Analysis of Potential Impacts on Water Quality and the Health of Ecosystems and Humans Due to the Proposed Talon Metals Corporation Tamarack North Mine

Report for Honor the Earth and WaterLegacy

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Questions Addressed

This report responds to several questions pertaining to the proposed Talon Metals mine in the Tamarack mineral intrusion in northern Minnesota:

If the proposed mine releases sulfate to surface water, wetlands, or shallow groundwater in the Tamarack North area, what would be the predictable effects on water quality in downstream waters? Specifically:

a. What are the effects on the downstream waterbodies' impairments and total maximum daily load projects (TMDLs) for excessive nutrients?
b. What are the effects on sulfide?
c. What are the effects on wild rice?
d. What are the effects on mercury and mercury methylation?
e. Are the effects of sulfate disproportionate to the magnitude of sulfate concentration?

Background and Experience

I hold a Ph.D. in Geology and B.A. in English, both from the University of Minnesota, where I also worked as a laboratory manager and researcher in the Department of Earth Sciences from 2002-2019 and was an affiliated faculty member from 2016-2019. My research focuses on the chemical and biological processes that occur in the waters and sediments of lakes and wetlands in Minnesota, including lakes that grow natural wild rice. From 2011-2014, I was the UMN-Twin Cities principal investigator for the Minnesota Pollution Control Agency's (MPCA) study of the sulfate standard to protect wild rice, and I led the field component of that study. I am the first author of two publications that resulted from this work and a coauthor on three others. One of these publications demonstrated that sulfide, the product of sulfate in anoxic lake sediments, clearly causes harm to wild rice (Myrbo et al. 2017a). Another showed that, furthermore, sulfate in water could lead to increases in phosphorus, nitrogen, mercury, methylmercury, and other substances of concern for water quality and for the health of ecosystems and humans (Myrbo et al., 2017b). I have served as a scientific expert on the dangers of sulfate to fresh waters. I currently own a small business, Amiable Consulting, and am a part-time employee of the St. Croix Watershed Research Station, Science Museum of Minnesota.

Summary

The watersheds in which the proposed Talon Metals Tamarack North mining project ("Talon Project") would be located flow downstream to lakes and streams that are impaired for nutrients and methylmercury, and to a minimum of 16 lakes and streams designated as waters used for the production of wild rice. Sulfate pollution from disturbance of the shallow aquifer, storage of ore and waste rock on the surface, and loading and transporting of ore[1], which would be likely if mining occurred, would cause increases in nutrients, methylmercury, and inorganic mercury, and generate toxic sulfide in the lakebed. The effects of these chemical releases would affect the health of ecosystems and humans: nutrient increases would cause increased algae blooms; increased total mercury and methylmercury could lead to higher mercury concentrations in fish; and sulfide has been shown to damage or extirpate wild rice populations. Although the information made public by Talon to date is not sufficient to allow a full evaluation of the potential mining impacts, the location, hydrology, and chemistry of the proposed mine are such that these effects can be predicted.

Environmental Context

There is substantial uncertainly about the scope and location of the Talon Project proposed mining of the Tamarack mineral intrusion. For this reason, the potential locations and severity of water quality impacts are also uncertain. Uncertainties include where Talon's proposed underground mine, mine shafts, ore storage, and waste rock storage would be located, how waters that had been in contact with those materials would be treated, or whether or how process-waters from mine dewatering would be treated before they are discharged. Talon has stated that they would process the ore in North Dakota (Talon 2022), but the proposed mine would still need to store ore and waste rock temporarily or permanently on the surface and in the subsurface, transport these within and beyond the site, discharge wastewater, and other activities that have the potential to release unwanted chemicals into the environment.

Information provided to the public states that the proposed mining would be conducted in an ore body with "massive sulphide mineralization" as well as more disseminated mineral zones.[2] Removing this material from belowground and pulverizing it (for removal, transport, and processing) would expose much more surface area of these sulfide-bearing rocks to the environment, which would increase their likelihood of dissolving. Storage on the Earth surface would subject the mine waste and ore to oscillations in moisture due to exposure to weather, and possibly oscillations in oxygen if wastes were submerged in water, which could occur in this wet environment. Together, these processes would dissolve sulfide minerals into water, including runoff, and potentially into surface water (streams, wetlands, bogs, lakes, etc., which are abundant in the area), and groundwater.

