Watershed retention of atmospherically-deposited mercury in Michigan

Implications for recovery of lakes from mercury pollution

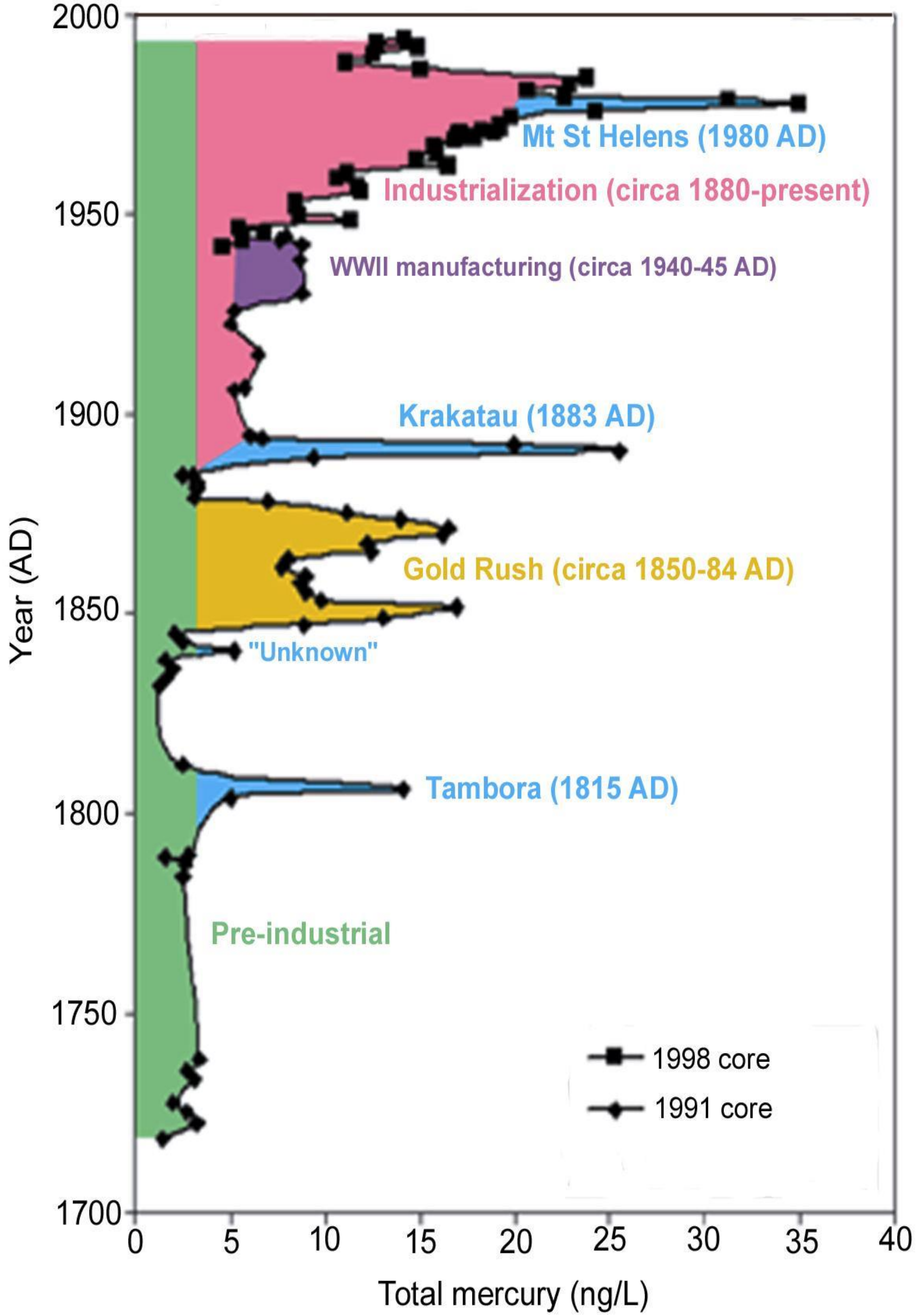
Paul Drevnick, University of Michigan

Defining the problem: methylmercury contamination of fish

789 waterbodies in Michigan currently exceed federal water quality standards for mercury and have been placed on the Section 303(d) list of the federal Clean Water Act

1,813 waterbodies exceed standard in LADCO member states

US EPA



Schuster et al. 2002

A 270-year record of Hg deposition in glacial ice (Upper Fremont Glacier, Wyoming)

Global and regional sources are evident

Last century:
70% anthropogenic
30% natural

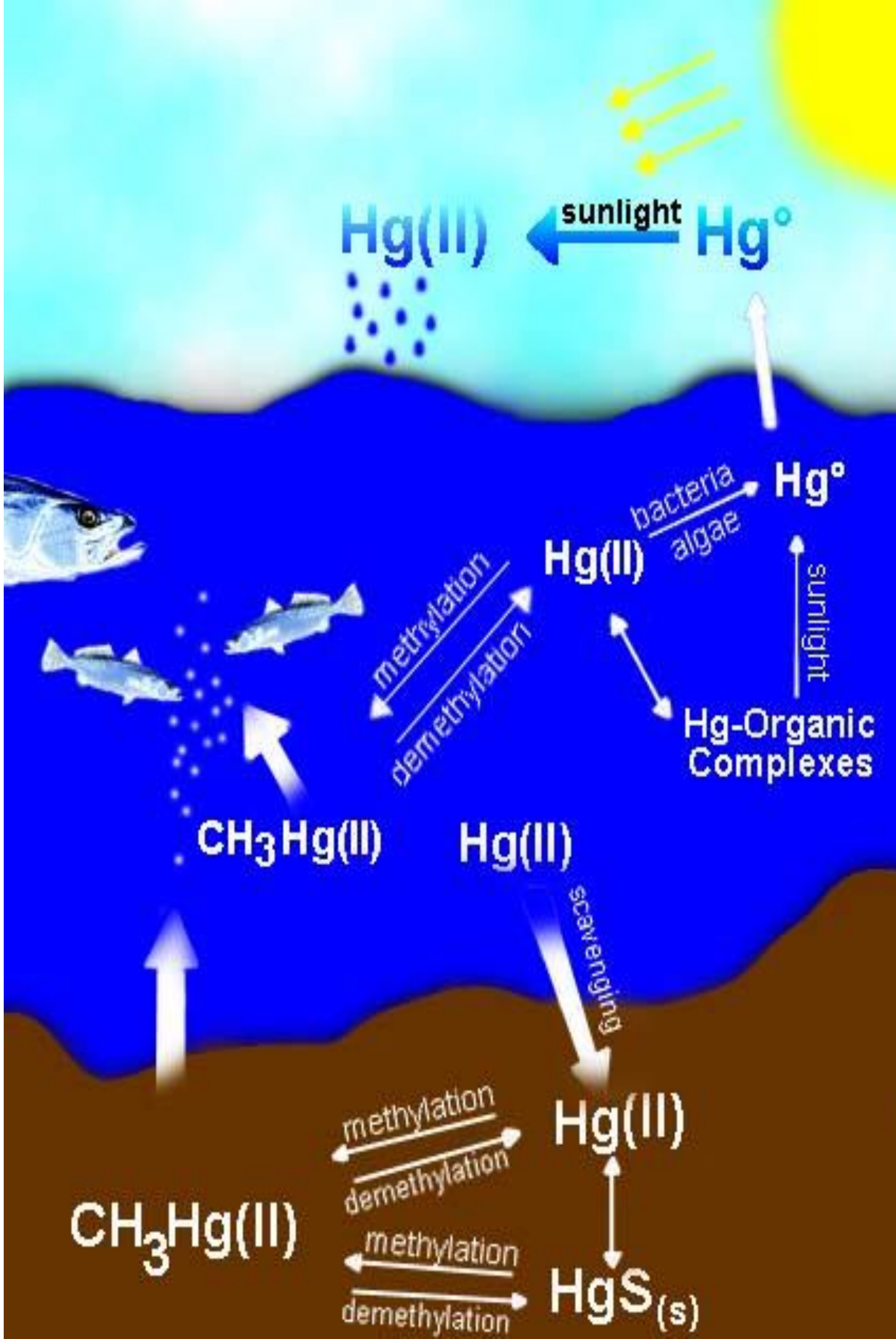
Last decade:
an apparent decline

Mercury in aquatic environs

Methylation of mercury

Biomagnification of methylmercury

High Hg_T concentrations in fish



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Biomagnification in Aquatic Food Webs

	Marine Bay		Wisconsin Lake	
	MeHg (ng/g)	% of Hg_T	MeHg (ng/g)	% of Hg_T
Predatory fish	2,300	>95	650	>95
Prey fish	450	93	100	>90
Invertebrates	150	45	20	29
Algae	7	10	4	13
Water	nd	nd	0.00005	5

Wiener et al. 2003

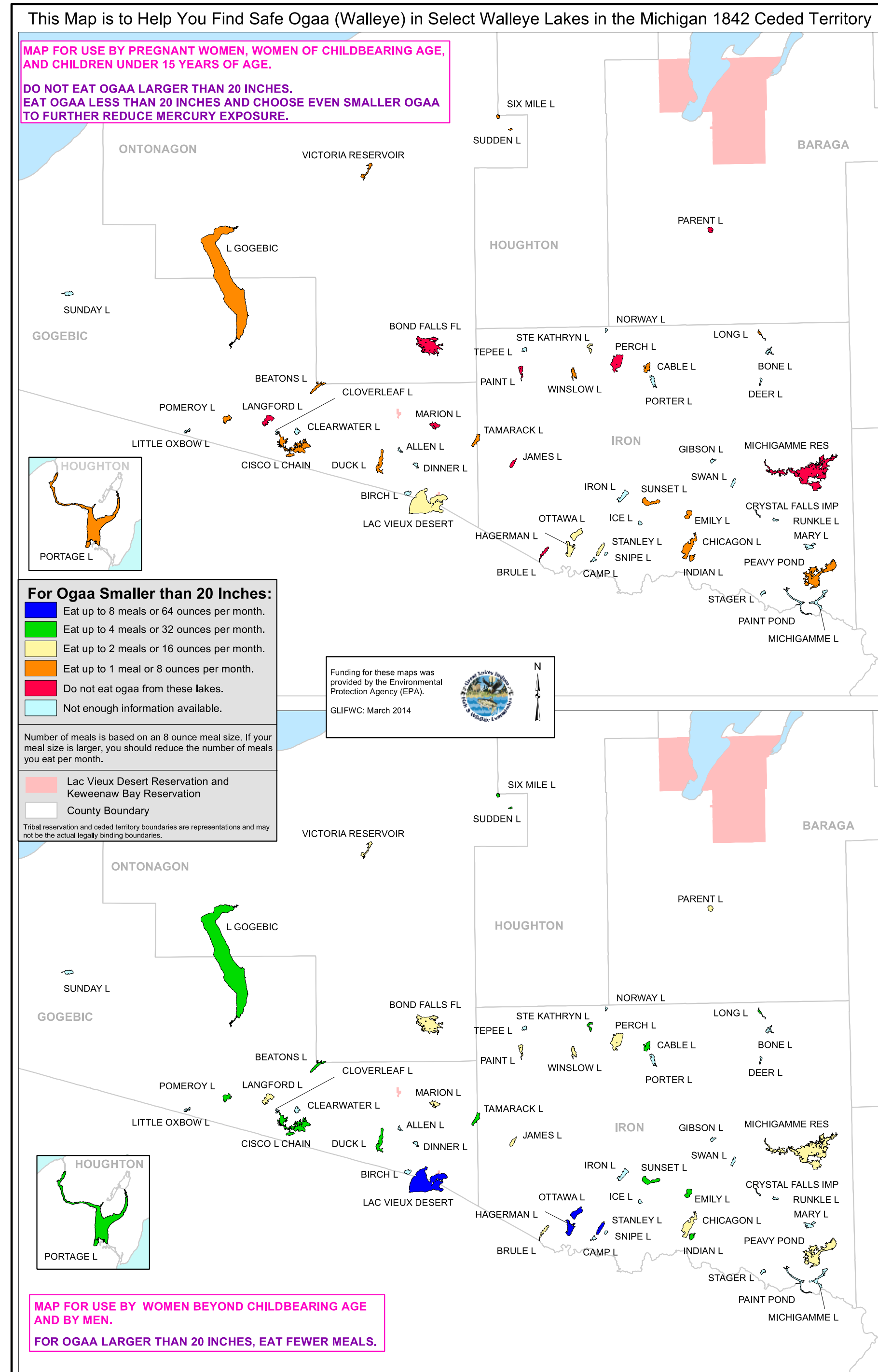
Potential adverse consequences of methylmercury contamination of fish

Health risks to human consumers of fish

Effects of methylmercury exposure on fish and wildlife

Managing the problem:

Fish consumption advisories



GLIFWC

Potential adverse consequences of methylmercury contamination of fish

Health risks to human consumers of fish

Effects of methylmercury exposure on fish and wildlife

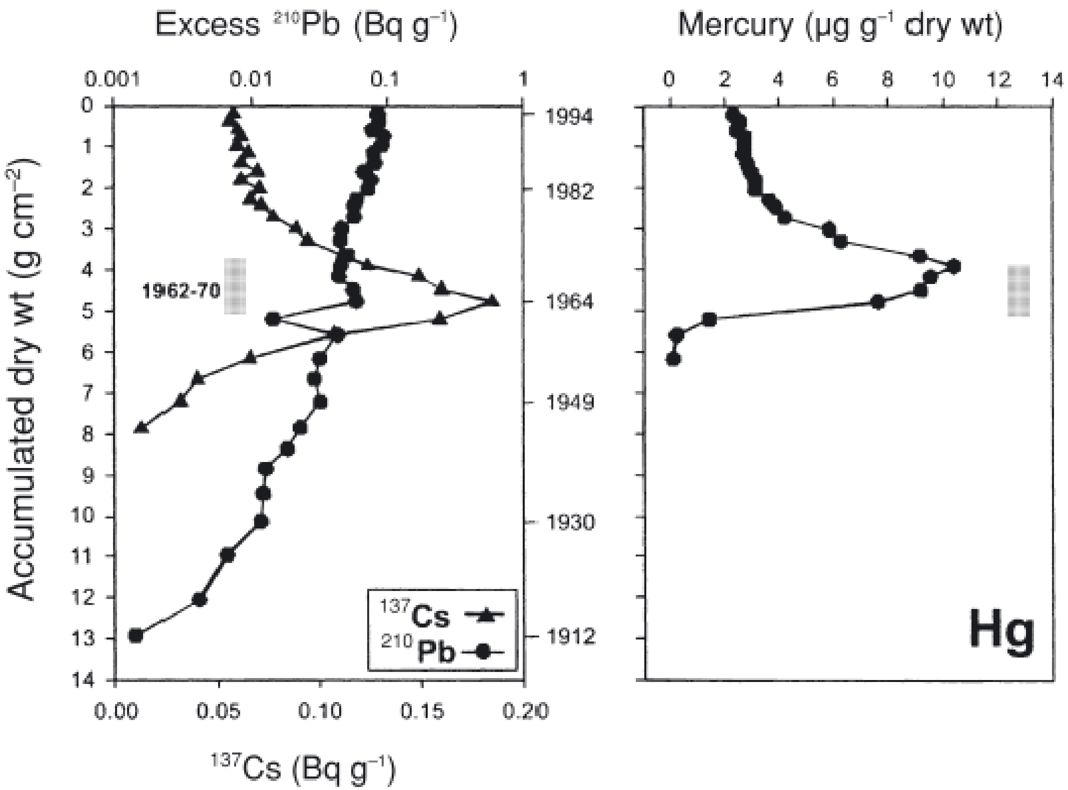
Diminished nutritional, socioeconomic, cultural, and recreational benefits of fishery resources

