection Act (Title 38) | Chapter 3, §§ 480-A to 480-Z | Regulates activities with the potential to have an effect on areas with protected resources | Obtain NRPA Permit from MEDEP, depending on location of discharge in conjunction with WQC, and USACE Individual 404 Permit when a planned activity is located in, on, or over any protected resource, or located adjacent to (A) a coastal wetland, great pond, river, stream or brook or significant wildlife habitat contained within a freshwater wetland, or (B) certain freshwater wetlands | Regulated activities include (A) dredging, bulldozing, removing or displacing soil, sand, vegetation or other materials; (B) draining or otherwise dewatering; (C) filling, including adding sand or other material to a sand dune; or (D) any construction, repair or alteration of any permanent structure | NRPA Permit and WQC would be obtained in conjunction with USACE Individual Permit for dredging, capping, amendment application in areas with protected resources |

**TABLE 4-2**

**APPLICABLE STATE REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| MEDEP Rules – Wetlands and Water Bodies | Chapter 310 | Regulates activities with the potential to have an effect on wetlands and water bodies | Obtain MNRPA Permit from MEDEP, depending on location of planned activities that may have an effect on wetlands and water bodies, in conjunction with USACE Individual Permit | MNRPA Permit required for any planned activities with the potential to have an effect on wetlands and water bodies | MNRPA Permit would be obtained in conjunction with USACE Individual Permit for dredging, capping, or amendment application in wetlands and waterbodies |
| MEDEP Rules – Significant Wildlife Habitat | Chapter 335 | Regulates activities with the potential to have an effect on significant wildlife habitat | Obtain MNRPA Permit from MEDEP, depending on location of planned activities that may have an effect on significant wildlife habitat, in conjunction with USACE Individual Permit | MNRPA Permit required for any planned activities with the potential to have an effect on significant wildlife habitat | MNRPA Permit would be obtained in conjunction with USACE Individual Permit for dredging, capping, or amendment application in areas of significant wildlife habitat |
| Maine Natural Areas Program Disturbance of Imperiled and Critically Imperiled Habitats | NA | Assigns rarity rank of S1 for critically imperiled species because of extreme rarity (five or fewer occurrences or very few remaining individuals or acres) or because some aspect of its biology makes it especially vulnerable to extirpation from the State of Maine | Obtain MNRPA Permit from MEDEP, depending on location of planned activities that may disturb S1 species, in conjunction with USACE Individual Permit | MNRPA Permit required for any planned activities that may disturb S1 species | MNRPA Permit would be obtained in conjunction with USACE Individual Permit for dredging, capping, amendment application in areas that may disturb S1 species |

**TABLE 4-2**

**APPLICABLE STATE REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| Maine Endangered Species Act (Title 12) | §12803 | Protects state-listed endangered and threatened species and their designated habitats, and prohibits local and state governments from funding, permitting, licensing, or carrying out projects that will significantly alter essential habitat or violate protection guidelines determined by the Commissioner of the Department of Inland Fisheries and Wildlife | Obtain MNRPA permit from MEDEP in conjunction with USACE Individual Permit when a planned activity is located in an area of essential habitat | MNRPA permit required for any planned activities in areas of essential habitat for state-listed endangered and threatened species in consultation with the Department of Inland Fisheries and Wildlife | MNRPA permit would be obtained in conjunction with USACE Individual Permit for dredging, capping, or amendment application in areas of essential habitat |
| Site Location of Development Law (Title 38) | Chapter 3, §§ 481-490 | Regulates large land developments that may have a substantial impact on the environment | Obtain Site Location of Development Review when a planned land development activity is 20 acres or more in size | Site Location of Development Review required for any development activities 20 acres or more in size that include construction, repair, or alteration of any permanent structure on land | Site Location of Development Review would be obtained for landside materials handling, processing, storage, transportation or disposal facilities 20 acres or more in size that include construction, repair, or alteration of any permanent structure for dewatered materials generated from dredging |
| Maine Waterway Development and Conservation Act | NA | Regulates structural alteration of existing hydropower projects and new hydropower projects in waters of the State of Maine | Obtain MWDCA Permit in conjunction with Site Location of Development Review when a planned activity includes dam modification or construction | MWDCA Permit required in conjunction with Site Location of Development Review when a planned activity includes dam modification or construction | MWDCA Permit would be obtained in conjunction with Site Location of Development Review for any planned activity that includes dam modification or construction for dredging, capping |

**TABLE 4-2**

**APPLICABLE STATE REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| Stormwater Discharges & Erosion and Sediment Control Law (Title 38) | § 420-D | Requires measures to prevent unreasonable erosion of soil or sediment beyond the project site or into a protected natural resource, such as a river, stream, brook, lake, pond, or wetland during activities such as filling, displacing, or exposing soil or other earthen materials | Erosion control measures must be installed before the activity begins, be maintained, and remain in place and functional until the project is permanently stabilized such that further erosion and sedimentation is no longer occurring or threatened | MEPDES Permit administered by MEDEP under MEPDES Program would include erosion control measures for any planned activities that could cause erosion | MEPDES Permit would be obtained in conjunction with USACE Individual Permit for landside facilities to support the dredging, capping, or application of amendments in waters of the State of Maine |
| Overboard & Groundwater Discharges (Title 38) | §§ 411-A, 413 and 414-A | Requires discharge license for process water from industrial or commercial activities to surface waters and groundwater | Obtain MEPDES Permit administered by MEDEP under MEPDES Program for discharges of process water to surface waters or groundwater | MEPDES Permit administered by MEDEP under MEPDES Program would include any planned activities that include process water discharges | MEPDES Permit may be obtained in conjunction with USACE Individual Permit for coincident industrial operations to support dredging, capping, or application of amendments process water discharges |
| Mandatory Shoreland Zoning Act (Title 38) | §§ 435-449 | Requires municipalities to adopt, administer, and enforce local ordinances that regulate land use activities in the shoreland zone | Requires enforcement of local ordinances in the shoreland zone for all land areas within 250 feet horizontal distance of: (1) normal high-water line of any great pond or river; (2) upland edge of a coastal wetland, including all areas affected by tidal action; (3) upland edge of defined freshwater wetlands; and (4) all land areas within a 75 foot horizontal distance of the normal high-water line of certain streams | Shoreland zoning regulations are administered and enforced by each municipality through municipal-specific ordinances | Local ordinances would be reviewed and considered, and review and development approval would be obtained during development of planned activities within the shoreland zone in conjunction with USACE |

**TABLE 4-2**

**APPLICABLE STATE REQUIREMENTS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Requirement | Section | Description | Action | Comments | Remedial Alternative Compliance |
|---|---|---|---|---|---|
| Submerged Lands Lease Program | NA | Requires a lease or easement for structures located on submerged lands that meet certain criteria | Obtain a lease or easement for structures constructed on submerged lands from the mean low-water mark out to the 3-mile territorial limit in coastal regions, and all land below the mean low-water mark of tidal rivers upstream to the farthest natural reaches of tides | The program is implemented by the Bureau of Parks and Lands within the Department of Agriculture, Conservation and Forestry | A Submerged Lands Lease or Easement would be obtained in conjunction with USACE Individual Permit for construction of underwater structures for dredging or capping |
| Maine Historic Preservation Commission Consultation | NA | Evaluation of potential impacts to historic and cultural resources from planned activities | Consult with SHPO and THPO prior to undertaking any action, including issuing permits, which may have an effect on properties listed on, or eligible for listing on the National Register of Historic Places | Consultation with SHPO and THPO is through Maine Historic Preservation Commission (the SHPO) for activities occurring within or adjacent to surface waters, or support activities on nearby lands that have the potential to affect listed properties or properties eligible for listing | SHPO would be consulted with on locations of historic and cultural resources in conjunction with obtaining USACE Individual Permit for dredging or capping in surface waters and landside materials handling, transportation, storage, and disposal of dredged materials |

Abbreviations:
µg/L = micrograms per liter
AWQC = Ambient Water Quality Criteria
LUPC = Land Use Planning Commission
MEDEP = Maine Department of Environmental Protection
MEPDES = Maine Pollutant Discharge Elimination System
mg/kg = milligrams per kilogram
MNRPA = Maine Natural Resources Protection Act
MRSA = Maine Revised Statutes Annotated
MWDCA = Maine Waterway Development and Conservation Act
NA = not applicable
SHPO =State Historical Preservation Office
THPO = Tribal Historical Preservation Office
USACE = United States Army Corps of Engineers
WQC = Water Quality Certification

Prepared by: ESS 3/1/18
Checked by: CPP 3/7/18

**TABLE 4-3**

**SUMMARY OF PERMITS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Regulation/ Act | Section (s) | Trigger | Permit Application | Commentary |
|---|---|---|---|---|
| **Federal** | | | | |
| Clean Water Act | 404 | Dredging/filling waters of the US | ENG Form 4345 | An Individual Permit will likely be required due to complexity of work and presence of listed species |
| | 401 | Water Quality Certification administered by MEDEP required when dredging/filling waters of the US with an Individual Permit | Contents prescribed by Maine Water Quality Criteria and Stormwater Rules | Required for 404 individual permit |
| | 402 | NPDES permit would be required for pollutant discharge to waters of the US | Program is administered by MEDEP | State of Maine regulations also require a permit for discharge of pollutants to water |
| National Historic Preservation Act | NA | 404 permit application; impacts to cultural resources. | Approved work plan and approved results by SHPO; consultation with federally recognized Native American tribes is also required | Coordinate with SHPO and Tribal Preservation Officers |
| Fisheries Consultation and Management Act | NA | 404 permit application; impacts to Essential Fish Habitat. | Required for 404 individual permit. | Will require coordination with NMFS, USFWS, and EPA |
| Rivers and Harbors Act of 1899 | Section 10 | Building of any structure in the channel or along the banks of navigable waters of the US that changes the course, conditions, location, or capacity of the waters | ENG Form 4345 | An Individual Permit will likely be required due to complexity of work and presence of listed species |
| Rivers and Harbors Act of 1899 and USC Section 408 | Section 14 of Rivers and Harbors Act | Alteration of the area within a USACE civil works project. | Review of the project against undesirable modification of the project area. | Review can be concurrent with CWA applications. |
| Endangered Species Act | NA | 404 permit application; potential take of listed species during remediation. | Incidental Take Permits for potentially affected species | Requires coordination with NOAA, USFWS, and EPA. |
| Marine Mammal Protection Act | NA | Need NOAA to issue Incidental Take Permits to support investigation and/or implementation of the preferred remedial alternative | Incidental Take Permits for potentially affected species | Will require coordination with NOAA; their concurrence on Individual Permit application is required for normal approval |
| Marine Protection, Research and Sanctuaries Act | All | Disposal and transportation of dredged material in the water of the US | ENG Form 4345 | USACE is responsible for overseeing this in coordination with EPA |
| Migratory Bird Treaty Act | NA | Need USFWS to issue Incidental Take Permits for certain species to support investigation and/or implementation of the preferred remedial alternative | ENG Form 4345 | Will require coordination with USFWS; their concurrence on Individual Permit application is required for normal approval |
| Coastal Zone Management Act | NA | Required for State NRPA Permits; Coastal Zone Management Consistency Determination | Required for State NRPA permits | Administered by the State of Maine |

**TABLE 4-3**

**SUMMARY OF PERMITS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Regulation/ Act | Section (s) | Trigger | Permit Application | Commentary |
|---|---|---|---|---|
| **State** | | | | |
| Site Location of Development Law | NA | For projects disturbing over 20 acres, 3 acres of impervious surface and/or subdivision of land | Site Location of Development-25 required areas of discussion | May not be needed for all alternatives |
| Natural Resource Protection Act | NA | Activities in or near a regulated resource | NRPA | |
| Chapter 335 Significant Wildlife Habitat | NA | Work within areas defined as Significant Wildlife Habitat | NRPA | Avoidance of Significant Wildlife Habitat is required |
| Maine Endangered Species Act | NA | 45 listed species | Incidental Take Permits for potentially affected species | |
| Maine Marine Endangered Species Act | NA | 9 listed species | Incidental Take Permits for potentially affected species | |
| Imperiled and Critically Imperiled Habitats | NA | Maine Natural Areas Program (threatened and endangered plants) | NRPA | A database search is required for project area if NRPA permit is applied for |
| MEDEP Stormwater Rules Chapters 500, 501, and 502 | NA | Disturbance of over 1 acre of land | Maine Stormwater Law Application; Stormwater Permit By Rule | For certain activities including but not limited to paving, building, and earth disturbance |
| MEDEP Solid Waste Rules Chapters 400, 401, 402, 403, 405, 409, 410, 411, and 418 | NA | Treatment of materials including dewatering of dredge spoils | Appropriate Solid Waste Application, depending on activity | For treatment and storage of solid wastes |
| Maine Waterway Development and Conservation Act | NA | Structural alteration of exiting hydropower projects and new hydropower projects | Maine Waterways Development and Conservation Act Application | Not likely to be needed as there are no plans for dam modication |
| Submerged Land Lease Program | NA | Temporary or permanent structures on submerged lands in tidally influenced waters of the state | Maine Department of Agriculture, Conservation, and Forestry | A lease is required to use submerged lands in Maine |
| Maine Hazardous Waste, Septage and Solid Waste Management Act | NA | The need to safely manage and transport harzardous waste. | Uniform Hazardous Waste Manifest or Uniform Bill of Lading | Applies if waste characterization indicates hazardous. |
| **Local** | | | | |
| Shoreland zoning or other zoning restrictions | NA | Research and evaluate local regulations in towns where regulated activities may occur. | Presentation and/or written application to the zoning/planning board. | Will depend on specific regulations in each municipality. |

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18

Abbreviations:
CWA – Clean Water Act
EPA = Environmental Protection Agency
MEDEP = Maine Department of Environmental Protection
NA = not applicable
NMFS = National Marine Fisheries Service
NOAA = Nation Oceanic and Atmospheric Administration
NPDES = National Pollutant Discharge Elimination System
NRPA = Natural Resource Protection Act
SHPO = State Historic Preservation Office
US = United States
USACE = US Army Corps of Engineers
USFWS = US Fish and Wildlife Service

# TABLE 5-1

## PENOBSCOT RIVER ESTUARY REACHES AND REACH BOUNDARIES
## Penobscot River Phase III Engineering Study
## Penobscot River Estuary, Maine

| Reach Name | Upgradient Boundary | Downgradient Boundary |
|---|---|---|
| Bangor | Former Veazie Dam | Souadabscook Stream |
| Orrington | Souadabscook Stream | Overhead Power Lines at Bucks Ledge |
| Winterport | Overhead Power Lines at Bucks Ledge | Northern Limit of Cable area at Drachm Point |
| Frankfort Flats | Northern Limit of Cable area at Drachm Point | Green Can #11 |
| Bucksport | Green Can #11 | Cable Crossing |
| Bucksport Harbor | East Side of Thalweg | Bucksport Verona Bridge |
| Bucksport Thalweg | Cable Crossing | Penobscot Narrows Bridge |
| Verona West | Penobscot Narrows Bridge | Sandy Point - Verona Island |
| Upper Penobscot Bay | Sandy Point - Verona Island | Fort Point - Wilson Point |
| Fort Point Cove | Fort Point - Sandy Point | Fort Point - Sandy Point |
| Cape Jellison | Fort Point - Wilson Point | Red Can #4 - Perkins Point |
| Verona Northeast | Bucksport Verona Bridge | Gross Point |
| Verona East | Gross Point | Confluence with Penobscot Bay |
| Orland River | Orland River Dam | Gross Point |
| Mendall Marsh | **Full Reach:** the upgradient extent of North and South Branches of Marsh River; **North Branch:** the dam in Frankfort; **South Branch:** 0.1 mile upstream of the railroad bridge on Colson Stream and 0.2 mile north of the Muskrat Farm Road on Carley Brook | Bowden Point |

Prepared by: KAM 3/1/18
Checked by: KC 3/8/17

## TABLE 5-2

## PENOBSCOT RIVER ESTUARY ZONES
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Zone Type | Description |
|---|---|
| Deep Thalweg | Subtidal area with a depth greater than 50 feet |
| Intertidal | Area between MLLW and MHW |
| Lawrence Cove Channel | A specific workable subtidal zone that was historically dredged |
| Pile | Area identified by geophysical survey as a wood chip deposit |
| Rocky Intertidal | Area between MLLW and MHW; area contains boulders that may limit in water remediation work |
| Shallow Subtidal | Subtidal area with a depth less than 10 feet at MLLW |
| Thalweg | Deepest section of the Estuary |
| Vegetated Marsh | Includes marsh platform and riverine bench |
| Workable Subtidal | Subtidal area with a depth greater than 10 feet at MLLW |

Abbreviations:
MLLW = mean lower low water
MHW = mean high water

Prepared by: KAM 3/1/18
Checked by: KC 3/7/18

## TABLE 5-3

### CALCULATED BOOTSTRAP MEANS – MENDALL MARSH 0–0.25 FOOT
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Mendall Marsh | Subtidal | West | 8 | NA | 4,957,839 | 688.1 | 292 | 1490 | 285 |
| Mendall Marsh | Intertidal | Main | 61 | 3.5 | 9,317,247 | 695.4 | 56 | 826 | 596 |
| Mendall Marsh | Marsh | Elevation 2 - 5.8 feet | 15 | NA | 2,353,002 | 665.8 | 84 | 811 | 446 |
| Mendall Marsh | Marsh | Elevation 5.8 - 7 feet | 22 | NA | 2,456,469 | 721.8 | 34 | 787 | 655 |
| Mendall Marsh | Marsh | Elevation 7 - 7.5 feet | 25 | NA | 3,103,348 | 513.2 | 43 | 587 | 418 |
| Mendall Marsh | Marsh | Elevation 7.5 feet to edge of platform | 57 | NA | 12,605,472 | 429.4 | 30 | 494 | 377 |

Notes:
1. N-Value = number of samples in that specific reach/zone

Prepared by: ESS 3/2/18
Checked by: KC 3/7/18
Modified by: RMB 8/15/18

Abbreviations:
NA = not analyzed
sf = square feet
ST DEV = standard deviation
CI = confidence interval

