Innovative strategies for remediation of downstream ecosystems impacted by mercury released from abandoned mine sites

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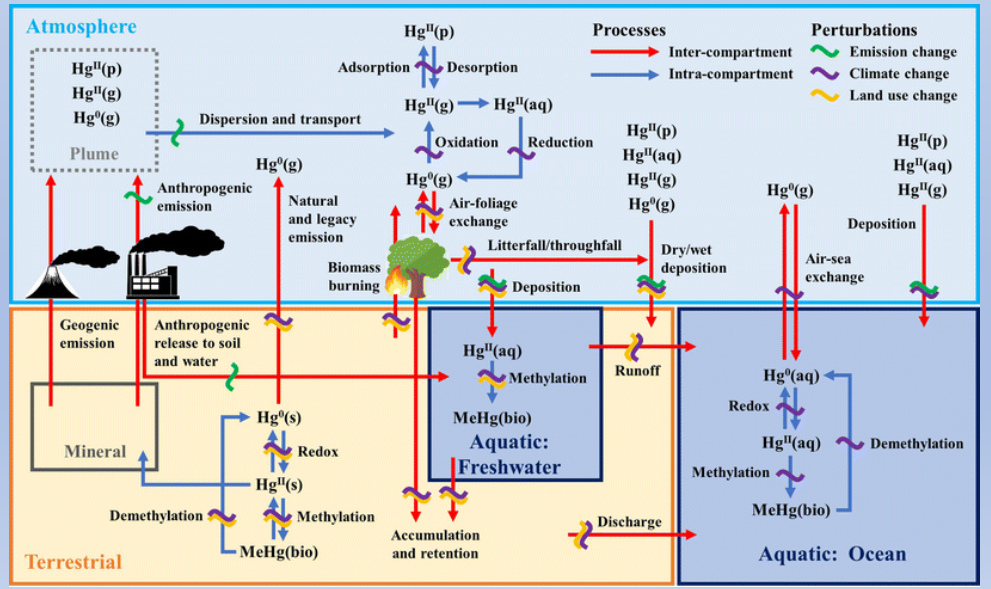
Introduction: Mercury pollution

Mercury Releases

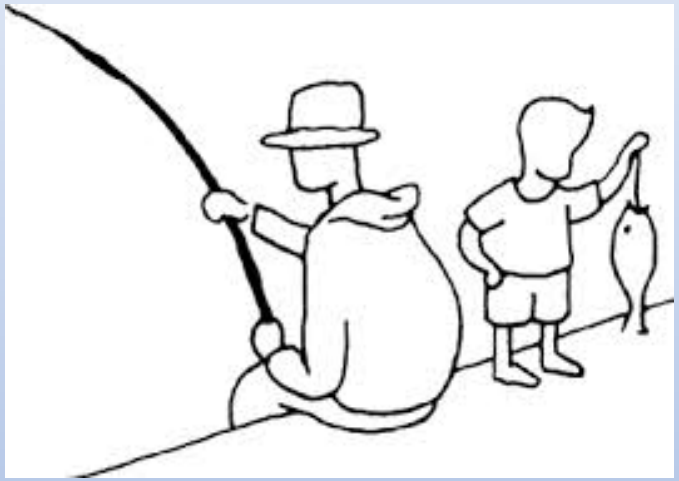
Mercury in the Environment

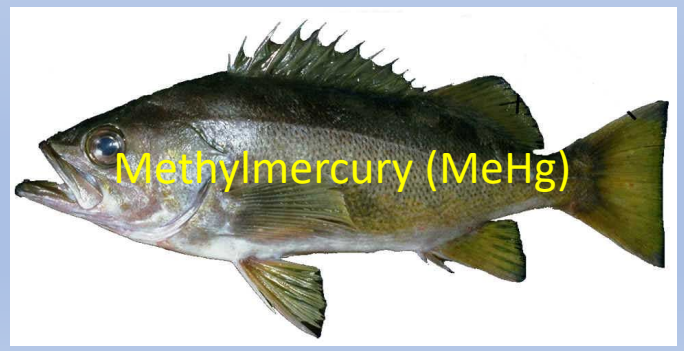
Transport, Methylation, Bioaccumulation



Source: Obrist et al, 2018

Mercury Exposure





Introduction: Mercury at mine sites

Types of mine sites with elevated Hg:

1) Mercury Mines

Examples:

New Idria Mine, CA

Cinnabar Mine, ID

Black Butte Mine, OR

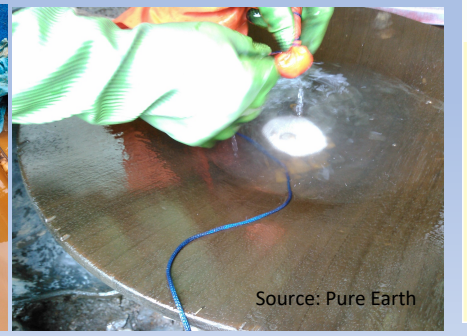
Introduction: Mercury at mine sites

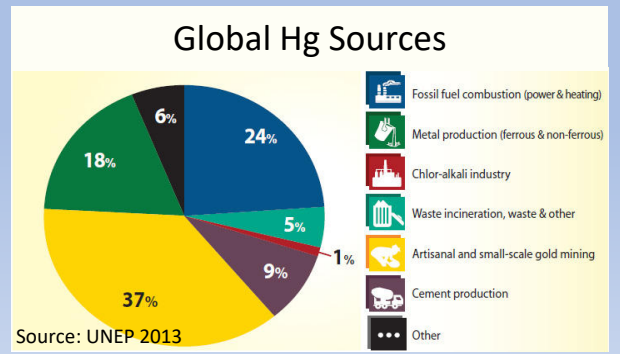
Types of mine sites with elevated Hg:

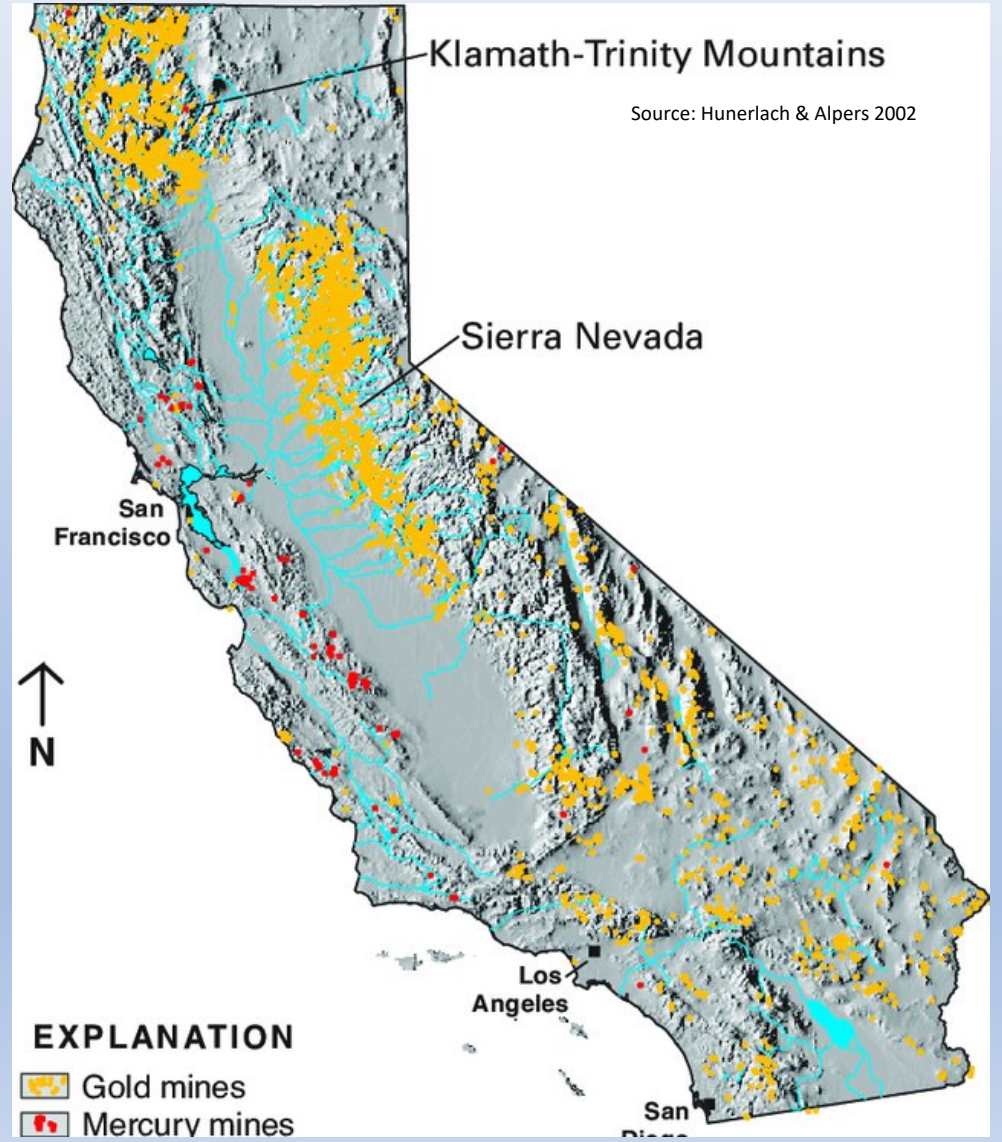
1) Mercury Mines

2) Gold and Silver Mines where Hg was used

Contemporary small-scale artisanal gold mining continues to use Hg







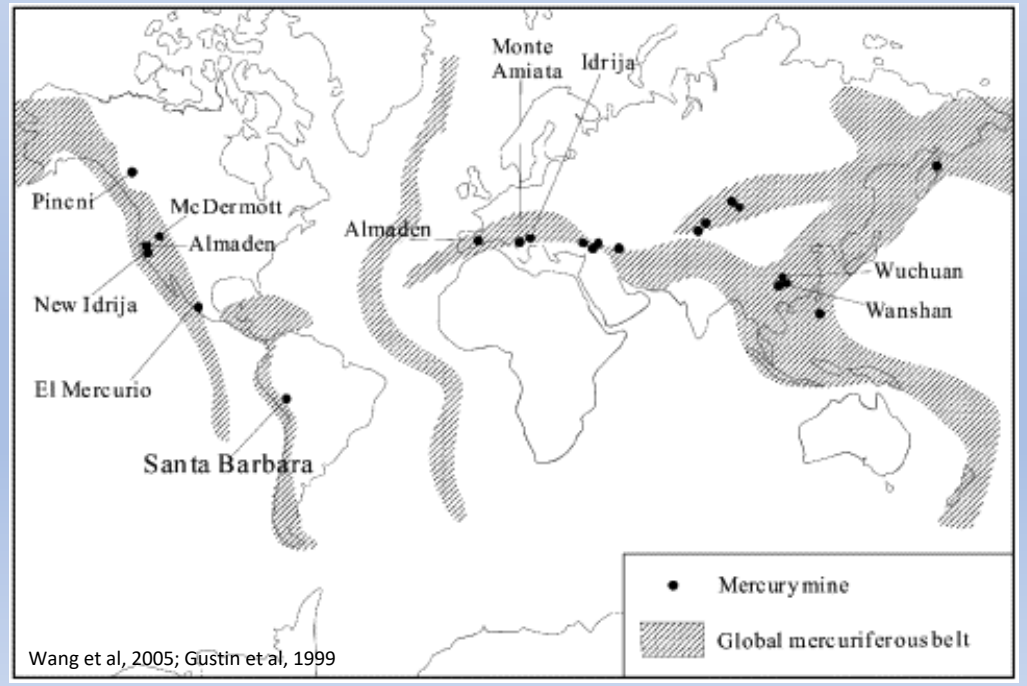
Introduction: Mercury at mine sites

Types of mine sites with elevated Hg:

1) Mercury Mines

2) Gold and Silver Mines where Hg was used

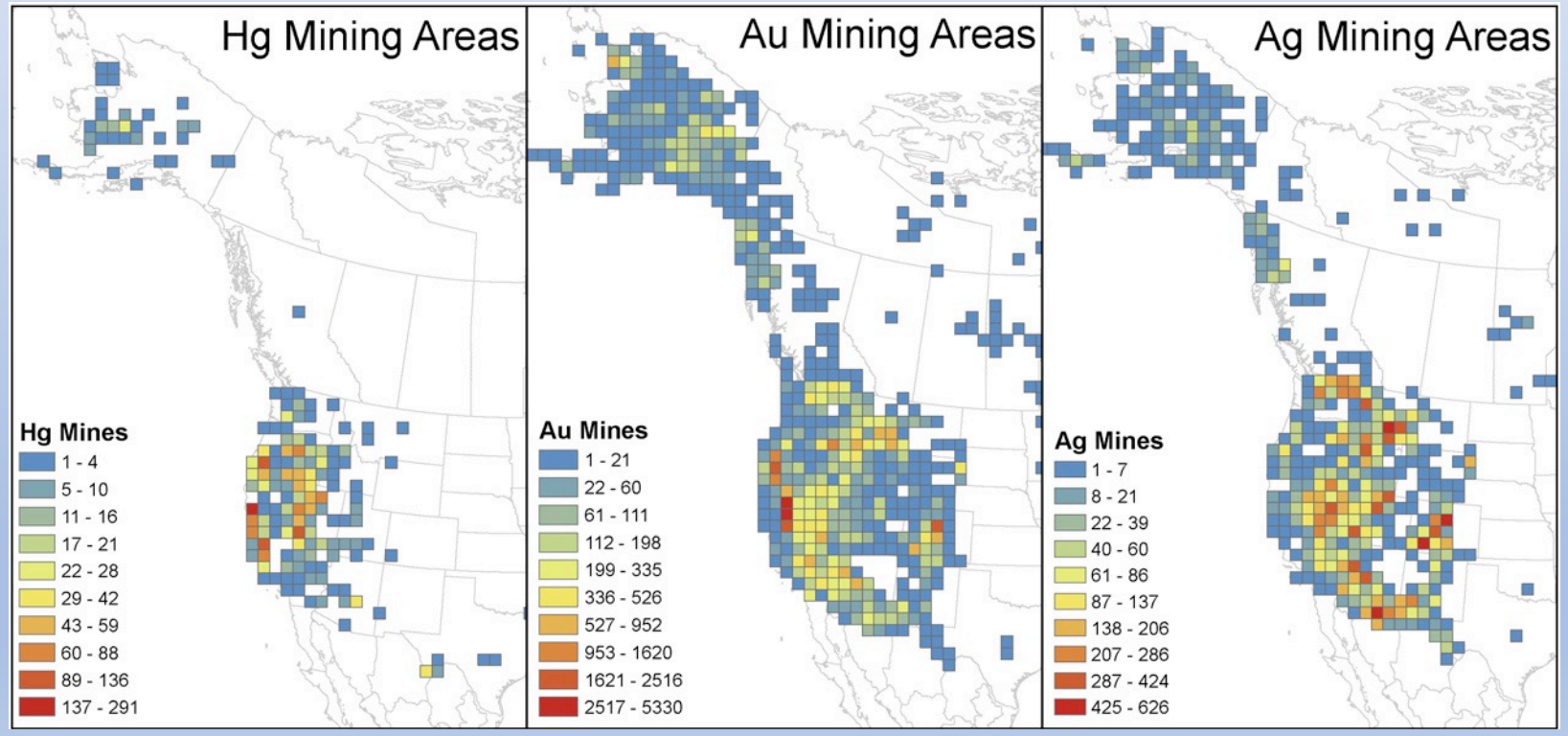
3) Mines where Hg is naturally geologically enriched



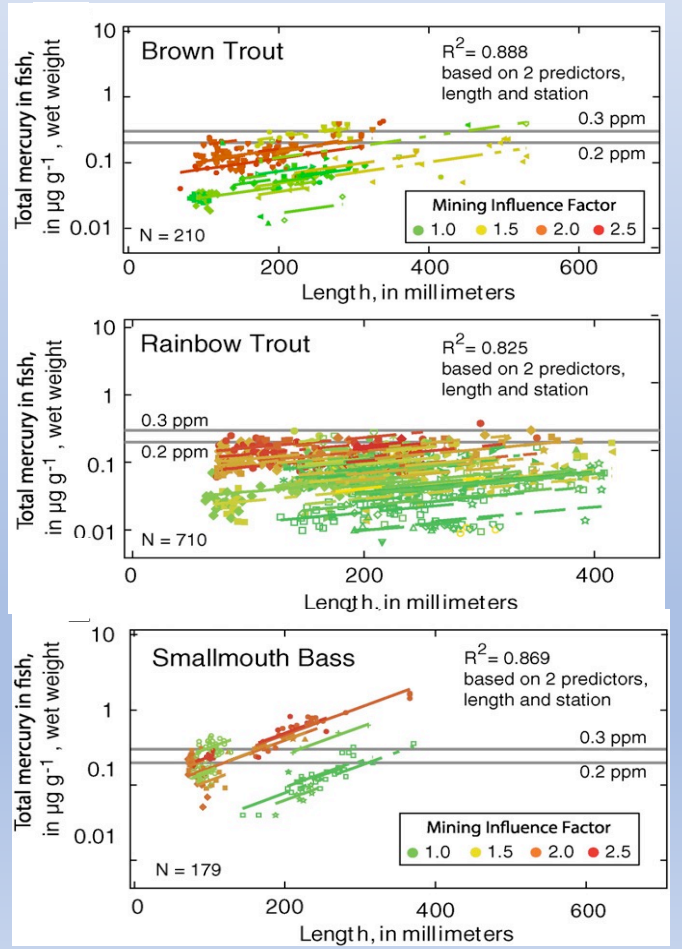
Wang et al, 2005; Gustin et al, 1999

Photo: Eckley

- Thousands of abandoned Hg mines (10,000 gold and silver mines) are located throughout the Western US
- Higher fish Hg concentrations are associated with areas with more watershed historical mining activity



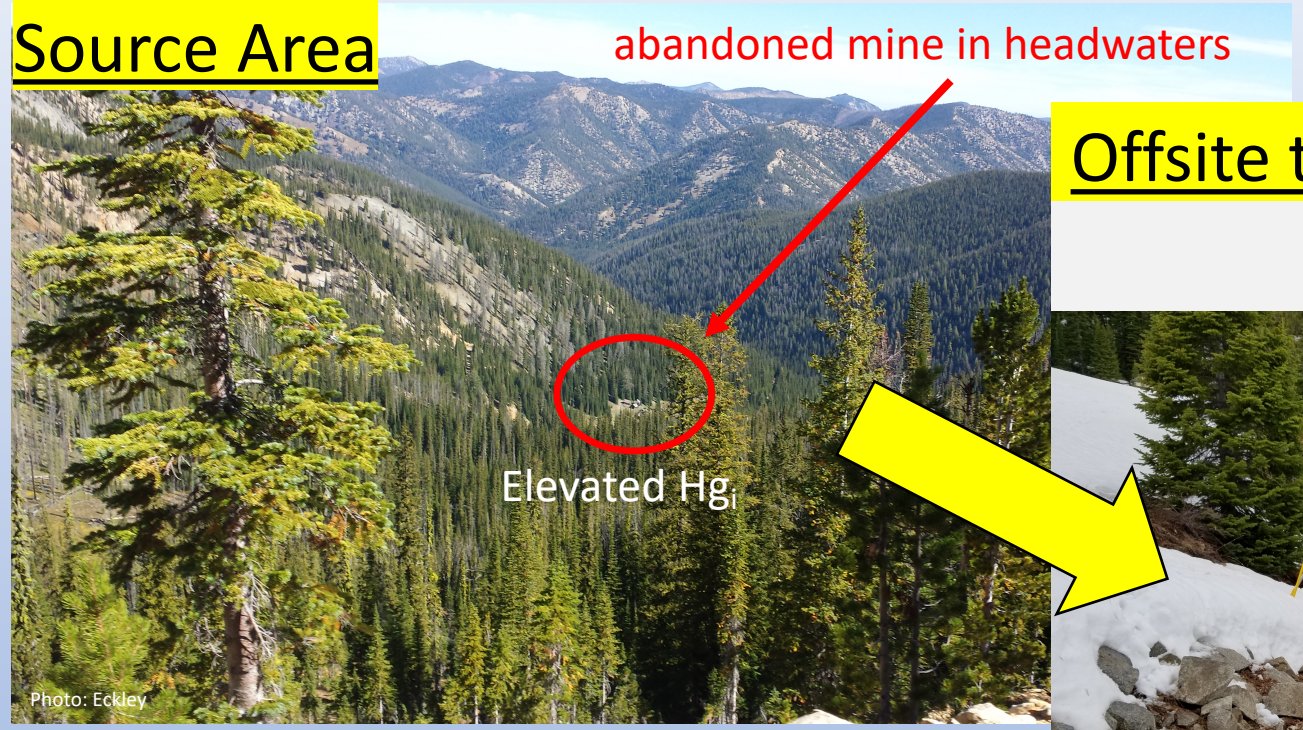
Source: Eagles-Smith et al, 2016



Source: Alpers et al, 2016

Downstream Risks

Source Area



Offsite transport

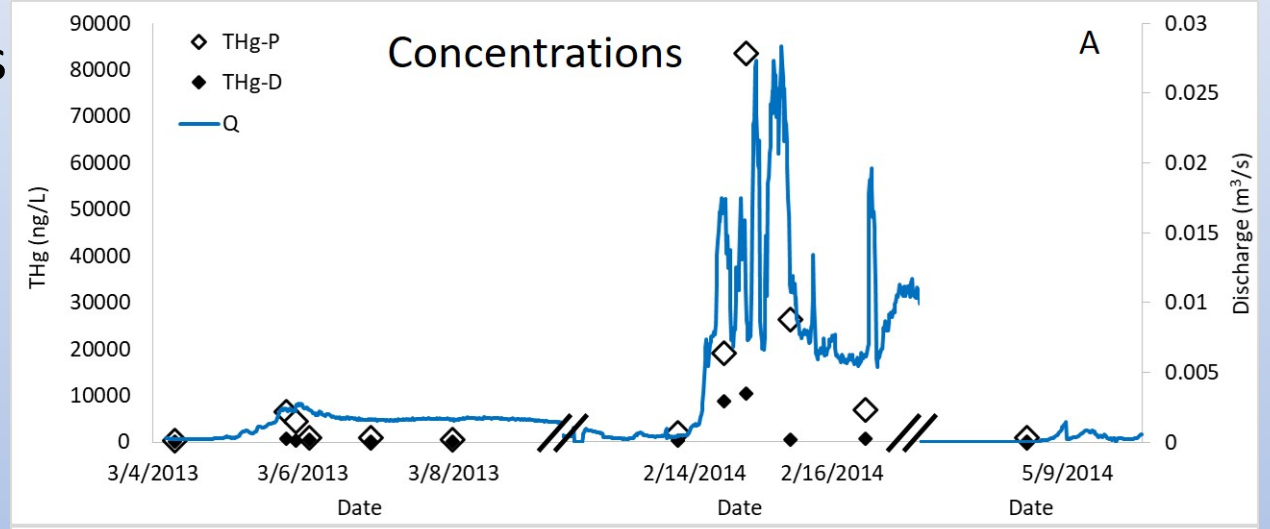
Conditions favorable for methylation & bioaccumulation