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[1] Additional sulfate would likely be released if ore processing and tailings storage were also to take place on site.

[2] NI 43-101 Technical Report uses the British/Canadian English spelling of "sulphide", but this report uses the American English spelling "sulfide" unless quoting others.

When sulfide minerals dissolve, sulfate (SO_4^{2-}) is produced. Sulfate is highly reactive in the types of water bodies that exist in Minnesota, and would cause multiple damaging effects on freshwater ecosystems like Sandy Lake, Lake Minnewawa, and others downstream of the proposed mining area. Lakes that are high in organic matter (mainly the remains of algae and other plants) are particularly reactive with sulfate, because organic matter is the "fuel" for naturally-occurring bacteria to convert sulfate to sulfide (Myrbo et al. 2017a, Myrbo et al. 2017b, Pollman et al 2017). These lakes are also particularly vulnerable because they are naturally low in sulfate: for example, Sandy Lake has an average of 1.2 mg/L sulfate, and Lake Minnewawa has about 1.6 mg/L sulfate (MPCA surface water data access). Addition of sulfate to these systems would be likely to have major ecological effects.

A prominent deleterious effect of the conversion of sulfate to sulfide is damage to wild rice populations (Myrbo et al. 2017a). Another is the release of undesirable chemicals from the sediments - known as "internal loading" because the source of chemicals is within the waterbody itself. The reactions of sulfate when it is added to low-sulfate environments cause internal loading of nitrogen and phosphorus compounds (nutrients) and inorganic mercury (Myrbo et al. 2017b). These reactions also cause the methylation of mercury (Myrbo et al. 2017b), which allows mercury to enter and accumulate in the food chain, where it is harmful to animals that eat fish, including humans, birds of prey, otters, and others. Sulfide mineral dissolution can also produce sulfuric acid (H_2SO_4), which can acidify lakes and rivers, and leach out heavy metals such as mercury, lead, arsenic, and other toxins from rocks to produce acid mine drainage and metal leaching (AMD/ML). For these reasons and others, mining of sulfide minerals has inherent environmental risks.

Hydrologic Context and Impaired Lakes and Streams

The mine is proposed in a water-rich location, with abundant wetlands, lakes, and streams that are hydrologically connected to shallow groundwater. Figure 1 on the next page shows the high percentage of wetlands in the area (violet color). This area receives about 25 inches of precipitation each year on average (DNR, 2023), which would make it difficult to control release of chemicals into surface waters and soils or release through shallow groundwater to surface waters. Sulfide mines in arid environments (e.g., Arizona, Nevada, New Mexico) have a poor track record of water contamination, with 100% of mines surveyed experiencing at least one pipeline spill or accidental release of pollution; at 13 of 14 mines studied, "water collection and treatment systems failed to control contaminated mine seepage, resulting in significant water quality impacts. water-rich environments" (Gestring, 2012). In a water-rich environment such as northern Minnesota, where surface waters are connected by flows that transport chemicals, it would be even more difficult to control damaging chemical releases to the environment.