Socio-cultural damage to Aboriginal communities that fish for subsistence

Managing the problem:

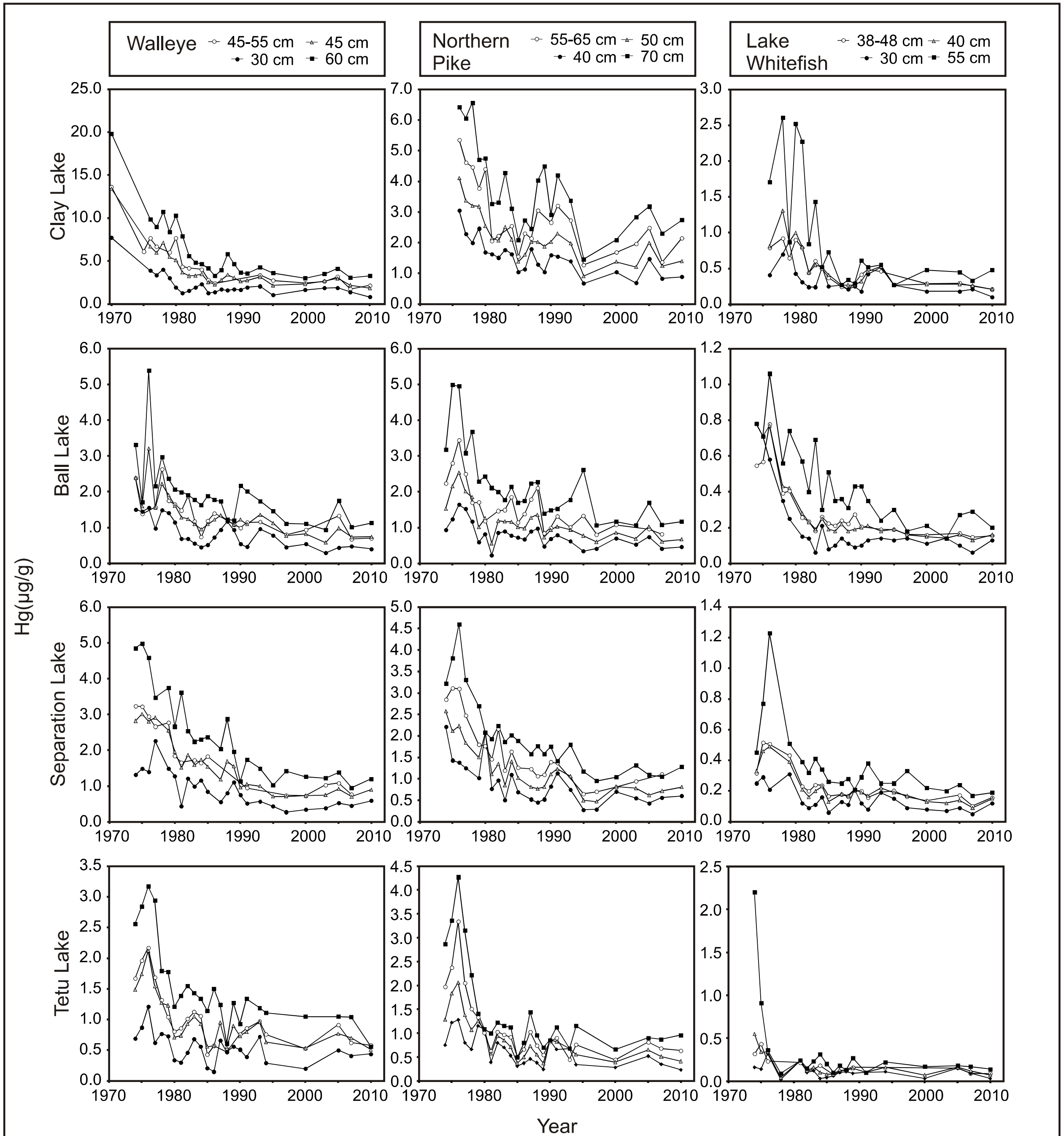
Control releases

Clay Lake, Ontario



Lockhart et al. 2000

Figure S1. Long term trendsi n raw fish mercury concentrations for Walleye, Northern Pike and Lake Whitefish in Clay, Ball (North Basin), Separation and Tetu Lakes.



Neff et al. 2012

Managing the problem: statewide TMDL proposed to address mercury impairment in inland water-bodies primarily due to atmospheric deposition

Requires reducing nonpoint source load by 82%

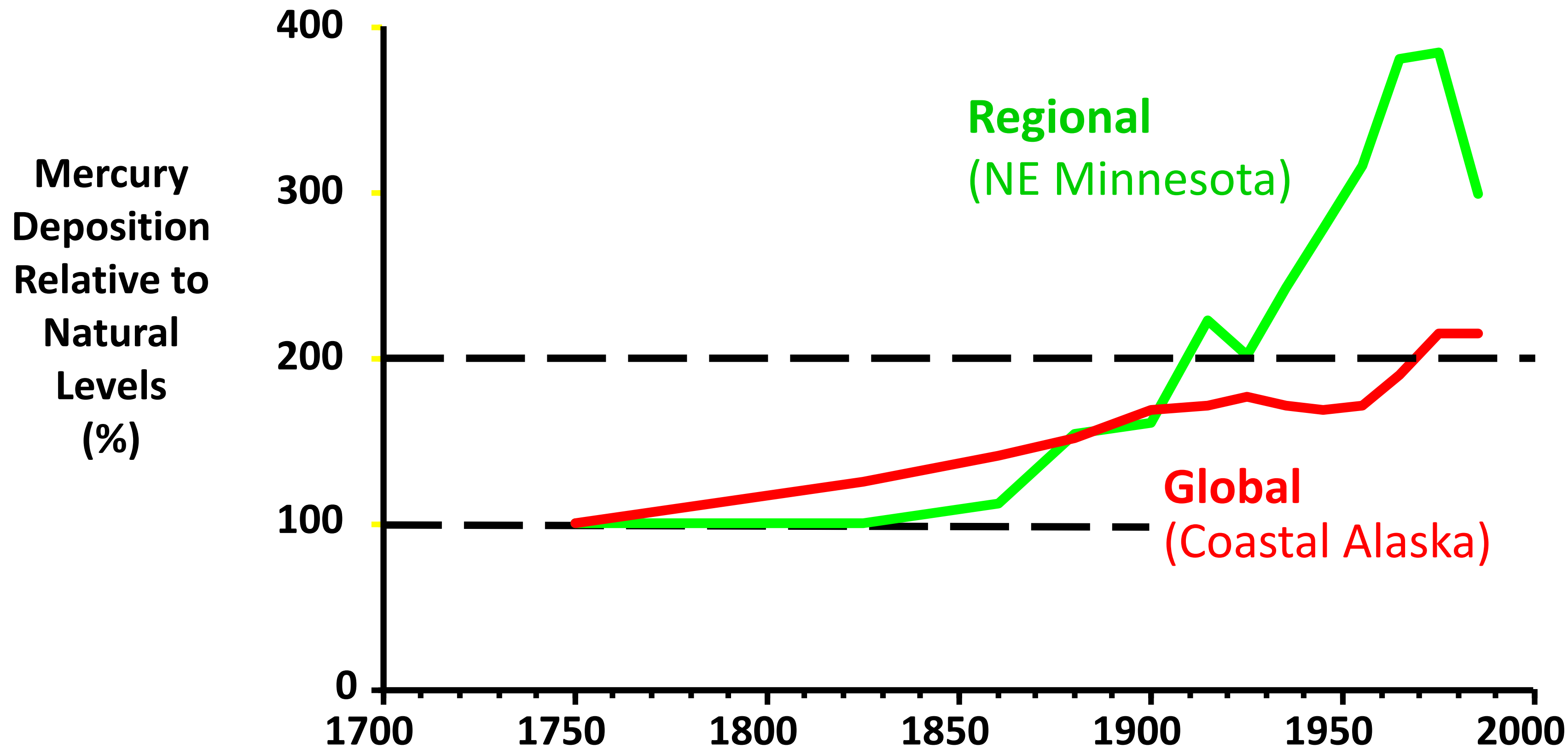
Ultimate goal is to reduce mercury concentration in a legal-size (24-inch) northern pike – statewide – to 0.35 ppm ww

Managing the problem: statewide TMDL proposed to address mercury impairment in inland water-bodies primarily due to atmospheric deposition

Reasonable solution to fulfill a federal requirement

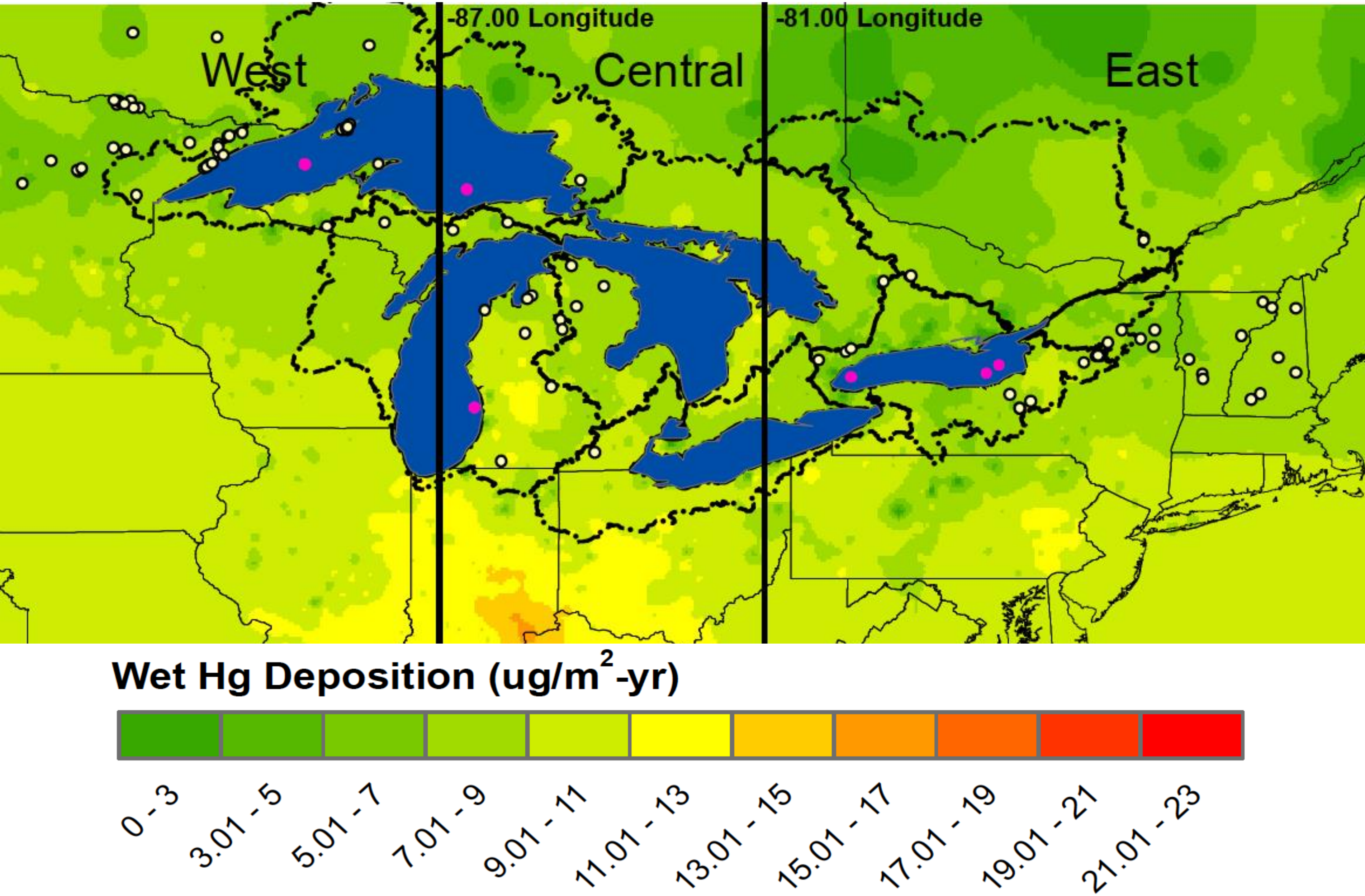
Goals will be difficult to achieve in the near term. Why?

1) State of MI and greater region have effectively managed sources*. Reliance will be on national and international efforts to control mercury releases to atmosphere.