## TABLE 5-4

## CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 0–0.5 FOOT
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | BOOTMEAN ASSIGNED[2] | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|
| Bangor | Intertidal | East | 13 | 29.0 | 2,594,863 | 288.9 | 288.9 | 104 | 533 | 122 |
| Bangor | Intertidal | West | 13 | 29.0 | 3,156,402 | 489.4 | 489.4 | 97 | 730 | 336 |
| Bangor | Thalweg/Main | Main | 5 | 17.1 | 14,743,457 | 566.6 | 566.6 | 289 | 1,217 | 16 |
| Bangor | Subtidal | East | 6 | 15.6 | 3,628,240 | 546.4 | 546.4 | 265 | 1,196 | 84 |
| Bangor | Subtidal | West | 6 | 6.1 | 2,353,096 | 681.1 | 681.1 | 166 | 983 | 297 |
| Bangor | Marsh | Marsh | 4 | NA | 3,133,390 | 183.7 | 183.7 | 42 | 242 | 78 |
| Bucksport Main | Intertidal | East | 4 | 22.0 | 1,397,311 | 464.3 | 464.3 | 113 | 620 | 82 |
| Bucksport Main | Intertidal | West | 3 | 22.0 | 2,502,091 | 885.5 | 885.5 | 41 | 975 | 806 |
| Bucksport Main | Thalweg/Main | Main | 11 | 1.5 | 8,523,106 | 769.6 | 769.6 | 102 | 937 | 550 |
| Bucksport Main | Subtidal | East | 2 | 5.3 | 3,556,176 | 852.0 | 852.0 | 102 | 994 | 695 |
| Bucksport Main | Subtidal | West | 20 | 13.5 | 15,559,226 | 826.2 | 826.2 | 160 | 1,302 | 598 |
| Bucksport Thalweg | Intertidal | East | NA | 62.0 | 514,669 | NA | **464.3** | NA | NA | NA |
| Bucksport Thalweg | Intertidal | West | NA | 62.0 | 133,959 | NA | **885.5** | NA | NA | NA |
| Bucksport Thalweg | Thalweg/Main | Main | 7 | 60.1 | 6,676,928 | 908.2 | 908.2 | 247 | 1,326 | 403 |
| Bucksport Thalweg | Subtidal | East | 1 | 47.1 | 863,776 | 669.0 | 669.0 | NA | NA | NA |
| Bucksport Thalweg | Subtidal | West | 2 | 78.4 | 1,679,785 | 604.5 | 604.5 | 5 | 612 | 597 |
| Cape Jellison | Intertidal | East | NA | 30.5 | 3,599,933 | NA | **492.5** | NA | NA | NA |
| Cape Jellison | Intertidal | West | NA | 30.5 | 478,036 | NA | **507.6** | NA | NA | NA |
| Cape Jellison | Thalweg/Main | Main | 5 | NA | 21,925,645 | 475.7 | 475.7 | 69 | 553 | 222 |
| Cape Jellison | Subtidal | East | 9 | NA | 131,890,198 | 492.5 | 492.5 | 83 | 631 | 304 |
| Cape Jellison | Subtidal | West | 3 | NA | 22,048,105 | 507.6 | 507.6 | 28 | 573 | 468 |
| Cape Jellison | Marsh | Marsh | 3 | NA | 2,814,275 | 71.5 | 71.5 | 25 | 105 | 12 |
| Fort Point Cove | Intertidal | West | 8 | 35.0 | 9,381,267 | 155.8 | 155.8 | 41 | 247 | 91 |
| Fort Point Cove | Subtidal | West | 27 | NA | 46,332,364 | 712.0 | 712.0 | 53 | 818 | 600 |
| Fort Point Cove | Marsh | Marsh | 3 | NA | 1,882,852 | 34.6 | 34.6 | 10 | 57 | 16 |
| Frankfort Flats | Other[3] | NA | 7 | NA | 4,463,457 | 919.4 | 919.4 | 137 | 1,150 | 553 |
| Frankfort Flats | Intertidal | East | 7 | 9.0 | 6,971,371 | 1,046.5 | 1,046.5 | 41 | 247 | 91 |
| Frankfort Flats | Intertidal | West | 10 | 9.0 | 5,057,180 | 732.2 | 732.2 | 53 | 818 | 600 |
| Frankfort Flats | Thalweg/Main | Main | 9 | 3.5 | 11,737,900 | 358.5 | 358.5 | 10 | 57 | 16 |
| Frankfort Flats | Subtidal | East | 27 | 2.8 | 26,665,447 | 361.1 | 361.1 | 41 | 247 | 91 |
| Frankfort Flats | Subtidal | West | 22 | 5.6 | 10,541,999 | 597.3 | 597.3 | 53 | 818 | 600 |
| Frankfort Flats | Marsh | Marsh | 18 | NA | 4,019,444 | 855.5 | 855.5 | 10 | 57 | 16 |
| Mendall Marsh | Subtidal | West | 8 | NA | 4,957,839 | 641.6 | 641.6 | 269 | 1,566 | 245 |
| Mendall Marsh | Intertidal | Main | 61 | 3.5 | 9,317,247 | 708.2 | 708.2 | 55 | 841 | 610 |
| Mendall Marsh | Marsh | Marsh | 15 | NA | 2,353,002 | 743.1 | 743.1 | 97 | 914 | 534 |
| Mendall Marsh | Marsh | Marsh | 22 | NA | 2,456,469 | 940.2 | 940.2 | 68 | 1,082 | 824 |
| Mendall Marsh | Marsh | Marsh | 25 | NA | 3,103,348 | 596.7 | 596.7 | 74 | 767 | 477 |

**TABLE 5-4**

**CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 0–0.5 FOOT**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | BOOTMEAN ASSIGNED[2] | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|
| Mendall Marsh | Marsh | Marsh | 57 | NA | 12,605,472 | 495.7 | 495.7 | 43 | 612 | 428 |
| Orland River | Other[3] | NA | 2 | NA | 288,438 | 1,409.4 | 1,409.4 | 37 | 1,470 | 1,355 |
| Orland River | Marsh | Marsh | 12 | NA | 1,871,555 | 940.4 | 940.4 | 72 | 1,092 | 814 |
| Orland River | Intertidal | East | 24 | 5.0 | 5,812,145 | 1,086.8 | 1,086.8 | 67 | 1,236 | 989 |
| Orland River | Intertidal | West | 29 | 5.0 | 6,271,906 | 867.7 | 867.7 | 50 | 967 | 760 |
| Orland River | Thalweg/Main | Main | 7 | NA | 4,628,944 | 569.3 | 569.3 | 133 | 838 | 299 |
| Orrington | Intertidal | East | 42 | 10.0 | 6,282,159 | 1,208.5 | 1,208.5 | 67 | 1,341 | 1,074 |
| Orrington | Intertidal | West | 10 | 10.0 | 5,397,614 | 978.6 | 978.6 | 111 | 1,234 | 767 |
| Orrington | Thalweg/Main | Main | 20 | 32.2 | 15,343,256 | 582.7 | 582.7 | 118 | 831 | 384 |
| Orrington | Subtidal | East | 26 | 14.7 | 10,642,953 | 819.2 | 819.2 | 121 | 1,035 | 600 |
| Orrington | Subtidal | West | 8 | 7.0 | 6,075,000 | 648.5 | 648.5 | 155 | 977 | 373 |
| Orrington | Marsh | Marsh | 21 | NA | 4,103,967 | 1,877.2 | 1,877.2 | 816 | 4,598 | 955 |
| Upper Penobscot | Intertidal | East | 2 | 21.5 | 7,174,261 | 56.6 | 56.6 | 7 | 66 | 45 |
| Upper Penobscot | Thalweg/Main | Main | 25 | NA | 121,726,846 | 478.6 | 478.6 | 35 | 542 | 400 |
| Upper Penobscot | Marsh | Marsh | 1 | NA | 1,786,058 | 19.3 | 19.3 | NA | NA | NA |
| Verona East | Other[3] | NA | NA | NA | 184,725 | NA | **1,113.3** | NA | NA | NA |
| Verona East | Other[3] | NA | NA | NA | 250,257 | NA | **1,113.3** | NA | NA | NA |
| Verona East | Intertidal | East | 9 | 25.5 | 4,337,637 | 935.7 | 935.7 | 101 | 1,286 | 805 |
| Verona East | Intertidal | West | 13 | 25.5 | 2,516,445 | 647.6 | 647.6 | 93 | 854 | 483 |
| Verona East | Thalweg/Main | Main | 9 | NA | 9,867,083 | 1,020.6 | 1,020.6 | 108 | 1,261 | 842 |
| Verona East | Marsh | Marsh | 1 | NA | 923,687 | 755.9 | 755.9 | NA | NA | NA |
| Verona East | Subtidal | East | 5 | NA | 6,739,305 | 320.0 | 320.0 | 172 | 883 | 85 |
| Verona East | Subtidal | West | 4 | NA | 3,667,825 | 312.5 | 312.5 | 90 | 532 | 182 |
| Verona NE | Other[3] | NA | 5 | NA | 1,276,709 | 1,113.3 | 1,113.3 | 156 | 1401 | 858 |
| Verona NE | Intertidal | East | 17 | 6.0 | 5,473,382 | 847.2 | 847.2 | 73 | 998 | 699 |
| Verona NE | Intertidal | West | 29 | 6.0 | 12,906,385 | 924.1 | 924.1 | 45 | 1,032 | 848 |
| Verona NE | Thalweg/Main | Main | 12 | 0.006 | 6,507,212 | 598.0 | 598.0 | 81 | 724 | 404 |
| Verona NE | Marsh | Marsh | 5 | NA | 2,445,418 | 961.1 | 961.1 | 278 | 1,517 | 426 |
| Verona NE | Subtidal | East | 8 | 0.006 | 5,418,041 | 562.0 | 562.0 | 83 | 730 | 422 |
| Verona NE | Subtidal | West | 18 | NA | 4,059,906 | 637.8 | 637.8 | 64 | 751 | 502 |
| Verona West | Intertidal | East | 1 | 40.0 | 3,923,792 | 92.2 | 92.2 | NA | NA | NA |
| Verona West | Intertidal | West | NA | 40.0 | 2,208,853 | NA | **92.2** | NA | NA | NA |
| Verona West | Thalweg/Main | Main | 11 | 69.6 | 19,152,738 | 473.6 | 473.6 | 108 | 687 | 277 |
| Verona West | Subtidal | East | 12 | 18.7 | 16,675,192 | 806.4 | 806.4 | 273 | 1,520 | 397 |
| Verona West | Subtidal | West | 11 | 32.7 | 25,369,156 | 505.0 | 505.0 | 92 | 694 | 329 |
| Verona West | Marsh | Marsh | 2 | NA | 2,161,307 | 220.5 | 220.5 | 54 | 290 | 137 |

## TABLE 5-4

### CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 0–0.5 FOOT
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | BOOTMEAN ASSIGNED[2] | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|
| Winterport | Intertidal | East | 1 | 7.5 | 3,104,730 | 856.6 | 856.6 | NA | NA | NA |
| Winterport | Intertidal | West | 12 | 7.5 | 6,163,461 | 747.0 | 747.0 | 101 | 924 | 556 |
| Winterport | Thalweg/Main | Main | 15 | 41.1 | 22,418,558 | 569.1 | 569.1 | 128 | 877 | 361 |
| Winterport | Subtidal | East | 3 | 5.3 | 4,542,930 | 332.6 | 332.6 | 16 | 361 | 297 |
| Winterport | Subtidal | West | 2 | 38.1 | 3,274,100 | 801.4 | 801.4 | 401 | 1,360 | 220 |
| Winterport | Marsh | Marsh | 9 | NA | 5,164,574 | 884.6 | 884.6 | 30 | 942 | 830 |

Prepared by: ESS 3/2/18
Checked by: KC 3/7/18
Modified by: RMB 8/15/18

Notes:

1. N-Value = number of samples in that specific reach/zone
2. Bootmean Assigned is the bootmean value used for the area weighted average concentration; green values signify reaches/zones that did not have any samples (N-Value = 0) and were assigned a bootmean value from an adjacent reach/zone
3. Wood-enriched sediment deposits; See Table 5-15

Abbreviations:

NA = not analyzed
sf = square feet
ST DEV = standard deviation
CI = confidence interval

## TABLE 5-5

## CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 0.5–1 FOOT
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Bangor | Intertidal | East | 8 | 29.0 | 2,594,863 | 442.0 | 106 | 764 | 296 |
| Bangor | Intertidal | West | 7 | 29.0 | 3,156,402 | 426.2 | 91 | 612 | 254 |
| Bangor | Thalweg/Main | Main | 1 | 17.1 | 14,743,457 | 1,231.2 | NA | NA | NA |
| Bangor | Subtidal | East | 2 | 15.6 | 3,628,240 | 788.6 | 394 | 1,360 | 250 |
| Bangor | Subtidal | West | 3 | 6.1 | 2,353,096 | 1,310.0 | 255 | 1,648 | 700 |
| Bangor | Marsh | Marsh | 1 | NA | 3,133,390 | 490.0 | NA | NA | NA |
| Bucksport Main | Intertidal | East | 2 | 22.0 | 1,397,311 | 657.6 | 7 | 666 | 646 |
| Bucksport Main | Intertidal | West | 1 | 22.0 | 2,502,091 | 1,036.0 | NA | NA | NA |
| Bucksport Main | Thalweg/Main | Main | 3 | 1.5 | 8,523,106 | 649.3 | 124 | 836 | 359 |
| Bucksport Main | Subtidal | East | 0 | 5.3 | 3,556,176 | NA | NA | NA | NA |
| Bucksport Main | Subtidal | West | 2 | 13.5 | 15,559,226 | 419.6 | 48 | 489 | 356 |
| Bucksport Thalweg | Intertidal | East | NA | 62.0 | 514,669 | NA | NA | NA | NA |
| Bucksport Thalweg | Intertidal | West | NA | 62.0 | 133,959 | NA | NA | NA | NA |
| Bucksport Thalweg | Thalweg/Main | Main | 0 | 60.1 | 6,676,928 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | East | 0 | 47.1 | 863,776 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | West | 1 | 78.4 | 1,679,785 | 478.0 | NA | NA | NA |
| Cape Jellison | Intertidal | East | NA | 30.5 | 3,599,933 | NA | NA | NA | NA |
| Cape Jellison | Intertidal | West | NA | 30.5 | 478,036 | NA | NA | NA | NA |
| Cape Jellison | Thalweg/Main | Main | 0 | NA | 21,925,645 | NA | NA | NA | NA |
| Cape Jellison | Subtidal | East | 3 | NA | 131,890,198 | 339.4 | 165 | 744 | 132 |
| Cape Jellison | Subtidal | West | 0 | NA | 22,048,105 | NA | NA | NA | NA |
| Cape Jellison | Marsh | Marsh | 0 | NA | 2,814,275 | NA | NA | NA | NA |
| Fort Point Cove | Intertidal | West | 1 | 35.0 | 9,381,267 | 15.1 | NA | NA | NA |
| Fort Point Cove | Subtidal | West | 9 | NA | 46,332,364 | 1,016.5 | 156 | 1,308 | 724 |
| Fort Point Cove | Marsh | Marsh | 0 | NA | 1,882,852 | NA | NA | NA | NA |
| Frankfort Flats | Other[2] | NA | 1 | NA | 4,463,457 | 1,066.0 | NA | NA | NA |
| Frankfort Flats | Intertidal | East | 4 | 9.0 | 6,971,371 | 1,071.3 | 328 | 1,853 | 549 |
| Frankfort Flats | Intertidal | West | 4 | 9.0 | 5,057,180 | 1,387.2 | 715 | 3,298 | 396 |
| Frankfort Flats | Thalweg/Main | Main | 0 | 3.5 | 11,737,900 | NA | NA | NA | NA |
| Frankfort Flats | Subtidal | East | 5 | 2.8 | 26,665,447 | 80.9 | 45 | 223 | 23 |
| Frankfort Flats | Subtidal | West | 2 | 5.6 | 10,541,999 | 29.1 | 279 | 1,066 | 26 |
| Frankfort Flats | Marsh | Marsh | 6 | NA | 4,019,444 | 1,572.7 | 500 | 2,478 | 638 |
| Mendall Marsh | Subtidal | West | 2 | NA | 4,957,839 | 80.2 | 46 | 146 | 14 |
| Mendall Marsh | Intertidal | Main | 34 | 3.5 | 9,317,247 | 660.5 | 114 | 915 | 461 |
| Mendall Marsh | Marsh | Marsh | 11 | NA | 2,353,002 | 1206.3 | 282 | 1,813 | 714 |
| Mendall Marsh | Marsh | Marsh | 15 | NA | 2,456,469 | 1868.9 | 217 | 2,254 | 1,440 |
| Mendall Marsh | Marsh | Marsh | 12 | NA | 3,103,348 | 410.9 | 159 | 837 | 178 |

