Table 1-1: Average total Hg concentrations in surface (0-3 cm) sediments in different zones of the Penobscot River Estuary. Low elevation sites are wetland sites, at slightly higher elevations than intertidal sites, but still subject to daily tidal inundation. Intertidal sites were sampled as part of the 2006-2007 sediment survey, the 2007 Wetland survey, and the 2008-2010 Seasonal wetland study. Depositional sites were the sites sampled by Yeager and Santschi for natural attenuation studies (Chapter 6), sampled by the study group. Higher elevations were medium and high elevations and platform elevations in wetlands, sampled by the study group. Offshore sites were sites sampled by WHOI during their study of mobile sediments and tended to be located further from shore than many of the depositional sites, which tended to be in coves and protected areas. These data are compiled in "PRMS Mapping file with corrected data January 25_2013 CK.xlsx".

	Low elevations, intertidal sites, depositional sites			Higher elevations in wetlands			Offshore sites			All samples		
THg, ng/gdw, 0-3 cm	**Avg**	**Std Dev**	**n**	**Avg**	**Std Dev**	**n**	**Avg**	**Std Dev**	**n**	**Avg**	**Std Dev**	**n**
Main river stem, from Brewer to southern tip of Verona Island, not including Mendall or the Orland River	885	374	57	704	298	20	358	493	79	595	495	156
Mendall Marsh	754	245	21	490	231	36	913	807	16	659	458	73
Orland River	1067	418	11	775	138	4	1032	417	7	1003	385	22
Ft Point Cove THg ng/gdw	354	355	14	111	109	7	473	230	12	345	300	33
Penobscot Bay, South of Fort Point to Islesboro Island	200	217	30	76	30	16	113	78	48	134	142	94

Table 1-2: Recovery half-times, expected surface sediment concentrations of total Hg when natural attenuation is complete, and years to recovery from 2009 for zones of the upper estuary of the Penobscot River, and for Fort Point Cove.

	Recovery Half-time	Background concentration ng/g dry wt.	Years to within 20% of background
Main stem	31	100	147 (2160)
Mendall Marsh	22	50	106 (2119)
Orland R	77	100	390 (2403)
Fort Point Cove	61	100	165 (2178)

Table 1-3: Areas (km^2) of long term depositional sediments and non-depositional sediments in different zones of the Penobscot estuary (see Chapter 5 for details).

	Depositional area km^2	Non-depositional area km^2	Total area km^2	% depositional
Upper estuary*	5.6	26	31.6	18
Fort Point Cove	8.68	11.3	20	43
Penobscot Bay (to Islesboro Island)	45	65	110	41
Penobscot estuary Total	59	102	162	37

* The upper estuary consists of the main stem of the Penobscot River as far south as the southern tip of Verona Island, Mendall Marsh, and the lower Orland River.

Table 1-4: Summary of conclusions regarding Hg levels in biota species sampled. n/a = not applicable to that species. ? = not certain; information lacking. "Yes" answers provided only if comparisons were conclusive (columns 2 and 3) or if a majority of samples from at least some sites exceeded levels of concern for human consumption, toxic effects or concern for predator health (columns 4, 5, and 6).

Biota group	Concentrations high compared to other areas?	Geographic patterns consistent with HoltraChem?	Levels of concern for human consumption?	Levels of concern for toxic effects on a species or groups of organisms	Levels of concern for wildlife health of predators?
Periwinkles	No	Yes	n/a	No	?
Freshwater snails	No	No	n/a	No	?
Lobster	Yes	Yes	Yes	No	?
Mussels	Yes	Yes	No	No	?
Nereis worms	No	Yes	n/a	No	?
Soft-shelled clams	Yes	Yes	No	No	?
Macoma clams	?	Yes	n/a	No	?
Green crabs	?	Yes	n/a	No	?
Rock crabs	Yes	No	Yes	No	?
Tomcod	?	Yes	n/a	No	Yes
Eels	Yes	Yes	Yes	Yes	n/a
Fundulus	Yes	Yes	n/a	No	Yes
Smelt	Yes	Yes	No	No	Yes
Flounder	Yes	Yes	No	No	No
Golden shiners	Yes	?	n/a	No	Yes
Songbirds	Yes	?	n/a	Yes	?
Shorebirds	Yes	?	n/a	Yes	?
Cormorants	Yes	Yes	n/a	No	n/a
Guillemots	Yes	?	n/a	Yes	n/a
Kingfishers	No	No	n/a	No	n/a
Black ducks	Yes	Yes	Yes	Yes	n/a

Table 1-4: Summary of conclusions regarding Hg levels in biota species sampled. n/a = not applicable to that species. ? = not certain; information lacking. "Yes" answers provided only if comparisons were conclusive (columns 2 and 3) or if a majority of samples from at least some sites exceeded levels of concern for human consumption, toxic effects or concern for predator health (columns 4, 5, and 6).

Biota group	Concentrations high compared to other areas?	Geographic patterns consistent with HoltraChem?	Levels of concern for human consumption?	Levels of concern for toxic effects on a species or groups of organisms	Levels of concern for wildlife health of predators?
Osprey	No	Yes	n/a	No	n/a
Bald eagles	No	?	n/a	No	n/a
Otters	No	No	n/a	No	n/a
Mink	No	No	n/a	No	n/a
Bats	Yes	Yes	n/a	Yes	n/a

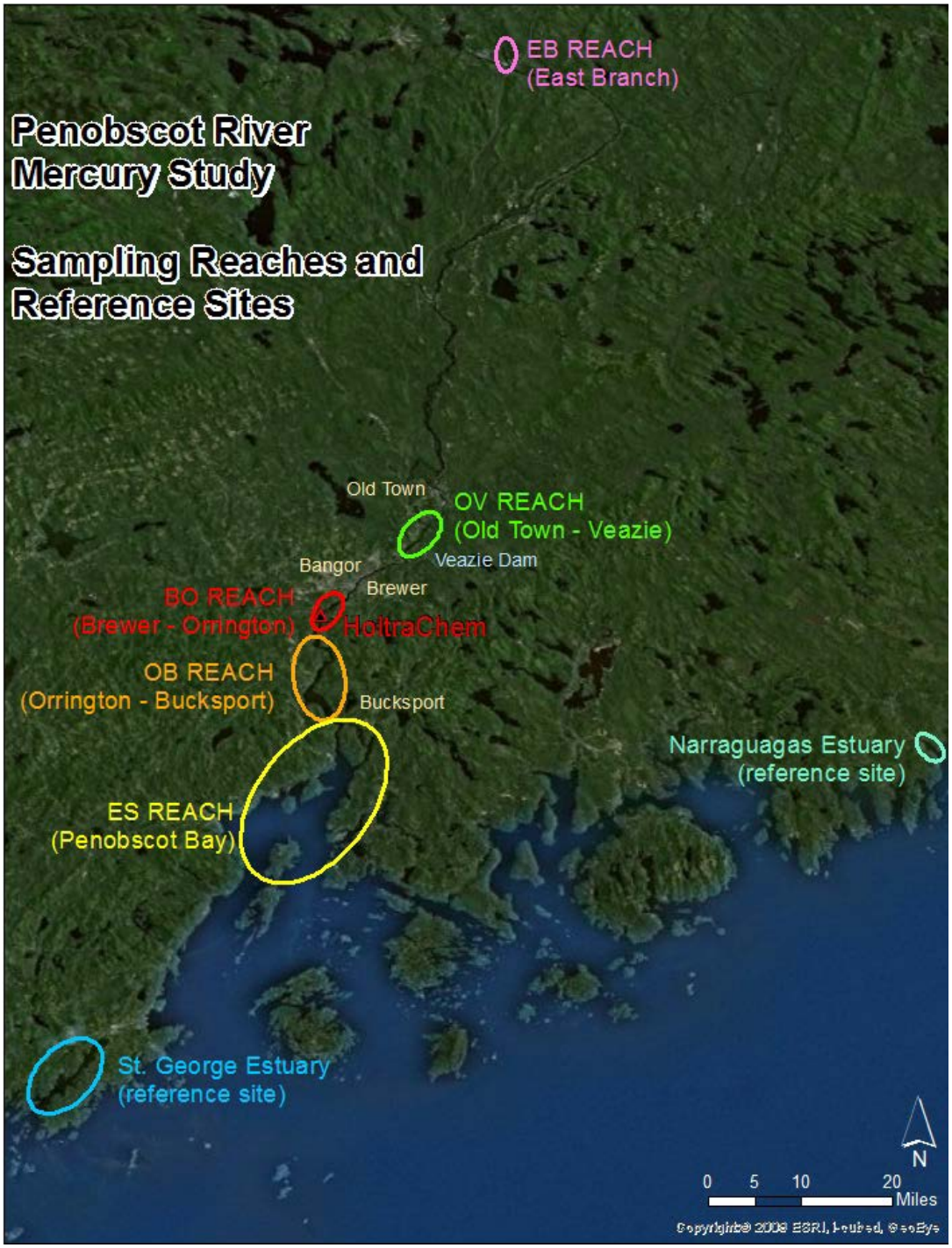


Figure 1-1. Map of the Penobscot River and estuary, showing sampling reaches, reference sites and major landmarks.