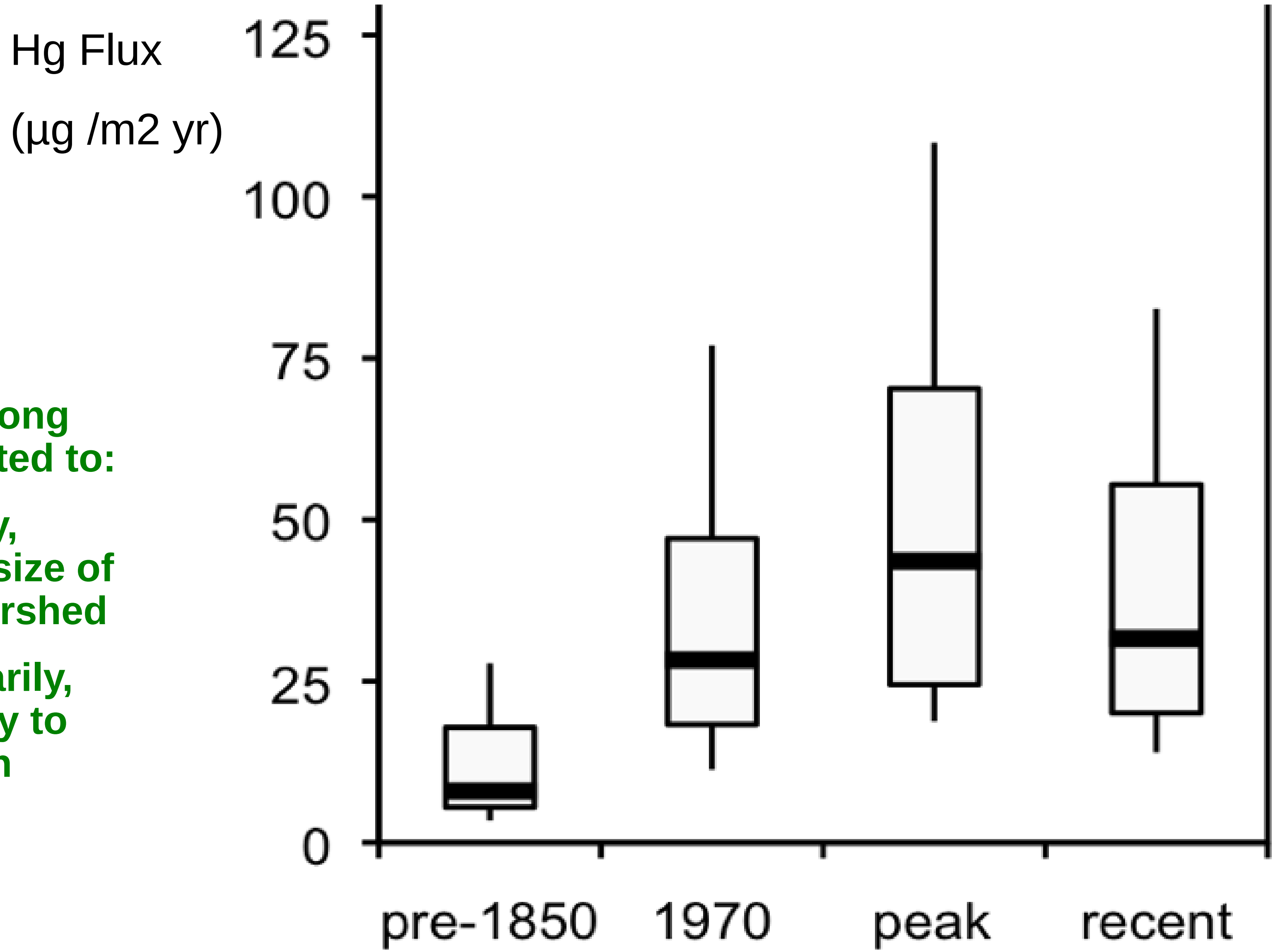


Engstrom and Swain 1997

Spatial and temporal patterns of mercury accumulation in sediment records from across the Great Lakes region; Drevnick et al. 2012



Flux of mercury in sediment cores from inland lakes in Great Lakes region (N=91)



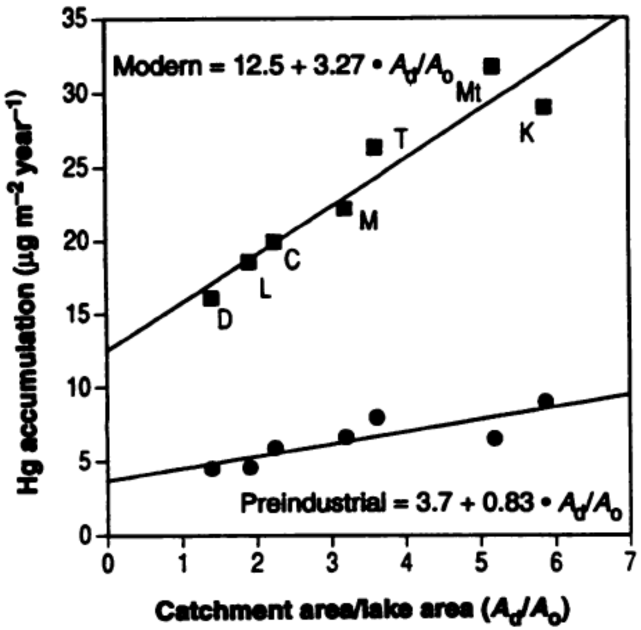
Variation among lakes attributed to:

- **Primarily, relative size of the watershed**
- **Secondarily, proximity to emission sources**

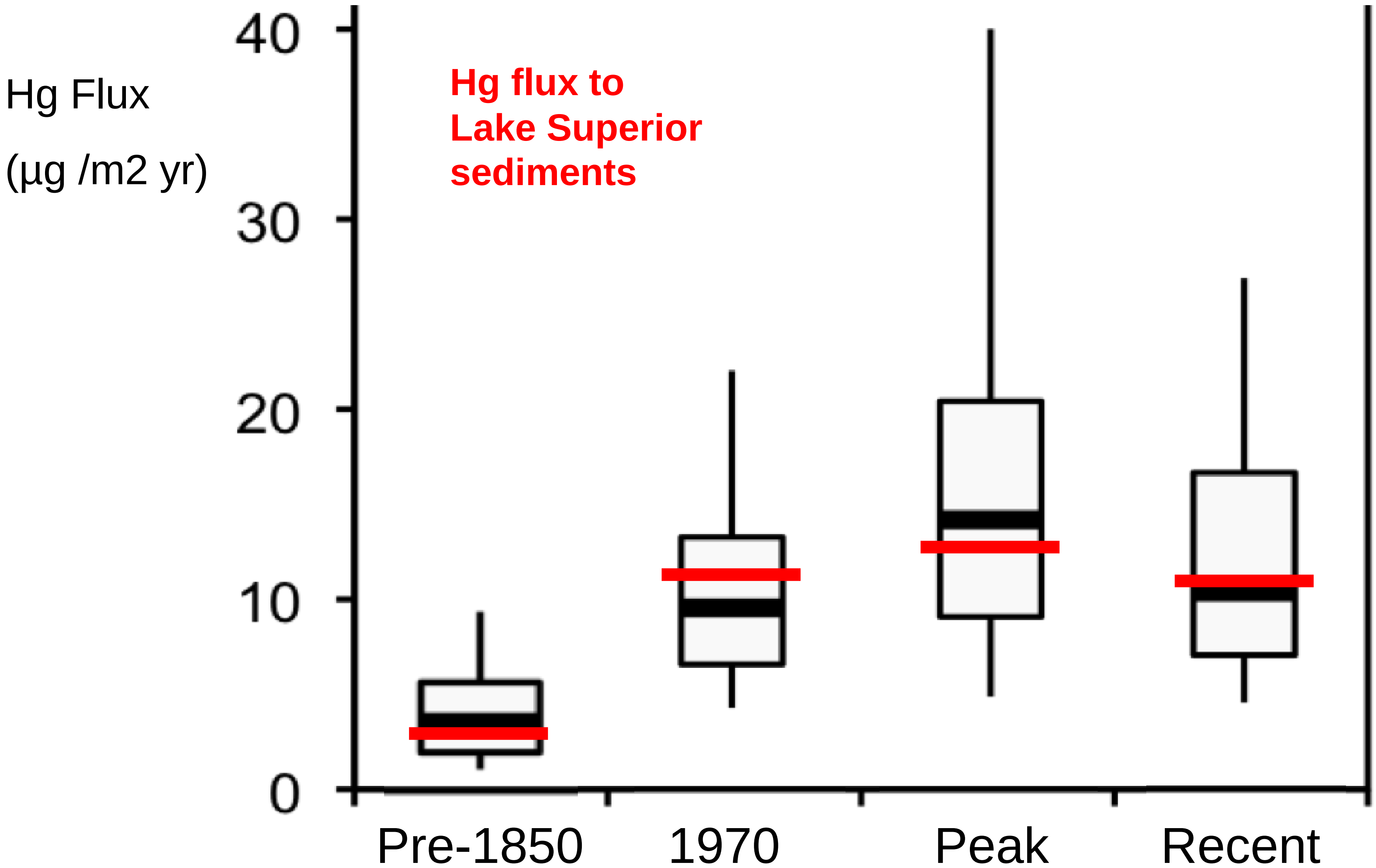
We calculated net atmospheric Hg deposition by correcting sediment Hg flux in each lake for the relative size of the lake's watershed

$$\text{Net Atmospheric Hg flux} = \frac{\text{focus-corrected sediment Hg flux}}{1 + (0.24\ A_W{:}A_L)}$$

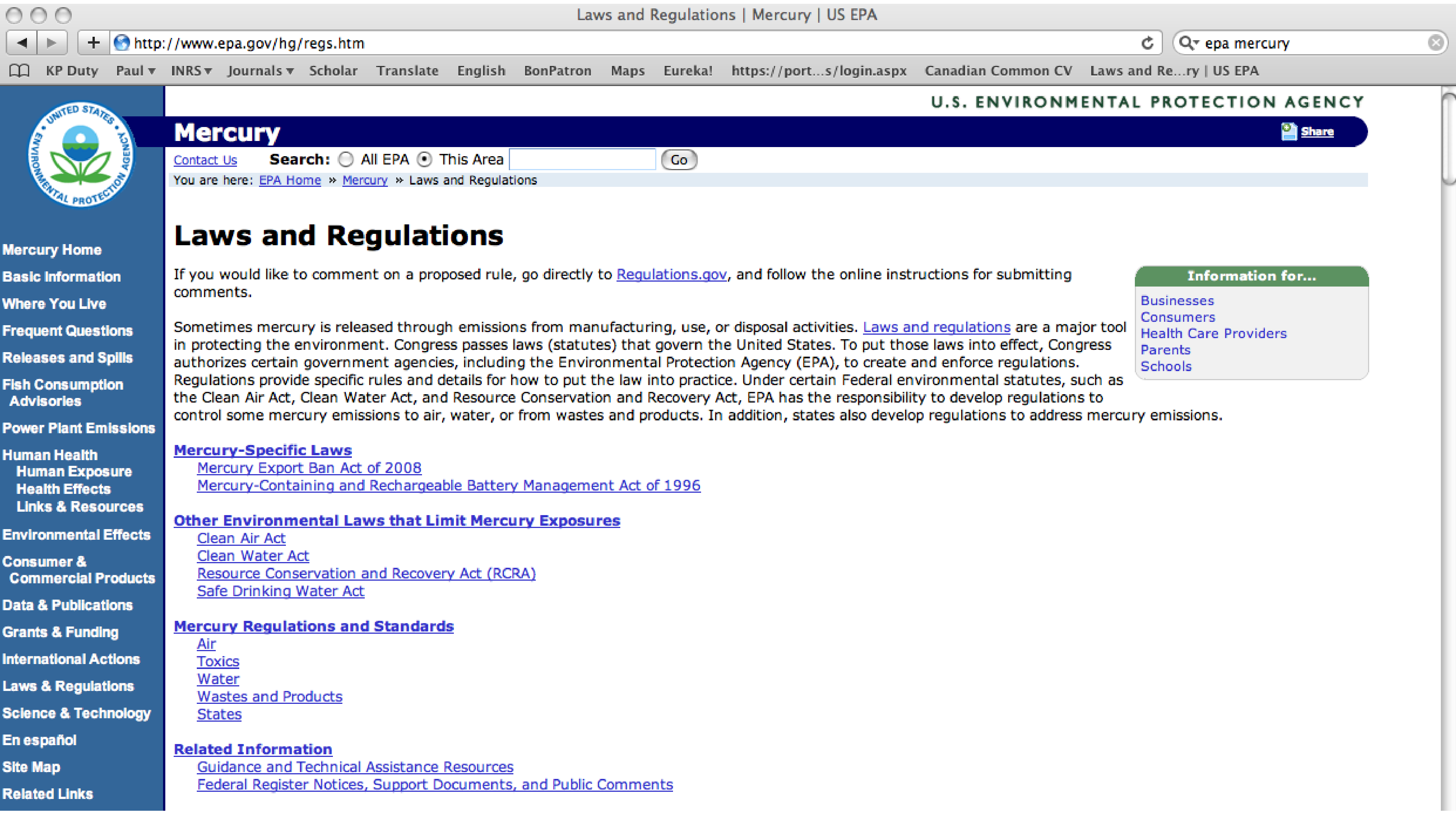
(Rearranged from Swain et al. 1992, assuming 24% of depostion to the watershed is exported to the lake.)



Net atmospheric mercury flux reconstructed from inland lakes in the Great Lakes region



State and National regulations can be effective



Laws and Regulations | Mercury | US EPA

http://www.epa.gov/hg/regs.htm

epa mercury

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Mercury

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Laws and Regulations

If you would like to comment on a proposed rule, go directly to Regulations.gov, and follow the online instructions for submitting comments.

Sometimes mercury is released through emissions from manufacturing, use, or disposal activities. Laws and regulations are a major tool in protecting the environment. Congress passes laws (statutes) that govern the United States. To put those laws into effect, Congress authorizes certain government agencies, including the Environmental Protection Agency (EPA), to create and enforce regulations. Regulations provide specific rules and details for how to put the law into practice. Under certain Federal environmental statutes, such as the Clean Air Act, Clean Water Act, and Resource Conservation and Recovery Act, EPA has the responsibility to develop regulations to control some mercury emissions to air, water, or from wastes and products. In addition, states also develop regulations to address mercury emissions.

