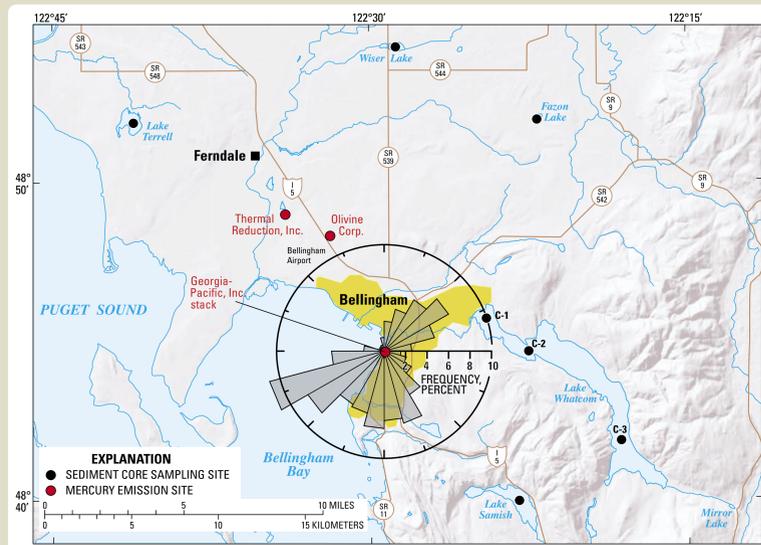


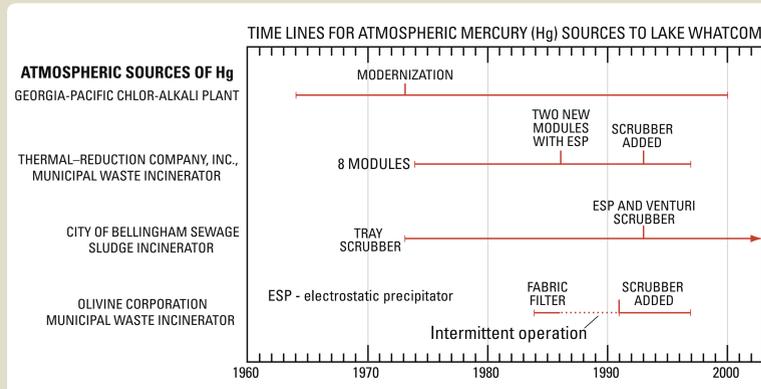
## Introduction

Concerns about mercury (Hg) contamination in Lake Whatcom (figure 1) have focused on the Georgia-Pacific, Inc. chlor-alkali plant that operated in the City of Bellingham upwind of Lake Whatcom and emitted mercury to the atmosphere from the early 1960s until 2000. Besides the chlor-alkali plant, other known emitters of atmospheric Hg included the sewage sludge incinerator of the City of Bellingham near downtown Bellingham, and two municipal waste incinerators in Ferndale (Thermal Reduction Company, Inc.) and the Bellingham Airport (Olivine Corp.).



**Figure 1.** Location of sources of mercury emissions and sediment core sampling sites, with the 1996 wind field at Georgia-Pacific meteorological station superimposed, Bellingham, Washington.

A change in operation and (or) the extent of atmospheric emission controls occurred during the operations of all major Hg emitters in Whatcom County (figure 2). Changes in Hg atmospheric deposition to lakes in Whatcom County were evaluated in the context of these changes in operations.



**Figure 2.** Timelines of local atmospheric sources of mercury.

## Deposition Model

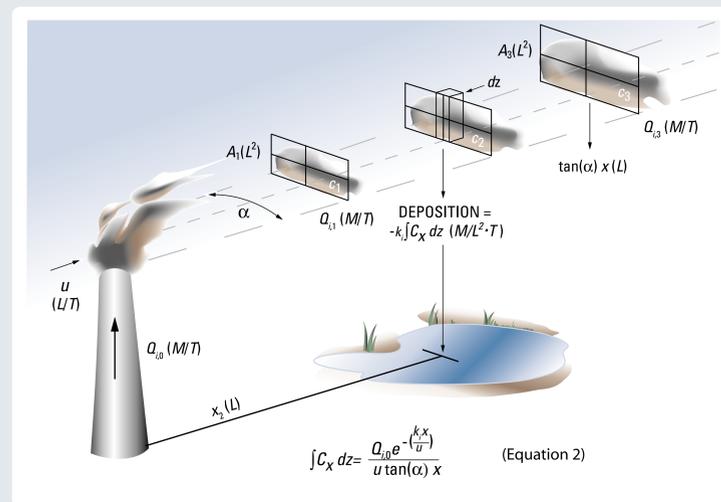
Given the paucity of local Hg emissions data and the lack of local Hg speciation data, only a simple model that provides a rough estimate of Hg deposition for the atmospheric emission sources is warranted.