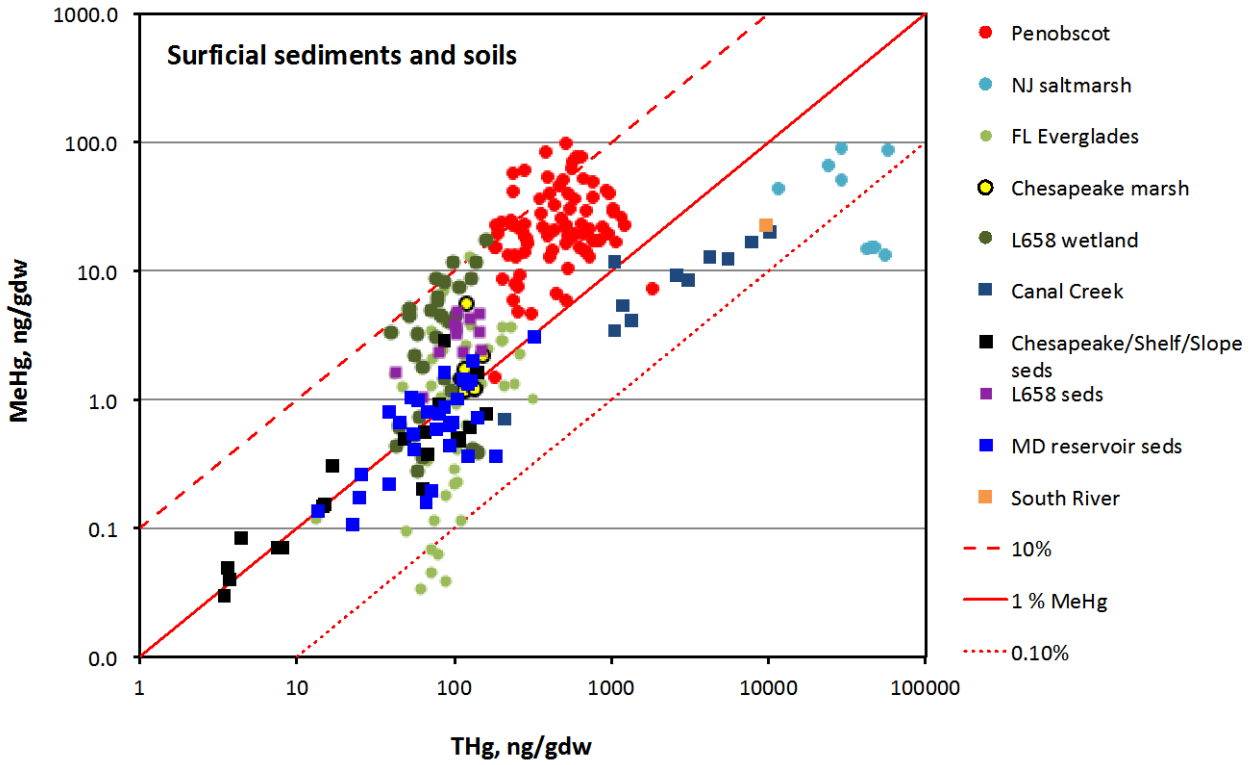


Figure 1-2. Cross – ecosystem comparison of methyl Hg concentration relative to sediment or wetland soil total Hg concentration in the Penobscot system and at nine other locations. Each point represents the average value for a site/date combination. Only surface sediment or soil data were included in this comparison. Data from marsh soils are shown as circles; bottom sediments as squares. The red lines show 0.1%, 1% and 10% of total Hg as methyl Hg, (see Chapter 11).

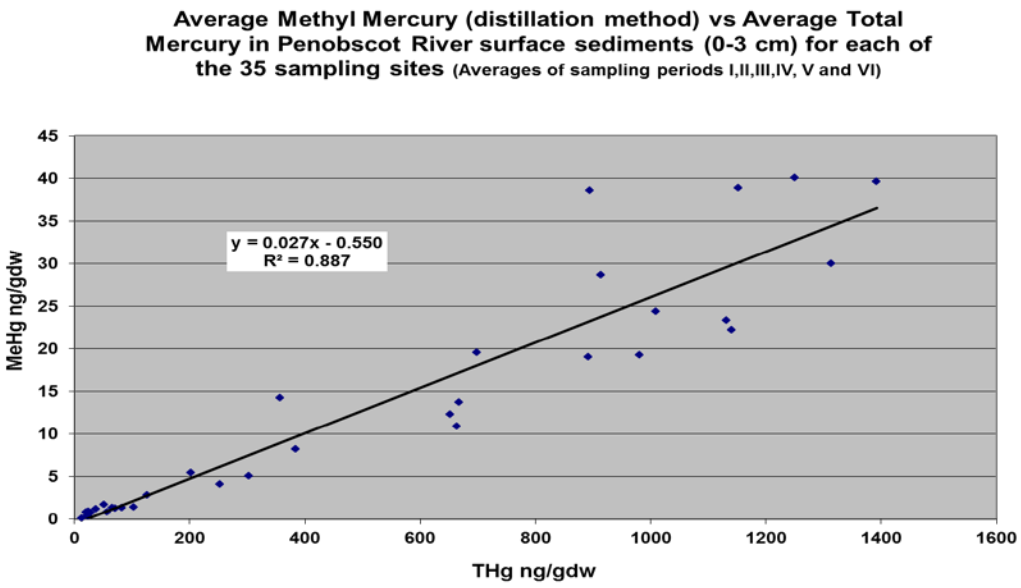


Figure 1-3a. Methyl Hg concentrations vs. total Hg concentrations in mudflats of the Penobscot River. Each point is the average of 6 sampling events

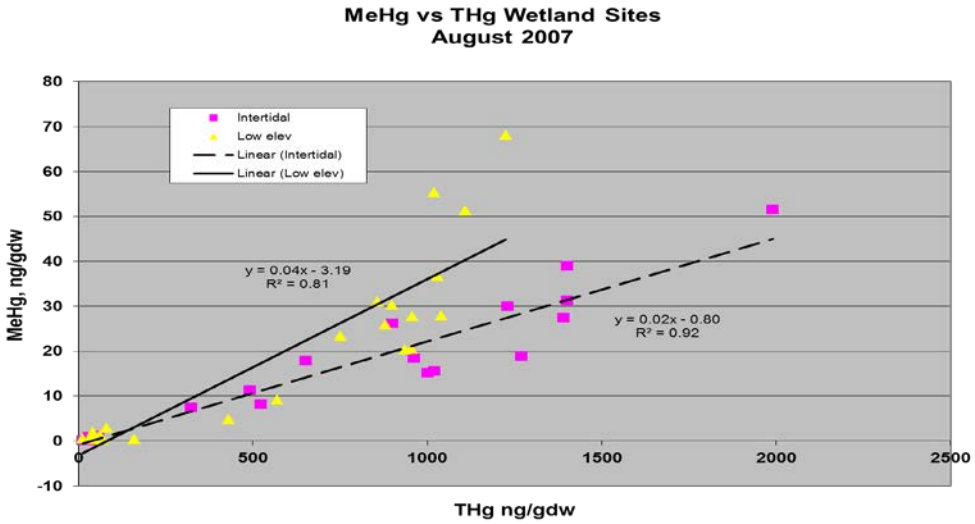


Figure 1-3b. Methyl Hg vs. total Hg concentrations in riverine intertidal sediments (pink) and marsh wetland sites (yellow) on the Penobscot River and tributaries. Low elevation sites are in the part of each wetland nearest the river, and intertidal sites are in the mudflat sediments, which are similar to the river and bay sediments shown in Figure 1-4.

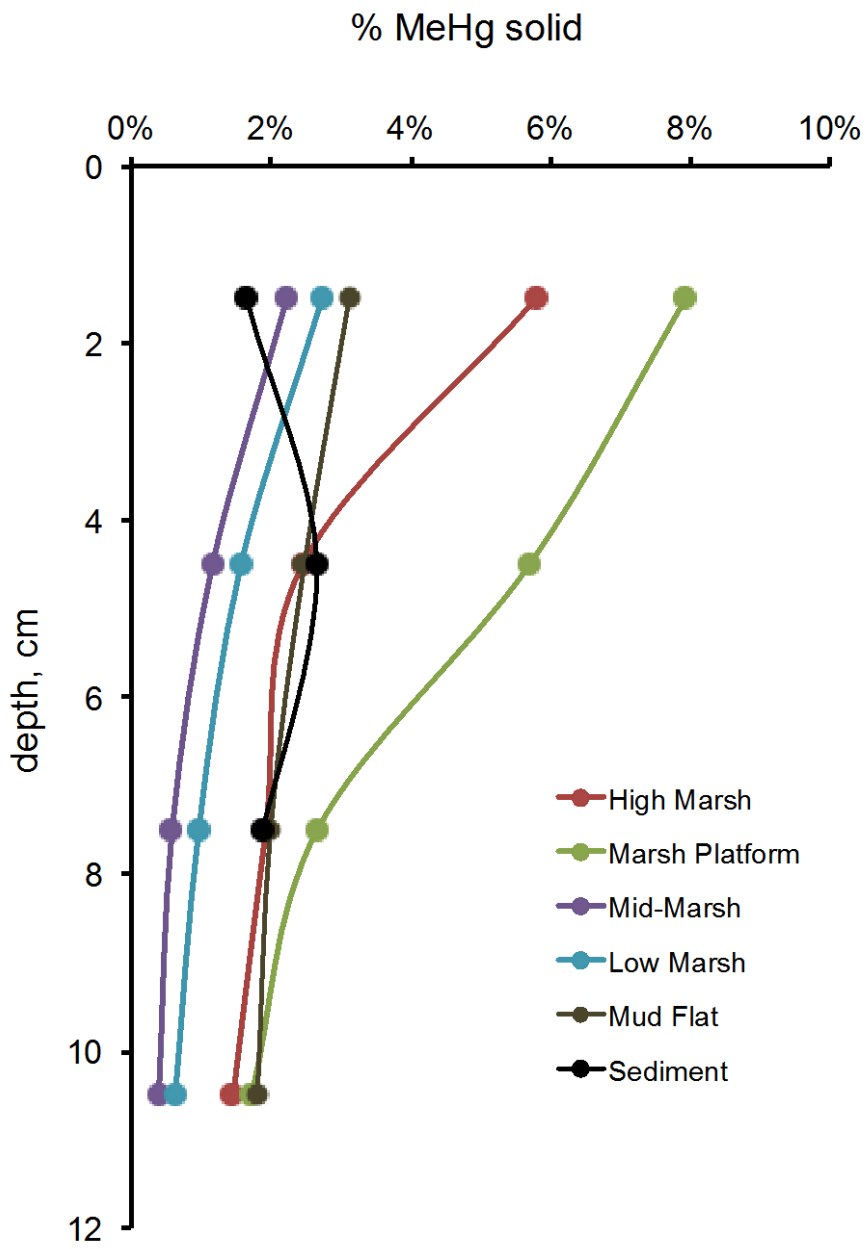
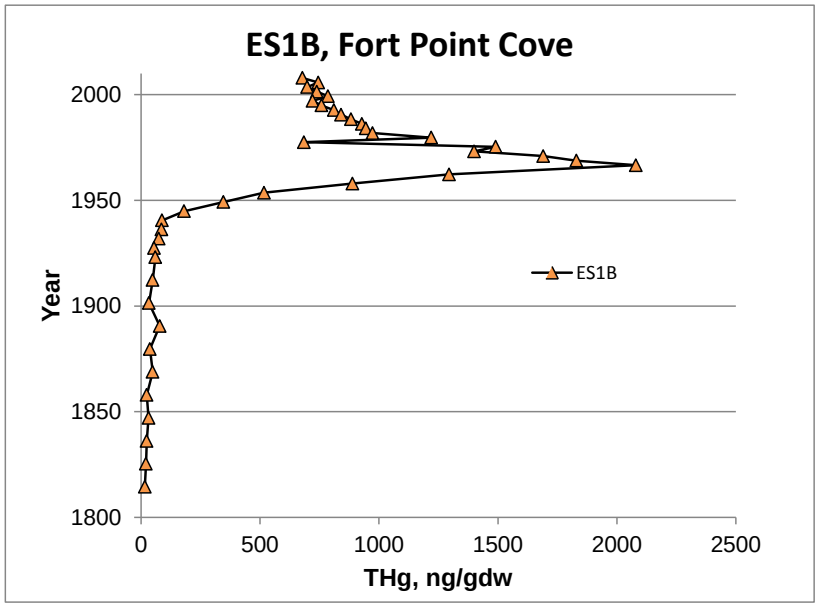


