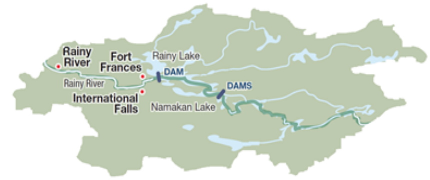


Factsheet #7

<u>Title: Mercury in Fish</u>

Mercury (Hg) is a chemical element. It is the only metallic element that is liquid at standard conditions of temperature and pressure. Hg is used in thermometers, barometers, manometers, sphygmomanometers, float valves, fluorescent lamps and other devices. It is also a metal with properties that can lead to substantial environmental and health concerns.

Mercury is natural

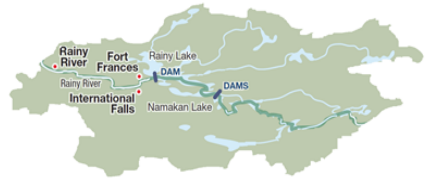
Hg occurs naturally in our environment in different forms. It can be found in deposits throughout the world mostly as cinnabar (mercuric sulfide). Natural sources also include volcanoes, forest fires, and fossil fuels such as coal and petroleum.

Mercury is anthropogenic

Although Hg occurred naturally long before humans walked the earth, human activity now releases, especially in the atmosphere, four times the amounts of Hg emitted by natural sources. The anthropogenic sources of Hg in the environment include discharges from hydroelectric, mining and pulp and paper industries. Incineration of municipal and medical waste and emissions from coal-using power plants also contribute to high levels of Hg in the atmosphere.

Mercury has a cycle

Since Hg is a liquid at room temperature, it is more volatile, an unusual property for a metal. That property allows Hg to easily spread into the atmosphere and travel over long distances as mercury vapor (Hg0). Once in the atmosphere, the Hg0 can circulate for up to a year and then be widely dispersed. The Hg0 can then experience photochemical oxidation to become inorganic Hg that can combine with water vapors and travel back to soil and waterbodies as rain (Figure 1). In soil, the Hg accumulates until a physical event causes it to be released again. In water, it can be converted into insoluble mercury sulphide that settles out of the water and into the sediment, or it can be converted by Sulphur-Reducing Bacteria (SRB). SRB is a special kind of microbe that feeds on the organic matter, mainly from decaying plants. When little oxygen is available, SRB have the ability to use sulphate to breathe instead of oxygen. Wetlands that are being inundated rapidly become oxygen-poor and conditions are established for SRB to thrive. Unfortunately, SRB have another crucial characteristic: they convert Hg to Methyl-mercury (Me-Hg).



