PENOBSCOT RIVER MERCURY STUDY

Chapter 13

Plan for long term monitoring of mercury in sediments and biota in Penobscot River and Bay

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By: R.A. Bodaly[1], A.D Kopec[1]

1. Penobscot River Mercury Study

1 SUMMARY

The purpose of this chapter is to lay out a framework for the long-term monitoring of mercury (Hg) in sediments, biota and water in the Penobscot River and Bay. The objectives of monitoring are to detect temporal and spatial changes; monitoring will be required whether the system will be allowed to undergo natural attenuation or whether active remediation measures are put in place to accelerate recovery from Hg contamination.

A number of general principles should form the basis of decisions about long-term monitoring. The following are some of the most important ones:

1. Monitoring should be able to detect temporal changes in Hg concentrations
2. Monitoring should be able to detect spatial differences in Hg concentrations
3. Monitoring of biota species consumed by humans should be a priority
4. Building on data already collected should be a consideration
5. Monitoring of biota species likely to be affected by the toxic effects of Hg should be given consideration
6. Wide-ranging species of biota, both within the Penobscot system to facilitate geographic comparisons and in other regions to facilitate comparisons to reference systems, should be a priority for monitoring
7. Sediments and water are important system components to monitor for Hg, especially because they indicate overall contamination levels and because sediments and water are the source of methyl Hg accumulated by biota

The priority species for the monitoring of Hg in biota are blue mussels, American lobster, American eel, prey fishes, wetland birds, double-crested cormorants, and zooplankton. Water and sediments should also be monitored for Hg. Power analyses are presented that provide estimates of the number of replicate samples that should be collected to provide reasonable power of detection of changes, assuming inter-replicate variance is similar to that estimated from past sampling, a 20 year half-time, and a 12 year monitoring period.

2 INTRODUCTION

This report was drafted as an internal document within the Penobscot River Mercury Study (PRMS), first in 2010 and with revisions in 2011, to guide discussions on long term monitoring of the Penobscot system and to guide specific proposals to the Court concerning monitoring of sediments and biota. Discussions on monitoring of sediments, water, and biota were held within PRMS at the Principal Investigator's Workshops in April, 2010 and in May, 2011 and many internal discussions took place when proposals for monitoring in 2010 and 2012 were drafted. This report received further editing so as to be able to include it as a chapter in the Phase II report. One of the main purposes of presenting this material is to preserve a record of the power analyses performed for the monitoring of Hg in various media in the Penobscot.

The purpose of this chapter is to provide a framework, starting from general principles and from consideration of existing data, for the long-term monitoring of mercury (Hg) in sediments, biota and water in the Penobscot River and Bay. The objectives of monitoring are to detect temporal and spatial changes. If Monitored Natural Attenuation (MNA) is the chosen path for the reduction of Hg contamination in the Penobscot system, long-term monitoring will be required to determine rates of natural attenuation. If active remediation measures are put in place to accelerate recovery from Hg contamination, then monitoring will likewise be required to determine the speed of recovery and to determine whether active remediation is having the desired effect and is not worsening the problem.

There are many considerations and decisions for the formulation of a monitoring plan, including what system compartments to monitor (including species of biota), the detection of temporal change and geographical differences, the co-location of biota and sediment sampling sites to help with data interpretation, sample sizes and frequency of monitoring had to be considered. Long-term monitoring of the Penobscot system began with a large program in 2010 that was considered to be the basis of monitoring into the future. The monitoring program proposed and carried out in 2012 was a reduced version of the program proposed in this report due to concerns that the 2010 program was large and expensive and risked being unsustainable in the long term.

3 GENERAL PRINCIPLES

There are a number of general principles that should underlay plans for monitoring Hg in sediments and biota. These general ideas should help guide the process of the selection of media, species, sites, and monitoring frequency.

