PENOBSCOT RIVER MERCURY STUDY

Chapter 21

Recommendations to the Court

Submitted to Judge John Woodcock
United States District Court (District of Maine)

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By J.W.M. Rudd[1], N.S. Fisher[2], C.G. Whipple[3]

1. R&K Research, Inc.
2. Stony Brook University, Stony Brook, New York
3. ENVIRON International Corporation

1 PREAMBLE

The level of our scientific understanding of mercury (Hg) cycling in the Penobscot estuary is now robust. As a result of the Phase I and II studies, the Penobscot estuary is now one of the best understood estuaries in terms of Hg contamination. The Phase I objectives were to determine the extent of Hg contamination downriver from the HoltraChem plant, and to determine if the contamination endangers human health or the environment. For Phase II, the two primary objectives were to establish the time for recovery of the Penobscot estuary from Hg contamination by natural attenuation, and to do some preliminary testing and development of possible remediation measures to determine their scientific feasibility. It is the opinion of the Study Panel these goals have been accomplished. In light of the long natural recovery times that have been found for this system, the Study Panel now recommends the establishing of a Remediation Program to prove the suggested remediation procedures by doing some limited additional scientific work and by engineering design studies to establish their feasibility from an engineering perspective.

We now have a scientific basis on which we can make recommendations towards remediation of the upper Penobscot estuary. We define the upper estuary as the zone of the Penobscot estuary below Veazie Dam and as far south as the southern tip of Verona Island, including Mendall Marsh and the lower Orland River. This is the zone in which Hg concentrations are highest in sediments and biota (Chapters 1 & 5, Appendix 2 and 3 of Chapter 1) and for which we have evidence that the active remediation procedures we recommend are scientifically feasible. It is also anticipated that any active remediations in the upper estuary will also have a positive impact on Fort Point Cove, which is immediately downstream of the upper estuary and still has high Hg concentrations in lobster.

The details of this scientific basis are presented in Chapter 23. Briefly, we now understand the degree and geographic extent of the Hg contamination of the Penobscot estuary for sediments, aquatic biota and birds. Certain wildlife species, especially songbirds, are at risk while there is less but definitely some risk to human consumers. We know that the present day importance of ongoing inputs from the HoltraChem site is small, as compared to legacy HoltraChem Hg, and therefore remediation should focus on the legacy Hg, which is still in the sediments and is still being methylated. We know that most of the Hg contamination occurred 46 years ago, and continued at a much lower rate until 2000. Since 1967, the Hg has been dispersed as far south as the southern end of Islesboro Island (Appendix 1-2 in Chapter 1). Surface sediment concentrations are much lower than they were during the peak discharge years, but are still elevated at about 9 times background levels in the upper estuary. If the situation continues as it has without significant changes we have calculated that the ongoing natural attenuation of the contamination problem for the main stem of the river between Veazie Dam and south Verona Island will take another 33 years (from 2013) to reach target Hg concentrations (450 ng/g dry wt. in surface sediments) and about 163 years to reach regional background levels of Hg concentration (Table 21-1). It will also take a long time (perhaps 60 years) for soils in Mendall Marsh to return to target levels of Hg

Table 21-1: Approximate years to reach target concentrations in sediments in the upper estuary of the river, and on the platform of Mendall Marsh.

	2009 concentration, ng Hg/g dry wt.	% reduction needed	Target concentration, ng/g dry wt.	Approximate years to Target (from 2013)	Approximate years to within 20% of recovery background
Upper estuary	890	50%	450	33 years* (2046)	163 years (2176)
Mendall Marsh Platform	490	80%	100	60 years** (2073)	106 years (2119)

*Using 1/2 time of 32 years, for main stem, Mendall Marsh and Orland River cores, to an asymptote of 100 ng/g dry wt. (expected background concentration in the main stem, after natural attenuation is complete)

**Using 1/2 time of 20 years, to an asymptote of 50 ng/g dry wt. (background concentration in Mendall Marsh platform

Original Core data halftimes from Chapter 6; data in "HALFTIMES-PBR-MM-ES-OR-CORES 2013 03 06-fnl March 20_13.xlsx".

Adjustment for non-zero asymptotes in "Estimates of recovery using Core data CK Mar 20_13.xlsx".

concentration (100 ng/g dry wt.), if there is no intervention. However, it will take a very long time - 106 yrs. – for soils in Mendall Marsh to reach background concentrations.

Our sediment target levels are our best estimates of the sediment concentrations at which there would be minimal toxic effects in the biota, or their wildlife or human consumers. The reason for the lower sediment target concentration in Mendall Marsh, in comparison to the river, is that the marsh has much higher efficiencies of Hg methylation, and methyl Hg bioavailability to the lower food chain (Chapters 11 & 12). We have found that the most important parameter determining methyl Hg production rates and concentrations of methyl Hg in surface sediments is the concentration of inorganic Hg in surface sediments (Chapter 1). Thus, actively lowering inorganic Hg concentrations in surface sediments will lower methyl Hg concentrations in sediments and biota. A new finding of this study is that a pool of mobile sediments, which is efficiently trapped by natural hydrodynamic processes in the upper estuary, is limiting the rate of recovery of the upper estuary to its present slow pace (Chapter 7).

The main difficulty in applying remediation procedures to the Penobscot estuary is the present wide dispersal of the HoltraChem Hg throughout the upper estuary. What started as a point source of very high Hg concentration at the HoltraChem site in 1967, has now become a much more widespread problem at lower (but still high) Hg concentrations throughout the upper estuary as a result of dispersal of the Hg by tidal movements of the mobile sediment pool. We now estimate that there is about 9.3 tonnes of Hg contaminating the sediments in the entire estuary (Chapter 5). A total of 330 kg of this Hg is now in either the mobile sediment pool, or in the surface sediments at long term depositional sites of the upper estuary, which is presently most involved in the ongoing problem. The remainder has been dispersed further south into Fort Point Cove and Penobscot Bay (Chapters 1 & 5).

