Stantec

Attachment SW Qual-03: Surface Water Quality – Methylmercury Production

1 Introduction

This memorandum has been prepared in response to an Information Request (IR) seeking an assessment of potential changes in methylmercury (MeHg) production and concentrations in the West Buskegau River (WBR) and the North Driftwood River (NDR) receiving effluent associated with discharge points from the Project. Specifically, the IR provides the following observations:

- *"The IS states that mercury is not anticipated to increase as a result of mining operations. Although there will be an increase in mercury concentrations in the receivers after full mixing, the concentration of total mercury in the North Driftwood River and the West Buskegau River would be below Canadian Water Quality Guidelines for the Protection of Aquatic Life.*
- *Chapter 15 states that the maximum average FDP total phosphorus discharge concentration and maximum average total phosphorus concentration at the point of complete mixing in the receiver in both the West Buskegau River and North Driftwood River are predicted to be below the Provincial Water Quality Objectives (PWQO) value. However, this is not true for the predicted results under regulatory conditions shown in Appendix C.5 Table 7.2 and Table 7.3, where phosphorus levels exceeding the PWQO extend downstream of the confluence with the Frederick House River and Abitibi River. It is unclear if phosphorus concentrations under regulatory conditions were considered in predictions of eutrophication. Eutrophication can lead to anoxic conditions that support methylation.*
- *The IS acknowledges that the average total inorganic nitrogen discharge via FDPs into the North Driftwood River would be expected to increase the potential for eutrophication in the watercourse segment from FDP-TMF-SP to up to 3.6km downstream of FDP-SP-02. It is unclear what mitigation measures will be considered to manage this.*
- *The proposed mine effluent limits in Table 6.16 of Appendix C.5 do not include sulphate. The high predicted sulphate concentrations in the treated mine effluent reveal that even after full mixing, the concentration of sulphate in receivers will be 4 to 15 times higher than baseline."*

Required information to resolve this comment include:

"Provide an assessment of the potential for methylmercury production in the North Driftwood River and West Buskegau River. The assessment should include the potential for anoxic conditions from the discharge of phosphorus and total inorganic nitrogen and increased concentrations of sulphates from both seepage and treated effluent under normal and regulatory conditions.

Confirm intentions to discuss appropriate effluent targets with MECP during permitting, as necessary, to manage the potential for methylmercury production, taking into account input from Indigenous communities."

This memorandum presents results of the evaluation of MeHg production under scenarios of increased sulphate concentrations and increased nutrient (nitrogen and phosphorus) loading. The memorandum applies a weight-of-evidence assessment based on established biogeochemical knowledge, predicted conditions in receivers, and findings from peer-reviewed studies of mining-impacted streams. The assessment considers both normal and regulatory operating conditions with the emphasis on distinguishing sustained or routine operating (i.e., normal) conditions from short-term and infrequent conditions used in regulatory or permitting applications.

Regulatory and normal discharge scenarios were previously defined in the assimilative capacity study (ACS) report included in the Impact Statement (Appendix C.5). The ACS results were subsequently updated in response to an additional IR presented in Attachment SW Qual-02.1. These updates involved adjusting effluent discharge and water quality parameters and re-running mass balance models to predict concentrations in receivers, downstream of final discharge points (FDPs).

The regulatory case represents worst-case conditions for mixing effluent with receiver flow. Initially, effluent discharge was set in the ACS to the maximum mine effluent rate, corresponding to the rated capacity of the water treatment plant. Receiver flow was defined as 7Q20, the seven-day low flow with a 20-year return period. In the updated ACS, effluent discharge was determined based on 7Q20 in receivers under two scenarios: one-to-one (1-to-1) and pre- and post-development (Pre-&-Post). In the 1-to-1 scenario, effluent discharge was set equal to 7Q20 in receivers, while in the Pre-&-Post scenario, discharge was set equal to the difference between 7Q20 flows under pre- and post-development conditions (i.e., matching the hydrograph so that the combination of post-development flows and discharge will be equal to pre-development flows).

Effluent water quality for the regulatory case was defined by maximum daily concentrations at FDPs after treatment, with limits established iteratively based on the assimilative capacity of local receiving waters and treatment technology recommendations. Receiver water quality was represented by the 75th percentile of baseline concentrations.

The normal case, intended to represent expected average conditions, originally defined effluent discharge based on average water balance model predictions, while receiver flow was set to mean annual flow (MAF) identified through regional assessment. In the updated ACS, effluent discharge was determined based on MAF in receivers, using the same two scenarios: discharge equal to MAF in the 1-to-1 scenario and equal to the difference between MAF under pre- and post-development conditions in the Pre-&-Post scenario.