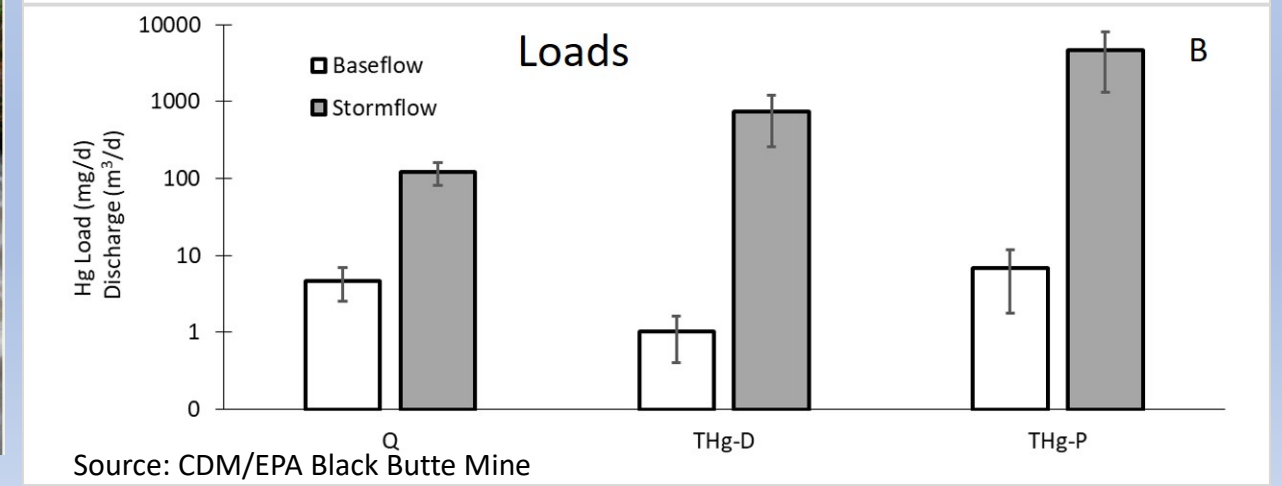
Offsite Transport: Fluxes to water

Releases are a concern due to the potential for downstream methylation & bioaccumulation

- Stormflow flux >>> baseflow flux
- Annual loads dominated by a few large events
- Mobilization from erosion of particles/sediment entrainment

Example: Black Butte Mine, OR



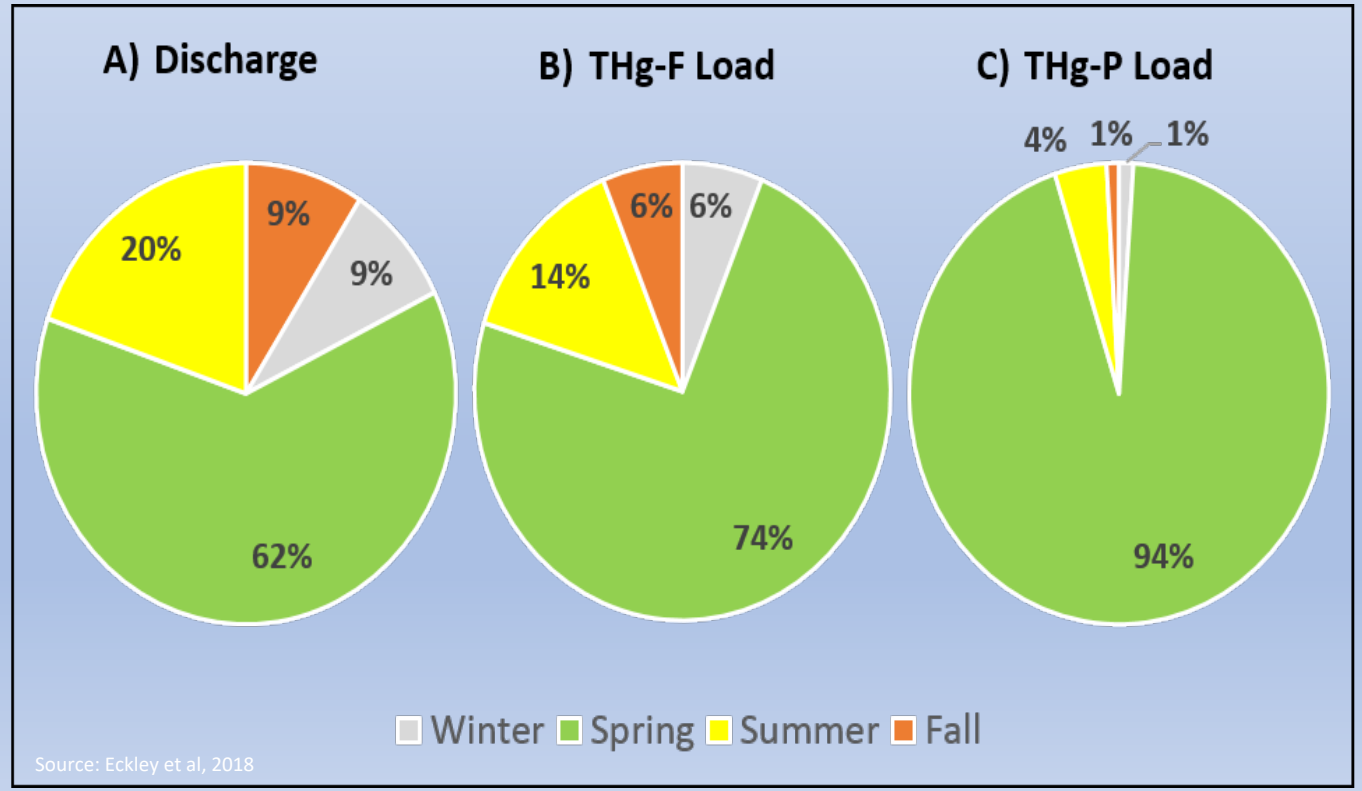


Source: CDM/EPA Black Butte Mine

Offsite Transport: Fluxes to water

- 83 ±15% of the Hg in Sugar Creek (Cinnabar Mine) is bound to particles
- The vast majority of the discharge and Hg load occurs during the spring snowmelt period

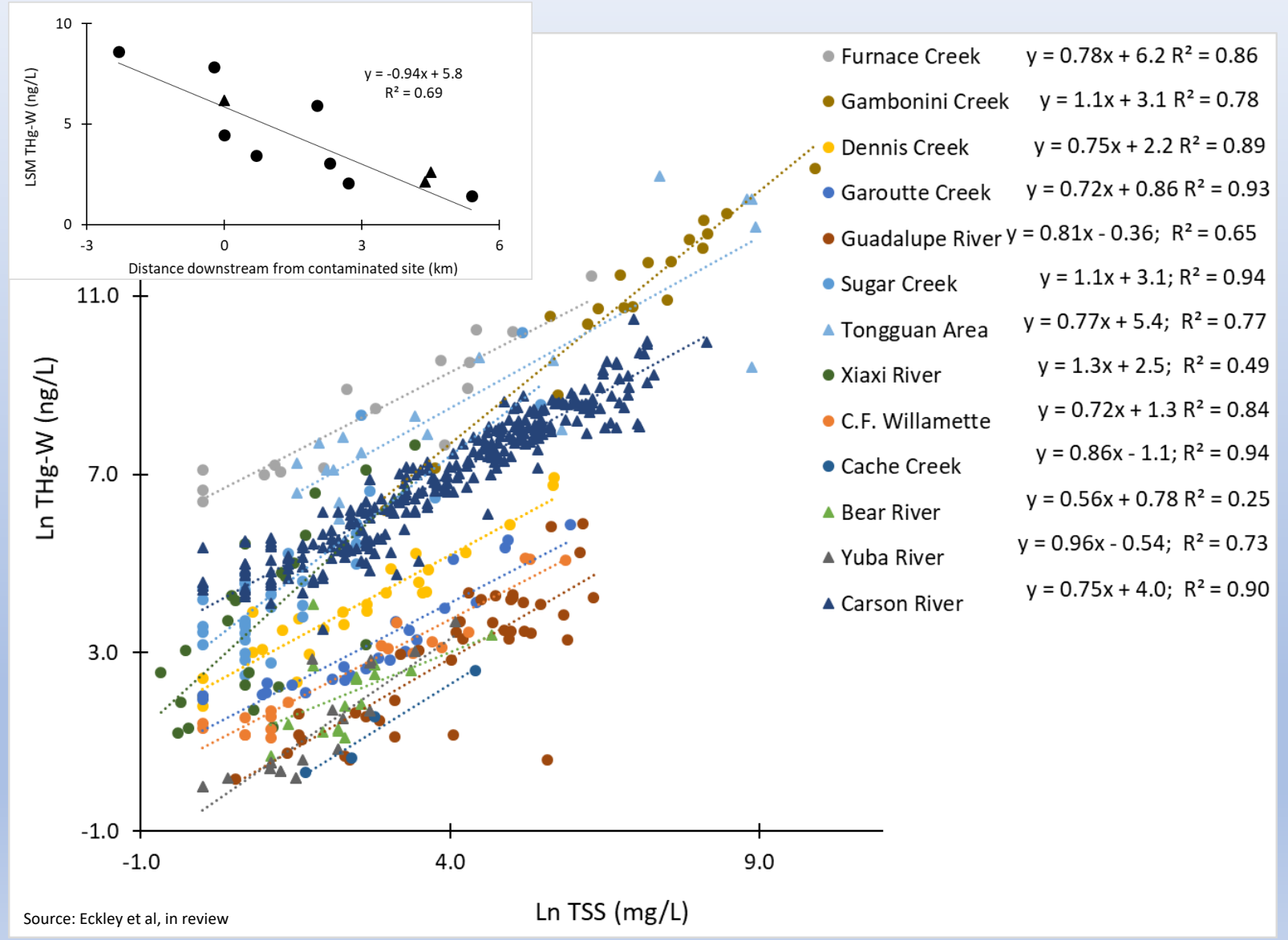
Example: Cinnabar Mine, ID



Offsite Transport: Fluxes to water

- Positive relationship between THg and total suspended solids (TSS).
- Most regression slopes not significantly different.

