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Framework for developing and evaluating site-specific sulfate standards for the protection of wild rice

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Introduction

Water quality standards (WQS) are critical regulatory tools for protecting aquatic resources from adverse pollutant impacts. Each standard specifies a beneficial use to be protected and the condition(s) under which protection is expected to be achieved as a numeric pollutant concentration threshold or narrative description of those conditions. A standard is generally developed on a statewide or ecoregional basis, and it is presumed that meeting the standard is sufficient to sustain the beneficial use at those broad geographic scales. However, due to substantial natural variability in the hydrologic, chemical, and biological characteristics of aquatic ecosystems – as well as in how the ecosystems respond to pollutants – no standard is perfectly suited to every waterbody. In some instances, a numeric water quality standard may be more stringent than is strictly necessary to protect the beneficial use in a specific waterbody; in others, it may not be sufficiently stringent to ensure protection. In these instances, it may be appropriate to consider a site-specific modification to the statewide or ecoregional water quality standard for that specific waterbody.

The Clean Water Act (40 CFR 131.11(b)(1)(i)) and Minnesota Rules (Minn. R. 7050.0220, subp. 7) provide the flexibility to tailor WQS to waterbodies where unique circumstances alter the typical or expected relationship between a pollutant and the protected beneficial use. This flexibility comes through the development and application of site-specific standards (SSS) reflecting localized environmental conditions. Development of a SSS for a particular waterbody may be initiated by the Minnesota Pollution Control Agency (MPCA) or requested by an external party if available information indicates that “a site-specific modification is more appropriate” than the existing statewide or ecoregional standard (Figure 1). Like all water quality standards, a SSS must comply with all requirements of WQS found in Minn. R. 7050 and 7052, including the need to protect downstream uses. For a request to receive approval, the proposed modification must demonstratively protect the beneficial use and be based on the best available science. The MPCA evaluates all relevant data and information, including recent scientific publications, to determine whether a SSS is justified.

Figure 1: Minnesota Rules, part 7050.0220, subp. 7 (A-B)

| § | Subp. 7. Site-specific modifications of standards. |
|   | A. The standards in this part and in parts 7050.0221 to 7050.0227 are subject to review and modification as applied to a specific surface water body, reach, or segment. If site-specific information is available that shows that a site-specific modification is more appropriate than the statewide or ecoregional standard for a particular water body, reach, or segment, the site-specific information shall be applied. |
|   | B. The information supporting a site-specific modification can be provided by the commissioner or by any person outside the agency. The commissioner shall evaluate all relevant data in support of a modified standard and determine whether a change in the standard for a specific water body or reach is justified. |

This document pertains to Minnesota’s Class 4A numeric sulfate standard of 10 mg/L – created in 1973 to protect the ecologically and culturally significant wild rice plant that grows in numerous lakes, streams, and wetlands – and potential site-specific modifications to that standard. It provides a framework for developing and evaluating site-specific standards that ensures the beneficial use, “production of wild rice”, will be protected within the waterbody of interest. Development of a SSS for a specific waterbody requires an understanding of the wild rice beneficial use, documentation of the extent and condition of wild rice in that location, collection and analysis of water-column sulfate concentration data, and a thorough exploration of scientific information regarding how sulfate impacts
wild rice within that specific environmental context. Evaluations of SSS applications will include
determinations on whether an applicant has met the minimum expectations described in this document,
followed a scientifically defensible approach to developing a sulfate numeric value, provided sufficient
data and information to demonstrate that the wild rice beneficial use will be protected at the proposed
sulfate standard, and adequately explained why the characteristics of the environmental setting
(chemical, hydrologic, biological, and/or physical) warrant a SSS that deviates from the statewide
standard of 10 mg/L sulfate.