Some general ideas:

1. Consider existing data from the Study and build upon it. Factors to take into account include length of record, media, biota species, and sites.
2. Consider supplemental data from other sources, e.g. government agencies, early study results (Livingston's (2000) sampling of sediments and biota), and data from the NOAA Mussel Watch program.

3. Biota that has been shown to be of concern for toxic effects should receive higher priority. However, it should be noted that species that are particularly sensitive to the toxic effects of Hg contamination may not be available for monitoring if their distribution in the Penobscot has been limited by reproductive or other effects of methyl Hg.
4. Biota that has been shown to be of concern for human consumption should receive higher priority.
5. Consider at least one biota species at the base of the food chain, perhaps one that would indicate benthic food chain pathways and one that would indicate pelagic food chain pathways.
6. Consider our past experience in being able to interpret data. Species for which we have had difficulty interpreting temporal patterns (e.g. cormorants) should be given lower priority.
7. Consider the ability of different media and species to reflect year-to-year differences in methyl Hg availability (i.e. do not monitor only long-lived species that will be slow to respond (i.e. eels), and do not monitor only species that can show large year-to-year variation (i.e. mussels).

Dr. Fisher put together a thoughtful analysis of priority biota to monitor, and his general ideas were as follows:

1. Give higher priority to species of biota for which data exist in North America and around the world, especially because this allows for regional, national and international comparisons.
2. Consider site fidelity.
3. Consider the distribution of the species of biota in relation to the contaminated zone of the Penobscot estuary. Widely distributed species will be of greater value. Distribution will largely be a function of tolerance of wide ranges of salinity.
4. Consider ease of collection.
5. Consider speed of response to changes in contaminant supply.
6. Species that have a constrained and well known diet should have priority because their supply of methyl Hg will be well defined.
7. Give priority to species that are consumed by people.
8. Give priority to species that live in areas of special concern (e.g. sparrows).
9. Consider the pathway of uptake of methyl Hg from their diet and try to monitor a species that represents the pelagic food chain and one that represents the benthic food chain.
10. Consider species that are important links in the food chain.

11. On the basis of the above considerations, we should be monitoring Hg in mussels, *Fundulus*, lobster, eels, sparrows and flounder. Other species with lower priority include bats, tomcod, cormorants and guillemots.

Recent book chapters on monitoring Hg in sediment, water and aquatic biota are also important sources of ideas and guiding principles (Krabbenhoft et al. 2007; Wiener et al. 2007). In the Chapter on water and sediments (Krabbenhoft et al. 2007), the following points were made:

1. Sediments are good indicators of trends in Hg contamination on time scales of years to decades.
2. Sediments are good indicators of overall contaminant levels of Hg.
3. Surficial sediments are usually the most important site of methyl Hg production.
4. Surficial sediments drive water concentrations.
5. Deciding on the depth of surface sediments to sample is key.
6. Percent methyl Hg is an important indicator for comparing different sites.
7. Sediments integrate variability over space and time.
8. Sampling and analysis costs are modest.
9. Take ancillary measurements to help with data interpretation.

In the same book, the chapter by Wiener et al. (2007) on aquatic biota indicators made the following points:

1. Piscivorous fish are preferred groups of fish to monitor over time. The large number of national and international data records on piscivorous fish make them desirable for comparisons. Piscivorous fish are most useful for the detection of multi-year trends. Fishing intensity can affect Hg in fish populations subject to exploitation.
2. Yearling prey fish are also a preferred group to monitor over time. Yearling fish should indicate year-to-year trends in methyl Hg availability. Hg in young fish can vary seasonally, a factor that must be accounted for.
3. Measurements of total Hg in predatory and prey fish provide valid estimates of methyl Hg concentrations, given that nearly all the Hg is methyl Hg. Analyses for total Hg is much less expensive that for methyl Hg.
4. Many species of fish and shellfish are consumed by people.
5. Monitoring of zooplankton and benthic inverts can be confounded by changes in species composition and our limited understanding of factors affecting uptake of methyl Hg. Zooplankton are important for the transfer of methyl Hg to fish, but their Hg concentrations will usually vary seasonally.