This model, based on first principles (figure 3), was developed to estimate, in a consistent manner, the deposition of Hg to lakes in Whatcom County from past local sources of Hg. Deposition to aquatic and terrestrial surfaces depends primarily on the reactivity constant for species  $i$ ,  $-k_i$ , which is the measure of how fast Hg is removed from the atmosphere and is inversely proportional to the atmospheric half-life of each species. In the model, deposition of the three forms of Hg (vaporous elemental, reactive gaseous [RGM], and particulate) initially emitted from a source is considered independently, and the total deposition is the sum of the deposition ( $Dep_i$ ) of the three species.

$$Dep_i = \frac{k_i \cdot Q_{i,0} e^{-\frac{k_i}{u} \cdot x}}{(u \cdot \tan(\alpha) \cdot x)} \quad (\text{Equation 1})$$

where

$Q_{i,0}$  is the emission of species  $i$  from the source,  $x$  is the distance between the source and lake of interest, and  $u$  is the wind speed, and  $\alpha$  is the angle of the plume dispersion.



**Figure 3.** Concepts of a simple model of the deposition of mercury.

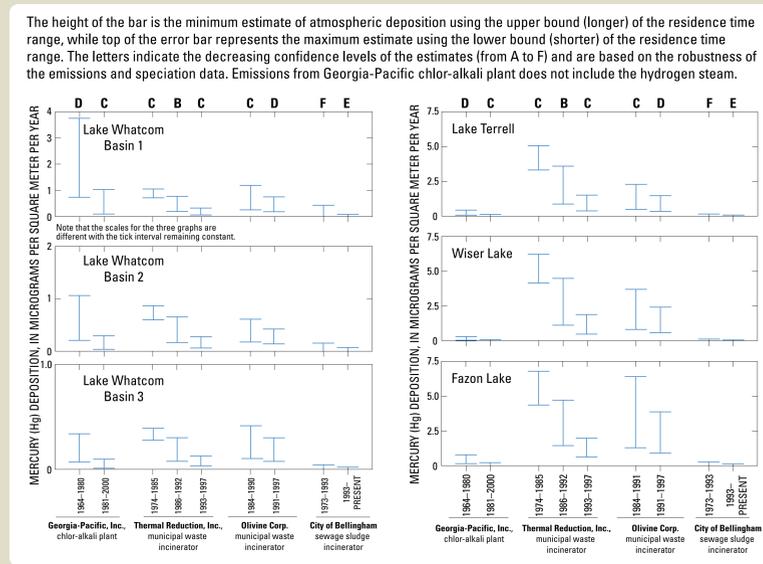
Equation 2 relates transport concepts (figure 3).

$$\frac{Q}{u} = \text{DILUTION OF SOURCE BY WIND} \quad e^{-\left(\frac{k_i x}{u}\right)} = \text{LOSS BETWEEN SOURCE AND LAKE} \quad \frac{1}{\tan(\alpha) x} = \text{DILUTION BY LATERALLY EXPANDING PLUME}$$

In most cases, deposition is independent of the plume angle. Given a specific wind field, deposition at a given point from the source was calculated knowing the emission rate of species  $i$  ( $Q_{i,0}$ ), and the reactivity constant ( $k_i$ ). The speciation of Hg in specific types of facilities and the atmospheric reactivity constant of each Hg species were taken from the literature. If the plume was above the target receptor (target-receptor direction is within wind direction  $\pm \frac{1}{2}\alpha$ ), direct deposition of Hg to the site was calculated for that hour.

## Model Estimates

The large estimated deposition to basin 1 (C-1) of Lake Whatcom from the Georgia-Pacific, Inc. chlor-alkali plant between 1964 and 1980 (figure 4) was a result of Hg emissions from chlorine production, which were assumed to be RGM. Emissions from this source were eliminated during the late 1970's modernization. The burning of the hydrogen gas produced by the alkali production in the lignin spray dryers of the pulp mill is unique among chlor-alkali plants in the United States and the associated deposition of Hg to nearby lakes could not be estimated because the speciation of the emitted Hg could not be evaluated. The deposition of Hg to lakes after 1980 was estimated from modern emissions and speciation data for fugitive emissions from the mercury. The deposition of Hg to basins 2 (C-2) and 3 (C-3) of Lake Whatcom from the Georgia-Pacific, Inc., plant was estimated to be significantly less because of their location relative to the primary wind direction. The estimated deposition to Lake Whatcom from the two municipal waste incinerators was greater than or equal to that of the chlor-alkali plant after its modernization.