Effluent water quality in the normal case was defined by mean monthly target objectives at FDPs after treatment or the modeled water quality, if raw water quality predicted by the model would be below the objectives. Receiver water quality was represented by mean baseline concentrations.

2 Conceptual Framework for Methylmercury Production in Streams

2.1 Overview of Methylmercury Production

Methylmercury production in aquatic ecosystems is primarily driven by microbial methylation of inorganic mercury (Hg^{2+}) under reducing conditions (Morel et al. 1998; Compeau and Bartha 1985; Gilmour et al. 1998). Organic matter plays a critical role by fueling microbial activity that may lead to the development of localized anoxic zones within sediments. Sulphate availability in combination with hypoxic (low oxygen) or anoxic (absence of oxygen) conditions further stimulates sulphate-reducing bacteria (SRB), which are key mercury methylators (Gilmour et al. 1992; Warner et al. 2003; Tang et al. 2020; Jeremiason et al. 2006). Oxygen dynamics influence the extent of these processes as low-oxygen microenvironments favour sulphate reduction and mercury methylation, whereas well-oxygenated conditions suppress these processes (Creswell et al. 2008; Ullrich et al. 2001). Upon the production of MeHg in anoxic or hypoxic sediment and porewater environments, MeHg can be released to the overlying water column.

Streams and rivers maintain strong hydrologic connectivity with their catchments. This connectivity means that catchment characteristics exert a major influence on in-stream physical (e.g., flow) and chemical (e.g., water chemistry and inputs of nutrients, dissolved and particulate organic carbon), conditions, which in turn play a critical role in governing mercury cycling within the stream (Marvin-DiPasquale et al. 2009; Branfireun et al. 2020). Literature on MeHg dynamics in rivers is limited in comparison to literature related to wetlands, lakes and estuaries. In a multi-watershed study conducted by Marvin-DiPasquale (2009), eight streams with diverse chemistry, ecology, basin size, and land use were evaluated with the focus on controls on methylmercury production and partitioning of total mercury and MeHg between sediments and pore water. Streams studied by Marvin-DiPasquale (2009) received mercury mainly from atmospheric deposition. Mathematical presentations in Marvin-DiPasquale (2009) indicated that MeHg concentrations were best described as a combined function of organic content and the activity of the mercury methylating microbial community and were comparable to MeHg concentrations in streams with mercury inputs from industrial and mining sources, which were presented elsewhere in a study where results of mercury and MeHg surveys for 106 stream were provided, including sites affected by mercury and gold mining (Krabbenhoft et al. 1999).

Literature also indicates that MeHg concentrations in streams are influenced by watershed-scale processes rather than in-stream production alone. For instance, research in boreal headwater systems demonstrated that catchment characteristics—such as wetland extent, soil organic content, and hydrologic flow paths—govern the export of MeHg to streams, more effectively than local in-stream methylation (Branfireun & Roulet 2002; Harrow-Lyle et al. 2023). Many other studies have also shown links between conditions within the catchment and MeHg production and export. Heyes et al. (2000) showed that elevated MeHg concentrations in the porewater of an experimentally impounded boreal peatland were attributed to increased net methylation driven by the decomposition of flooded vegetation. Similar patterns were observed in seasonally inundated soils of tropical river floodplains, where MeHg production was enhanced by the breakdown of fresh forest litter following inundation (Roulet et al. 2001). Overall, watershed export of MeHg tends to increase with the proportion of wetlands in the catchment (Grigal 2002).

These studies highlight that variability in watershed properties drives differences in stream MeHg levels, emphasizing that potential environmental effects of mining and mine effluent discharge must be considered within the context of upstream and watershed-scale source areas and biogeochemical controls.

2.2 Interaction with Oxygen Depletion and Nutrients

Nitrogen (N) and phosphorus (P) enrichment can increase primary productivity, promoting algal growth and leading to increased organic matter deposition to sediments and enhanced microbial respiration. In extreme cases, algal and microbial mats on the river bed can create zones of anoxia in the underlying sediment where MeHg formation can occur. As organic matter decomposes, microbial respiration consumes dissolved oxygen, often leading to hypoxic or anoxic conditions in sediments or bottom waters. The level of biological productivity, largely controlled by N and P availability, controls the trophic state, which is commonly used to classify aquatic ecosystems into categories ranging from oligotrophic (low nutrient concentrations, low productivity, clear water, high oxygen) to hypereutrophic (extremely high nutrient enrichment and excessive algal growth that may cause hypoxia or anoxia) (Dodds and Jones 1998).