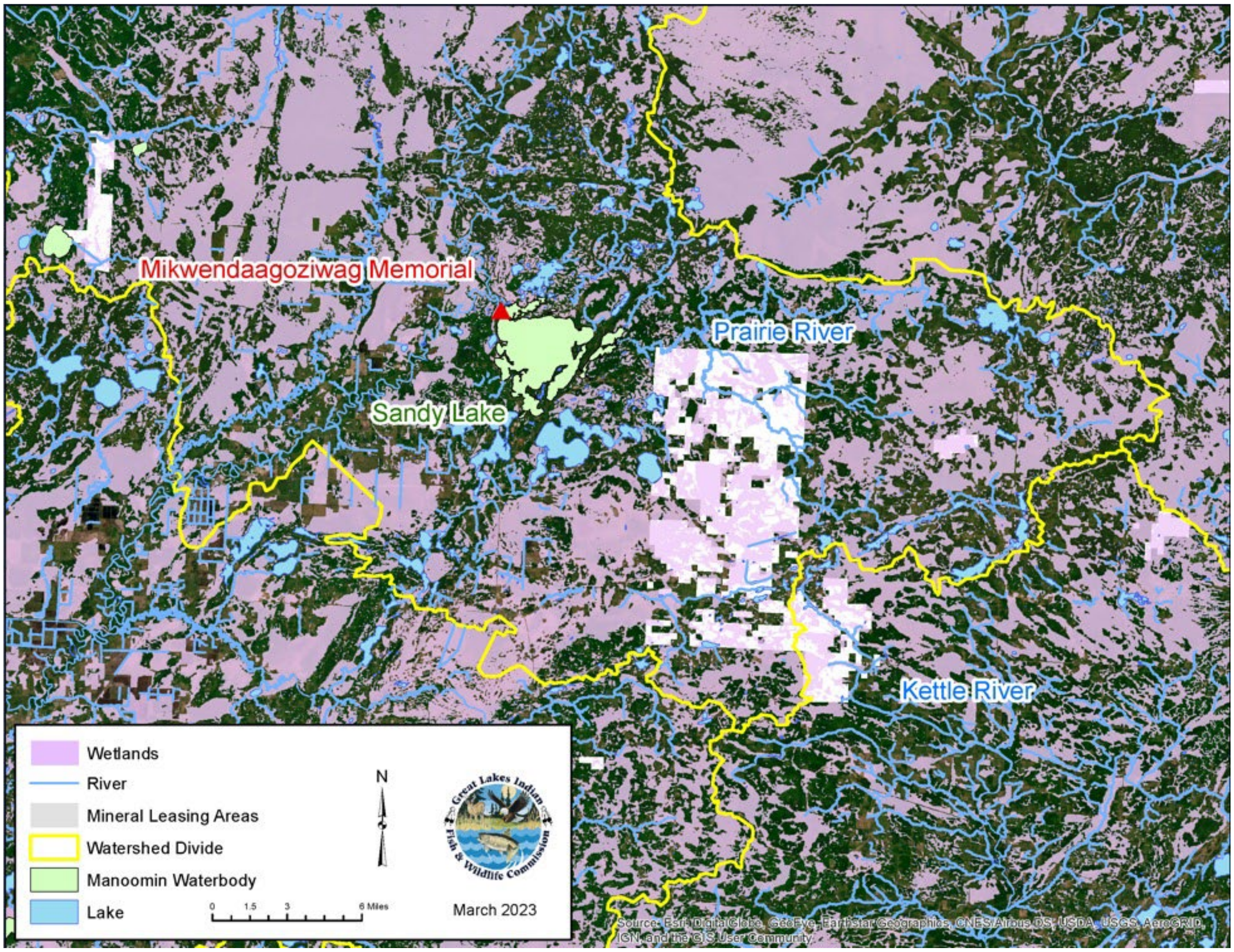

Figure 1. Map of the area highlighting extent of wetlands (violet color) and showing proposed mining area ("Mineral Leasing Areas" in gray, center of image) and lakes to its west that would be likely to receive mining discharge, including Sandy Lake (in green). The southeastern area of the mineral leasing area lies in the watershed that drains to the Kettle River and St. Croix River. Figure courtesy of the Great Lakes Indian Fish and Wildlife Commission (GLIFWC).

The Tamarack River flows northwestward through Talon's Tamarack North area and joins the Prairie River before flowing into Sandy Lake, which discharges to the Mississippi River. Talon is also exploring discharging mining waste into ditches that flow to Minnewawa Creek (NI 43-101 technical report, p. 20-20), which flows to the Sandy River and then to Sandy Lake. Ditches are not lined, and so chemicals discharged to ditches and streams could seep into the soil and into shallow groundwater as well as reaching and affecting the lakes, wetlands, and streams downstream.