Figure 1-4. The average % methyl Hg in core sections from Penobscot River sediments and wetland soils. Profiles shown are averages by habitat type for August 2009 and May-June 2010. Error bars are omitted for clarity, but can be found in Chapter 11.



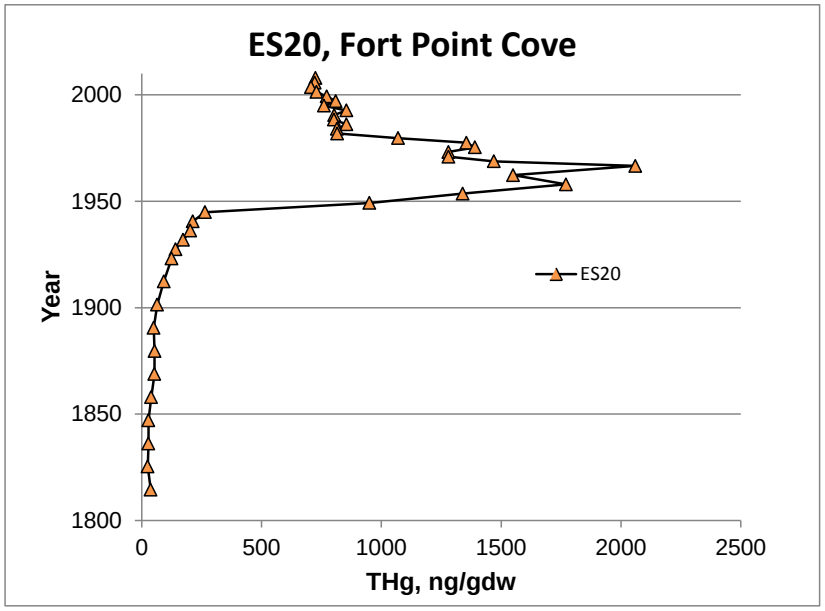


Figure 1-5. Depth profiles of total Hg concentrations in two cores taken from Fort Point Cove showing very low total Hg concentrations prior to 1850; followed by higher concentrations in the time period from about 1850 to the first half of the 1990's when industrialization of the Penobscot basin was occurring; followed by a peak in Hg concentrations in 1967 of HoltraChem Hg; followed by declining concentrations until the present because of natural attenuation. Details of dating techniques are given in Chapter 6.

Figure 1-6. Maximum concentrations of total Hg (at “deep peaks”) of profiles in Hg concentration obtained from 90 cm long sediment cores taken at 58 long-term depositional sites located throughout the Penobscot estuary, detailed data presentation in Chapter 5.

N

1:63,360

1 inch = 1 miles

0 1 2 Miles

Legend

Deep Peak (Hg maximum), ng THg/gdw

- 0 - 800
- 800 - 1,000
- 1,000 - 1,500
- 1,500 - 2,000
- 2,000 - 3,000
- 3,000 - 4,000
- 4,000 - 10,000
- 10,000 - 15,000
- 15,000 - 20,000
- >20,000

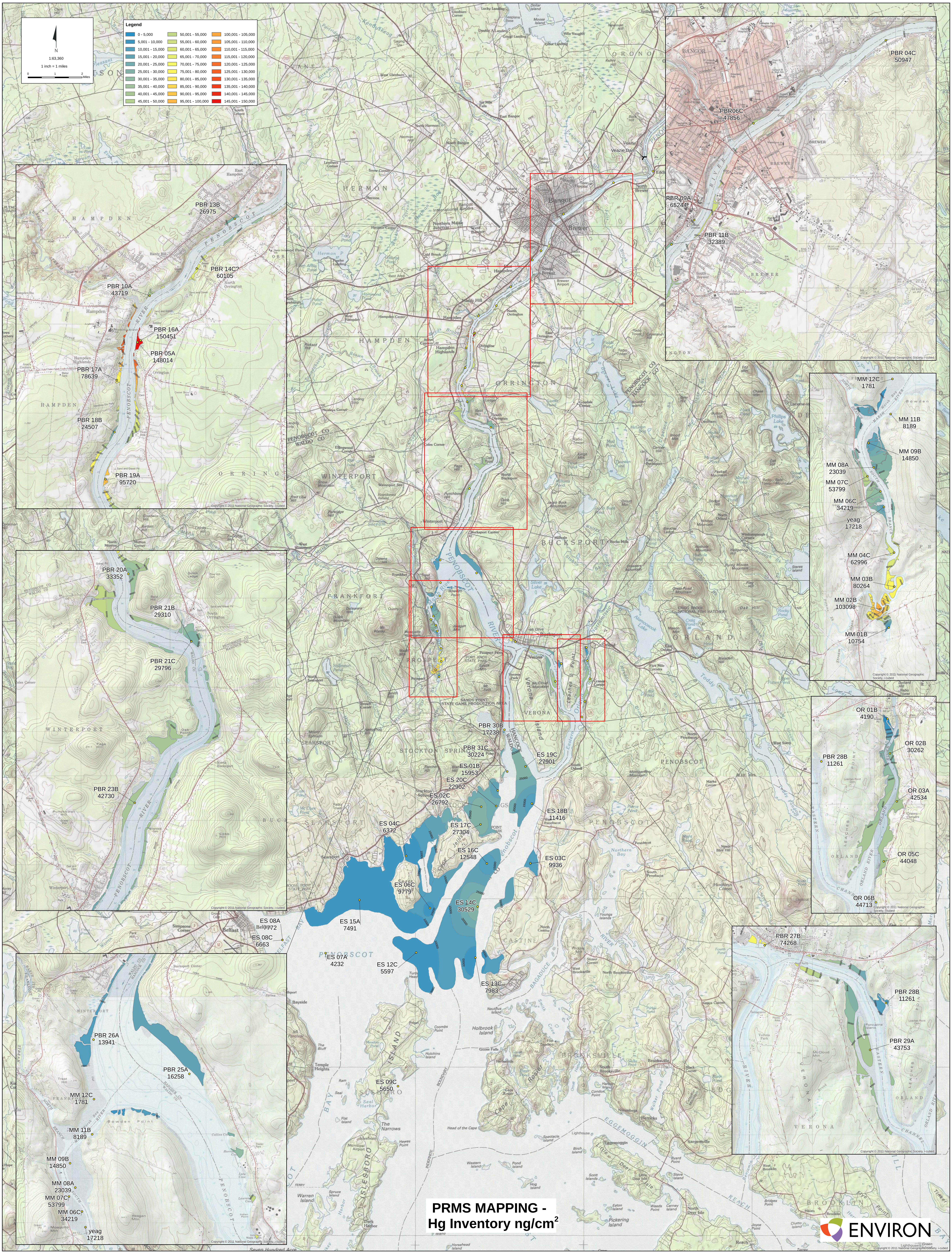
Note: Some higher deep peaks in MM than elsewhere, but not really high enough to predict the really high inventories at the distal end of the marsh.

Veazie Dam

PRMS MAPPING - Deep Peak

ENVIRON

Figure 1-7. Inventories of the mass total Hg (ng/cm^2) estimated from 90 cm long sediment cores taken at 58 sites throughout the Penobscot estuary, details are presented in Chapter 5.