Unlike lakes, where trophic categories describe whole-system conditions with vertical or depth stratification, streams exhibit the effects of nutrient enrichment as longitudinal zones, or as a function of distance from a source of inputs, with natural recovery occurring at locations farther downstream. This pattern means eutrophic conditions are typically confined to segments of a watercourse, rather than the entire watercourse. Furthermore, it is important to distinguish transient effects (e.g., short-term occurrences during low flow conditions) such as those represented by the regulatory flow regime (i.e., 7Q10 or 7Q20, the lowest stream flow for 7 consecutive days that would be expected to occur once in 10 or 20 years, respectively) from sustained nutrient enrichment due to long term nutrient loadings that may drive whole ecosystem changes in productivity and oxygen regime. Essentially, trophic state classifications are fundamentally linked to sustained nutrient enrichment and corresponding ecological responses such as primary productivity.

Furthermore, suspended solids and dissolved organic carbon (DOC) may influence primary productivity. While suspended solids restrict light transmission through the water column via scattering and absorption, DOC, particularly humic substances derived from soils and wetlands, can colour the water increasing light attenuation with depth. These processes limit the transmission of photosynthetically active radiation, which can inhibit the growth of submerged macrophytes and suppress phytoplankton and periphyton productivity (Allan and Castillo 2007). Total suspended sediment (TSS) concentrations in watercourses in the area had an average and a 75th percentile of 6.6 mg/L and 7.67 mg/L, respectively (Appendix B.5 of the Impact Statement). The average and 75th percentile DOC concentrations in watercourses were 31.1 mg/L and 42 mg/L, respectively. While TSS concentrations are not high and represent a stream with generally clear flow, DOC concentrations are very high. In a study on lakes, Karlsson et al. (2009) showed a strong negative influence by DOC on light penetration in lakes with DOC concentrations up to 16.8 mg/L, lower than concentrations observed in the present study area.

While the Karlsson et al. (2009) study demonstrates the influence of DOC on light penetration in lakes, it is important to note that light limitation in streams is different due to shallow depths and flowing conditions. In addition, the growth of periphyton and benthic algae in stream systems is influenced by factors such as substrate stability, flow velocity, and shading from riparian vegetation, in addition to DOC-driven light attenuation (Bernot et al., 2010). Despite these points, recent studies (not in boreal systems, however) suggest that high concentrations of DOC in streams can attenuate light and thereby constrain benthic algal growth (Leggieri et al., 2013) in the same way as has been observed in northern lakes (Karlsson et al., 2009).

As such, it is anticipated that DOC would influence light penetration in streams and limit primary productivity, thereby reducing algal growth and associated oxygen production, which in turn affects carbon cycling and microbial processes including those involved in mercury methylation.

2.3 Role of Sulphate

Sulphate is a key electron acceptor for SRB and therefore plays a central role in MeHg production. The relationship between sulphate concentration and MeHg production in hypoxic and anoxic environments is non-linear:

- At low sulphate concentrations, MeHg production is limited by sulphate availability.
- At intermediate concentrations, MeHg production increases.
- At high sulphate concentrations, production may decrease due to sulphide accumulation, which reduces mercury bioavailability through precipitation and complexation and also inhibits sulphate reduction due to sulphide toxicity to SRB (Gilmour et al. 1992).

Many research studies in sulphate-impacted freshwater ecosystems have identified increased MeHg production at intermediate sulphate levels (Bailey et al. 2017; Gilmour et al. 1998; Myrbo et al. 2017; Orem et al. 2020; Poulin et al. 2025). As a result, the relationship between sulfate concentration and MeHg production may follow a unimodal pattern with increasing availability of sulphate, i.e., initial stimulation followed by inhibition at higher concentrations (Gilmour et al. 1992; Poulin et al. 2025). When the utilization of sulphate by SRB is high, the system may accumulate sulphides as a byproduct of sulphate reduction (e.g., as metal sulphides which are generally insoluble, or as soluble H_2S) (Winfrey and Rudd 1990; Gilmour et al. 1992). Elevated sulphide levels strongly bind inorganic mercury, forming stable mercury-sulphide complexes that are not bioavailable for methylation (Hsu-Kim et al. 2013). Consequently, MeHg production declines under these conditions.

Whereas the effects of sulphate additions to lakes and wetland experimental plots and the resulting enhanced MeHg production have been reported in many studies (e.g., Branfireun et al. 1999; Branfireun et al. 2001; Jeremiason et al. 2006; Mitchell et al. 2008; Gilmour et al. 1992; Rudd 1995), comparable experimental studies do not appear to have been conducted in river environments. Observational studies comparing streams within catchments impacted by high sulphate from mining versus those in low-sulphate settings (e.g., studies in the St. Louis River watershed in northern Minnesota, Berndt & Bavin, 2012; Berndt et al., 2014) have found no consistent or meaningful effect of sulphate on stream methylmercury concentrations. These findings are relevant in the present case because receiving watercourses (i.e., the WBR and NDR) are predicted to experience sulphate concentrations during mining operations that are predicted to be higher than baseline sulphate levels.

