Penobscot River Estuary, ME

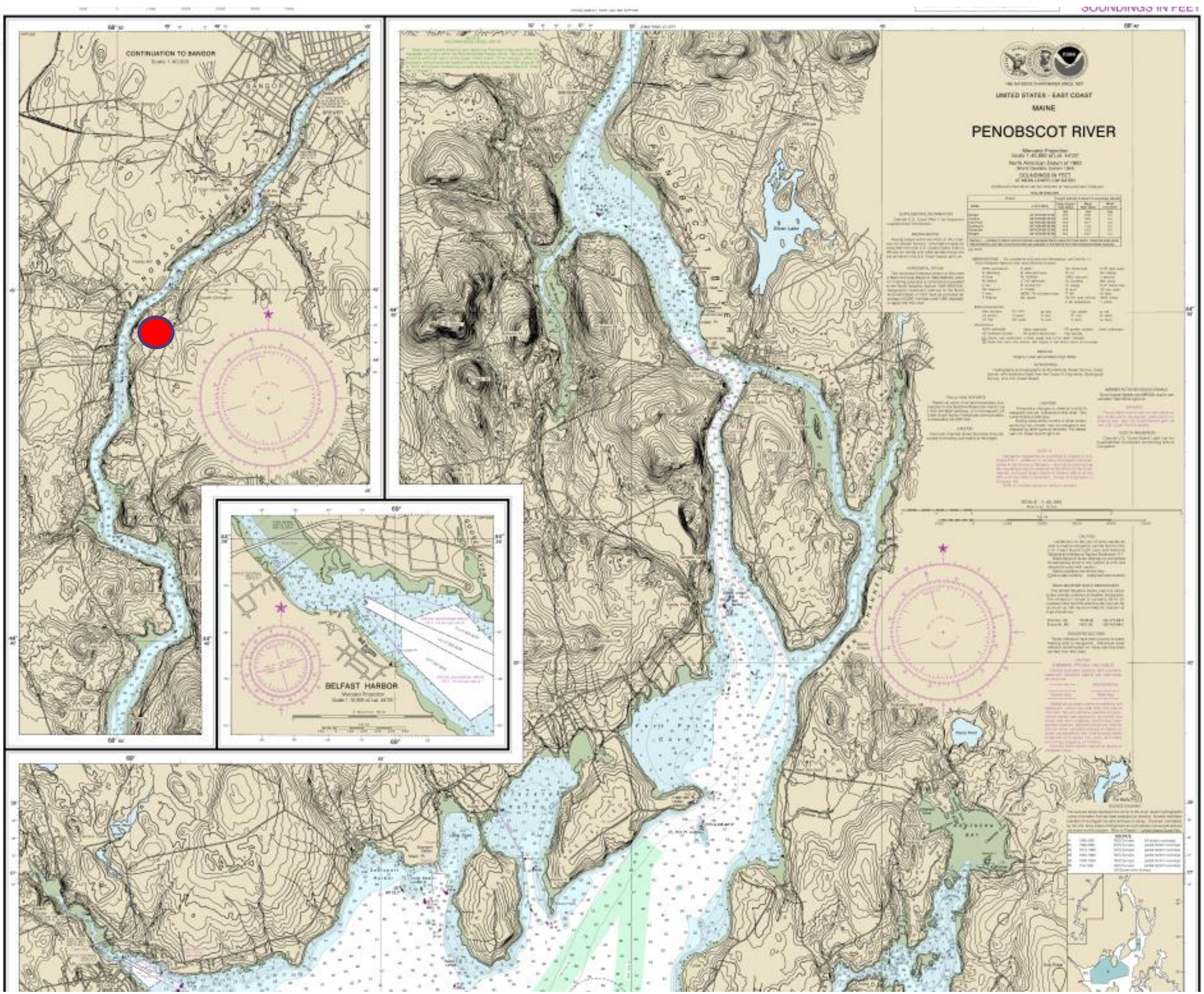
Evaluating and Understanding Contamination for a Mercury-Impacted Site

Overview

- Site Background
- History & Legal Framework
- What is the Problem With Mercury Contamination?

Site Background

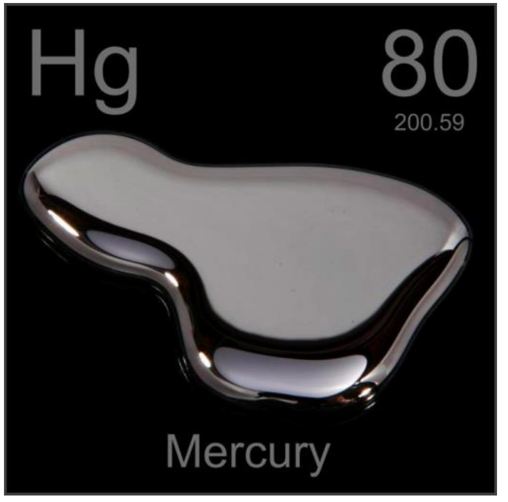
- The Penobscot River is the second largest river system in New England
- The estuary is:
  - ~20 miles long
  - 12 ft tidal range
- Seasonally variable discharge:
  - 5000 – 60,000 cfs
- Glaciated terrain and bedrock framing


UNITED STATES - EAST COAST
MAINE
PENOBSCOT RIVER
CONTINUATION TO BANGOR
BELFAST HARBOR

Site Background (cont.)