N
1:63,360
1 inch = 1 miles
0 1 2 Miles
Legend
0 - 5,000
5,001 - 10,000
10,001 - 15,000
15,001 - 20,000
20,001 - 25,000
25,001 - 30,000
30,001 - 35,000
35,001 - 40,000
40,001 - 45,000
45,001 - 50,000
50,001 - 55,000
55,001 - 60,000
60,001 - 65,000
65,001 - 70,000
70,001 - 75,000
75,001 - 80,000
80,001 - 85,000
85,001 - 90,000
90,001 - 95,000
95,001 - 100,000
100,001 - 105,000
105,001 - 110,000
110,001 - 115,000
115,001 - 120,000
120,001 - 125,000
125,001 - 130,000
130,001 - 135,000
135,001 - 140,000
140,001 - 145,000
145,001 - 150,000
PBR 13B 26975
PBR 14C? 60105
PBR 10A 43719
PBR 16A 150451
PBR 05A 148014
PBR 17A 78639
PBR 18B 24507
PBR 19A 95720
PBR 04C 50947
PBR06C 47856
PBR 09A 65244
PBR 11B 32389
Veazie Dam
MM 12C 1781
MM 11B 8189
MM 09B 14850
MM 08A 23039
MM 07C 53799
MM 06C 34219
yeag 17218
MM 04C 62996
MM 03B 80264
MM 02B 103098
MM 01B 10754
PBR 20A 33352
PBR 21B 29310
PBR 21C 29796
PBR 23B 42730
OR 01B 4190
OR 02B 30262
PBR 28B 11261
OR 03A 42534
OR 05C 44048
OR 06B 44713
PBR 30B 17238
PBR 31C 30224
ES 01B 15953
ES 19C 27901
ES 20C 22902
ES 02C 26792
ES 18B 11416
ES 04C 6372
ES 17C 27304
ES 16C 12548
ES 03C 9936
ES 06C 9779
ES 14C 30529
ES 15A 7491
ES 08A 7772
ES 08C 6663
ES 07A 4232
ES 12C 5597
ES 13C 7983
ES 09C 5650
PBR 26A 13941
PBR 25A 16258
PBR 27B 74268
PBR 29A 43753
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PRMS MAPPING -
Hg Inventory ng/cm²
ENVIRON

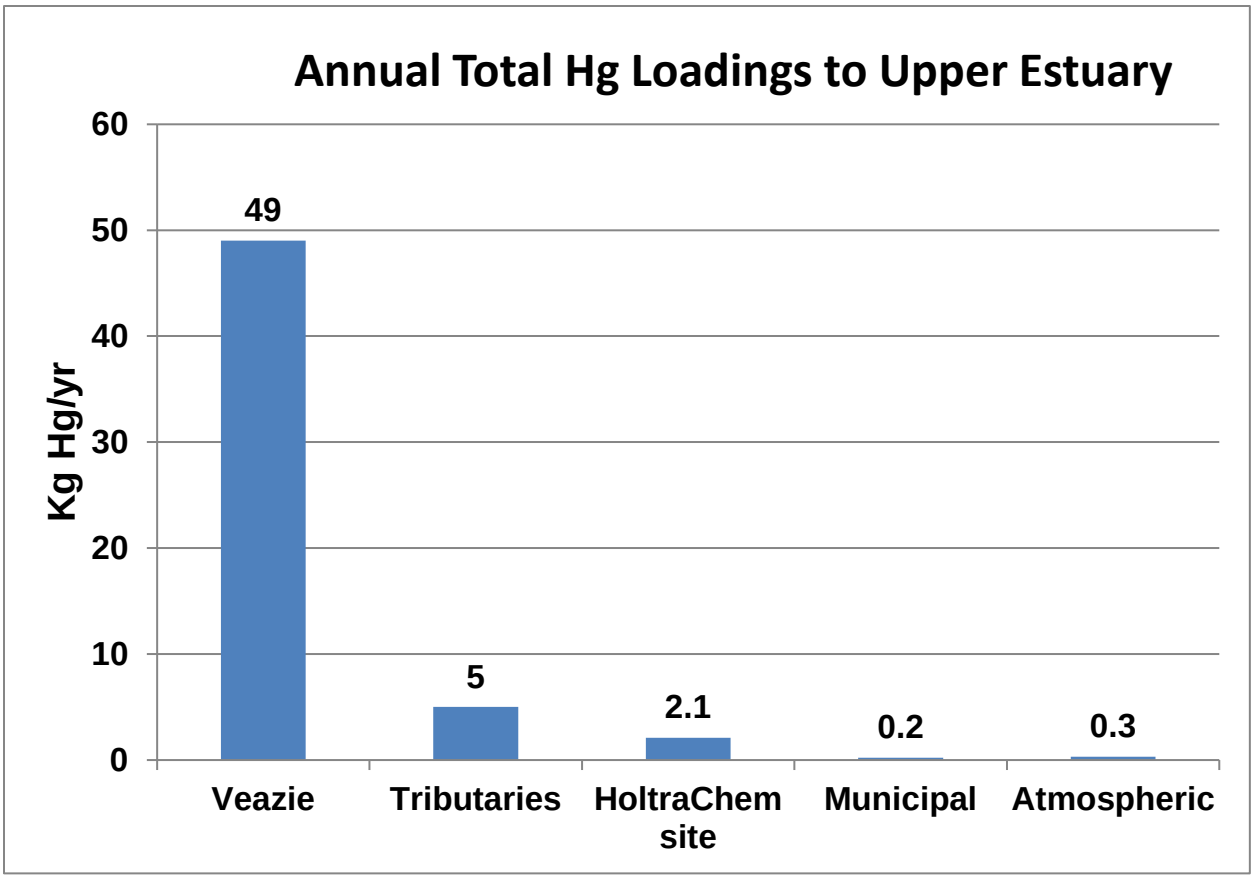


Figure 1-8. Estimated annual loadings of total Hg (unfiltered) to the upper estuary of the Penobscot River during Phase II of the PRMS study showing that present-day loading is dominated by flow over Veazie Dam, followed by loading from tributaries below Veazie Dam, and then by loading from the HoltraChem site (HoltraChem plant outfall + plant-site stream discharge + groundwater discharge), and from all municipal sources. Not all estimates were made for the same years (see Chapter 3).

Details: ***Municipal Discharges*** were calculated from Sterling Pierce concentration data, using sites located between Veazie Dam and Bucksport (Chapter 3). see File = Penobscot River Mercury 6-2009 from Sterling Pierce June 2009 Ralph Turner Sep_09.xlxs ***Tributaries*** were Kenduskeag R., Souadabscook R., and NB Marsh R.; data from D Bodaly. see file "sediment loading lower tribs dbMay2012" for calculations. ***Direct atmospheric deposition*** estimated using an annual deposition rate of 10 ug/m2 and a upper estuary area of 53 km^2. ***HoltraChem inputs*** include regularly monitored 001 pipe discharges, Northerly and Southerly streams, groundwater flows during the years 2004-2007, R. Turner, Chapter 3. ***Veazie Dam*** see Chapter 3.

Figure 1-9. Concentrations of total Hg (ng/g dry wt.) in surface sediments and wetland soils of the Penobscot estuary. This map was constructed using samples collected by the study group (Appendix 2), long term depositional site samples (Chapters 5 and 6) and in non-mobile grab sediment samples taken during the study presented in Chapters 7,8. All data are for the top 3 cm of each sediment sample.

N

1:63,360

1 inch = 1 miles

0 1 2 Miles

Samples from intertidal sites, depositional core sites, vegetated sites in wetlands, non-mobile grab samples, but not including mobile grab samples

Legend

THg ng/g d.w. 0-3 cm

- 0 - 100
- 100 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- 500 - 600
- 600 - 700
- 700 - 800
- 800 - 900
- 900 - 1,000
- 1,000 - 1,100
- >1,100