Several lakes and streams that are listed by the MPCA as impaired for nutrients, methylmercury in fish tissue, and/or aquatic life bioassessments (MPCA 2022) are downstream of the mining area. These lakes and streams would be likely to receive sulfate loading, which has been shown to lead to increases in internal loading of nutrients and mercury, and increases in methylmercury, the only form of mercury that accumulates in fish tissue.

Water flow in the proposed mining area and mineral lease area is shown in Figure 2: small blue arrowheads are shown inline with streams and rivers, and on blue lines darker than the blue of lakes.

Figure 2. Map showing direction of surface water flow as small blue arrowheads on waterways. Note that flow to Sandy Lake, from both the Tamarack and Prairie rivers, and to Lake Minnewawa, through Island and Horseshoe lakes, all intersect the proposed mining area and mineral lease area. The Kettle River, which flows to the St. Croix, flows through the southern part of the Tamarack Intrusive Complex (purple dashed outlines). Talon is exploring discharging to the ditches (straight watercourses) to the southwest of the Tamarack Intrusive Complex, which also flow to Sandy Lake. See text for discussion. Figure 20.10 of NI 43-101 Technical Report.

Sandy Lake is impaired for excessive nutrients (phosphorus) and has a total maximum daily load (TMDL) allocation (Barr Engineering 2011). TMDL implementation strategies to reduce nutrient loading include treatment of stormwater and runoff; lakeshore and stream channel erosion management; ditch cleaning; agricultural management; and inactivation of phosphorus in the sediments to diminish internal loading of phosphorus. Sulfate loading to Sandy Lake would *increase* internal loading of phosphorus, as well as another nutrient, nitrogen, from the sediments, counteracting these efforts to reduce nutrient loading. Sandy Lake is also impaired for mercury in fish tissue. Sulfate loading to Sandy Lake would increase the methylation of mercury in that lake and exacerbate the problem of mercury in fish tissue.

Sandy Lake has a "large watershed with a high percentage of wetlands" and high organic matter (Barr Engineering 2011). Because decomposition of organic matter provides the fuel for the sulfate reactions that lead to internal loading of nutrients and mercury, damage to wild rice populations, and increases in methylmercury in fish, high-organic Sandy Lake may be particularly vulnerable to damage from increased sulfate loading from the proposed mining activities.

Lake Minnewawa is also impaired for excessive nutrients (phosphorus) and has a TMDL allocation (Barr Engineering 2011). Implementation strategies for reducing nutrients are similar to those for Sandy Lake, with the exception that internal phosphorus loading has not been identified as a large part of the phosphorus budget in Lake Minnewawa. Because Lake Minnewawa is relatively shallow, it may not currently experience internal loading, which requires lake stratification and anoxia (absence of oxygen) of the bottom waters, conditions that occur in deeper lakes. However, even in the absence of stratification and anoxia, sulfate loading would lead to internal phosphorus and nitrogen loading (Myrbo et al. 2017b). If sulfate loading occurred in Lake Minnewawa, internal loading could become a significant part of its nutrient budget.

Horseshoe Lake flows into Lake Minnewawa, and also has a TMDL for nutrients (MPCA 2019). Internal phosphorus loading in the lake and in the wetlands surrounding Musselshell Creek, which flows to Horseshoe Lake, has been identified as a concern for Horseshoe Lake. As described in the case of Lake Minnewawa above, Horseshoe Lake and its tributary are vulnerable to increased internal phosphorus and nitrogen loading from sulfate loading. Increased sulfate loading would undermine the efforts to reduce nutrients in Horseshoe Lake.

The **Mississippi River** also has a TMDL for mercury in fish tissue. Increased sulfate loading would exacerbate the problem of mercury in fish tissue.

The **Sandy River** and **Minnewawa Creek** are impaired for benthic macroinvertebrate and fish bioassessments. Increased sulfate loading can lead to large changes in the ecology of waterbodies (Myrbo et al. 2017a; Lamers et al. 2013), and would exacerbate these impairments.

Round Lake has a TMDL for mercury in fish tissue. Round Lake’s southeastern shoreline is within the mineral lease area. Increased sulfate loading would exacerbate the problem of mercury in fish tissue.