The goals of this framework are to:

1. Define what constitutes protection of the wild rice beneficial use (i.e., when the wild rice is
   “healthy”, or “self-sustaining” and “productive”)
2. Establish expectations for applicants requesting a SSS and for agency staff reviewing those
   applications
3. Identify informational needs that should be satisfied before advancing a SSS and encourage data
collection consistent with meeting those needs.

Understand the beneficial use

What is the Class 4A wild rice beneficial use?
Minnesota’s Class 4 water quality standards are intended to protect the “the agriculture and wildlife
designated uses” of waters of the state. The 4A subclass designation applies to waterbodies for which
water quality must be sufficient “to permit their use for irrigation without significant damage or adverse
effects upon any crops or vegetation usually grown in the waters or area” (Minn. R. 7050.0224, subp 2).
A unique subset of waters within the 4A subclass, described as “water used for production of wild rice”,
was established alongside a numeric sulfate standard to protect the production of the wild rice grain.

The wild rice designated use is defined in Minn. R. 7050.0224, subp. 1 as “The harvest and use of grains
from this plant (i.e. wild rice) serve as a food source for wildlife and humans”. The water quality
standard to protect wild rice exists in rule as “10 mg/L sulfate - applicable to water used for production
of wild rice during periods when the rice may be susceptible to damage by high sulfate levels” (Minn. R.
7050.0224, subp. 2). Since the standard applies to “water used for production of wild rice”, the MPCA
identified production of wild rice as a food source for wildlife and humans as the beneficial use.

Where does the beneficial use apply?
The MPCA has determined that certain waterbodies are to be recognized as “waters used for production
of wild rice” (WUFPOWR) under Minn. R. 7050.0224, subp. 2 (MPCA public data viewer of water used for
production of wild rice). The list of WUFPOWR will be public noticed in MPCA’s 2024 Guidance Manual
for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report
and 303(d) List during the fall of 2023. These designations are based primarily on documentations of
wild rice presence in primary sources, including various wild rice inventories, biological monitoring
reports, agency databases, and responses to a public request for wild rice data and information. Due to
the often-cyclical pattern of wild rice growth and high degree of natural variability in wild rice
population sizes, the MPCA does not require a specific population-size threshold to be met for the
purpose of assigning a WUFPOWR designation. The MPCA has instead determined that stand-level
documentation of wild rice presence is sufficient to consider a waterbody WUFPOWR and for beneficial
use protections to apply. Minimal stands or sparse rice still constitutes a “production of wild rice” that
has the potential to provide food for wildlife and humans. The MPCA is therefore applying the wild rice
beneficial use to waters with documented wild rice presence, current or historical, because it shows the
beneficial use has occurred and thus is an existing use. The 10 mg/L sulfate standard to protect wild rice is applicable to these waters.

The process to identify an existing beneficial use to be added as a WUFPOWR is different from the beneficial use attainment demonstration required in a SSS application. For the waters MPCA has determined to be WUFPOWR, documentation that wild rice stands have been present – whether through observations or measurements of spatial extent, history of harvest, or collections of data on other suitable wild rice growth metrics – is sufficient to consider that water a WUFPOWR. When constructing or evaluating a SSS for a specific waterbody, it is already known that wild rice is present and that Class 4A is an existing use. The demonstration to be made for a SSS is that at the proposed sulfate standard, the wild rice beneficial use will be protected and attained in the specific waterbody. This framework aims to outline how such a demonstration can be made. If available data and research findings do not illustrate that wild rice will be healthy in an environment under a sulfate standard that differs from 10 mg/L, then a SSS is not appropriate.

**Is the beneficial use protected?**

The two key aspects of the beneficial use, production of wild rice and availability of wild rice for harvest by humans and consumption by wildlife, must be shown as achievable under any site-specific standard proposal. The wild rice-sulfate rule language and related rulemaking documents do not formally define “production” with regards to wild rice. In the absence of a formal definition of “production”, the MPCA uses a definition consistent with the understanding of production as detailed in the 2017 wild rice rulemaking SONAR (MPCA, 2017b). We interpret “production” to be akin to a definition of ecological production – that is, the generation of biomass. Furthermore, for a population of wild rice to yield sufficient grain for harvest by humans and to act as a food source for wildlife, it must produce enough nutritious, filled seeds to provide for the growth of future generations of wild rice in that environment. Therefore, for the purposes of evaluating site-specific standard requests, the MPCA will require a demonstration that the waterbody has and will maintain a “*wild rice population that is self-sustaining and productive*”.