Veazie Dam

PRMS MAPPING - All Data Except Mobile
THg ng/g d.w. 0-3 cm

ENVIRON

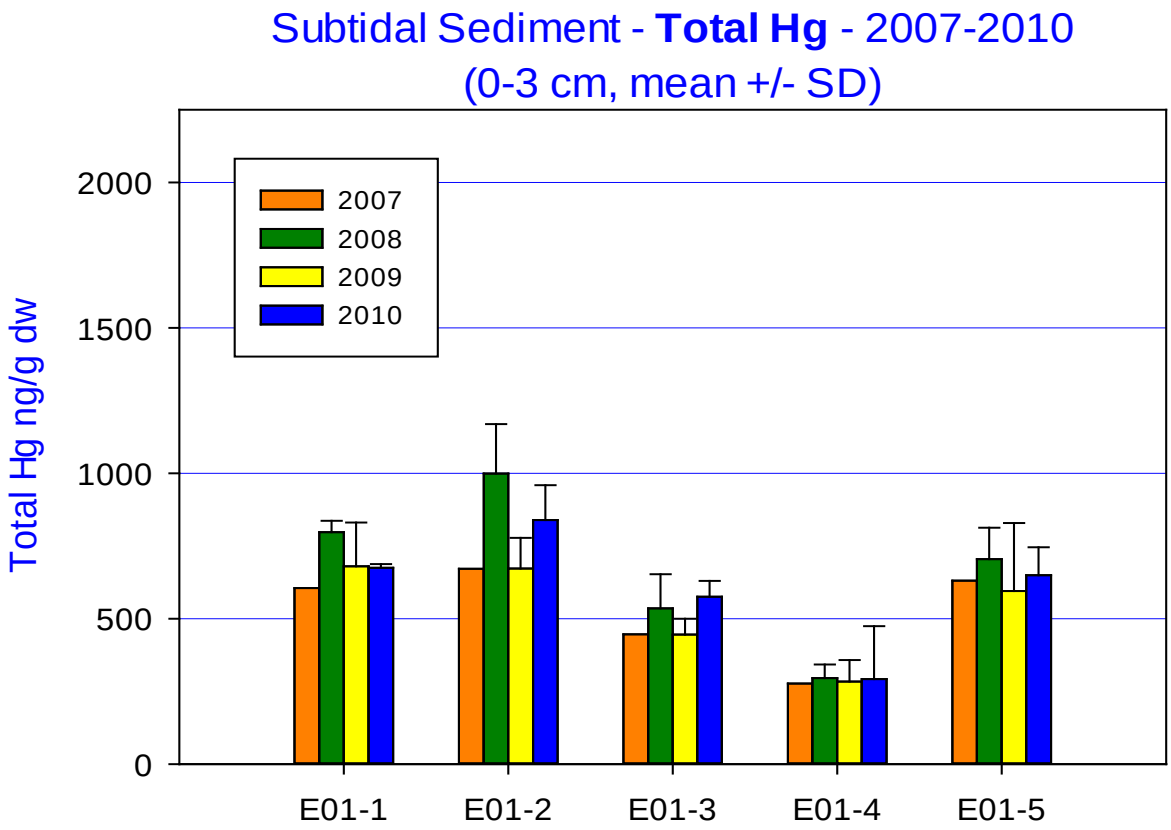
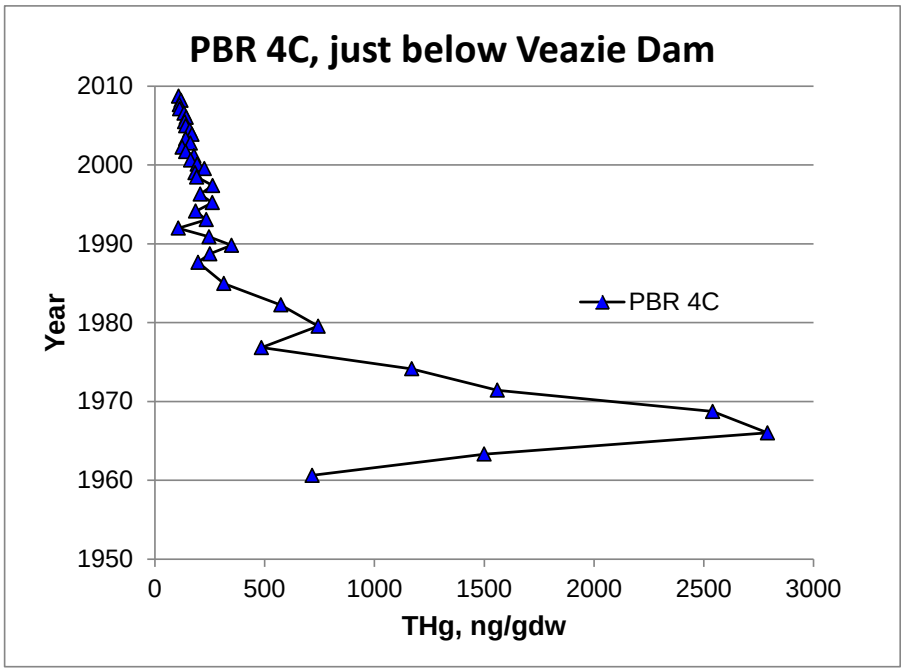


Figure 1-10. Concentrations of total Hg in surface (0-3cm) sediments of a transect of samples taken across Fort Point Cove in the years 2007 - 2010, details presented in Chapter 15.



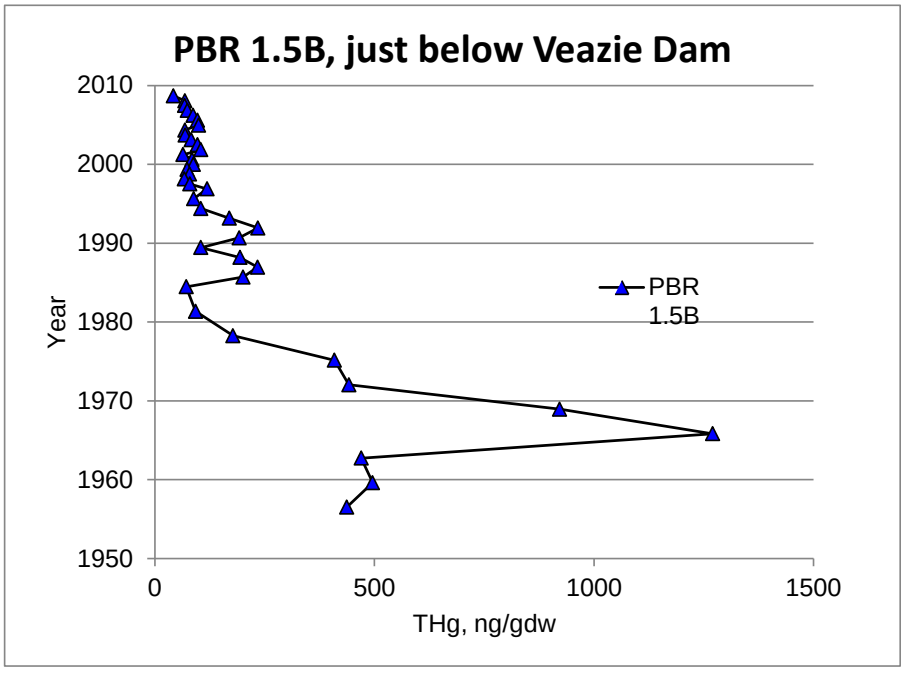


Figure 1-11. Depth profiles of total Hg concentrations in two cores taken from 1 and 4 km below Veazie Dam showing the 1967 peak in Hg concentrations at the time of high Hg discharges from the HoltraChem site; followed by declining concentrations to near regional background levels in 2009. Details of dating techniques are given in Chapter 6

Figure 1-12. Rates of sediment accumulation (cm/yr) at 58 sites of long-term deposition in in the Penobscot estuary (see Chapters 5 and 6 for details).

Sediment Accumulation Rate, cm/yr

N

1:63,360

1 inch = 1 miles

0 1 2 Miles

Legend

(cm/yr)

- 0 - 0.16
- 0.16 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 0.6
- 0.6 - 0.7
- 0.7 - 0.8
- 0.8 - 0.9
- 0.9 - 1
- 1.0 - 1.1
- 1.1 - 1.2
- 1.2 - 1.3
- 1.3 - 1.4
- 1.4 - 1.5

Veazie Dam

PENOBSCOT RIVER

PENOBSCOT BAY

PRMS MAPPING - SEDIMENTATION RATE, DEPTH ACCUMULATION

ENVIRON

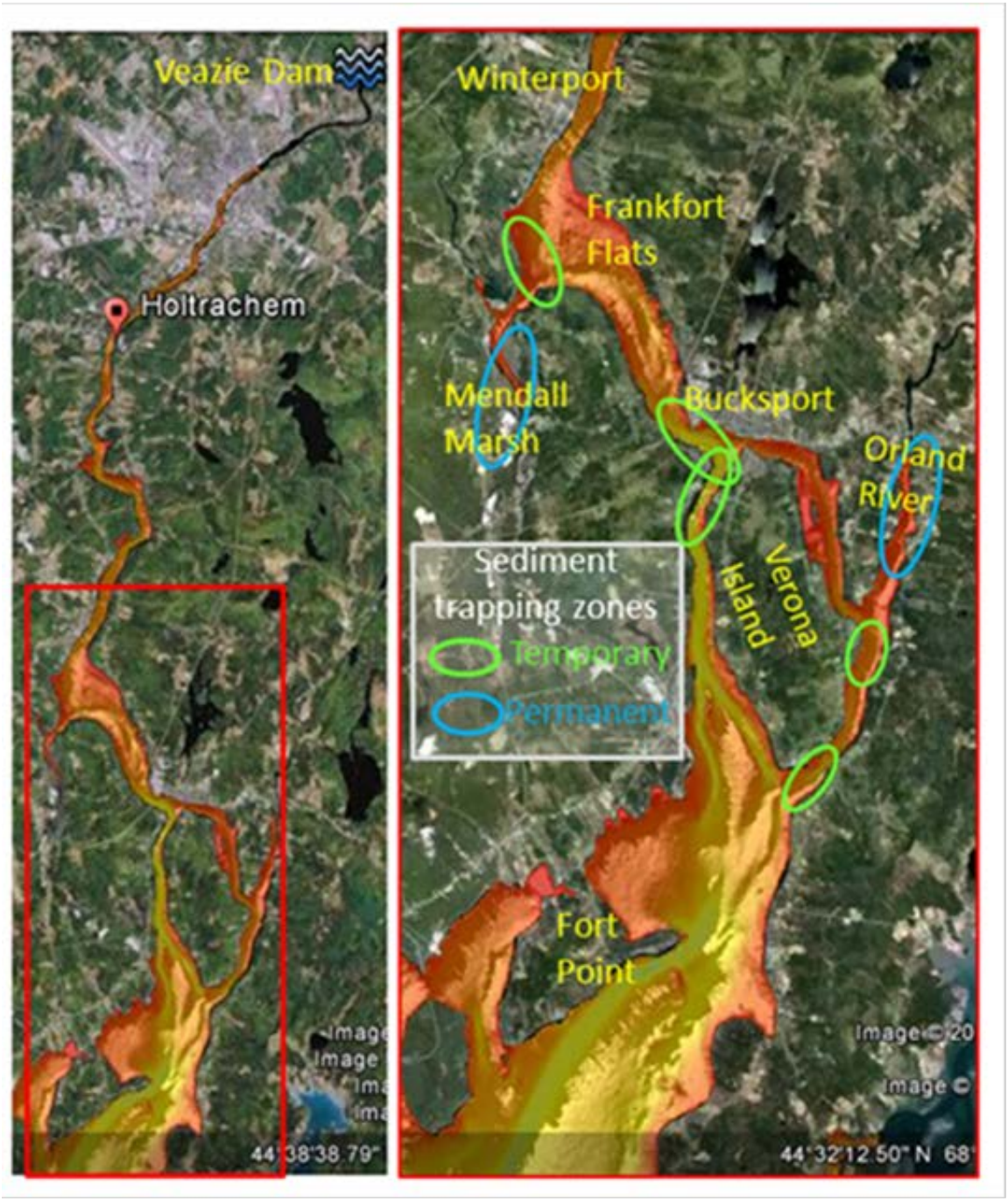


Figure 1-13. Aerial image of the Penobscot River study area. NOAA bathymetry is shown and the HoltraChem site, Veazie Dam, and other locations of interest are noted. On the right, regions of enhanced estuarine sediment trapping at temporary (seasonal) and longer time scales are indicated (green and blue ovals respectively), for details see Chapter 7.