It is important to note that the conditions observed in the Wabigoon River and the experimental work on sulphate (Branfireun 2024; Bento and Hintlemann 2024) are not directly comparable to the present study. Elevated MeHg concentrations in the Wabigoon River system were largely driven by massive historical loadings of elemental mercury from industrial sources, which created a legacy contamination issue (Rudd et al. 1983). In addition, ongoing discharges from the pulp mill at Dryden continue to supply both sulphate and organic matter, and the organic content in the Wabigoon River sediment is correlated with methylation potential (Bento and Hintlemann 2024). These combined factors create a unique biogeochemical environment that amplifies MeHg production. Because these conditions are not present in the current case, the Wabigoon River studies cannot be directly applied or used in the present study.

3 Assessment

The assessment followed a stepwise framework linking water quality predictions in average and regulatory conditions to site-specific characteristics of the receiving environment to evaluate the potential for MeHg production. Predicted post-discharge sulphate, nitrate (as the measure of total inorganic N) and total P concentrations were taken from the Impact Statement mixing zone and downstream modelling results presented in the updated ACS (Attachment SW Qual-02.1). These predictions were updated based on IR comments and differ from those presented in the Impact Statement.

3.1 Evaluation of Eutrophication Potential

Normal (Average) Case

Changes in nitrogen and phosphorus levels due to effluent discharge in normal conditions were evaluated in the Impact Statement in relation to shifts in eutrophication rates. Eutrophication in surface waters refers to nutrient enrichment, which drives increased biological productivity and alters ecosystem dynamics (Hutchinson 1973).

Phosphorus is widely recognized as the primary limiting nutrient in most freshwater ecosystems and, therefore, the key driver of eutrophication. Unlike nitrogen, which can be supplemented through atmospheric fixation by certain cyanobacteria (blue-green algae), phosphorus has no comparable external source and must be supplied from watershed inputs or internal loading within waterbodies. Consequently, when phosphorus concentrations increase, algal biomass often proliferates, even if nitrogen availability is low, because nitrogen-fixing species can compensate for nitrogen limitation (Schindler, 1977; Smith, 1983).

Conversely, if phosphorus remains limiting, neither cyanobacteria nor other algal groups can sustain excessive growth, regardless of nitrogen availability. This fundamental principle is the rationale for controlling phosphorus inputs as the most effective approach to preventing or mitigating eutrophication in lakes and rivers (Schindler et al. 2008; Carpenter, 2008).

As presented in the Impact Statement (Surface Water Resources Assessment, Appendix C.5):

- *"Average Total Phosphorus (TP) concentrations at FDPs are not predicted to increase receiver TP concentrations above the PWQO value, which was developed to prevent excessive plant growth, in the West Buskegau River and North Driftwood River.*
- *Average Total Inorganic Nitrogen (TIN) (total ammonia + nitrate + nitrite) concentrations in the FDP discharges to the West Buskegau River are not predicted to increase the potential for eutrophication. The average TIN concentration in the FDP discharges to the North Driftwood River would be expected to increase the potential for eutrophication from FDP-TMF-SP to up to 3.6 km downstream of FDP-SP-02."*

In response to another IR comment regarding mixing zone assessments, assimilative capacity analyses were updated (as detailed in Attachment SW Qual-02.1) indicating no change in TP predictions in average conditions in comparison to TP levels presented in the Impact Statement. This implies that updated TP conclusions are similar to those presented in the Impact Statement, implying that predicted average conditions are below PWQO thresholds for rivers intended to prevent excessive plant growth.

Updated assessments for TIN (i.e., Attachment SW Qual-02.1) indicated that, whereas the original mixing zone presented in the Impact Statement extended 3.6 km in the NDR and 0.03 km in the WBR, the updated mixing zone presented in Attachment SW Qual-02.1 extended only to the point of full mixing in receivers, i.e., between 6 to 174 m downstream of FDPs. As a result, for TIN with nitrate as the main driver, concentrations returned below CWQG-FAL of 3 mg/L within a few hundred metres compared with a distance of 3.6 km as presented in the Impact Statement. This indicates that, under average conditions, discharge of TIN via the FDPs is not expected to cause a substantial increase in eutrophication potential within the watercourse.

Regulatory (Low Flow) Case

The potential for eutrophication in the regulatory case involves assessing changes in trophic state during extreme low-flow conditions based on the 7Q20 flow statistic, which represents the lowest average flow over seven consecutive days expected to occur once every 20 years. These conditions are extreme, of short duration, and infrequent, as indicated by the definition of the 7Q20 statistic.

