Effects of the PolyMet NorthMet Mine on Downstream Mercury in Water and Biota

Dr. Brian Branfireun

Public hearing in response to an objection from the Fond du Lac Band of Lake Superior Chippewa under Section 401(a)(2) of the Clean Water Act (CWA) to the Corps' Section 404 permit for the PolyMet NorthMet Project

Outline of Presentation

1) **Introduction and Qualifications**
2) **Overview: The mercury cycle, sulfate and methylmercury**
3) **Flaws in prior submissions that undermine all statements of no/environmental mercury impact by the project**
   a) Failure to characterize and understand the background environmental conditions
   b) Reliance on unproven water treatment strategies to achieve regulatory limits.
   c) Reliance on a scientifically indefensible mass balance model to avoid simulating mercury processes.
   d) Reliance on a flawed assumption of proportionality between Total Hg loading and Fish Hg
4) **Failure to consider the formation of methylmercury resulting from direct and indirect effects of mine operations** (concerning the Will Affect Notification and Objection)
   e) Enhanced release of mercury, methylmercury and sulfate due to water table drawdown from mine operations will increase methylmercury in downstream waters and biota.
   f) Enhanced release of mercury, methylmercury and sulfate due to direct mine discharges to proximal wetlands downstream will increase methylmercury in downstream waters and biota.
5) **Summary and Synthesis.**

1) Qualifications

Area of Expertise:

Mercury biogeochemistry; mercury-sulfate interactions; wetland hydrology and biogeochemistry, climate change interactions.

Training and Employment

- PhD (1999) McGill University, Montreal, CA
- 1999-2010: Professor, University of Toronto, Toronto, CA
- 2010-2022: Professor and Canada Research Chair, University of Western Ontario, London, CA

Evidence of Qualifications

- 152 published papers, book chapters and reports*
- Expert contributions to State of California, US DOE, USFS, Canadian Federal and Provincial agencies.
- Extensive prior work in Minnesota (USFS Marcell Experimental Forest; Minnesota Power/Fond du Lac)

*Google Scholar Apr 27/22

2) Overview: The mercury cycle, sulfate and methylmercury

Hg

- Mercury (Hg) is a high priority global pollutant
- Released to the environment through a range of natural and human sources
- Distributed globally in gaseous form in the atmosphere as well as discharged from point sources.
- Dominantly released in inorganic forms, but is most toxic in organic forms.

Some Terminology

Elemental Mercury: can exist both as a liquid (“quicksilver”) or as a gas.

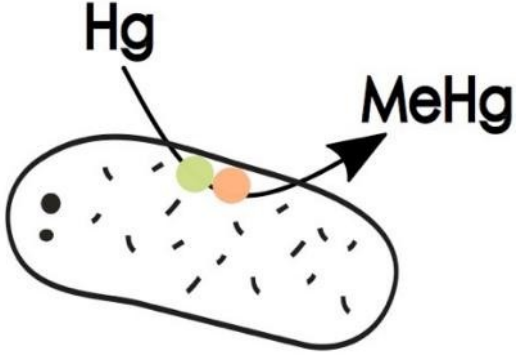
Inorganic Mercury (IHg): the ionic forms of mercury (e.g. Hg(II)) that are most abundant in water, soils and sediments.

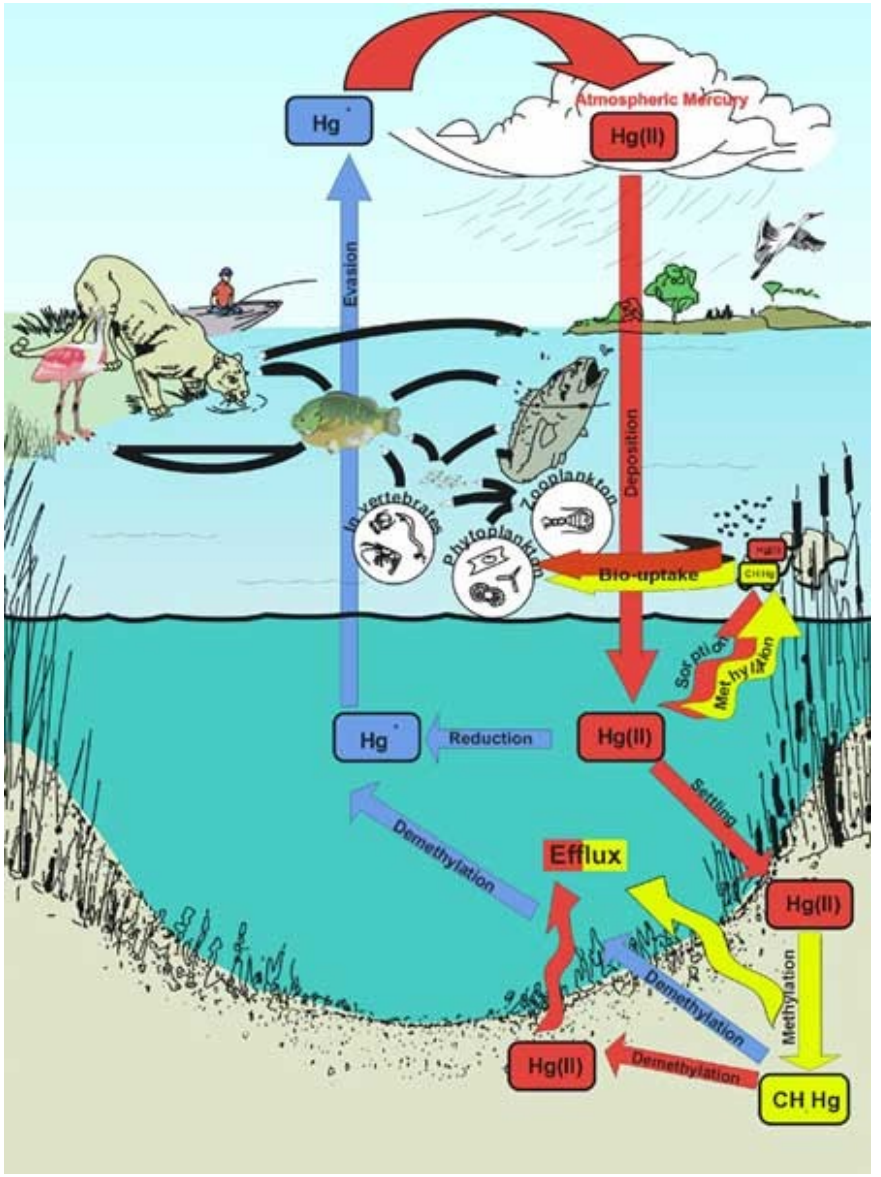
Methylmercury (MeHg): an organic form of mercury that bioaccumulates and is potently **neurotoxic**.

Total Mercury (THg): the sum of all forms mercury in a sample (IHg + MeHg). Is an operational term because of an analytical method.