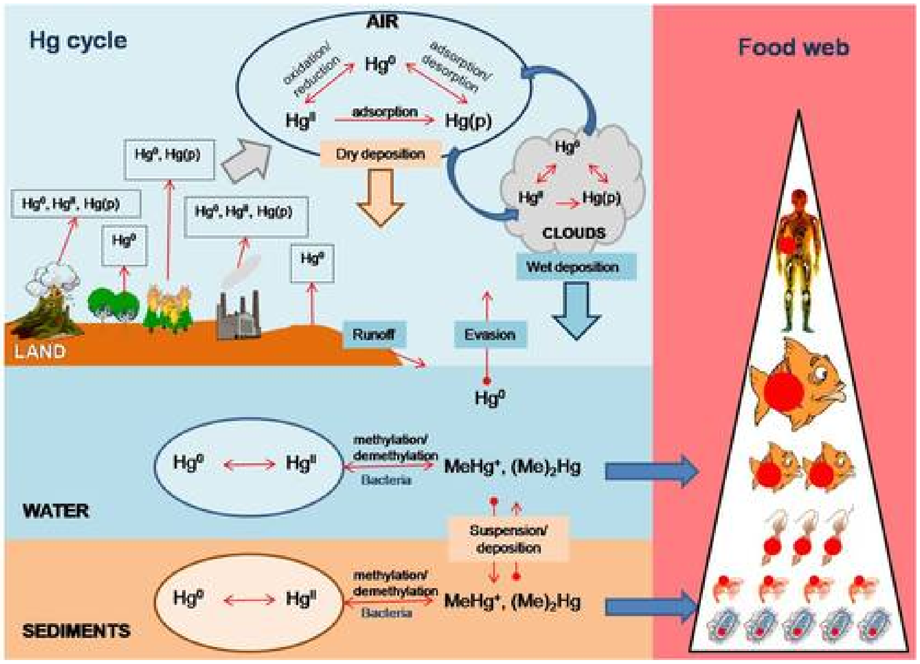


Figure 1: Relationship between the bio-geochemical cycle of mercury (left) and the food web (right). (Source: www.geo-tasks.org)

Mercury does bioaccumulate

The SRB may be consumed by the next higher organism up the food chain, or the bacteria may release the Me-Hg into the water where it can stick to plankton, which can also be consumed by the next higher organism up the food chain. Me-Hg binds very effectively to food and is not easily eliminated from the organism. As such, fish feeding on other fish tend to have higher Hg concentration then fish feeding on plants and long-lived animals accumulate more Hg than short-lived ones. Larger fish, and especially older fish, have higher concentrations of Hg due to their higher position in the food web and a longer time spent accumulating Hg. This phenomenon is called bioaccumulation (Figure 1).

Mercury is toxic

Accumulation of Me-Hg in fish tissue is considered a substantial threat to the health of wildlife and humans. Hg is a champion among toxic heavy metals. Toxic effects include damage to the brain, kidneys and lungs. Its greater toxicity stems from its interaction with an essential element called selenium (Se). Se is a mandatory nutrient to protect the body against chemical damages naturally associated with oxygen use. Hg deactivates Se protection, leaving organs that are heavy oxygen users, such as the brain and the liver, at great risk, especially for unborn babies.

Mercury and water-level regulation: is there a link?

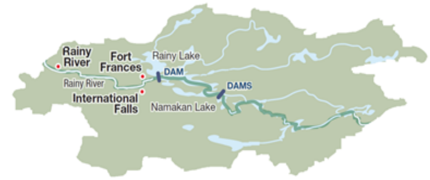
Assessing the link between fish Hg concentrations and environmental factors is important because of the human and ecosystem health consequences associated with Hg contamination. If there is a link between annual water-level fluctuations and Hg entering the aquatic food web each year, management actions reducing the annual water-level fluctuations may reduce Hg bioaccumulation.

Mercury in Rainy Lake and Namakan Reservoir: the case of the yellow perch

Rainy Lake and Namakan Reservoir water-level fluctuations have been regulated by different Rule Curves (RC) since 1949. RCs are requisite maximum and minimum water levels between which the private dam owners are required to operate. Since the area is known for its sport and commercial fisheries, looking at the impact of RC on Hg concentration in fish is important. A U.S. Geological Survey/National Park Service water quality partnership study was conducted to assess Me-Hg in young-of-year (YOY) Yellow Perch (Perch that are less than one year old) as a function of water-level fluctuations in the past decade. The studies showed that positive trends in fish Hg concentration with increasing water-level fluctuations sometimes occurred in reservoirs. Using the data of this study and other data available in the area, we developed a mercury-driven Performance Indicator (PI) to be used in the Rainy-Namakan RC review study of 2017.

The PI uses total Hg concentration in YOY Yellow Perch as a target organism and focuses on the larger lakes within Voyageur National Park (VNP), namely Rainy Lake and the Namakan Chain of Lakes, which encompasses Little Vermilion Lake, Crane Lake, Sand Point Lake, Namakan Lake and Kabetogama Lake. The Hg was measured in YOY Yellow Perch, a prey species of Walleye, in a way to quantify short-time Hg accumulation. The PI was built using a regularized regression method and was applied to observed water-level time series (i.e. the “Measured” time series).