4 PLAN FOR MONITORING AQUATIC BIOTA

4.1 Mussels

Mussels are obviously an essential species. There are many reasons that make monitoring Hg in mussels a priority: mussels are eaten by people, are high in Hg in the Penobscot compared to other areas, and have a good historical record in the Penobscot system, including our data, data from the Mussel Watch program and data from Livingston (2000). Mussels are at the base of the pelagic food chain (they eat mainly phytoplankton). Hg in mussels appears to undergo changes on a multi-year basis, and the historical record from Mussel Watch and our data appear to show long-term trends, either upward or downward, on a five year or longer basis, that may not reflect differences in the supply of Hg to the system. Thus, it probably would be desirable to monitoring Hg in mussels every year, but every second year may be sufficient to detect these long-term trends.

It was proposed in 2010 that mussels be sampled at eight sites in Penobscot Bay, including sampling in spring and fall at selected sites to attempt to see the effect of spawning on Hg in the soft tissue of mussels. These eight sites were chosen because of previous data, to provide reasonable geographic coverage, and because sites were co-located with sediment and other biota sampling. In 2012, the number of sites sampled for mussels was reduced from eight to seven to reduce costs.

4.2 Lobster

Lobster is also an important species for monitoring of Hg. Lobsters are eaten by people and have a large economic and symbolic importance to the State of Maine. There is a large amount of reference data for other sites, and we have a good record. Because lobsters are relatively long-lived, they probably need to be sampled only every two years.

It was proposed in 2010 that lobsters be sampled at eight sites in Penobscot Bay. These sites were chosen to build on data collected in previous years and to provide a reasonable geographic coverage. In 2012, these same eight sites were retained, based on the perceived iconic status of lobster in Maine.

4.3 Eels

Eels are important because we have historic data back to 2007, because they are consumed by people and because present levels put them at risk for toxic effects. They are at the top of the food chain, integrating the biotic environment of the river. Eels in the yellow (freshwater resident) stage show relatively good site fidelity. However, they are only found in the river itself. Because eels are quite long-lived, they probably need to be sampled only every three years, however to keep field work synchronized to reduce costs, they could be sampled every second year.

In 2010, eels were collected at a total of 9 sites: 2 sites in Old Town-Veazie (OV, control reach), 3 sites in Brewer to Orrington (BO) and 4 sites in Orrington to Bucksport (OB), over the whole range that this species occurs in the Penobscot. In 2012, the total number of sites was reduced to six, while maintaining a broad geographic range and comparisons between control and contaminated sites.

4.4 Other fish

Sampling that is designed to collect small fish in the lower river will produce samples of all of the major species of prey fish, including rainbow smelt, *Fundulus*, winter flounder, and tomcod. Thus, all these species can be analyzed for Hg for relatively little extra cost. Rainbow smelt are zooplanktivores and are therefore important to define the food chain leading to fish from zooplankton. *Fundulus* show strong site fidelity, are well studied, and there are large amounts of background data for this species. Tomcod and winter flounder will also be caught as part of fishing activities. Tomcod are especially important because we have good samples starting in 2006 and it is relatively widely dispersed, and therefore is an excellent biosentinel species for detecting geographic patterns. Both tomcod and winter flounder are thought to be relatively site specific, especially winter flounder. All fish species were collected over the complete range of occurrence in the study area. Because these small fish are relatively short lived, at least for the average size that are typically caught in the Penobscot system, they should be sampled every two years.

In 2010, tomcod were collected from 17 sites in BO, OB and estuarine sites (ES), rainbow smelt were collected in 12 sites in OB and ES, flounder were collected in 11 sites in OB and ES, and *Fundulus* were collected at 9 sites in BO, OB and ES. These sites were reduced by 11 in 2012 to reduce costs.

