TECHNICAL MEMORANDUM

DATE 18 December 2019 **Project No.** 19127573-450-TM-Rev0

TO Michel Groleau, Agnico Eagle Mine Limited

CC Jennifer Range, David Brown, John Faithful

FROM Kristina Skeries **EMAIL** kskeries@golder.com

EFFECTS OF CRYO-CONCENTRATION ON THE DOWNSTREAM RECEIVING LAKES WATER QUALITY

1.0 INTRODUCTION

To support responses to KivIA-WL-TC#3 for the Water Licence Amendment application (Agnico Eagle 2019), Agnico Eagle retained Nuqsana Golder to update the Site and Downstream Water Balance and Water Quality model used in the Water Licence Amendment application. KivIA-WL-TC#3 request that Agnico Eagle:

> *Please update the water quality model to include cryo-concentration. This update should be provided as soon as possible but no later than 30 days prior to the public hearings to provide sufficient time for technical review*

The updates presented in this memorandum are intended to provide insight into how the formation of ice cover will affect constituent concentrations in the receiving environment.

2.0 APPLICATION OF CRYO-CONCENTRATION

The Downstream Water Quality model used in the Water Licence Amendment application (Golder 2019) was updated to include the formation of ice cover in the winter months to assess the effects on constituent concentrations during this time. With the development of ice-cover in northern lakes, the freezing of the surface waters results in the transfer of solute mass to the remaining water below the ice layer. This salt rejection to the underlying water mass, results in increasing constituent concentrations; a process called cryo-concentration (see Pieters and Lawrence 2009, 2014).

Ice formation was applied only to Mammoth Lake and Whale Tail Lake (South Basin); it is not accounted for in any management ponds on site nor was it applied to the flooded pit lake in closure and post-closure. Under ice concentrations in these water bodies will have limited influence to the receiving lakes; in operations, water is discharged, as a maximum, at the treatment limits, and in post-closure there will be no flow from the pit lakes to the receiving lakes while there is ice cover.

The model presents an updated discharge plan whereby effluent is discharged only to Mammoth Lake and water is transferred from Whale Tail Lake (South Basin) during the open-water seasons of 2022 through 2025. This updated discharge plan reduces operational risk related to the Whale Tail Dike by reducing the water head upstream to the dike.

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The following assumptions were applied for the update:

1) The total ice thickness used in the updated model was 2 m. Monitored data shows the maximum ice thickness at lakes at the Mine site is consistently between 1.5 and 1.8 m; therefore, 2 m is a conservative value. Based on the stage-storage curves of the lakes, the volume calculated from surface to a depth of 2 m was used as the ice volume.

2) The entire 2 m of ice was assumed to form on October 1 of every year. While the ice is expected to form gradually over the winter months, there are complications that prevent applying a gradual ice formation in the model. This assumption leads to conservative early winter cryo-concentration effects.

   The ice is assumed to form as pure water; therefore, all constituent mass present in the lakes at the time of ice formation will be concentrated in the remaining free volume after the ice is formed. High rates of salt exclusion have been reported in northern lakes when ice forms during the winter months. Salt exclusion ranging from 78 to 99% has been reported in the literature, with the extent of exclusion dependent on the rate of ice formation (Pieters and Lawrence 2009). There are some cases where lower rates of salt exclusion or salt retainment in the ice cover volume; this can happen during early freeze and thaw cycles or when snow accumulates on the ice to levels that result in lake water overtopping the ice from the weight of the overlying snow pushing ice into the water column.

   Salt exclusion processes have been observed for lakes in the proximity of the Whale Tail Expansion projects. In particular, Whale Tail and Mammoth lakes have shown salt elevation in under-ice conditions; for example, where under-ice and open water conditions were sampled between 2014 and 2017 (Azimuth 2018), measurements of specific conductivity in under-ice conditions were on average 38% higher than measurements collected in corresponding open water conditions.

3) The ice is assumed to melt at a constant rate over a 30-day period throughout June.

4) Effluent was modelled as being discharged to Mammoth Lake only; however, dewatering activities to Whale Tail Lake (South Basin) is maintained during 2019.

5) Water was transferred from Whale Tail Lake (South Basin) into Mammoth Lake at a volume of approximately 4 Mm^3 in 2022, and 3 Mm^3 in 2023 through 2025.