2) Overview: The mercury cycle

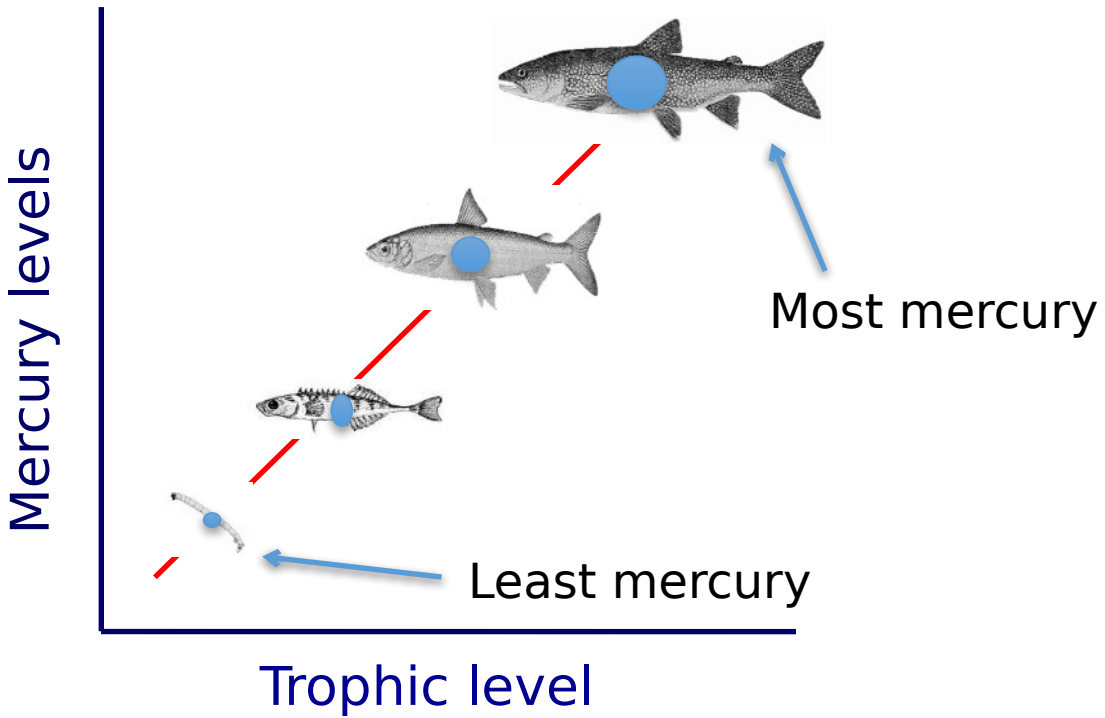
- Elemental Hg circulates in the atmosphere
- IHg is deposited to watersheds
- In oxygen-free waters and sediments, a very small fraction (usually <1%) of IHg is converted to MeHg
- MeHg is dominantly formed by bacteria in the environment (sulfate-reducing bacteria).





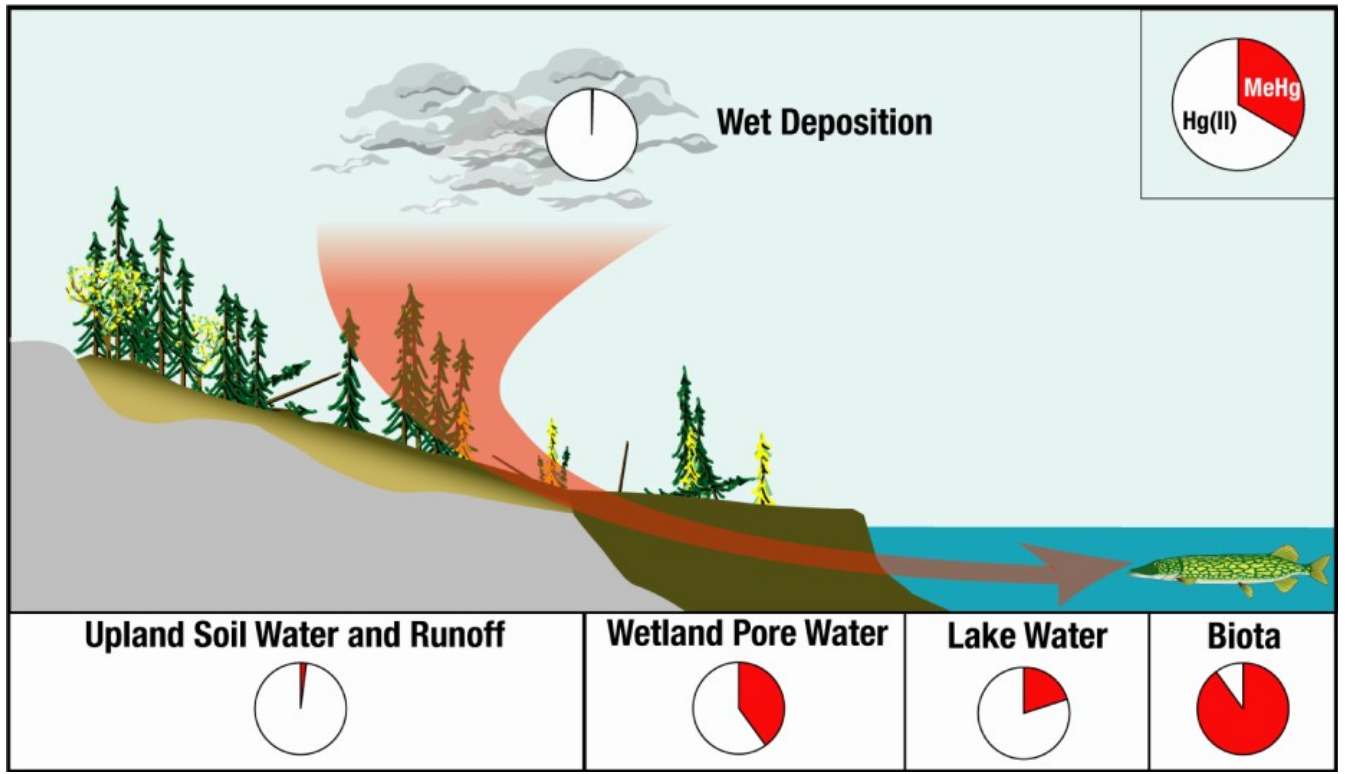
2) Overview: Bioaccumulation and Biomagnification

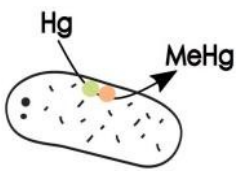
- MeHg is the only form of mercury that bioaccumulates (is strongly retained in tissues) and biomagnifies (increases up the food chain through diet).
- MeHg in a fish is about one million times higher than in the water where it lives.
- Top consumers (birds, mammals, humans) are exposed to elevated MeHg primarily through a fish diet.
- If MeHg was not formed in the environment, there would not be mercury problem.



2) Overview: MeHg Formation in the Environment

- MeHg is formed by methylating microbes (sulfate reducing bacteria) in oxygen-free environments.
- Suitable environments for methylation include, lake and river sediments, and **wetland soils.**
- Sulfate reducing bacteria “breathe” sulfate, and “eat” organic matter, and convert IHg to MeHg.