4.5 Zooplankton

Zooplankton are an important indicator of Hg in the pelagic food web. Although it is not practical to sample zooplankton in the river because of large amounts of debris, clean samples can be obtained easily in the bay.

5 PLAN FOR MONITORING BIRDS

5.1 Songbirds and shorebirds

Songbirds that are resident in contaminated wetlands along the Penobscot are an essential group for monitoring Hg, especially because we are proposing active remediation of Hg in these wetlands (see Chapter 21 of this report). Nelson’s sparrows, song sparrows, swamp sparrow and red-winged blackbirds should be sampled in Mendall Marsh and other wetlands. This will build on our multi-year record of Hg in songbirds. Also, many sites to be collected are near to intensive sediment sites such as W21.

Eight species of birds (not including cormorants, see below) were sampled in 2010 at four different sites (two contaminated sites and two reference sites). The number of species was reduced to three (Nelson’s sparrows, swamp sparrows and red winged blackbirds) in 2012 to reduce costs.

5.2 Cormorants

Cormorants are important because we have a good record of Hg in this species, because they integrate consumption from the fish community in Penobscot Bay and because their levels are relatively high. On the other hand, there have been problems interpreting the data collected thus far because the Hg concentrations have been confounded with sampling data, thereby making the interpretation of changes in Hg concentrations difficult. Cormorant eggs were sampled at 8 sites in 2010 and at a reduced number of sites (four) in 2012. It should be noted that cormorants are not particularly sensitive to Hg, compared to other bird species (Heinz et al. 2009).

6 PLAN FOR WATER MONITORING

Water continues to be an important element of any long-term monitoring plan. Although levels of total Hg and methyl Hg in water have been shown to not be elevated in relation to the HoltraChem site, it is important to continue to monitor Hg in water as an indication of mercury entering food webs via the water column (Krabbenhoft et al. 2007). Also, water concentrations of Hg are included in modeling estimates of recovery. Water sampling should include estimates of total Hg (dissolved, particulate, and unfiltered), methyl Hg (dissolved, particulate, and unfiltered), with ancillary measurements of dissolved organic matter (DOM), total suspended solids (TSS), and salinity. Water total Hg and methyl Hg was sampled in 2012 during one synoptic survey in the Penobscot system in late June and at three sites (one at Veazie Dam and two downstream in the contaminated zone of the river) at three other times (May, August and September).

7 PLAN FOR MONITORING SEDIMENTS

It is important to monitor Hg in sediments in the Penobscot system for a number of reasons. First, Hg in sediments will provide an overall assessment of changes in the extent and severity of Hg contamination in the Penobscot. Second, sediments are relatively easy to sample, store and transport. Third, concentrations of Hg in sediments can directly affect the health of organisms living in sediments. It was shown in the Phase I Report for the Study that sediments in the contaminated zone of Penobscot River and Bay exceeded NOAA guidelines for toxicity to benthic fauna. Fourth, sediments are an important site for methyl Hg production, the highly toxic form that biomagnifies up aquatic food chains to concentrations that can adversely affect fish, wildlife, and humans. In the Penobscot system, methyl Hg concentrations in sediment are tightly linked to total Hg concentrations in sediments. The importance of surficial sediments as a source of methyl Hg in higher-food chain organisms such as lobster, mussels, fishes and birds has been demonstrated by the existence of statistically significant correlations between mercury in sediments and mercury in many of these animals. It is vital, therefore, in assessing changes to the health of the Penobscot system, that mercury concentrations in sediments be monitored over time.

Monitoring Hg in surficial sediments should build on existing data for sediments and biota by using sites for which we have data. Surficial samples should continue to be taken at 0-3 cm depths, as before, to provide continuity with historical data. Samples should not be composited, rather replicate samples from each site should be analyzed separately to improve our ability to observe changes. Measuring both total Hg and methyl Hg to be able to continue to compare % methyl Hg among regions and over time – however, to reduce costs, it will probably not be necessary to analyze every sample for methyl mercury. Grain size distributions and total organic carbon (TOC) should continue to be measured to help compare and interpret the sedimentary Hg data.