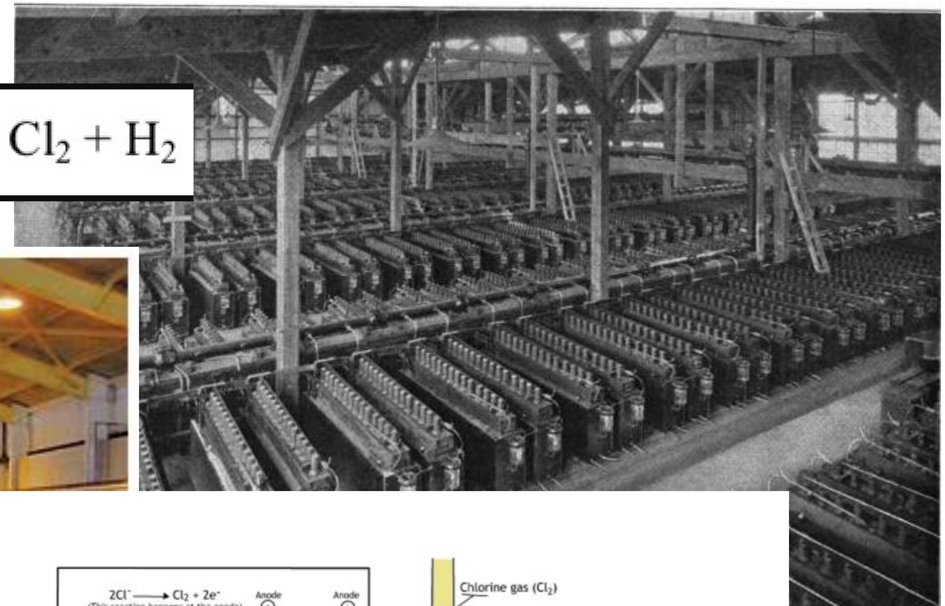
- A **mercury cell chlor-alkali facility** operated within the estuary from 1967 – 2000
- Process uses mercury in an electrolytic cell to generate caustic soda and chlorine from brine
- Facility operations released ~ 10 tons of mercury into the estuary (plus unquantified volume into the atmosphere)

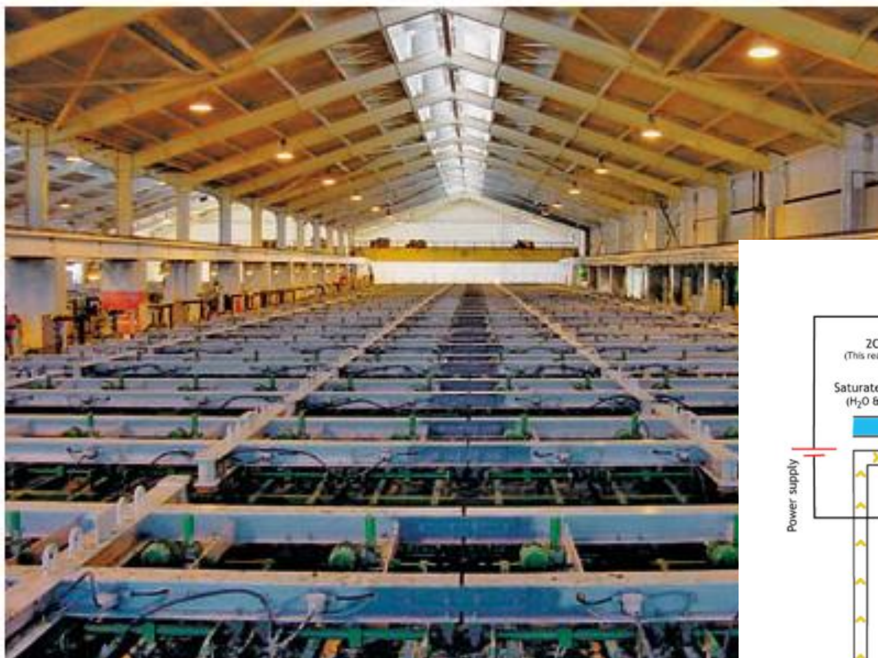
site was one of ~ 200 such sites operating globally from (1950 – now) that use(d) the mercury cell process to make caustic soda and chlorine

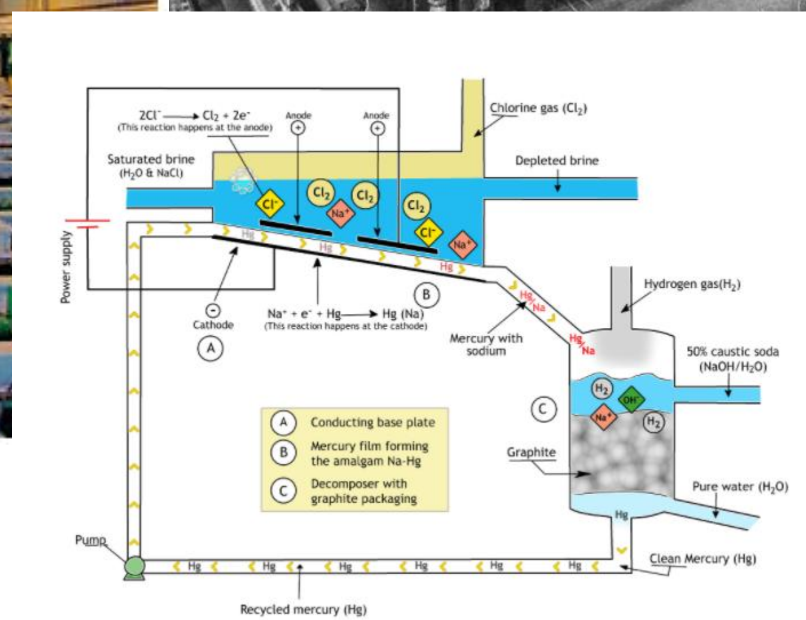


Mercury cell chlor-alkali process

$$2NaCl + 2H_2O + ☀ \rightarrow 2NaOH + Cl_2 + H_2$$







History & Legal Framework

- **2002** - Suit filed by NRDC and MPA in Federal District Court against site owner (Mallinckrodt)
- **2003** – Federal court decision results in beginning of estuary studies (Phase I)
- **2008 – 2013 –** Phase II ecological study completed
- **2016** – **2018** – Phase III engineering study completed
- **2021** – Federal Court hands substantive victory to NRDC and MPA mandating estuary clean-up
- **2023*** – Phase IV remediation work begins
- **2023 - ?** – remediation efforts will likely take 15 – 20 years

What Is the Problem With Mercury Contamination?

If we want to think about *how* to evaluate contamination, we need to understand its impacts….