We are confident on scientific grounds that the recommendations we make below would be successful in reducing methyl Hg concentrations to target levels, if the procedures we recommend could be applied as envisioned. Without some further focused study, we are not yet confident of the practical feasibility of these recommendations from an engineering perspective. The main reason for this uncertainty is the need for better estimates of the size of the mobile pool and some particle input rates. Therefore we recommend that these science-based remediation plans be further investigated and proven by engineering feasibility studies before they are applied.

2 RECOMMENDATIONS

Based on the degree and extent of existing contamination in the upper Penobscot estuary, along with consideration of the now established slow rate of natural mercury (Hg) attenuation, we have concluded that there is a need for active remediation (see Chapters 2, 22, 23). We have also concluded that any active remediation actions should be confined to the upper Penobscot estuary (between Veazie Dam and the southern tip of Verona Island) because the upper estuary is where Hg-contaminated particles are efficiently trapped, and where Hg concentrations in sediments and biota are highest. Biota concentrations in the upper estuary are high enough to be of concern, in some cases to human consumers, and often to wildlife.

2.1 Overall recommendation to the Court

The Study Panel unanimously recommends that a Court ordered Remediation Program be established with the objective of increasing the rate of recovery of the upper Penobscot estuary from its present state of Hg contamination, and that the system be monitored during and after active remediation or as natural attenuation proceeds if no active remediation is undertaken.

We present seven specific recommendations (see below) consisting of four remediation options, a recommendation for the continuation of long-term Hg monitoring, and two additional recommendations concerning how the remediation options and monitoring should be addressed as part of an overall Remediation Program. The scientific basis supporting these recommendations is presented in Chapter 23. The four remediation options recommended below are scientifically sound, but need some further limited scientific study and engineering design before full-scale implementation of one of more of these options should take place.

During active remediation, the Study Panel recognizes the risk of disturbance of large quantities of deeply buried Hg in the depositional sediments of the upper estuary and Fort Point Cove, which would aggravate the Hg contamination problem (Chapters 5 & 6). To minimize this risk we strongly recommend that scientists familiar with Hg cycling in the Penobscot estuary be teamed with engineers to test and design any active remediation procedures ordered by the Court. To assist with this, we recommend that the first element of a future Remediation Program should be a meeting of scientists familiar with Hg cycling in the Penobscot estuary and engineers experienced in sediment remediation in order to merge the scientific bases of each approach with the engineering expertise needed to evaluate the feasibility of each approach.

Thus we further recommend that the first step of this Remediation Program be an assessment of the feasibility of the science-based remediation procedures outlined below - followed by their design and testing before full-scale implementation, and that both scientists and engineers be involved in the design, testing, and implementation stages.

The Study Panel considered the possibility of traditional dredging/disposal of Hg-contaminated consolidated sediments in the upper estuary to a sediment depth of background Hg concentration. This remediation option was rejected because of the risk of aggravating the ongoing Hg contamination problem by disturbance and exposure of highly contaminated sediments (Committee on sediment dredging, 2007), which are still lying on average only about 30-40 cm below the sediment surface at sites of long term deposition throughout the upper estuary and Fort Point Cove (Chapter 6). A second consideration was the prohibitively high estimated cost of an extensive dredging operation (very roughly estimated to be about $600 million[1]).

While we do not recommend large scale dredging, there are four other remediation options, which have lower risk, and are much less costly than large scale dredging. Before a final decision can be made on which of these options would be most beneficial, some further scientific and engineering information is needed for design purposes, and to demonstrate that the chosen option(s) are likely to be successful at minimal risk. A very rough estimate of the costs of each of these remediation options is given in Table 21-2.

Table 21-2: Very rough estimate of costs of the four of active remediation options. Note that there are various permutations and combinations of how the 3 recommended remediation procedures could be applied in the upper estuary. Four examples are listed below.

Remediation option	Cost	Treated Area
Dredging to 40 cm transportation and disposal	$600 million	4.4 km^2 soft depositional sediments in main stem of upper estuary, not including Mendall Marsh, transport and disposal
1. Mobile sediment removal/dispersal	$40 Million	Total of 320,000 tonnes mobile sediments removed and then dispersed one time from upper estuary at $125/tonne, *in-situ* disposal
2. Mendall Marsh, inflowing particle removal/dispersal	$25 Million	Annual removal/dispersal over a 20 year period of 10,000 tonnes/yr., at $125/tonne, *in-situ* disposal**
3. Treatment with SediMite or similar material	$170 Million	Mendall Marsh, assuming treatment repeated 3x*
4. Combination of 2&3	$82 Million	Mendall Marsh***

* Early testing suggests that SediMite™ efficacy decreases with time. Cost is based on assumed retreatment three times over a 20 year period.
** This treatment would improve the situation in Mendall Marsh for a 10 year period while the river was naturally attenuating. Thereafter Mendall Marsh would continue to improve at the same rate as the main stem of the river, but the 100 ng/g dry wt. target for total Hg in Mendall Marsh soils would not be achieved for several decades.
***Assumes a single SediMite™ treatment, and incoming particle removal and replacement at $125/tonne for 20 years.

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[1] The rough cost estimate was made assuming a dredging cost of $350 per ton, which includes the cost of dredging, dewatering and transportation to a disposal site. It was assumed that 4.4 km^2 of contaminated sediments in the upper estuary (not including Mendall Marsh) would be removed to depth of 40 cm below the sediment-water interface.