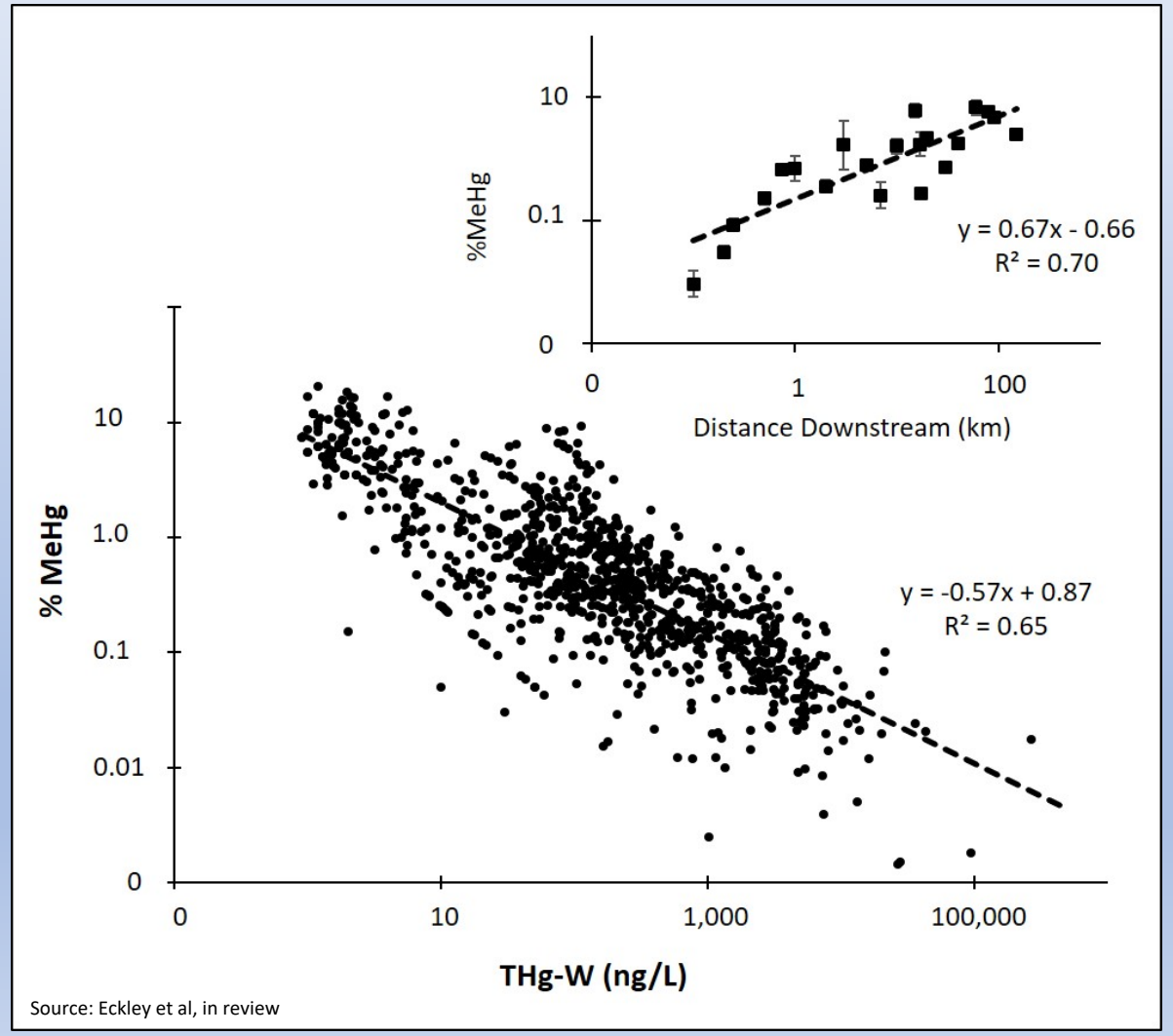
- Most intercepts were significantly different and were correlated with the distance downstream from the contaminated source area.



Source: Eckley et al, in review

Offsite Transport: Fluxes to water

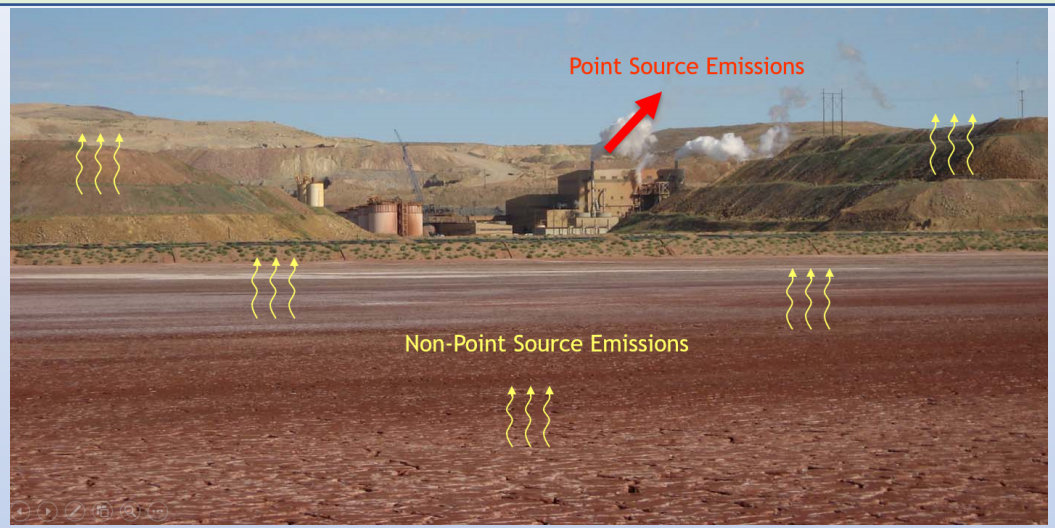
The % MeHg increases with distance downstream of Hg mine sites

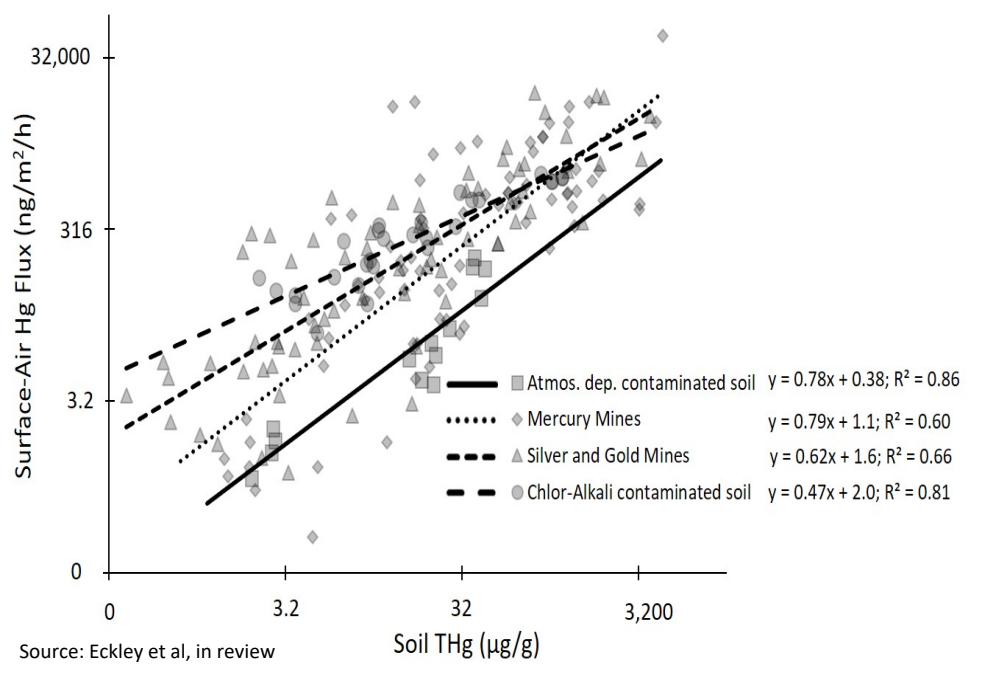


Source: Eckley et al, in review

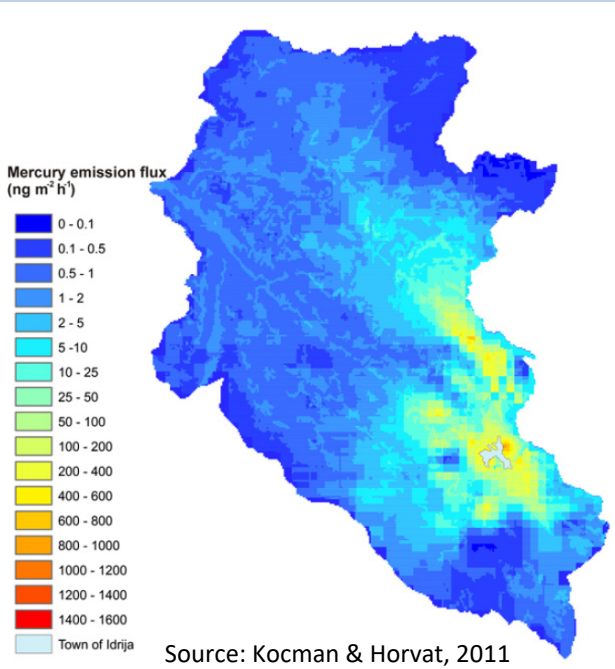
Offsite Transport: Fluxes to air

- Relative magnitude of surface-air versus water flux depends on hydrological/meteorological conditions.
- Annual fluxes to the air can be 50-100 kg/year from some contaminated sites.
- Soil Hg speciation (along with several environmental parameters) affect surface-air fluxes.