Wild rice that is both self-sustaining and productive is considered healthy. A self-sustaining population of wild rice is regularly and observably present in the waterbody (i.e., does not exist only theoretically in the seed bank), recurring annually or following multi-year boom-bust cycles (Pastor and Walker, 2006; Walker et al., 2010) without trending towards local extirpation (contrast the “high sulfate” and “low sulfate” scenarios depicted in Figure 7 within LaFond-Hudson et al., 2022). A single boom-bust cycle is defined as a period of high biomass production (boom) followed by a population crash (bust) and then gradual recovery. Boom-bust cycles, which often span 3-5 years, can occur due to delays in nutrient cycling caused by slow decomposition of plant litter (Pastor and Walker, 2006; Walker et al., 2010). A productive wild rice population will show continued annual and long-term growth of the plant and the establishment of an ongoing seed bank in the sediment.

Gathering wild rice is essential to sovereign tribal nations’ culture and way of life. Losses of wild rice have been linked to cultural disruptions and negative health consequences (Ballinger, 2018; Fond du Lac Band of Lake Superior Chippewa, 2018). Access to and harvesting of wild rice maintains religious, ceremonial, medicinal, subsistence, and economic needs for members of those nations. In many parts of Minnesota, Tribal Nations possess reserved treaty rights to harvest wild rice. Any site-specific sulfate standard for the protection of wild rice must support the exercise of applicable tribal treaty rights to gather wild rice as well as protect downstream water quality standards for tribes that have Treatment as a State under the Clean Water Act. Thus, applications for a SSS must demonstrate that the proposed
numeric sulfate concentration will allow wild rice to not only persist in the short term but also sustain itself – undergo consistent production across multiple growth cycles – over the long term.

**Approaches to developing a site-specific sulfate standard**

The MPCA has historically followed one of two broad approaches when developing a site-specific standard. The first is to consider the use of national recommended ambient water quality criteria provided by the U.S. Environmental Protection Agency (EPA) (e.g. ammonia in the Red River of the North or selenium in the lower Minnesota River), which may be especially appropriate if developed more recently than the existing statewide or ecoregional standard. The second is to independently develop the expression of, and scientific rationale for, a SSS (e.g. specific conductance on the Rock River or phosphorus in Lake Byllesby). In general, the first approach is more streamlined because the scientific information justifying the selected pollutant threshold has already been assembled and evaluated by EPA. Since no federal water quality criteria exist for the protection of wild rice from elevated sulfate, MPCA and applicants must pursue the second approach when developing a site-specific modification of the statewide 10 mg/L Class 4A sulfate standard. Because there is no pre-existing quantitative goal or threshold defined in rule to demonstrate that the beneficial use is met in site-specific contexts, significant work must be undertaken to develop, *de novo*, the scientific basis for a SSS. Supporting information must establish the appropriateness of the site-specific modification.

There is an abundance of important scientific information, produced between 2010 and 2017 when the MPCA conducted a review of its existing statewide standard, as well as in more recent publications, that should be considered in a SSS proposal (see references at the end of this document as a starting point). For example, recent research has provided important insights into the effects of elevated sulfate on wild rice plant growth and reproduction, population cycles, sediment porewater chemistry in the rooting zone, and root plaque development (Johnson et al., 2019; LaFond-Hudson et al., 2022; LaFond-Hudson et al. 2018). Because research concerning sulfate and wild rice continues to be relatively active, requests for a SSS should include a meaningful evaluation of all relevant scientific information available as of the date of submission.