Information for...
- Businesses
- Consumers
- Health Care Providers
- Parents
- Schools

Mercury-Specific Laws
- Mercury Export Ban Act of 2008
- Mercury-Containing and Rechargeable Battery Management Act of 1996

Other Environmental Laws that Limit Mercury Exposures
- Clean Air Act
- Clean Water Act
- Resource Conservation and Recovery Act (RCRA)
- Safe Drinking Water Act

Mercury Regulations and Standards
- Air
- Toxics
- Water
- Wastes and Products
- States

Related Information
- Guidance and Technical Assistance Resources
- Federal Register Notices, Support Documents, and Public Comments

State and National regulations can be effective

Laws and Regulations | Mercury | US EPA

http://www.epa.gov/hg/regs.htm

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Mercury Regulations and Standards

Air

In December 2011, EPA issued the first national standards for mercury pollution from power plants. MATS are the first national standards to protect American families from power plant emissions of mercury and toxic air pollution like arsenic, acid gas, nickel, selenium, and cyanide. The standards will slash emissions of these dangerous pollutants by relying on widely available, proven pollution controls that are already in use at more than half of the nation's coal-fired power plants. Read the press release | Learn more about these actions | Read the final rule (PDF) | View President Obama's video blog about protecting American families and the environment from mercury pollution (1:32 minutes).

Power Plants and Air Pollution

- Power plants and air pollution
- Ozone and particle pollution (Cross-State Air Pollution Rule)
- Greenhouse gas emissions
- Mercury and air toxics

On August 9, 2010, EPA issued a final rule to limit emissions of mercury and other toxics from Portland cement plants. This rule was published in the Federal Register on September 9, 2010. The rule adds or revises, as applicable, emission limits for mercury, total hydrocarbons (THC), and particulate matter (PM) from new and existing kilns located at major and area sources, and for hydrochloric acid (HCl) from new and existing kilns located at major sources. The standards for new kilns apply to facilities that commence construction, modification, or reconstruction after May 6, 2009.

On April 22, 2004, EPA issued a regulation to control emissions from iron and steel foundries. The rule included emission limits for manufacturing processes and pollution prevention-based requirements to reduce air toxics from furnace charge materials and coating/binder formulations. The rule also included a work practice requirement to ensure removal of auto mercury switches from scrap.

On May 20, 2005, EPA issued a direct final rule amending the work practice requirements for materials certification and scrap selection/inspection programs. The direct final amendments added clarification and flexibility but do not materially change the requirements of the April 22, 2004 rule.

On December 28, 2007, EPA issued a final National Emission Standards for Hazardous Air Pollutants (NESHAP) rule for electric arc furnace steelmaking facilities. The final rule established requirements for the control of mercury emissions that are based on the maximum achievable control technology and requirements for the control of other hazardous air pollutants that are based on generally available control technology or management practices. The Quicksilver Caucus of the Environmental Council of the States issued a fact sheet about this rule designed to help state and local agencies (PDF) (8 pp, 86K) EXIT Disclaimer understand how this rule applies to mercury emissions.

View more information about the iron and steel foundries NESHAP.

Development of standards for emissions of mercury from power plants / Clean Air Mercury Rule (vacated February 2008)

Reduction of Toxic Air Pollutants from Mercury Cell Chlor-Alkali Plants; Final Rule - December 19, 2003 - The final rule reduces mercury emissions from mercury cell chlor-alkali plants that are considered "major sources" of hazardous air pollutants as well as facilities considered to be "area sources." Mercury cell chlor-alkali plants produce chlorine and caustic using mercury cells.

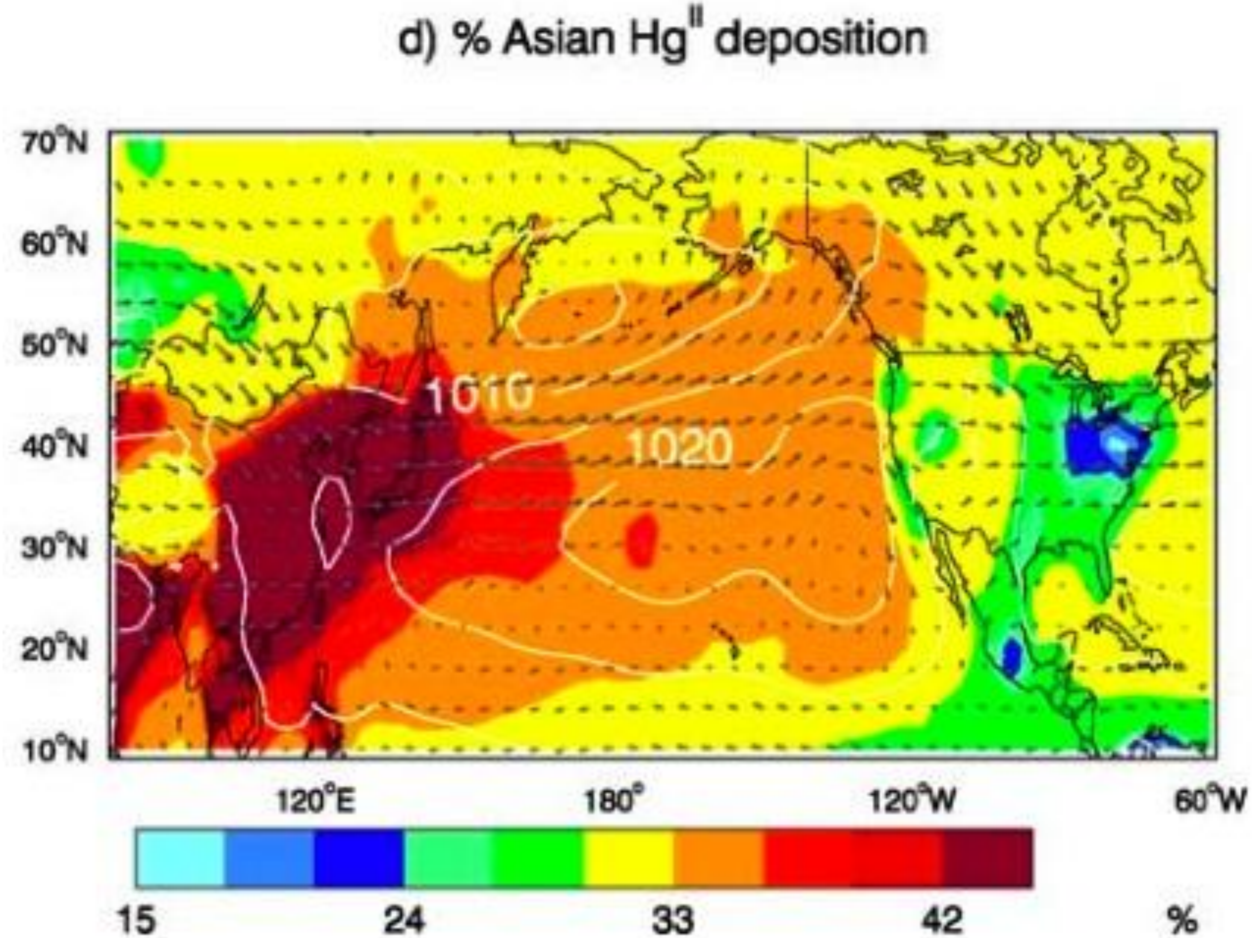
Solid Waste Combustion Rules (Section 129) (PDF) (1 pg, 13K) - Find information about EPA's air emission regulations for large and small municipal waste combustors; hospital, medical and infectious waste incinerators; and commercial and industrial solid waste incinerators and, other solid waste incinerators (e.g., very small municipal waste combustors, institutional waste incinerators, etc.). Regulatory text, technical information, compliance and enforcement information, implementation guidance for states, and related links are provided.

Reduction of Toxic Air Emissions from Combustion Sources that Burn Hazardous Waste - This proposed rule would reduce emissions of toxic air pollutants, including mercury, from five types of combustion sources that burn hazardous waste (incinerators, cement kilns, lightweight aggregate kilns, boilers, and hydrochloric acid production furnaces). Sources that would be affected by the proposal combust hazardous waste in order to treat or detoxify the waste.

Reduction of Toxic Air Emissions from Industrial, Commercial, and Institutional Boilers and Process Heaters - This final rule reduces toxic air pollutants, including mercury, from industrial, commercial, and institutional boilers and process heaters. Boilers burn coal and/or other substances such as wood to produce steam. The steam is used to produce electricity or provide heat. Process heaters heat raw or intermediate material during an industrial process. This rule limits the amount of air toxics that may be released from exhaust stacks of all new (built after January 13, 2003) and existing large and limited use solid fuel boilers and process heaters that are located at facilities considered to be major sources of air toxics.

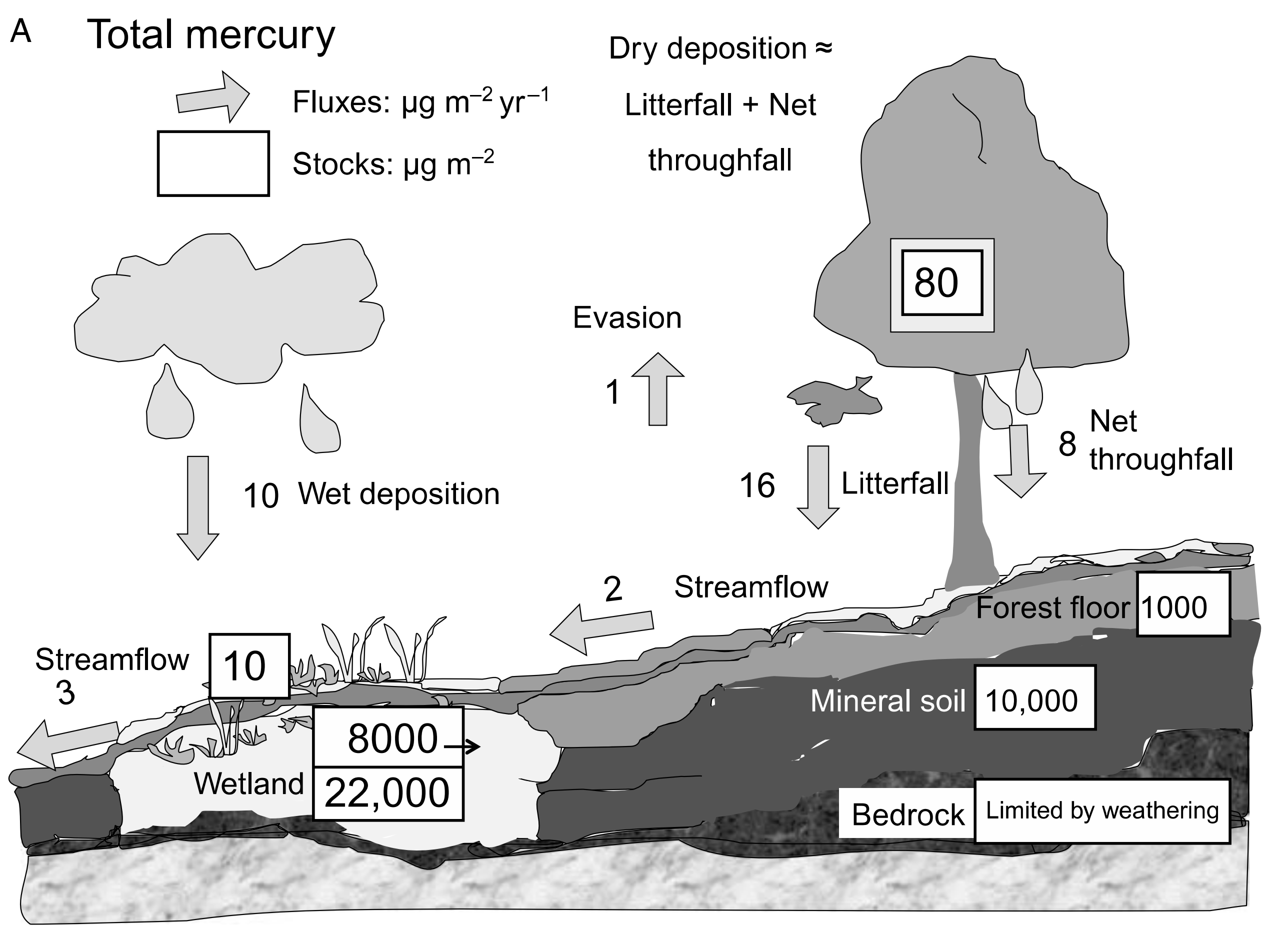
Top of page

Strode et al. 2008



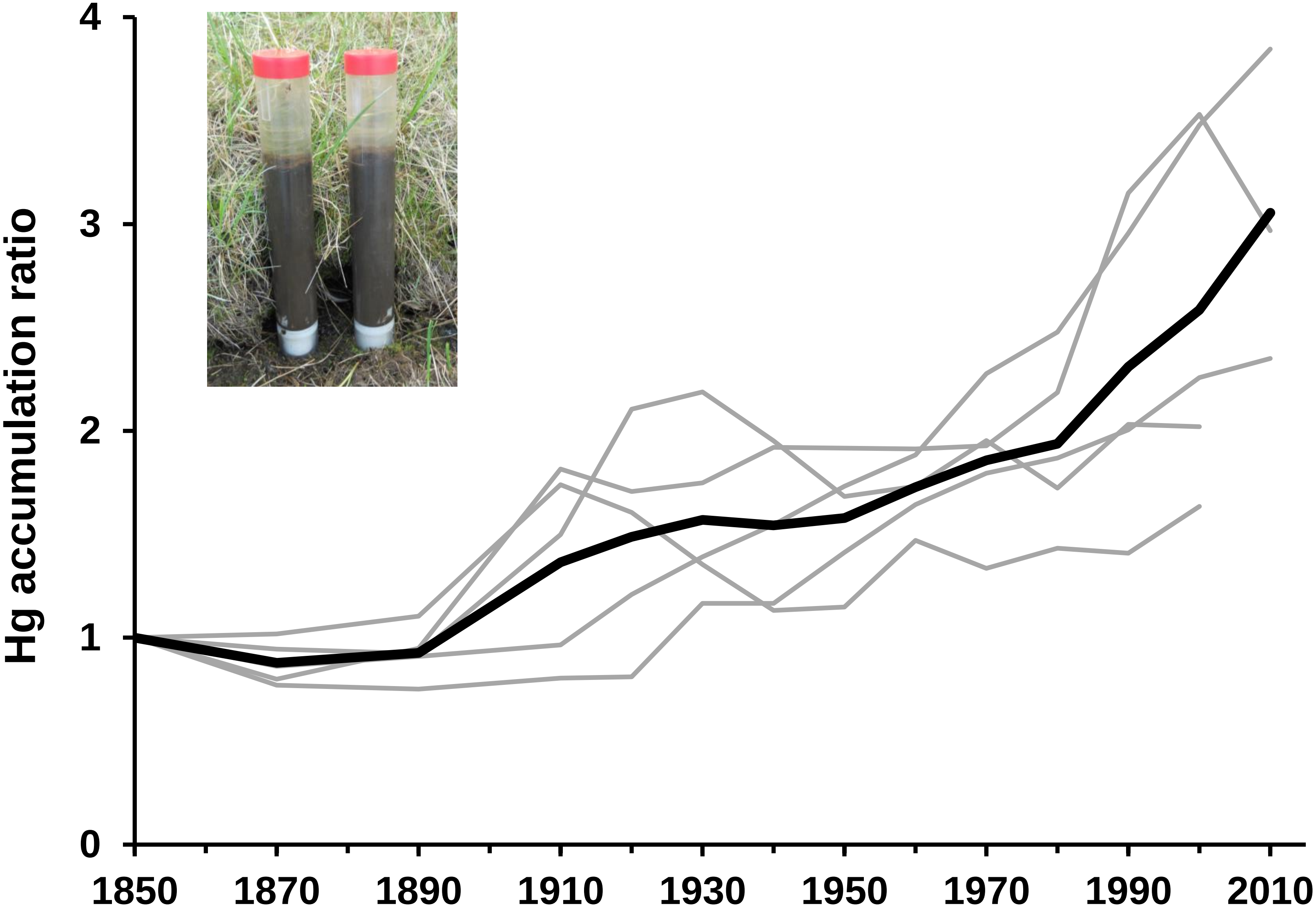
The new UN Minamata Convention on Mercury includes a ban on new mercury mines, the phase-out of existing ones, control measures on air emissions, and the international regulation of the informal sector for artisanal and small-scale gold mining.