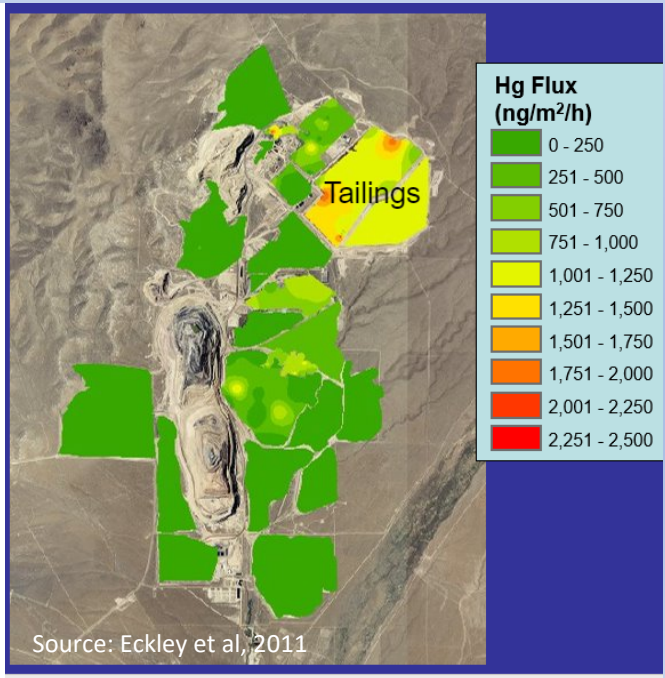




Source: Eckley et al, in review



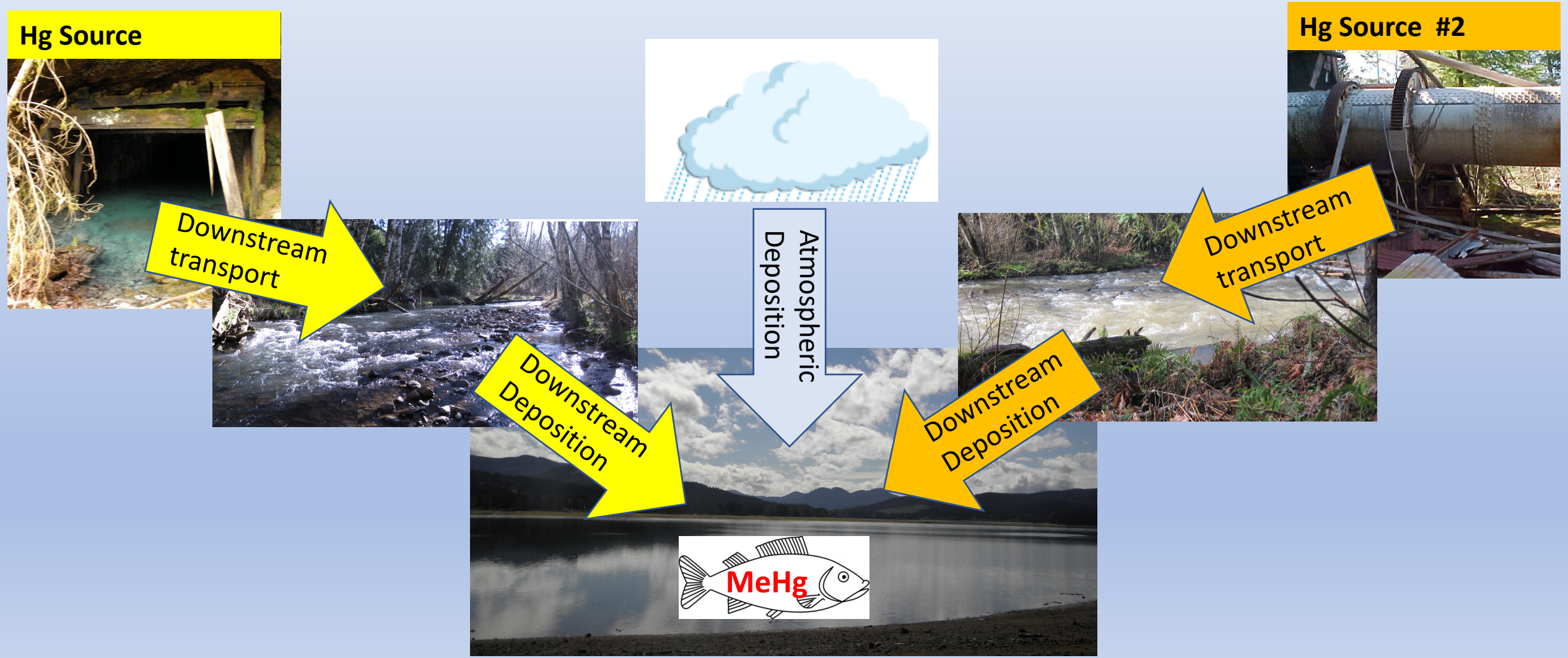
Source: Kocman & Horvat, 2011



Source: Eckley et al, 2011

Source attribution using Hg stable isotopes

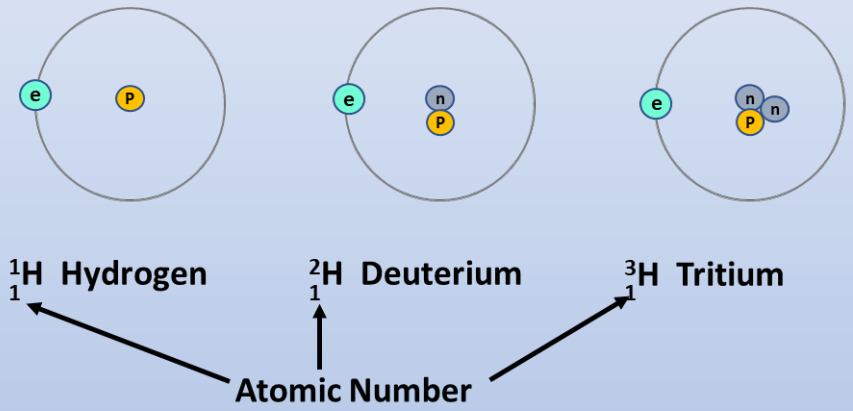
- Downstream/wind of contaminated sites the source of Hg pollution can be more difficult to discern, especially when there are multiple potential sources



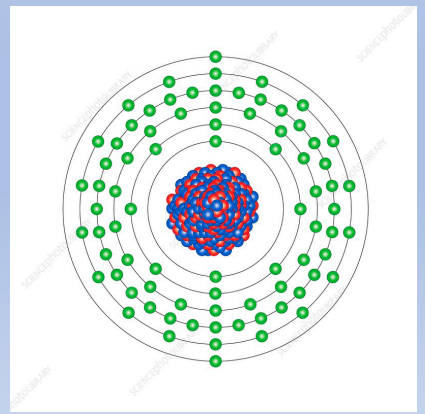
Source attribution using Hg stable isotopes

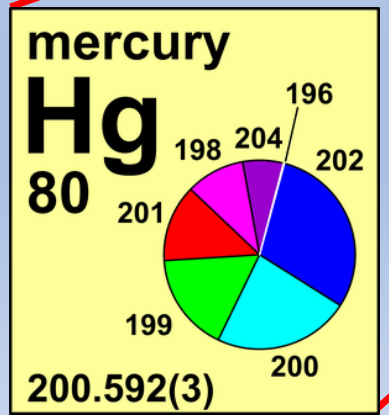
What are stable isotopes?

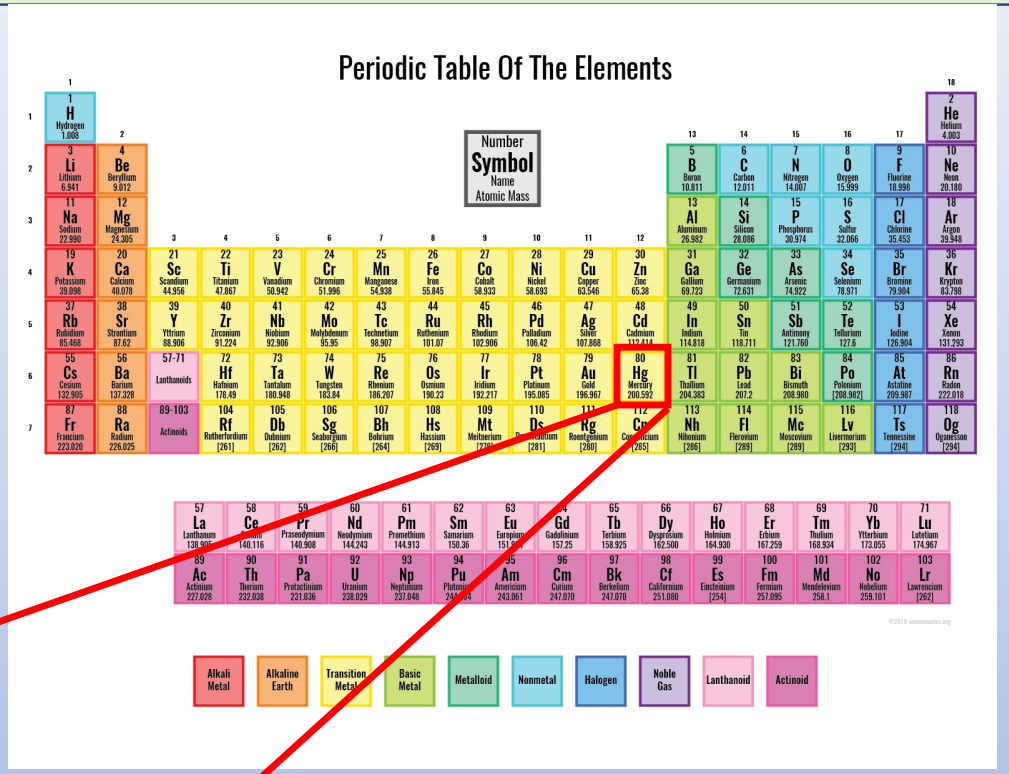
Example: Hydrogen



Example: Mercury





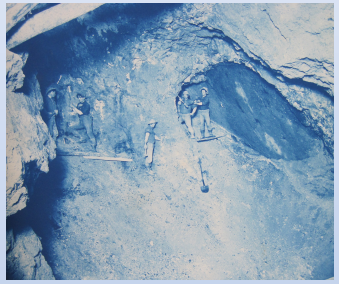


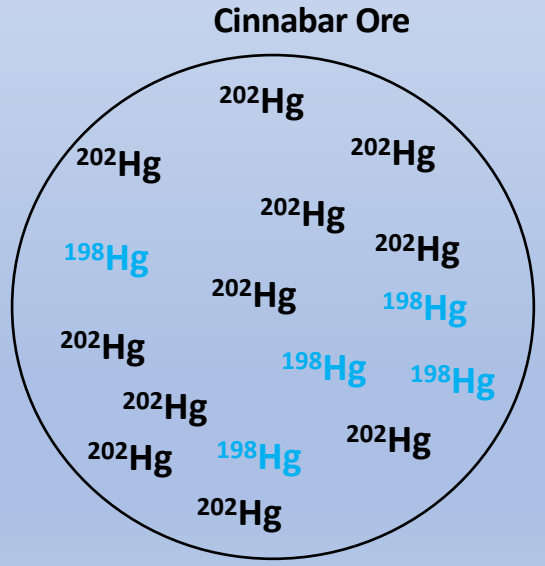
Hg Stable Isotopes	Abundances
^{196}Hg	0.16%
^{198}Hg	10.0%
^{199}Hg	16.9%
^{200}Hg	23.1%
^{201}Hg	13.2%
^{202}Hg	29.7%
^{204}Hg	6.8%

Source attribution using Hg stable isotopes

<u>Isotope fractionation</u>: process that change the abundance of individual isotopes

Hg ore





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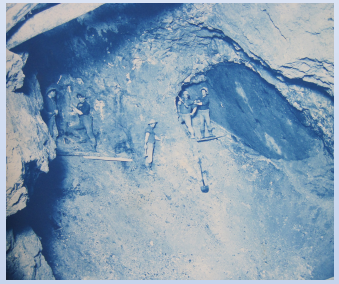
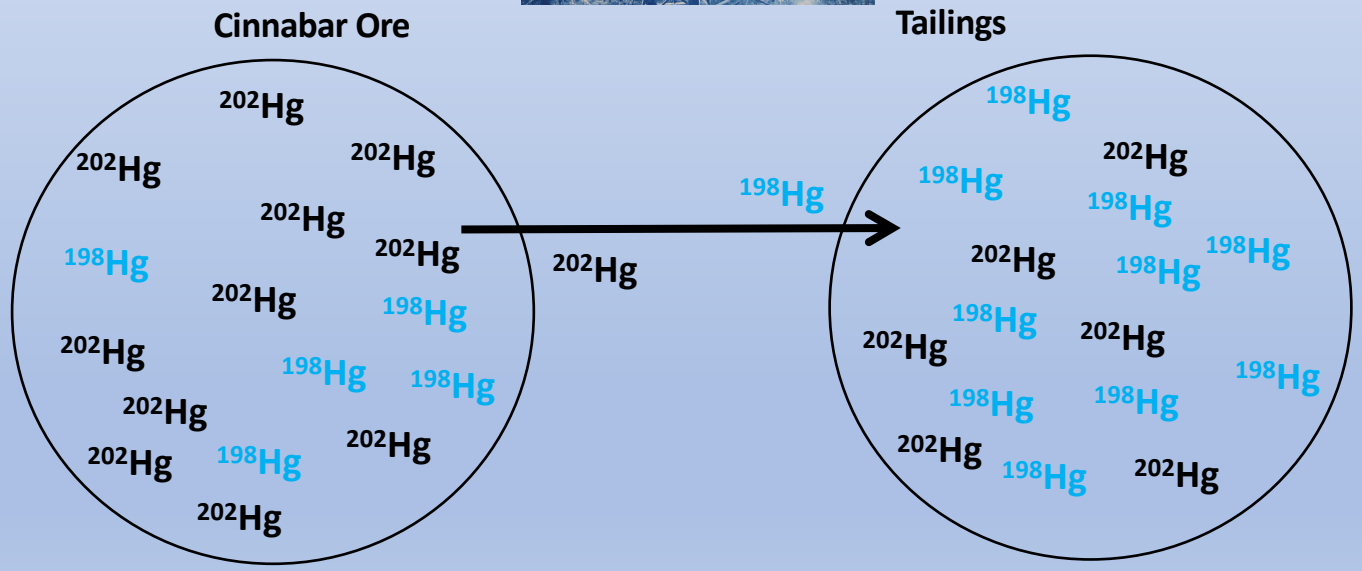