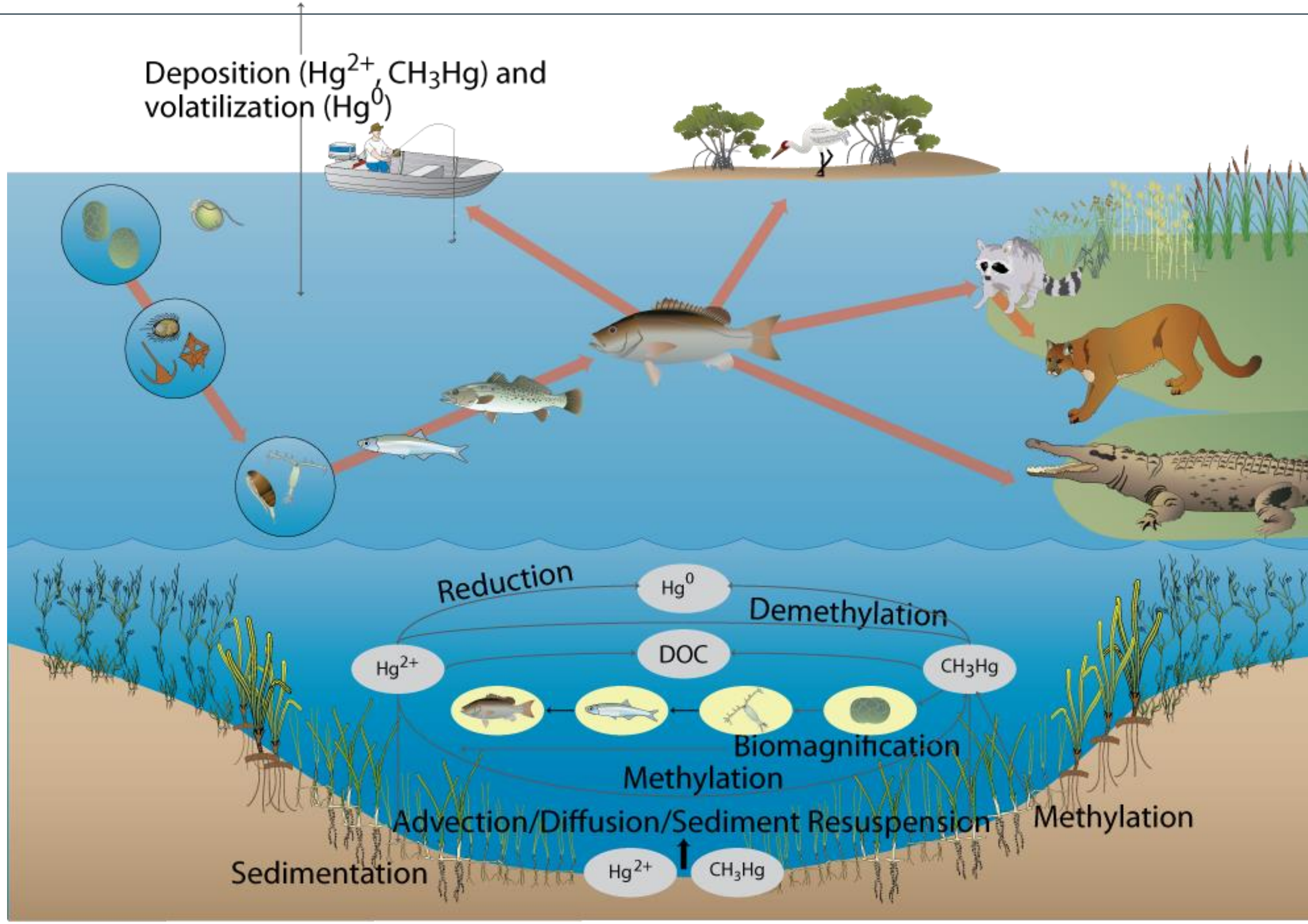
…which means we need to understand the environment into which discharge has happened

What are the:

- Physical;
- Chemical;
- Biological; and
- Socio-cultural

variables that matter in understanding '*how bad is bad*'?

Transformation in Aquatic Environments



Conceptual diagram illustrating mercury biomagnification within the aquatic food chain.

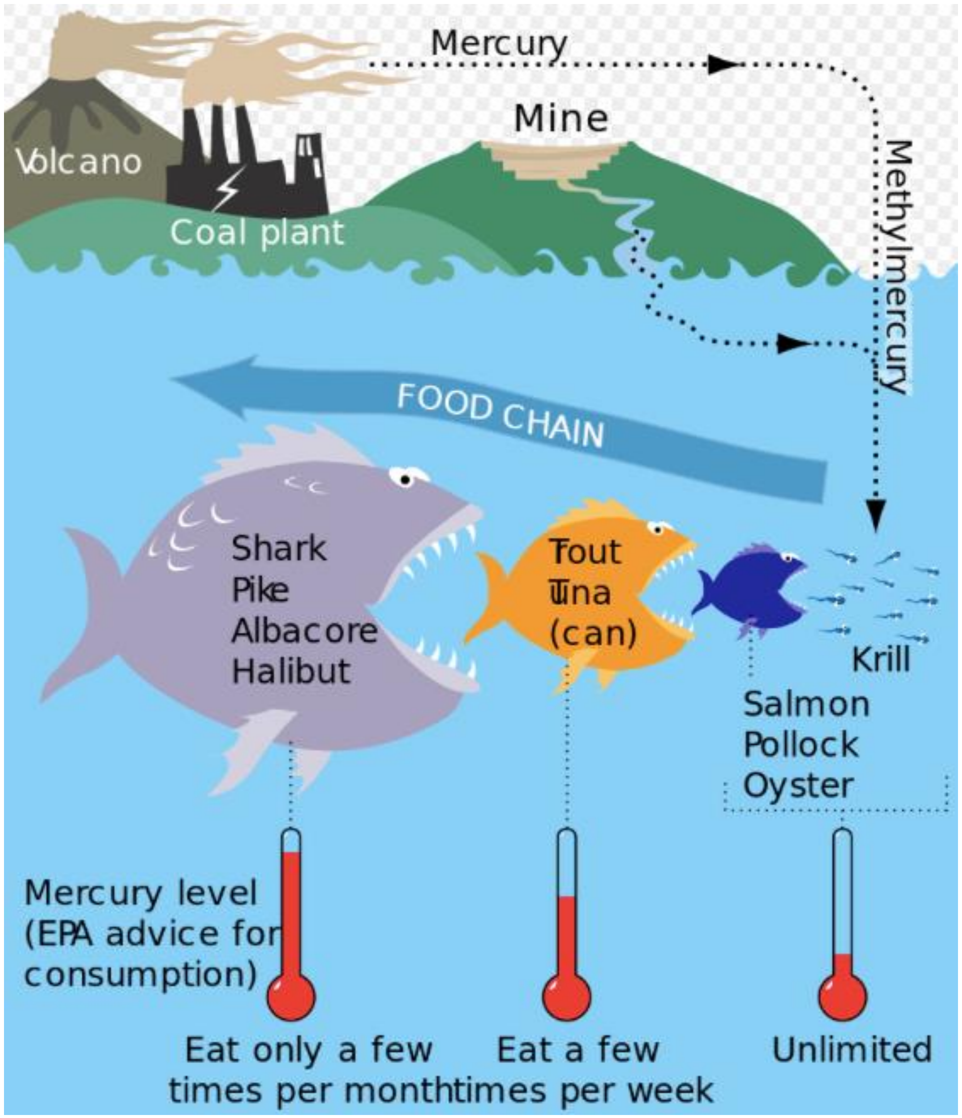
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Kruczynski, W.L., and P.J. Fletcher (eds.). 2012. Tropical Connections: South Florida's marine environment. IAN Press, University of Maryland Center for Environmental Science, Cambridge, Maryland. 492 pp.