6) TSS concentrations in the effluent was modelled at the following concentrations:

   a) Effluent in operations: 7.5 mg/L

   b) Flooded pit lake in post-closure: 1 mg/L

   c) Runoff from Whale Tail WRSF to Mammoth Lake: 10 mg/L

2.1 Results

Water quality results for Mammoth Lake and Whale Tail Lake (South Basin), specifically for arsenic and phosphorus, are provided below (Figures Figure 1 through Figure 4). Results are presented for cryo-concentration applied to the NWB Water Licence Amendment (Golder 2019) water quality model (red lines) as well the updated discharge plan described in Section 2.0, bullets 4) and 5) (blue lines). The results indicate that as a result of ice formation, arsenic and phosphorus concentrations increase by a factor of two during winter conditions.

As Mammoth Lake and Whale Tail Lake (South Basin) have large surface areas relative to depth, there is a large portion of the open water volume that contributes to the formation of ice. Based on the ratio of remaining water in each lake to the lake's total volume, it can therefore be expected that ice formation will result in increases in constituent concentrations up to two times higher than predicted to occur in the summer period.

Accounting for cryo-concentration effects, total arsenic in Mammoth Lake (Figure 1) is expected to remain below the SSWQO of 0.025 mg/L throughout operations, closure, and post-closure, with peak under-ice concentrations approximating 0.025 mg/L. As Whale Tail Lake (South Basin) (Figure 2) does not receive any effluent discharge in this scenario, the water quality remains relatively close to baseline conditions and under-ice concentrations remain far below the SSWQO for operations, closure, and post-closure. In closure, concentrations start to decline immediately and baseline levels well below the SSWQO are re-established approximately 15 years into closure. The breaching of the dikes, which signifies the start of post-closure, does not cause total arsenic concentrations in Mammoth Lake to exceed the SSWQO in open water or under ice.

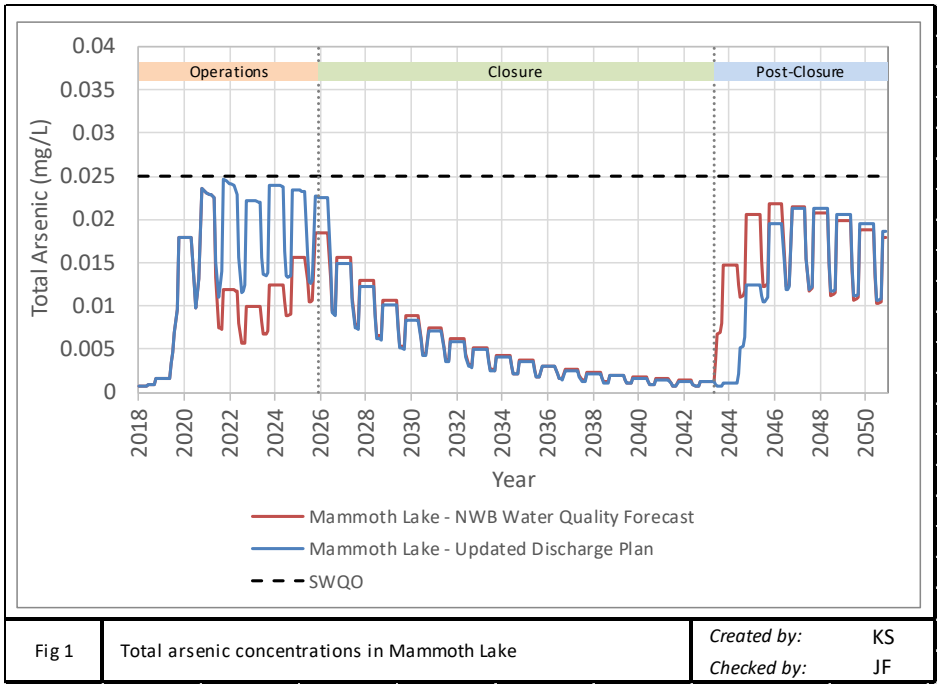

Figure 1: Total arsenic concentrations in Mammoth Lake.