Sampling should be done once in a given year in mid August. We have data to build on from intertidal sites in 2006 and 2007 done in mid August; we have wetland sites done in 2007, 2008 and 2009 done in mid August and we have estuarine sediment sites done in mid August 2007, 2008 and 2009. Mid-August is the time when % methyl Hg seems to be at its maximum in the Penobscot.

We need to have a range of different depths and sediment types sampled. This should include intertidal sediments, wetland sediments and subtidal (bay) sediments.

7.1 Intertidal sites

It would be prudent to locate at least one site in a reference area (to continue to serve as a reference) but most in contaminated areas (to serve as monitors of concentration changes over time in the contaminated zone). We also suggest that it would be best to choose sediment monitoring sites that are important with respect to biota. For those reasons we suggest two intertidal sites in the OV reach (to serve as a reference area), and two in BO, two in OB and three in ES (in the contaminated zone of the river/bay). There was consideration given to the possibility of a site in the EB (East Branch) reach, which has very low background concentrations, but we will have no biota sites there and travel costs would be high.

Suggested intertidal monitoring sites and their rationale are shown in the following table:

REACH	SITE	Pros/Cons
OV	OV1	Representative of mainstem of river; randomly chosen; probably not high sedimentation rate; High CV among temporal replicates; no core sites in OV; accessible by land
	OV4	Eel sampling site; not randomly chosen; moderately low CV; a site high in organic C
OB	OB1	In area of several core sites; fish sampling site; low CV
	OB5	Fish sampling site; low CV; adjacent to core site
ES	ES02	Adjacent to a core site; fish collection site; high CV (0.53); randomly chosen

REACH	SITE	Pros/Cons
	ES04	Near to several core sites; fish collection site; low CV (0.19); mussel site including Mussel Watch; randomly chosen
	ES13	Fish and lobster site; higher CV; not randomly chosen

We have examined the number of replicates needed to detect change in the concentrations of total Hg in 0-3 cm sediments using power analysis, in consultation with biostatisticians from Applied BioMathematics. Power analysis is the simulation of the statistical probability of detecting change, based on assumptions of number of replicates to be collected, the length of sampling, inter-replicate variation (usually known from previous sampling), and half-times of change. The power of a proposed sampling scheme should be reasonably high (e.g. 0.8) so that the scheme has a reasonable power to detect change. Power analyses performed for this chapter used estimates of coefficients of variation among replicates that were based on variance among temporal replicates from existing data at various selected sites. Table 13-1 shows the coefficients of variation (CV's) that were observed among these temporal replicates for total Hg at intertidal, estuarine and wetland surficial sediment sites.

Table 13-1: Ranges of coefficients of variance (CV) for intertidal, estuarine and wetland sediment sampling sites (0-3 cm, total Hg, ug/g dry wt.) from temporal replicates. Power analysis was run on BOLD sites. Outliers, as defined by Dixon (1950) and Verma and Quiroz-Ruiz (2006) were removed from data sets.

Sediment Samples	SITES N->S	Elevation	CV range for total Hg ng/g dry wt.					
			0.01-0.09	0.10-0.19	0.20-0.29	0.30-0.39	0.40-0.49	0.50-0.59
Intertidal	OV1						X	
(2006-07) n=5-6	**OV4**				X			
	OB5			X				
	OB1			X				
	ES02							X
	ES13					X		
	ES04			X				
Estuarine (2007-08) n=7-8	**E01-1**		X					
	E01-2				X			
	E01-3				X			
	E01-4			X				

Table 13-1: Ranges of coefficients of variance (CV) for intertidal, estuarine and wetland sediment sampling sites (0-3 cm, total Hg, ug/g dry wt.) from temporal replicates. Power analysis was run on BOLD sites. Outliers, as defined by Dixon (1950) and Verma and Quiroz-Ruiz (2006) were removed from data sets.