Kettle River and St. Croix River. Talon’s Tamarack South area is in a different major watershed than Tamarack North, that of the St. Croix River, part of the National Wild and Scenic Rivers System. The West Branch Kettle River, which flows through the mineral lease area, is impaired for mercury in fish tissue. The Kettle River flows to the upper St. Croix River, which also has a TMDL for mercury in fish tissue. Increased sulfate loading would exacerbate the problem of mercury in fish tissue.

Additional waterbodies, such as **Salo Marsh** (TMDL for mercury in fish tissue) may also be affected, depending on the scope of the Talon/Tamarack mining project. Sulfate releases from any mine have the potential to exacerbate these impairments and counteract any progress on reduction of nutrient loading, as well as internal loading of mercury and methylation of mercury, leading to increased mercury in fish tissue.

Chemical Processes

Sulfate would be a significant environmental contaminant in the Mississippi River and St. Croix River watersheds, and more proximately, the Sandy Lake, Lake Minnewawa, and West Branch Kettle River watersheds. Minnesota's lakes and streams usually have anoxic (oxygen-free) conditions in their sediments, because of the abundant organic matter there (primarily remains of dead algae and other plants). In such anoxic environments, sulfate is highly reactive. The reactions of sulfate with naturally occurring organic matter, mediated by naturally occurring bacteria, cause a cascade of deleterious water quality and health-related effects: (1) **sulfide**, which is toxic to most organisms, is generated in the sediments, where it can harm rooted plants, including wild rice (Pastor et al 2017, Myrbo et al 2017a) ; (2) decomposition of organic matter releases **nutrients, mercury, and other chemicals** that can have harmful ecosystem and health effects (Myrbo et al., 2017b.; (3) critically, mercury (from air deposition and release) is converted into **methylmercury**, the only type that enters the food web and bioaccumulates in fish (e.g., Gilmour et al., 1992; Myrbo et al., 2017b)

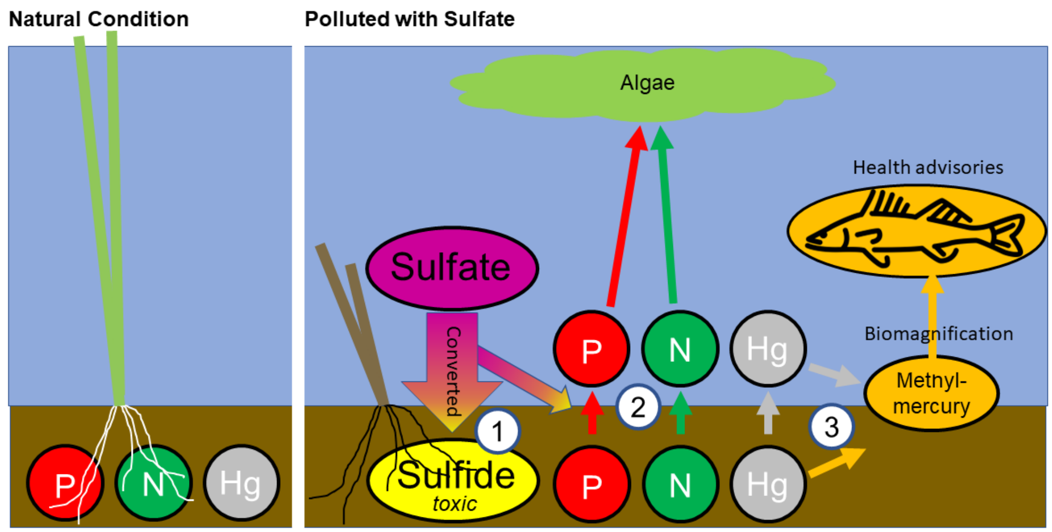

Figure 3. LEFT: Healthy waterbody where low oxygen and low sulfide in sediments prevent decomposition of organic matter. Nitrogen (N) and phosphorus (P) in organic matter remain in the sediment, as does mercury (Hg) that is adsorbed (stuck) to the organic matter.