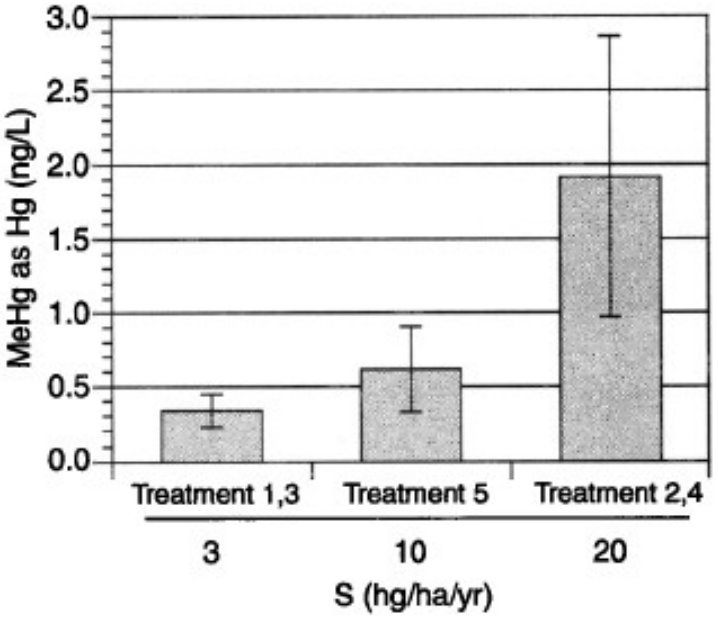




From: Krabbenhoft, Branfireun and Heyes, 2005

2) Overview: Sulfate and Methylmercury Formation

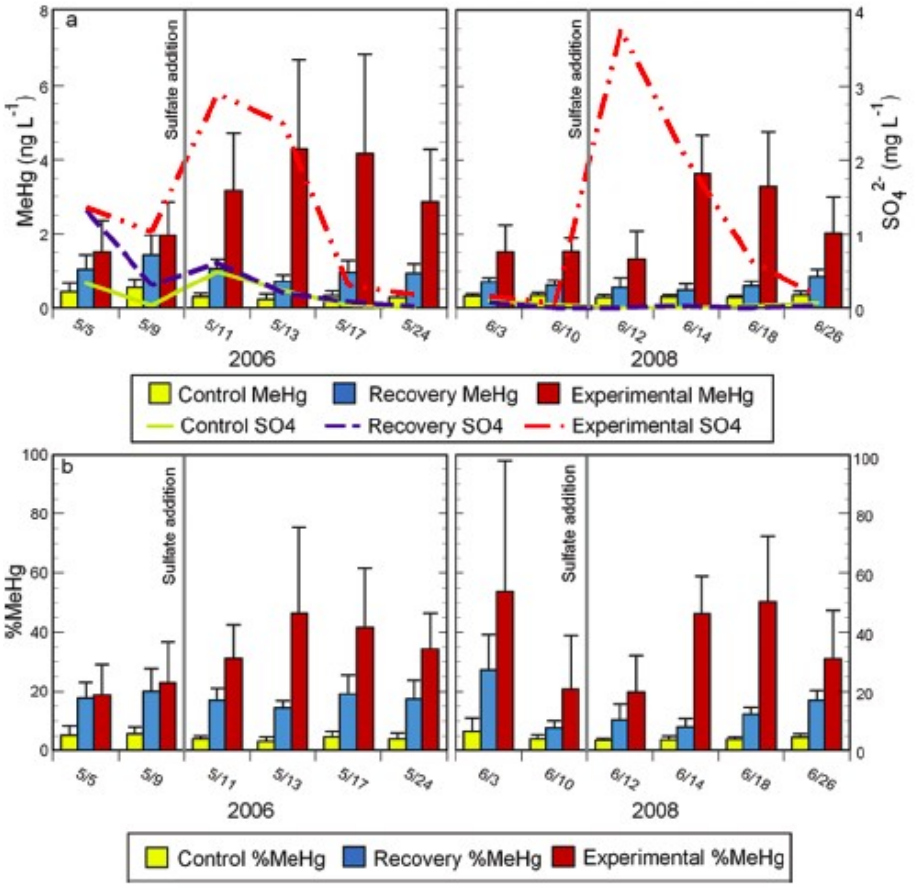
- The activity of sulfate-reducing bacteria increases when they have more sulfate available.
- It has been known since the early 1990s that additions of sulfate (e.g. from atmospheric pollution) increase MeHg production in lake sediments.
- This relationship is even more clear for wetlands and has been known since the late 1990s (my own PhD research, and others).



When there is more sulfate added to wetland soils, there is more methylmercury (from Branfireun et al. 2001)

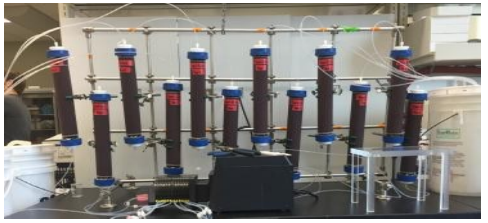
2) Overview: Sulfate, Methylmercury and Wetlands

- Important research on the role of sulfate and MeHg formation was conducted in a long term experiment at the **Marcell Experimental Forest** in Minnesota.
- Additions of sulfate dramatically increased wetland water MeHg concentrations (red bars on figure at left) and increased export of MeHg in stream outlet water.



2) Overview: Sulfate, Methylmercury and Wetlands

- Even small amounts of additional sulfate can significantly increase MeHg concentrations in wetland soils.
- Recent lab experiment from my group:
- **1 mg/L sulfate = 4x MeHg**
- **5 mg/L sulfate = 20x MeHg**
- **30 mg/L sulfate = 30x MeHg**
- Similar responses measured in field experiments



2) Overview: Why does this matter?

a) Increases in water MeHg are directly related to increases in MeHg in biota.

b) MeHg is the only form of Hg that bioaccumulates.

c) MeHg impacts the behaviour, reproduction, and survival of wildlife (fish, migratory songbirds, piscivorous birds and mammals).

d) The predominant pathway for human exposure to MeHg is from consuming fish contaminated with MeHg.

e) Health effects of MeHg exposure on humans can be severe and life-long.

2) Overview: Human Health Impacts

- Severe MeHg poisoning causes “**Minamata Disease”** (loss of vision, muscle weakness, paralysis, impaired hearing/speech).
- The developing brain is most sensitive to MeHg toxicity. Exposure for children and pregnant women has been linked to neurodevelopmental delays that persist over the lifetime, even with exposure levels below that are currently considered “safe”.
- In addition to neurotoxicity, MeHg exposure causes other adverse health effects, including cardiovascular abnormalities.
- **Biologically, there does not appear to be a safe level of methylmercury exposure for humans.**

Tomoko Kamimura, Minamata disease victim (https://en.wikipedia.org/wiki/Minamata_disease)

3) Flaws in Prior Submissions*

a) Failure to characterize and understand the background environmental conditions

b) Reliance on unproven water treatment strategies to achieve regulatory limits.

c) Reliance on a scientifically indefensible mass balance model to avoid simulating mercury processes.

d) Reliance on a flawed assumption of proportionality between Total Hg loading and Fish Hg

e) Failure to consider the formation of methylmercury resulting from direct and indirect effects of mine operations (as discussed in Will Affect Notification and Objection)

* See various materials referred to in Will Affect Notification and Objection to section 404 permit, August 3, 2021

a) Failure to characterize and understand the background environmental conditions

- Comprehensive pre-development monitoring is essential to assess change, but is was not done for mercury as part of this project.
- No characterization of methylmercury in stream sediments or wetland soils (where it is formed)
- No biomonitoring data (small bodied fish, invertebrates) from streams which is necessary to protect downstream resources.
- Uncertainty analyses were conducted on select groundwater solutes (FEIS 4-43) and variability for important metals exceeded **plus or minus 100%.**
- **Hg and MeHg** were not evaluated because “only solutes included in the water quality modeling … are assessed.” (Barr, 2012p) (*N.B. we will return to this point in a few slides*).
- The range and variability in concentrations of Hg and MeHg in sediments, waters, and biota are **effectively unknown** despite the fact that these present the greatest risk to downstream resources and fish consumers.

DeBeers Victor Diamond Mine, Ontario, Canada **annual** mercury monitoring program to protect aquatic resources of downstream community (Attiwapiskat FN):

- 5-700 young-of-year fish (“biosentinels”)
- large-bodied fish program (for consumption risk assessment).
- Monthly surface water and groundwater at >30 sites (plus reference sites)
- Filtered and unfiltered Total Hg, MeHg, sulfate, dissolved metals, dissolved organic carbon.
- Annual reporting to provincial regulator pre-development (3 years), during operations, and post-closure (effectively in perpetuity).

a) Failure to characterize and understand the background environmental conditions

- Background characterization is particularly important here because it is clear that the landscape in the headwaters of the St. Louis River has very potential to form **methylmercury** (based on Percentage of THg as MeHg)
- Embarrass and Partridge Rivers have **>10 % MeHg** in downstream waters.
- When %MeHg is this high, the source of MeHg is **wetlands** draining into tributaries (Hurley *et al*., 1995 and subsequent scientific consensus).
- These tributaries will receive sulfate and Hg from the proposed development, and will increase MeHg concentrations. Sulfate and Hg are the ingredients required to form MeHg.
- **These data existed, but were never reported in the project FEIS, nor considered in any decision-making about the project.**

TABLE 1: Percent of Total Mercury as Methylmercury as an indicator of mercury methylation potential

<1%	1-3%	>3%

Location	Mean MeHg (ng/L)	Mean %MeHg
Longnose Creek (LN-1)	0.21	**6.0**
West Pit Outlet Creek (WP-1)	0.82	**5.9**
Wetlegs Creek (WL-1)	0.48	**9.6**
Wyman Creek (PM-5)	0.15	**12.5**

Source of concentration data: Barr, 2014d; Percent calculations are my own in Branfireun, 2015.

b) Reliance on unproven water treatment strategies to achieve regulatory limits.