Sedimentary Processes and Methylation Dynamics

- Methylation of inorganic mercury mostly happens in sediment; the rate of methylation in sediment is a function of the total mercury concentration present.
- Biological exposure through the foodweb mostly begins in sediment; biological uptake and trophic transfer of mercury are a function of the rate of lower trophic level exposure.

- If sedimentation rates are high, contamination is buried quickly; quickly buried contamination doesn't interact significantly with the foodweb and biological exposure is overall lower;
- If sedimentation rates are low, methylation *can* occur within the biological exposure depth and the potential for biological exposure and trophic transfer is much higher

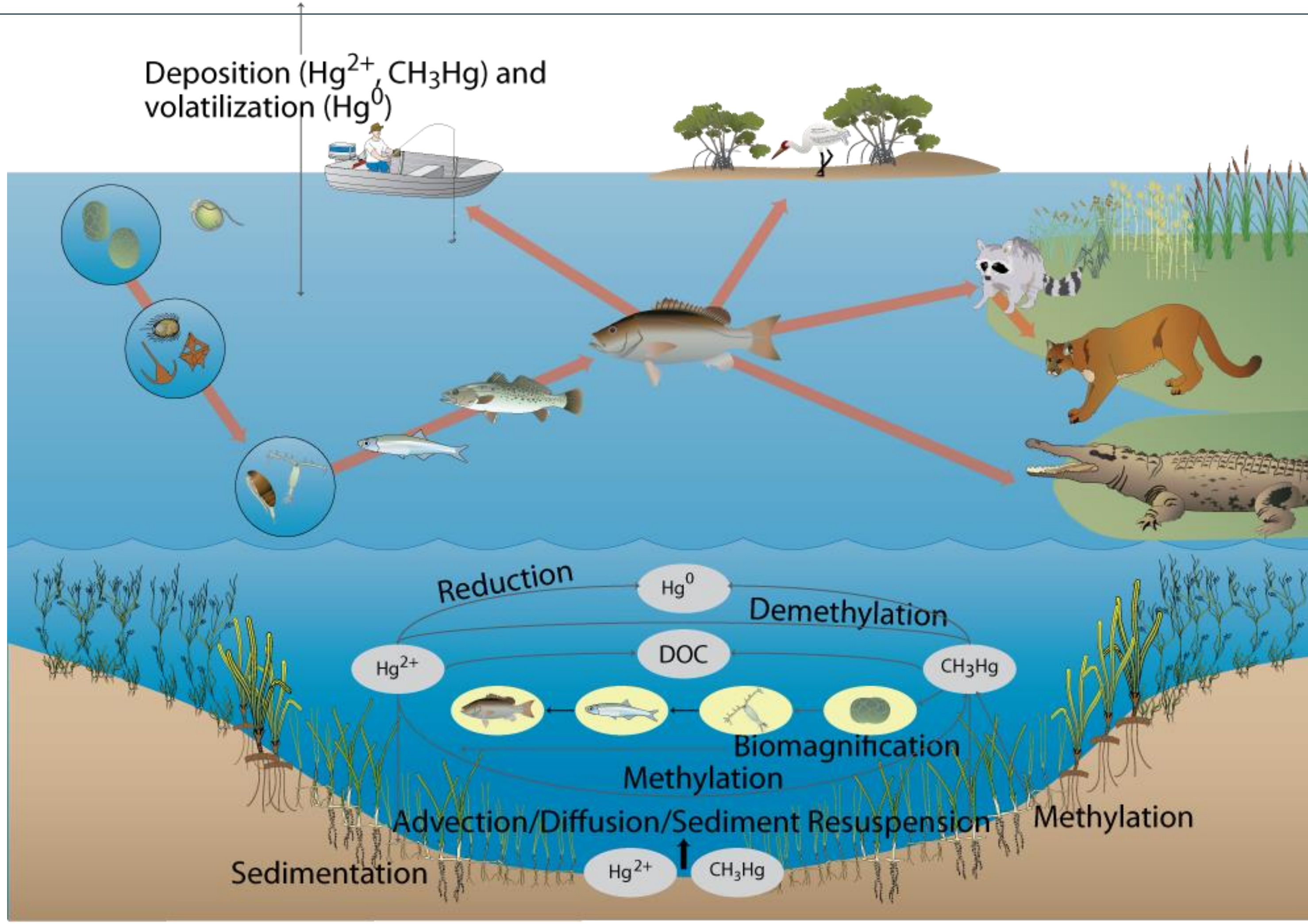
Bioaccumulation and Biomagnification



Methyl mercury is retained (accumulates) in biological tissue more than inorganic mercury

Biomagnification happens through food web transfer as each higher trophic level takes in the chemical body burden of its prey

Transformation in Aquatic Environments (again!)



Conceptual diagram illustrating mercury biomagnification within the aquatic food chain.