**TABLE 5-5**

**CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 0.5–1 FOOT**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Mendall Marsh | Marsh | Marsh | 34 | NA | 12,605,472 | 194.1 | 58 | 359 | 118 |
| Orland River | Other[2] | NA | 1 | NA | 288,438 | 1,420.9 | NA | NA | NA |
| Orland River | Marsh | Marsh | 7 | NA | 1,871,555 | 1,365.9 | 301 | 2,112 | 911 |
| Orland River | Intertidal | East | 18 | 5.0 | 5,812,145 | 1,291.2 | 161 | 1,654 | 1,058 |
| Orland River | Intertidal | West | 20 | 5.0 | 6,271,906 | 995.1 | 128 | 1,226 | 708 |
| Orland River | Thalweg/Main | Main | 3 | NA | 4,628,944 | 45.9 | 15 | 82 | 20 |
| Orrington | Intertidal | East | 29 | 10.0 | 6,282,159 | 5,300.7 | 1,840 | 11,736 | 2,440 |
| Orrington | Intertidal | West | 7 | 10.0 | 5,397,614 | 1,058.2 | 195 | 1,493 | 730 |
| Orrington | Thalweg/Main | Main | 4 | 32.2 | 15,343,256 | 848.4 | 32 | 907 | 784 |
| Orrington | Subtidal | East | 8 | 14.7 | 10,642,953 | 1,289.0 | 555 | 2,714 | 464 |
| Orrington | Subtidal | West | 0 | 7.0 | 6,075,000 | NA | NA | NA | NA |
| Orrington | Marsh | Marsh | 13 | NA | 4,103,967 | 1,779.4 | 1,006 | 6,188 | 647 |
| Upper Penobscot | Intertidal | East | 0 | 21.5 | 7,174,261 | NA | NA | NA | NA |
| Upper Penobscot | Thalweg/Main | Main | 8 | NA | 121,726,846 | 537.4 | 119 | 733 | 251 |
| Upper Penobscot | Marsh | Marsh | 0 | NA | 1,786,058 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 184,725 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 250,257 | NA | NA | NA | NA |
| Verona East | Intertidal | East | 8 | 25.5 | 4,337,637 | 1,368.3 | 83 | 1,532 | 1,203 |
| Verona East | Intertidal | West | 7 | 25.5 | 2,516,445 | 495.1 | 189 | 971 | 227 |
| Verona East | Thalweg/Main | Main | 0 | NA | 9,867,083 | NA | NA | NA | NA |
| Verona East | Marsh | Marsh | 1 | NA | 923,687 | 1,660.0 | NA | NA | NA |
| Verona East | Subtidal | East | 0 | NA | 6,739,305 | NA | NA | NA | NA |
| Verona East | Subtidal | West | 1 | NA | 3,667,825 | 604.0 | NA | NA | NA |
| Verona NE | Other[2] | NA | 1 | NA | 1,276,709 | 1,547.4 | NA | NA | NA |
| Verona NE | Intertidal | East | 11 | 6.0 | 5,473,382 | 838.2 | 148 | 1,113 | 554 |
| Verona NE | Intertidal | West | 24 | 6.0 | 12,906,385 | 1,136.5 | 81 | 1,337 | 996 |
| Verona NE | Thalweg/Main | Main | 2 | 0.006 | 6,507,212 | 542.6 | 197 | 808 | 255 |
| Verona NE | Marsh | Marsh | 2 | NA | 2,445,418 | 1,053.9 | 246 | 1,330 | 631 |
| Verona NE | Subtidal | East | 5 | 0.006 | 5,418,041 | 522.7 | 62 | 619 | 370 |
| Verona NE | Subtidal | West | 7 | NA | 4,059,906 | 624.8 | 175 | 947 | 285 |
| Verona West | Intertidal | East | 1 | 40.0 | 3,923,792 | 9.7 | NA | NA | NA |
| Verona West | Intertidal | West | NA | 40.0 | 2,208,853 | NA | NA | NA | NA |
| Verona West | Thalweg/Main | Main | 1 | 69.6 | 19,152,738 | 24.2 | NA | NA | NA |
| Verona West | Subtidal | East | 3 | 18.7 | 16,675,192 | 676.8 | 122 | 824 | 367 |
| Verona West | Subtidal | West | 2 | 32.7 | 25,369,156 | 1,517.9 | 667 | 2,615 | 656 |
| Verona West | Marsh | Marsh | 2 | NA | 2,161,307 | 35.0 | 3 | 38 | 30 |

## TABLE 5-5

## CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 0.5–1 FOOT
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Winterport | Marsh | East | 1 | 7.5 | 3,104,730 | 841.0 | NA | NA | NA |
| Winterport | Intertidal | West | 5 | 7.5 | 6,163,461 | 427.0 | 165 | 794 | 216 |
| Winterport | Thalweg/Main | Main | 1 | 41.1 | 22,418,558 | 905.8 | NA | NA | NA |
| Winterport | Subtidal | East | 0 | 5.3 | 4,542,930 | NA | NA | NA | NA |
| Winterport | Subtidal | West | 0 | 38.1 | 3,274,100 | NA | NA | NA | NA |
| Winterport | Marsh | Marsh | 5 | NA | 5,164,574 | 1,415.3 | 456 | 2,266 | 564 |

Notes:
1. N-Value = number of samples in that specific reach/zone
2. Wood-enriched sediment deposits; See Table 5-15

Prepared by: ESS 3/2/18
Checked by: KC 3/7/18
Modified by: RMB 8/15/18

Abbreviations:
NA = not analyzed
sf = square feet
ST DEV = standard deviation
CI = confidence interval

## TABLE 5-6

## CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 1–2 FEET
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Bangor | Intertidal | East | 2 | 29.0 | 2,594,863 | 256.4 | 30 | 298 | 211 |
| Bangor | Intertidal | West | 3 | 29.0 | 3,156,402 | 578.9 | 115 | 861 | 438 |
| Bangor | Thalweg/Main | Main | 1 | 17.1 | 14,743,457 | 1,484.4 | NA | NA | NA |
| Bangor | Subtidal | East | 1 | 15.6 | 3,628,240 | 1,842.9 | NA | NA | NA |
| Bangor | Subtidal | West | 2 | 6.1 | 2,353,096 | 1,067.5 | 32 | 1,111 | 1,021 |
| Bangor | Marsh | Marsh | 0 | NA | 3,133,390 | NA | NA | NA | NA |
| Bucksport Main | Intertidal | East | 1 | 22.0 | 1,397,311 | 70.6 | NA | NA | NA |
| Bucksport Main | Intertidal | West | 1 | 22.0 | 2,502,091 | 1,093.0 | NA | NA | NA |
| Bucksport Main | Thalweg/Main | Main | 3 | 1.5 | 8,523,106 | 606.9 | 271 | 964 | 19 |
| Bucksport Main | Subtidal | East | 0 | 5.3 | 3,556,176 | NA | NA | NA | NA |
| Bucksport Main | Subtidal | West | 2 | 13.5 | 15,559,226 | 383.3 | 119 | 535 | 187 |
| Bucksport Thalweg | Intertidal | East | NA | 62.0 | 514,669 | NA | NA | NA | NA |
| Bucksport Thalweg | Intertidal | West | NA | 62.0 | 133,959 | NA | NA | NA | NA |
| Bucksport Thalweg | Thalweg/Main | Main | 0 | 60.1 | 6,676,928 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | East | 0 | 47.1 | 863,776 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | West | 0 | 78.4 | 1,679,785 | NA | NA | NA | NA |
| Cape Jellison | Intertidal | East | NA | 30.5 | 3,599,933 | NA | NA | NA | NA |
| Cape Jellison | Intertidal | West | NA | 30.5 | 478,036 | NA | NA | NA | NA |
| Cape Jellison | Thalweg/Main | Main | 0 | NA | 21,925,645 | NA | NA | NA | NA |
| Cape Jellison | Subtidal | East | 3 | NA | 131,890,198 | 201.7 | 161 | 622 | 21 |
| Cape Jellison | Subtidal | West | 0 | NA | 22,048,105 | NA | NA | NA | NA |
| Cape Jellison | Marsh | Marsh | 0 | NA | 2,814,275 | NA | NA | NA | NA |
| Fort Point Cove | Intertidal | West | 0 | 35.0 | 9,381,267 | NA | NA | NA | NA |
| Fort Point Cove | Subtidal | West | 8 | NA | 46,332,364 | 436.2 | 130 | 724 | 194 |
| Fort Point Cove | Marsh | Marsh | 0 | NA | 1,882,852 | NA | NA | NA | NA |
| Frankfort Flats | Other[2] | NA | 1 | NA | 4,463,457 | 948.0 | NA | NA | NA |
| Frankfort Flats | Intertidal | East | 2 | 9.0 | 6,971,371 | 386.0 | 65 | 479 | 297 |
| Frankfort Flats | Intertidal | West | 1 | 9.0 | 5,057,180 | 16.3 | NA | NA | NA |
| Frankfort Flats | Thalweg/Main | Main | 0 | 3.5 | 11,737,900 | NA | NA | NA | NA |
| Frankfort Flats | Subtidal | East | 5 | 2.8 | 26,665,447 | 19.8 | 2 | 23 | 15 |
| Frankfort Flats | Subtidal | West | 2 | 5.6 | 10,541,999 | 22.6 | 252 | 948 | 20 |
| Frankfort Flats | Marsh | Marsh | 0 | NA | 4,019,444 | NA | NA | NA | NA |
| Mendall Marsh | Subtidal | West | 2 | NA | 4,957,839 | 24.6 | 3 | 29 | 20 |
| Mendall Marsh | Intertidal | Main | 14 | 3.5 | 9,317,247 | 359.9 | 138 | 741 | 151 |
| Mendall Marsh | Marsh | Marsh | 8 | NA | 2,353,002 | 954.8 | 267 | 1,541 | 514 |
| Mendall Marsh | Marsh | Marsh | 12 | NA | 2,456,469 | 646.5 | 158 | 972 | 389 |
| Mendall Marsh | Marsh | Marsh | 2 | NA | 3,103,348 | 87.9 | 52 | 165 | 16 |

**TABLE 5-6**

**CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 1–2 FEET**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Mendall Marsh | Marsh | Marsh | 9 | NA | 12,605,472 | 40.1 | 11 | 76 | 26 |
| Orland River | Other[2] | NA | 1 | NA | 288,438 | 1,549.9 | NA | NA | NA |
| Orland River | Marsh | Marsh | 2 | NA | 1,871,555 | 490.7 | 133 | 664 | 275 |
| Orland River | Intertidal | East | 10 | 5.0 | 5,812,145 | 1,231.2 | 298 | 1,897 | 737 |
| Orland River | Intertidal | West | 7 | 5.0 | 6,271,906 | 775.9 | 292 | 1,411 | 293 |
| Orland River | Thalweg/Main | Main | 2 | NA | 4,628,944 | 17.5 | 1 | 18 | 17 |
| Orrington | Intertidal | East | 13 | 10.0 | 6,282,159 | 23,608.8 | 10,606 | 52,777 | 7,546 |
| Orrington | Intertidal | West | 4 | 10.0 | 5,397,614 | 857.2 | 434 | 1,754 | 27 |
| Orrington | Thalweg/Main | Main | 2 | 32.2 | 15,343,256 | 864.3 | 55 | 942 | 785 |
| Orrington | Subtidal | East | 6 | 14.7 | 10,642,953 | 136.7 | 85 | 420 | 46 |
| Orrington | Subtidal | West | 0 | 7.0 | 6,075,000 | NA | NA | NA | NA |
| Orrington | Marsh | Marsh | 7 | NA | 4,103,967 | 948.8 | 454 | 2,423 | 361 |
| Upper Penobscot | Intertidal | East | 0 | 21.5 | 7,174,261 | NA | NA | NA | NA |
| Upper Penobscot | Thalweg/Main | Main | 5 | NA | 121,726,846 | 564.7 | 254 | 1,092 | 94 |
| Upper Penobscot | Marsh | Marsh | 0 | NA | 1,786,058 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 184,725 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 250,257 | NA | NA | NA | NA |
| Verona East | Intertidal | East | 5 | 25.5 | 4,337,637 | 1,075.6 | 205 | 1,533 | 657 |
| Verona East | Intertidal | West | 2 | 25.5 | 2,516,445 | 17.3 | 4 | 23 | 12 |
| Verona East | Thalweg/Main | Main | 0 | NA | 9,867,083 | NA | NA | NA | NA |
| Verona East | Marsh | Marsh | 0 | NA | 923,687 | NA | NA | NA | NA |
| Verona East | Subtidal | East | 0 | NA | 6,739,305 | NA | NA | NA | NA |
| Verona East | Subtidal | West | 1 | NA | 3,667,825 | 604.0 | NA | NA | NA |
| Verona NE | Other[2] | NA | 1 | NA | 1,276,709 | 1,310.0 | NA | NA | NA |
| Verona NE | Intertidal | East | 5 | 6.0 | 5,473,382 | 709.9 | 348 | 1,430 | 71 |
| Verona NE | Intertidal | West | 11 | 6.0 | 12,906,385 | 758.6 | 145 | 1,098 | 520 |
| Verona NE | Thalweg/Main | Main | 2 | 0.006 | 6,507,212 | 436.3 | 266 | 808 | 49 |
| Verona NE | Marsh | Marsh | 0 | NA | 2,445,418 | NA | NA | NA | NA |
| Verona NE | Subtidal | East | 2 | 0.006 | 5,418,041 | 731.2 | 117 | 897 | 565 |
| Verona NE | Subtidal | West | 4 | NA | 4,059,906 | 578.2 | 195 | 936 | 107 |
| Verona West | Intertidal | East | 0 | 40.0 | 3,923,792 | NA | NA | NA | NA |
| Verona West | Intertidal | West | NA | 40.0 | 2,208,853 | NA | NA | NA | NA |
| Verona West | Thalweg/Main | Main | 1 | 69.6 | 19,152,738 | 22.0 | NA | NA | NA |
| Verona West | Subtidal | East | 2 | 18.7 | 16,675,192 | 77.6 | 13 | 97 | 58 |
| Verona West | Subtidal | West | 2 | 32.7 | 25,369,156 | 91.7 | 57 | 178 | 18 |
| Verona West | Marsh | Marsh | 0 | NA | 2,161,307 | NA | NA | NA | NA |

## TABLE 5-6

## CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 1–2 FEET
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Winterport | Marsh | East | 0 | 7.5 | 3,104,730 | NA | NA | NA | NA |
| Winterport | Intertidal | West | 3 | 7.5 | 6,163,461 | 308.1 | 122 | 600 | 155 |
| Winterport | Thalweg/Main | Main | 1 | 41.1 | 22,418,558 | 2,465.0 | NA | NA | NA |
| Winterport | Subtidal | East | 0 | 5.3 | 4,542,930 | NA | NA | NA | NA |
| Winterport | Subtidal | West | 0 | 38.1 | 3,274,100 | NA | NA | NA | NA |
| Winterport | Marsh | Marsh | 0 | NA | 5,164,574 | NA | NA | NA | NA |

Notes:
1. N-Value = number of samples in that specific reach/zone
2. Wood-enriched sediment deposits; See Table 5-15

Prepared by: ESS 3/2/18
Checked by: KC 3/7/18
Modified by: RMB 8/15/18

Abbreviations:
NA = not analyzed
sf = square feet
ST DEV = standard deviation
CI = confidence interval

## TABLE 5-7

## CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 2–3 FEET
### Penobscot River Phase III Engineering Study
### Penobscot River Estuary, Maine

| Reach | Zone | Ribbon Compass | N-Value[1] | ock Exclusion Percer | Shape Area (sf) | BOOTMEAN | ST DEV | pper 95% | ower 95% ( |
|---|---|---|---|---|---|---|---|---|---|
| Bangor | Intertidal | East | 0 | 29.0 | 2,594,863 | NA | NA | NA | NA |
| Bangor | Intertidal | West | 3 | 29.0 | 3,156,402 | 219.2 | 93 | 417 | 23 |
| Bangor | Thalweg/Main | Main | 1 | 17.1 | 14,743,457 | 393.3 | NA | NA | NA |
| Bangor | Subtidal | East | 0 | 15.6 | 3,628,240 | NA | NA | NA | NA |
| Bangor | Subtidal | West | 1 | 6.1 | 2,353,096 | 31.9 | NA | NA | NA |
| Bangor | Marsh | Marsh | 0 | NA | 3,133,390 | NA | NA | NA | NA |
| Bucksport Main | Intertidal | East | 0 | 22.0 | 1,397,311 | NA | NA | NA | NA |
| Bucksport Main | Intertidal | West | 0 | 22.0 | 2,502,091 | NA | NA | NA | NA |
| Bucksport Main | Thalweg/Main | Main | 2 | 1.5 | 8,523,106 | 1,513.1 | 246 | 1,860 | 1,171 |
| Bucksport Main | Subtidal | East | 0 | 5.3 | 3,556,176 | NA | NA | NA | NA |
| Bucksport Main | Subtidal | West | 2 | 13.5 | 15,559,226 | 174.8 | 75 | 279 | 69 |
| Bucksport Thalweg | Intertidal | East | 0 | 62.0 | 514,669 | NA | NA | NA | NA |
| Bucksport Thalweg | Intertidal | West | 0 | 62.0 | 133,959 | NA | NA | NA | NA |
| Bucksport Thalweg | Thalweg/Main | Main | 0 | 60.1 | 6,676,928 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | East | 0 | 47.1 | 863,776 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | West | 0 | 78.4 | 1,679,785 | NA | NA | NA | NA |
| Cape Jellison | Intertidal | East | 0 | 30.5 | 3,599,933 | NA | NA | NA | NA |
| Cape Jellison | Intertidal | West | 0 | 30.5 | 478,036 | NA | NA | NA | NA |
| Cape Jellison | Thalweg/Main | Main | 0 | NA | 21,925,645 | NA | NA | NA | NA |
| Cape Jellison | Subtidal | East | 3 | NA | 131,890,198 | 35.2 | 17 | 76 | 6 |
| Cape Jellison | Subtidal | West | 0 | NA | 22,048,105 | NA | NA | NA | NA |
| Cape Jellison | Marsh | Marsh | 0 | NA | 2,814,275 | NA | NA | NA | NA |
| Fort Point Cove | Intertidal | West | 0 | 35.0 | 9,381,267 | NA | NA | NA | NA |
| Fort Point Cove | Subtidal | West | 8 | NA | 46,332,364 | 47.0 | 9 | 68 | 32 |
| Fort Point Cove | Marsh | Marsh | 0 | NA | 1,882,852 | NA | NA | NA | NA |
| Frankfort Flats | Other[2] | NA | NA | NA | 4,463,457 | NA | NA | NA | NA |
| Frankfort Flats | Intertidal | East | 2 | 9.0 | 6,971,371 | 239.8 | 98 | 376 | 102 |
| Frankfort Flats | Intertidal | West | 1 | 9.0 | 5,057,180 | 15.1 | NA | NA | NA |
| Frankfort Flats | Thalweg/Main | Main | 0 | 3.5 | 11,737,900 | NA | NA | NA | NA |
| Frankfort Flats | Subtidal | East | 4 | 2.8 | 26,665,447 | 17.5 | 2 | 21 | 12 |
| Frankfort Flats | Subtidal | West | 3 | 5.6 | 10,541,999 | 358.2 | 267 | 1,030 | 22 |
| Frankfort Flats | Marsh | Marsh | 0 | NA | 4,019,444 | NA | NA | NA | NA |
| Mendall Marsh | Subtidal | West | 2 | NA | 4,957,839 | 14.0 | 5 | 21 | 7 |
| Mendall Marsh | Intertidal | Main | 12 | 3.5 | 9,317,247 | 242.4 | 149 | 685 | 39 |
| Mendall Marsh | Marsh | Marsh | 6 | NA | 2,353,002 | 842.3 | 431 | 1,884 | 96 |
| Mendall Marsh | Marsh | Marsh | 12 | NA | 2,456,469 | 318.8 | 124 | 677 | 140 |
| Mendall Marsh | Marsh | Marsh | 2 | NA | 3,103,348 | 26.7 | 3 | 31 | 22 |
| Mendall Marsh | Marsh | Marsh | 9 | NA | 12,605,472 | 22.7 | 2 | 26 | 19 |
| Orland River | Other[2] | NA | NA | NA | 288,438 | NA | NA | NA | NA |
| Orland River | Marsh | Marsh | 1 | NA | 1,871,555 | 116.9 | NA | NA | NA |
| Orland River | Intertidal | East | 10 | 5.0 | 5,812,145 | 429.8 | 186 | 1,075 | 214 |