2.2 Recommendation 1

The Study Panel recommends that some further scientific and engineering work be undertaken, as outlined below, to design and test a procedure for the remediation of the upper estuary of the Penobscot River. Remediation would be done by removal of Hg contaminated mobile sediments from the upper estuary of the river followed by dispersal of clean mobile sediments into the upper estuary. This procedure would hasten recovery in both the upper estuary, and Fort Point Cove.

This possible remediation procedure offers the widest ranging benefit of the four remediation procedures recommended, at a relatively low estimated cost. It would treat the entire upper estuary, including Mendall Marsh, the main stem of the river and the lower Orland River. This treatment would also benefit Fort Point Cove because it is immediately downstream of the upper estuary. The drawback of this approach is that has the most remaining uncertainty, which would need to be resolved before the procedure should be applied on a full-scale basis.

2.2.1 Rationale

There is a large pool of mobile sediments (approx. 300,000 tonnes, Chapter 7) in the upper estuary that still have high Hg concentrations (averaging 730 ng/g dry wt., Chapter 8), decades after the major releases of Hg from HoltraChem plant. These continuing high Hg concentrations are the result of natural hydrodynamic conditions in the upper Penobscot estuary, which limit the escape of the contaminated mobile sediments to Fort Point Cove (see Chapters 1 & 7 for more detailed explanations). The fine particles (muds) in this mobile pool, which have total Hg concentrations of 920 ng/g dry wt. (Chapter 8), are the source of particles to the surface sediments at sites of long term deposition (average 885 ng/g dry wt., Chapter 1). This means that the concentration of total Hg in the surface sediments is controlled by the slowly recovering concentration of total Hg in the muds of the mobile pool. The surface sediments and mobile pool are where the methyl Hg is produced, and its production rate is dependent on inorganic Hg concentration, which is recovering very slowly (Chapter 1). Thus, the recovery of the methyl Hg contamination of the upper Penobscot estuary is presently very slow (recovery half-time averaging approximately 32 years). For example, it will take about 33 years (2046) for total Hg concentrations in surface sediments at long term depositional sites in the upper estuary, which in 2010 were about 890 ng/g dry wt., to reach our target concentration of 450 ng/g dry wt. (Table 21-1).

Our remediation plan is to increase the natural attenuation rate by about a factor of 8 in the upper estuary by removing one-half the contaminated mobile sediments and dispersing an equal quantity of low-Hg sediments into the surface waters of the upper estuary where they would join the mobile pool, thereby reducing its concentration by one-half to the target concentration of 450 ng/g dry wt. The removal of contaminated sediments and dispersal of clean sediments in the upper estuary would be carried out over as short a time as practically feasible, hopefully one year.

We estimate that within the next 5 years total Hg concentration in surface sediments, where methyl Hg production also occurs, would also reach target levels of 450 ng total

Hg/g dry wt. (based on measured sedimentation rates and the depth of the surface active layer of sediments, Chapters 5 & 6). This would result in an overall decrease in recovery time from about 33 years (Table 21-1) to about 5 years.

If there was no local remediation in Mendall Marsh itself, the treatment of the upper estuary as described above would reduce the recovery time of Mendall Marsh from about 60 years (Table 21-1) to about 40 years (Chapter 23). It should be noted that the Orland River will not have reached target levels within 5 years. The Orland has a much slower estimated recovery half-time than the main stem of the river (77 years, Chapters 1 & 6), but the situation will be much improved in both Mendall Marsh and in the Orland River compared to what it is now, and the situation will continue to improve thereafter.

A detailed discussion of the scientific basis of this plan is described in Chapter 23. Briefly, our Phase 1 & II studies (Chapter 1, Appendix 1-2 and 1-3) have shown that lowering inorganic Hg concentrations in surface sediments to 450 ng/g dry wt. would lower methyl Hg concentrations in the biota of the upper estuary to their target levels (Chapter 2). (Target levels for sediments were derived from the reduction needed in Hg concentrations of biota to reduce harm to themselves, natural predators or humans consuming them to acceptable levels, and then applying these percentage reductions to present-day total Hg concentrations in surface sediments. See Chapter 2 for details.) The removal of contaminated sediments followed by dispersal of clean mobile sediments should need to be done only once because relatively clean inflowing particles from upstream will continue to lower total Hg concentration in the upper estuary (Chapter 1). This treatment would also provide particles at lower total Hg concentration to Mendall Marsh and would lower methyl Hg concentrations in Mendall Marsh by about a factor of two, which would be a significant improvement to the marsh. However, additional treatment(s) would be necessary to Mendall Marsh to reduce methyl Hg concentrations in biota to acceptable levels within the next decade (Table 21-1).

The Study Panel convened a remediation workshop in July 2009. One of the invitees was Dr. Todd Bridges of the U.S. Army Corps of Engineers. Dr. Bridges offered the following conceptual design, based on a variation of Confined Aquatic Disposal (CAD) approach remediation method (Polermo et al. 1998). CADs are large *in-situ* disposal pits dug in soft sediments at contaminated locations. After being filled with contaminated sediment, a CAD is capped with an erosion resistant material to prevent possible future redistribution of the buried contaminated sediment by storm events. A recent example is at: http://www.oar.noaa.gov/spotlite/archive/spot_dredge.html

There are also many other examples of CAD installations of various sizes at other contaminated sites:

- 1981 - Rotterdam, Netherlands, 1.1 million cubic yards (MCY)
- 1981 - Norwalk Harbor VA, ~ 2,500 cubic meters (m^3)
- 1984 - Seattle, WA Duwamish, 1100 cubic yards
- 1987 - One Tree Island Marina, WA