**Basis for a new numeric standard: the sulfate concentration value**

Since an application for a SSS must demonstrate that the newly proposed site-specific sulfate standard will support a productive and self-sustaining wild rice population within the specific waterbody, the basis for deriving the sulfate SSS must be considered in that light. The approaches to developing a numeric SSS listed below are divided into two categories. First are standalone approaches that illustrate the association between the surface water sulfate concentration with metrics tracking wild rice abundance and health which can be used independently to justify the proposed site-specific sulfate standard.

The second grouping includes supporting information that can only be used in a weight-of-evidence approach to support a numeric standard constructed via a separate approach in the first grouping. The MPCA acknowledges the value in considering other potential lines of evidence to further support the proposed sulfate SSS. The applicant’s chosen basis for the proposed sulfate concentration value should be described in detail.

Standalone approaches:

- Applying the current ambient sulfate concentration if wild rice is healthy:
  - This approach requires long-term monitoring of both surface water sulfate concentrations and wild rice abundance (multiple metrics). If there is no increase in sulfate concentration
over time and wild rice is demonstrated to be healthy (including clear indication that it is not declining in abundance), then the current ambient sulfate concentrations could be used as the numeric site-specific sulfate standard.

- **A novel approach**

**Supporting evidence:**

- **Calculating a sulfate concentration value using the sediment-based equation proposed during the 2017 rulemaking process**
  - The proposed equation from the 2017 rulemaking established a statistical relationship between sediment iron, organic carbon, and surface water sulfate of wild rice waterbodies and that relationship could be used to inform the development of a SSS. When paired with information demonstrating that wild rice has not declined over time, this statistical relationship could be used as one line of evidence in a SSS application.

- **Determining a likely sulfate effect threshold based on a review of all available literature pertaining to sulfate & sulfide effects on wild rice, with special attention to sulfate and wild rice health data collected in analogous settings**
  - Literature-based analyses should include laboratory studies (mesocosm or bucket experiments, hydroponics, etc.) as well as any field studies conducted in wild rice waters. Any explicit or inferential connections of wild rice health indices to measured sulfate levels would need to be highlighted for consideration.

- **Determining ambient sulfate concentrations in regional waterbodies that contain healthy wild rice, with special attention given to nearby waterbodies (and waterbodies with analogous environmental characteristics) that are known to contain wild rice and that are unimpacted by sulfur-containing discharges to local surface water or groundwater**
  - Report the full distribution of data and propose a sulfate concentration value that is statistically and scientifically justifiable (e.g., median of sulfate concentrations recorded in waterbodies containing healthy wild rice in the same watershed).

- **Measuring sulfide concentrations in sediment porewater within the rooting zone of wild rice plants during the seed production phase of their life cycle**
  - Accumulation of sulfide in sediment porewater is a primary controlling factor on wild rice occurrence (Myrbo et al., 2017). At elevated levels, sulfide is directly toxic to seedlings, causing reductions in emergence and survival (Pastor et al. 2017). Wild rice is also vulnerable to sulfide during later life stages, when nutrient uptake and seed production may be inhibited (Johnson et al., 2019; LaFond-Hudson 2018, 2020). MPCA recommends collecting porewater samples from multiple wild rice stands — specifically within the rooting zone of existing wild rice plants during their seed production phase — and then comparing measured porewater sulfide concentrations to potential toxicity effect thresholds that have been explored in the scientific literature, some of which can be found in a previous technical support document published by MPCA (MPCA, 2017b).

**Expectations of detailed supporting data and analysis**

Wild rice plant biology and sulfur biogeochemistry is complex and there is significant natural variability in hydrology and other features of aquatic environments that support wild rice. Consequently, MPCA is unable to prescribe a fixed, step-by-step approach to developing a SSS that would suffice in all circumstances. Scientific data and information provided in support of a SSS application will need to be uniquely tailored to the specific waterbody in question.
SSS proposals must include a close examination of the local environmental context in which the proposed SSS would apply, as well as consideration and description of all relevant data — historical and recent — available for the location of interest. The applicant must provide scientific evidence to demonstrate that the proposed sulfate concentration value will allow the waterbody to support a wild rice population that is self-sustaining and productive (i.e., healthy).