**TABLE 5-7**

**CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 2–3 FEET**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | ock Exclusion Perce | Shape Area (sf) | BOOTMEAN | ST DEV | pper 95% | ower 95% ( |
|---|---|---|---|---|---|---|---|---|---|
| Orland River | Intertidal | West | 7 | 5.0 | 6,271,906 | 175.4 | 77 | 385 | 62 |
| Orland River | Thalweg/Main | Main | 2 | NA | 4,628,944 | 19.6 | 2 | 23 | 16 |
| Orrington | Intertidal | East | 1 | 10.0 | 6,282,159 | 42.4 | NA | NA | NA |
| Orrington | Intertidal | West | 3 | 10.0 | 5,397,614 | 662.5 | 533 | 1,920 | 22 |
| Orrington | Thalweg/Main | Main | 2 | 32.2 | 15,343,256 | 945.1 | 572 | 1,725 | 112 |
| Orrington | Subtidal | East | 3 | 14.7 | 10,642,953 | 41.6 | 10 | 54 | 17 |
| Orrington | Subtidal | West | 0 | 7.0 | 6,075,000 | NA | NA | NA | NA |
| Orrington | Marsh | Marsh | 3 | NA | 4,103,967 | 403.7 | 161 | 650 | 6 |
| Upper Penobscot | Intertidal | East | 0 | 21.5 | 7,174,261 | NA | NA | NA | NA |
| Upper Penobscot | Thalweg/Main | Main | 5 | NA | 121,726,846 | 729.3 | 444 | 1,997 | 13 |
| Upper Penobscot | Marsh | Marsh | 0 | NA | 1,786,058 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 184,725 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 250,257 | NA | NA | NA | NA |
| Verona East | Intertidal | East | 3 | 25.5 | 4,337,637 | 44.8 | 10 | 59 | 22 |
| Verona East | Intertidal | West | 2 | 25.5 | 2,516,445 | 8.5 | 3 | 13 | 4 |
| Verona East | Thalweg/Main | Main | 1 | NA | 9,867,083 | 1,330.0 | NA | NA | NA |
| Verona East | Marsh | Marsh | 0 | NA | 923,687 | NA | NA | NA | NA |
| Verona East | Subtidal | East | 0 | NA | 6,739,305 | NA | NA | NA | NA |
| Verona East | Subtidal | West | 0 | NA | 3,667,825 | NA | NA | NA | NA |
| Verona NE | Other[2] | NA | NA | NA | 1,276,709 | NA | NA | NA | NA |
| Verona NE | Intertidal | East | 4 | 6.0 | 5,473,382 | 69.8 | 25 | 120 | 19 |
| Verona NE | Intertidal | West | 7 | 6.0 | 12,906,385 | 53.0 | 12 | 82 | 33 |
| Verona NE | Thalweg/Main | Main | 1 | 0.006 | 6,507,212 | 35.1 | NA | NA | NA |
| Verona NE | Marsh | Marsh | 0 | NA | 2,445,418 | NA | NA | NA | NA |
| Verona NE | Subtidal | East | 1 | 0.006 | 5,418,041 | 916.5 | NA | NA | NA |
| Verona NE | Subtidal | West | 2 | NA | 4,059,906 | 36.3 | 13 | 56 | 18 |
| Verona West | Intertidal | East | 0 | 40.0 | 3,923,792 | NA | NA | NA | NA |
| Verona West | Intertidal | West | 0 | 40.0 | 2,208,853 | NA | NA | NA | NA |
| Verona West | Thalweg/Main | Main | 1 | 69.6 | 19,152,738 | 27.6 | NA | NA | NA |
| Verona West | Subtidal | East | 1 | 18.7 | 16,675,192 | 44.4 | NA | NA | NA |
| Verona West | Subtidal | West | 2 | 32.7 | 25,369,156 | 14.0 | 1 | 16 | 12 |
| Verona West | Marsh | Marsh | 0 | NA | 2,161,307 | NA | NA | NA | NA |
| Winterport | Marsh | East | 0 | 7.5 | 3,104,730 | NA | NA | NA | NA |
| Winterport | Intertidal | West | 3 | 7.5 | 6,163,461 | 153.7 | 80 | 353 | 52 |
| Winterport | Thalweg/Main | Main | 1 | 41.1 | 22,418,558 | 242.0 | NA | NA | NA |
| Winterport | Subtidal | East | 0 | 5.3 | 4,542,930 | NA | NA | NA | NA |
| Winterport | Subtidal | West | 0 | 38.1 | 3,274,100 | NA | NA | NA | NA |
| Winterport | Marsh | Marsh | 0 | NA | 5,164,574 | NA | NA | NA | NA |

Notes:
1. N-Value is the number of samples in that specific reach/zone
2. Wood-enriched sediment deposits; See Table 5-15

Prepared by: ESS 3/2/18
Checked by: KC 3/7/18
Modified by: RMB 8/15/18

Abbreviations:
NA = not analyzed

**TABLE 5-7**

**CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES 2–3 FEET**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | ock Exclusion Percei | Shape Area (sf) | BOOTMEAN | ST DEV | pper 95% | ower 95% C |
|---|---|---|---|---|---|---|---|---|---|

sf = square feet
ST DEV = standard deviation
CI = confidence interval

## TABLE 5-8

## CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES >3 FEET
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Bangor | Intertidal | East | 0 | 29.0 | 2,594,863 | NA | NA | NA | NA |
| Bangor | Intertidal | West | 0 | 29.0 | 3,156,402 | NA | NA | NA | NA |
| Bangor | Thalweg/Main | Main | 0 | 17.1 | 14,743,457 | NA | NA | NA | NA |
| Bangor | Subtidal | East | 0 | 15.6 | 3,628,240 | NA | NA | NA | NA |
| Bangor | Subtidal | West | 0 | 6.1 | 2,353,096 | NA | NA | NA | NA |
| Bangor | Marsh | Marsh | 0 | NA | 3,133,390 | NA | NA | NA | NA |
| Bucksport Main | Intertidal | East | 0 | 22.0 | 1,397,311 | NA | NA | NA | NA |
| Bucksport Main | Intertidal | West | 0 | 22.0 | 2,502,091 | NA | NA | NA | NA |
| Bucksport Main | Thalweg/Main | Main | 2 | 1.5 | 8,523,106 | 1,306.8 | 226 | 1,636 | 989 |
| Bucksport Main | Subtidal | East | 0 | 5.3 | 3,556,176 | NA | NA | NA | NA |
| Bucksport Main | Subtidal | West | 1 | 13.5 | 15,559,226 | 103.7 | NA | NA | NA |
| Bucksport Thalweg | Intertidal | East | 0 | 62.0 | 514,669 | NA | NA | NA | NA |
| Bucksport Thalweg | Intertidal | West | 0 | 62.0 | 133,959 | NA | NA | NA | NA |
| Bucksport Thalweg | Thalweg/Main | Main | 0 | 60.1 | 6,676,928 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | East | 0 | 47.1 | 863,776 | NA | NA | NA | NA |
| Bucksport Thalweg | Subtidal | West | 0 | 78.4 | 1,679,785 | NA | NA | NA | NA |
| Cape Jellison | Intertidal | East | 0 | 30.5 | 3,599,933 | NA | NA | NA | NA |
| Cape Jellison | Intertidal | West | 0 | 30.5 | 478,036 | NA | NA | NA | NA |
| Cape Jellison | Thalweg/Main | Main | 0 | NA | 21,925,645 | NA | NA | NA | NA |
| Cape Jellison | Subtidal | East | 0 | NA | 131,890,198 | NA | NA | NA | NA |
| Cape Jellison | Subtidal | West | 0 | NA | 22,048,105 | NA | NA | NA | NA |
| Cape Jellison | Marsh | Marsh | 0 | NA | 2,814,275 | NA | NA | NA | NA |
| Fort Point Cove | Intertidal | West | 0 | 35.0 | 9,381,267 | NA | NA | NA | NA |
| Fort Point Cove | Subtidal | West | 1 | NA | 46,332,364 | 11.8 | NA | NA | NA |
| Fort Point Cove | Marsh | Marsh | 0 | NA | 1,882,852 | NA | NA | NA | NA |
| Frankfort Flats | Other[2] | NA | NA | NA | 4,463,457 | NA | NA | NA | NA |
| Frankfort Flats | Intertidal | East | 2 | 9.0 | 6,971,371 | 55.0 | 13 | 72 | 37 |
| Frankfort Flats | Intertidal | West | 0 | 9.0 | 5,057,180 | NA | NA | NA | NA |
| Frankfort Flats | Thalweg/Main | Main | 0 | 3.5 | 11,737,900 | NA | NA | NA | NA |
| Frankfort Flats | Subtidal | East | 2 | 2.8 | 26,665,447 | 20.7 | 0 | 21 | 20 |
| Frankfort Flats | Subtidal | West | 1 | 5.6 | 10,541,999 | 361.0 | NA | NA | NA |
| Frankfort Flats | Marsh | Marsh | 0 | NA | 4,019,444 | NA | NA | NA | NA |
| Mendall Marsh | Subtidal | West | 0 | NA | 4,957,839 | NA | NA | NA | NA |
| Mendall Marsh | Intertidal | Main | 0 | 3.5 | 9,317,247 | NA | NA | NA | NA |
| Mendall Marsh | Marsh | Marsh | 3 | NA | 2,353,002 | 770.1 | 412 | 1,724 | 226 |
| Mendall Marsh | Marsh | Marsh | 1 | NA | 2,456,469 | 59.4 | NA | NA | NA |
| Mendall Marsh | Marsh | Marsh | 0 | NA | 3,103,348 | NA | NA | NA | NA |
| Mendall Marsh | Marsh | Marsh | 0 | NA | 12,605,472 | NA | NA | NA | NA |
| Orland River | Other[2] | NA | NA | NA | 288,438 | NA | NA | NA | NA |
| Orland River | Marsh | Marsh | 0 | NA | 1,871,555 | NA | NA | NA | NA |
| Orland River | Intertidal | East | 4 | 5.0 | 6,271,906 | 49.2 | 10 | 71 | 29 |

**TABLE 5-8**

**CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES >3 FEET**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Orland River | Intertidal | West | 0 | NA | 4,628,944 | NA | NA | NA | NA |
| Orland River | Thalweg/Main | Main | 0 | 5.0 | 5,812,145 | NA | NA | NA | NA |
| Orrington | Intertidal | East | 0 | 10.0 | 6,282,159 | NA | NA | NA | NA |
| Orrington | Intertidal | West | 1 | 10.0 | 5,397,614 | 18.5 | NA | NA | NA |
| Orrington | Thalweg/Main | Main | 1 | 32.2 | 15,343,256 | 1,019.4 | NA | NA | NA |
| Orrington | Subtidal | East | 0 | 14.7 | 10,642,953 | NA | NA | NA | NA |
| Orrington | Subtidal | West | 0 | 7.0 | 6,075,000 | NA | NA | NA | NA |
| Orrington | Marsh | Marsh | 0 | NA | 4,103,967 | NA | NA | NA | NA |
| Upper Penobscot | Intertidal | East | 0 | 21.5 | 7,174,261 | NA | NA | NA | NA |
| Upper Penobscot | Thalweg/Main | Main | 1 | NA | 121,726,846 | 330.4 | NA | NA | NA |
| Upper Penobscot | Marsh | Marsh | 0 | NA | 1,786,058 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 184,725 | NA | NA | NA | NA |
| Verona East | Other[2] | NA | NA | NA | 250,257 | NA | NA | NA | NA |
| Verona East | Intertidal | East | 0 | 25.5 | 4,337,637 | NA | NA | NA | NA |
| Verona East | Intertidal | West | 0 | 25.5 | 2,516,445 | NA | NA | NA | NA |
| Verona East | Thalweg/Main | Main | 1 | NA | 9,867,083 | 567.6 | NA | NA | NA |
| Verona East | Marsh | Marsh | 0 | NA | 923,687 | NA | NA | NA | NA |
| Verona East | Subtidal | East | 0 | NA | 6,739,305 | NA | NA | NA | NA |
| Verona East | Subtidal | West | 0 | NA | 3,667,825 | NA | NA | NA | NA |
| Verona NE | Other[2] | NA | NA | NA | 1,276,709 | NA | NA | NA | NA |
| Verona NE | Intertidal | East | 0 | 6.0 | 5,473,382 | NA | NA | NA | NA |
| Verona NE | Intertidal | West | 1 | 6.0 | 12,906,385 | 17.3 | NA | NA | NA |
| Verona NE | Thalweg/Main | Main | 1 | 0.006 | 6,507,212 | 20.5 | NA | NA | NA |
| Verona NE | Marsh | Marsh | 0 | NA | 2,445,418 | NA | NA | NA | NA |
| Verona NE | Subtidal | East | 1 | 0.006 | 5,418,041 | 756.2 | NA | NA | NA |
| Verona NE | Subtidal | West | 2 | NA | 4,059,906 | 19.0 | 1 | 20 | 18 |
| Verona West | Intertidal | East | 0 | NA | 3,923,792 | NA | NA | NA | NA |
| Verona West | Intertidal | West | 0 | 40.0 | 2,208,853 | NA | NA | NA | NA |
| Verona West | Thalweg/Main | Main | 1 | 69.6 | 19,152,738 | 13.1 | NA | NA | NA |
| Verona West | Subtidal | East | 0 | 18.7 | 16,675,192 | NA | NA | NA | NA |
| Verona West | Subtidal | West | 0 | 32.7 | 25,369,156 | NA | NA | NA | NA |
| Verona West | Marsh | Marsh | 0 | NA | 2,161,307 | NA | NA | NA | NA |
| Winterport | Marsh | East | 0 | 7.5 | 3,104,730 | NA | NA | NA | NA |
| Winterport | Intertidal | West | 0 | 7.5 | 6,163,461 | NA | NA | NA | NA |
| Winterport | Thalweg/Main | Main | 1 | 41.1 | 22,418,558 | 26.5 | NA | NA | NA |
| Winterport | Subtidal | East | 0 | 5.3 | 4,542,930 | NA | NA | NA | NA |
| Winterport | Subtidal | West | 0 | 38.1 | 3,274,100 | NA | NA | NA | NA |
| Winterport | Marsh | Marsh | 0 | NA | 5,164,574 | NA | NA | NA | NA |

Notes:
1. N-Value is the number of samples in that specific reach/zone
2. Wood-enriched sediment deposits; See Table 5-15

Prepared by: ESS 3/2/18
Checked by: KC 3/7/18
Modified by: RMB 8/15/18

**TABLE 5-8**

**CALCULATED BOOTSTRAP MEANS – PENOBSCOT RIVER ESTUARY REACH/ZONES >3 FEET**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Zone | Ribbon Compass | N-Value[1] | Bedrock Exclusion Percentage | Shape Area (sf) | BOOTMEAN | ST DEV | Upper 95% CI | Lower 95% CI |
|---|---|---|---|---|---|---|---|---|---|

Abbreviations:
NA = not analyzed
sf = square feet
ST DEV = standard deviation
CI = confidence interval

## TABLE 5-9

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

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

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.

Abbreviations:
% = percent
NA = not available

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

**TABLE 5-10**

**REMEDIAL AREA AND VOLUME CALCULATION FOR 500 ng/g PRG – MAIN CHANNEL**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| | Pre-Remedy | Post-Remedy |
|---|---|---|
| **Total Area (sf)** | 417,646,688 | 417,646,688 |
| **Area Weighted Average Concentration (ng/g)** | 586.5 | 496.4 |
| **Remediation Area (sf)** | NA | 45,270,470 |
| **Remediation Volume @ 0.5 foot depth plus 0.5 foot overdredge (cy)** | NA | 1,676,684 |

| | Remediation Area/Volume |
|---|---|
| **Area (sf) intertidal/marsh** | 31,982,485 |
| **Area (sf) subtidal** | 0 |
| **Volume (cy) intertidal/marsh** | 1,676,684 |
| **Volume (cy) subtidal** | 0 |
| **Area (sf) marsh restoration** | 13,287,985 |