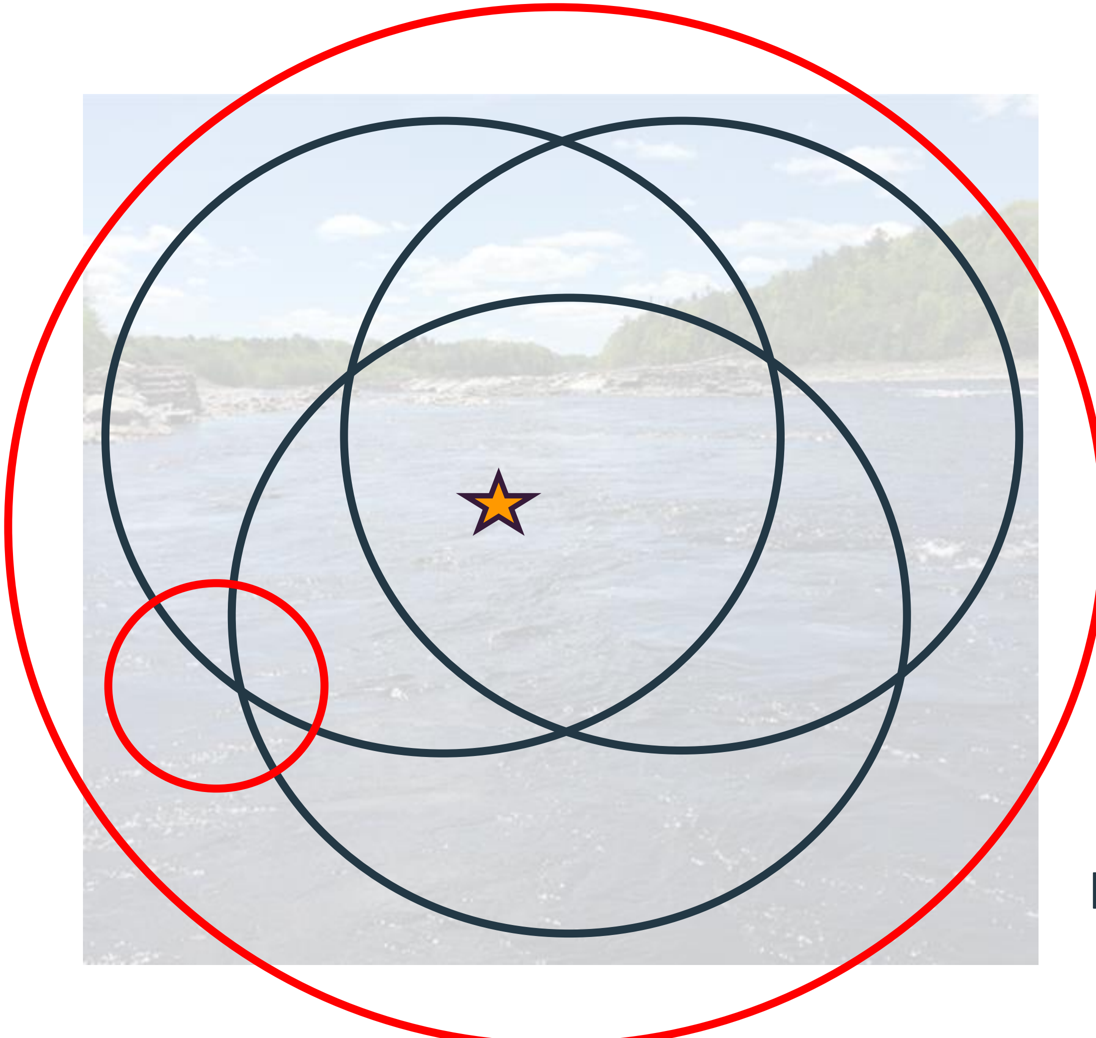
Diagram courtesy of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Kruczynski, W.L., and P.J. Fletcher (eds.). 2012. Tropical Connections: South Florida's marine environment. IAN Press, University of Maryland Center for Environmental Science, Cambridge, Maryland. 492 pp.

PHYSICAL

How sediment-rich is the environment? Is contaminant burial possible?

BIOLOGICAL

How complex is the foodweb? What trophic level(s) is/are principally consumed? Are Endangered and/or culturally important species present?



CHEMICAL

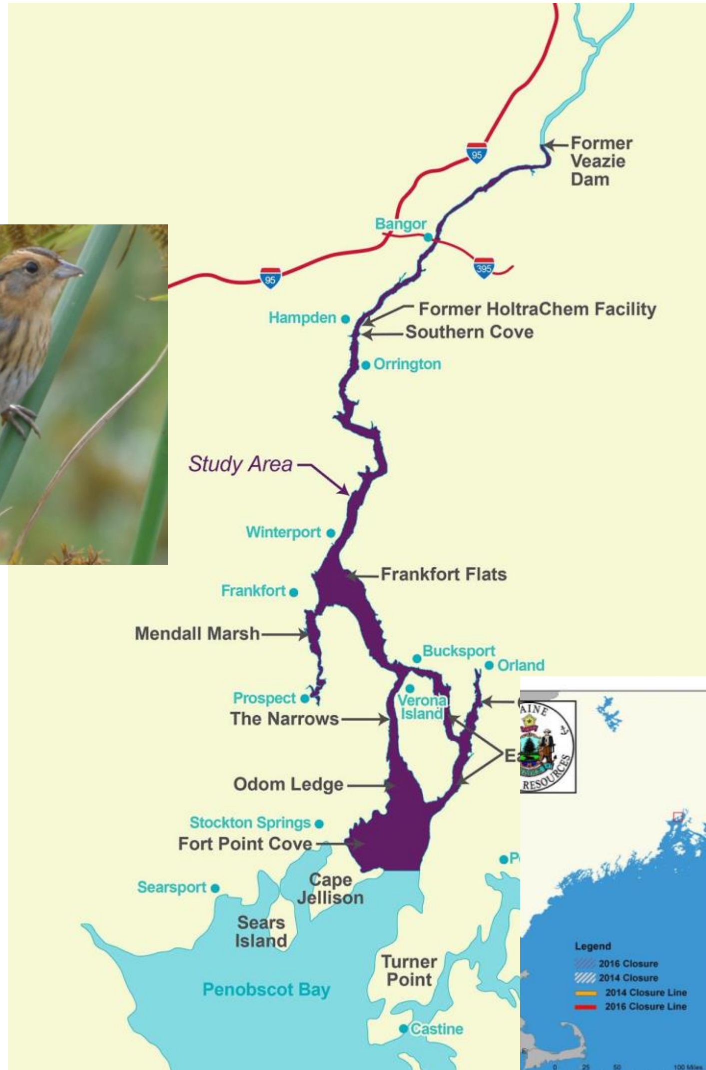
How significantly present are factors contributing to heightened methylation potential (water quality [D.O.], water chemistry [SO_4^{2}], presence of Hg_i)?