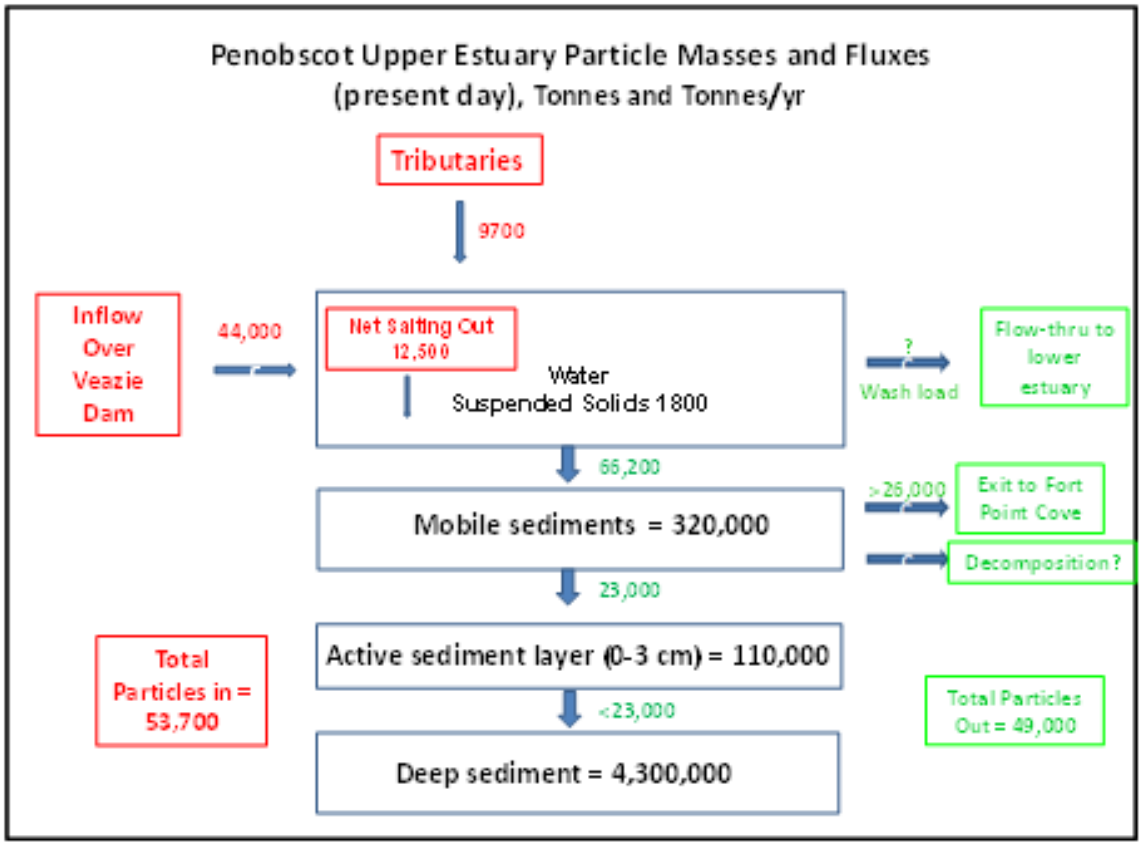


Figure 1-14. Estimated annual fluxes of particles into and out of the Penobscot upper estuary, to the sediments of the upper estuary, and masses of particles in the sediments of the upper estuary.

*Upper Estuary = area below Veazie Dam and above the southern tip of Verona I, including Mendall Marsh and the Orland River = 32 km^2. t Point cove = 20 km^2
Total particles to mobile pool = 66,200 tons per yr, including coagulation of DOC: system expected to be at steady state wrt particles, but sedimentation and loss into fort Point Cove only added up to 49,000 tons per yr. Unaccounted for particles (17,200 T/yr) could be lost as wash load and/or decomposition, or exit to the south of Fort Point..
Veazie Dam flow Data from Ch 3
Tributary input from Chapter 3
Water column suspended solids estimated using average TSS = 7 mg/L calculated from the 3 periods of 2006-2007 sampling where TSS was available, and volume = 1.7 x 10e8 m^3.
Water volume calculated from 31.6 km^2 (area above S tip Verona Island) and mean depth= 5.4 m (from Chapter 18, R. Harris)
Mobile sediment pool from Geyer et al report (Chapter 7); Total pool above S. tip of Verona I.= 318,000 T
Exit from trapping zone north of the southern tip of Verona Island estimated as the sedimentation of particles in Fort Point Cove (26,000T/yr). This is a minimum estimate, because additional particles likely pass through Fort Point cove and exit to the south of Fort Point.
Wash Load is defined as particles that wash through the estuary, without mixing with the mobile pool of sediments, but no measurements of this were made, so a ? Is placed on the wash load arrow.
Decomposition could be a loss term, but was not measured.
Active Sediment layer (0-3 cm) from average bulk density (0.67 g/cm^3)and depositional areas.
Deep sediment mass (3 to 90 cm) = average bulk density (0.89g/cm^3) and depositional areas.
Depositional area = 5.6 km^2, from Yeager Chapter 5.
Sedimentation rate from depositional area * average sedimentation rate in upper estuary (Chapter 5).

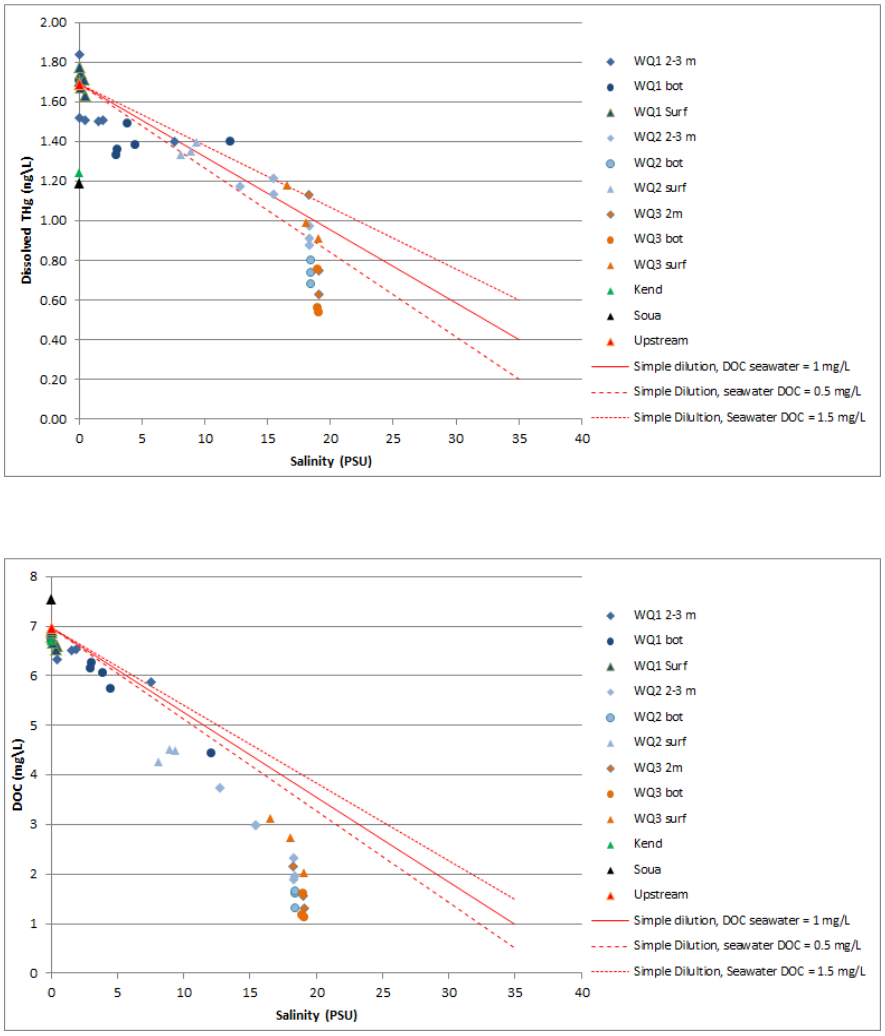
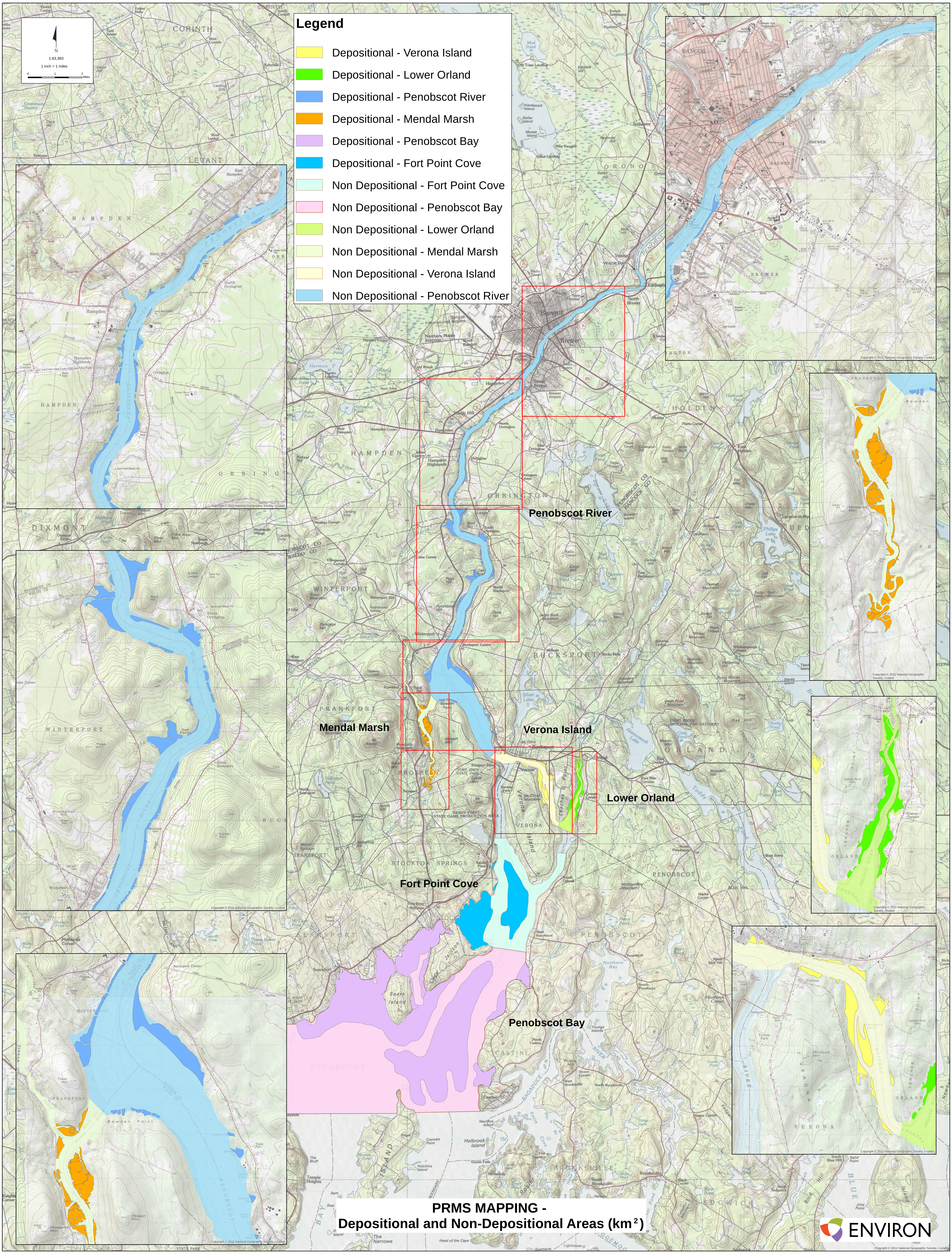