While reduced flow can increase water residence time and limit assimilation, the frequency and duration of 7Q20 events is insufficient to cause a sustained change in trophic state. Nutrient concentrations may temporarily rise due to lower assimilation, but the short-term nature of these events means that significant eutrophication effects—such as persistent algal blooms or structural shifts in aquatic communities—are not anticipated. Consequently, 7Q20 conditions are considered unlikely to result in meaningful or lasting eutrophication within the receiving streams.

Table A3.1 presents nutrient concentrations for the regulatory case where mass balance results were updated in response to the IR comment related to mixing zone assessment (see Attachment SW Qual-02.1 for details). Concentrations presented in Table A3.1 are related to the point of full mixing in receivers to the confluence with the Frederick House River (for the WBR) and with the Abitibi River (for the NDR).

Under the regulatory (7Q20) case, nutrient concentrations in both receivers show increases relative to baseline conditions. For example, in the WBR, phosphorus concentrations rise from a baseline of 0.037 mg/L (which is above the PWQO of 0.03 mg/L for rivers) to 0.055 mg/L near the FDP, and then gradually decrease along the watercourse to 0.039 mg/L. In the NDR, phosphorus concentrations rise from the baseline concentration of 0.027 mg/L to 0.048 mg/L downstream of the FDP and decrease to the baseline concentration at the end of the watercourse. These patterns indicate a minor increase in phosphorus concentrations. While elevated phosphorus can stimulate primary productivity, the observed concentrations are unlikely to drive substantial algal growth or organic matter accumulation, particularly given the short duration of regulatory flow conditions.

Concentrations of total inorganic nitrogen, i.e., combined inorganic nitrogen species (nitrite, nitrate, and ammonia), increase from 0.10 mg/L in baseline conditions to 4.40 mg/L and 4.41 mg/L downstream of FDPs in the WBR and NDR, respectively. These concentrations then decrease along the watercourse to 0.49 mg/L in the WBR and to 0.11 mg/L in the NDR. These changes represent moderate TIN enrichment but, given the short duration of 7Q20 conditions in the regulatory case, the potential for oxygen depletion and associated anoxia is anticipated to be minor.

Based on the assessment of nutrient dynamics under both normal flow and regulatory low-flow conditions (i.e., 7Q20), neither scenario is expected to result in significant eutrophication or associated oxygen depletion in the receiving streams. Given this low risk, the focus of further evaluation shifts to other factors influencing MeHg production, particularly the role of sulphate and site-specific biogeochemical conditions within the receiving environment.

Table A3.1. Nutrient Concentrations in the West Buskegau River and the North Driftwood River in the Regulatory Case

Receiver	Parameter	Unit	Baseline (75th %tile)	Distance from FDP (km)									
				0.069	**3.4**	**9**	**10**	**14.2**	**21.7**	**26.9**	**33.2**	**41.2**	**41.3***
West Buskegau River	Nitrite as N	mg/L	0.01	0.17	0.17	0.17	0.16	0.10	0.09	0.08	0.08	0.08	0.03
	Nitrate as N	mg/L	0.02	4.0	4.0	3.8	3.6	2.3	1.9	1.8	1.7	1.7	0.4
	Total Ammonia as N	mg/L	0.069	0.21	0.21	0.20	0.19	0.15	0.14	0.13	0.13	0.13	0.08
	Nitrite+Nitrate+ Ammonia as N	mg/L	0.10	4.40	4.36	4.21	3.94	2.56	2.17	1.97	1.95	1.86	0.49
	Phosphorus	mg/L	0.037	0.055	0.055	0.054	0.053	0.047	0.046	0.045	0.045	0.044	0.039

Receiver	Parameter	Unit	Baseline (75th %tile)	Distance from FDP (km)											
				0.006	**0.9**	**3.6**	**5.3**	**8.4**	**14.1**	**30.4**	**38.2**	**58.1**	**66.5**	**87.1**	**87.1****
North Driftwood River	Nitrite as N	mg/L	0.01	0.17	0.15	0.12	0.12	0.11	0.10	0.05	0.04	0.03	0.03	0.03	0.01
	Nitrate as N	mg/L	0.02	4.0	3.4	2.8	2.6	2.5	2.2	1.0	0.8	0.6	0.6	0.5	0.0
	Total Ammonia as N	mg/L	0.048	0.23	0.20	0.17	0.17	0.16	0.15	0.09	0.08	0.08	0.07	0.07	0.05
	Nitrite+Nitrate+ Ammonia as N	mg/L	0.08	4.41	3.75	3.11	2.92	2.79	2.45	1.19	0.91	0.74	0.69	0.58	0.11
	Phosphorus	mg/L	0.027	0.048	0.045	0.042	0.041	0.040	0.038	0.032	0.031	0.030	0.030	0.029	0.027

