

**PENOBSCOT RIVER MERCURY STUDY**

**FINAL REPORT**

**Mercury Contamination of the Penobscot River Estuary:  
Current Situation, Remediation Targets  
and Possible Remediation Procedures**

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

**April 2013**

By: The Penobscot River Mercury Study Panel

## Table of Contents

### Executive Summary

Chapter 1. A Synthesis of Mercury Studies on the Penobscot River Estuary.

By John W.M. Rudd, R.A. Bodaly, Nicholas S. Fisher, C.A. Kelly, A.D. Kopec and C.G. Whipple

*The Penobscot system is contaminated with legacy mercury (Hg) from the HoltraChem site, and this results in continued elevated levels of methyl mercury in biota. Current inputs to the system are small and are not contributing substantially to the problem of high Hg in biota. Recovery of the system has been slow and therefore active remediation is needed to speed recovery.*

Chapter 2. Setting mercury remediation targets for surface sediments in the Penobscot estuary.

By R.A. Bodaly, A.D. Kopec, J.W.M. Rudd, N.S. Fisher and C.G. Whipple

*Target concentrations for Hg are established for various species and groups of biota, and reasons given for why these targets would be acceptable. Many animals have higher concentrations than the targets.*

Chapter 3. Total Mercury Loading to the Penobscot River from the HoltraChem Plant Site, Orrington, Maine and from Other Point Sources.

By Ralph R. Turner.

*There are presently only small amounts of Hg coming from the HoltraChem site and these amounts are small compared to inputs over the Veazie Dam. HoltraChem is the largest known single point source in the area, however.*

Chapter 4. Field Data and Experiments on in situ Particle Formation in the Penobscot River.

By Ralph R. Turner

*Dissolved organic carbon coagulates in the Penobscot estuary, taking some Hg out of solution and contributing to the Hg particle loading in the estuary.*

Chapter 5. Total Mercury Sedimentary Inventories and sedimentary fluxes in the lower Penobscot River and estuary, Maine.

By Kevin M. Yeager

*Estimates of depositional areas, current fluxes and total inventories of Hg in the sediments of the lower Penobscot River and Bay are provided, based on the analysis of data from sediment cores dated by radio-isotope methods.*

Chapter 6. Estimates of recovery from mercury contamination in the Penobscot River Estuarine System by an assessment of sedimentation rates.

By P.H Santschi

*The history of Hg inputs to the sediment is defined using sediment cores dated by radioisotope methods. Hg in the surface sediments of the contaminated zone of the Penobscot system is only gradually declining over time.*

Chapter 7. Field Investigations of Hydrodynamics and Particle Transport in Penobscot River and Bay.

By W.Rockwell Geyer and David K. Ralston

*The Penobscot estuary retains contaminated particles in the form of a large, mobile pool of sediments, trapped by tidal movements and salinity gradients.*

Chapter 8. Total and Methyl Mercury Concentrations in mobile and surface sediments in the Upper Penobscot Estuary.

By C. A. Kelly

*Mercury in mobile sediments is dependent on the characteristics of the sediment, not their location in the system. Hg concentrations in mobile sediments are very similar to Hg concentrations in surface sediments.*

Chapter 9. Upstream limit of mercury contamination in surface sediments.

By R.A. Bodaly and A.D. Kopec.

*Sediments in the area north of Brewer were contaminated with mercury during the late 1960's and early 1970's, but mercury has returned to background concentrations in surface sediments, unlike other sites in the system. These sites are close to the source of lower Hg particles coming over Veazie Dam and have high sedimentation rates.*

Chapter 10. Investigation of Total and Methyl Hg Export from Mendall Marsh Via South Branch of Marsh River, a Tributary to the Penobscot River.

By R.R. Turner, C. Mitchell, A.D. Kopec and R.A. Bodaly.

*Mendall Marsh is a sink for particles contaminated with mercury that enter the Marsh River and the marsh from the Penobscot River on incoming tides – 40% of particles coming in from the Penobscot are retained by the marsh. Mendall Marsh is not a large source of methyl Hg for the Penobscot River.*

Chapter 11. Mercury Methylation Studies: Distribution and Biogeochemical Controls on Net Methylmercury Production in Penobscot River Marshes and Sediments, 2009-2012.

By C.C. Gilmour, T. Bell, A. Bullock, A. Graham, A. Maizel, G. Riedel, G. Riedel, and A.D. Kopec.