| Reach | Ribbon_classification | ZONE | N-Value[1] | Shape Area (sf) | BOOTMEAN Pre-Remedy[2] (ng/g) | BOOTMEAN Post-Remedy (ng/g) | Area Targeted For Remedy[3] |
|---|---|---|---|---|---|---|---|
| Bucksport Main | Bucksport_Main_Int_W | Intertidal | 3 | 1,951,631 | 885.5 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Main_Int_E | Intertidal | 7 | 6,343,948 | 1,046.5 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Main_Int_W | Intertidal | 10 | 4,602,034 | 732.2 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Marsh | Marsh | 18 | 4,019,444 | 855.5 | 180.0 | x |
| Orrington | Orrington_Main_Int_E | Intertidal | 42 | 5,653,943 | 1,208.5 | 180.0 | x |
| Orrington | Orrington_Main_Int_W | Intertidal | 10 | 4,857,852 | 978.6 | 180.0 | x |
| Orrington | Orrington_Marsh | Marsh | 21 | 4,103,967 | 1,877.2 | 180.0 | x |
| Winterport | Winterport_Main_Int_E | Intertidal | 1 | 2,871,876 | 856.6 | 180.0 | x |
| Winterport | Winterport_Main_Int_W | Intertidal | 12 | 5,701,202 | 747.0 | 180.0 | x |
| Winterport | Winterport_Marsh | Marsh | 9 | 5,164,574 | 884.6 | 180.0 | x |
| Bangor | Bangor_Main_Int_E | Intertidal | 13 | 1,842,352 | 288.9 | 288.9 | |
| Bangor | Bangor_Main_Int_W | Intertidal | 13 | 2,241,045 | 489.4 | 489.4 | |
| Bangor | Bangor_Main_Main | Subtidal | 5 | 12,218,249 | 566.6 | 566.6 | |
| Bangor | Bangor_Main_Sub_E | Subtidal | 6 | 3,063,527 | 546.4 | 546.4 | |
| Bangor | Bangor_Main_Sub_W | Subtidal | 6 | 2,210,677 | 681.1 | 681.1 | |
| Bangor | Bangor_Marsh | Marsh | 4 | 3,133,390 | 183.7 | 183.7 | |
| Bucksport Main | Bucksport_Main_Int_E | Intertidal | 4 | 1,089,903 | 464.3 | 464.3 | |
| Bucksport Main | Bucksport_Main_Main | Subtidal | 11 | 8,393,990 | 769.6 | 769.6 | |
| Bucksport Main | Bucksport_Main_Sub_E | Subtidal | 2 | 3,369,202 | 852.0 | 852.0 | |
| Bucksport Main | Bucksport_Main_Sub_W | Subtidal | 20 | 13,463,520 | 826.2 | 826.2 | |
| Bucksport Thalweg | Bucksport Thalweg_Int_E | Intertidal | NA | 195,574 | 464.3 | 464.3 | |
| Bucksport Thalweg | Bucksport Thalweg_Int_W | Intertidal | NA | 50,905 | 885.5 | 885.0 | |
| Bucksport Thalweg | Bucksport Thalweg_Main_Main | Subtidal | 7 | 2,662,612 | 908.2 | 908.2 | |
| Bucksport Thalweg | Bucksport Thalweg_Main_Sub_E | Subtidal | 1 | 456,684 | 669.0 | 669.0 | |
| Bucksport Thalweg | Bucksport Thalweg_Main_Sub_W | Subtidal | 2 | 362,900 | 604.5 | 604.5 | |
| Fort Point Cove | Fort Point Cove_Main_Int_W | Intertidal | 8 | 6,097,823 | 155.8 | 155.8 | |
| Fort Point Cove | Fort Point Cove_Main_Sub_W | Subtidal | 27 | 46,332,364 | 712.0 | 712.0 | |
| Fort Point Cove | Fort Point Cove_Marsh | Marsh | 3 | 1,882,852 | 34.6 | 34.6 | |
| Frankfort Flats | Frankfort Flats_Main_Main | Subtidal | 9 | 11,330,591 | 358.5 | 358.5 | |
| Frankfort Flats | Frankfort Flats_Main_Sub_E | Subtidal | 27 | 25,918,954 | 361.1 | 361.1 | |
| Frankfort Flats | Frankfort Flats_Main_Sub_W | Subtidal | 22 | 9,956,488 | 597.3 | 597.3 | |
| Orrington | Orrington_Main_Main | Subtidal | 20 | 10,401,016 | 582.7 | 582.7 | |
| Orrington | Orrington_Main_Sub_E | Subtidal | 26 | 9,076,556 | 819.2 | 819.2 | |
| Orrington | Orrington_Main_Sub_W | Subtidal | 8 | 5,647,649 | 648.5 | 648.5 | |
| Upper Penob | Upper Penobscot Bay_Main_Int_E | Intertidal | 2 | 5,631,795 | 56.6 | 56.6 | |
| Upper Penob | Upper Penobscot Bay_Main_Sub | Subtidal | 25 | 121,726,846 | 478.6 | 478.6 | |
| Upper Penob | Upper Penobscot Bay_Marsh | Marsh | 1 | 1,786,058 | 19.3 | 19.3 | |
| Verona West | Verona West_Main_Int_E | Intertidal | 1 | 2,354,275 | 92.2 | 92.2 | |
| Verona West | Verona West_Main_Int_W | Intertidal | NA | 1,325,312 | 92.2 | 92.2 | |
| Verona West | Verona West_Main_Main | Subtidal | 11 | 5,822,655 | 473.6 | 473.6 | |
| Verona West | Verona West_Main_Sub_E | Subtidal | 12 | 13,564,329 | 806.4 | 806.4 | |
| Verona West | Verona West_Main_Sub_W | Subtidal | 11 | 17,071,629 | 505.0 | 505.0 | |
| Verona West | Verona West_Marsh | Marsh | 2 | 2,161,307 | 220.5 | 220.5 | |
| Winterport | Winterport_Main_Main | Subtidal | 15 | 13,205,976 | 569.1 | 569.1 | |
| Winterport | Winterport_Main_Sub_E | Subtidal | 3 | 4,300,253 | 332.6 | 332.6 | |
| Winterport | Winterport_Main_Sub_W | Subtidal | 2 | 2,026,960 | 801.4 | 801.4 | |

Notes:
1. N-Value is the number of samples in that specific reach/zone
2. Error estimates for BOOTMEAN values included in Table 5-3 through 5-8 and Appendix I.
3. Area targeted for remedy to meet PRG

Prepared by: ESS 3/1/18
Checked by: KC 3/7/18
Modified by: ESS 9/12/18

Abbreviations:
cy = cubic yard
NA = not applicable
ng/g = nanograms per gram
PRG = preliminary remediation goal
sf = square foot

**TABLE 5-11**

**REMEDIAL AREA AND VOLUME CALCULATION FOR 300 ng/g PRG – MAIN CHANNEL**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| | Pre-Remedy | Post-Remedy |
|---|---|---|
| **Total Area (sf)** | 417,646,688 | 417,646,688 |
| **Area Weighted Average Concentration (ng/g)** | 586.5 | 267.8 |
| **Remediation Area (sf)** | NA | 263,686,448 |
| **Remediation Volume @ 0.5 foot depth plus 0.5 foot overdredge (cy)** | NA | 9,766,165 |

| | Remediation Area/Volume |
|---|---|
| **Area (sf) intertidal/marsh** | 48,652,322 |
| **Area (sf) subtidal** | 215,034,125 |
| **Volume (cy) intertidal/marsh** | 1,801,938 |
| **Volume (cy) subtidal** | 7,964,227 |
| **Area (sf) marsh restoration** | 13,287,985 |

| Reach | Ribbon_classification | ZONE | N-Value[1] | Shape Area (sf) | BOOTMEAN Pre-Remedy[2] (ng/g) | BOOTMEAN Post-Remedy (ng/g) | Area Targeted For Remedy[3] |
|---|---|---|---|---|---|---|---|
| Bangor | Bangor_Main_Int_W | Intertidal | 13 | 2,241,045 | 489.4 | 180.0 | x |
| Bangor | Bangor_Main_Main | Subtidal | 5 | 12,218,249 | 566.6 | 180.0 | x |
| Bangor | Bangor_Main_Sub_E | Subtidal | 6 | 3,063,527 | 546.4 | 180.0 | x |
| Bangor | Bangor_Main_Sub_W | Subtidal | 6 | 2,210,677 | 681.1 | 180.0 | x |
| Bucksport Main | Bucksport_Main_Int_E | Intertidal | 4 | 1,089,903 | 464.3 | 180.0 | x |
| Bucksport Main | Bucksport_Main_Int_W | Intertidal | 3 | 1,951,631 | 885.5 | 180.0 | x |
| Bucksport Main | Bucksport_Main_Main | Subtidal | 11 | 8,393,990 | 769.6 | 180.0 | x |
| Bucksport Main | Bucksport_Main_Sub_E | Subtidal | 2 | 3,369,202 | 852.0 | 180.0 | x |
| Bucksport Main | Bucksport_Main_Sub_W | Subtidal | 20 | 13,463,520 | 826.2 | 180.0 | x |
| Bucksport Thalweg | Bucksport Thalweg_Int_W | Intertidal | NA | 50,905 | 885.5 | 180.0 | x |
| Bucksport Thalweg | Bucksport Thalweg_Main_Main | Subtidal | 7 | 2,662,612 | 908.2 | 180.0 | x |
| Bucksport Thalweg | Bucksport Thalweg_Main_Sub_E | Subtidal | 1 | 456,684 | 669.0 | 180.0 | x |
| Bucksport Thalweg | Bucksport Thalweg_Main_Sub_W | Subtidal | 2 | 362,900 | 604.5 | 180.0 | x |
| Fort Point Cove | Fort Point Cove_Main_Sub_W | Subtidal | 27 | 46,332,364 | 712.0 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Main_Int_E | Intertidal | 7 | 6,343,948 | 1,046.5 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Main_Int_W | Intertidal | 10 | 4,602,034 | 732.2 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Main_Main | Subtidal | 9 | 11,330,591 | 358.5 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Main_Sub_E | Subtidal | 27 | 25,918,954 | 361.1 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Main_Sub_W | Subtidal | 22 | 9,956,488 | 597.3 | 180.0 | x |
| Frankfort Flats | Frankfort Flats_Marsh | Marsh | 18 | 4,019,444 | 855.5 | 180.0 | x |
| Orrington | Orrington_Main_Int_E | Intertidal | 42 | 5,653,943 | 1,208.5 | 180.0 | x |
| Orrington | Orrington_Main_Int_W | Intertidal | 10 | 4,857,852 | 978.6 | 180.0 | x |
| Orrington | Orrington_Main_Main | Subtidal | 20 | 10,401,016 | 582.7 | 180.0 | x |
| Orrington | Orrington_Main_Sub_E | Subtidal | 26 | 9,076,556 | 819.2 | 180.0 | x |
| Orrington | Orrington_Main_Sub_W | Subtidal | 8 | 5,647,649 | 648.5 | 180.0 | x |
| Orrington | Orrington_Marsh | Marsh | 21 | 4,103,967 | 1,877.2 | 180.0 | x |
| Verona West | Verona West_Main_Sub_E | Subtidal | 12 | 13,564,329 | 806.4 | 180.0 | x |
| Verona West | Verona West_Main_Sub_W | Subtidal | 11 | 17,071,629 | 505.0 | 180.0 | x |
| Winterport | Winterport_Main_Int_E | Intertidal | 1 | 2,871,876 | 856.6 | 180.0 | x |
| Winterport | Winterport_Main_Int_W | Intertidal | 12 | 5,701,202 | 747.0 | 180.0 | x |
| Winterport | Winterport_Main_Main | Subtidal | 15 | 13,205,976 | 569.1 | 180.0 | x |
| Winterport | Winterport_Main_Sub_E | Subtidal | 3 | 4,300,253 | 332.6 | 180.0 | x |
| Winterport | Winterport_Main_Sub_W | Subtidal | 2 | 2,026,960 | 801.4 | 180.0 | x |
| Winterport | Winterport_Marsh | Marsh | 9 | 5,164,574 | 884.6 | 180.0 | x |
| Bangor | Bangor_Main_Int_E | Intertidal | 13 | 1,842,352 | 288.9 | 288.9 | |
| Bangor | Bangor_Marsh | Marsh | 4 | 3,133,390 | 183.7 | 183.7 | |
| Bucksport Thalweg | Bucksport Thalweg_Int_E | Intertidal | NA | 195,574 | 464.3 | 464.3 | |
| Fort Point Cove | Fort Point Cove_Main_Int_W | Intertidal | 8 | 6,097,823 | 155.8 | 155.8 | |
| Fort Point Cove | Fort Point Cove_Marsh | Marsh | 3 | 1,882,852 | 34.6 | 34.6 | |
| Upper Penob | Upper Penobscot Bay_Main_Int_E | Intertidal | 2 | 5,631,795 | 56.6 | 56.6 | |
| Upper Penob | Upper Penobscot Bay_Main_Sub | Subtidal | 25 | 121,726,846 | 478.6 | 478.6 | |
| Upper Penob | Upper Penobscot Bay_Marsh | Marsh | 1 | 1,786,058 | 19.3 | 19.3 | |
| Verona West | Verona West_Main_Int_E | Intertidal | 1 | 2,354,275 | 92.2 | 92.2 | |
| Verona West | Verona West_Main_Int_W | Intertidal | NA | 1,325,312 | 92.2 | 92.2 | |
| Verona West | Verona West_Main_Main | Subtidal | 11 | 5,822,655 | 473.6 | 473.6 | |
| Verona West | Verona West_Marsh | Marsh | 2 | 2,161,307 | 220.5 | 220.5 | |

Prepared by: ESS 3/1/18
Checked by: KC 3/7/18
Modified by: ESS 09/12/18

Notes:
1. N-Value is the number of samples in that specific reach/zone
2. Error estimates for BOOTMEAN values included in Table 5-3 through 5-8 and Appendix I.
3. Area targeted for remedy to meet PRG

Abbreviations:
cy = cubic yard
NA = not applicable
ng/g = nanograms per gram
PRG = preliminary remediation goal
sf = square foot

## TABLE 5-12

## REMEDIAL AREA AND VOLUME CALCULATION FOR 500 ng/g AND 300 ng/g PRG – ORLAND RIVER/VERONA NORTHEAST/VERONA EAST
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| | Pre-Remedy | Post-Remedy |
|---|---|---|
| Total Area (sf) | 79,991,381 | 79,991,381 |
| Area Weighted Average Concentration (ng/g) | 766.6 | 303.5 |
| Remediation Area (sf) | NA | 48,970,864 |
| Remediation Volume @ 0.5 foot depth plus 0.5 foot overdredge (cy) | NA | 1,813,736 |

| | Remediation Area/Volume |
|---|---|
| Area (sf) intertidal/marsh | 39,103,782 |
| Area (sf) subtidal | 9,867,083 |
| Volume (cy) intertidal/marsh | 1,448,288 |
| Volume (cy) subtidal | 365,448 |
| Area (sf) marsh restoration | 5,240,661 |

| Reach | Ribbon_classification | ZONE | N-Value[1] | Shape Area (sf) | BOOTMEAN Pre-Remedy[2] (ng/g) | BOOTMEAN Post-Remedy (ng/g) | Area Targeted For Remedy[3] |
|---|---|---|---|---|---|---|---|
| Orland River | Orland River_Marsh | Marsh | 12 | 1,871,555 | 940.4 | 180.0 | x |
| Orland River | Orland_Int_E | Intertidal | 24 | 5,521,538 | 1,086.8 | 180.0 | x |
| Orland River | Orland_Int_W | Intertidal | 29 | 5,958,311 | 867.7 | 180.0 | x |
| Verona East | Verona_E_Int_E | Intertidal | 9 | 3,231,540 | 935.7 | 180.0 | x |
| Verona East | Verona_E_Int_W | Intertidal | 13 | 1,874,751 | 647.6 | 180.0 | x |
| Verona East | Verona_E_Main | Subtidal | 9 | 9,867,083 | 1,020.6 | 180.0 | x |
| Verona East | Verona_E_Marsh | Marsh | 1 | 923,687 | 755.9 | 180.0 | x |
| Verona NE | Verona_NE_Int_E | Intertidal | 17 | 5,144,979 | 847.2 | 180.0 | x |
| Verona NE | Verona_NE_Int_W | Intertidal | 29 | 12,132,002 | 924.1 | 180.0 | x |
| Verona NE | Verona_NE_Marsh | Marsh | 5 | 2,445,418 | 961.1 | 180.0 | x |
| Orland River | Orland_Main | Subtidal | 7 | 4,628,944 | 569.3 | 569.3 | |
| Verona East | Verona_E_Sub_E | Subtidal | 5 | 6,739,305 | 320.0 | 320.0 | |
| Verona East | Verona_E_Sub_W | Subtidal | 4 | 3,667,825 | 312.5 | 312.5 | |
| Verona NE | Verona_NE_Main | Subtidal | 12 | 6,506,812 | 598.0 | 598.0 | |
| Verona NE | Verona_NE_Sub_E | Subtidal | 8 | 5,417,724 | 562.0 | 562.0 | |
| Verona NE | Verona_NE_Sub_W | Subtidal | 18 | 4,059,906 | 637.8 | 637.8 | |

Prepared by: ESS 3/1/18
Checked by: KC 3/7/18
Modified by: ESS 09/12/18

Notes:
1. N-Value is the number of samples in that specific reach/zone
2. Error estimates for BOOTMEAN values included in Table 5-3 through 5-8 and Appendix I.
3. Area targeted for remedy to meet PRG

Abbreviations:
cy = cubic yard
NA = not applicable
ng/g = nanograms per gram
PRG = preliminary remediation goal
sf = square foot

# TABLE 5-13

## REMEDIAL VOLUME CALCULATION FOR 500 ng/g PRG – MENDALL MARSH
## Penobscot River Phase III Engineering Study
## Penobscot River Estuary, Maine

| | Pre-Remedy | Post-Remedy |
|---|---|---|
| **Total Area (sf)** | 34,707,401 | 34,707,401 |
| **Area Weighted Average Concentration (ng/g)** | 578.1 | 498.5 |
| **Cap Area (sf) 100% of marsh platform (elevation 2–7.5 feet NAVD88 zone) and 20% of marsh platform (elevation 7.5 feet - boundary edge zone)** | NA | 10,347,937 |
| **Cap Import Volume (cy) (3" thick with 3" overplacement)** | NA | 191,628 |
| **Dredge Remediation Area (sf)** | NA | NA |
| **Remediation Volume @ 0.5 foot depth plus 0.5 foot overdredge (cy)** | NA | NA |

| Reach | Ribbon_classification | ZONE | N-Value[1] | Shape Area (sf) | BOOTMEAN Pre-Remedy[2] (ng/g) | BOOTMEAN Post-Remedy (ng/g) | Area Targeted For Remedy[3] |
|---|---|---|---|---|---|---|---|
| Mendall Marsh | MM_Elev1 (2-5.8 ft elev) | Marsh | 15 | 2,353,002 | 665.8 | 342.9 | x |
| Mendall Marsh | MM_Elev2 (5.8-7 ft elev) | Marsh | 22 | 2,370,493 | 721.8 | 370.9 | x |
| Mendall Marsh | MM_Elev3 (7-7.5 ft elev) | Marsh | 25 | 3,103,348 | 513.2 | 266.6 | x |
| Mendall Marsh | MM_Elev4 (7.5-boundary edge) | Marsh | 57 | 12,605,472 | 429.4 | 388.5 | x |
| Mendall Marsh | Mendall Marsh_Main_Sub_W | Subtidal | 8 | 4,957,839 | 641.6 | 641.6 | |
| Mendall Marsh | Mendall Marsh_Mendall_Int | Intertidal | 61 | 9,317,247 | 708.2 | 708.2 | |

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18
Revised by: KAM 8/31/18

Notes:
1. N-Value is the number of samples in that specific reach/zone
2. Error estimates for BOOTMEAN values included in Table 5-3 through 5-8 and Appendix I.
3. Area targeted for remedy to meet PRG

Abbreviations:
cy = cubic yard
NA = not applicable
NAVD88 = North American Vertical Datum of 1988
ng/g = nanograms per gram
PRG = preliminary remediation goal
sf = square foot