Notes:

* Confluence with the Frederick House River

** Confluence with the Abitibi River

3.2 Effects Caused by Sulphate in Effluent

Predicted sulphate concentrations in the WBR and the NDR are presented in the updated ACS memorandum (Attachment SW Qual-02.1). Mass balance analysis was conducted in the ACS to simulate sulphate levels in different reaches of receiving streams. The model considered only dilution without any attenuation processes. As such, simulated sulphate concentrations represent an upper-bound estimate of what would occur under complete mixing.

Under normal conditions, the highest sulphate concentrations (approximately 25 to 35 mg/L using mass balance models presented in Attachment SW Qual-02.1) occur near the FDP and then decrease downstream due to assimilation reaching 2.1 mg/L in the WBR at the confluence with the Frederick House River (41 km downstream of the FDP), and 0.9 m/L in the NDR at the confluence with the Abitibi River (87 km downstream of the FDP). The incremental sulphate concentrations after the mixing of WBR and NDR waters with larger rivers would be negligible. The baseline sulphate concentration as reported in the Impact Statement is 0.8 mg/L (which is the average baseline concentration). These predictions indicate substantial attenuation of sulphate with distance downstream.

In the regulatory (7Q20) case, sulphate concentrations at the point of full mixing are 79 mg/L and 73 mg/L in the WBR and NDR, respectively, higher than those predicted in the normal case (i.e., average river flow conditions). Baseline sulphate concentration was 0.9 mg/L in receivers in this case. Concentrations decrease to 10.0 mg/L in the WBR (41 km downstream, at the confluence with the Frederick House River) and to 1.6 mg/L in the NDR (87 km downstream, at the confluence with the Abitibi River). The baseline sulphate (i.e., 75^{th} percentile) sulphate concentration for the regulatory case is 0.9 mg/L. As a result, the regulatory case sulphate predictions imply greater enrichment relative to baseline conditions, as compared with the normal case. However, as was the case for nutrient loadings, the regulatory case represents an extreme, short-duration, and infrequent event that will remain confined to the river channel without extending into riparian wetlands (due to the extreme low flow condition), and is therefore not likely to result in persistent or lasting effects on biogeochemical processing of mercury in the watershed.

Unlike lakes, which can stratify and develop anoxic conditions in bottom waters and sediments, natural rivers are typically shallow, well-mixed, and characterized by continuous flow. Dissolved oxygen concentrations in watercourses during baseline conditions were up to 22 mg/L with an average of 8.31 mg/L and a 25^{th} percentile of 6.5 mg/L, which confirms that receivers were oxygenated during the sampling period. These conditions promote high oxygenation throughout the water column, limiting the creation of anaerobic zones in the water column where MeHg formation typically occurs. Sulphate reduction is strongly inhibited in the presence of oxygen because SRB require anoxic conditions to thrive (Compeau & Bartha, 1985; Gilmour et al. 1992). In rivers with limited labile organic carbon inputs, carbon metabolism in sediments remains relatively low, even when sulphate concentrations increase, because organic matter availability—not sulphate alone—controls microbial growth (Hsu-Kim et al. 2013; Furutani and Rudd 1980). Therefore, without substantial organic enrichment or prolonged stagnation, the potential for widespread anoxia and enhanced MeHg production in riverine environments is minor compared to stratified lakes.

As noted in Section 23, previous studies in St. Louis River, MN, indicated that MeHg concentrations were consistent between mining-impacted and non-impacted streams. The St. Louis River basin lies within the Lake Superior watershed with the Mesabi Iron Range (MIR), a major iron ore mining district, being located in the northern fringe of the watershed (Berndt and Bavin 2012). Mining activities in the MIR has resulted in release of sulphate to the St. Louis River. Streams draining mine lands typically had sulphate concentrations exceeding 10 mg/L, and at times surpassing 100 mg/L (Berndt and Bavin 2012). As presented by Berndt and Bavin (2012), lower sulphate concentrations were observed during high-flow periods when precipitation and runoff diluted dissolved components. In contrast, streams in non-mining watersheds consistently had sulphate levels below 10 mg/L, often less than 1.0 mg/L during wetter periods. From a sulphate concentrations standpoint, the St. Louis River study sites could be considered similar to the WBR and NDR. Consistency between MeHg concentrations in stream within the St. Louis River watershed, regardless of sulphate concentrations augmented by mining activities, indicates that sulphate alone may not stimulate MeHg production in riverine environments under typical conditions.