Results from the Measured time series can be split into four periods of different water-level management: before 1949 where no RC was applied; 1950-1970 when water was under the 1949-1957 RC; 1970-2000 when water was regulated according to the 1970RC; and 2000-2015, when the 2000 RC was used. In Namakan Reservoir, the implementation of the first RC around 1950 reduced the variability of Hg concentration in the YOY Yellow Perch. After 2000, when the 2000 RC was implemented, the Hg concentration seemed to increase. In Rainy Lake, the concentration of Hg in the YOY Yellow Perch seems more stable during the observed period (Figure 2).



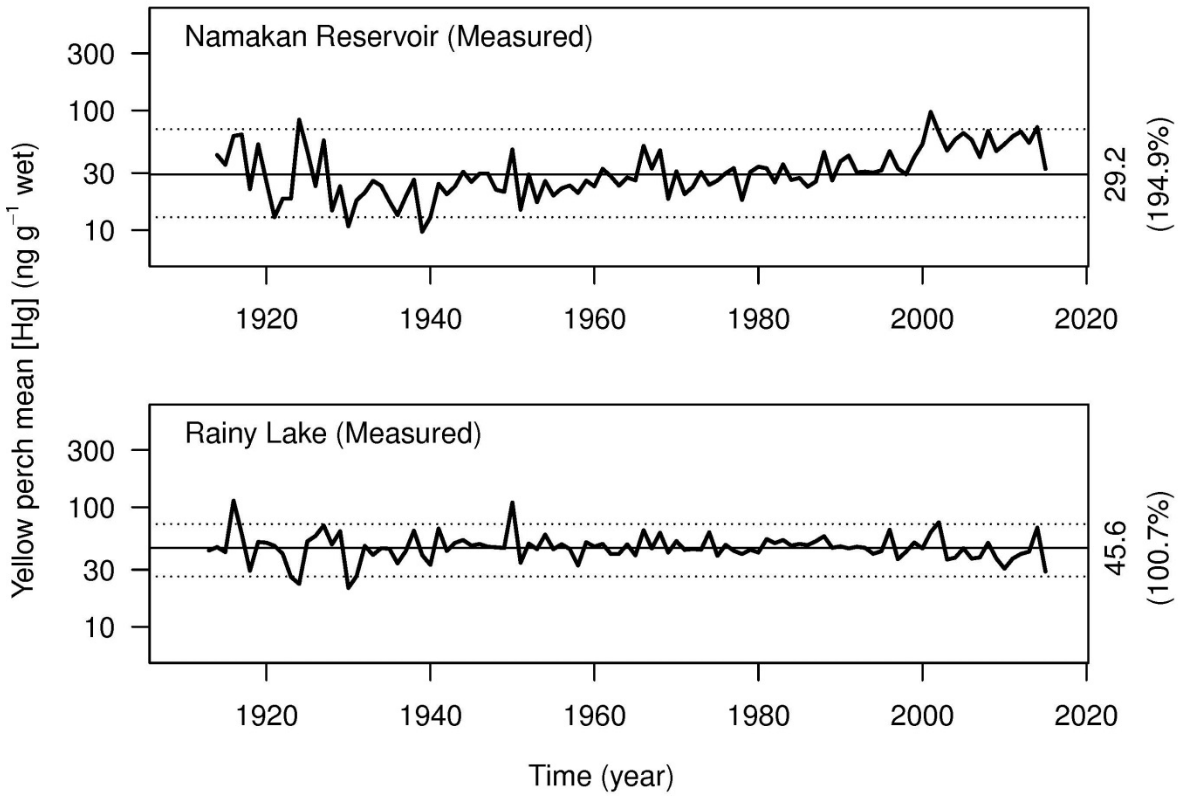


Figure 2: Mercury-PI: Yellow Perch mean mercury concentration ([Hg]) predicted for Namakan Reservoir and Rainy Lake using the model involving water-level fluctuations estimated in the present study. The horizontal solid line represents the median of the mean annual values (shown on the right margin of each plot), whereas the dotted lines delimit the interval where 95% of the mean annual values are found. Predictions for Namakan Reservoir are the average Hg predicted of its four constituent lakes (Kabetogama Lake, Namakan Lake, Crane Lake, and Sand Point Lake) weighted by their respective surface areas.