Demonstrate wild rice health

The MPCA recommends a multi-part evaluation of wild rice health metrics and data to demonstrate the wild rice beneficial use will be protected. Ideally, an application would include long-term data on wild rice stand spatial extent and stalk density paired with sulfate concentrations and water depth, as well as measurements on other variables related to wild rice condition or productivity. These waterbody-specific data should be evaluated alongside any available historical data, followed by a discussion of how they relate to findings in the scientific literature, including field studies, mesocosm experiments, and hydroponic growth tests.

The applicant should begin by determining what potential metrics of wild rice health can be evaluated at the waterbody of interest and whether any might effectively demonstrate that wild rice in that location is self-sustaining and productive. Minnesota statutes and rules do not specify or limit options for metrics that may be used for such a demonstration.

There are many ways to measure wild rice health; metrics of wild rice health can be qualitative (grain texture, taste, visual appearance, etc.) or quantitative (stand area, stalk density, seed content, porewater sulfide, etc.). Appropriate data collection might occur during in-situ field sampling, remote observation, or experimental endeavor.

The scale at which data collection occurs might also vary, as both plant-specific and population-level indicators of wild rice health can be meaningfully explored. A SSS application must provide population-scale data, including long-term trends in spatial extent and stand density. The ability to compare current population productivity relative to historical benchmarks is valuable, if available and known.

Plant-specific measures that relate to the presence or absence of sulfate-induced plant stress — outward physical manifestations of impacts, or internal cellular or physiologic changes, for example — may be particularly helpful to monitor and include in an application. Potential measurement options include stem height, seed mass or fill ratio, plant biomass, germination rate, photosynthetic activity, and many others.

Tracking a combination of metrics over time at both population and plant scales will provide a stronger picture of the population dynamics for wild rice in a specific waterbody, and arguably the more metrics, the better. Furthermore, the applicant must provide a scientifically defensible rationale for pursuing the metrics chosen and explain why they are appropriate for understanding and characterizing wild rice health in that particular environmental context.

A useful resource to review prior to establishing a sampling plan or beginning data collection efforts is the Wild Rice Monitoring Handbook (Kjerland, 2015), which organizes a set of core wild rice variables and offers a standardized method for monitoring wild rice health (Table 1).
Table 1. Core wild rice variables (Kjerland, 2015.)

<table>
<thead>
<tr>
<th>Core Wild Rice Variables</th>
<th>Potential Stressors (Field Notes)</th>
<th>Optional</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Biomass &amp; Productivity (Annual Yield)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (number of stalks per area)</td>
<td>Observed shoreline use</td>
<td>Plant dry weight</td>
</tr>
<tr>
<td>Average Stem Height</td>
<td>Observed water use</td>
<td>Number of viable (filled hulls) and non-viable seeds collected</td>
</tr>
<tr>
<td>Water depth</td>
<td>Brown spot fungal presence and severity index</td>
<td>Calculate new site-specific biomass equation</td>
</tr>
<tr>
<td>Number of potential seeds (# pedicels per stalk)</td>
<td>Animals, birds, pests, pathogens presence</td>
<td>Presence of worm holes in seeds (observed in the lab)</td>
</tr>
<tr>
<td>Presence of other plants co-occurring with wild rice (List)</td>
<td>Weather (current and past 2-3 days)</td>
<td></td>
</tr>
<tr>
<td>Estimate of wild rice stand area</td>
<td>Other possible concerns for wild rice growth (i.e. pollutants)</td>
<td></td>
</tr>
</tbody>
</table>