2) watersheds: output of "old" mercury (from a legacy of past deposition) and/or changes in the retention of "new" mercury



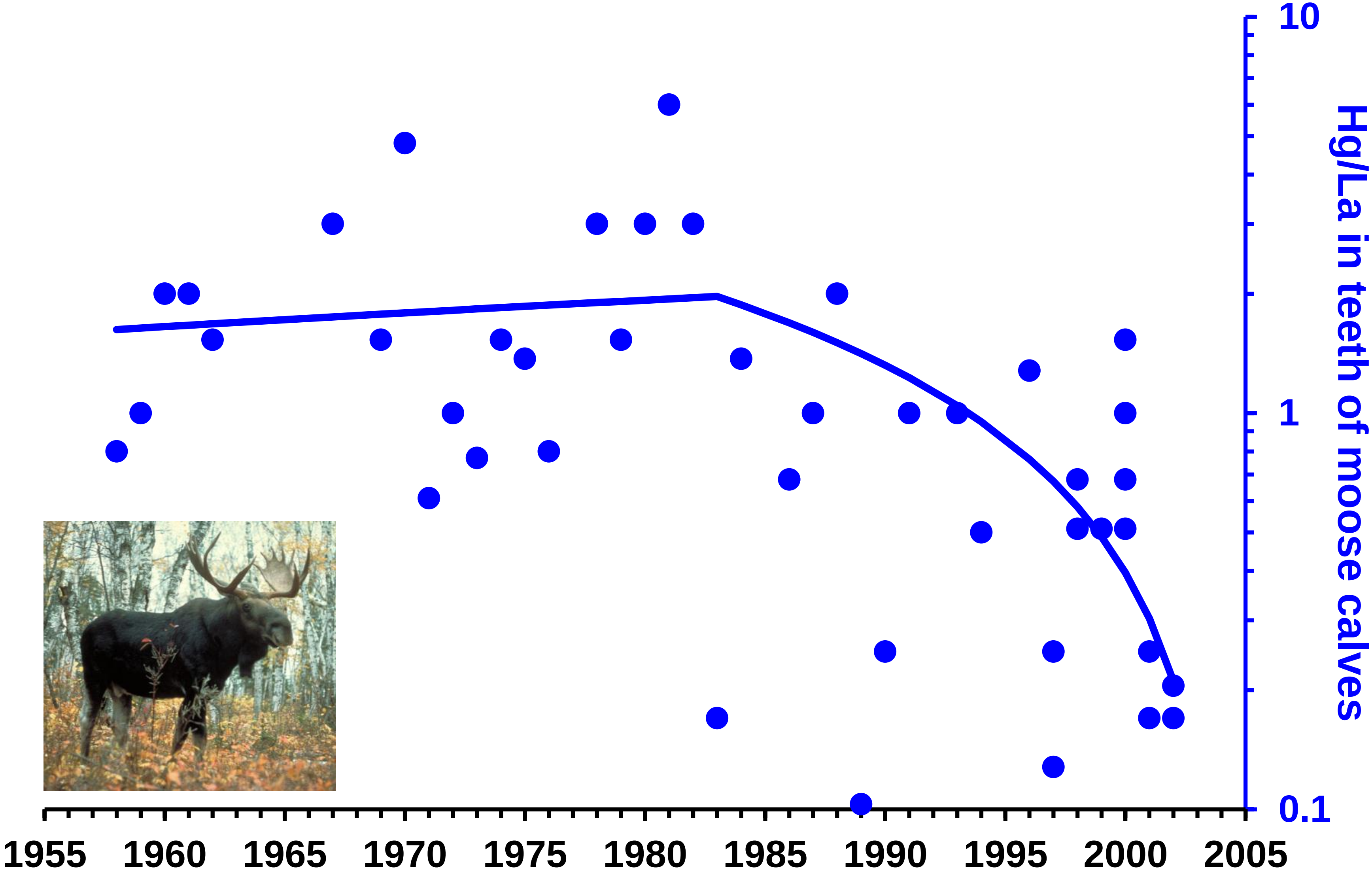
Shanley and Bishop 2012

Isle Royale: of mud and moose



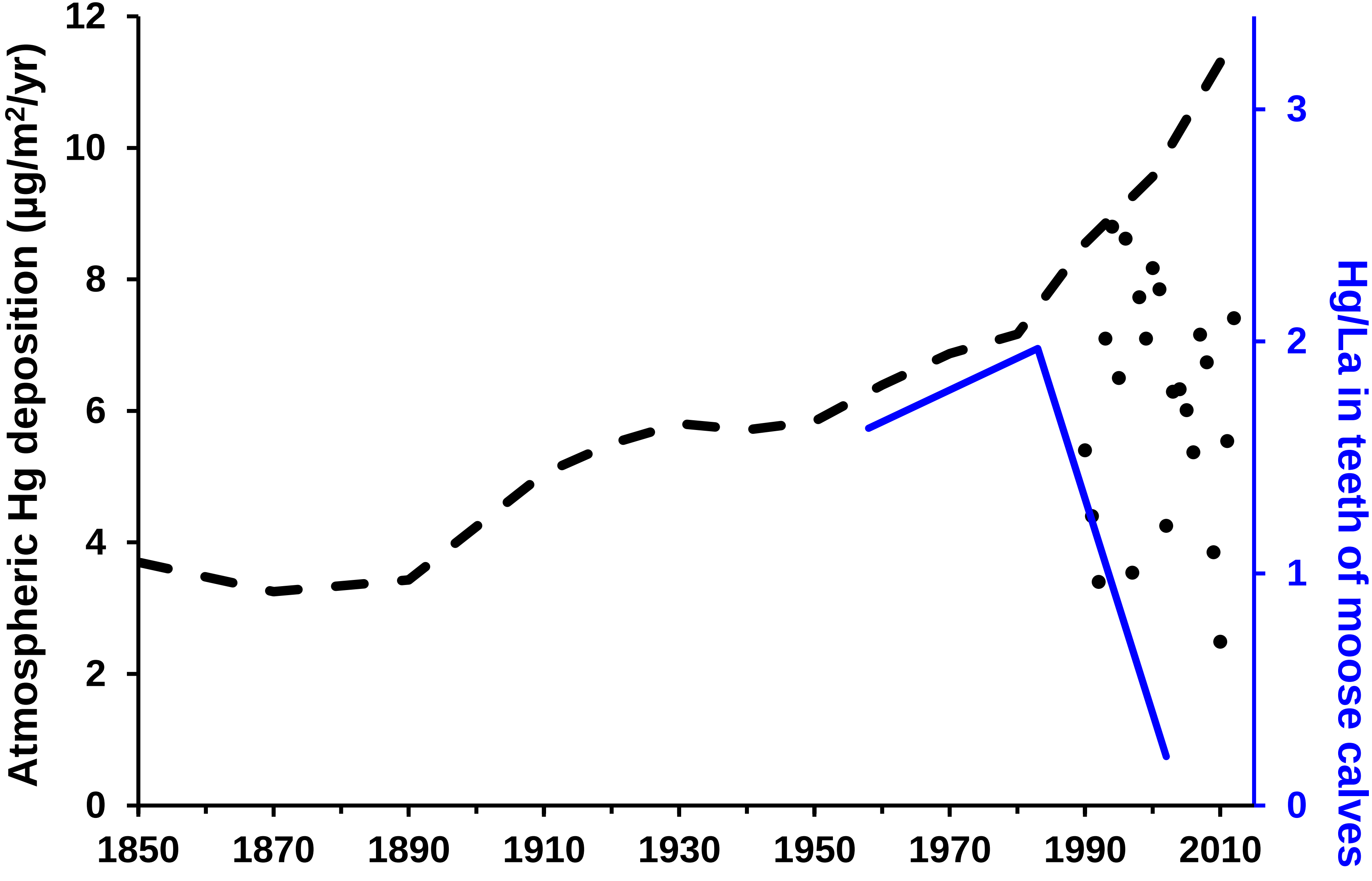
Drevnick et al. 2007; Campbell and Drevnick 2015

Isle Royale: of mud and moose



Vucetich et al. 2009; Campbell and Drevnick 2015

Isle Royale: of mud and moose



Vucetich et al. 2009; Campbell and Drevnick 2015

3) Recent increases in Hg_T in biota

Recent Increases in Mercury in Fish and Wildlife

Several studies report that in some areas and in certain species in the Great Lakes region, mercury concentrations may again be on the rise (Figure 17). Since the 1990s, increases in previously declining mercury concentrations have been found in walleye from the province of Ontario and in walleye and northern pike from Minnesota (Monson et al. 2011, Monson 2009), though levels are still lower than peak mercury concentrations in the 1970s. A more recent increase, beginning in 2005, was identified in walleye from Lake Erie (Bhavsar et al. 2010, Zananski et al. 2011). Mercury has also increased in adult loon blood mercury from northern Wisconsin (Meyer et al. 2011) and bald eagles from Voyageur National Park (Pittman et al. 2011). Beyond North America, a similar biphasic pattern has been detected in northern pike in Swedish lakes (Akerblom et al. 2011).

The reasons for these recent apparent increases—and whether they are consistent trends or short-term oscillations within a long-term decline—are not fully understood. Several hypotheses have been presented to explain this shift including factors influenced by changing climate (Monson 2009), lower water levels, and greater exposed shoreline associated with drought (Meyer et al. 2011), changes in food webs associated with introduced exotic species (Monson et al. 2011), and reversal of the biodilution effect through decreases in nutrient loading (Zananski et al. 2011).

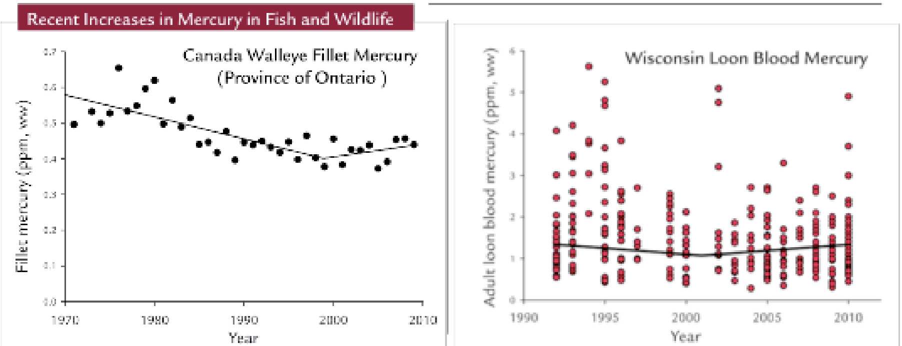
Focused research and monitoring are needed to confirm and interpret these trends, yet it seems plausible that changes in disturbance regimes can increase mercury sensitivity and therefore change the trajectory of methylmercury concentrations in fish and wildlife (Munthe et al. 2007). These interactive effects complicate predictions of how mercury may change over time in the future and further highlight the need for enhanced mercury monitoring.

The complexity of interpreting the spatial patterns and temporal trends in environmental contamination and methylmercury in biota highlight the need for mercury monitoring that is comprehensive (e.g., linking measurements in air, water, sediment, and biota) and large-scale (i.e., regional to national), and that utilizes a probability-based design with repeat sampling to improve prediction and assessment capabilities.

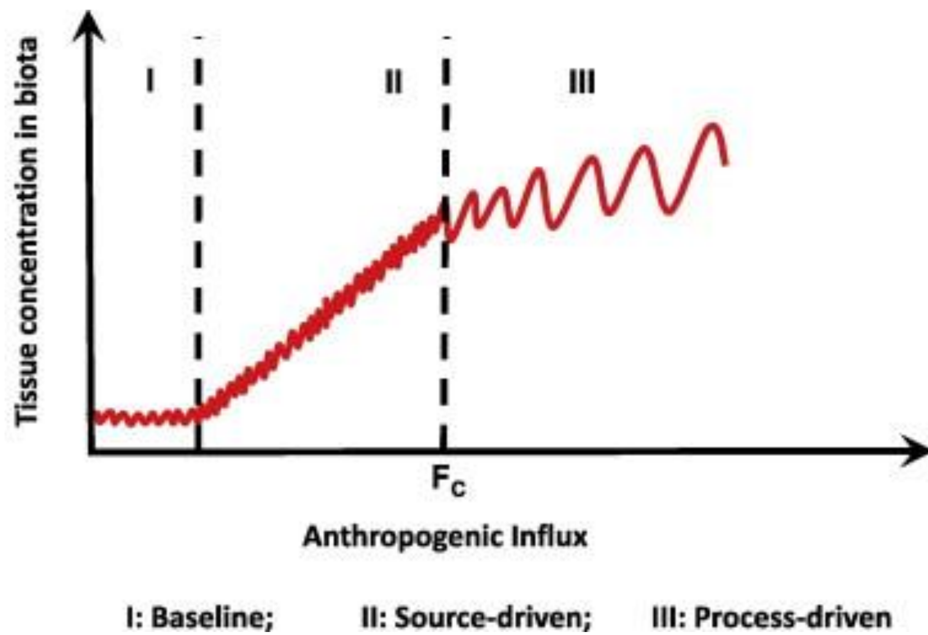
Figure 17

Several studies have found evidence that in some areas and in certain biological species in the Great Lakes region, mercury concentrations may again be on the rise. Monson et al. (2011) found a recent increase in previously declining mercury concentrations in walleye fillets from the province of Ontario. Meyer et al. (2011) saw a 1.8 percent per year increase in common loon adult and chick blood mercury concentrations from northern Wisconsin.