To conclude that there is a link between RC and Hg concentration in YOY Yellow Perch with the results of Figure 2 is premature. Since 1920, there is not only the RC that has changed in the Rainy-Namakan system. To isolate the effect of the RC on Hg concentration, we used three simulated water-level time series: no water-level regulation (i.e. “Natural”), regulation under the 1970 rule curves (i.e. “1970 RC”), and regulation under the 2000 Rule Curves (i.e. “2000 RC”). Those series were simulated between 1950 and 2012. We found evidence for an effect of water-level regulation on Hg concentration in YOY Yellow Perch in both systems (Figure 3).

The application of the models to the different water-level time series used to assess RCs revealed that natural water-level fluctuations were associated with higher YOY Yellow Perch Hg concentration in Namakan Reservoir but lower Hg concentrations in Rainy Lake. Natural water-level fluctuations also make Hg concentration more variable among years. The Natural time series afterwards shows that, all else being equal, Hg concentration in YOY Yellow Perch would have varied almost 2.5-fold among consecutive years in Namakan Reservoir and Rainy Lake whereas controlled time (1970RC and 2000RC) series were associated with more modest among-year variability (around 70%).

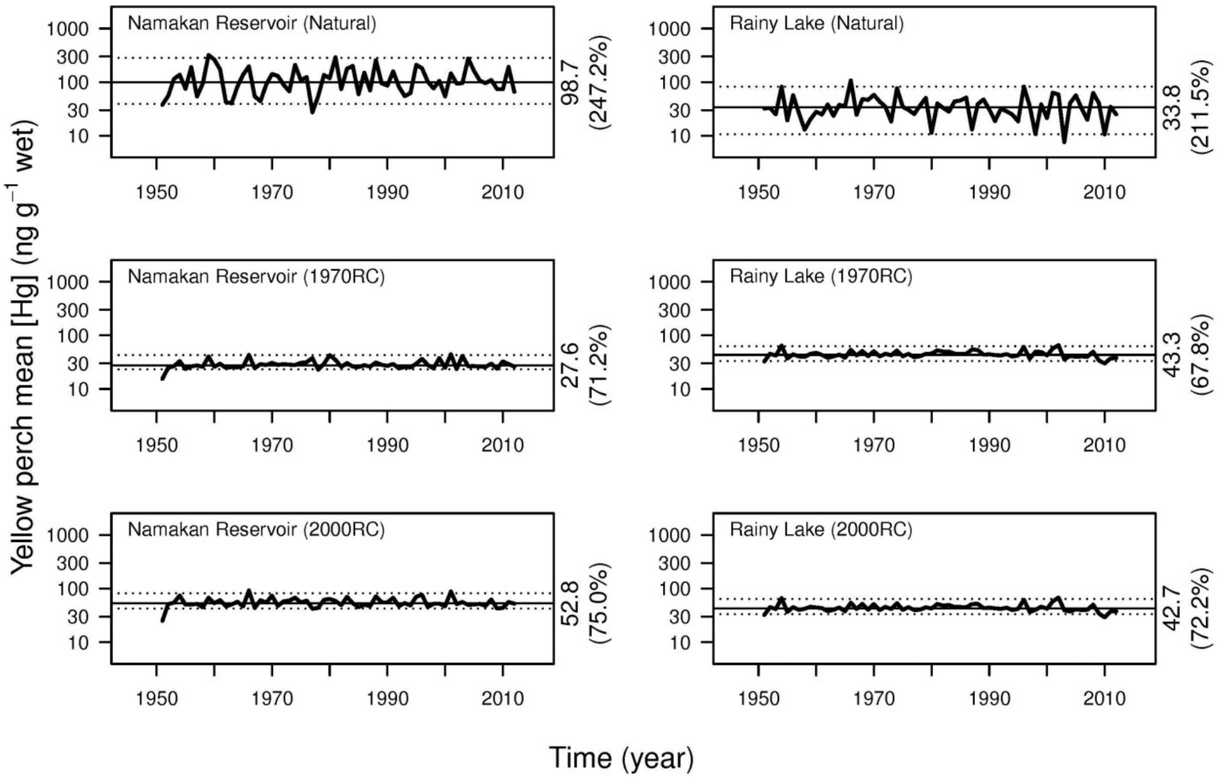


Figure 3: Yellow Perch mean mercury concentration ([Hg]) predicted between 1950 and 2015 for Namakan Reservoir and Rainy Lake using the models involving water-level fluctuations developed for the PI. Predictions were done on the basis of three theoretical time series assuming either the absence of water-level regulation (Natural), or applying the 1970 (1970R C) or 2000 (2000 RC) rule curves over the wholetime period. The horizontal solid line represents the median of the mean annual values (shown on the right margin of each plot), whereas the dotted lines delimit the interval where 95% of the mean annual values are found. Predictions for Namakan Reservoir are the average Hg predicted of its four constituent lakes (Kabetogama Lake, Namakan Lake, Crane Lake, and Sand Point Lake) weighted by their respective surface areas.

Mercury and larger fish: the case of the northern pike