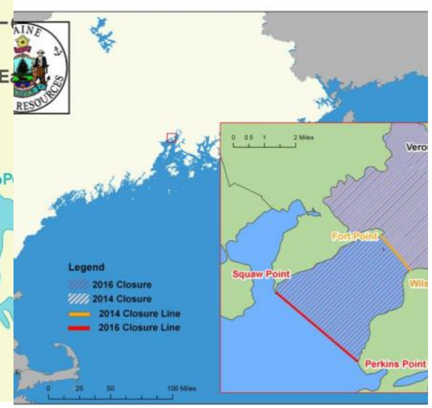
What about the socio-cultural dimension?

How We Understand the Problem (is what guides us)

- Assessment of **potential system-wide recovery** rates w/o active remedy (baseline) – *What if we do nothing to change the rate of system recovery?*
- Evaluation of **risks** and potential **risk reduction** following remedy – *What if we do something? Do we know enough to not do the wrong something?*
- Evaluation of **feasibility**, **potential effectiveness** and **costs** associated with remedial alternatives – *Do we have a good handle on what could go wrong? Do we have plans for the possibility? How about for how to measure the benefits of what goes right to demonstrate that site conditions are improving (and by whose metrics)?*

So, Penobscot…there are additional concerns…





- 700-acre salt marsh in the estuary as a special (and diminishing) habitat for ground-nesting Nelson’s sparrow
- 12 mi^2 in Upper Penobscot Bay closed to lobstering

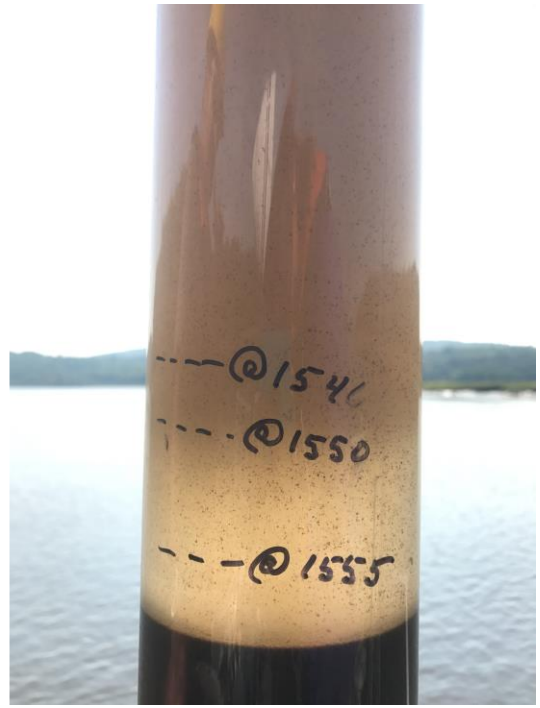
....plus, there's the other industrial use history of the river....

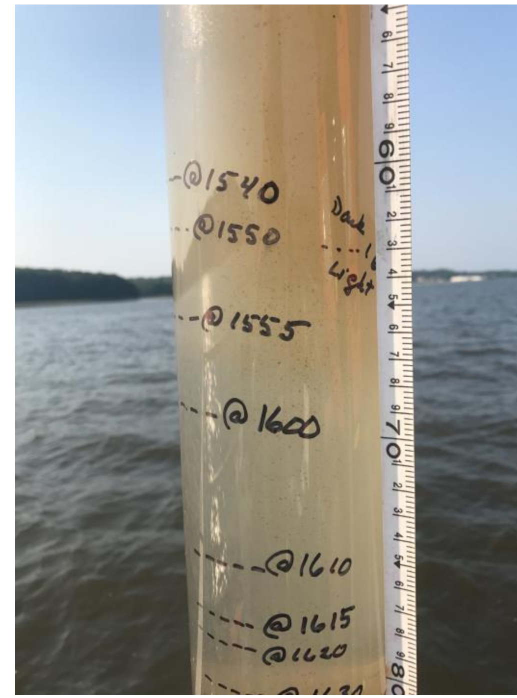
The Penobscot was a lumberman's dream. There were two and a half million acres of the finest White Pine forests in the world and all of it was accessible through the Penobscot River. As a lumber port, Bangor and the Penobscot were without peers. In the fifty-odd years from 1832 to 1888, a total of 8,738,000,000 board feet of lumber were shipped. At its zenith in 1872, Bangor was shipping 250,000,000 board feet of lumber a year. Old-timers today still talk of the times when as boys they jumped from deck to deck of merchant ships to cross the river from Bangor to Brewer. (5) At this time there were four-hundred-ten sawmills on the river and fifty-two of them were between Bangor and Old Town.

Today there are still great islands and bogs of sawdust in the estuary section of the Penobscot. Some of these deposits are up to thirty feet thick. A student hoping to do a thesis on the effect of this sawdust on bottom life in the lower Penobscot had to abandon his original plans when he could not find an area without sawdust present for a control area.

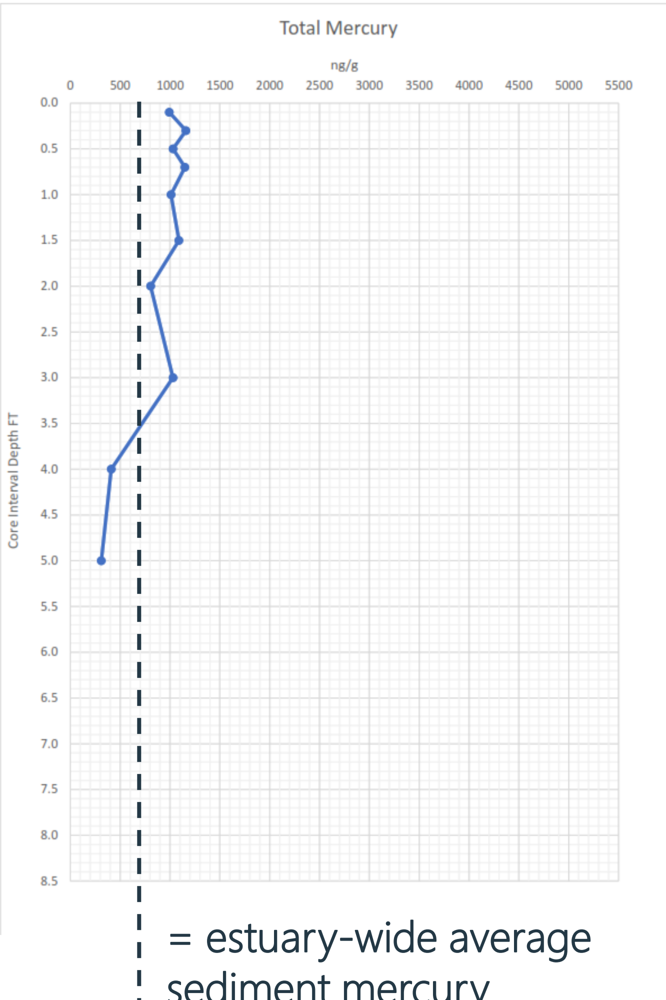
[Bloom, 1971; UMaine MS Thesis]