- 1989 - New Bedford Harbor Pilot, MA
- 1992 - Hong Kong, 13 MCY
- 1992 - Ross Island, Portland OR, 160 thousand cubic yards (KCY)
- 1997 - Newark Bay, 2 MCY
- 1997-2000 - Boston Harbor, MA, 1,200,000 m^3
- 1998 - Hyannis Harbor, MA, 57,000 m^3
- 2000 - Puget Sound Naval Shipyard, WA, 377 KCY
- 2001 - Los Angeles, Energy Island, CA, 100 KCY
- 2003 - Providence Harbor, RI, 900,000 m^3
- 2006 - New London Harbor, 117,000 m^3
- 2006 - Oslofjord, Norway, 880 KCY
- 2006 - Norwalk Harbor, 27,000 m^3
- 2008 - Port Hueneme, CA, 327 KCY
- 2008 - Melbourne, Australia, 23 MCY
- 2010 - Manila, Philippines

We propose that a variation of the CAD approach (Polermo et al. 1998) be further investigated for Hg remediation of the upper estuary of the Penobscot. The variation involves the trapping of mobile sediments in large sediments traps excavated at known sites of natural short-term mobile sediment deposition (Figure 21-1). Natural lateral movement of the mobile sediments in the upper estuary, as described in Chapter 7, would result in their being trapped at these sites. When full, the Hg contaminated contents of the traps would be pumped or barged to CADs in Penobscot Bay for long term burial and capping - to prevent remobilization (Figure 21-2). Hg concentrations of sediment laid down decades ago in Penobscot Bay are very low (20-50 ng/g dry wt., Chapter 1). So, the material removed during the digging of the CADs could be moved north into the upper estuary (above the sediment trapping zones Figure 21-1) to replace the previously trapped contaminated material. The clean sediments would be dispersed into the surface water so that they would join the mobile pool of sediments. This would serve two purposes: 1) replacement of the particles removed is needed to prevent changes in particle hydrodynamics in upper estuary, which might otherwise cause surface sediment erosion, and 2) the addition of clean sediments to the mobile pool would lower its total Hg concentration to the target concentration of 450 ng/g dry wt.

Basically, this approach would replace contaminated upper estuary mobile sediments with very clean (i.e. mostly pre-1950, Chapter 1) Penobscot Bay sediments.

Concentrations of total Hg in the surface sediments at long term deposition sites would also decrease by about a factor of two within about 5 years, as the cleaner muds from the mobile pool are deposited onto the sediment surface and mix into the surface layer of sediments where methylation occurs.

2.2.2 Advantages of this approach as compared to traditional dredging:

- Almost no highly contaminated sediments in the upper estuary, which are approximately 30 cm below the surface, will be disturbed.
- Mobile sediments removed would be replaced with equal quantities of clean sediments, which would avoid disruption of the normal hydrodynamics and sediment deposition in the upper estuary.
- The clean sediments used will come from the same estuary, so no foreign sediments will be introduced to the system
- Our understanding is that this would be a one-time treatment, which would not have to be repeated at a later date
- The cost would be a small fraction of the cost of traditional dredging because smaller amounts of sediment would be removed, the sediments would not have to be de-watered, they would not have to be transported long distances, and costs for disposal in a surface disposal facility would be avoided.
- Dispersal of clean sediments in the main stem of the river will improve the situation in Mendall Marsh, at no additional cost, because particles entering the marsh from the main stem of the river, and accumulating on the marsh platform, would contain half the present Hg concentration.

2.2.3 Remaining uncertainty

Before this remediation procedure should be attempted, a remaining uncertainly should be addressed. The average recovery half times of the cores in the upper estuary is 32 years. We view these core data as the definitive recovery data for the upper estuary. However, our best current information, based on our mass budget of total Hg in the upper estuary (Chapters 1 & 23) and modeling (Chapter 18), give a much shorter recovery half-time time of Hg in the mobile pool – about 6 years. This shorter half-time is calculated from Hg and particle inputs and outputs, and the masses in the mobile pool (Chapter 23), and each of these parameters has uncertainties. Several limited studies could provide information that would reduce these uncertainties, and provide additional measurements that would be useful in determining that this approach would work. Necessary studies include better estimates of the size of the mobile pool and/or it's interaction with transitional sediments[2] (which we think is most likely explanation for the

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[2] There are three types of sediments in the upper estuary: 1) Fine grain sediments that accumulate permanently at sites of long term deposition sediments; 2) mobile sediments that periodically are moved up and down the estuary; 3) transitional sediments that accumulate for time periods of years at certain location (e.g. east channel of Verona Island, Marsh River channel) before being moved to sites of long term deposition.

difference described above, Chapter 23), the rate of export of particles to Fort Point Cove (Chapter 23). These uncertainties should be resolved early in Remediation Program, because if the mobile pool is larger than we have currently estimated, remediation would be more costly.

2.2.4 Elements of design and testing

For design purposes, this remediation procedure requires some further gathering of information about the mobile sediments that are naturally transported up and down the upper estuary, including the size of the mobile pool, how and where the contaminated sediments would be trapped, recovered and buried in the lower estuary, and how the clean "replacement" sediments would be dispersed in the upper estuary. Specific elements of the design and testing are as follows:

2.2.4.1 Science based elements

- Improved estimate of the size (tonnage) of the mobile pool in the upper estuary of the Penobscot, and the efficiency of mobile sediment trapping in the upper estuary, as well as the possible importance of wash load[3] and transitional sediments. *(Required expertise: experts on hydrodynamics sedimentology, and geochemical processes in estuaries)*
- Assessment of the risk, in the lower estuary, of removing the surface, contaminated sediments in order to access the clean material below about 30 cm. The Hg in these sediments is lower than in the upper estuary, and they are located south of the trapping salt front, so we anticipate that this would be an acceptable risk to the lower estuary. However, this risk would need to be further assessed *(expertise required: Hg cycling and bioaccumulation in estuaries)*
- Improved estimate of the ongoing input of Hg to the upper estuary by the redistribution (erosion) of Hg contaminated materials from mudflats *(required expertise: physical processes controlling erosion of mudflats in estuaries i.e. sedimentology, geochemistry).*

2.2.4.2 Engineering elements

- Engineering design and location of *in-situ* sediment traps and CADs, drawing on the experience of previous applications listed above.
- Assessment of the quantity and availability of clean sediments in Penobscot Bay – our present data indicates that there are large quantities of material available in Penobscot Bay.