*Mendall Marsh and other mesohaline marshes in the contaminated zone of the Penobscot system are areas of high production of methyl Hg, compared to other sites in N. America. Hotspots are patchy and localized within those marshes.*

Chapter 12. Factors controlling methyl mercury production in intertidal, wetland and bay sediments in the Penobscot estuary.

By R.A. Bodaly, C.A. Kelly, and A.D. Kopec.

*Methyl mercury is related to total mercury concentrations within habitats. Seasonal effects on mercury methylation are slight but a spring pulse of methylation is significant.*

Chapter 13. Plan for Long Term Monitoring of Mercury in sediments and biota in Penobscot River and Bay.

By R.A. Bodaly and A.D. Kopec.

*A plan for the long term monitoring of biota, sediments and water in the Penobscot system is presented. Discussion includes criteria, species, habitats and sites selected and power analysis of various assumed plans*

Chapter 14. Temporal and Geographic Trends in Mercury in Biota in the Penobscot Estuary.

By A.D. Kopec and R.A. Bodaly

*Mercury in most species of biota has not changed significantly in the Penobscot system over the period 2006-2010. Geographic trends in relation to the location of the HoltraChem site are confirmed.*

Chapter 15. Temporal trends of total and methyl mercury in surface sediments, 2006-2010.

By R.A. Bodaly and A.D. Kopec.

*Total mercury concentrations in surface sediments in the contaminated zone of the Penobscot have not declined measurably at most sites since 2006.*

Chapter 16. Analysis of Aquatic and Wetland Food Webs in the Penobscot Estuary.

By A.D. Kopec and R.A. Bodaly.

*Biota in the upper estuary are feeding mainly on benthic-based food chains. Mercury in birds, fish and lobster is not related to food chain length, but rather to mercury in prey.*

Chapter 17. Background concentrations of mercury in central Maine estuaries.

By R.A. Bodaly.

*Data from three estuaries on the central Maine coast are used to establish regional background concentrations.*

Chapter 18. Simulations of the Rate of Decline of Mercury Concentrations in the Penobscot Estuary.

By R. Harris, C. Beals and D. Hutchinson.

*Mercury in the Penobscot system is modeled using a one-compartment model. The results point out uncertainties in estimates of the size of the mobile pool of sediments.*

Chapter 19. In-situ amendment plot studies.

By C. Gilmour, G. Riedel, T. Bell, A. Bullock, A. Graham, A. Maizel and U. Ghosh.

*The effect of various chemical amendments on methyl mercury levels was investigated in Mendall Marsh. Sedimite® was shown to significantly reduce methyl mercury in porewater.*

Chapter 20. Investigation of Two Materials for Potential Application in Reducing Filter-passing Mercury in the Penobscot River.

By R.R. Turner and A.D. Kopec.

*The adsorption of mercury to two types of clays did not vary significantly by clay type. Adsorption was not large for either clay.*

Chapter 21. Recommendations to the Court.

By John W. M. Rudd, Nicholas S. Fisher and Chris G. Whipple.

*Recommendations are made to the Court to explore the feasibility of various active remediation plans. Long term monitoring of the Penobscot system is also recommended.*

Chapter 22. Risk Overview.

By C.G. Whipple

*Mercury concentrations in the Penobscot are currently high, but were formerly much higher. Recovery is slow and harm is still present. Concerns for human consumption and toxicity to biota are discussed.*

Chapter 23. The Scientific Basis for Active Remediation of the Upper Penobscot Estuary.

By John W.M. Rudd, R.A. Bodaly, Nicholas S. Fisher, C.A. Kelly, A.D. Kopec and Chris G. Whipple.

*Specific scientific findings of the PRMS study that support each remediation recommendation are presented.*

## 1 EXECUTIVE SUMMARY

Between 1967 and early 1970's, 6-12 tonnes of mercury (Hg) were discharged from the HoltraChem plant at Orrington, Maine (ME), to the Penobscot River, with smaller amounts being released since that time. At least 9 tonnes are found today in the sediments of the upper and lower Penobscot estuary. Much of this Hg is now buried beneath the surface layer of the sediments, but enough is still present in surface sediments to make the concentrations 10-20 times as high as regional background concentrations. These high concentrations are now widely dispersed throughout the upper estuary, which includes the main stem of the river below Veazie Dam, Mendall Marsh, and the lower Orland River. Hg has also been dispersed into Fort Point Cove, and further south in Penobscot Bay as far as Vinalhaven Island at lower surface concentrations, but still elevated above regional background levels. The geographic pattern of distribution of mercury, both in deep sediments (dated ca. 1967) and in surface sediments, and in biota, is consistent with the HoltraChem site being the major source to the estuary.