- In EIS submissions, PolyMet has indicated that internal water quality will meet limits of **10 mg/L** for sulfate, and **1.3 ng/L** Total Hg.
- PolyMet contends that water flowing through mine tailings will reduce total Hg concentrations to acceptable concentrations through adsorption with minerals and will **remain stable for centuries**. This statement is based on a scientifically indefensible experiment (FIGURE 1).
  - Two jugs, one containing just water, the other containing water and tailings material. Mercury was added, and the jugs were shaken for 8 hours.
  - No replication
  - No attempt to mimic environmental conditions
  - **An 8 hour** experiment extrapolated to **100s of years**.
  - Actual results show substantial re-release, which if experiment had continued, would have **exceeded the 1.3 mg/L in four more hours**. (Experiment was not in equilibrium),

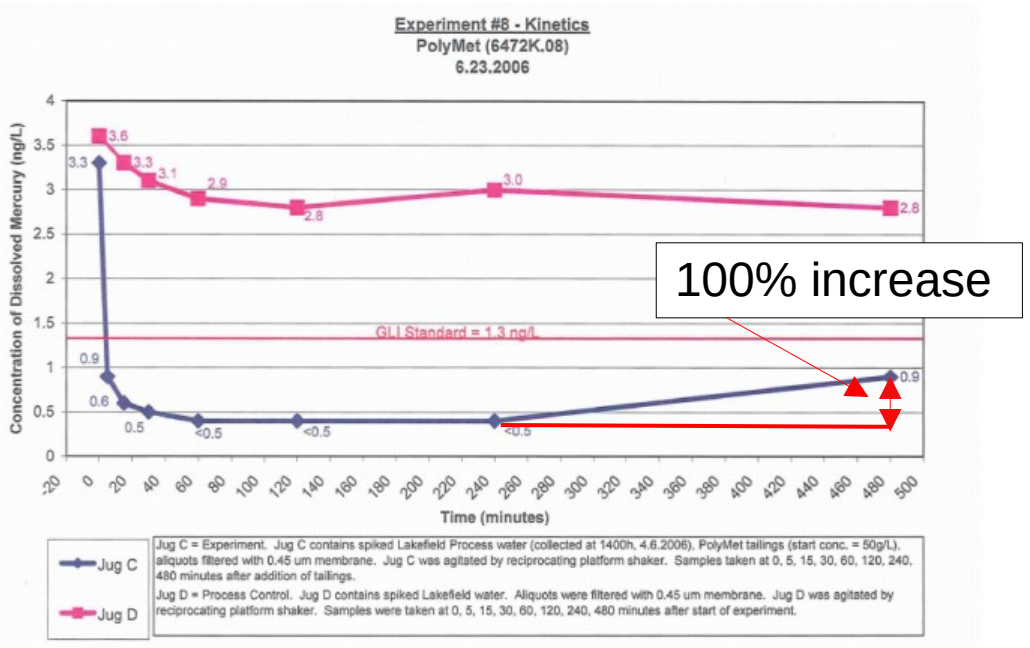


FIGURE 1: Reproduced from expert opinion of D. Pauly, 2014; originally from report provided to Pauly upon request from Minnesota DNR.

"*Another strange aspect of the results is that it reports testing was done on Jug C and Jug D. What might be shown in Jugs A and B? Were they analyzed? If so, what does their data show?*" D. Pauly, 2014, p. 22

b) Reliance on unproven water treatment strategies to achieve regulatory limits.

- The EPA objected to this mechanism as lacking scientific integrity, yet it remains as the foundation of the project meeting Great Lakes water quality targets (that are substantially higher than those set by Fond du Lac).
- Another experiment in fact DID exist, and was conducted using far superior experimental approaches over a much longer time period (~ 1 year).
- Report concluded "*[t]here were no clear increasing or decreasing mercury concentration trends along the flow path through the LTVSMC tailings*" (Quoted from Pauly 2014; originally from SRK (2007).
- This experiment was **never reported** as part of the EIS or any other permitting for the project.
- Final waste water treatment using Reverse Osmosis technology at both the tailings basin (current) and mine site (future closure) is proposed to manage water quality, but was never evaluated for mercury removal potential.

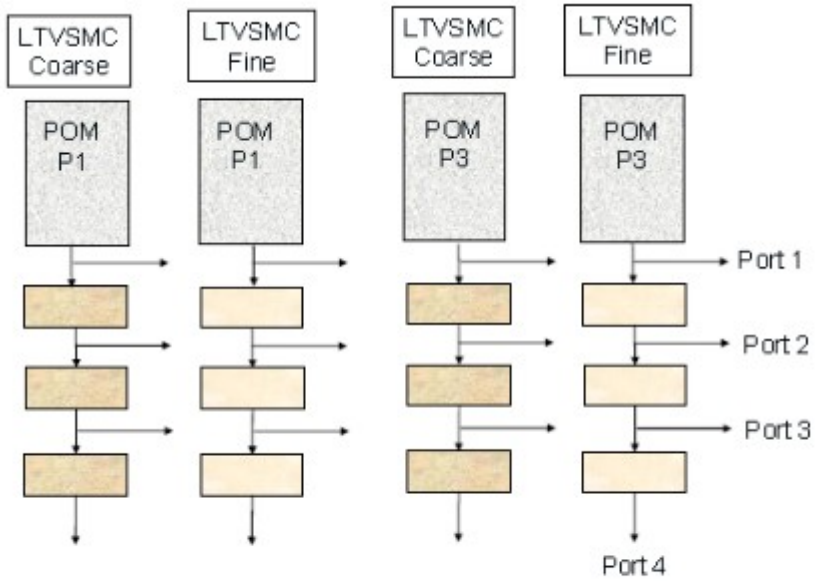


FIGURE 2: Reproduced from expert opinion of D. Pauly, 2014; originally from report from SRK (2007).

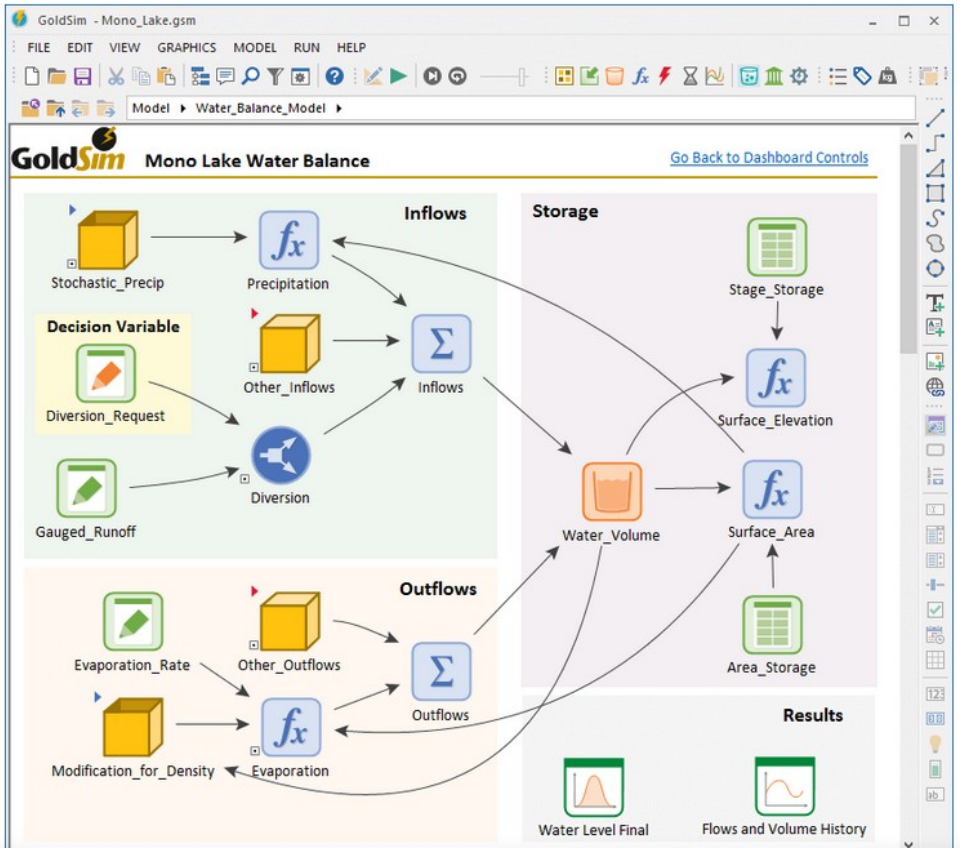
"[t]here were no clear increasing or decreasing mercury concentration trends along the flow path through the LTVSMC tailings"

c) Reliance on a scientifically indefensible mass balance approach to avoid simulating mercury processes.