Sediment Samples	SITES N->S	Elevation	CV range for total Hg ng/g dry wt.					
			0.01-0.09	0.10-0.19	0.20-0.29	0.30-0.39	0.40-0.49	0.50-0.59
	E01-5			X				
Wetland (2008) n = 8	**W63**	**High**					X	
		Medium		X				
		Low			X			
		Intertidal		X				
	W10	High		X				
		Medium		X				
		Low				X		
		Intertidal		X				
	W17	**High**		X				
		Medium		X				
		Low				X		
		Intertidal		X				
	W21	High		X				
		Medium		X				
		Low		X				
		Intertidal		X				
	W25	High				X		
		Medium		X				
		Low		X				
		Intertidal		X				
	W26	**High**			X			
		Medium					X	
		Low	X					
		Intertidal				X		

We used a power analysis of a simulated regression trend for total Hg in 0-3 cm sediments (Monte Carlo, with 2,000 replicates), for a range of expected total Hg half-times (10, 20 and 30 years) in the sediment. These time periods were chosen based on preliminary estimates, from sediment core studies on the Penobscot (see Chapters 5 and 6 of this report) of recovery half-times in the system. The power analyses employed determined the number of replicates needed to achieve a statistical power of 0.8 or greater, for different monitoring periods, and for various sampling frequencies, given various CV's. A Type I error of 0.05 was specified in the analyses.

For intertidal sediments, Table 13-2 shows the number of replicates needed to achieve a power of 0.8 or greater to detect change assuming half-times of 10, 20 and 30 years, for sampling frequencies of 1, 2 3, and 4 years, and monitoring periods of 12 and 16 years (simulations were also done for monitoring periods of 6 and 20 years but are not shown here). For a half-time of 20 years and a monitoring time of 12 years, n=5 replicates will provide reasonable power for most intertidal sites, given a sampling frequency of 2 years. Variance can be reduced at most sites by having field samplers pay particular attention to elevation (previous sampling was mostly done to look at geographic variation, not to detect change over time). Data can be examined after sampling has been underway to determine actual inter-replicate variation, and adjustments can be made in the number of replicates to be collected. Thus, it may be possible to reduce the number of replicates in the future.

Table 13-2: Number of replicates of intertidal sediment needed to achieve a power of at least 0.8 at various sites with different coefficients of variation (CV = SD/mean).

INTERTIDAL SEDIMENT - POWER ANALYSES Of REGRESSION TRENDS In TOTAL Hg

CV	SITE	MONITORING TIME SPAN (years)	Hg HALF-LIFE (years)	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:				SITE	MONITORING TIME SPAN (years)	Hg HALF-LIFE (years)	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:			
				4 years	3 years	2 years	1 year				4 years	3 years	2 years	1 year
0.11	**OB5**	12	10	2	1	1	1	**OB5**	16	10	1	1	1	1
0.15	**OB1**	12	10	2	1	1	1	**OB1**	16	10	1	1	1	1
0.28	**OV4**	12	10	3	2	2	1	**OV4**	16	10	2	2	1	1
0.32	**ES13**	12	10	3	3	2	1	**ES13**	16	10	2	2	1	1
0.40	**BO3**	12	10	4	4	3	2	**BO3**	16	10	2	2	2	1
0.59	**BO5**	12	10	7	7	5	3	**BO5**	16	10	4	3	3	2
0.11	**OB5**	12	20	2	2	2	1	**OB5**	16	20	2	1	1	1
0.15	**OB1**	12	20	3	3	2	2	**OB1**	16	20	2	2	1	1
0.28	**OV4**	12	20	7	7	5	3	**OV4**	16	20	4	3	3	2

Table 13-2: Number of replicates of intertidal sediment needed to achieve a power of at least 0.8 at various sites with different coefficients of variation (CV = SD/mean).