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[3] Wash load is sediment carried by river flow such that it always remains close the surface of a river. It is transported without deposition, essentially passing straight through the upper estuary to Penobscot Bay. It consists of the finest particles, which remain suspended because the turbulent mixing velocity of the river water is far greater than the settling velocity.

- Practicality of locating CADs at sites that can also be used as a source for clean sediments to use for replacing of contaminated sediments.

- Determination of regulatory and permitting requirements. Our information is that these procedures would be covered by the Clean Water Act and related state water quality regulations.

- Firm estimate of costs for the one-time removal of Hg contaminated mobile sediments from the upper estuary and dispersal of clean sediments

2.2.5 Schedule

As an initial step, the information as described above would be gathered on the mobile sediment pool, and clean sediment availability. To do this field work, crews would need to be on site with equipment installed and calibrated prior to the beginning of the spring freshet. Work would continue periodically throughout the first field season. Concurrently, an engineering firm would be exploring both the regulatory and technical feasibility of *in-situ* disposal and the ease of accessing the low Hg sediments under the zone of surface sediment contamination, as well as the design and testing of sediment traps. As described, the material would be moved without dewatering. How efficiently this could be done would need to be established.

Assuming the tests described in the previous paragraph are successful, full scale implementation could occur in the second year of the Remediation Program. At this time, because the preliminary work described above has not been done, we don’t yet know whether half of the mobile sediments could be removed and replaced in one year, or whether this operation would take two or three years. This is because we do not yet know how efficient the sediment traps will be.

2.2.6 Very rough estimate of cost

We presently estimate that the size of the mobile pool in the upper estuary is about 320, 000 tonnes. Based on discussions with Dr. Todd Bridges of the U.S. Army Corps of Engineers, the cost of removal of sediments would be about $125 per ton, assuming that the sediments were neither dewatered nor transported long distances because of *in-situ* disposal in CADs located in Penobscot Bay. Half of the mobile sediment pool would need to be removed in order to decrease the average Hg concentration to about 450 ng/g dry wt., which is our target concentration. A very rough estimate of the cost of this removal of one-half of the mobile pool is $20M. An equal amount of clean sediment would need to be removed from Penobscot Bay and dispersed in the upper estuary, at a similar cost, so the overall rough estimate is on the order of $40M. This does not include the cost of the first year of exploratory work, which would likely cost about $2M. The total cost ($42M) could be an underestimate if the size if the mobile or its possible interaction with transitional sediments has been underestimated.

The upper estuary requires an average target of 450 ng/g total Hg g dry wt. Treating the upper estuary, as described in Recommendation 1, would also decrease Hg concentrations on suspended particulate material entering Mendall Marsh to 450 ng/g dry wt. However, the target for sediments in Mendall Marsh is much lower (100 ng/g dry wt.) because of the higher efficiency of methyl Hg production and bioaccumulation there. Therefore whether Recommendation 1 goes forward or not, we recommend that at least one of the additional recommendations (2, 3, or 4 below) also be applied to Mendall Marsh.

2.3 Recommendation 2

The Study Panel recommends the design, testing and installation of a sediment trap at the mouth of the Marsh River to hasten the recovery of Mendall Marsh. This active remediation procedure would remove the incoming Hg contaminated mobile sediments as they flow into Mendall Marsh. They would then be replaced by clean sediments obtained from Penobscot Bay.

2.3.1 Rationale

Mendall Marsh presently has the highest levels of methyl Hg in the system, with several bird species having concentrations that are about 5 fold above toxic levels (Chapters 2, 14, 16 Appendix 2, 3 of Chapter 1). Our study shows that methyl Hg concentrations are high because of a combination of retention of Hg contaminated particles, after they enter the marsh from the river (Chapter 10), and because the marsh ecosystem has characteristics that promote efficient production and bioaccumulation of methyl Hg (Chapter11). (A more complete explanation for these exceptionally high methyl Hg concentrations in Mendall Marsh and its biota is provided in Chapter 1.) If no active remediation of Mendall Marsh is done, and if the main stem of the river is not treated, the target concentration of 100 ng/g dry wt. in surface soils of the marsh would require approximately 60 years of natural attenuation, if trends observed over the past decades continue (Table 21-1).

The conceptual design of Recommendation 2 would be to trap contaminated sediments coming into Mendall Marsh at the mouth of the Marsh River (near Frankfort Flats). Under normal circumstances, the marsh constantly receives contaminated mobile sediments from the main stem of the river. These sediments are transported into the marsh during each tidal cycle, and then deposited on the marsh platform during spring tides (Chapter 10). Construction of a sediment trap, by deepening the channel at the mouth of the Marsh River, would slow current velocity, resulting in the deposition of fine particulates in the trap, instead of their being transported into the marsh[4]. Reducing the amount of contaminated material entering the marsh would lower the major source of

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[4] Further study of the transport and deposition of Hg contaminated sediments within Mendall Marsh is recommended. There are three types of sediments in the system. First, the long term depositional sediments that accumulate and bury Hg on the long term in marshes and mudflats. Second, the mobile sediments, which are deposited temporarily throughout the upper estuary and then redistributed elsewhere. Third, a transitional pool of Hg contaminated sediments in Mendall Marsh, which accumulate in the Marsh River on the medium term and then are thought to be transported and deposited onto the marsh platform at times of high flow in the marsh. This transitional pool of sediments likely contains significant quantities of Hg and if is transported onto the marsh platform it could feed methyl Hg production on the marsh platform for some time. This pool of Hg within Mendall Marsh needs to better understood and removed before sediments trapping in the marsh begins, if it is an ongoing threat to the marsh.