- As part of the permitting process, PolyMet relied on a software program called *GoldSim* to model water and chemical transport.
- GoldSim is a simple model to that can model fate and transport of chemicals using the “CT” submodel, and can incorporate chemical processes.
- PolyMet contended that “Mercury was not included in the GoldSim model, as **insufficient data*** and a general lack of definitive understanding of mercury dynamics prevented modeling mercury like the other solutes.” (SDEIS 5-201).
- This statement is unsupportable and implies that mercury does not conform to basic chemical laws and is unmodellable. This is false.
- Recall that there was no assessment of variability in Hg or MeHg was conducted because “only solutes included in the water quality modeling … are assessed.”

insufficient data ↔ no model ↔ no uncertainty analyses

*** as a result of their own insufficient baseline monitoring**

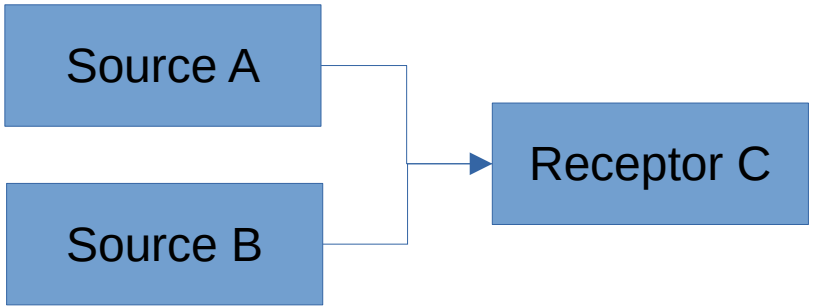


From: www.goldsim.com

c) Reliance on a scientifically indefensible mass balance approach to avoid simulating mercury processes.

- Instead, a simple mass balance model with no uncertainty (i.e. a “plus or minus” range”) was used to arrive at the total loadings to tributaries used to conclude *de minimus* contributions (even a HIGHLY conservative margin of error would significantly change conclusions).
- PolyMet contended:

  “*This simple estimation method was preferred over a detailed mechanistic model because it incorporated the important input and removal processes for mercury, was very transparent with regard to data inputs, and allowed for easy assessment of the effects of changing parameter values on mercury concentrations.*” (FEIS 5-223)
- This is a misleading statement. There is nothing more transparent about a mass balance approach, unless “transparent” is used to mean “simple”. It cannot simulate important processes of chemical transformations/interactions.



Mass A + Mass B = Mass C

A mass balance model is a naïve approach that cannot simulate the real impacts of mine operations on the most important watershed-scale mercury processes. Yet, this is the basis for the conclusion of changes in mercury loading from the project will be inconsequential. This conclusion has been erroneously accepted as valid.

d) Reliance on a flawed assumption of proportionality between Total Hg loading and Fish Hg.

- To demonstrate no impact on fish mercury concentrations, PolyMet maintains that methylmercury content in fish are roughly proportional to Total Hg concentrations within individual watersheds and cites the MPCA's Mercury Risk Estimation Method (MMREM) principle of proportionality between mercury in fish and atmospheric deposition (FEIS 5-22).
- This is an outdated conceptualization that does not align with scientific information, even that generated in Minnesota.
- Brigham et al. (2014) showed that Hg inputs to lakes in Voyageurs National **decreased** by 32% between 1998 and 2012, but MeHg in fish **increased** by 80% in one lake.
- They attribute the variable response to "watershed-specific hydrologic conditions and disturbances".

IS TOTAL MERCURY CONCENTRATION A GOOD PREDICTOR OF METHYL MERCURY CONCENTRATION IN AQUATIC SYSTEMS?[4]

CAROL A. KELLY[1], JOHN W.M. RUDD[2], VINCENT L. ST.LOUIS[1], and ANDREW HEYES[3]

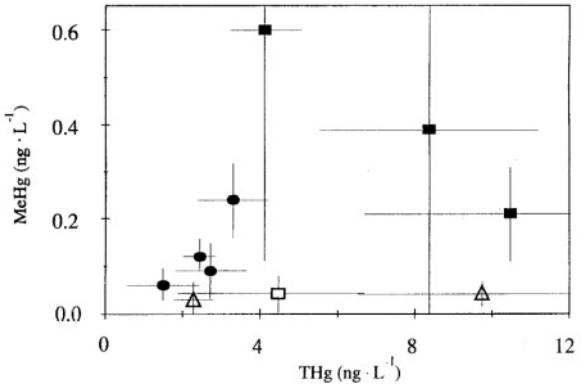


Fig. 4. Average concentrations of MeHg, with 1 standard deviation shown, plotted against the average concentration of THg for all the sampling sites. Data taken from Table I. Triangles are upland streams, squares are combination upland/wetland streams, and circles are ponds/lakes at ELA.

No.

"This study shows that THg inputs and/or concentrations are not very useful in predicting MeHg concentrations, and that factors within ecosystems are very important in controlling MeHg concentrations." Kelly et al. (**1995**)

Flaws in Prior Submissions Concerning Mercury – Summary so far.

- Selective presentation of data about water treatment and a failure to collect sufficient background data predestine the conclusion that the proposed project would have no measurable impact on fish mercury concentrations.
- These deficiencies have not adequately considered, particularly in the context of the Fond du Lac Band's water quality standards.
- Instead of having confidence that the project will not change (or even reduce) Total mercury concentrations, the entire analysis should be rejected by the Corp.

No effect on fish mercury

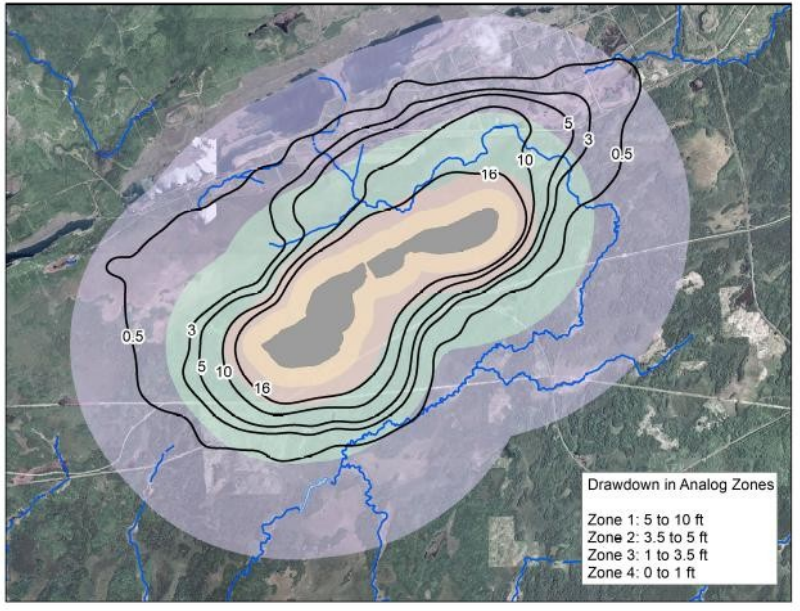
Inappropriate models

Insufficient/selective use of background data

4) Failure to consider the formation of methylmercury resulting from direct and indirect effects of mine operations

(concerning the Will Affect Notification and Objection)

- Additions of sulfate and changes in hydrology are critical drivers of increased MeHg production and export in Minnesota watersheds, and are as, or more important than the addition of mercury.
- These factors have either been ignored, or carefully discounted by PolyMet in prior submissions, despite the clear scientific burden of proof and concerns raised in Opinions and public submissions (since 2015).
- The primary causes of these additions of sulfate and changes in hydrology are:
  a) the drawdown effect due to the dewatering of the proposed open pit
  b) direct effluent discharges from the mine operations.
- For the Band's Will Affect Notification and Objection, these factors were explored in more detail to demonstrate the impacts on downstream resources associated with Fond du Lac's designated uses.