INTERTIDAL SEDIMENT - POWER ANALYSES Of REGRESSION TRENDS In TOTAL Hg

CV	SITE	MONITORING TIME SPAN (years)	Hg HALF-LIFE (years)	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:				SITE	MONITORING TIME SPAN (years)	Hg HALF-LIFE (years)	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:			
				4 years	3 years	2 years	1 year				4 years	3 years	2 years	1 year
0.32	**ES13**	12	20	10	10	7	4	**ES13**	16	20	4	4	3	2
0.40	**BO3**	12	20	20	20	10	7	**BO3**	16	20	7	7	4	3
0.59	**BO5**	12	20	>20	>20	20	20	**BO5**	16	20	20	20	10	5
0.11	**OB5**	12	30	3	3	2	2	**OB5**	16	30	2	2	1	1
0.15	**OB1**	12	30	5	4	4	3	**OB1**	16	30	3	3	2	1
0.28	**OV4**	12	30	20	20	10	7	**OV4**	16	30	7	7	5	3
0.32	**ES13**	12	30	20	20	20	10	**ES13**	16	30	10	10	7	4
0.40	**BO3**	12	30	>20	>20	20	20	**BO3**	16	30	20	20	10	5
0.59	**BO5**	12	30	>20	>20	>20	>20	**BO5**	16	30	>20	>20	20	20

7.2 Wetland sites

It is planned to continue to monitor 4 of the 6 wetlands sampled in 2007, 2008 and 2009. There are four elevations per site. We suggest dropping W10 (one of the two most “fresh” sites) and W26 (one of the two “saltiest” sites). These sites have quite high CV’s at one or more elevations and/or atypical total Hg concentrations. The remaining 4 sites (W63, W17, W21 and W25) will provide one freshwater-dominated site, two transitional sites and one salt-dominated site.

Power analyses were also conducted for these sites, as shown in Table 13-3. Results of power analysis suggested that for a half-time of 20 years and a monitoring time of 12 years, n=4 replicates will provide reasonable power for most sites, if sampling was conducted every 2 years. As for intertidal sites, we expect that variance can be reduced at most sites. Also, as for intertidal sites, data should be examined after the first year of monitoring to determine actual spatial variation at the various sites, making adjustments in the future as required.

Table 13-3: Number of replicate samples required at 4 elevations for representative wetland sites to achieve a power of 0.8 or greater. Monitoring times of 12 and 16 years were assumed, for half-lives of 10, 20, and 30 years. Sampling every 1, 2, 3, and 4 years were simulated. Coefficients of variation based on temporal replicates for various sites are shown.

WETLAND SEDIMENT - POWER ANALYSES of REGRESSION TRENDS in TOTAL Hg

CV	SITE	ELEVATION	MONITORING TIME SPAN (years)	Hg HALF-TIME (years)	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:				SITE	ELEVATION	MONITORING TIME SPAN (years)	Hg HALF-TIME (years)	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:			
					4 years	3 years	2 years	1 year					4 years	3 years	2 years	1 year
0.08	**W26**	**LOW**	12	10	1	1	1	1	**W26**	**LOW**	16	10	1	1	1	1
0.10	**W63**	**INT**	12	10	1	1	1	1	**W63**	**INT**	16	10	1	1	1	1
0.10	**W17**	**MED**	12	10	1	1	1	1	**W17**	**MED**	16	10	1	1	1	1
0.12	**W63**	**MED**	12	10	2	1	1	1	**W63**	**MED**	16	10	1	1	1	1
0.14	**W17**	**HI**	12	10	2	1	1	1	**W17**	**HI**	16	10	1	1	1	1
0.17	**W17**	**INT**	12	10	2	2	1	1	**W17**	**INT**	16	10	1	1	1	1
0.20	**W63**	**LOW**	12	10	2	2	1	1	**W63**	**LOW**	16	10	1	1	1	1
0.21	**W26**	**HI**	12	10	2	2	1	1	**W26**	**HI**	16	10	2	2	1	1
0.33	**W17**	**LOW**	12	10	3	3	2	2	**W17**	**LOW**	16	10	2	2	1	1
0.38	**W26**	**INT**	12	10	4	3	3	2	**W26**	**INT**	16	10	2	2	2	1
0.42	**W26**	**MED**	12	10	4	4	3	2	**W26**	**MED**	16	10	3	2	2	1
0.46	**W63**	**HI**	12	10	5	5	4	2	**W63**	**HI**	16	10	3	3	2	1