3.3 Nitrate–Sulphate Interactions and Implications for Methylmercury Production

Methylmercury production in stream sediments is primarily mediated by anaerobic microorganisms (e.g., SRB) under reducing conditions. The availability of suitable electron acceptors strongly controls which microbial pathways dominate and, consequently, the potential for mercury methylation. Predictions in the WBR and NDR indicate increasing nitrate concentrations relative to baseline conditions. Specifically, in the normal case, nitrate concentrations increase from the baseline concentration of 0.02 mg/L up to 1.6 mg/L and 2.7 mg/L downstream of FDPs in the WBR and NDR, respectively. Nitrate concentrations decrease along watercourses to 0.11 mg/L in the WBR at the confluence with the Frederick House River, and to 0.03 mg/L in the NDR at the confluence with the Abitibi River. These moderately elevated nitrate concentrations are below the CWQG-FAL of 3 mg/L, but have implications for sediment redox processes, which may limit MeHg production by suppressing sulphate reduction.

Microbial respiration in aquatic sediments follows a thermodynamic hierarchy of electron acceptors, and microorganisms preferentially utilize certain electron acceptors (Stumm 1996). Along the redox ladder, nitrate reduction is energetically favored over sulfate reduction, because, in the sequence of dominant terminal electron-accepting processes, nitrate is less preferred than oxygen, but more preferred than sulphate (Stumm 1996). As such, when nitrate is present in porewater or overlying water and can diffuse into sediments, denitrification and dissimilatory nitrate reduction processes tend to dominate, delaying/suppressing the onset of sulphate reduction. As a result, the presence of nitrate can inhibit mercury methylation even when sulphate is available (Gilmour et al. 1998; Todorova et al. 2009; Matthews et al. 2013).

Overall, if nitrate concentrations also increase and organic matter availability remains unchanged, increases in sulphate alone do not necessarily translate into increased MeHg production. Instead, nitrate can act as a biogeochemical brake on MeHg formation by maintaining conditions unfavorable for sulphate-reducing microorganisms. Given the predicted increases in nitrate relative to baseline conditions in the present system, inhibition of sulphate reduction represents a plausible mechanism limiting stimulation of methylmercury production in stream sediments.

3.4 Interpretation of Predicted Mercury Trends

Model simulations under normal conditions using mass balance models presented in Attachment SW Qual-02.1 indicate no change in total mercury concentrations in the WBR. In the NDR, a slight increase in total mercury concentrations is predicted from a baseline concentration of 2 ng/L to 4 ng/L downstream of the FDP, which then decreases to the baseline concentration of 2 ng/L in the NDR at the confluence with the Abitibi River. Despite this increase, site-specific data imply that MeHg production is process-limited and not mercury-limited, as discussed in this section.

It is important to note that MeHg production is controlled primarily by biogeochemical processes rather than total mercury availability alone. While mercury availability is a necessary condition for methylation, it is not typically the limiting factor in riverine systems where redox conditions, electron acceptor availability, and microbial activity govern methylation efficiency. This is the case in the present study because the predicted increase in total mercury concentrations in the NDR occurs in the absence of conditions for enhanced methylation. As discussed previously, persistent reducing conditions within river sediments are not anticipated, and sulphate reduction may be inhibited in the presence of nitrate. Nutrient and dissolved organic carbon conditions likewise do not indicate a shift toward elevated microbial activity capable of supporting increased methylmercury production.

The magnitude of the predicted increase in total mercury concentrations is small relative to baseline variability and remains within ranges reported for natural river systems (e.g., predicted concentrations fall close to the lower bound of mercury concentrations presented in CCME (2003) for natural surface waters, which was <1 ng/L to 20 ng/L). As such, the predicted changes are not expected to alter the dominant biogeochemical controls governing mercury transformation processes. Accordingly, incremental increases in total mercury are not expected to translate into proportional increases in methylmercury formation in the NDR due to limitations in other control factors that were discussed earlier in this memorandum.

3.5 Adaptive Management and Effluent Target Considerations

The second part of the IR requests the following:

Confirm intentions to discuss appropriate effluent targets with MECP during permitting, as necessary, to manage the potential for methylmercury production, taking into account input from Indigenous communities."

Effluent targets are a primary subject of discussion with MECP during the permitting phase. Those discussions have commenced during the Impact Statement, through comments and input received directly to IAAC from MECP on the Impact Statement as well as two virtual meetings held with MECP on the subject of effluent target development.

