Stantec

Memo

To: Steve Lines
Environmental Assessment and Permitting Manager, GGM
Greenstone Gold Mines GP Inc.

From: Igor Iskra, Ph.D., P.Eng.
Water Resources Engineer
Markham, ON Office

File: 160961111

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Reference: Assessment of Potential Thermal Effect of Effluent Treatment Plant Discharge on the Southwest Arm of Kenogamisis Lake

The Project includes discharge of treated effluent to the Southwest Arm of Kenogamisis Lake from the Effluent Treatment Plant (ETP). The primary source of inflow to the ETP is pond M1 water, which is made up of dewatering water from the open pit and historical underground workings and surface water from the contact water collection system.

The objective of this memo is to estimate the potential thermal effect of the ETP treated effluent on the thermal regime of the Southwest Arm of Kenogamisis Lake.

METHODOLOGY

The potential thermal effect of treated effluent discharge on the Southwest Arm of Kenogamisis Lake was estimated using a series of volumetric and energy balance equations. A schematic diagram of the thermal assessment is presented in Figure 1. The assessment is based on the following assumptions:

- surface water flows (Q_W) from the contact water collection system to pond M1 (i.e., precipitation, runoff, snowmelt, intercepted seepage) at temperature T_W;
- dewatering flows (Q_g) from the open pit/historical underground workings at temperature T_g;
- hydraulic residence time in pond M1 is a minimum of 3 days, therefore, the surface water and groundwater inputs to the pond ($Q_{M1\ in}$) are anticipated to be fully mixed and defined as follows:

$$T_{M1_{in}} = \frac{Q_w \cdot T_w + Q_g \cdot T_g}{Q_w + Q_g} \qquad \textbf{Equation 1}$$

- water in pond M1 will equilibrate with the ambient air temperature according to a Newtonian thermal diffusion coefficient for a small sheltered water body of 0.1046 kilojoules per square centimeter (kJ/cm^2) of exposed pond surface, per day, and per 1 degrees Celsius (°C) of air-water temperature difference (Williams, G.P. 1963). Outflow temperature ($T_{M1\ out}$) from pond M1 is estimated as follows:

$$T_{M1_{out}} = \frac{Q_{M1_{in}} \cdot T_{M1_{in}} + T_a H_{aM1} \cdot SA_{M1}}{Q_{M1_{in}} + H_{aM1} \cdot SA_{M1}} \qquad \textbf{Equation 2}$$

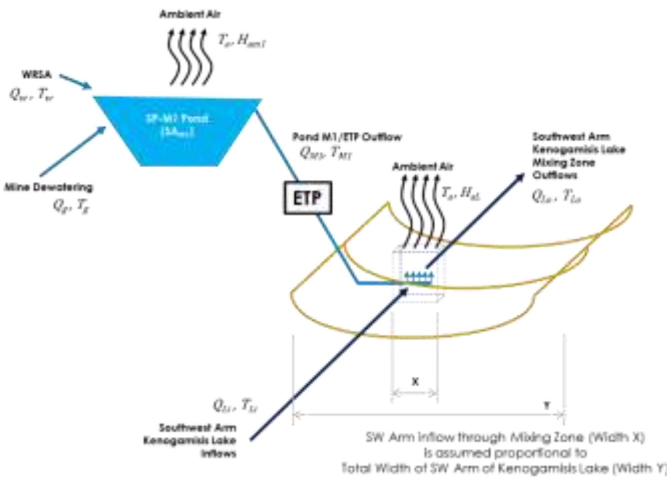
- effluent from the pond M1 is assumed to discharge without being altered by the ETP process with respect to water quantity or temperature
- treated effluent from the ETP is assumed to be discharged through a 7 metre (m) wide diffuser with 15 nozzles and mix instantaneously (as per CORMIX modelling presented in Stantec 2017b)

Reference: Assessment of Potential Thermal Effect of Effluent Treatment Plant Discharge on the Southwest Arm

within the Southwest Arm of Kenogamisis Lake. The mixing zone was assumed to be proportional to the width of the Southwest Arm of Kenogamisis Lake at the diffuser location (1,000 m). Resulting temperature of the plume is calculated as follows:

$$T_{Lo} = \frac{(0.007 \cdot Q_{Li} \cdot T_{Li}) + (Q_{M1} \cdot T_{M1})}{Q_{Li} + Q_{M1}}$$ **Equation 3**