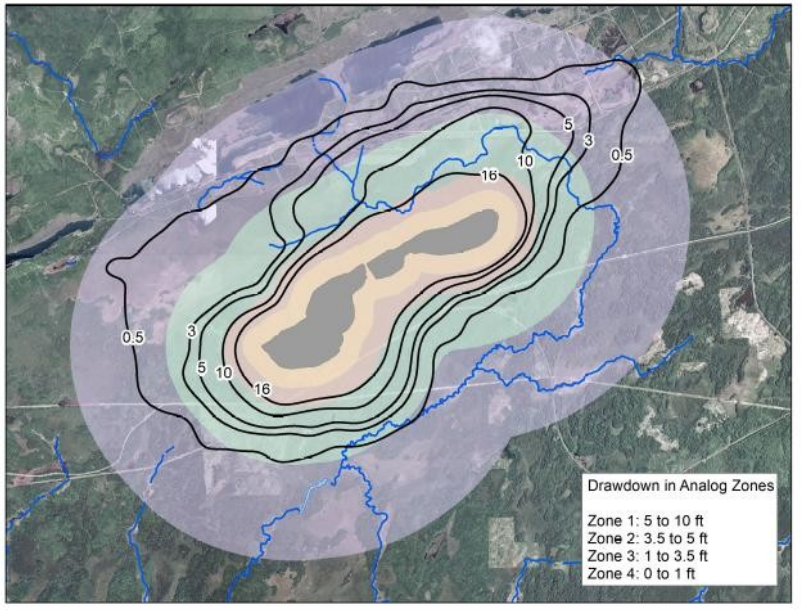


e) Changes in regional wetland hydrology due to de-watering operations will result in the release of sulfate, inorganic mercury and methylmercury*

- PolyMet has contended that a hydrogeological model that could could be used to estimate impacts on wetland hydrology was not feasible for the proposed project. Prior expert Opinions challenged this:

  > "While a numerical model (MODFLOW) was used extensively to determine pumping rates, etc., the proponents incongruently argue that it cannot be used to predict a cone of depression that would identify wetlands potentially susceptible to impact. While it is acknowledged that identification of individual wetlands' susceptibility cannot be predicted without a detailed characterization of overburden thicknesses, a sensitivity analysis using the same model setup as that used topredict pumping rates, would constitute an appropriate scientific investigation that can identify the potential cone of depression that affect wetland function." (J. Price, Expert Opinion, 2017)

- As previously presented, such a model has been generated independently by two different agencies (GLIFWC, USGS) and are in strong agreement with each other.

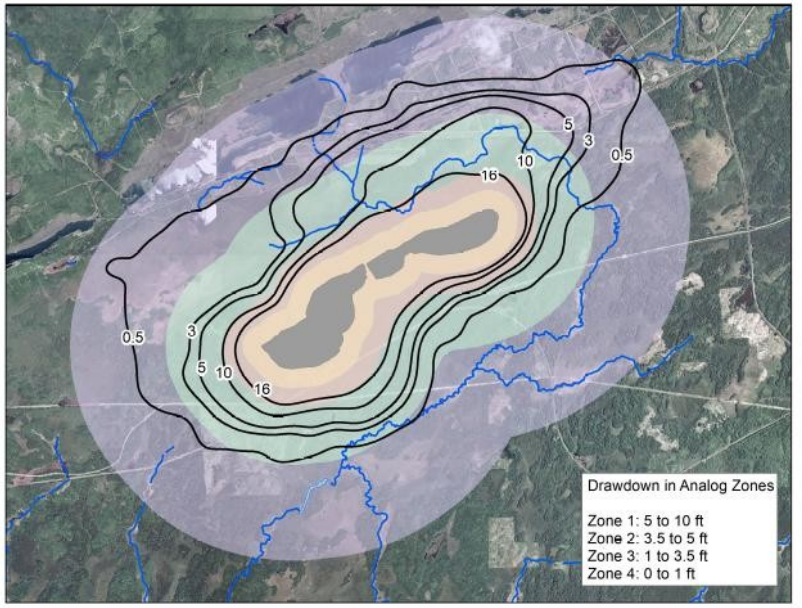


Analog drawdown zones used in this analysis. Mapping and spatial analysis from GLIFWC (2022)

*Section C of Fond du Lac's "Will Affect" Memo, August 3, 2021

e) Changes in regional wetland hydrology due to de-watering operations will result in the release of sulfate, inorganic mercury and methylmercury*

- PolyMet has contended with no physical evidence that many of the wetland types found in the viscinity of the proposed project open pit are “perched” and as such are not coupled to regional groundwater.
- This is not scientifically accurate – even “bog” type peatlands are connected to larger scale groundwater systems.
- They are not decoupled, but under **natural hydrological conditions**, water exchanges with groundwater are slow, which promotes surface wetness.
- The predicted cone of depression will create **unnatural hydrological conditions in over 6000ac of wetlands**. Downward flows will cause water levels in wetlands to decrease.

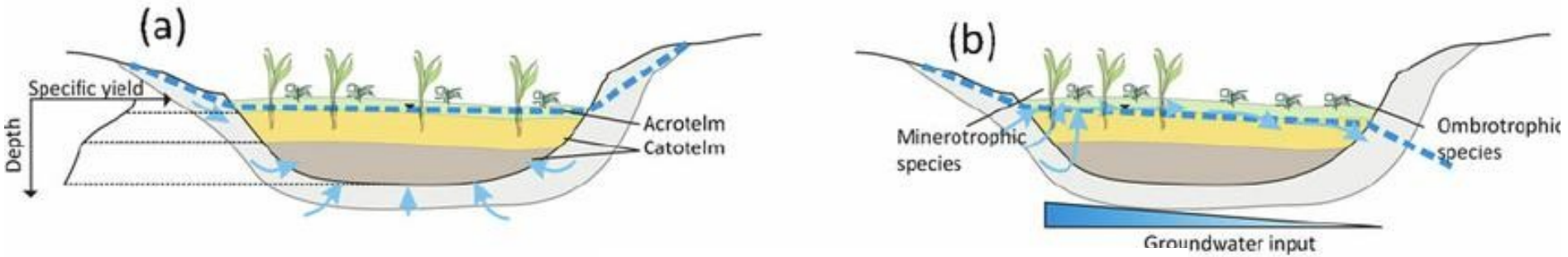


Analog drawdown zones used in this analysis. Mapping and spatial analysis from GLIFWC (2022)

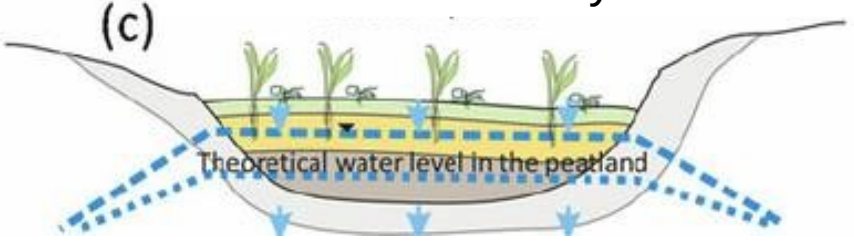
*Section C of Fond du Lac’s “Will Affect” Memo, August 3, 2021