Hg to the marsh. Replacing these high Hg mobile sediments with clean sediments would dilute the present high levels of inorganic Hg in the surface soils of the marsh platform. This would slow production of methyl Hg in the marsh, and thus lower methyl Hg concentrations in the food web and birds. The application of clean sediments to dilute inorganic Hg in surface sediments has been tested before in large mesocosm studies and was found to be very effective (Rudd et al. 1983).

The trapping of incoming contaminated sediments, and dispersal of clean sediments, would increase the recovery rate of the marsh, which is presently progressing at a half-time of about 22 years (Chapter 6). The target total Hg concentration of 100 ng/g dry wt. of surface soils on the marsh platform would be reached in about 5 years instead of an estimated 60 years without intervention (Table 21-1).

The trapping of sediments would be a continuous process, with removal of trapped sediments occurring at least annually. An equal volume of clean sediments from Penobscot Bay would be added, likely during spring tides, to facilitate particle distribution onto the marsh platform.

Transitional sediments accumulate as mudflats in the channels of the Marsh River inside the marsh itself. This material could be deposited on the marsh platform at a later time, lengthening the recovery time. This material should be removed prior to the beginning of active remediation of the marsh.

2.3.2 Elements of design and testing

The main elements of design for this procedure would be the design, testing, and permitting of an appropriate sediment trap, and design and testing of the procedure for the addition of clean sediments to the marsh in a manner that would enable them to be distributed onto the marsh platform, either by inflowing tidal currents during spring tides or by mechanical means. Specific elements of the design and testing are as follows:

2.3.2.1 Engineering elements

- Design and testing of the particulate trap, which would include efficiency of particulate removal from inflowing water, and the size of the trap necessary, as well as the frequency of removal of the trapped particulate materials.

- Design and testing of a procedure for addition of the clean sediment to the system, which should enable natural transport and deposition of the clean sediments onto the marsh platform, mimicking the current accumulation rate of 0.6 cm/yr (Chapters 5 & 6).

- Trap construction and disposal of contaminated sediments in CADs (likely in Penobscot Bay). This will need to be done in a manner that does not release high Hg concentration sediments into the system.

- Assessment of the tonnage and cost of one-time removal of transitional sediments in the Marsh river channel within Mendall Marsh - followed by disposal of the contaminated sediments in CADs, and replacement of the contaminated sediments inside the marsh by clean sediments from Penobscot Bay.

2.3.2.2 Science based element

- Design a schedule for additions of clean material - to best mimic natural accumulation of new material on the marsh platform. (*Required expertise: sediment geochemist, salt marsh ecologist.*

2.3.3 Schedule

Design of the sediment trap and design of the procedure for addition of clean sediments inside the marsh would begin prior to the first field season of year one of the Remediation Program. Testing of the trap performance and of the sediment addition method would begin in the spring of year one and would continue until freeze up. Any additional information needed would be collected concurrently. Assuming that the testing was successful during year one, full scale implementation could begin during year two of the Remediation Program.

2.3.4 Very rough estimate of cost

Approximately 5,000 tonnes of particles accumulate in Mendall Marsh **each year**. Trapping of this sediment as well as replacement with an equal tonnage of clean sediments would cost about $1.2M per year (estimated at a rate of $125 per tonne for trapping and removal followed by replacement. One scenario would be continuing removal for 20 years for a total roughly estimated cost of $25 million (Table 21-2). This does not include the cost of designing and constructing the trap, testing the dispersal method for clean sediments, one-time removal of contaminated transitional sediments, and monitoring the outcome of the treatment.

2.4 Recommendation 3:

The Study Panel recommends further testing of SediMite™ application to Mendall Marsh as a possible active remediation procedure to hasten the recovery of the marsh.

2.4.1 Rationale

Most of the methyl Hg production and bioaccumulation in the Mendall Marsh lower food web occurs in the top 3-5 cm of the marsh soils (Chapter 11). Through treatment of small test plots in Mendall Marsh (Chapter 19), we have shown that while addition of binding agents did not shut down production of methyl Hg, it did inhibit the movement of the methyl Hg into the soil porewaters. This lowered methyl Hg concentrations in porewater by 50% to 90%. Because methyl Hg is bioaccumulated from the dissolved phase this treatment would very likely lower methyl Hg concentrations in the food web and birds, but this would need to be verified by some further testing as outlined below.

Of the amendments tested, SediMite™ and Biochar showed the most promise (Chapter 19). Both amendments reduced methyl Hg concentrations in soil pore water over a 1 year time period. However concentrations on methyl Hg on the soil particles increased in both of the Biochar experimental plots (Chapter 19). It is possible that this methyl Hg could continue accumulating with time on the soil particles and be released at some later date, so we are not recommending further investigation of the Biochar amendment. The inhibition of methyl Hg in porewater continued into a second year, but to a lesser extent. The experiment continued for a third year, but we do not have the results yet, so we don't know how long these treatments would continue to be effective. We also do not know the fate of the methyl Hg associated with the binding agents on the long term.