Recent Increases in Mercury in Fish and Wildlife

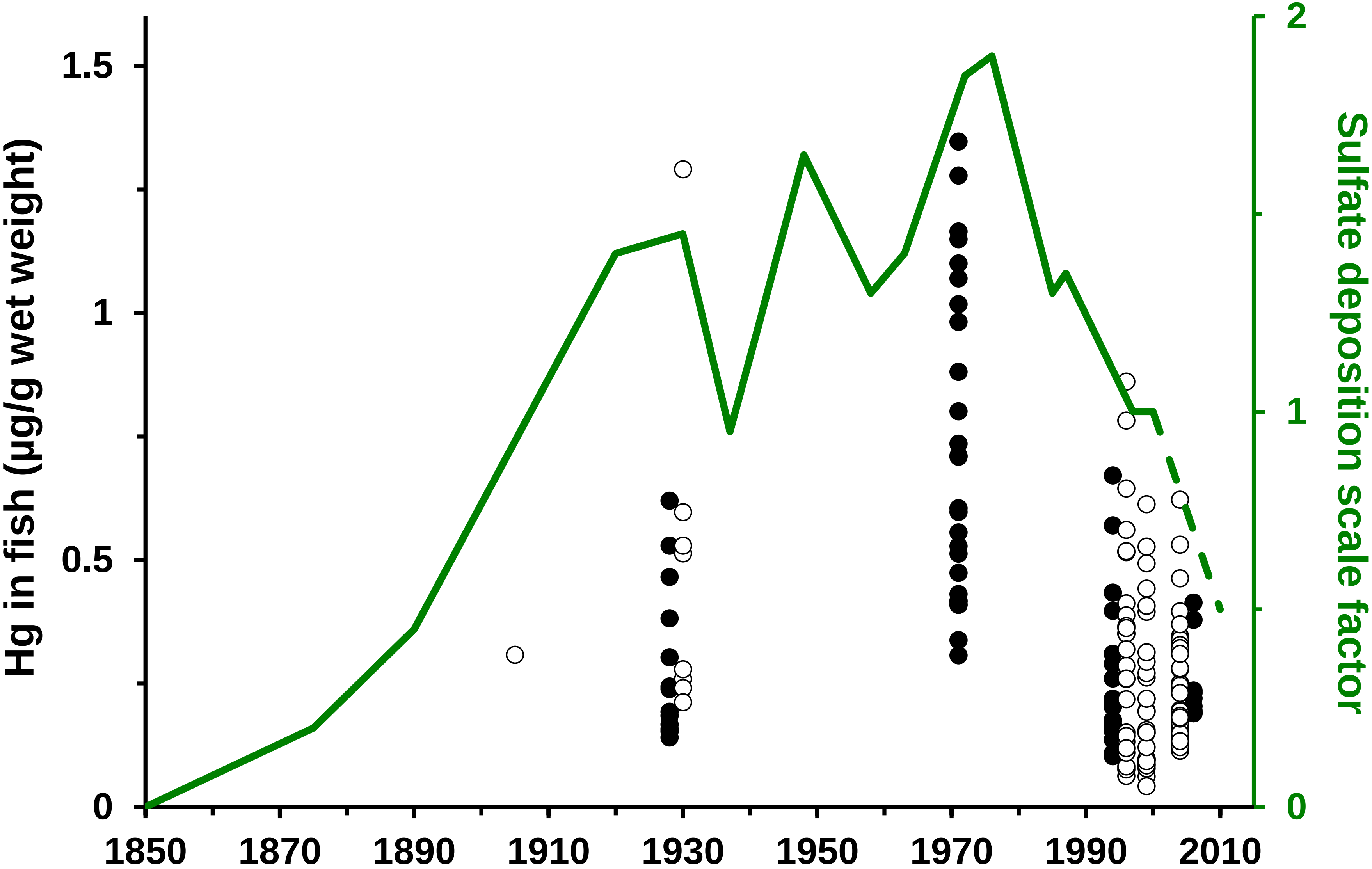


Evers et al. 2011



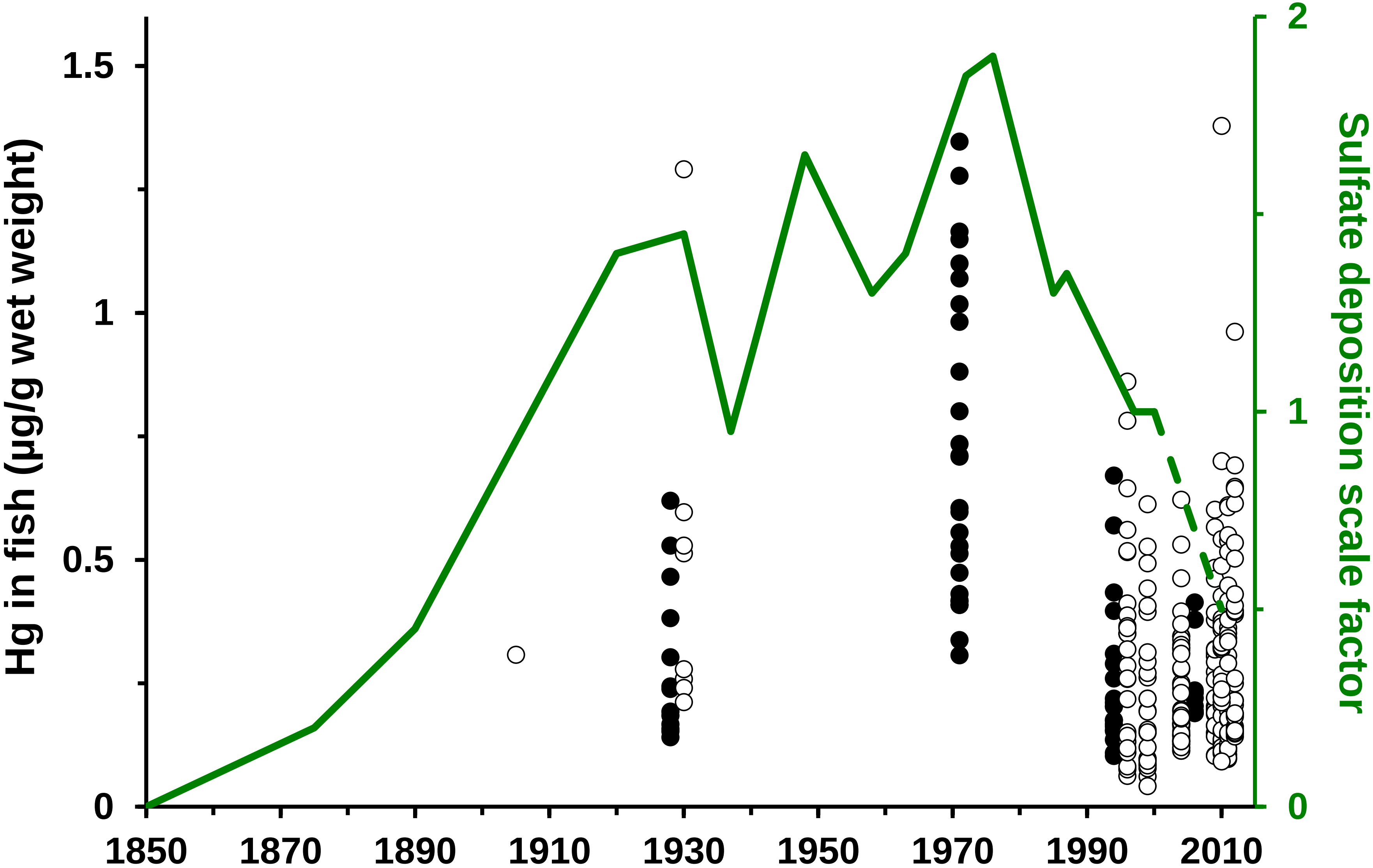
Wang et al. 2010

Putting recent increases in perspective



Drevnick et al. 2007

Putting recent increases in perspective



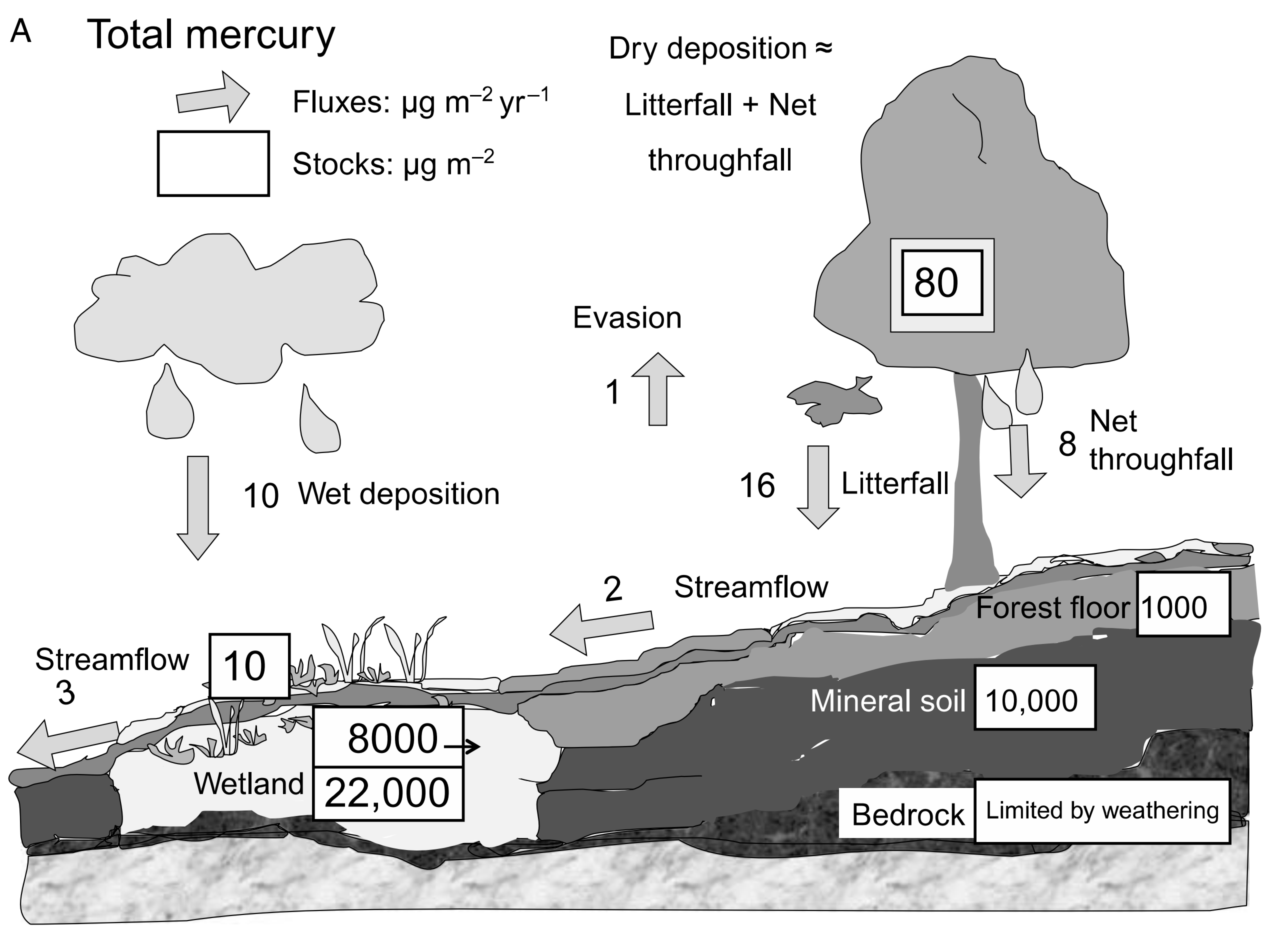
Drevnick et al. 2007; Sandheinrich and Wiener unpublished

Managing the problem: statewide TMDL proposed to address mercury impairment in inland water-bodies primarily due to atmospheric deposition

A worthwhile endeavor!

Comprehensive research and monitoring, as called for in the statewide mercury TMDL document, is necessary to understand how waterbodies respond to changes in mercury deposition rates.

2) watersheds: output of "old" mercury (from a legacy of past deposition) and/or changes in the retention of "new" mercury



Shanley and Bishop 2012

Test the null hypothesis that watershed retention rates of mercury have not changed with time

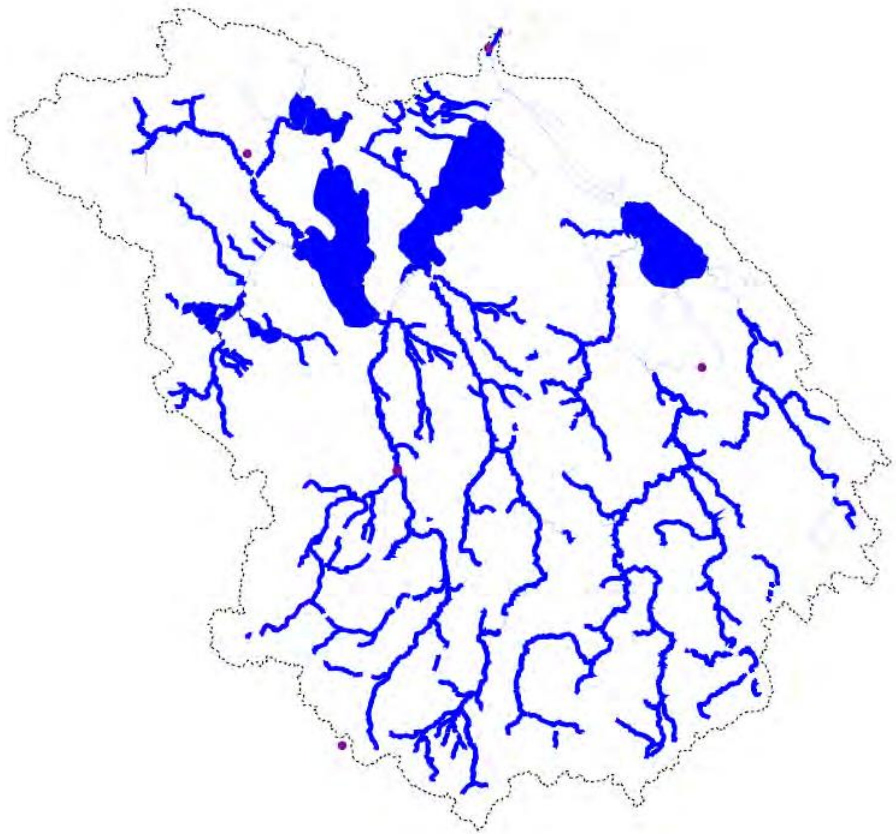
Approach 1: paleo model (Swain et al.)