Figure 1- 15. Concentrations of Dissolved THg and DOC in the Penobscot estuary (WQ sites) and in three tributaries flowing into the estuary below the Veazie Dam. The decrease in dissolved mercury and DOC concentrations at about 18 PSU is indicative of DOC coagulation and stripping of dissolved Hg form the surface water.

Figure 1-16. Areas of the Penobscot Estuary that are non-depositional (light shading) and depositional on the long term (dark shading)


Legend
Depositional - Verona Island
Depositional - Lower Orland
Depositional - Penobscot River
Depositional - Mendal Marsh
Depositional - Penobscot Bay
Depositional - Fort Point Cove
Non Depositional - Fort Point Cove
Non Depositional - Penobscot Bay
Non Depositional - Lower Orland
Non Depositional - Mendal Marsh
Non Depositional - Verona Island
Non Depositional - Penobscot River
N
1:63,360
1 inch = 1 miles
0 1 2 Miles
Penobscot River
Mendal Marsh
Verona Island
Lower Orland
Fort Point Cove
Penobscot Bay
Veazie Dam
PRMS MAPPING -
Depositional and Non-Depositional Areas (km²)
ENVIRON
Copyright:© 2011 National Geographic Society, i-cubed

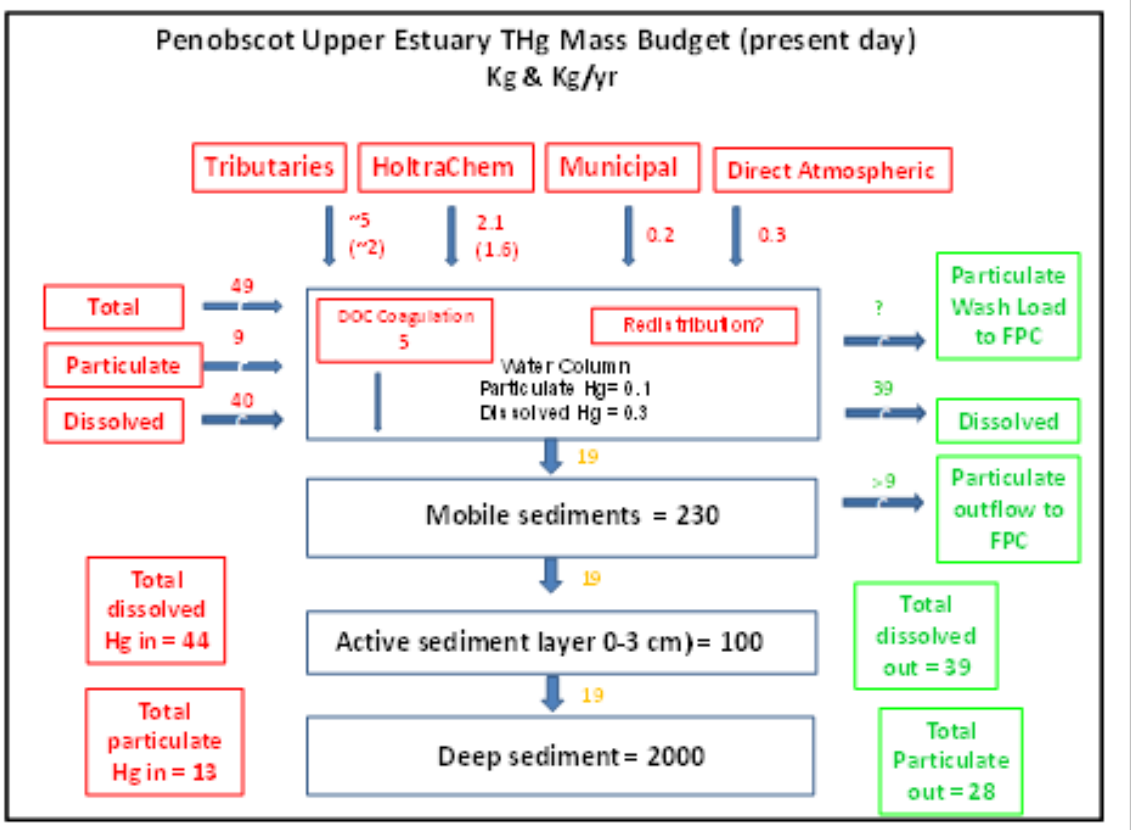


Figure 1-17. Estimated annual inputs (red), outflows (green) and burial (yellow) of total Hg in the Penobscot upper estuary. Masses of total Hg in the water column and sediments or wetland soils are in black lettering.

Total in = (49+5+2.1+0.2+0.3) = 57 Kg Hg /yr, total out = (39+19+9) = 67 Kg Hg/yr
Total out is greater because contaminated particles are settling and being replaced by cleaner particles, system not at steady state. Note that the Particulate outflow to FPC is a minimum estimate, based on sedimentation within FPC. Additional particulate Hg might sediment further south of Fort Point.
Dissolved and particulate THg over Veazie from Chapter 3
Tributary inputs see Chapter 3
Atmospheric input is direct input onto water surface, calculated from 10 ugm^2/yr and area of 31.6 km^2 from Veazie Dam to Fort Point
HoltraChem site and Municipal inputs from Chapter 3, R Turner
Water column masses from average Hg concentration and water column volume
Mobile sediment masses from Geyer et al., Chapter 7 and average THg concentration from Chapter 8.
Active sediment layer mass from average 0-3 cm total Hg concentration in surface sediments (885 g ng/g dry wt., Table 1-1, Chapter 1, in low elevation, intertidal, and depositional samples), average bulk density (0.67 g/cm^3) and depositional area = 5.6 km^2 (Chapter 5)
Deep sediment mass from Yeager-Santschi core inventories and depositional areas for each subarea, Chapter 5
Sediment Accumulation rates from Yeager-Santschi core data and depositional areas (Chapter 5), calculated individually for main stem of river, Mendall Marsh, and Orland River sub-areas, and summed.
Particulate outflow to Fort Point Cove (FPC) estimated as mass of Hg sedimenting onto depositional area, using sediment accumulation rates from Yeager-Santschi core data and depositional area from Chapter 5. This is a minimum estimate, because additional particles likely sediment south of Fort Point.
For calculations, all of the above, see "Upper Estuary Mass Balance September 23 CK Mar 27 2013.xlxs"
DOC coagulation from ratio of Hg to DOC = 0.36 in "WQ data lat long 2008_2009_2010 October 16_2011 CK Feb 13a.xlxs", and coagulation in "Upper Estuary Mass Balance September 23 CK Mar 27_ 2013.xlxs". Gross coagulation of Hg was used, because Hg not expected to return to water, even though we estimate that 50% of the OC will be decomposed.
Particles out = (19+9=28) Kg/yr. There could be some escape by "wash load", which is flow through of particles that enter over Veazie Dam and never mix with the mobile pool, and additional particles that don't sediment in FPC, but exit further to the south.
Dissolved Hg out = Dissolved in minus coagulation. This could be an overestimate, if some dissolved Hg adsorbs to particles as it passes through the system, or is converted to DGM and fluxes to the atmosphere.