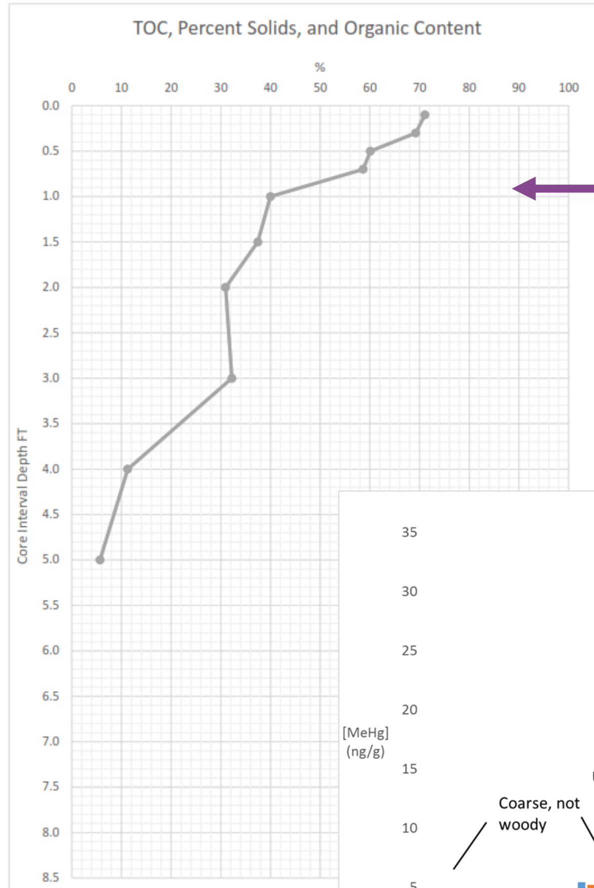
Wood waste - it looks like this:





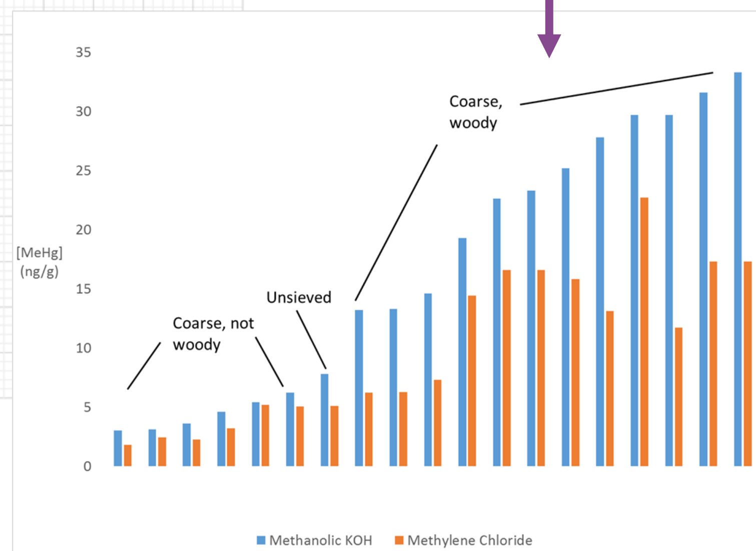
And it acts like this:





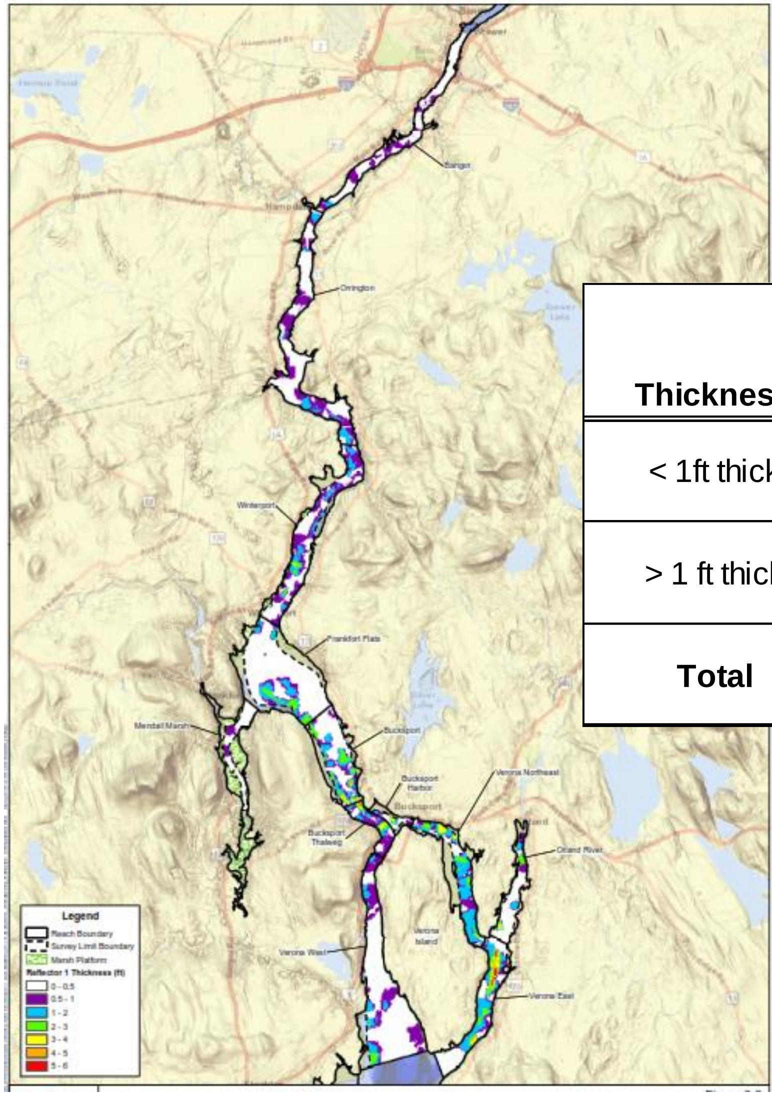
Mercury Transport

Laboratory Analysis



= estuary-wide average sediment mercury concentration

And there's a lot of it (and it's everywhere):