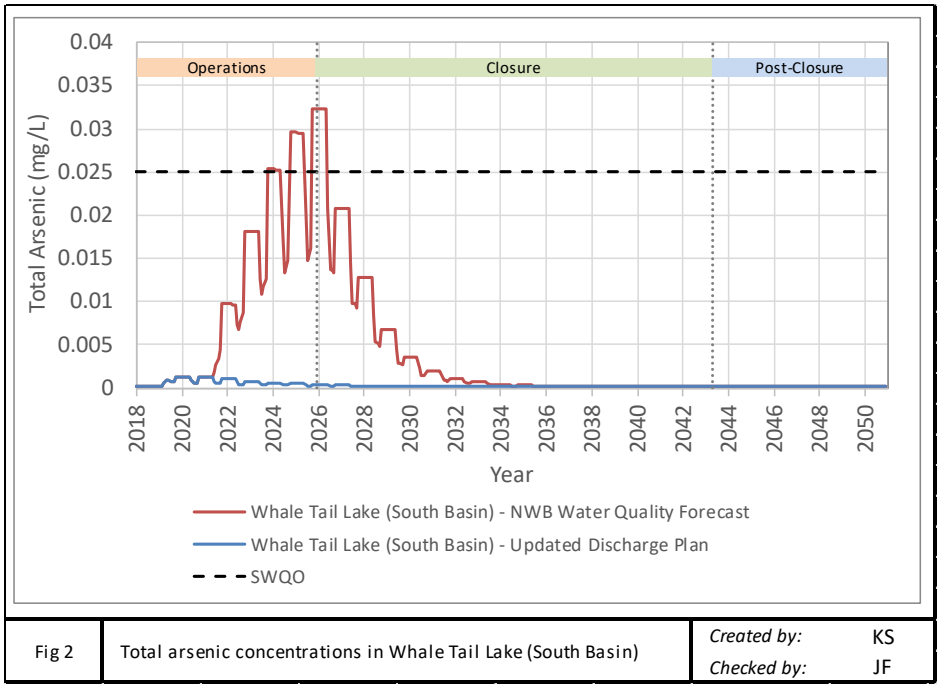

Fig 2	Total arsenic concentrations in Whale Tail Lake (South Basin)	*Created by:* KS *Checked by:* JF

Figure 2: Total arsenic concentrations in Whale Tail Lake (South Basin).

Total phosphorus (Figure 3) concentrations in Mammoth Lake show peak under-ice concentrations at approximately 0.025 mg/L in the winter of 2020; however, open water and under-ice concentrations remain in the CEQG mesotrophic range for the duration of operations. Open water concentrations recover within the first year of closure to oligotrophic conditions; under-ice concentrations recover to oligotrophic conditions within four years of closure.

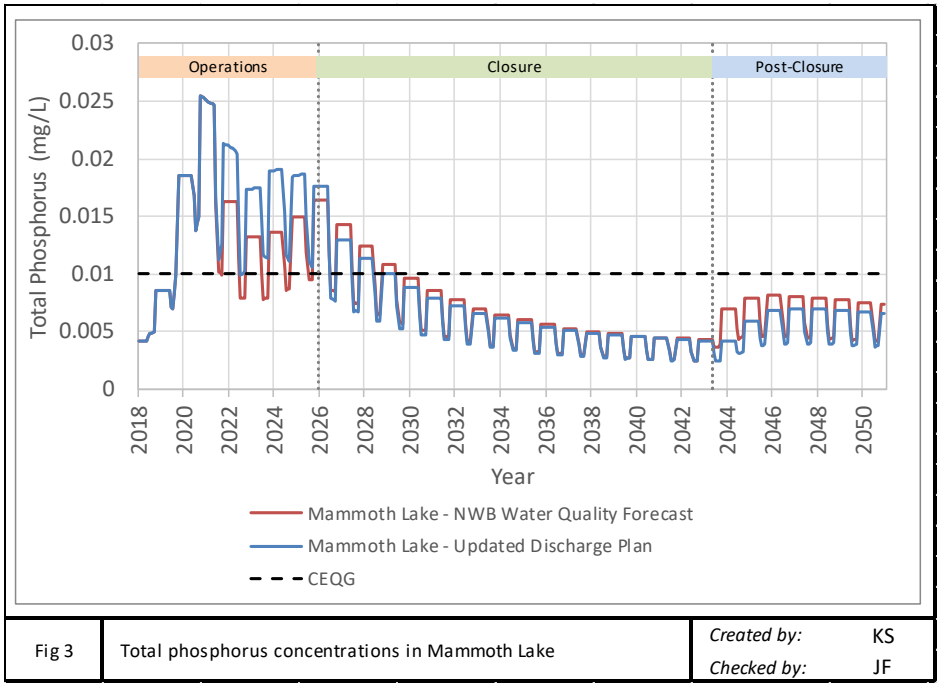

Fig 3	Total phosphorus concentrations in Mammoth Lake	*Created by:* KS *Checked by:* JF

Figure 3: Total phosphorus concentrations in Mammoth Lake.

Although Whale Tail Lake (South Basin) (Figure 4) is not receiving any effluent discharge in 2019, there is a slight increase of total phosphorus concentrations due to dewatering activities in Whale Tail Lake (North Basin). Slightly elevated total phosphorus in the dewatering discharge results in elevated under-ice concentrations above the CEQG oligotrophic-mesotrophic threshold of 0.01 mg/L during the early stage of operations, which start to reduce immediately after the 2019/2020 winter. Under ice concentrations in Whale Tail Lake (South Basin) return to oligotrophic conditions by 2023. Open water concentrations of total phosphorus in Whale Tail Lake (South Basin) remain below the threshold in all years.