In Ontario effluent targets in the form of effluent limits and in some cases objectives are set through a site-specific, receiver-based process described in MECP Procedure B-1-5. The B-1-5 process was followed in the Impact Statement submission assimilative capacity study and has been revised based on MECP comments (Attachment SW Qual-02.1 Surface Water Quality - Effluent Mixing). The assimilative capacity study (ACS) proposed effluent criteria (effluent limits and objectives) for the Project discharges. Revisions to the ACS based on MECP comments have been focussed on reducing the effluent mixing zone extent which has been accomplished through discharge management. While effluent criteria discussions have commenced with MECP, they are not envisioned to conclude with the Impact Statement and will continue with MECP during the permitting phase. MECP's permitting process mandates consideration of indigenous community input.

Although scientific studies in the literature (as provided in previous sections of this memorandum) and site-specific conditions indicate that MeHg production in the receiving streams is unlikely, it is recognized that precautionary measures and collaborative decision-making are important during the permitting process. To address stakeholder concerns about environmental protection, an adaptive management framework is recommended for guiding effluent quality management throughout operations.

The adaptive management framework will involve discussion with the MECP during permitting on effluent targets for parameters such as sulphate, nutrients, and organic carbon to manage potential risk of MeHg formation. This process will incorporate inputs from Indigenous communities so that traditional knowledge and local priorities will be considered alongside scientific evidence. Adaptive management will include monitoring in receiving streams, evaluation for periodic review of monitoring data and assessing consistency with predictions, and response if monitoring identifies unexpected trends or elevated MeHg levels. This framework will aim to mitigate potential impacts with respect to MeHg production.

4 Summary and Closing

This assessment evaluated the potential for methylmercury (MeHg) production within the WBR and NDR under regulatory and normal discharge conditions associated with the study area, which may occur due to eutrophication potential and increased sulphate concentrations in receivers. The analysis considered site-specific water quality data and hydraulic conditions, assessed eutrophication, and subsequently established scientific understanding of mercury methylation processes in stream environments.

Methylmercury production is generally associated with sustained anoxic or suboxic conditions, active sulphate-reducing microbial activity, and sufficient bioavailable organic carbon within fine-grained sediments. Based on the available data and predicted conditions, these controlling factors are not expected to occur concurrently at levels necessary to support meaningful or sustained MeHg production within the water column or sediments in the study rivers.

Eutrophication potential was evaluated using predicted N and P concentrations under both the regulatory and normal discharge scenarios. The regulatory case represents extreme low-flow conditions (7Q20), which are short-lived and therefore not relevant for sustained eutrophication processes, as algal growth and organic matter accumulation require prolonged nutrient enrichment. Under the normal case, which reflects expected average conditions, P concentrations were predicted to increase only slightly, while N exhibited a moderate increase. These changes remain well below levels typically associated with a trophic state shift and are not expected to cause a substantial increase in eutrophication potential within the watercourse. In addition, high DOC concentrations in the WBR and NDR negatively influence the growth of algae due to the corresponding light attenuation effect. Consequently, it is anticipated that the likelihood of significant oxygen depletion or related ecological impacts remains minor.

Observed and predicted sulphate and nitrate concentrations, together with flow conditions indicate that geochemical conditions are more consistent with environments where sulphate reduction is limited or inhibited. In addition, the dynamic nature of the river system, including sediment transport and periodic re-oxygenation, further limits the persistence of reducing conditions required for MeHg formation. These findings are consistent with previous studies in streams receiving elevated sulphate concentrations from lands impacted by mining activities.

Consequently, MeHg production within the WBR or NDR is not anticipated to represent a significant pathway for mercury transformation in the water column and/or in river sediments under predicted conditions. This conclusion is consistent with established literature and reflects a conservative interpretation of available data for the purposes of environmental assessment and regulatory review.

This assessment is subject to the following assumptions and limitations:

- The analysis assumes that measured and predicted water quality parameters (e.g., sulphate, nitrate, organic content, etc.) are representative of long-term conditions within the study area.
- Seasonal variability in flow, temperature, and organic matter availability was considered qualitatively; other than the regulatory case where extreme low flows were considered, other short-term episodic events such as flooding with high organic loading events were not explicitly addressed.
- The assessment assumes that physical sediment disturbance and resuspension processes due to variability in flow do not create prolonged large-scale anoxic environments that enhance methylation, consistent with findings in other stream environments studied in this memorandum.

- Potential localized micro-scale zones of MeHg production may occur but are not expected to materially influence reach-scale or system-scale MeHg concentrations.
- Unforeseen alterations in land use, hydrology, or water chemistry could influence mercury cycling processes beyond the scope of the present study.

MECP has taken an active role in reviewing effluent criteria proposed in this project and will continue to do so in the permitting process subsequent to the Impact Statement. Indigenous community input consideration is mandated in the permitting phase for effluent criteria.

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