Approach 2: small watershed study at UMBS

mercury isotopes!

In the Cheboygan River watershed:

Groundwater-dominated headwater streams support valuable cold-water fisheries and serve as constant sources of clean water for lakes that are the economic engines for northern MI tourism.



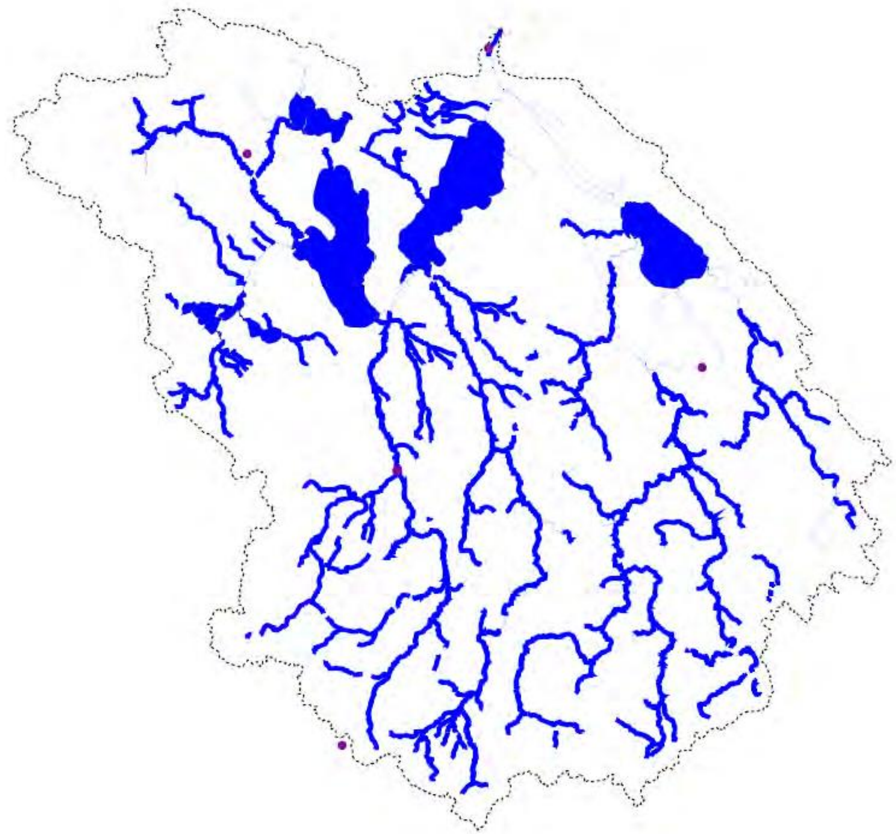
Groundwater seepage (i.e, subsurface, nonchannelized flow) may be more important than streams as a renewable water source for lakes.

Management decisions regarding land development and uses of groundwater must take into account the importance of groundwater for maintaining high water quality in streams and lakes.

MI DNR

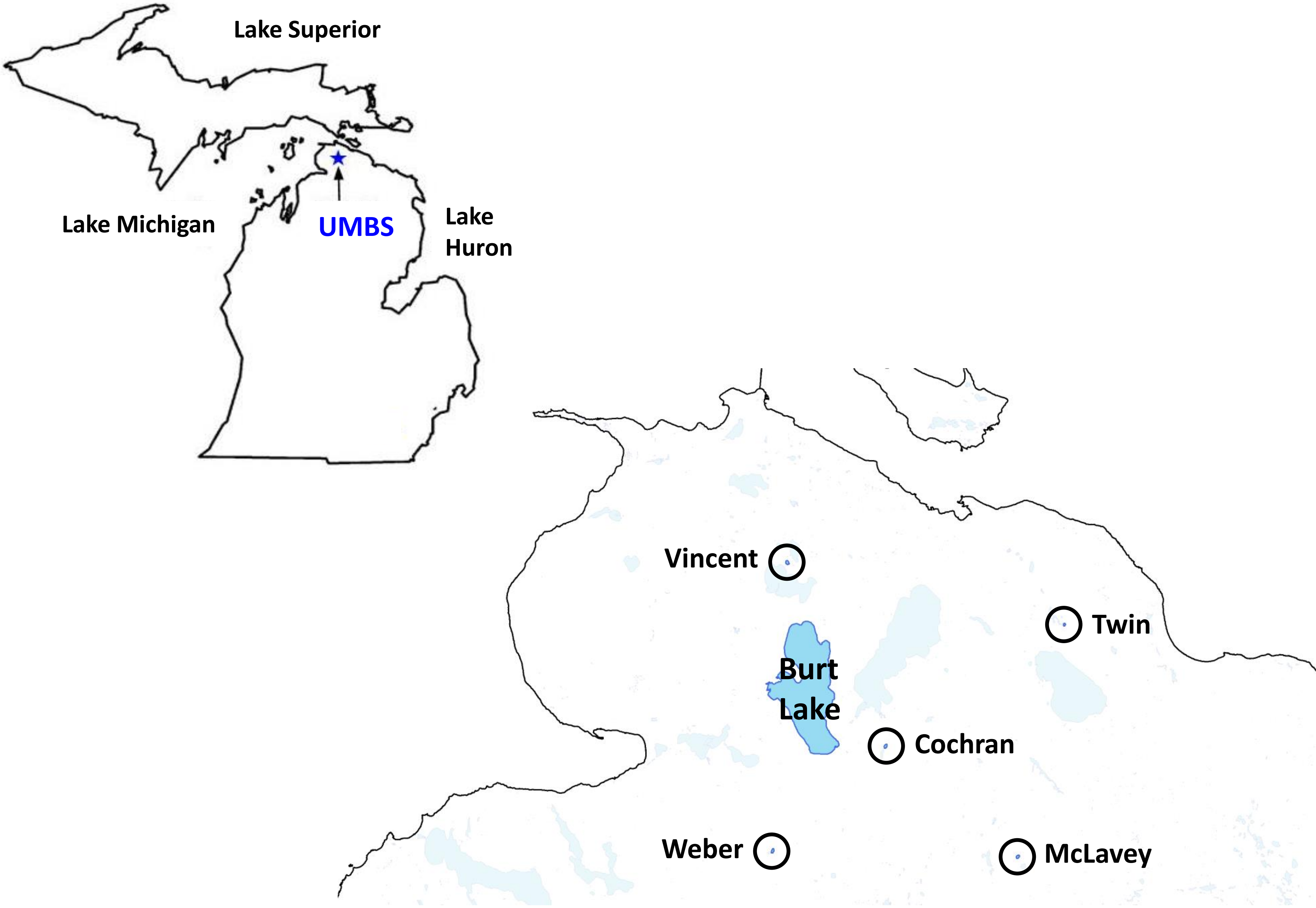
Also in the Cheboygan River watershed:

A mercury problem!



Crooked, Pickerel, Burt, and Mullett Lakes are listed as federally impaired for exceeding the U.S. EPA water quality criterion for methylmercury in fish tissue for the protection of human health.

MI DNR


Lake Superior
Lake Michigan
UMBS
Lake
Huron
Vincent
Twin
Burt
Lake
Cochran
Weber
McLavey

Test the null hypothesis that watershed retention rates of mercury have not changed with time

Approach 1
paleo model

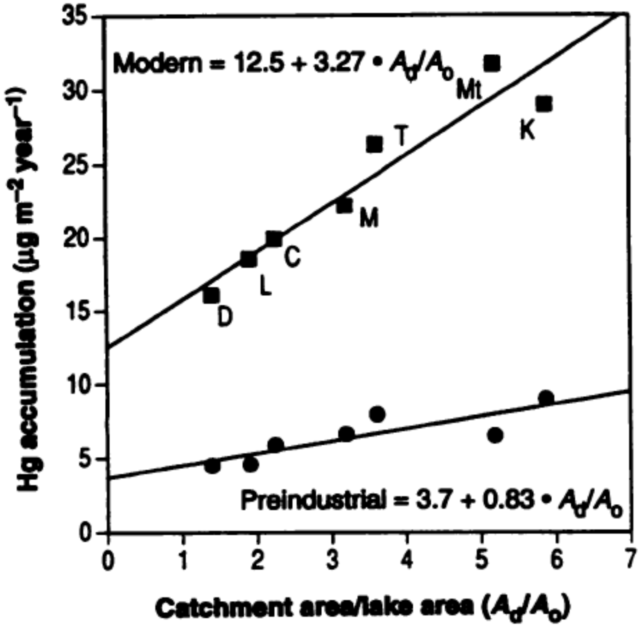
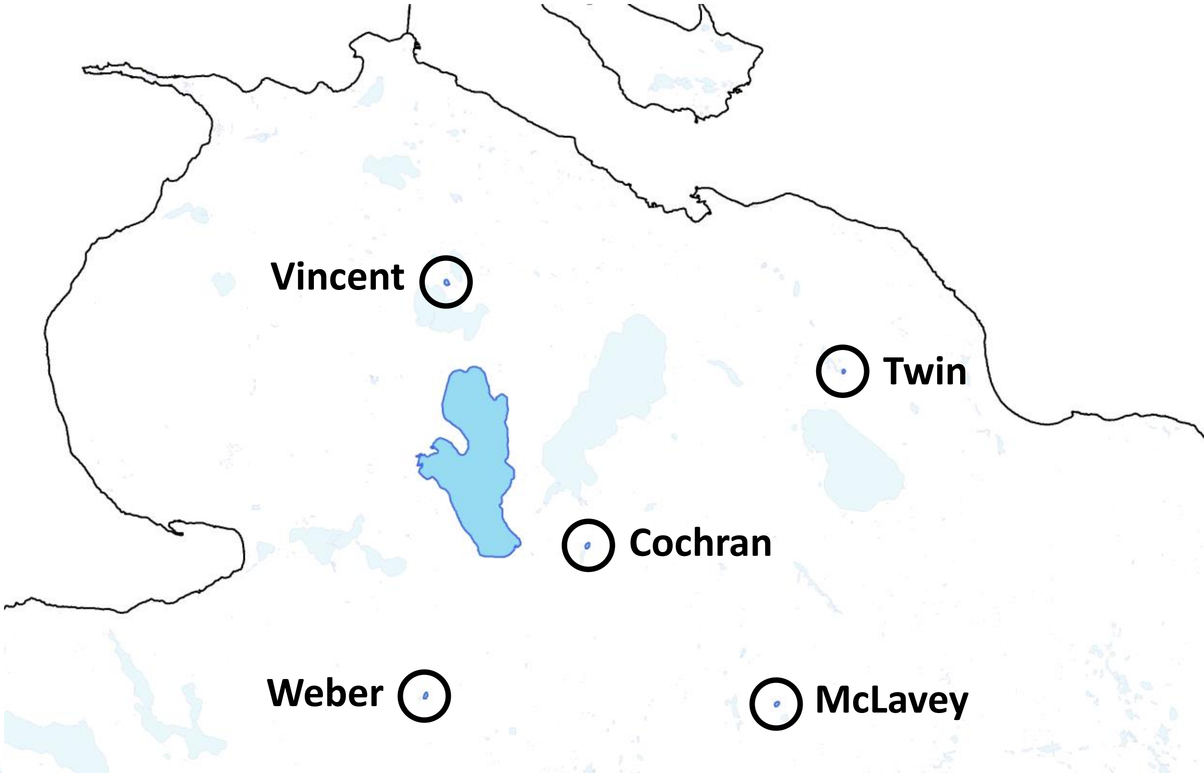
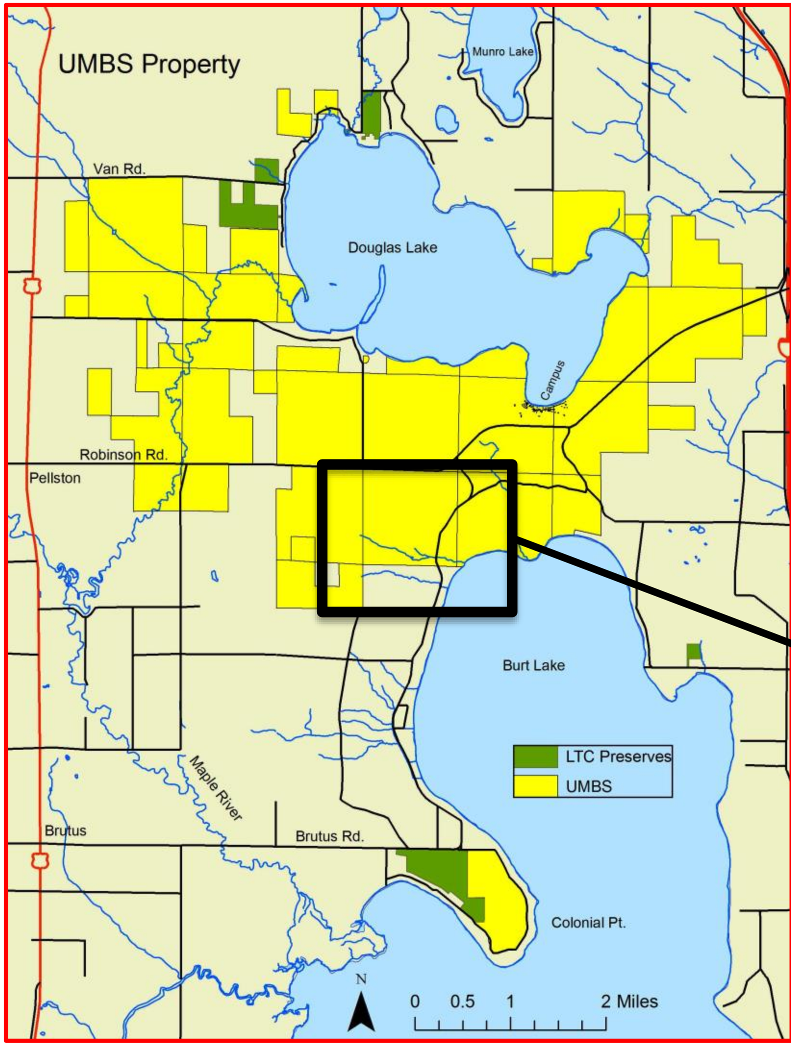