**TABLE 5-14**

**REMEDIAL VOLUME CALCULATION FOR 300 ng/g PRG – MENDALL MARSH**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| | Pre-Remedy | Post-Remedy |
|---|---|---|
| | | |
| **Total Area (sf)** | 34,707,401 | 34,707,401 |
| **Area Weighted Average Concentration (ng/g)** | 578.1 | 287.5 |
| **Cap Area (sf) 100% of marsh platform (elevation 2–7.5 feet NAVD88 zone) and 20% of marsh platform (elevation 7.5 feet - boundary edge zone)** | NA | 10,347,937 |
| **Cap Import Volume (cy) (3" thick with 3" overplacement)** | NA | 191,628 |
| **Dredge Remediation Area (sf)** | NA | 14,275,086 |
| **Remediation Volume @ 0.5 foot depth plus 0.5 foot overdredge (cy)** | NA | 528,707 |

| Reach | Ribbon_classification | ZONE | N-Value[1] | Shape Area (sf) | BOOTMEAN Pre-Remedy[2] (ng/g) | BOOTMEAN Post-Remedy (ng/g) | Area Targeted For Remedy[3] |
|---|---|---|---|---|---|---|---|
| Mendall Marsh | MM_Elev1 (2-5.8 ft elev) | Marsh | 15 | 2,353,002 | 665.8 | 342.9 | x |
| Mendall Marsh | MM_Elev2 (5.8-7 ft elev) | Marsh | 22 | 2,370,493 | 721.8 | 370.9 | x |
| Mendall Marsh | MM_Elev3 (7-7.5 ft elev) | Marsh | 25 | 3,103,348 | 513.2 | 266.6 | x |
| Mendall Marsh | MM_Elev4 (7.5-boundary edge) | Marsh | 57 | 12,605,472 | 429.4 | 388.5 | x |
| Mendall Marsh | Mendall Marsh_Main_Sub_W | Subtidal | 8 | 4,957,839 | 641.6 | 180.0 | x |
| Mendall Marsh | Mendall Marsh_Mendall_Int | Intertidal | 61 | 9,317,247 | 708.2 | 180.0 | x |

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18
Revised by: KAM 8/31/18

Notes:
1. N-Value is the number of samples in that specific reach/zone
2. Error estimates for BOOTMEAN values included in Table 5-3 through 5-8 and Appendix I.
3. Area targeted for remedy to meet PRG

Abbreviations:
cy = cubic yard
NA = not applicable
NAVD88 = North American Vertical Datum of 1988
ng/g = nanograms per gram
PRG = preliminary remediation goal
sf = square foot

3. Area targeted for remedy to meet PRG

**TABLE 5-15**

**REMEDIAL VOLUME OF WOOD ENRICHED SEDIMENT DEPOSITS**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Reach | Ribbon_classification | ZONE | N-Value[1] | Shape Area (sf) | BOOTMEAN Pre-Remedy[2] (ng/g) | Pile Thickness (feet) | Overdredge = 0.5 feet | Pile Depth (feet) | Volume (cy) |
|---|---|---|---|---|---|---|---|---|---|
| Frankfort Flats | Elev_Hg_FF | NA | 7 | 4,463,457 | 919 | 3 | 1 | 4 | 578,596 |
| Orland River | Elev_Hg_Orland | NA | 2 | 288,438 | 1,409 | 3 | 1 | 4 | 37,390 |
| Verona East | Elev_Hg_V_E | NA | NA | 184,725 | NA | 1 | 1 | 2 | 10,262 |
| Verona NE | Elev_Hg_V_NE | NA | 5 | 1,276,709 | 1,113 | 6 | 1 | 7 | 307,356 |
| Verona East | Elev_Hg_V_S | NA | NA | 250,257 | NA | 1 | 1 | 2 | 13,903 |
| **TOTAL** | | | | | | | | | **947,508** |

Prepared by: ESS 3/1/18
Checked by: CP 3/7/18
Revised by: KAM 8/31/18

Notes:
1. N-Value is the number of samples in that specific reach/zone.
2. Error estimates for BOOTMEAN values included in Table 5-3 through 5-8 and Appendix I.

Abbreviations:
cy = cubic yard
NA = not applicable
ng/g = nanograms per gram
sf = square feet

3. Area targeted for remedy to meet PRG

**TABLE 6-1A**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO MEDEP BENEFICIAL USE OF SOLID WASTE SCREENING LEVELS[1, 2, 3]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | MEDEP Benefical Use of Solid Waste[4] | MEDEP Benefical Use of Solid Waste, "Reduced Procedure"[4] | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| **TCLP Metals** | | | | | | | | | | |
| Arsenic | mg/L | 5 | - | - | 0.039 | J | 1 | U | 0.052 | J |
| Barium | mg/L | 100 | - | - | 0.035 | J | 0.5 | U | 0.047 | J |
| Cadmium | mg/L | 1 | - | - | 0.1 | U | 0.1 | U | 0.1 | U |
| Chromium | mg/L | 5 | - | - | 0.2 | U | 0.2 | U | 0.2 | U |
| Lead | mg/L | 5 | - | - | 0.5 | U | 0.5 | U | 0.5 | U |
| Mercury | mg/L | 0.2 | - | - | 0.001 | U | 0.001 | U | 0.0004 | UJ |
| Selenium | mg/L | 1 | - | - | 0.5 | U | 0.5 | U | 0.5 | U |
| Silver | mg/L | 5 | - | - | 0.1 | U | 0.1 | U | 0.1 | U |
| **Total Metals** | | | | | | | | | | |
| Arsenic | mg/kg | 100 | 7.9 | 16 | **10.6** | | **10.4** | | **18.1** | |
| Barium | mg/kg | 2000 | 10000 | - | 13.7 | | 17.8 | | 13.1 | |
| Cadmium | mg/kg | 20 | 22 | 22 | 1.03 | | 0.599 | | 0.923 | |
| Chromium | mg/kg | 100 | 10000 | - | 34.4 | | 43.6 | | 53.5 | J |
| Copper | mg/kg | - | 1700 | - | 21.3 | | 16.8 | | 22.3 | |
| Lead | mg/kg | 100 | 200 | 200 | 22.9 | | 20.8 | | 23.2 | |
| Mercury | mg/kg | 4 | - | - | 0.75 | | 0.798 | | 1.34 | |
| Nickel | mg/kg | - | 530 | - | 19.1 | | 23 | | 20 | |
| Selenium | mg/kg | 20 | 456 | - | 1.61 | | 1.88 | | 3.77 | J |
| Silver | mg/kg | 100 | 456 | - | 0.233 | J | 0.18 | J | 0.193 | J |
| Zinc | mg/kg | - | 10000 | - | 80.4 | | 76.6 | | 207 | |
| **TPH** | | | | | | | | | | |
| Gasoline Range Organics | µg/kg | - | - | - | 4600 | J | 3000 | J | 9700 | J |
| Total Petroleum Hydrocarbons | µg/kg | - | - | - | 65700 | J | 58000 | J | 124000 | J |
| **PCB Congeners** | | | | | | | | | | |
| Cl2-BZ#8 | µg/kg | - | - | - | 1.38 | UJ | 1.37 | UJ | 1.29 | U |
| Cl3-BZ#18 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl3-BZ#28 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#44 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#49 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#52 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#66 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#101 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.3 | |
| Cl5-BZ#105 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#118 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#87 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl6-BZ#128 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl6-BZ#138 | µg/kg | - | - | - | 1.1 | J | 0.966 | J | 1.92 | |
| Cl6-BZ#153 | µg/kg | - | - | - | 0.897 | J | 0.794 | J | 1.65 | |
| Cl7-BZ#170 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl7-BZ#180 | µg/kg | - | - | - | 0.779 | J | 1.37 | U | 1.63 | |
| Cl7-BZ#183 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl7-BZ#184 | µg/kg | - | - | - | 1.38 | U | 1.03 | J | 1.29 | U |
| Cl7-BZ#187 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 0.677 | J |
| Cl8-BZ#195 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl9-BZ#206 | µg/kg | - | - | - | 1.24 | J | 1.37 | U | 1.29 | U |
| Cl10-BZ#209 | µg/kg | - | - | - | 1.02 | J | 1.37 | U | 1.29 | U |
| Total PCBs | µg/kg | - | 2700 | 2700 | 4.139 | | 2.79 | | 4.86 | |

**TABLE 6-1A**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO MEDEP BENEFICIAL USE OF SOLID WASTE SCREENING LEVELS[1, 2, 3]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | MEDEP Benefical Use of Solid Waste[4] | MEDEP Benefical Use of Solid Waste, "Reduced Procedure"[4] | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| **Dioxins** | | | | | | | | | | |
| 1234678-HpCDD | ng/kg | - | - | - | 239 | | 431 | | 666 | |
| 1234678-HpCDF | ng/kg | - | - | - | 242 | | 104 | | 167 | |
| 123478-HeCDD | ng/kg | - | - | - | 2.58 | J | 3.97 | J | 6.86 | J |
| 123478-HeCDF | ng/kg | - | - | - | 17.8 | J | 13.7 | | 29.8 | |
| 1234789-HpCDF | ng/kg | - | - | - | 4.41 | J | 5.56 | J | 10.1 | J |
| 123678-HeCDD | ng/kg | - | - | - | 15.2 | J | 19.3 | | 34.8 | |
| 123678-HeCDF | ng/kg | - | - | - | 7.96 | J | 6.02 | J | 10.3 | J |
| 12378-PeCDD | ng/kg | - | - | - | 3.2 | J | 3.64 | J | 6.79 | J |
| 12378-PeCDF | ng/kg | - | - | - | 13.1 | J | 13.2 | | 24.6 | |
| 123789-HeCDD | ng/kg | - | - | - | 6.6 | J | 9.89 | J | 18.6 | |
| 123789-HeCDF | ng/kg | - | - | - | 2.87 | J | 3.07 | J | 4.87 | J |
| 234678-HeCDF | ng/kg | - | - | - | 10.8 | J | 7.26 | J | 10.7 | J |
| 23478-PeCDF | ng/kg | - | - | - | 12 | J | 8.41 | J | 17.2 | |
| 2378-TCDD | ng/kg | - | - | - | 0.865 | J | 1.07 | J | 1.58 | J |
| 2378-TCDF | ng/kg | - | - | - | 29.4 | | 14.9 | | 46 | |
| OCDD | ng/kg | - | - | - | 2130 | | 3700 | | 5180 | |
| OCDF | ng/kg | - | - | - | 131 | | 189 | | 308 | |
| Total HpCDD | ng/kg | - | - | - | 737 | | 1130 | | 1620 | |
| Total HpCDF | ng/kg | - | - | - | 419 | J | 243 | | 420 | J |
| Total HxCDD | ng/kg | - | - | - | 127 | J | 169 | | 293 | J |
| Total HxCDF | ng/kg | - | - | - | 237 | J | 124 | | 227 | J |
| Total PeCDD | ng/kg | - | - | - | 37.9 | | 37.1 | | 74.6 | J |
| Total PeCDF | ng/kg | - | - | - | 127 | J | 73.7 | | 174 | J |
| Total TCDD | ng/kg | - | - | - | 34 | | 27.2 | | 58 | J |
| Total TCDF | ng/kg | - | - | - | 172 | | 88.4 | | 243 | J |
| Total TEQ | ng/kg | - | 55.8 | 55.8 | 22.9 | | 22 | | 40.6 | |
| **PAHs** | | | | | | | | | | |
| Acenaphthene | mg/kg | - | 78 | - | 0.0446 | J | 0.0192 | J | 0.0303 | |
| Acenaphthylene | mg/kg | - | 74 | - | 0.0905 | J | 0.0555 | J | 0.0683 | |
| Anthracene | mg/kg | - | 825 | - | 0.11 | | 0.0586 | | 0.0961 | |
| Benzo(a)anthracene | mg/kg | - | 13 | 13 | 0.444 | J | 0.277 | | 0.393 | |
| Benzo(a)pyrene | mg/kg | - | 1.3 | 1.3 | 0.346 | J | 0.235 | | 0.377 | |
| Benzo(b)fluoranthene | mg/kg | - | 13 | 13 | 0.404 | J | 0.296 | | 0.329 | |
| Benzo(ghi)perylene | mg/kg | - | 2090 | - | 0.272 | | 0.188 | | 0.234 | |
| Benzo(k)fluoranthene | mg/kg | - | 134 | 134 | 0.238 | J | 0.145 | | 0.283 | |
| Chrysene | mg/kg | - | 1340 | 1340 | 0.348 | J | 0.231 | | 0.37 | |
| Dibenz(a,h)anthracene | mg/kg | - | 1.3 | 1.3 | 0.0569 | J | 0.0379 | | 0.0596 | |
| Fluoranthene | mg/kg | - | 2790 | - | 0.69 | | 0.437 | | 0.646 | |
| Fluorene | mg/kg | - | 75 | - | 0.0499 | J | 0.0236 | J | 0.0301 | |
| Indeno(1,2,3-cd)pyrene | mg/kg | - | 13 | 13 | 0.309 | | 0.224 | | 0.226 | |
| Naphthalene | mg/kg | - | 0.078 | - | **0.0935** | J | 0.0386 | J | 0.0747 | |
| Phenanthrene | mg/kg | - | 83 | - | 0.423 | | 0.232 | | 0.361 | J |
| Pyrene | mg/kg | - | 2090 | - | 0.653 | | 0.388 | | 0.54 | |

**TABLE 6-1A**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO MEDEP BENEFICIAL USE OF SOLID WASTE SCREENING LEVELS[1, 2, 3]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| | | | | | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | Anticipated | MEDEP Benefical | MEDEP Benefical Use of | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| Analyte | Units | Disposal Requirement | Use of Solid Waste[4] | Solid Waste, "Reduced Procedure"[4] | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| **Total Pesticides** | | | | | | | | | | |
| 4,4'-DDD | µg/kg | - | 26000 | - | 5.58 | J | 1.76 | J | 16.3 | J |
| 4,4'-DDE | µg/kg | - | 23000 | - | 1.87 | J | 1.28 | J | 2.96 | J |
| 4,4'-DDT | µg/kg | - | 22000 | - | 0.977 | J | 1.04 | J | 0.645 | U |
| Aldrin | µg/kg | - | 460 | - | 0.688 | UJ | 0.684 | UJ | 0.645 | UJ |
| Alpha-Chlordane | µg/kg | 600 | 20000 | - | 0.688 | U | 0.684 | U | 0.645 | U |
| cis-Nonachlor | µg/kg | - | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Dieldrin | µg/kg | - | 400 | - | 0.688 | U | 0.684 | U | 1.6 | J |
| Endosulfan I | µg/kg | - | 548000 | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Endosulfan II | µg/kg | - | 548000 | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Endrin | µg/kg | 400 | 22000 | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Gamma-BHC/Lindane | µg/kg | 8000 | 1500 | - | 0.688 | UJ | 0.684 | UJ | 0.645 | UJ |
| Gamma-Chlordane | µg/kg | - | 20000 | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Heptachlor | µg/kg | 160 | 1600 | - | 0.688 | UJ | 0.684 | UJ | 0.645 | U |
| Heptachlor epoxide | µg/kg | 160 | 830 | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Hexachlorobenzene | µg/kg | - | 1700 | - | 1.38 | UJ | 1.37 | UJ | 1.29 | U |
| Methoxychlor | µg/kg | 200000 | 369000 | - | 6.88 | U | 6.84 | U | 6.45 | U |
| Oxychlordane | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Toxaphene | µg/kg | 10000 | - | - | 34.5 | U | 34.3 | U | 32.4 | U |
| trans-Nonachlor | µg/kg | - | - | - | 0.688 | U | 0.758 | J | 0.645 | U |
| **Other** | | | | | | | | | | |
| Moisture Content | % | - | - | - | 65 | | 64.9 | | | |
| Percent Moisture | % | Free Flowing Liqu | - | - | - | | - | | 63.9 | |
| Percent Moisture | % | Free Flowing Liqu | - | - | - | | - | | 64.8 | |
| Percent Solids, Residual | % | - | - | - | 35 | | 35.1 | | 36.1 | |
| Total Organic Carbon | % | No Limit | - | - | 6.88 | | 6.135 | | 5.78 | J |
| Total Organic Carbon (1) | % | No Limit | - | - | 6.65 | | 6.34 | | 6.05 | J |
| Total Organic Carbon (2) | % | No Limit | - | - | 7.11 | | 5.93 | | 5.51 | |

Prepared by: DF 3/1/18
Revised by: CP 4/24/18
Checked by: ESS 4/24/18

Notes:
1. Bold values exceed the provisionally adopted MEDEP Maine Solid Waste Management Rules Chapter 418 Beneficial Use of Solid Waste - Screening Levels for Beneficial Use (Appendix A)
2. Bold and gray shaded values exceed the provisionally adopted MEDEP Maine Solid Waste Management Rules Chapter 418 Beneficial Use of Solid Waste, 'Reduced Procedure' for the beneficial use of dewatered dredge material as construction fill
3. Data qualifiers are as follows:
   U - analyzed but not detected
   J - estimated value
   UJ - estimated concentration below the method reporting limit
4. MEDEP. Maine Solid Waste Management Rules: Chapter 418, Beneficial Use of Solid Wastes provisionally adopted rules provided to Amec Foster Wheeler by MEDEP on 23 January 2018.