Peatlands can, and do exchange water with groundwater systems

Normal peatland hydrology



Peatland affected by drawdown

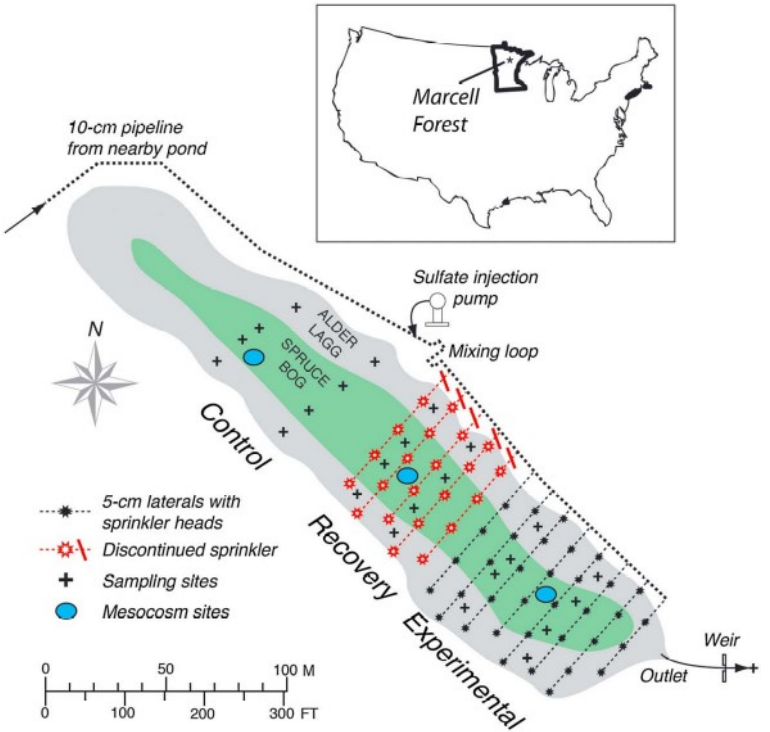


Different groundwater flow exchanges with peatlands. Example (c) shows flow direction that would be expected affected by the open pit cone of depression.

Modified from Bertrand et al. Hydrogeol. J. (2012)

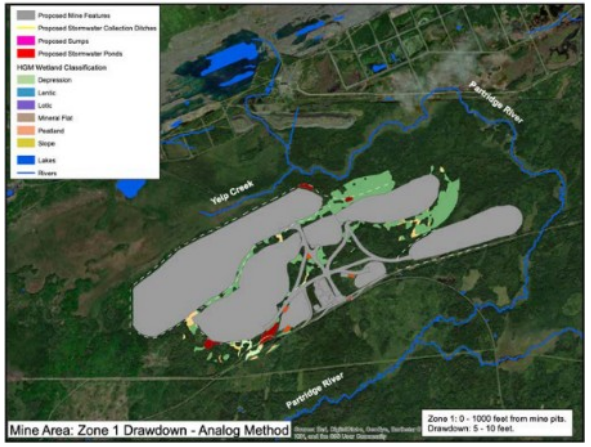
Water level fluctuations release sulfate and mercury from wetlands

- Numerous studies have shown that drying and re-wetting cycles increase the decomposition of wetland soils and flushing of organic matter and associated chemicals like sulfate and mercury.
- Coleman-Wasik et al. (2015) showed in a wetland in the Marcell Experimental Forest (Minnesota) that period of extended drought resulted in:
  - Release of sulfate, inorganic mercury (up to **400%** more) and methylmercury
  - Enhanced production of methylmercury during re-wetting because of “recycled” sulfate available to methylating bacteria (**129%** increase).
- Drawdown from the open pit cone of depression will effectively create an extended ‘drought’ condition of varying severity depending on proximity to the open pit.

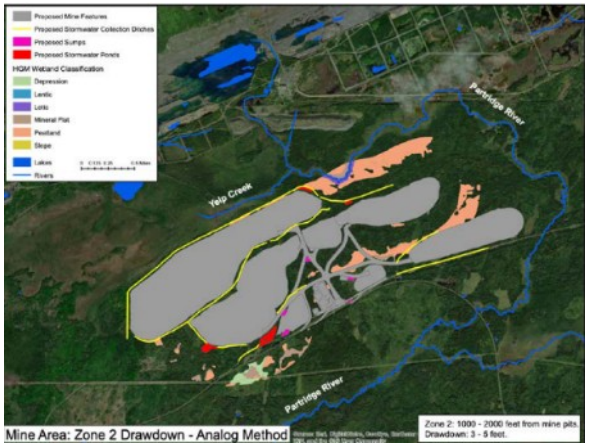


How much mercury and methylmercury is in the analog zone?

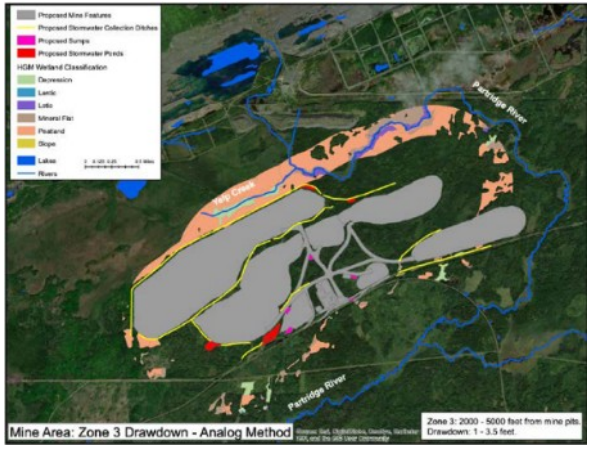
- Using wetland soil mercury and methylmercury concentrations from an extensive survey of wetlands in the St. Louis River Watershed (Branfireun et al., 2008) and wetland type and areas provided by GLIFWC we calculated that:
- There is **131 kg** of Hg stored in the top foot of soil over the analog drawdown zone, **7 kg** of that as MeHg.
- Pore water concentrations would average **8.3 ng/L THg and 1.6 ng/L MeHg**, consistent with other data in Minnesota.
- Even a small amount of drawdown would both release sulfate, THg and MeHg from these soils, and enhance MeHg production.
- During rewetting (like spring snowmelt) there would be large downstream contributions of sulfate, THg and MeHg that are not accounted for in any mass balances used to justify meeting permitting thresholds.
- Cumulative contributions to downstream loads would not be detected nor mitigated because there is no required monitoring of wetland water quality in place for the project during operations or closure.