Hg ore processing

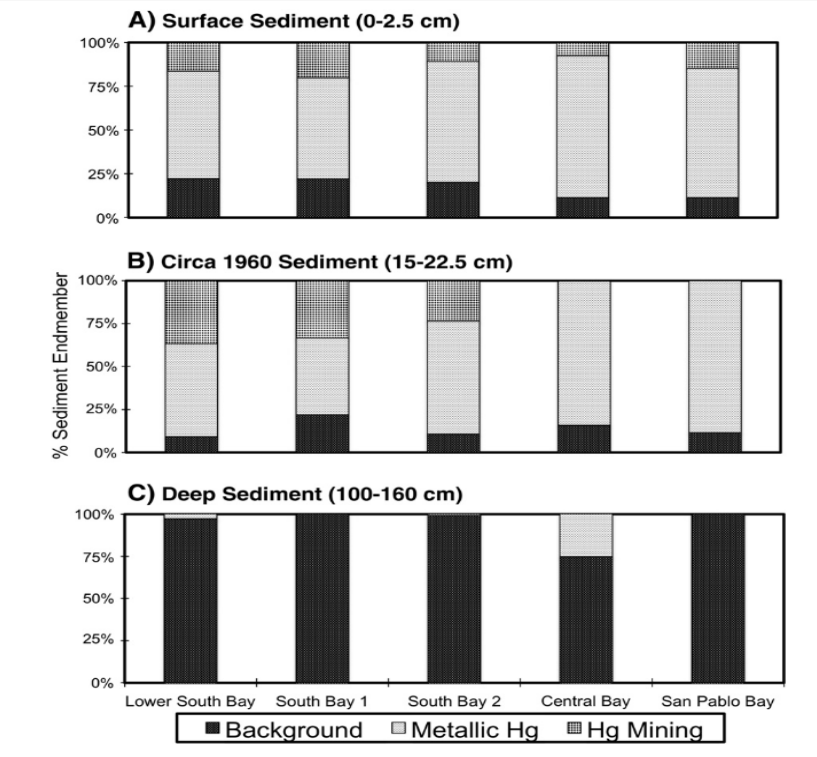
Hg tailings



Mass dependent fractionation: Lighter isotopes react faster and become enriched in the products

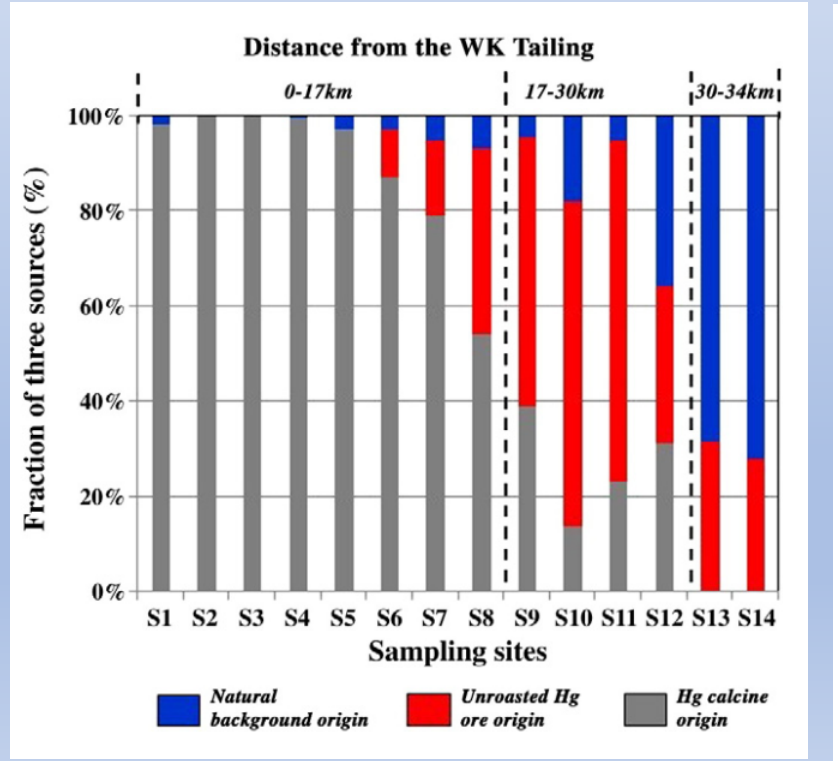
- Hg stable isotope analysis has provided insights into different sources of Hg—requires unique end-members (and minimal post-source transformation)

Example: San Francisco Bay, OR



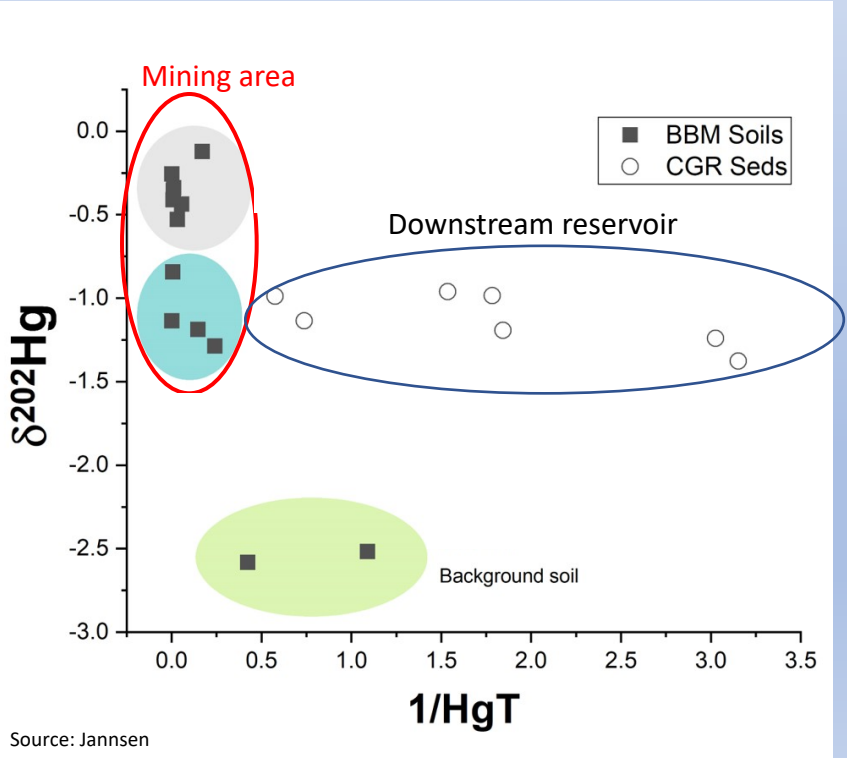
Donovan et al, 2013

Example: Wanshan Hg ming area, China



Yin et al, 2013

Example: Black Butte Mine, OR



Source: Jannsen

Site Remediation Options:

Soils:

Commonly applied options:

- Excavation & removal
- Containment in-place

Other options:

- Soil-washing
- Solidification/stabilization
- Thermal treatment
- Electrochemical/kinetic recovery
- Bioremediation/biotreatment
- Phytoremediation/stabilization
- Chelating agents

Groundwater, surface water, or sediment:

Commonly applied options:

- Sediment excavation/dredging/containment
- Erosion reduction
- Hydraulic groundwater containment
- Pump and treat
- Permeable reactive barriers