RIGHT: When sulfate is released to water, it mixes into the sediments. There, sulfate is used by bacteria to convert sulfate to toxic sulfide, decomposing organic matter in the process (1). This decomposition releases nitrogen and phosphorous (plant nutrients) into the water (2). Excessive nutrients result in increased algae in waters that were once clear. The decomposition also releases the mercury that was adsorbed to the organic matter, and the *bacteria convert mercury to methylmercury (the only form of mercury that accumulates in the food web) (3). Sulfide, phosphorus, nitrogen, and methylmercury can adversely affect wildlife, plants that provide wildlife habitat, water quality, and human health.*

As shown in Figure 3, when sulfate is added to fresh, low-sulfate waters, this sulfate mixes into the anoxic porewaters of the sediment. There it comes into contact with organic matter and bacteria, resulting in a biochemical process that converts sulfate to sulfide, releases phosphorus, nitrogen, and mercury, and methylates mercury. As described in the "plain language summary" of a publication (Myrbo 2017b) on the results of a large mesocosm experiment in northeastern Minnesota that demonstrated these multiple negative effects:

> In the water-saturated soils of wetlands, which are usually anoxic, decomposition of dead plants and other organic matter is greatly retarded by the absence of oxygen. However, the addition of sulfate can allow bacteria that respire sulfate, instead of oxygen, to decompose organic matter that would not otherwise decay. The accelerated decay has multiple consequences that are concerning. The bacteria that respire sulfate "breathe out" hydrogen sulfide (also called sulfide), analogous to the conversion or respiration of oxygen to CO_2. Sulfide is very reactive with metals, which makes it toxic at higher concentrations. In addition to the release of sulfide, the sulfate-accelerated decomposition of plants releases phosphorus and nitrogen, fertilizing the waterbody. Decomposition also mobilizes mercury (which is everywhere, thanks to atmospheric transport) into the surface water. The microbes that convert sulfate to sulfide also methylate mercury, producing methylmercury, the only form of mercury that contaminates fish. **This study demonstrates that adding sulfate to a wetland can not only produce toxic levels of sulfide but also increase the surface water concentrations of nitrogen, phosphorus, mercury, and methylmercury** (Myrbo et al., 2017b, p.1; emphasis added).

The following equation (Boudreau and Westrich, 1984) shows the reactants (left of arrow) and products (right of arrow) of the microbial reaction that converts sulfate to sulfide:

$$2(CH_2O)_x(NH_3)_y(H_3PO_4)_z + xSO_4^{2-} \rightarrow 2xHCO_3^- + xH_2S + 2yNH_3 + 2zH_3PO_4$$

or, in words:

organic matter + sulfate
[is converted by bacteria into]
bicarbonate + sulfide + ammonia + phosphate

In this reaction, organic matter is oxidized – broken down, and destroyed – as sulfate is converted to sulfide. This accelerated decomposition of organic matter releases the components of organic matter, including sulfide, ammonia (a form of nitrogen), and phosphate (a form of phosphorus). Each of these compounds can have powerful ecosystem effects. that are described individually below.

Sulfide and Wild Rice

The harmful effects of sulfide on wild rice, which grows in Sandy Lake and at least 15 other lakes and streams downstream of the Talon site, are well-established (e.g., Pastor et al 2017, Myrbo et al 2017a). Sulfide is "a potent phytotoxin [plant poison], profoundly affecting plant fitness and ecosystem functioning in the full range of wetland types" (Lamers et al 2013). Sulfide also poisons other rooted aquatic plants, which provide food and habitat for birds, amphibians, mammals, and other wildlife, as well as food and medicine for people.

Nutrients

Ammonium (NH_3) and phosphate (H_3PO_4) are plant nutrients that are readily taken up by primary producers such as algae. These nutrients have the potential to cause eutrophication in the rivers and lakes to which sulfate would be discharged, and to potentially cause an exceedance of Sandy and Minnewawa lakes' TMDLs. Nutrient inputs, especially excess phosphorus, can also lead to harmful cyanobacterial blooms that can poison wildlife and domestic animals. Both types of algae also make surface waters less transparent, shading out rooted aquatic plants (including but not limited to wild rice).