Abbreviations:
- = no standard or sample not analyzed for that parameter
% = percent
µg/kg = micrograms per kilogram
MEDEP = Maine Department of Environmental Protection
mg/kg = milligrams per kilogram
PAHs = polycyclic aromatic hydrocarbons
PCB = polychlorinated biphenyls
TCLP = toxicity characteristic leaching procedure
TPH = total petroleum hydrocarbons
ng/kg = nanograms per kilogram

**TABLE 6-1A**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO MEDEP BENEFICIAL USE OF SOLID WASTE SCREENING LEVELS[1, 2, 3]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | MEDEP Benefical Use of Solid Waste[4] | MEDEP Benefical Use of Solid Waste, "Reduced Procedure"[4] | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |

mg/L = milligrams per liter

**TABLE 6-1B**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO MEDEP REMEDIAL ACTION GUIDELINES[1, 2]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | Maine RAGs - Soil Park User (mg/kg) | Maine RAGs - Soil Commerical User (mg/kg) | Maine RAGs - Soil Construction User (mg/kg) | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| **TCLP Metals** | | | | | | | | | | | |
| Arsenic | mg/L | 5 | - | - | - | 0.039 | J | 1 | U | 0.052 | J |
| Barium | mg/L | 100 | - | - | - | 0.035 | J | 0.5 | U | 0.047 | J |
| Cadmium | mg/L | 1 | - | - | - | 0.1 | U | 0.1 | U | 0.1 | U |
| Chromium | mg/L | 5 | - | - | - | 0.2 | U | 0.2 | U | 0.2 | U |
| Lead | mg/L | 5 | - | - | - | 0.5 | U | 0.5 | U | 0.5 | U |
| Mercury | mg/L | 0.2 | - | - | - | 0.001 | U | 0.001 | U | 0.0004 | UJ |
| Selenium | mg/L | 1 | - | - | - | 0.5 | U | 0.5 | U | 0.5 | U |
| Silver | mg/L | 5 | - | - | - | 0.1 | U | 0.1 | U | 0.1 | U |
| **Total Metals** | | | | | | | | | | | |
| Arsenic | mg/kg | 100 | 2.3 | 4.2 | 42 | 10.6 | | 10.4 | | 18.1 | |
| Barium | mg/kg | 2000 | 10000 | 10000 | 10000 | 13.7 | | 17.8 | | 13.1 | |
| Cadmium | mg/kg | 20 | 18 | 94 | 19 | 1.03 | | 0.599 | | 0.923 | |
| Chromium | mg/kg | 100 | 10000 | 10000 | 10000 | 34.4 | | 43.6 | | 53.5 | J |
| Copper | mg/kg | - | 40000 | 10000 | 4300 | 21.3 | | 16.8 | | 22.3 | |
| Lead | mg/kg | 100 | 530 | 1100 | 950 | 22.9 | | 20.8 | | 23.2 | |
| Mercury | mg/kg | 4 | - | - | - | 0.75 | | 0.798 | | 1.34 | |
| Nickel | mg/kg | - | 850 | 5100 | 930 | 19.1 | | 23 | | 20 | |
| Selenium | mg/kg | 20 | - | - | - | 1.61 | | 1.88 | | 3.77 | J |
| Silver | mg/kg | 100 | 1400 | 8500 | 1500 | 0.233 | J | 0.18 | J | 0.193 | J |
| Zinc | mg/kg | - | 10000 | 10000 | 10000 | 80.4 | | 76.6 | | 207 | |
| **TPH** | | | | | | | | | | | |
| Gasoline Range Organics | µg/kg | - | - | - | - | 4600 | J | 3000 | J | 9700 | J |
| Total Petroleum Hydrocarbons | µg/kg | - | - | - | - | 65700 | J | 58000 | J | 124000 | J |
| **PCB Congeners** | | | | | | | | | | | |
| Cl2-BZ#8 | µg/kg | - | - | - | - | 1.38 | UJ | 1.37 | UJ | 1.29 | U |
| Cl3-BZ#18 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl3-BZ#28 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#44 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#49 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#52 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#66 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#101 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.3 | |
| Cl5-BZ#105 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#118 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#87 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl6-BZ#128 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl6-BZ#138 | µg/kg | - | - | - | - | 1.1 | J | 0.966 | J | 1.92 | |
| Cl6-BZ#153 | µg/kg | - | - | - | - | 0.897 | J | 0.794 | J | 1.65 | |
| Cl7-BZ#170 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl7-BZ#180 | µg/kg | - | - | - | - | 0.779 | J | 1.37 | U | 1.63 | |
| Cl7-BZ#183 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl7-BZ#184 | µg/kg | - | - | - | - | 1.38 | U | 1.03 | J | 1.29 | U |
| Cl7-BZ#187 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 0.677 | J |
| Cl8-BZ#195 | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl9-BZ#206 | µg/kg | - | - | - | - | 1.24 | J | 1.37 | U | 1.29 | U |
| Cl10-BZ#209 | µg/kg | - | - | - | - | 1.02 | J | 1.37 | U | 1.29 | U |
| Total PCBs | µg/kg | - | 4100 | 12000 | 6500 | 4.14 | | 2.79 | | 4.86 | |

**TABLE 6-1B**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO MEDEP REMEDIAL ACTION GUIDELINES[1, 2]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | Maine RAGs - Soil Park User (mg/kg) | Maine RAGs - Soil Commerical User (mg/kg) | Maine RAGs - Soil Construction User (mg/kg) | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| **Dioxins** | | | | | | | | | | | |
| 1234678-HpCDD | ng/kg | - | - | - | - | 239 | | 431 | | 666 | |
| 1234678-HpCDF | ng/kg | - | - | - | - | 242 | | 104 | | 167 | |
| 123478-HeCDD | ng/kg | - | - | - | - | 2.58 | J | 3.97 | J | 6.86 | J |
| 123478-HeCDF | ng/kg | - | - | - | - | 17.8 | J | 13.7 | | 29.8 | |
| 1234789-HpCDF | ng/kg | - | - | - | - | 4.41 | J | 5.56 | J | 10.1 | J |
| 123678-HeCDD | ng/kg | - | - | - | - | 15.2 | J | 19.3 | | 34.8 | |
| 123678-HeCDF | ng/kg | - | - | - | - | 7.96 | J | 6.02 | J | 10.3 | J |
| 12378-PeCDD | ng/kg | - | - | - | - | 3.2 | J | 3.64 | J | 6.79 | J |
| 12378-PeCDF | ng/kg | - | - | - | - | 13.1 | J | 13.2 | | 24.6 | |
| 123789-HeCDD | ng/kg | - | - | - | - | 6.6 | J | 9.89 | J | 18.6 | |
| 123789-HeCDF | ng/kg | - | - | - | - | 2.87 | J | 3.07 | J | 4.87 | J |
| 234678-HeCDF | ng/kg | - | - | - | - | 10.8 | J | 7.26 | J | 10.7 | J |
| 23478-PeCDF | ng/kg | - | - | - | - | 12 | J | 8.41 | J | 17.2 | |
| 2378-TCDD | ng/kg | - | - | - | - | 0.865 | J | 1.07 | J | 1.58 | J |
| 2378-TCDF | ng/kg | - | - | - | - | 29.4 | | 14.9 | | 46 | |
| OCDD | ng/kg | - | - | - | - | 2130 | | 3700 | | 5180 | |
| OCDF | ng/kg | - | - | - | - | 131 | | 189 | | 308 | |
| Total HpCDD | ng/kg | - | - | - | - | 737 | | 1130 | | 1620 | |
| Total HpCDF | ng/kg | - | - | - | - | 419 | J | 243 | | 420 | J |
| Total HxCDD | ng/kg | - | - | - | - | 127 | J | 169 | | 293 | J |
| Total HxCDF | ng/kg | - | - | - | - | 237 | J | 124 | | 227 | J |
| Total PeCDD | ng/kg | - | - | - | - | 37.9 | | 37.1 | | 74.6 | J |
| Total PeCDF | ng/kg | - | - | - | - | 127 | J | 73.7 | | 174 | J |
| Total TCDD | ng/kg | - | - | - | - | 34 | | 27.2 | | 58 | J |
| Total TCDF | ng/kg | - | - | - | - | 172 | | 88.4 | | 243 | J |
| Total TEQ | ng/kg | - | 170 | 310 | 31000 | 22.9 | | 22 | | 40.6 | |
| **PAHs** | | | | | | | | | | | |
| Acenaphthene | mg/kg | - | 10000 | 10000 | 9800 | 0.0446 | J | 0.0192 | J | 0.0303 | |
| Acenaphthylene | mg/kg | - | 10000 | 10000 | 10000 | 0.0905 | J | 0.0555 | J | 0.0683 | |
| Anthracene | mg/kg | - | 10000 | 10000 | 3800 | 0.11 | | 0.0586 | | 0.0961 | |
| Benzo(a)anthracene | mg/kg | - | 4.4 | 35 | 430 | 0.444 | J | 0.277 | | 0.393 | |
| Benzo(a)pyrene | mg/kg | - | 0.44 | 3.5 | 430 | 0.346 | J | 0.235 | | 0.377 | |
| Benzo(b)fluoranthene | mg/kg | - | 4.4 | 3.5 | 43 | 0.404 | J | 0.296 | | 0.329 | |
| Benzo(ghi)perylene | mg/kg | - | 6200 | 10000 | 10000 | 0.272 | | 0.188 | | 0.234 | |
| Benzo(k)fluoranthene | mg/kg | - | 44 | 350 | 4300 | 0.238 | J | 0.145 | | 0.283 | |
| Chrysene | mg/kg | - | 440 | 3500 | 10000 | 0.348 | J | 0.231 | | 0.37 | |
| Dibenz(a,h)anthracene | mg/kg | - | 0.44 | 3.5 | 43 | 0.0569 | J | 0.0379 | | 0.0596 | |
| Fluoranthene | mg/kg | - | 8300 | 10000 | 10000 | 0.69 | | 0.437 | | 0.646 | |
| Fluorene | mg/kg | - | 8300 | 10000 | 10000 | 0.0499 | J | 0.0236 | J | 0.0301 | |
| Indeno(1,2,3-cd)pyrene | mg/kg | - | 4.4 | 35 | 430 | 0.309 | | 0.224 | | 0.226 | |
| Naphthalene | mg/kg | - | 4200 | 10000 | 10000 | 0.0935 | J | 0.0386 | J | 0.0747 | |
| Phenanthrene | mg/kg | - | 62000 | 10000 | 8900 | 0.423 | | 0.232 | | 0.361 | J |
| Pyrene | mg/kg | - | 6200 | 10000 | 10000 | 0.653 | | 0.388 | | 0.54 | |
| **Total Pesticides** | | | | | | | | | | | |
| 4,4'-DDD | µg/kg | - | 75000 | 120000 | 1400000 | 5.58 | J | 1.76 | J | 16.3 | J |
| 4,4'-DDE | µg/kg | - | 53000 | 85000 | 980000 | 1.87 | J | 1.28 | J | 2.96 | J |
| 4,4'-DDT | µg/kg | - | 64000 | 120000 | 140000 | 0.977 | J | 1.04 | J | 0.645 | U |
| Aldrin | µg/kg | - | 1100 | 1700 | 10000 | 0.688 | UJ | 0.684 | UJ | 0.645 | UJ |
| Alpha-Chlordane | µg/kg | 600 | 60000 | 110000 | 170000 | 0.688 | U | 0.684 | U | 0.645 | U |
| cis-Nonachlor | µg/kg | - | - | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Dieldrin | µg/kg | - | 1100 | 1800 | 21000 | 0.688 | U | 0.684 | U | 1.6 | J |

**TABLE 6-1B**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO MEDEP REMEDIAL ACTION GUIDELINES[1, 2]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | Maine RAGs - Soil Park User (mg/kg) | Maine RAGs - Soil Commerical User (mg/kg) | Maine RAGs - Soil Construction User (mg/kg) | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| Endosulfan I | µg/kg | - | 1300000 | 6200000 | 1400000 | 0.688 | U | 0.684 | U | 0.645 | U |
| Endosulfan II | µg/kg | - | - | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Endrin | µg/kg | 400 | 67000 | 310000 | 480000 | 0.688 | U | 0.684 | U | 0.645 | U |
| Gamma-BHC/Lindane | µg/kg | 8000 | 1000 | 5400 | 2800 | 0.688 | UJ | 0.684 | UJ | 0.645 | UJ |
| Gamma-Chlordane | µg/kg | - | - | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Heptachlor | µg/kg | 160 | 2200 | 6400 | 24000 | 0.688 | UJ | 0.684 | UJ | 0.645 | U |
| Heptachlor epoxide | µg/kg | 160 | 2000 | 3200 | 3100 | 1.38 | U | 1.37 | U | 1.29 | U |
| Hexachlorobenzene | µg/kg | - | 11000 | 18000 | 190000 | 1.38 | UJ | 1.37 | UJ | 1.29 | U |
| Methoxychlor | µg/kg | 200000 | 1100000 | 5100000 | 1200000 | 6.88 | U | 6.84 | U | 6.45 | U |
| Oxychlordane | µg/kg | - | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Toxaphene | µg/kg | 10000 | - | - | - | 34.5 | U | 34.3 | U | 32.4 | U |
| trans-Nonachlor | µg/kg | - | - | - | - | 0.688 | U | 0.758 | J | 0.645 | U |
| **Other** | | | | | | | | | | | |
| Moisture Content | % | - | - | - | - | 65 | | 64.9 | | - | |
| Percent Moisture | % | No Free Flowing Liquids | - | - | - | - | | - | | 63.9 | |
| Percent Moisture | % | No Free Flowing Liquids | - | - | - | - | | - | | 64.8 | |
| Percent Solids, Residual | % | - | - | - | - | 35 | | 35.1 | | 36.1 | |
| Total Organic Carbon | % | No Limit | - | - | - | 6.88 | | 6.135 | | 5.78 | J |
| Total Organic Carbon (1) | % | No Limit | - | - | - | 6.65 | | 6.34 | | 6.05 | J |
| Total Organic Carbon (2) | % | No Limit | - | - | - | 7.11 | | 5.93 | | 5.51 | |

Prepared by: ESS 3/1/18
Checked by: KC 3/7/18

Notes:
1. Color coding on this table signifies the following:

| | |
|---|---|
| **Anticipated Disposal Requirement** | Exceeds the anticipated disposal requirements based on conversations with Waste Management Crossroads Landfill, Pine Tree Landfill, and Republic Waste |
| Maine RAGs - Soil Park User (mg/kg) | Exceeds the Maine Soil Park User RAG |
| Maine RAGs - Soil Commerical User (mg/kg) | Exceeds the Maine Soil Commerical Worker RAG |
| Maine RAGs - Soil Construction User (mg/kg) | Exceeds the Maine Construction Worker RAG |

2. Data qualifiers are as follows:
U - analyzed but not detected
J - estimated value
UJ - estimated concentration below the method reporting limit

Abbreviations:
- = no standard or sample not analyzed for that parameter
% = percent
µg/kg = micrograms per kilogram
MEDEP = Maine Department of Environmental Protection
mg/kg = milligrams per kilogram
mg/L = milligrams per liter
ng/kg = nanograms per kilogram
PAHs = polycyclic aromatic hydrocarbons
PCB = polychlorinated biphenyls
RAGS = Risk Assessment Guidance for Superfund
TCLP = toxicity characteristic leaching procedure
TPH = total petroleum hydrocarbons

**TABLE 6-1C**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO ECOTOX ERL AND PEL THRESHOLDS[1,2]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | ERL | PEL | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| **TCLP Metals** | | | | | | | | | | |
| Arsenic | mg/L | 5 | - | - | 0.039 | J | 1 | U | 0.052 | J |
| Barium | mg/L | 100 | - | - | 0.035 | J | 0.5 | U | 0.047 | J |
| Cadmium | mg/L | 1 | - | - | 0.1 | U | 0.1 | U | 0.1 | U |
| Chromium | mg/L | 5 | - | - | 0.2 | U | 0.2 | U | 0.2 | U |
| Lead | mg/L | 5 | - | - | 0.5 | U | 0.5 | U | 0.5 | U |
| Mercury | mg/L | 0.2 | - | - | 0.001 | U | 0.001 | U | 0.0004 | UJ |
| Selenium | mg/L | 1 | - | - | 0.5 | U | 0.5 | U | 0.5 | U |
| Silver | mg/L | 5 | - | - | 0.1 | U | 0.1 | U | 0.1 | U |
| **Total Metals** | | | | | | | | | | |
| Arsenic | mg/kg | 100 | 8.2 | 41.6 | 10.6 | | 10.4 | | 18.1 | |
| Barium | mg/kg | 2000 | - | - | 13.7 | | 17.8 | | 13.1 | |
| Cadmium | mg/kg | 20 | 1.2 | 4.21 | 1.03 | | 0.599 | | 0.923 | |
| Chromium | mg/kg | 100 | 81 | 160 | 34.4 | | 43.6 | | 53.5 | J |
| Copper | mg/kg | - | 34 | 108 | 21.3 | | 16.8 | | 22.3 | |
| Lead | mg/kg | 100 | 46.7 | 112 | 22.9 | | 20.8 | | 23.2 | |
| Mercury | mg/kg | 4 | 0.15 | 0.7 | 0.75 | | 0.798 | | 1.34 | |
| Nickel | mg/kg | - | 20.9 | 42.8 | 19.1 | | 23 | | 20 | |
| Selenium | mg/kg | 20 | - | - | 1.61 | | 1.88 | | 3.77 | J |
| Silver | mg/kg | 100 | 1 | 1.77 | 0.233 | J | 0.18 | J | 0.193 | J |
| Zinc | mg/kg | - | 150 | 271 | 80.4 | | 76.6 | | 207 | |
| **TPH** | | | | | | | | | | |
| Gasoline Range Organics | µg/kg | - | - | - | 4600 | J | 3000 | J | 9700 | J |
| Total Petroleum Hydrocarbons | µg/kg | - | - | - | 65700 | J | 58000 | J | 124000 | J |
| **PCB Congeners** | | | | | | | | | | |
| Cl2-BZ#8 | µg/kg | - | - | - | 1.38 | UJ | 1.37 | UJ | 1.29 | U |
| Cl3-BZ#18 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl3-BZ#28 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#44 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#49 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#52 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl4-BZ#66 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#101 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.3 | |
| Cl5-BZ#105 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#118 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl5-BZ#87 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl6-BZ#128 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl6-BZ#138 | µg/kg | - | - | - | 1.1 | J | 0.966 | J | 1.92 | |
| Cl6-BZ#153 | µg/kg | - | - | - | 0.897 | J | 0.794 | J | 1.65 | |
| Cl7-BZ#170 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl7-BZ#180 | µg/kg | - | - | - | 0.779 | J | 1.37 | U | 1.63 | |
| Cl7-BZ#183 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl7-BZ#184 | µg/kg | - | - | - | 1.38 | U | 1.03 | J | 1.29 | U |
| Cl7-BZ#187 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 0.677 | J |
| Cl8-BZ#195 | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Cl9-BZ#206 | µg/kg | - | - | - | 1.24 | J | 1.37 | U | 1.29 | U |
| Cl10-BZ#209 | µg/kg | - | - | - | 1.02 | J | 1.37 | U | 1.29 | U |
| Total PCBs | µg/kg | - | 22.7 | 189 | 4.139 | | 2.79 | | 4.86 | |