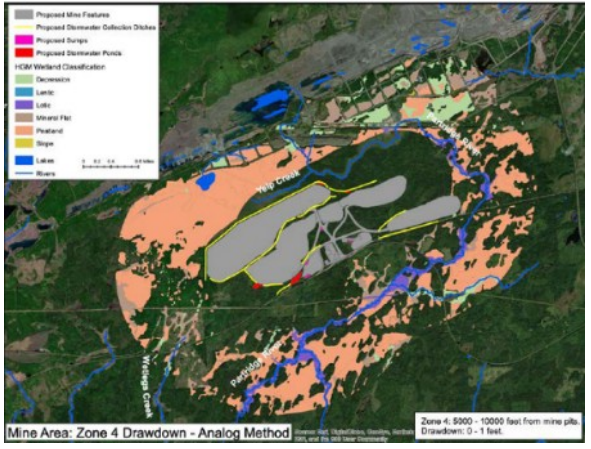
Zone 1 (5-10ft) 360 ac



Zone 2 (3-5ft) 375 ac



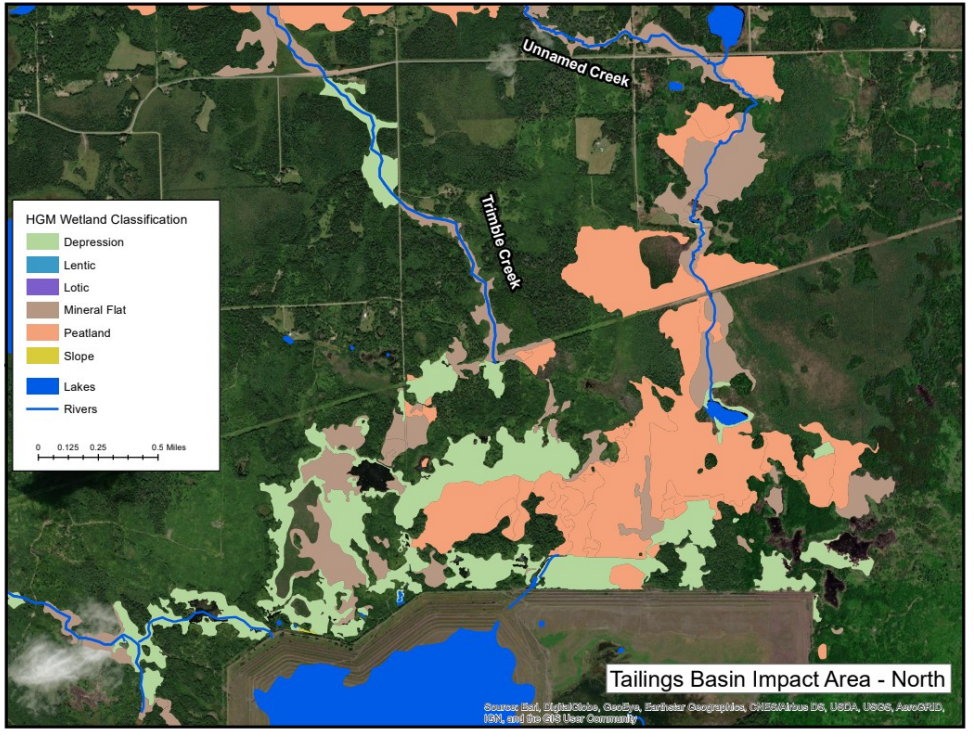
Zone 3 (5-10ft) 683 ac



Zone 4 (5-10ft) 4733 ac

f) Direct discharges of water, sulfate and mercury to surface waters and wetlands will increase methylmercury production during mine operations

- Seven direct waste water outfalls associated with the mine processing facility will discharge to the headwater wetlands of a single tributary north of the tailings basins (Trimble Creek).
- If we accept PolyMet's contention that their internal waste water targets can be met for sulfate (10 mg/L) and THg (1.3 ng/L) then these wetlands will receive an additional:
  - **2.7 million gallons** of water per day on average
  - **220 lbs (100 kg)** of sulfate*
  - **0.2 oz (5 g)** of mercury

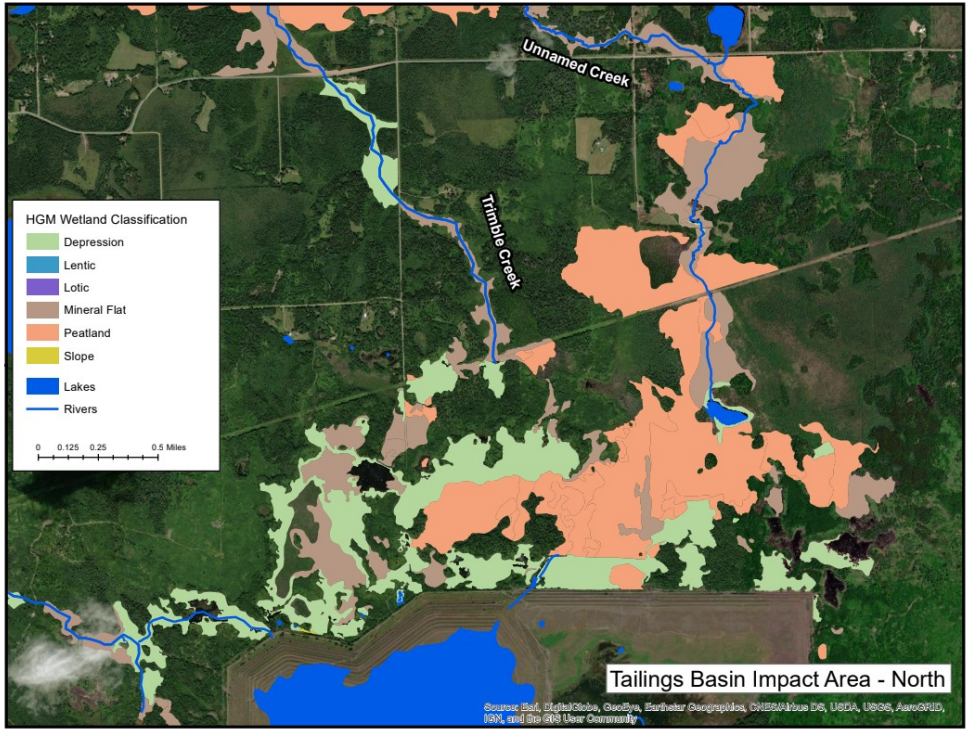


Map of wetlands receiving waste water from the proposed mine processing facility

*this value for sulfate is **per day** for all outfalls, not per year as written in memo

Direct discharges of water, sulfate and mercury to surface waters and wetlands will increase methylmercury production during mine operations

- **0.2 oz** of mercury per year loaded to half of the 1198 ac of wetlands is equivalent to **~16%** of annual deposition of Hg from the atmosphere. Total annual sulfate loading is equivalent **~40x*** the annual deposition from the atmosphere.
- Previously discussion about the unreliability of PolyMet's approach to reach the THg water quality target of 1.3 ng/L means that the direct load or mercury will be even larger.
- Water discharge concentrations of 10 mg/L will increase MeHg production, as demonstrated in Minnesota and elsewhere. Recall that prior experimental work showed that sulfate concentrations of 5 mg/L increased MeHg concentrations by 20x.



Map of wetlands receiving waste water from the proposed mine processing facility

*using total annual sulfate load from discharges.

Water discharges alone will increase Hg loading.

- Discharged process waters will interact with wetland soils that already contain THg and MeHg.
- The amounts can be estimated using the same calculations as used in the analog zone.
- Since discharged mine waters are theoretically of lower Hg concentrations than the pore waters, they will equilibrate to **higher** concentrations as they flow through the wetlands and ultimately reach the headwater tributaries of the St. Louis River.
- The discharged water could reach an equilibrated THg concentration of **8.5 ng/L** before ever reaching a tributary, loading 47 g (1.66 oz) of Hg per year.
- This is a contribution to the cumulative load of the St. Louis River that is a direct result of proposed mine operations, and completely unaccounted for in mass balance estimates.

Even accepting the contention that mine water discharges may be compliant at the “end of the pipe” (1.3 ng/L), that same water could exceed State and Great Lakes Water Quality guidelines by **>650%**, and the Fond du Lac Band’s by **1300%** before it ever reaches a surface water stream.

These calculations are intended to illustrate that there can only be an **increase** in THg and MeHg concentrations and an **increase** in loading to tributaries of the St. Louis River contributing to downstream cumulative effects.

SUMMARY and SYNTHESIS (1)

1) Reliance on flawed water treatment approaches means that the projected mercury concentrations in discharged waters that are contended are unreliable and likely unattainable.

2) Insufficient background data and the application of an inappropriate modeling approach means that estimates of *de minimus* loads of THg cannot be accepted, and are an underestimate.

3) Insufficient background data and deficient proposed monitoring preclude change detection and responses to unavoidable operational upsets.

4) Conclusions about no impact of the proposed project on fish mercury levels must be rejected because of scientifically unsupportable omissions and assumptions, and no consideration of direct and indirect sources of MeHg.

SUMMARY and SYNTHESIS (2)

4) Effects of drawdown and loading to adjacent wetlands that will release additional mercury and methylmercury are unaccounted for in the mass balances used to justify meeting permitting thresholds.

5) Cumulative contributions to downstream loads cannot be detected nor mitigated under the current proposal, resulting in irreparable harm to downstream resources.

6) These contributions will further interact with extensive riparian wetlands in the watershed that extend continuously downstream up to, and through, the Fond du Lac Reservation.

7) These factors have not been adequately considered in the context of the Fond du Lac Band's Water Quality Standards, and in most cases have not be considered at all.