7.3 Estuarine (subtidal) sediments.

We suggest continuing to monitor the five sites along the upper estuary transect (E-01), in Fort Point Cove. For these 5 sites in the upper estuary, we have sediment data from 2007, 2008, and 2009. The results for power analysis for these sites are shown in Table 13-4. Because temporal variation is lower at these sites, as compared to intertidal and wetland sites, power analysis suggests that fewer replicates or less frequent sampling could be conducted. We suggest that sampling begin with n=3 replicates. Sampling would be carried out, as for intertidal and wetland sediments, every 2 years. When monitoring is conducted using replicates that are sampled from the same platform at the same time, even lower CV's might be expected than for the temporal replicates that the power analysis was based on. As for the intertidal and wetland sampling, variance in total Hg concentrations would be evaluated after the first year of sampling, and if warranted, adjustments made to the sampling protocol.

Table 13-4: Number of replicate samples required at 5 subtidal estuarine sites to achieve a power of 0.8 or greater. Monitoring times of 12 and 16 years were assumed, for half-lives of 10, 20, and 30 years. Coefficients of variation (CV) are shown for various sites.

ESTUARINE SEDIMENT E01 - POWER ANALYSES of REGRESSION TRENDS in TOTAL Hg

CV	SITE	MONITORING TIME SPAN (years)	Hg HALF-TIME	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:				SITE	MONITORING TIME SPAN (years)	Hg HALF-TIME	MINIMUM N for POWER = 0.8 for SAMPLING INTERVALS of:			
				4 years	3 years	2 years	1 year				4 years	3 years	2 years	1 year
0.05	**E01-1**	12	10	1	1	1	1	**E01-1**	16	10	1	1	1	1
0.15	**E01-4**	12	10	2	1	1	1	**E01-4**	16	10	1	1	1	1
0.15	**E01-5**	12	10	2	1	1	1	**E01-5**	16	10	1	1	1	1
0.20	**E01-2**	12	10	2	2	1	1	**E01-2**	16	10	1	1	1	1
0.21	**E01-3**	12	10	2	2	2	1	**E01-3**	16	10	2	1	1	1
0.05	**E01-1**	12	20	1	1	1	1	**E01-1**	16	20	1	1	1	1
0.15	**E01-4**	12	20	3	3	2	1	**E01-4**	16	20	2	2	1	1
0.15	**E01-5**	12	20	3	3	2	1	**E01-5**	16	20	2	2	1	1
0.20	**E01-2**	12	20	4	4	3	2	**E01-2**	16	20	3	2	2	1
0.21	**E01-3**	12	20	5	4	3	2	**E01-3**	16	20	3	2	2	1
0.05	**E01-1**	12	30	2	1	1	1	**E01-1**	16	30	1	1	1	1
0.15	**E01-4**	12	30	5	5	4	2	**E01-4**	16	30	3	3	2	1
0.15	**E01-5**	12	30	5	5	4	2	**E01-5**	16	30	3	3	2	1
0.20	**E01-2**	12	30	10	7	7	4	**E01-2**	16	30	5	4	3	2
0.21	**E01-3**	12	30	10	10	7	4	**E01-3**	16	30	5	5	3	2

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