2.4.2 Elements of design and testing

The initial positive results to date of SediMite™, in very small (1 m x 1 m) test plots, support further testing of their effectiveness and practicality in larger test plots (approx. 0.5 acre). Several elements need to be addressed to ensure its effectiveness and safe usage:

2.4.2.1 Science based elements

- Determine the impact of SediMite™ applications on plant and the food web located on the marsh platform. *(Required expertise: Salt marsh ecologist).*
- Confirmation that the reduction of methyl Hg concentrations in marsh soil porewaters, which we observed, also results in a lowering of methyl Hg concentrations in lower food web organisms living in the marsh.
- Several 0.5 acre pots (control and test plots) should be used to determine the minimum rate of application of SediMite™ that is effective over at least a two year time period. *(Required expertise: salt marsh biogeochemistry).*

2.4.2.2 Engineering element

- An engineering firm would also need to design a procedure for large scale application of SediMite™ to the marsh platform.

2.4.3 Schedule

Planning and selection of contractors and engineering firms would need to begin several months prior to the first field season (May) of the Remediation Program. During the first spring, several test plots would be established. These test plots would be followed over a two year period to determine their safety to the marsh ecosystem and to determine how effective the SediMite™ will be over a two year period. Assuming that this final testing is successful, full scale application would take place during the third summer of the Remediation Program. Ongoing monitoring (see Recommendation 5) would determine the need and timing for further applications of the binding agent.

2.4.4 Very rough estimate of cost

An estimate of cost of $200,000 per acre for SediMite™ treatment is available at (http://www.serdp.org/Program-Areas/Environmental-Restoration/Contaminated-Sediments/ER-200835http://www.serdp.org/Program-Areas/Environmental-

Restoration/Contaminated-Sediments/ER-200835). Based on this information a single treatment of SediMite™ to the marsh platform would cost about $58M. If it is assumed that the main stem of the river receives no active remediation, and if it is further assumed that treatment would need to be repeated three times during the roughly 33 year natural attenuation period that will be required for the river to reach its target of 450 ng/g dry wt., then the total application cost would be about $170M (Table 21-2). Additional costs would include the cost of pilot studies of about 0.5 acres each to determine the optimal application rate of SediMite™, as well as tests to determine SediMite™'s efficacy for reducing methyl Hg bioaccumulation into invertebrates, and tests to ensure that there is not toxicity to plant species in the marsh (our preliminary plot experiments suggested that there may be some toxicity to certain plant species (Chapter 19). The cost estimate of this final testing is estimated to be about $5M.

2.5 Recommendation 4

The Study Panel recommends that depending on decisions made with respect to active remediation of the main stem of the Penobscot River that combinations of the previously described treatments be considered to hasten recovery of Mendall Marsh. We view Mendall Marsh as a special case because of the very high concentrations of Hg found there which pose the greatest risks to bird populations and to humans who consume ducks inhabiting the marsh.

Two examples of a combination of treatments that could be employed are:

- If the main stem of the upper estuary is not treated as outlined in Recommendation 1, a combination of a single treatment with SediMite™ (as outlined in Recommendation 3) followed by trapping of incoming contaminated sediment and dispersal of clean sediments (Recommendation 2) on an as-needed basis could be considered.
- If the main stem of the upper estuary is treated as described in Recommendation 1, sediment particles entering the marsh would have a Hg concentration of about 450 ng/g (and lower in later years). In this case a single treatment with SediMite™ might suffice (Table 21-2).

2.6 Recommendation 5

We recommend that the long term monitoring program be carried out as described in Chapter 13. This program is necessary 1) to follow the recovery of Hg concentrations in the biota of the upper estuary; 2) to evaluate the success of any remediation method that is chosen, and to make adjustments to treatments in response to rates of improvement of Hg concentration in target organisms.

2.6.1 Estimated Cost

The estimated cost of the long-term monitoring program is $450K every other year. This includes costs for sampling, sample analyses, data analyses and report writing.

2.7 Recommendation 6

The Study Panel recommends that some limited further scientific studies, as well as engineering design and feasibility studies be done as described in Recommendations 1,2, and 3 before any of the remediation procedures outlined proceed to full-scale implementation.

2.8 Recommendation 7

The Study Panel recommends that any future Remediation Program be carried out by a team of scientists and engineers who understand Hg in the Penobscot system and how the recommended active remediation procedures can be practically applied to the Penobscot ecosystem.