Provide ten years (or two boom-bust cycles) of recent, consecutive wild rice population data

Long-term annual population data are needed to describe the trajectory of a wild rice population. A downward trend in spatial extent, stalk density, biomass, or other indicator of population-level health raises concerns about the potential for local extirpation of wild rice and negates any claim that the wild rice beneficial use will be supported under a sulfate water quality standard that is less stringent than the 10 mg/L Class 4A WQS. MPCA requires population data spanning ten years or two boom-bust cycles, whichever is shorter. Although such cycles are often 3-5 years in length, they may be considerably longer or not occur at all (Nyblade, 2022). If an applicant for a SSS chooses to submit population data spanning fewer than ten years, that data must show an obvious cyclical pattern (see Figure 2, for example) and encompass at least two full boom-bust cycles.
Figure 2. Long-term wild rice monitoring data on Kettle Lake collected by the 1854 Treaty Authority (Vogt, 2023). The data clearly show wild rice productivity cycles, with boom years following years of no wild rice at all and indicate no statistically significant downward trend in wild rice abundance. The red line at 2005 indicates that the 1854 Treaty Authority changed its sampling methodology in that year.

Explore multiple lines of evidence
Multiple lines of evidence may be necessary to support a demonstration that wild rice is healthy in a specific waterbody because there may be considerable natural variability in the physical expression of healthy wild rice.

Example – Mississippi River
The Mississippi River at Pool 8 is a good example of using a long-term dataset to evaluate wild rice health. Since 1989, the USGS has been sampling wild rice in Pool 8 and has been tracking wild rice location and relative abundance over that time (Figures 3 and 4). Wild rice within Pool 8 has been increasing in abundance and extent consistently since 1989 and is clearly not in decline. Sulfate concentrations have been sampled for over forty years in the Mississippi River and over this period sulfate concentrations are consistently between 30 and 50 mg/L.

In this case, complex wild rice health metrics are not necessary to determine that the wild rice beneficial use is protected in Pool 8 because the most important metrics are well understood in both extent and relative abundance. Multiple lines of evidence, including sulfate concentrations, population abundance, and location over time support this conclusion. These persuasive multiple lines of evidence that wild rice in Pool 8 is not at risk of decline due to sulfate concentrations in the Mississippi River.
Figure 3: USGS data showing wild rice abundance in the Mississippi River Pools over time (Figure F11 in Houser et al., 2022).
Review recent scientific findings, evaluate all relevant data, and address uncertainties

It is important to evaluate all relevant chemical, hydrological, and biological data – especially including those published in recent studies – to demonstrate that arguments supplied in the SSS application are consistent with current scientific knowledge. Minnesota’s tribal communities and the Minnesota DNR have also collected important data that are publicly available on their websites. Additionally, it is important to evaluate data uncertainties and acknowledge statistical uncertainties, as the growth and expression of wild rice is inherently variable, as may be the relationship between ambient sulfate and wild rice health. Use of statistical tools such as confidence limits, Type I/II error analyses and statistical, sampling errors, etc., are needed to describe and justify a protective site-specific standard.

Provide historical context

In considering the need to look at data over a long period of a time, the historical context of wild rice in the waterbody of interest is also relevant and can directly address a key question of the SSS: Is the wild rice population sustainable in this specific waterbody? Relatively few waterbodies have this type of long-term data, but when available this can provide the most robust demonstration of wild rice population sustainability. This can also include evaluating indigenous knowledge of wild rice in the surrounding area and of the waterbody of interest. Tribal ecological knowledge (TEK) can provide invaluable insight to the history of wild rice and should be considered.

Although the history of wild rice in a specific waterbody may not be definitive in understanding whether the beneficial use is met today and can be supported by a SSS, the investigation for and evaluation of
available historical data related to wild rice health and sulfate concentrations should be discussed in the application.