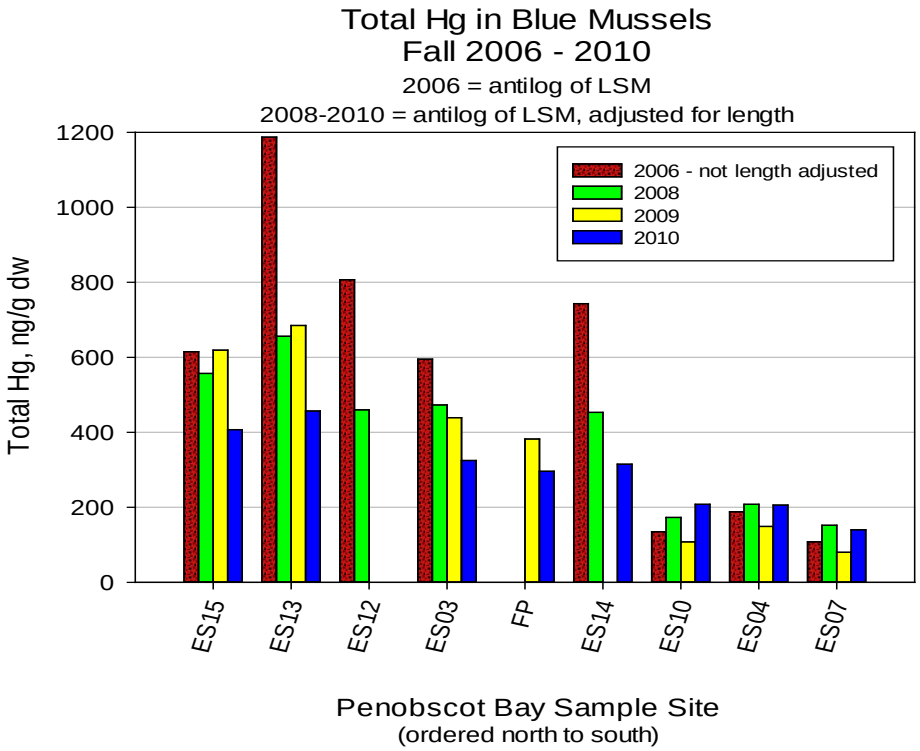


Figure 1-18. Mean total Hg concentrations in the soft tissues of blue mussels (*Mytilus edulis*) at nine sites in the Penobscot system, 2006-2008. Means for 2006 are the antilog of least square means (not adjusted for animal size), whereas means for 2008, 2009 and 2010 are the antilog of least square means adjusted for length. Sites are ordered from north (closest to HoltraChem) to south (furthest away from HoltraChem).

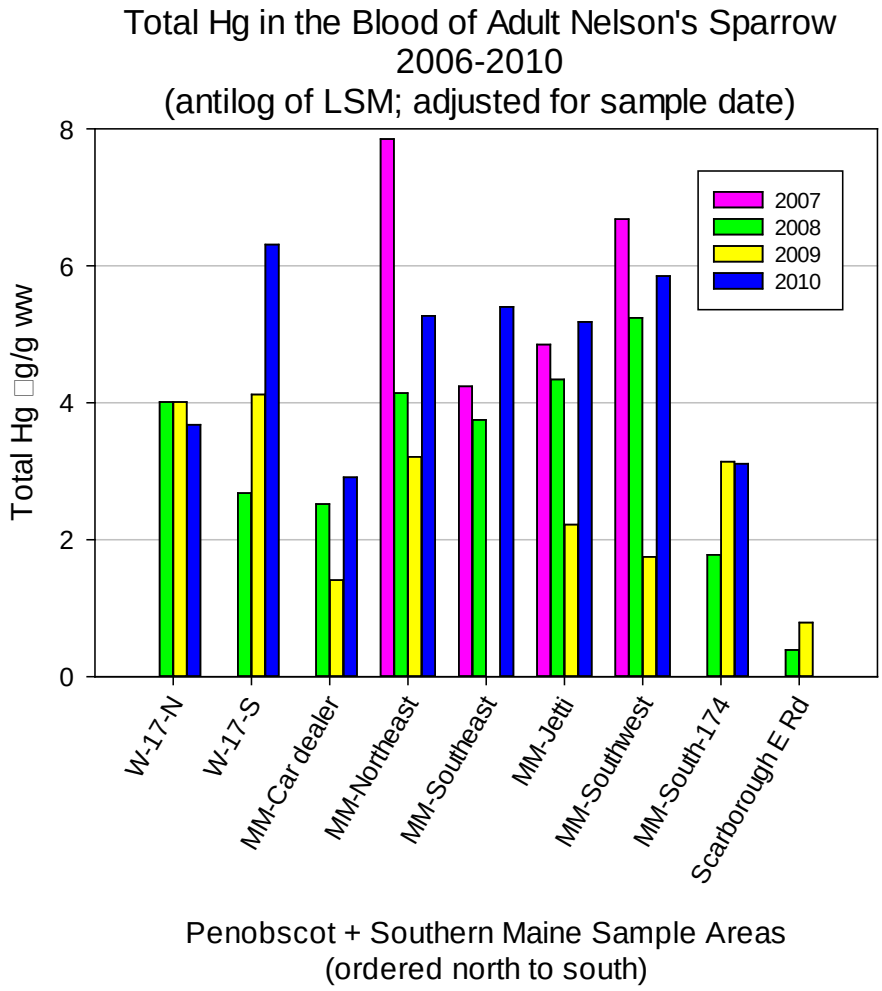


Figure 1-19. Total Hg in the blood of Nelson's sparrows, collected 2006-2010. Birds were sampled in two areas near W-17, just north of Mendall Marsh, at five sites in Mendall Marsh, and at one reference area (Scarborough) in southern Maine. Data have been statistically adjusted for the covariate sample date.

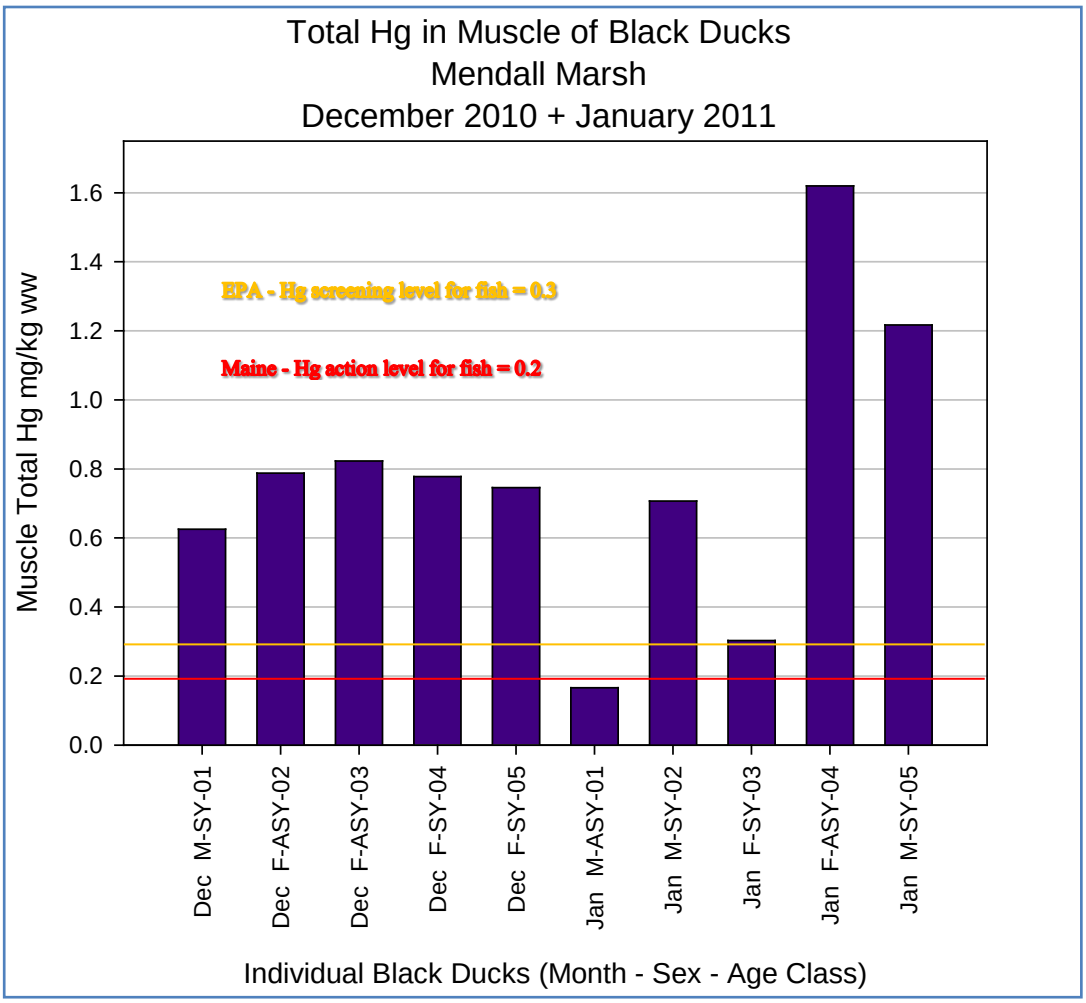


Figure 1-20. Hg concentrations in most black duck muscle samples from Mendall Marsh exceeded state and federal screening levels for methyl Hg in fish muscle, the only Hg screening levels currently available.