Present-day elevated Hg concentrations in biota are due primarily to legacy Hg that still elevates surface sediment Hg concentrations. For some bird and fish species, Hg concentrations are at remarkably high levels, exceeding known toxicity thresholds for these animals. Present-day elevated biota concentrations are not due to ongoing inputs from the HoltraChem site, or from other point sources in the upper estuary.

The form of Hg released from chlor-alkali plants is inorganic Hg, but the form of Hg that is most toxic to biota and humans is methyl Hg. Inorganic Hg is transformed to methyl Hg by bacteria that reside in sediments and wetland soils. Production of methyl Hg in the Penobscot estuary, especially in some wetlands, is more efficient than at most other studied locations. Methyl Hg concentrations are positively related to the total Hg concentrations (the total concentration of all forms of Hg present) in the surface sediments and wetlands. Some habitats in the Penobscot estuary, such as Mendall Marsh, have much higher concentrations of methyl Hg than others, relative to total Hg, but within each habitat, it is clear that sites with higher total Hg concentrations have higher methyl Hg concentrations. In addition, studies of biota showed that there is a link between sediment Hg and biota Hg. Thus, remediation approaches that lower total Hg concentrations in sediments will also lower methyl Hg concentrations in biota.

Methyl Hg biomagnifies in food chains, and certain biota have methyl Hg levels that are either toxic to themselves or to their consumers. In particular, some bird species living in Mendall Marsh and other contaminated marshes in the Penobscot estuary (sites of high Hg methylation rates) are at risk due to the very high levels of Hg in their tissues. In some cases, aquatic prey species were found to be at methyl Hg concentrations that cause toxicity to predatory fish or birds. There is also concern for humans that consume ducks and eels from the upper Penobscot estuary, and lobster in Fort Point Cove.

Hg concentrations in surface sediments and wetlands have been declining since the peak discharge years just following 1967. However, the rate of decline has been slow, as evidenced by the decline of Hg concentrations in dated sediment cores, and the fact that these surface sediment concentrations are still 10-20 times background, 46 years

since discharges began, and still high enough to be hazardous to biota and to human consumers. At current rates of decline, it is estimated that it will take about 33 years for Hg concentrations to be low enough in the main stem of the river to not cause problem levels in biota. In Mendall Marsh it will take longer (about 60 years), because of the high efficiency of methylation in that marsh.

The slow rate of recovery is due to the presence of a large pool of Hg contaminated mobile sediments (estimated at 320,000 tonnes) that has been trapped in the upper estuary. These mobile sediments are efficiently retained in the upper estuary by hydrodynamic processes, which slow the loss of Hg contaminated particles to Fort Point Cove and Penobscot Bay.

Because of this slow rate of recovery, and the continuing risk to biota and human consumers, the Study Panel recommends the establishment of a Remediation Program. This Program involves three types of active remediation procedures that we specifically recommend, including a description of information needed to resolve some scientific and engineering uncertainties that remain before full scale remediation is undertaken. These remediation treatments could be applied separately or in combination. Two of these remediation treatments involve the removal of contaminated mobile sediments either in the entire upper estuary or from Mendall Marsh, and replacement with clean sediments. These treatments would lower the total Hg concentrations in the mobile sediment pool and in the surface sediments where methyl Hg is produced. In turn, methyl Hg concentrations would be lowered in the food chain and in prey species. This would also reduce the risk to human consumers. A third proposed remediation treatment would specifically address the serious situation in Mendall Marsh. For this treatment a Hg binding agent, SediMite™, would be added to the surface soils of the marsh where methyl Hg is produced. This material reduced methyl Hg concentrations in the sediment pore water, and so retards the movement of methyl Hg into the food chain and birds, which are most at risk in Mendall Marsh.

The Study Panel has set targets for total Hg concentrations in certain key aquatic and marsh species and for surface sediments in the upper estuary and Mendall Marsh (450 ng/g dry wt. and 100 ng/g dry wt., respectively). These targets are based on the percentage reduction of methyl Hg in biota that is needed to achieve non-toxic levels in biota. If the remaining uncertainties for the treatments we recommend are satisfied, our studies indicate that recovery times to target levels in the biota would be reduced from several decades to about 5 years.