**Example – Mississippi River**

The Mississippi River upstream of Winona is listed as an impaired wild rice water for excess sulfate. There are numerous wild rice stands on the back waters of the Mississippi River that are connected to the main channel during periods of high river flow. The sulfate concentration in the main channel of the Mississippi River is between 30 and 50 mg/L and due to their hydraulic connectivity, the back channels are expected to have no greater sulfate levels than the main channel.

The Mississippi River is an altered waterway with seven lock and dams, a dredged main channel with some man-built islands. The hydrology of the river is significantly different than before these hydraulic structures were in place and collectively these structures help slow down flow and prevent surges of water elevation during flood events. Prior to these structures, water level would have been significantly higher in the springtime high flow period when wild rice emerges from seed. High water levels make it more difficult for wild rice to reach the water’s surface because it takes more energy for the seed to produce a stalk long enough to emerge at those higher water levels; this is one reason why wild rice does not typically exist in water deeper than 3-4 feet.

The larger point of this example is that noting other factors in the waterbody, such as hydrology, provides important context when considering the wild rice health overall and with regards to sulfate. Noting other factors does not mean that sulfate concentrations are unimportant, but that other factors matter too. Ultimately, if one understands other factors that influence wild rice health, then one can better understand how sulfate concentrations impact a population of wild rice.

**Example – Perch Lake**

Perch Lake is listed as impaired WUFPOWR for excess sulfate. The key factor influencing sulfate levels is sulfate loading from the nearby United Taconite Tailings Basin cell 2. High sulfate water emerging as groundwater from the taconite tailings basin flows less than two miles into Perch Lake. Perch Lake has a very small watershed (<4 square miles), and the non-point watershed contribution of sulfate is approximately 1 mg/L.

Prior to the construction of cell 2 of the tailings basin in 1981, sulfate was measured in Perch Lake at 1 mg/L. Nearby and immediately adjacent waters to Perch Lake not receiving flow from the tailings basin have sulfate levels less than 2 mg/L. Wild rice has been documented by western science on Perch Lake since 1968 but only six times since then and has ranged significantly in abundance over that time.

Because of sulfate loading from United Taconite, there has been over 80-100 times the diffusive pressure forcing sulfate into Perch Lake sediments because sulfate concentrations have increased by over 80-100 fold. The enhanced diffusive flux of sulfate into the lake sediment has likely increased microbial production of sulfide, with potential negative impacts on wild rice health.

The historical context of sulfur concentrations in Perch Lake provides important information for evaluating wild rice health over time with regards to sulfate concentrations and suggests that the historical population health of wild rice in Perch Lake could have been affected by increased sulfate levels.

**Document and examine ambient sulfate in the context of regional baseline levels**

Minnesota has surface water sulfate concentrations that vary widely by ecoregion ranging from upwards of 5,000 mg/L along the South Dakota border to less than 1 mg/L near the Boundary Waters. This wide
range of sulfate concentrations means that many wild rice waters in the southern and western regions of the state have sulfate concentrations that are naturally above the 10 mg/L wild rice sulfate standard.

The variability of sulfate concentrations can be seen in Figure 5 below. In the figure, the left map illustrates the average sulfate concentration at each location sulfate has been sampled in Minnesota. Sulfate in the northeastern Northern Lakes and Forest ecoregion is always below 10 mg/L, except for waters flowing from the Iron Range where the taconite mines and tailings basins contribute anthropogenic loading of sulfate.

The figure on the right shows median “baseline” sulfate concentration by major watershed; in order to calculate the median baseline, all sample locations with an upstream wastewater discharger were removed. This allows for an estimation of the levels of sulfate in a watershed without any point source loading. This is not a rigorous natural background calculation but rather a way to understand point versus non-point sulfate contributions on a regional basis.

Except for the northeastern ecoregion, sulfate concentrations vary substantially across ecoregions. For example, within the Western Corn Belt Plain ecoregion, sulfate concentrations can vary from upwards of 500 mg/L along the western edge to less than 10 mg/L along the eastern edge. The Northern Lakes and Forest ecoregion is the only Minnesota ecoregion with baseline sulfate concentrations consistently below 10 mg/L.