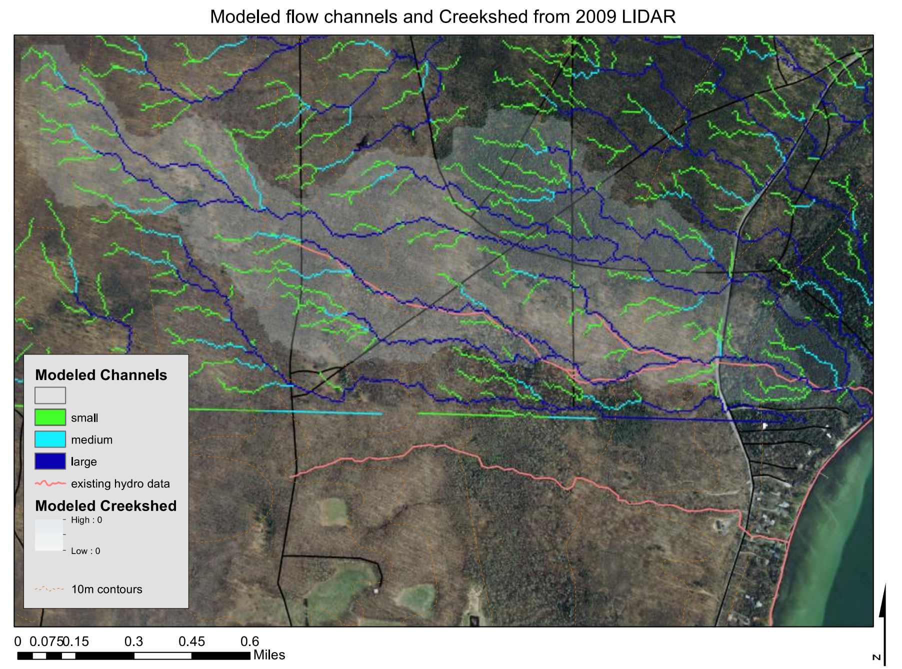
Fig. 2. Whole-basin Hg accumulation rates as linear functions of the ratio of terrestrial catchment area to lake area (A_d/A_o). Modern rates



Test the null hypothesis that watershed retention rates of mercury have not changed with time

Approach 2
small watershed study

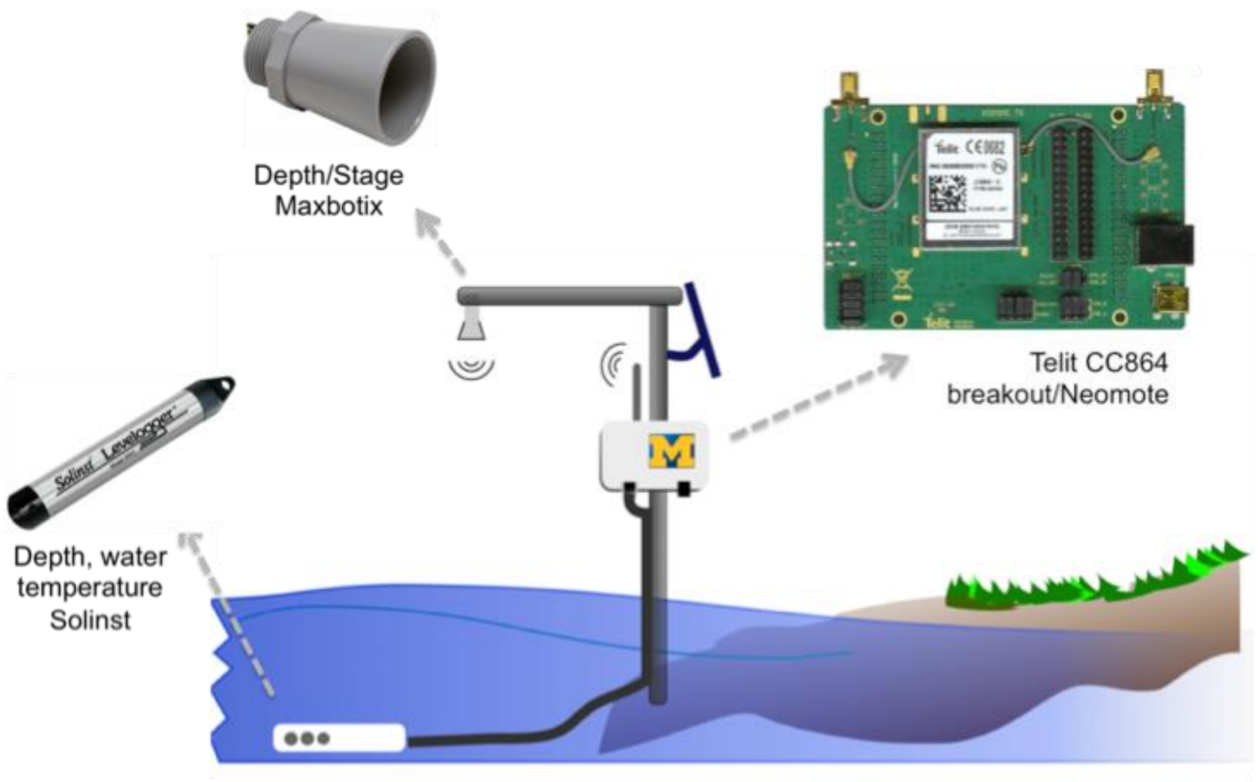




Must understand hydrology before we can understand energy or materials exchange among air, land, and water

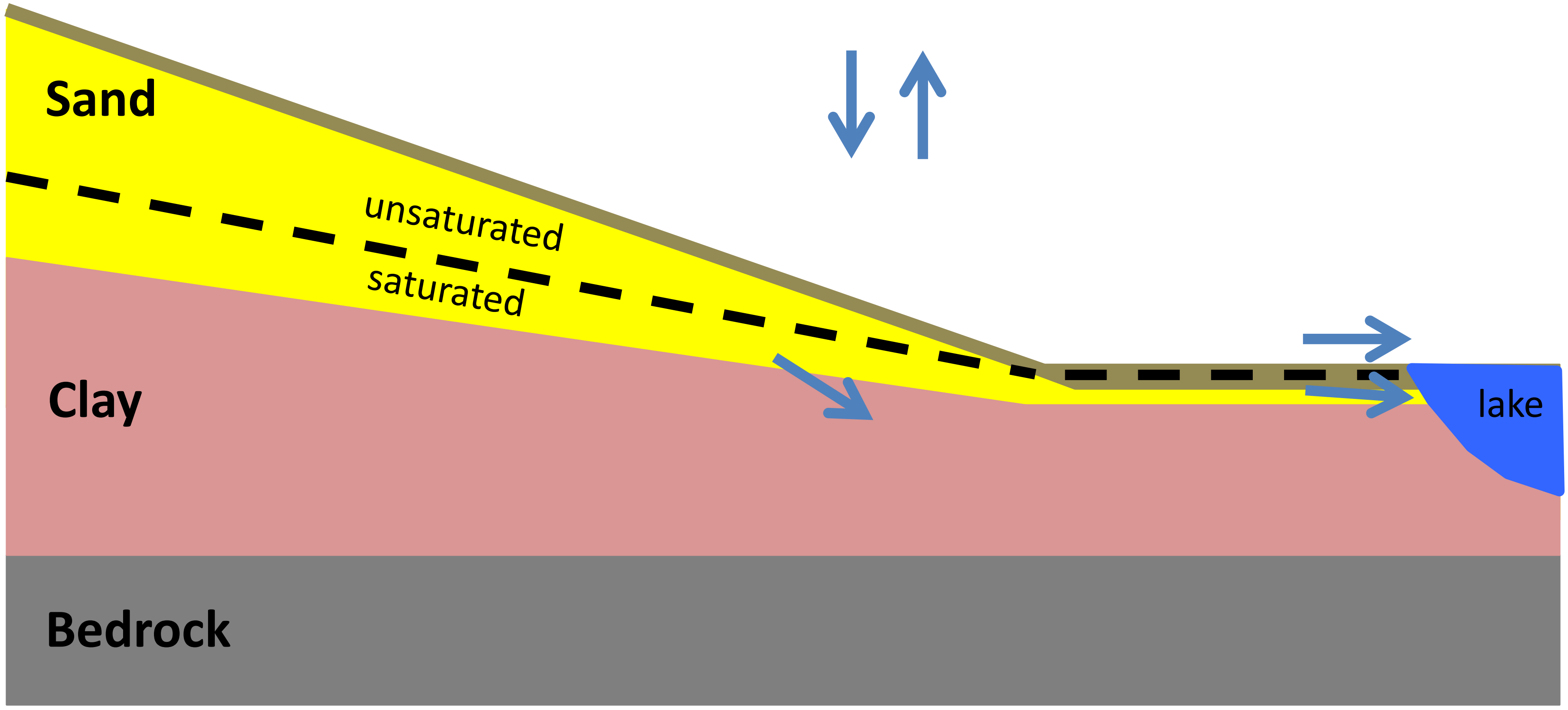
Define topographic and phreatic boundaries

Monitor precipitation, evapotranspiration, and stream discharge.

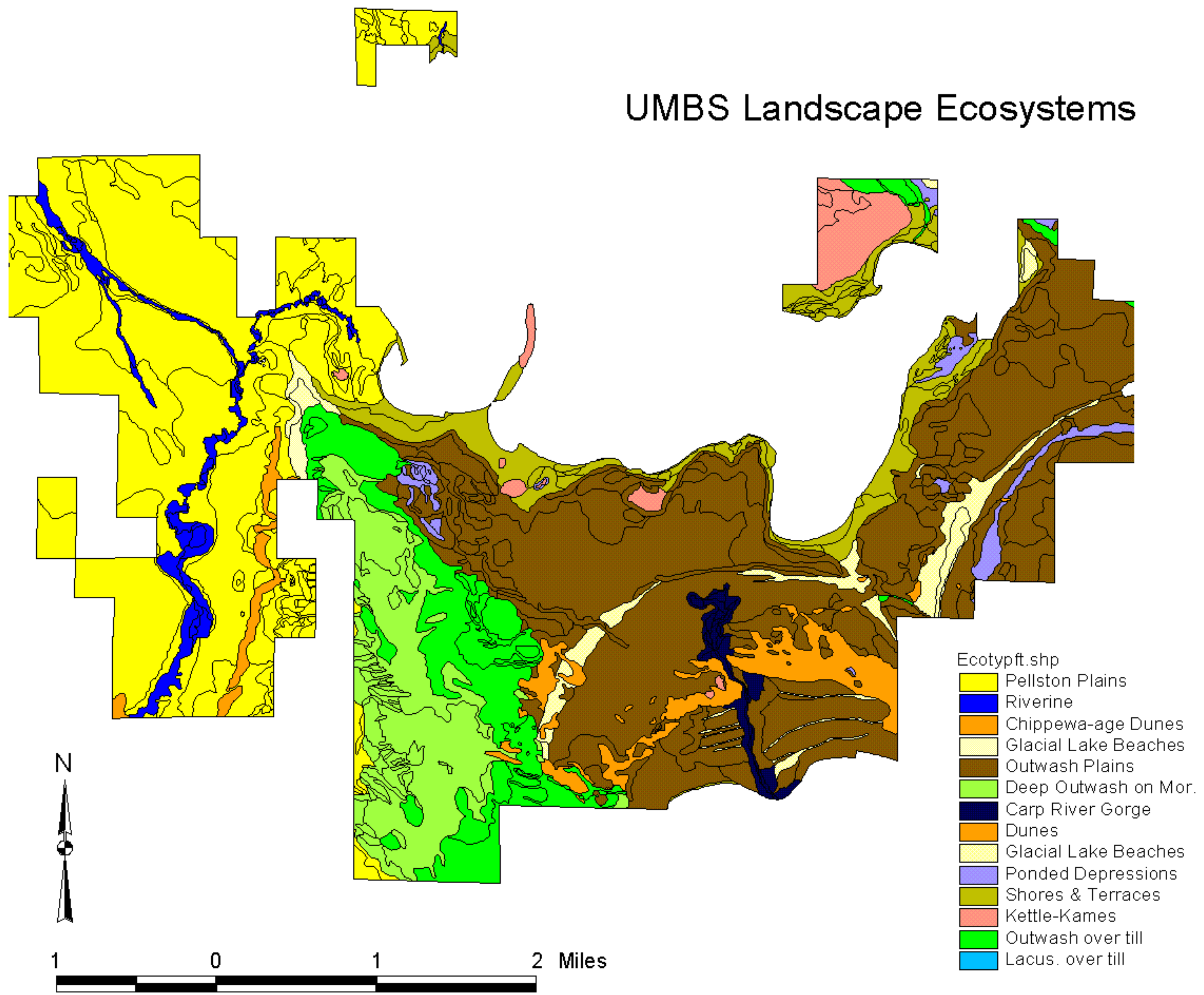


Must understand hydrology before we can understand energy or materials exchange among air, land, and water

Because we are in violation of assumption of small watershed model (shallow, impermeable bedrock), we must monitor groundwater loss to lake and to below (glacial deposits, bedrock).



Characterize ecosystem components, i.e., above- and belowground biomass, soils and parent material, and quantify mercury and carbon stocks therein



Watershed-scale study to understand inputs, outputs, retention of mercury

Plot-scale studies to understand processes that affect retention

Goals are to:

-evaluate responses to policy (controls) on mercury pollution

-understand forest management practices that maximize retention

Funding from LADCO and USDA