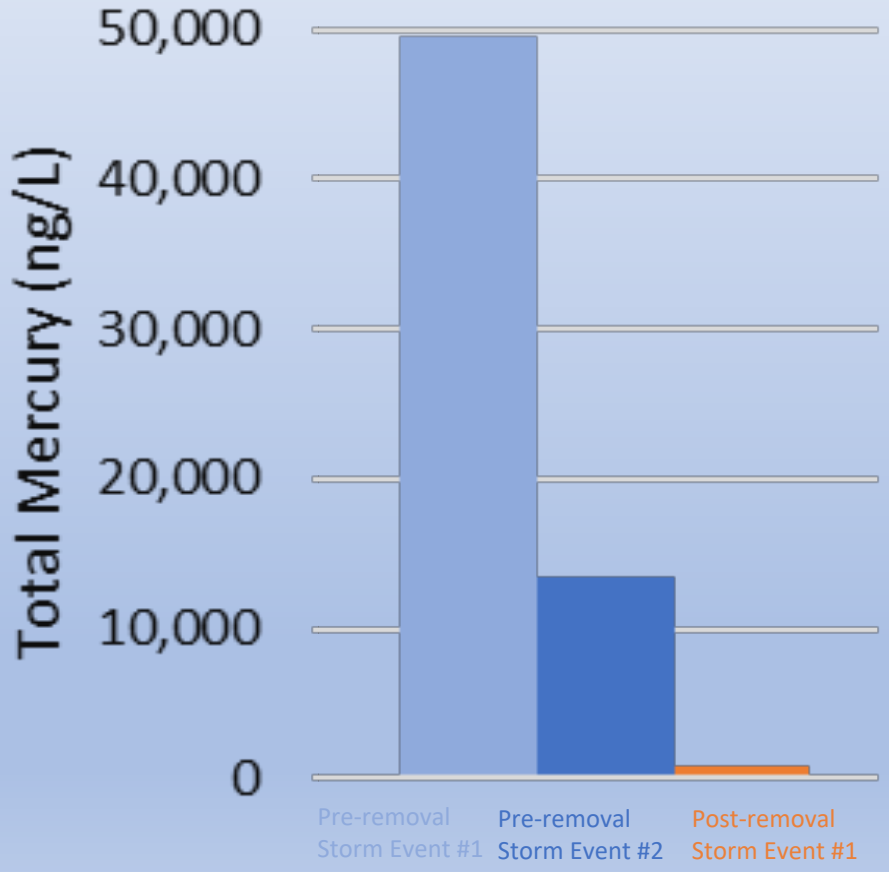

Photo: EQM


Photo: CDM/EPA


Photo: Dune Technologies

Site Remediation Options: *Removal*

Example: Furnace Creek, Black Butte Mine, OR



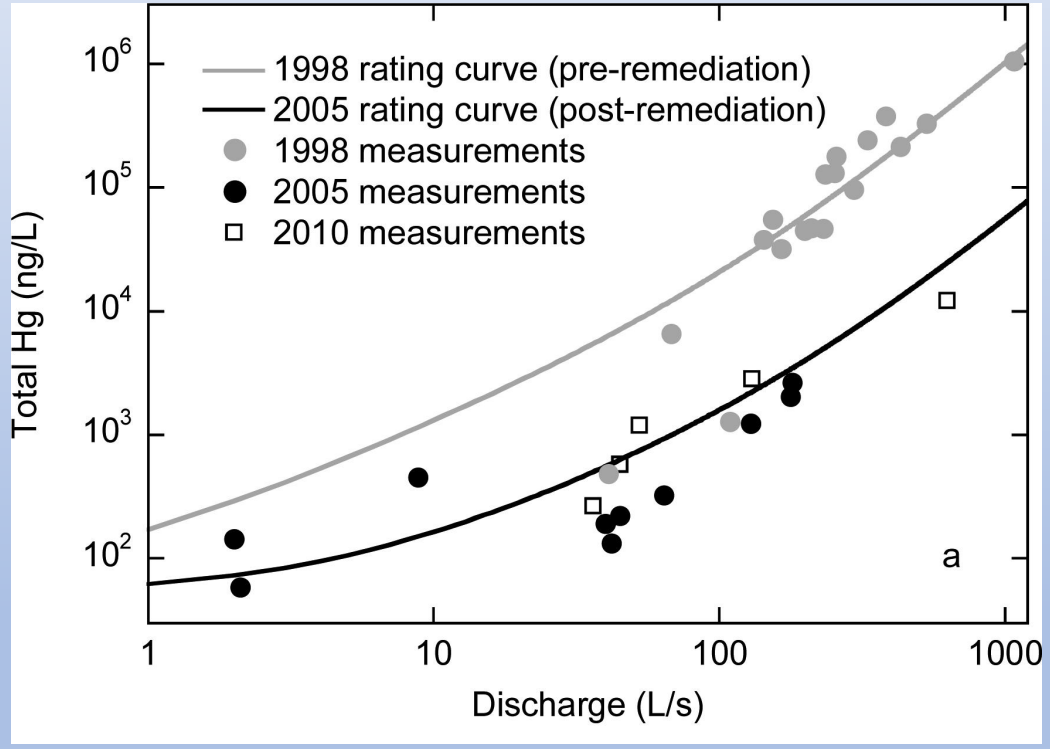
Data: CDM/EPA

Photos: CDM Smith

Source controls can reduce Hg mobilization downstream

Site Remediation Options: *Removal*

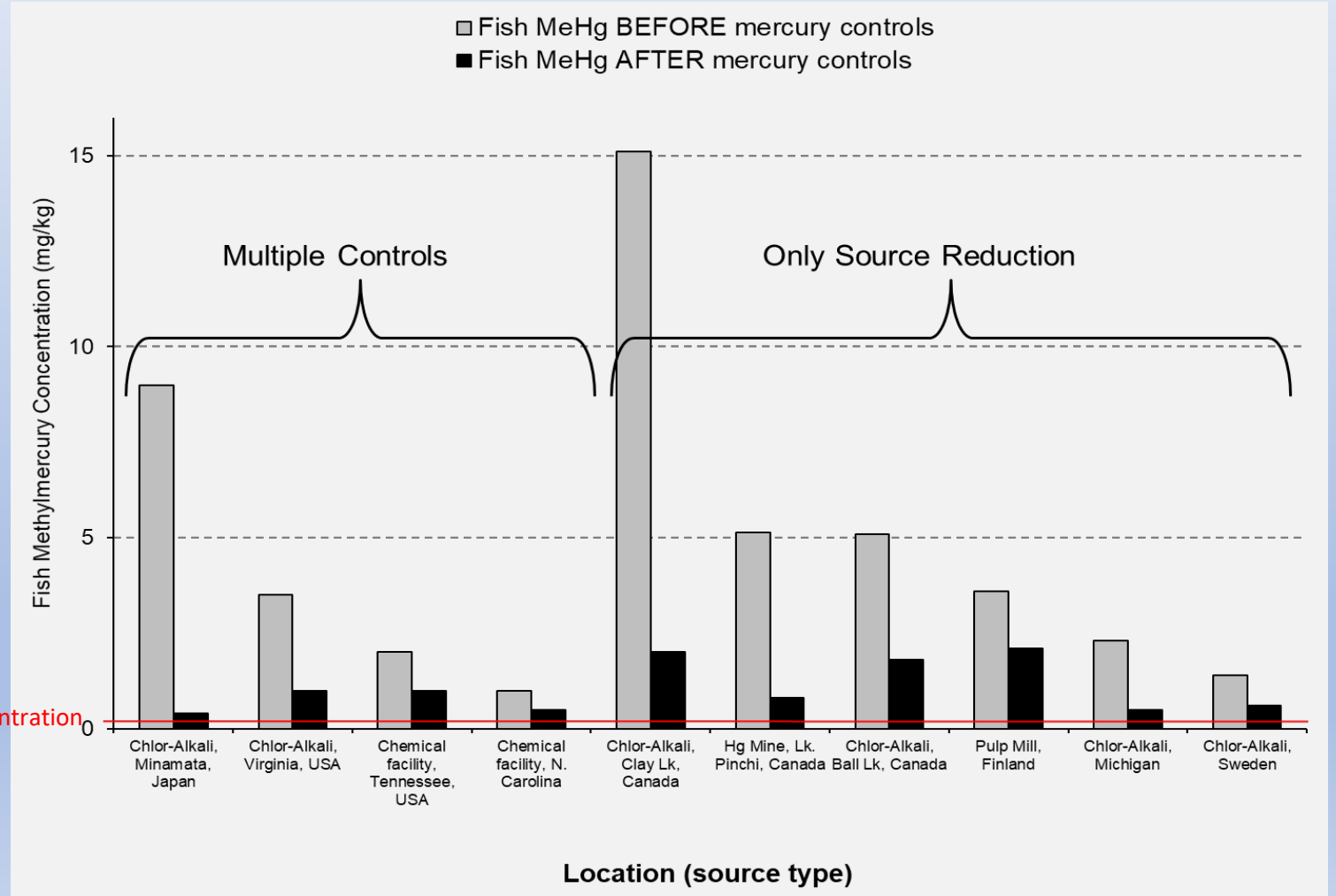
Example: Gambonini Hg Mine, CA



Source controls can reduce Hg mobilization downstream

Site Remediation Options: *Removal*

Source controls can be effective in reducing MeHg in downstream fish



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Commonly applied options:

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Most effective when the sites are:

- Highly contaminated
- Cover relatively small area
- Easily accessible
- Large remediation budgets

Alternative options needed when:

- Moderate concentrations
- Widely dispersed
- Remote area/difficult access
- Limited funding

Alternative Remediation Options: *In Situ Amendments*

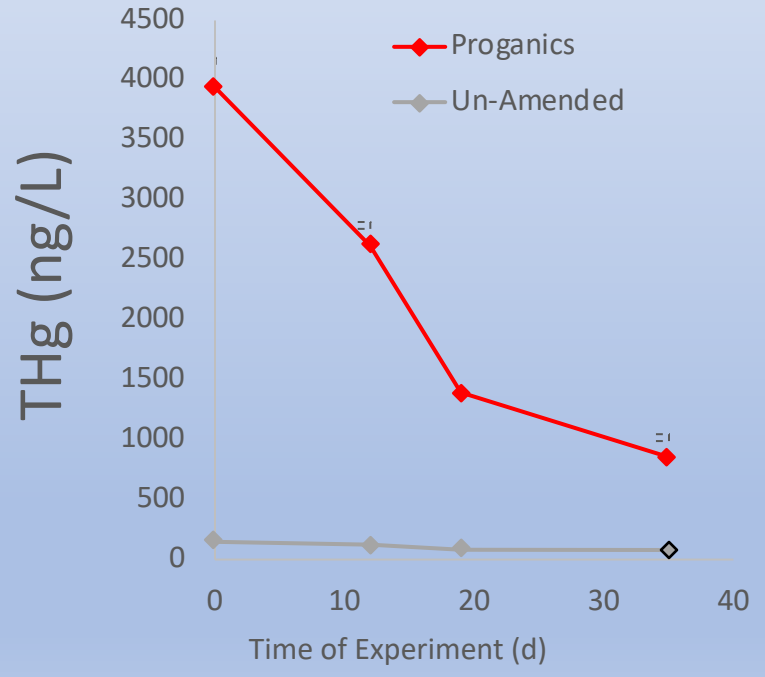
- Hg is mobilized from abandoned mine sites through surface erosion
- Surface stabilization through vegetation can reduce Hg (and other metals) transport downstream

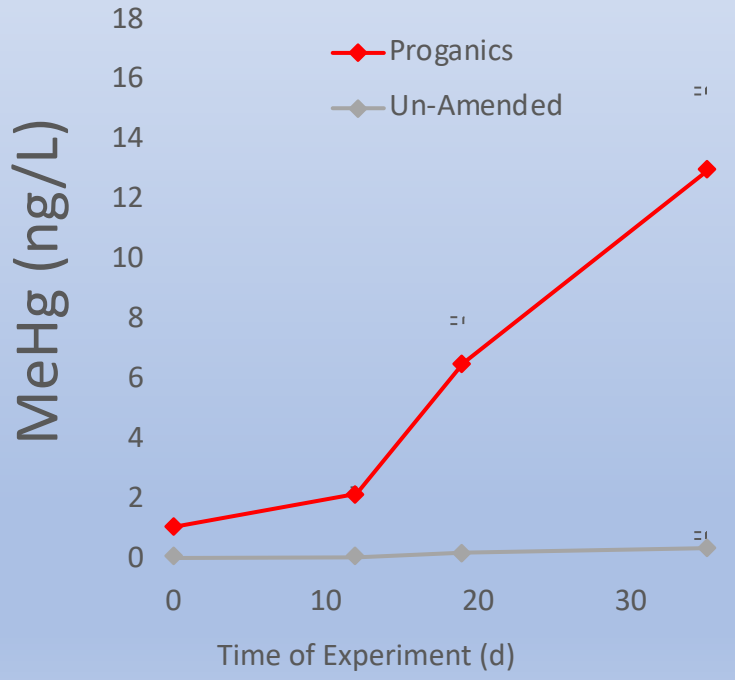
Alternative Remediation Options: *In Situ Amendments*

Cinnabar Mine, ID

How do organic carbon soil amendments impact Hg in mine tailings?

Alternative Remediation Options: *In Situ Amendments*





- Amended tailings had higher THg concentrations than un-amended tailings
- Amended tailings had higher MeHg concentration than un-amended

Soil amendments need to be selected that:

1) promote vegetation
2) sequester Hg

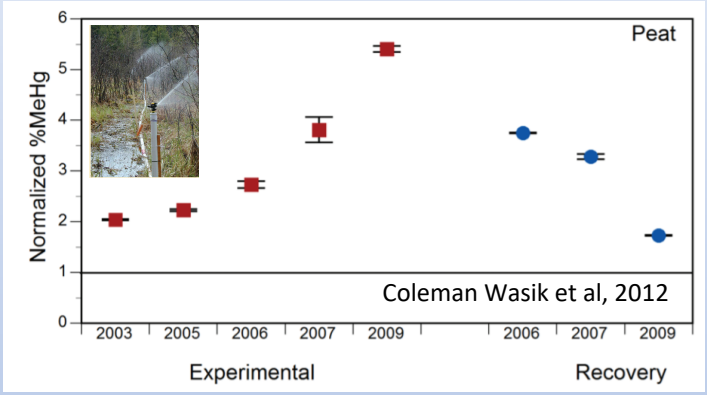
Biochar is a customizable type of soil amendment that has the potential to meet both objectives.