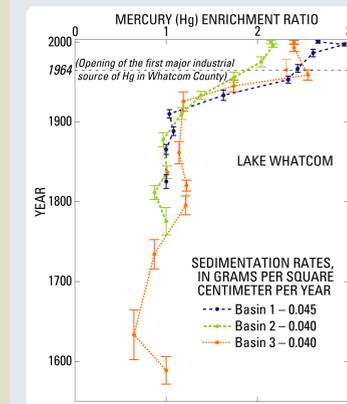


**Figure 4.** Estimates of atmospheric deposition of mercury as a function of times of significantly different operations for the three basins of Lake Whatcom and Lake Terrell and Fazon and Wisser Lakes, Whatcom County, Washington.

The largest estimates of atmospheric deposition of Hg found in this study were to three lakes north of Bellingham from the two municipal waste incinerators. Estimated depositions were especially high during the early periods of operation that included little pollution control of air emissions. The dominance of the RGM form in flue gas in municipal waste incinerators (Prestbo and Bloom, 1995) was largely responsible for the larger deposition to these lakes. The presence of chlorine gas from the combustion of vinyl chloride plastics is thought to stabilize Hg in the RGM form.

## Comparison of Trends

Local emission sources do not seem to dominate the flux of Hg to sediments of Whatcom County lakes because:

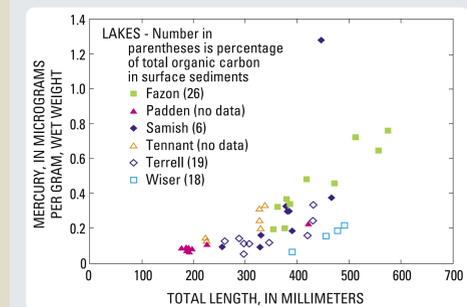


**Figure 5.** Relation of enrichment ratio of mercury with time in sediment cores from the three basins of Lake Whatcom.

- Major increases in Hg in the sediments of Whatcom County lakes occurred before the operation of the major local Hg sources (figure 5).

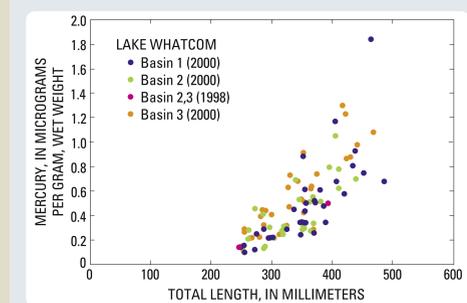
- Geographic trends in Hg enrichment ratios (the ratio of Hg concentrations to an established background concentration) do not follow the trends in estimated atmospheric deposition. For instance, the model suggests a decrease in Hg deposition from basin 1 to basin 3 of Lake Whatcom, yet the enrichment ratios of basins 1 and 3 are similar.

Local emission sources also do not seem to be related to the bioaccumulation of Hg in fish because:



**Figure 6.** Relation of concentrations of mercury in fillets to total length of largemouth bass in selected lakes of Whatcom County (data from Washington State Department of Ecology collected in 2002, and 2003).

- The estimated atmospheric Hg depositions to Wisser and Fazon Lakes from local Hg sources were similar, but Hg concentrations in largemouth bass of a given length from Fazon Lake were much higher than similar size bass from Wisser Lake (figure 6).



**Figure 7.** Relation of concentrations of mercury in fillets to total length of smallmouth bass in Lake Whatcom.

- The higher Hg concentrations in smallmouth bass from basin 3 of Lake Whatcom than from basins 1 and 2 (figure 7), is opposite to the decreasing in model deposition of atmospheric Hg to basin 1 relative to basin 3.

## Reference

Prestbo, E.M., and Bloom, N.S., 1995. Mercury speciation adsorption (MESA) method for combustion flue gas: Methodology, artifacts, intercomparison, and atmospheric implications: Water, Air, and Soil Pollution, v. 80, p. 145-158.