3 REFERENCES

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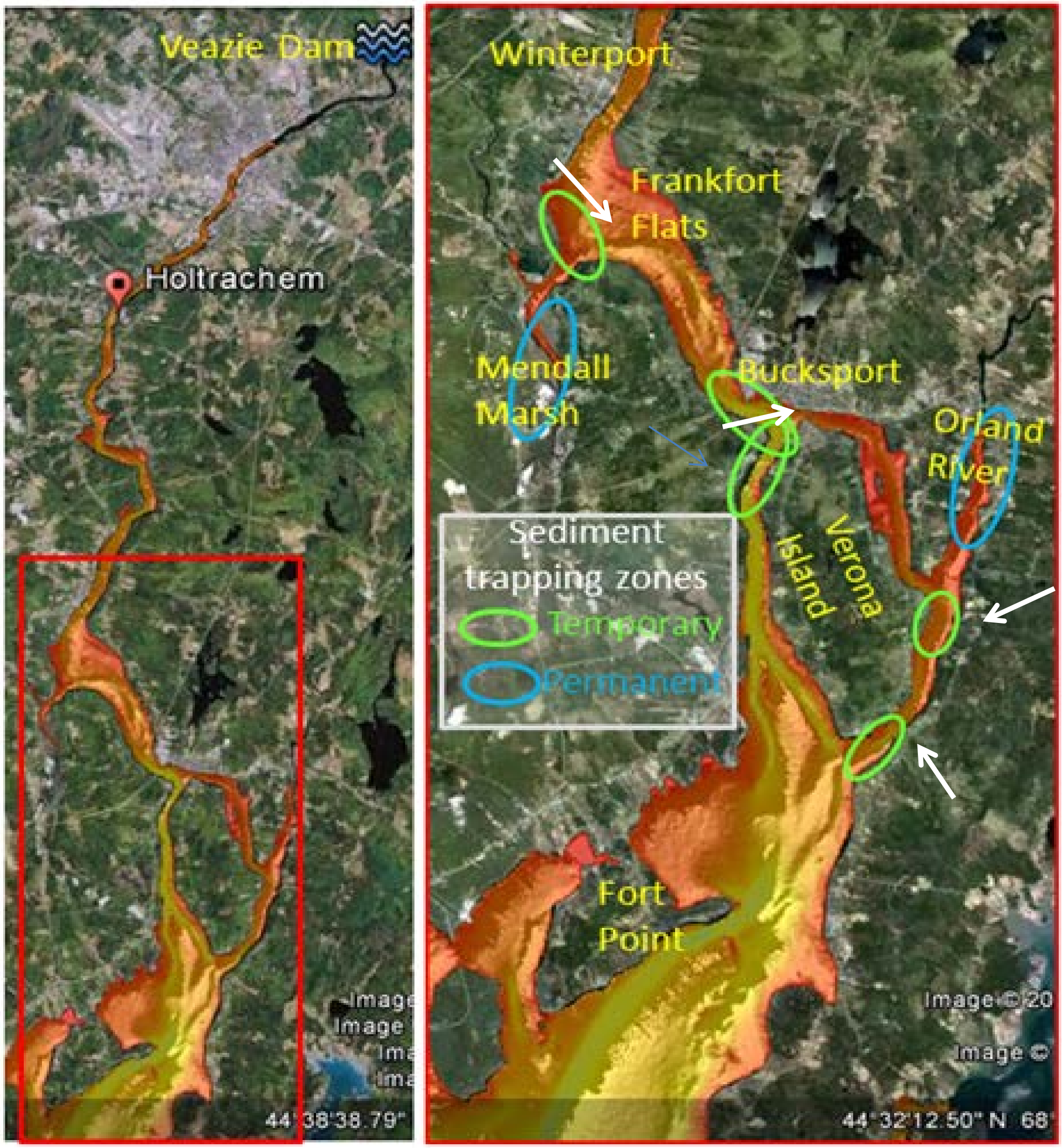

Figure 21-1. Map of temporary sites of mobile sediment deposition (light green ovals), and permanent sediment accumulations (blue ovals) sediment Chapter 7, and possible sites for trapping of mobile sediment, which would later be disposed of in CADs

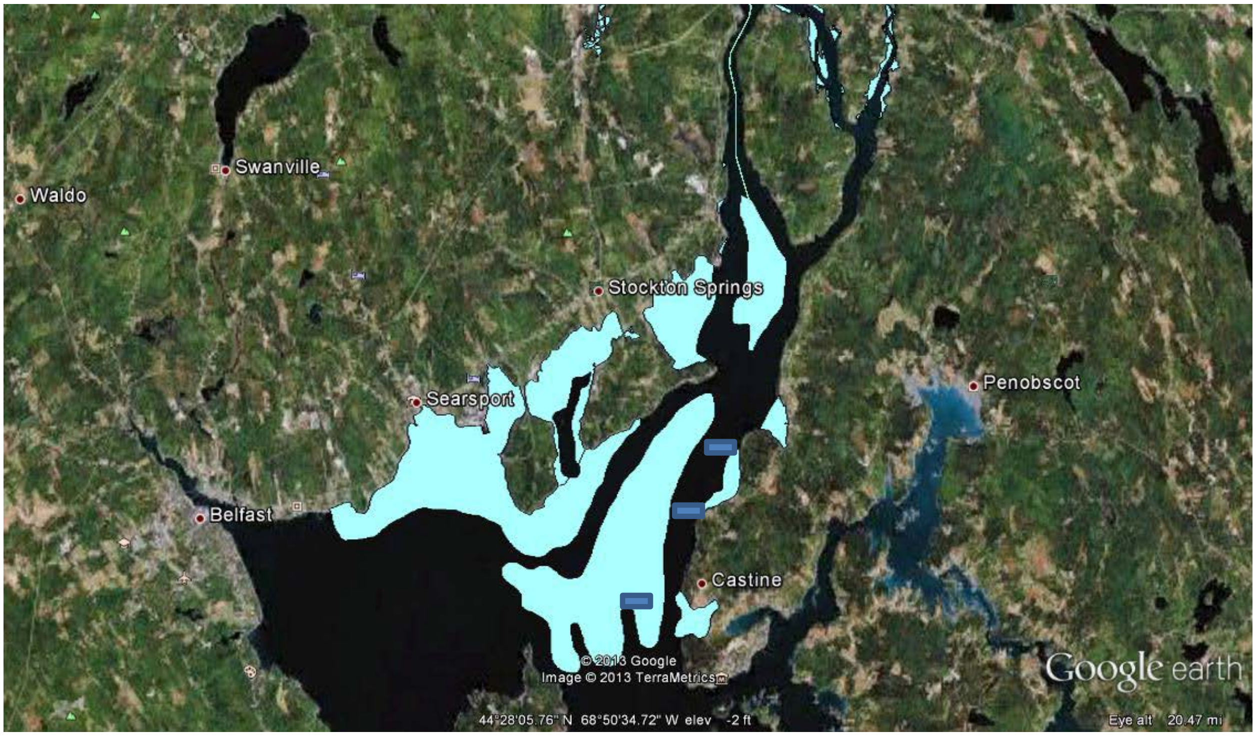

Figure 21-2. Possible location of CADs in Penobscot Bay - for excavation of clean sediments and disposal of contaminated sediments (dark blue rectangles).