This form of analysis is important because it provides context for how sulfate concentrations have changed over time and whether baseline levels of sulfate are high or low. If baseline levels of sulfate are high or low, then it would make sense to develop a site-specific standard criterion to consider that information.

Figure 5. Sulfate concentrations visualized by sample location and by HUC8 major watershed with sample locations with an upstream discharger removed.
Example – Mississippi River at Winona

The Mississippi River is the largest watershed in the state with a drainage area of over 59,000 square miles across Minnesota and Wisconsin. Sulfate concentrations in the Mississippi River at Winona average 33 mg/L. This sulfate concentration is an integration of all upstream loading of sulfate from point and non-point sources across low and high sulfate ecoregions.

There are over 1,000 wastewater dischargers within this watershed and if every one of these dischargers reduced their discharge to zero sulfate, sulfate concentrations in the Mississippi River would decrease by approximately 18% to about 27 mg/L. Clearly, sulfate loading in the Mississippi River watershed at Winona is dominated by non-point sulfate loading (82% of total load) with the majority of that loading coming from the western edges of the watershed. There is no clear trend between watershed sulfate concentrations and agricultural land use because some highly agricultural watersheds have high sulfate levels while adjacent watersheds with similar agricultural uses have low sulfate concentrations.

Evaluating regional background sulfate concentrations by watershed is a useful tool to understand the sources of sulfate in a wild rice waterbody because it can provide insight into whether wild rice in specific have adapted to specific levels of sulfate.

Example – St. Louis River Estuary

The St. Louis River Estuary is an impaired WUFPOWR for excess sulfate located in the Northern Lakes and Forest ecoregion, where sulfate baseline concentrations are less than 10 mg/L. Sulfate in the St. Louis River Estuary is dominated by loading from taconite mines with upwards of 95% of sulfate loading to the estuary coming from the mines. There are municipal wastewater point source dischargers in this watershed, but their cumulative sulfate loading is small, making up less than 2% of total sulfate load. In this watershed, if all loading from point sources were eliminated the estuary would have a sulfate level less than 10 mg/L, reflecting the regional baseline sulfate.

A load duration curve that plots sulfate concentration in the St. Louis River at Scanlon against daily flow in that river shows a classic curve demonstrating point source dominance (Figure 6). The St. Louis River at Scanlon is several miles upstream of the estuary and is a good physical location to measure cumulative loading into the estuary. Sulfate concentrations increase at low flows and decrease at high flows which is an indicator that point sources dominate sulfate loading. This load duration curve evaluation is one tool that can be used to understand sources of sulfate to a waterbody, providing that the waterbody has sufficient data.
Discuss confounding factors
The MPCA understands elevated sulfate in the water column and the resulting sulfide in the porewater is not the only factor potentially damaging the productivity and recurrence of wild rice. Issues like water level changes, whether anthropogenic or natural, groundwater upwelling, harvesting pressure due to wildlife, competition due to the presence of co-occurring plants, and water clarity, amongst others can all impact the annual productivity and long-term sustainability of a wild rice population. The MPCA recognizes that controlling for each of these confounding factors would be an impossible task, but a thoughtful consideration of these potential factors should be included in supporting documentation, particularly if the applicant believes that they are suppressing wild rice productivity.

Future wild rice monitoring
If a site-specific sulfate standard for the protection of wild rice were approved, future sulfate monitoring would be required within in the NPDES wastewater discharge permit upstream of that water. The MPCA may also choose to monitor the wild rice water as part of the regular water quality assessment monitoring. If wild rice health declines in the waterbody after the site-specific standard is approved, then a new or lowered wastewater permit limit for sulfate would be included in those permits that are either causing or contributing to the exceedance of the site-specific standard.
References