Total phosphorus concentrations in Mammoth Lake following the breaching of the dikes, which signifies the start of post-closure, remain below the CEQG oligotrophic-mesotrophic threshold in post-closure.

It should be noted that the model conservatively assumes that all total phosphorus in the treated effluent discharge and from dewatering is biologically available, and that there is no biological uptake of phosphorus, nor is there any loss through settlement.

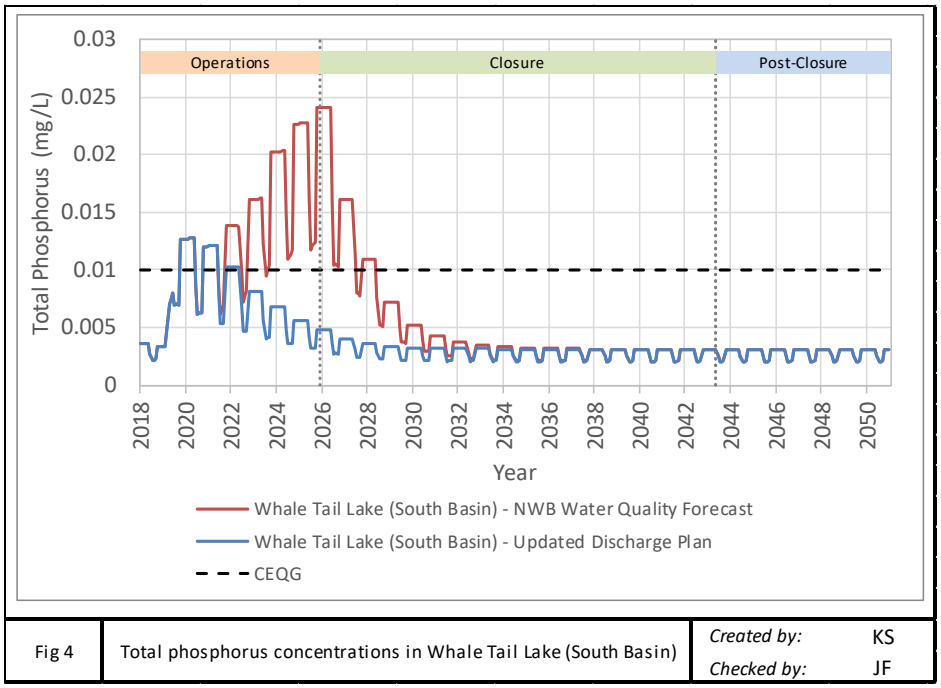

Fig 4	Total phosphorus concentrations in Whale Tail Lake (South Basin)	*Created by:*	KS
		Checked by:	JF

Figure 4: Total phosphorus concentrations in Whale Tail Lake (South Basin).

3.0 CONCLUSION

To assess the effect of cryo-concentration on constituent concentrations in the downstream receiving environment, the Downstream Water Quality model used in the Water Licence Amendment application was updated to include ice formation in Mammoth Lake and Whale Tail Lake (South Basin) during operations, closure, and post-closure.

Under the updated discharge plan, total arsenic in Mammoth Lake remains below the SSWQO under ice, and total phosphorus concentrations are elevated through operations but recover through the closure period. Whale Tail Lake (South Basin) concentrations remain near or at baseline conditions, except for under-ice phosphorus concentrations in 2019 and 2020, which are briefly elevated above the CEQG oligotrophic-mesotrophic threshold due to the dewatering activities of Whale Tail Lake (North Basin). Open water concentrations remain in the oligotrophic range throughout all of operations, and under-ice concentrations in Whale Tail Lake (South Basin) return to oligotrophic conditions in 2022.

As Mammoth Lake and Whale Tail Lake (South Basin) have large surface areas relative to depth, there is a large portion of the open water volume that contributes to the formation of ice. Based on the ratio of remaining water in each lake to the lake's total volume, it can therefore be expected that ice formation will result in brief increases in constituent concentrations during the winter months, which may be up to two times higher than predicted to occur in the corresponding open water conditions.

4.0 CLOSURE

This technical memorandum was prepared and reviewed by the undersigned.

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https://golderassociates.sharepoint.com/sites/113014/project files/5 technical work/stage-1_irs/03_model_updates/rev0/19127573-450-tm-effectsofcryocondownstreamwq-rev0.docx

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