Mercury and methylmercury

In addition to the chemicals shown above, there is mercury stuck to (adsorbed on) the organic matter. Because of human industrial processes, mercury is ubiquitous in soils and sediments, having fallen onto the Earth surface from the atmosphere. Mercury has a strong affinity for organic matter (Feyte et al 2010), which is abundant in the sediments of most water bodies in Minnesota. Because it sticks to organic matter, the mercury is gradually buried and "locked away" as sediments accumulate over years and decades. However, should that organic matter be decomposed (in this case, by bacteria "breathing" sulfate), the mercury is released into the waterbody. This inorganic mercury is then available to be methylated, rather than being buried in the sediments. In the presence of elevated sulfate, bacteria thus cause a "double whammy" of increased inorganic mercury plus increased methylation of that mercury.

Methylmercury is biomagnified up the food chain, so that predators at the top of the food chain can have millions of times higher mercury concentrations than in the water (e.g., Lavoie et al. 2013) and can experience mercury poisoning. Sulfate loading to Sandy Lake, Lake Minnewawa, and others downstream of the proposed mining area would increase methylmercury in fish; otters, eagles, and other fish-eating wildlife; birds, bats, and other insect- and spider-eating wildlife; and of course, the human consumers of fish from impacted waters.

Mercury methylation can be suppressed by *high* levels of pore water sulfide (over about 600 µg/L sulfide; Gilmour et al. 1998; Bailey et al. 2017; Myrbo et al. 2017b), which could be achieved by high loading of sulfate to low-sulfate, organic-rich waters. However, such high levels of sulfide would cause severe damage to ecosystems: MPCA (2017) found levels over 120 µg/L sulfide to be harmful to wild rice populations, and in a literature review Lamers et al.

(2013) found that many freshwater aquatic plant species had sulfide toxicities ranging from 50 to 300 µg/L sulfide.

Quantification of effects

Myrbo et al. (2017b) experimentally showed the degree to which different levels of sulfate loading increased the loading of nitrogen, phosphorus, and mercury, and the methylation of mercury. The water in miniature lake "mesocosms" treated with up to 300 mg/L sulfate was observed to have about double the nitrogen, phosphorus, and total mercury of water in 7 mg/L treatments. The 300 mg/L treatments also had almost 6 times more methylmercury, and the sediment pore waters had 7.5 times more available phosphorus, than the 7 mg/L treatment. These experimental mesocosms do not perfectly replicate the natural world, and for reasons described by Myrbo et al. (2017), the values of different chemicals in natural lakes and rivers could be higher or lower than the percentages seen in the mesocosms. But importantly, they demonstrate that the sulfate conversion to sulfide can have substantial effects on water chemistry.

Disproportionate effects of sulfate pollution with respect to sulfate concentration

The effects of the conversion of sulfate to sulfide have the potential to cause these deleterious effects out of proportion to the amount of sulfate released to the ecosystem, because each sulfur molecule can be recycled many times. Sulfate is converted to sulfide, then can be re-converted to sulfate (e.g., as sulfide diffuses out of anoxic pore waters), then converted again to sulfide and oxidized to sulfate, ad infinitum, in what is known as the “cryptic sulfur cycle” (Canfield et al., 2010). Each time it is converted from sulfate to sulfide, more organic matter is oxidized, more nutrients and mercury are released, and more mercury is methylated.

Conclusion

The eventual scope and extent of Talon/Tamarack mining facilities is uncertain. However the following conclusions can be drawn from the existing scientific evidence. If sulfate is released from the proposed Talon/Tamarack mining project, it would be converted to sulfide in lake and river sediments, which would damage known wild rice populations in at least 16 lakes and streams. It would increase the amount of nutrients, total mercury, and methylmercury in downstream waters including Lake Minnewawa, Sandy Lake, Horseshoe Lake, Round Lake, Minnewawa Creek, Sandy River, Mississippi River, Kettle River, and St. Croix River, as well as numerous other lakes and streams in the potentially affected watersheds.

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