In general, sport fishermen do not fish Yellow Perch, they fish larger prey, like Northern Pike that are at a higher position in the food web, meaning they may have more bioaccumulated Hg. Besides the Yellow Perch, Minnesota Department of Natural Resources has collected data on Hg concentration in Northern Pike larger than 55 cm from the 1970s that show three-fold variability during a period of 45 years (Figure 4). Those results highlight that Hg uptake by a large predatory fish is relatively consistent between two nearby systems and are variable in time, suggesting that it may be predictable to some extent. However, we did not find a suitable model predicting Hg concentration in Northern Pike.

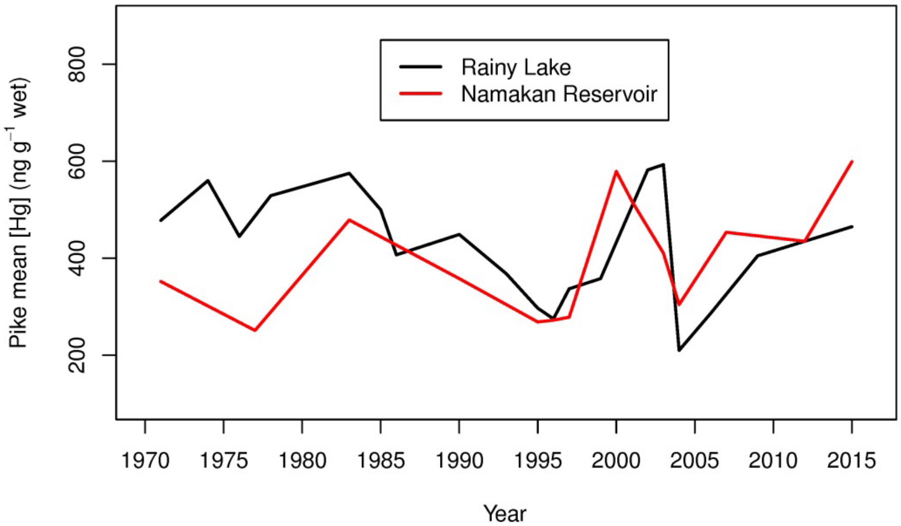


Figure 4: Mean mercury concentration ([Hg]) in Northern Pike larger than 55 cm between 1970 and 2015 in Northern Pike from Namakan Reservoir and Rainy Lake by Minnesota Department of Natural Resources. Data for Namakan Reservoir were the averages from Namakan Lake, Kabetogama Lake, and Sand Point Lake weighted by their respective surface areas.

Mercury is complex: The Study Board perspective

Given that previous studies that found that water-level fluctuations affect Hg concentration in YOY Yellow Perch were further confirmed by the present work, it was possible to take it into account during the RC review process. The PI we developed can be used for that purpose. However, besides water-level fluctuations, the new analysis showed that Hg concentrations in YOY Yellow Perch depend on several factors that are out of our control, such as atmospheric deposition rates. The concentration of Hg the models predicted in the past assume similar Hg deposition rates as those of the study period. Mercury deposition rates have been found to vary extensively during the period when water levels were recorded in the system. Therefore, the estimate we obtained from the water-level time series should not be regarded as historic, but rather as projections, under rather constant environmental conditions, for RC assessment purposes. Moreover, the relationship between water level fluctuations and Hg concentration in fish is relatively recent work and more analysis needs to be produced to show a clear and unambiguous trend.