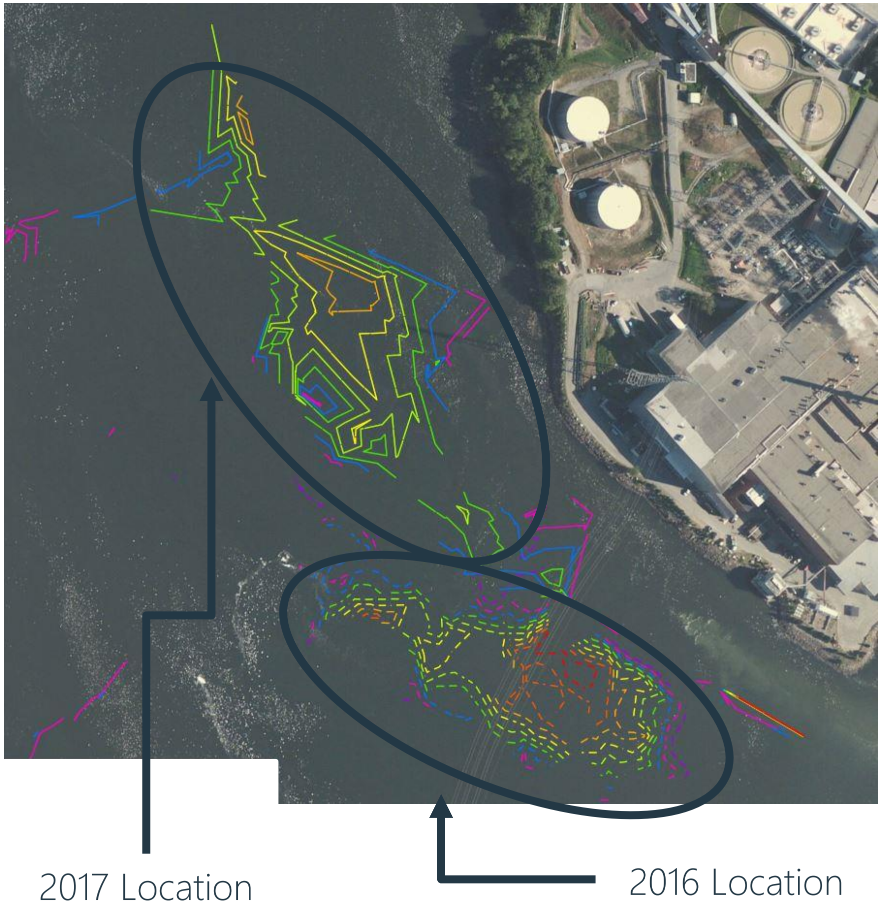
Thickness	Approximate Total Mass (Tons; Wet Weight)	Approximate Total Mass (Tons; Dry Weight)
< 1ft thick	3,340,000	1,620,000
> 1 ft thick	3,120,000	1,510,000
Total	**6,460,000**	**3,130,000**

And some of it appears to move around:

Bucksport Mill Pile:

- Dotted contours = 2016
- Solid contours = 2017

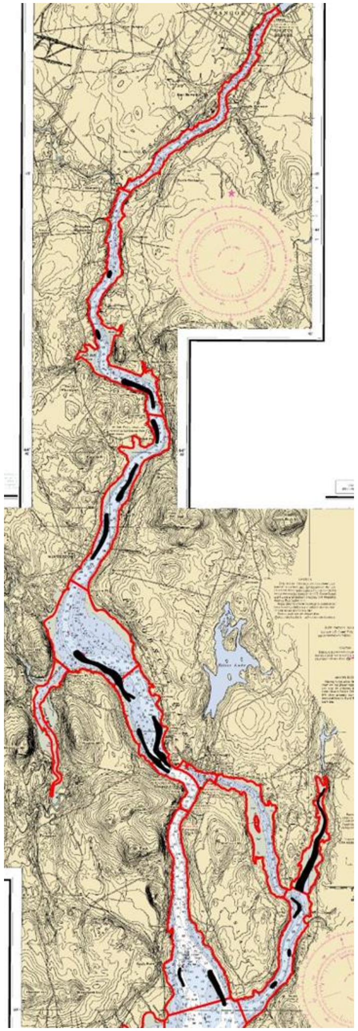
- 2016 Thickness = 8 feet
- 2017 Thickness = 6 feet



And prior to the Phase III Engineering Study:

The wood waste component of particulate matter cycling in the estuary:

- Under-characterized (fate & transport)
- Under-mapped (spatial distribution)
- Under-evaluated ($\tau_{hg} >> \tau_{sed}$)



[Results of 2017 sub-bottom profiling; distribution of Reflector 1 layer; confirmatory coring identified significant wood waste throughout the Reflector 1 layer]

What does this mean for recovery and remedy?

- Lower density than mineral sediment so different transport properties
- Lower density and higher water content than mineral sediment so different material handling needs if dredged
- Doesn't really degrade underwater so loss is principally by washing out of the estuary (1-2% per year?)
- Transport onto marshes may explain very high methylation rates previously measured on Mendall Marsh
- Presence may still be impacting the benthic food web
- Whose responsibility is this co-occurring contaminant?
- How do we evaluate shifting background – sea level rise?
- What does this mean for lobsters and songbirds?

Field Sampling Programs – Overview

How Do We Do This Work? (ex: Phase III Project)

- Project team:
  - 20+ offices in the U.S. and Canada
  - 200+ staff
  - Scientists, risk assessors, statisticians, engineers, project managers, numerical modelers, communications specialists, database managers, GIS mappers, technical writers and production assistants (plus boat captains, sub-contractors etc.)

Field Sampling!

- Biota, sediment and surface water monitoring for eco-risk assessment
- Sediment coring for characterization of COCs and sedimentation rates
- Geophysical surveys to identify sediment types and thicknesses

- Bench-scale treatability studies for dewatering and material handling
- Sediment toxicity testing
- Material erodibility testing

Report Writing (and integrating! and more writing!)