**TABLE 6-1c**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO ECOTOX ERL AND PEL THRESHOLDS[1,2]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | ERL | PEL | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| **Dioxins** | | | | | | | | | | |
| 1234678-HpCDD | ng/kg | - | - | - | 239 | | 431 | | 666 | |
| 1234678-HpCDF | ng/kg | - | - | - | 242 | | 104 | | 167 | |
| 123478-HeCDD | ng/kg | - | - | - | 2.58 | J | 3.97 | J | 6.86 | J |
| 123478-HeCDF | ng/kg | - | - | - | 17.8 | J | 13.7 | | 29.8 | |
| 1234789-HpCDF | ng/kg | - | - | - | 4.41 | J | 5.56 | J | 10.1 | J |
| 123678-HeCDD | ng/kg | - | - | - | 15.2 | J | 19.3 | | 34.8 | |
| 123678-HeCDF | ng/kg | - | - | - | 7.96 | J | 6.02 | J | 10.3 | J |
| 12378-PeCDD | ng/kg | - | - | - | 3.2 | J | 3.64 | J | 6.79 | J |
| 12378-PeCDF | ng/kg | - | - | - | 13.1 | J | 13.2 | | 24.6 | |
| 123789-HeCDD | ng/kg | - | - | - | 6.6 | J | 9.89 | J | 18.6 | |
| 123789-HeCDF | ng/kg | - | - | - | 2.87 | J | 3.07 | J | 4.87 | J |
| 234678-HeCDF | ng/kg | - | - | - | 10.8 | J | 7.26 | J | 10.7 | J |
| 23478-PeCDF | ng/kg | - | - | - | 12 | J | 8.41 | J | 17.2 | |
| 2378-TCDD | ng/kg | - | - | - | 0.865 | J | 1.07 | J | 1.58 | J |
| 2378-TCDF | ng/kg | - | - | - | 29.4 | | 14.9 | | 46 | |
| OCDD | ng/kg | - | - | - | 2130 | | 3700 | | 5180 | |
| OCDF | ng/kg | - | - | - | 131 | | 189 | | 308 | |
| Total HpCDD | ng/kg | - | - | - | 737 | | 1130 | | 1620 | |
| Total HpCDF | ng/kg | - | - | - | 419 | J | 243 | | 420 | J |
| Total HxCDD | ng/kg | - | - | - | 127 | J | 169 | | 293 | J |
| Total HxCDF | ng/kg | - | - | - | 237 | J | 124 | | 227 | J |
| Total PeCDD | ng/kg | - | - | - | 37.9 | | 37.1 | | 74.6 | J |
| Total PeCDF | ng/kg | - | - | - | 127 | J | 73.7 | | 174 | J |
| Total TCDD | ng/kg | - | - | - | 34 | | 27.2 | | 58 | J |
| Total TCDF | ng/kg | - | - | - | 172 | | 88.4 | | 243 | J |
| Total TEQ | ng/kg | - | - | 21.5 | 22.9 | | 22 | | 40.6 | |
| **PAHs** | | | | | | | | | | |
| Acenaphthene | mg/kg | - | 0.016 | 0.0889 | 0.0446 | J | 0.0192 | J | 0.0303 | |
| Acenaphthylene | mg/kg | - | 0.044 | 0.128 | 0.0905 | J | 0.0555 | J | 0.0683 | |
| Anthracene | mg/kg | - | 0.0853 | 0.245 | 0.11 | | 0.0586 | | 0.0961 | |
| Benzo(a)anthracene | mg/kg | - | 0.261 | 0.693 | 0.444 | J | 0.277 | | 0.393 | |
| Benzo(a)pyrene | mg/kg | - | 0.43 | 0.763 | 0.346 | J | 0.235 | | 0.377 | |
| Benzo(b)fluoranthene | mg/kg | - | - | - | 0.404 | J | 0.296 | | 0.329 | |
| Benzo(ghi)perylene | mg/kg | - | - | - | 0.272 | | 0.188 | | 0.234 | |
| Benzo(k)fluoranthene | mg/kg | - | - | - | 0.238 | J | 0.145 | | 0.283 | |
| Chrysene | mg/kg | - | 0.384 | 0.846 | 0.348 | J | 0.231 | | 0.37 | |
| Dibenz(a,h)anthracene | mg/kg | - | 0.0634 | 0.135 | 0.0569 | J | 0.0379 | | 0.0596 | |
| Fluoranthene | mg/kg | - | 0.6 | 1.494 | 0.69 | | 0.437 | | 0.646 | |
| Fluorene | mg/kg | - | 0.019 | 0.144 | 0.0499 | J | 0.0236 | J | 0.0301 | |
| Indeno(1,2,3-cd)pyrene | mg/kg | - | - | - | 0.309 | | 0.224 | | 0.226 | |
| Naphthalene | mg/kg | - | 0.16 | 0.391 | 0.0935 | J | 0.0386 | J | 0.0747 | |
| Phenanthrene | mg/kg | - | 0.24 | 0.544 | 0.423 | | 0.232 | | 0.361 | J |
| Pyrene | mg/kg | - | 0.665 | 1.398 | 0.653 | | 0.388 | | 0.54 | |
| **Total Pesticides** | | | | | | | | | | |
| 4,4'-DDD | µg/kg | - | 2 | 7.81 | 5.58 | J | 1.76 | J | 16.3 | J |
| 4,4'-DDE | µg/kg | - | 2.2 | 374 | 1.87 | J | 1.28 | J | 2.96 | J |
| 4,4'-DDT | µg/kg | - | 1 | 4.77 | 0.977 | J | 1.04 | J | 0.645 | U |

**TABLE 6-1c**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO ECOTOX ERL AND PEL THRESHOLDS[1,2]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | ERL | PEL | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| Aldrin | µg/kg | - | - | - | 0.688 | UJ | 0.684 | UJ | 0.645 | UJ |
| Alpha-Chlordane | µg/kg | 600 | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| cis-Nonachlor | µg/kg | - | - | _ | 0.688 | U | 0.684 | U | 0.645 | U |
| Dieldrin[3] | µg/kg | - | 0.02 | 4.3 | 0.688 | U | 0.684 | U | 1.6 | J |
| Endosulfan I | µg/kg | - | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Endosulfan II | µg/kg | - | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Endrin | µg/kg | 400 | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Gamma-BHC/Lindane | µg/kg | 8000 | - | 0.99 | 0.688 | UJ | 0.684 | UJ | 0.645 | UJ |

**TABLE 6-1c**

**PRELIMINARY WASTE CHARACTERIZATION RESULTS COMPARED TO ECOTOX ERL AND PEL THRESHOLDS[1,2]**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Analyte | Units | Anticipated Disposal Requirement | ERL | PEL | Sediment Sample Results | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | FFBU_60WCH | | VN_25WCH | | BU-10-02-C | |
| | | | | | FFBU_60WCH_092817_SED_05 | | VN_25WCH-092817_SED_05 | | BU-10-02-C-17_SED_00-55 | |
| | | | | | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier | Analytical Result | Laboratory Qualifier |
| Gamma-Chlordane | µg/kg | - | - | - | 0.688 | U | 0.684 | U | 0.645 | U |
| Heptachlor | µg/kg | 160 | - | - | 0.688 | UJ | 0.684 | UJ | 0.645 | U |
| Heptachlor epoxide | µg/kg | 160 | - | 2.74 | 1.38 | U | 1.37 | U | 1.29 | U |
| Hexachlorobenzene | µg/kg | - | - | - | 1.38 | UJ | 1.37 | UJ | 1.29 | U |
| Methoxychlor | µg/kg | 200000 | - | - | 6.88 | U | 6.84 | U | 6.45 | U |
| Oxychlordane | µg/kg | - | - | - | 1.38 | U | 1.37 | U | 1.29 | U |
| Toxaphene | µg/kg | 10000 | - | - | 34.5 | U | 34.3 | U | 32.4 | U |
| trans-Nonachlor | µg/kg | - | - | - | 0.688 | U | 0.758 | J | 0.645 | U |
| **Other** | | | | | | | | | | |
| Moisture Content | % | - | - | - | 65 | | 64.9 | | - | |
| Percent Moisture | % | No Free Flowing Liquids | - | - | - | | - | | 63.9 | |
| Percent Moisture | % | No Free Flowing Liquids | - | - | - | | - | | 64.8 | |
| Percent Solids, Residual | % | - | - | - | 35 | | 35.1 | | 36.1 | |
| Total Organic Carbon | % | No Limit | - | - | 6.88 | | 6.135 | | 5.78 | J |
| Total Organic Carbon (1) | % | No Limit | - | - | 6.65 | | 6.34 | | 6.05 | J |
| Total Organic Carbon (2) | % | No Limit | - | - | 7.11 | | 5.93 | | 5.51 | |

Prepared by: ESS 3/1/18
Checked by: KC 3/1/18

Notes:
1. Color coding on this table signifies the following:

| | |
|---|---|
| **Anticipated Disposal Requirement** | Exceeds the anticipated disposal requirements based on conversations with Waste Management Crossroads Landfill, Pine Tree Landfill, and Republic Waste |
| ERL | Exceeds the Effects Range Low, Ecotox. 1996, 5(4):253 |
| PEL | Exceeds the Probable Effects Level, Ecotox. 1996, 5(4):253 |

2. Data qualifiers are as follows:
   - U - analyzed but not detected
   - J - estimated value
   - UJ - estimated concentration below the method reporting limit
3. ERL standard for Dieldrin (0.02 µg/kg) is below detection limit (0.688 µg/kg)

Abbreviations:
- = no standard or sample not analyzed for that parameter
% = percent
µg/kg = micrograms per kilogram
ERL = Effects Range Low
mg/kg = milligrams per kilogram
mg/L = milligrams per liter
ng/kg = nanograms per kilogram
PAHs = polycyclic aromatic hydrocarbons
PCB = polychlorinated biphenyls
PEL = Probable Effects Level
TCLP = toxicity characteristic leaching procedure
TPH = total petroleum hydrocarbons

## TABLE 7-1

## SUMMARY OF REMEDIAL ALTERNATIVES
## Penobscot River Phase III Engineering Study
## Penobscot River Estuary, Maine

| Alternative | Remedial Technology Components | | | | Hydrodynamic Zone | | | |
|---|---|---|---|---|---|---|---|---|
| | Institutional Controls[1] | Place Clean Sediment[2] | Remove Sediment[3] | Apply Amendments[4] | Marsh | Intertidal | Subtidal | Thalweg/Main Channel |
| Monitored Natural Recovery | ✓ | - | - | - | ✓ | ✓ | ✓ | ✓ |
| Enhanced Monitored Natural Recovery | ✓ | ✓ | - | - | ✓ | ✓ | ✓ | ✓ |
| Dredging | ✓ | ✓ | ✓ | - | ✓ | ✓ | ✓ | ✓ |
| Thin Layer Capping | ✓ | ✓ | - | - | ✓ | - | - | - |
| Amendments | ✓ | - | - | ✓ | ✓ | - | - | - |

Notes:

1. Institutional controls consist of the following:
   - Monitor sediment & biota concentrations/trends
   - Enact or maintain species-specific fishing/consumption advisories and bans
   - Conduct public outreach/education programs
2. Place clean sediment consists of the following:
   - Procure clean sediments
   - Apply clean sediments
3. Remove sediment consists of the following:
   - Dredge sediments
   - Replace with clean sediment
   - Dewater sediments
   - Reuse or dispose of sediments off-site
4. Apply amendments consists of the following:
   - Procure amendments
   - Apply amendments

Prepared by: MS 3/2/18
Checked by: ESS 3/5/18

**TABLE 7-2**

**ESTIMATED COST OF REMEDIAL ALTERNATIVES SUMMARY**
**Penobscot River Phase III Engineering Study**
**Penobscot River Estuary, Maine**

| Description | Alternative 1: Monitored Natural Recovery | Alternative 2: Enhanced Monitored Natural Recovery (500 ng/g) | Alternative 2: Enhanced Monitored Natural Recovery (300 ng/g) | Alternative 3: Dredging (500 ng/g with Offsite Disposal) | Alternative 3: Dredging (500 ng/g with Beneficial Reuse) | Alternative 3: Dredging (300 ng/g with Offsite Disposal) | Alternative 3: Dredging (300 ng/g with Beneficial Reuse) | Alternative 4 and 6: Thin-Layer Capping | Alternative 5: Amendment Application | Alternative 6: Dredging in Intertidal and Subtidal Zones (with Offsite Disposal) | Alternative 6: Dredging in Intertidal and Subtidal Zones (with Beneficial Reuse) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Performance and Payment Bond | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| Work Plans, Permits and Submittals | $0 | $180,000 | $490,000 | $1,050,000 | $1,050,000 | $2,240,000 | $2,240,000 | $80,000 | $20,000 | $150,000 | $150,000 |
| Mobilization | $0 | $9,970,000 | $73,600,000 | $112,510,000 | $112,510,000 | $646,760,000 | $646,760,000 | $2,280,000 | $70,000 | $2,590,000 | $2,590,000 |
| Temporary Construction | $0 | $2,710,000 | $2,710,000 | $14,850,000 | $14,850,000 | $14,850,000 | $14,850,000 | $2,710,000 | $2,710,000 | $0 | $0 |
| Surveys | $0 | $4,290,000 | $11,660,000 | $6,640,000 | $6,640,000 | $18,020,000 | $18,020,000 | $710,000 | $200,000 | $670,000 | $670,000 |
| Environmental Monitoring | $0 | $4,630,000 | $12,700,000 | $19,350,000 | $19,350,000 | $28,110,000 | $28,110,000 | $700,000 | $0 | $580,000 | $580,000 |
| Debris Removal | $0 | $0 | $0 | $3,150,000 | $3,150,000 | $9,900,000 | $9,900,000 | $0 | $0 | $1,210,000 | $1,210,000 |
| Dredging and Offloading | $0 | $0 | $0 | $119,730,000 | $119,730,000 | $236,330,000 | $236,330,000 | $0 | $0 | $14,340,000 | $14,340,000 |
| Dredge Material Processing | $0 | $0 | $0 | $73,150,000 | $73,150,000 | $203,590,000 | $203,590,000 | $0 | $0 | $8,420,000 | $8,420,000 |
| Backfill Material Procurement and Delivery | $0 | $149,070,000 | $408,990,000 | $144,120,000 | $144,120,000 | $491,730,000 | $491,730,000 | $7,510,000 | $21,020,000 | $21,730,000 | $21,730,000 |
| Backfilling and Loading of Backfill | $0 | $40,130,000 | $109,920,000 | $96,910,000 | $96,910,000 | $227,920,000 | $227,920,000 | $21,550,000 | $2,540,000 | $15,410,000 | $15,410,000 |
| T&D Offsite | $0 | $0 | $0 | $497,930,000 | $0 | $1,375,340,000 | $0 | $0 | $0 | $57,350,000 | $0 |
| T&D Beneficial Reuse | $0 | $0 | $0 | $0 | $197,290,000 | $0 | $544,940,000 | $0 | $0 | $0 | $22,730,000 |
| Water Treatment | $0 | $0 | $0 | $5,880,000 | $5,880,000 | $12,300,000 | $12,300,000 | $0 | $0 | $0 | $0 |
| Restoration Plantings and Access Agreements | $0 | $0 | $0 | $23,410,000 | $23,410,000 | $69,050,000 | $69,050,000 | $0 | $0 | $0 | $0 |
| Demobilization | $0 | $9,970,000 | $73,600,000 | $112,510,000 | $112,510,000 | $646,760,000 | $646,760,000 | $2,280,000 | $70,000 | $2,590,000 | $2,590,000 |
| **Total No Contingency** | $0 | $220,950,000 | $693,670,000 | $1,231,190,000 | $930,550,000 | $3,982,900,000 | $3,152,500,000 | $37,820,000 | $26,630,000 | $125,040,000 | $90,420,000 |
| 20% Contingency | $0 | $44,190,000 | $138,730,000 | $246,240,000 | $186,110,000 | $796,580,000 | $630,500,000 | $7,560,000 | $5,330,000 | $25,010,000 | $18,080,000 |
| **Total with Contingency** | $0 | $265,140,000 | $832,400,000 | $1,477,430,000 | $1,116,660,000 | $4,779,480,000 | $3,783,000,000 | $45,380,000 | $31,960,000 | $150,050,000 | $108,500,000 |
| Project Management (5%) | $0 | $13,260,000 | $41,620,000 | $73,870,000 | $55,830,000 | $238,970,000 | $189,150,000 | $2,270,000 | $1,600,000 | $7,500,000 | $5,430,000 |
| Remedial Design (5%) | $0 | $13,260,000 | $41,620,000 | $73,870,000 | $55,830,000 | $238,970,000 | $189,150,000 | $2,270,000 | $1,600,000 | $7,500,000 | $5,430,000 |
| Construction Management (6%) | $0 | $15,910,000 | $49,940,000 | $88,650,000 | $67,000,000 | $286,770,000 | $226,980,000 | $2,720,000 | $1,920,000 | $9,000,000 | $6,510,000 |
| **Total Capital Cost** | **$0** | **$307,570,000** | **$965,580,000** | **$1,713,820,000** | **$1,295,320,000** | **$5,544,190,000** | **$4,388,280,000** | **$52,640,000** | **$37,080,000** | **$174,050,000** | **$125,870,000** |
| Long Term Monitoring Program | **$16,540,000** | **$18,300,000** | **$21,620,000** | **$12,460,000** | **$12,460,000** | **$15,780,000** | **$15,780,000** | **$5,910,000** | **$6,290,000** | **$11,250,000** | **$11,250,000** |
| Pilot Test #1 | **$0** | **$10,000,000** | **$10,000,000** | **$0** | **$0** | **$0** | **$0** | **$2,500,000** | **$2,500,000** | **$0** | **$0** |
| Pilot Test #2 | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$0** | **$5,000,000** | **$5,000,000** | **$0** | **$0** |
| **Total Cost** | **$16,540,000** | **$335,870,000** | **$997,200,000** | **$1,726,280,000** | **$1,307,780,000** | **$5,559,970,000** | **$4,404,060,000** | **$66,050,000** | **$50,870,000** | **$185,300,000** | **$137,120,000** |
| **Unit Cost Per Cubic Yard** | **-** | **-** | **-** | **$390** | **$290** | **$440** | **$350** | **$270** | **$4,010** | **$330** | **$240** |
| **Unit Cost Per Acre** | **-** | **-** | **-** | **$800,000** | **$600,000** | **$190,000** | **$780,000** | **$230,000** | **$80,000** | **$540,000** | **$390,000** |

Notes:
ng/g = nanograms per gram

Prepared by: ESS 9/4/18
Checked by: KM 9/5/18