Moreover, the Study Board did not consider any potential RC that would substantially affect the year-to-year change in maximum levels. For those reasons, and given our lack of control and the underlying uncertainty regarding the other drivers controlling Hg in fish, the Study Board did not attempt to rank water-level management plans on the basis of predicted changes in fish Hg concentration.

Mercury and fish consumption

As a consequence of Hg toxicity, Minnesota and Ontario governments are monitoring Hg in fish and make specific recommendations for human consumption. These recommendations are based on a recommended number of fish meals per month, depending on function of the species and size. These recommendations can be found for Minnesota (Minnesota Department of Health - Fish Consumption Guidelines) at:

http://www.health.state.mn.us/divs/eh/fish/eating/genpoplakes.pdf)

and for Ontario (Ministry of the Environment and Climate Change, Guide to Eating Ontario Fish at: https://dr6j45jk9xcmk.cloudfront.net/documents/4460/fishguide2015-final-aoda-en-final.pdf)

Mercury: if you want to learn more

Heath, J. C. and Banna, K. M. and Reed, M. N. and Pesek, E. F. and Cole, N. and Li, J. and Newland, M. C., "Dietary selenium protects against selected signs of aging and methylmercury exposure.", Neurotoxicology 31 (2010), pp. 169--179.

Larson, J. H. and Maki, R. P. and Knights, B. C. and Gray, B. R., "Can mercury in fish be reduced by water level management? Evaluating the effects of water-level fluctuation on mercury accumulation in Yellow Perch (*Perca flavescens*).", Ecotoxicology 23 (2014), pp. 1555--1563.

Minnesota Department of Health, "Fish consumption guidelines for women who are or may become pregnant and children under age 15." (2016a), pp. 1—195

Minnesota Department of Health, "Fish consumption guidelines for the general population." (2016b), pp. 1—191.

Morin, J. and Bachand, M. and Richard, J. H. and Martin, S., "Modeling the Rainy Lake and Namakan Reservoir ecosystem response to water-level regulation.", Hydrology and Ecohydraulic Section, Environment Canada, Québec (2016).

Ontario Ministry of the Environment and Climate Change, "Guide to eating fish." (2015), pp. 1—234

Ralston, N. V. C. and Raymond, L. J., "Dietary selenium's protective effects against methylmercury toxicity.", Toxicology 278 (2010), pp. 112—123.

Ralston, N. V. C. and Ralston. C. R. and Lloyd Blackwell, J. III and Raymond, L. J., "Dietary and tissue selenium in relation to methylmercury toxicity.", NeuroToxicology 29 (2008), pp. 802—811.

Raymond, L. J. and Ralston, N. V. C., "Selenium's importance in regulatory issues regarding mercury.", Fuel Process. Technol. 90 (2009), pp. 1333—1338.

Sorensen, J. A. and Kallemeyn, L. W. and Sydor, M., "Relationship between mercury accumulation in young-of-the-year Yellow Perch and water-level fluctuations.", Environ. Sci. Technol. 39 (2005), pp. 9237—9243.

Thompson 2015Thompson, A. F., "Rainy and Namakan hydrologic response model documentation.", Environment Canada (2015).

Willaker, J. J. and Eagles-Smith, C. A. and Lutz, M. A. and Tate, M. T. and Lepak, J. M. and Ackerman, J. T., "Reservoirs and water management influence fish mercury concentrations in the western United States and Canada.", Sci. Tot. Env. 568 (2016), pp. 738—748.

United States Department of Interior USGS, "Glacial ice cores reveal a record of natural and anthropogenic atmospheric mercury deposition for the last 270 years." (2002).