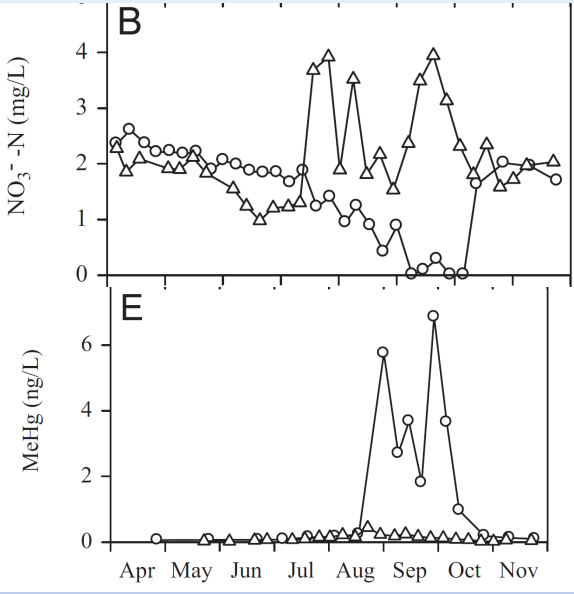
Source: Johnson

Alternative Remediation Options: *Reduce MeHg*

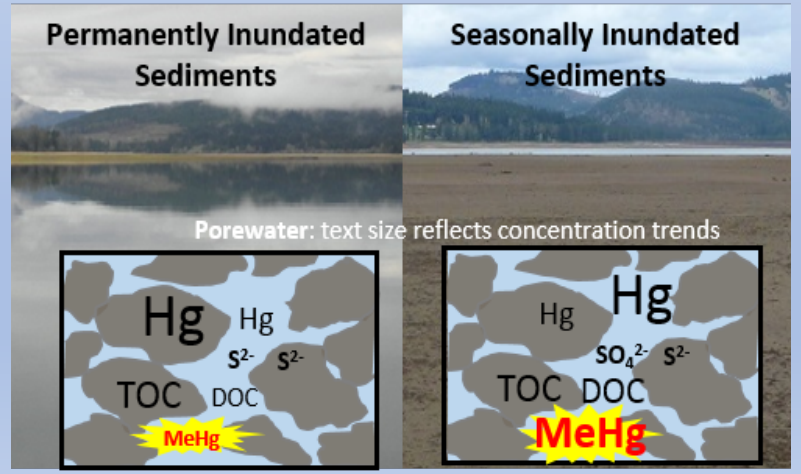
Strategies to reduce methylation, without reducing Total-Hg:

- Redox poising: O_2, NO_3^-, Mn additions
- Sulfate reductions
- Carbon reductions
- Hydrological alterations

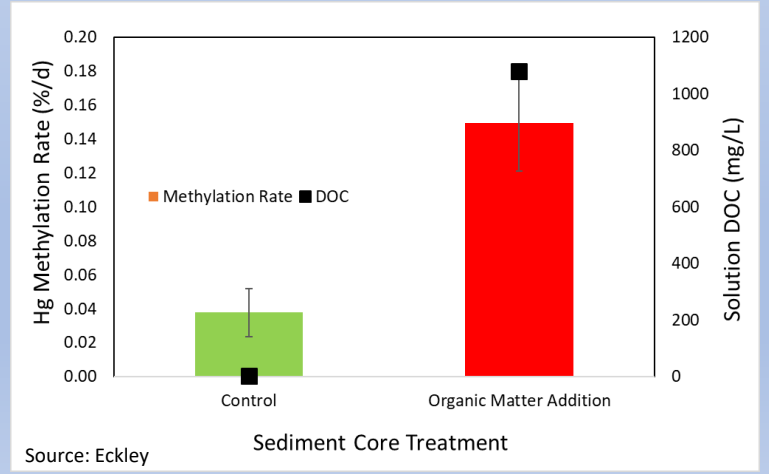


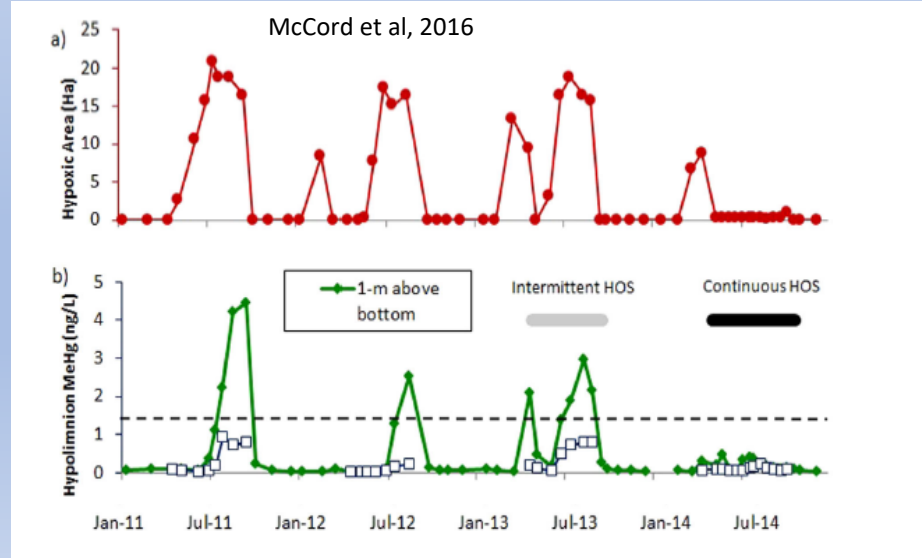


Mathews et al, 2013



Eckley et al., 2017

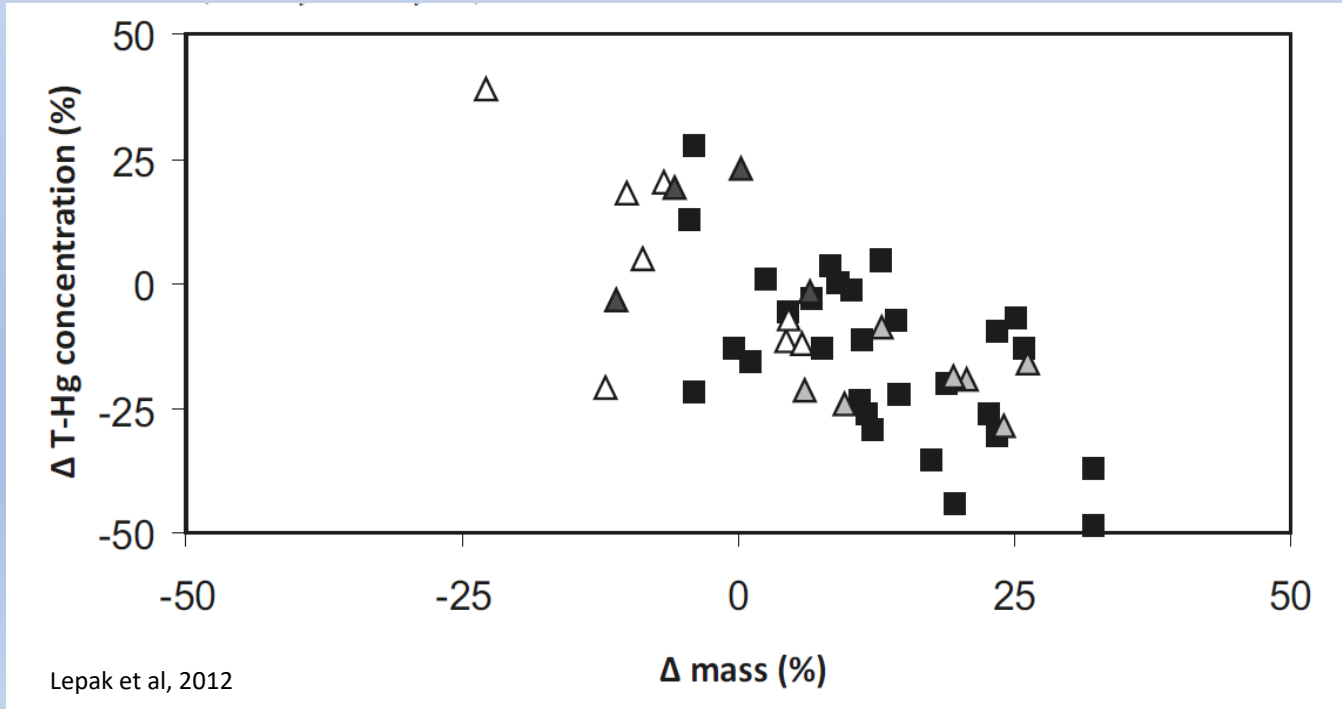




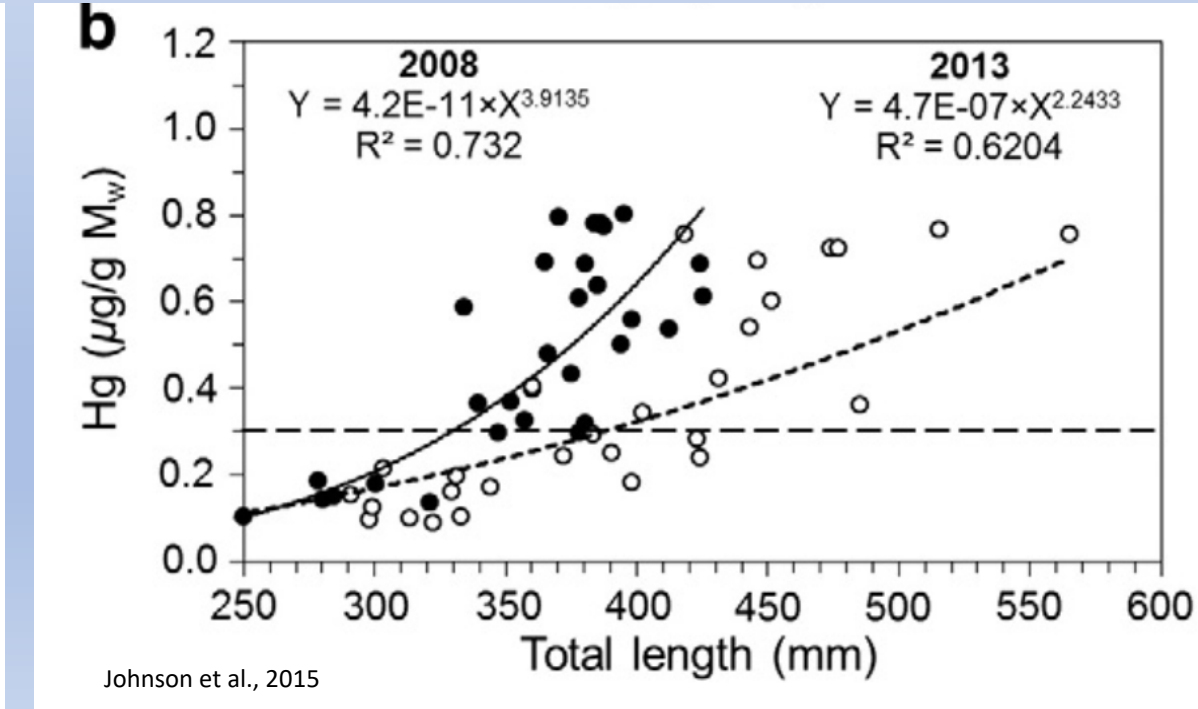
Alternative Remediation Options: *Foodweb manipulation*

Strategy to reduce MeHg in fish, without reducing methylation or sediment/water Total-Hg:

- Foodweb and fish growth manipulations
  - ➢ Introduction of low Hg prey fish
- Only applicable to closed systems amenable to manipulations



Lepak et al, 2012



Johnson et al., 2015

Summary

Hg mine assessments and remediation can be optimized by:

- Using stable isotope fractionation to identify sources of contamination
- Targeting source control/remediation actions on major downstream transport pathways
- Using alternative methods to reduce Hg transport and/or MeHg production and/or bioaccumulation—which may not require total-Hg concentration reductions

Requires significant investments in research aimed at understanding the site dynamics

Next Steps:

- Novel approaches to addressing contaminated sites have been identified at the laboratory and test plot scale;
- However, more examples of large-scale applications are needed to encourage broader adoption of these methods

Questions