Figure 1: Temperature Balance Assessment



Q_w = flow from contact water collection system to pond M1
T_w = water temperature in WRSA
Q_g = dewatering (groundwater) from open pit/historical underground workings
T_g = open pit dewatering (groundwater) temperature
Q_{M1} = flow from pond M1 to SW Arm
T_{M1} = water temperature in pond M1
SA_{M1} = surface area of pond M1
H_{aM1} = air-water thermal exchange coefficient
Q_{Li} = inflow to mixing zone
T_{Li} = ambient temperature in Southwest Arm
Q_{Lo} = outflow from mixing zone
T_{Lo} = water temperature in mixing zone

FLOW DATA

Pond M1 water balance for the 25-year wet scenario is discussed in the "Technical Data Report: Hardrock Project - Water Balance and Water Quality Model" (Stantec 2017c) and summarized in Table 1 (Attachment). The simulated contribution of groundwater to pond M1 ranges from between 13% and 94% of the total inflows to the pond.

The minimum monthly flows in the Southwest Arm of Kenogamisis Lake are used as a conservative basis for thermal assessment. The monthly minimum flows are discussed in the "Environmental Baseline Data Report (Combined 2014 and 2015) – Hardrock Project: Hydrology" (Stantec 2016a) and summarized in Table 2 (Attachment).

TEMPERATURE DATA

Groundwater is assumed to have a constant year-round temperature of 5°C based on the median groundwater temperature measured as part of the baseline study, as discussed in the "Environmental Baseline Data Report – Hardrock Project: Hydrogeology" (Stantec 2015) and the "Supplemental 2015 Hydrogeology Characterization Data Report – Hardrock Project" (Stantec 2016b), and presented in Table 3 (Attachment).

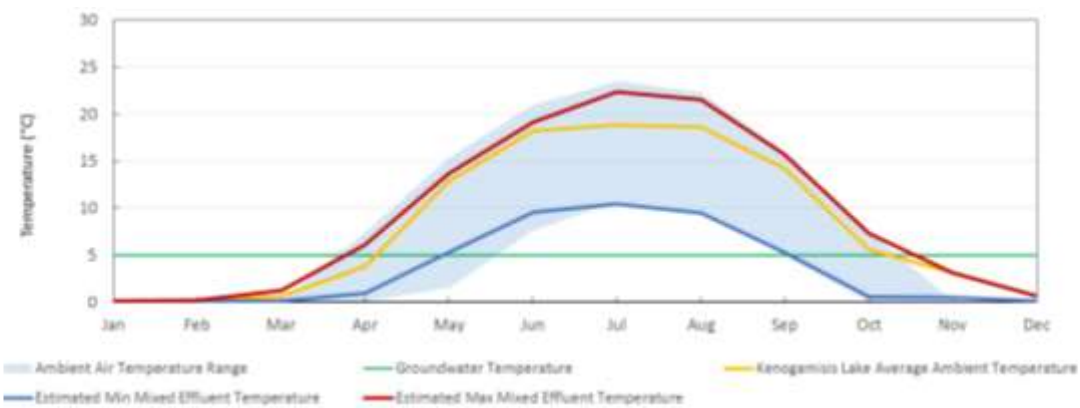
Surface water temperature within the contact water collection system is assumed to follow ambient air temperatures at temperatures above 0.1°C and remain at 0.1°C when atmospheric conditions fall below freezing. The nearest climate station to the Project is the Geraldton Airport Weather Station (Climate ID 6042716). The Geraldton airport station holds a 36 year historical record available for analysis. Climate normal values are presented in Table 4 (Attachment). The warmest month is July and the coldest month is January.

Surface water temperature in the Southwest Arm of Kenogamisis Lake was estimated based on data from water quality stations 1, 23, 24, and 46 collected from 2013-2016 (Stantec 2016a). Observed temperatures range between 16.1°C and 22.7°C in July and between -0.1 °C and 0.3°C in January. Average monthly surface water temperatures in the Southwest Arm are presented in Table 5 (Attachment).

RESULTS

A summary of thermal sources forming the extent of mixing zone is presented in Figure 2. The maximum differential between the treated effluent and lake temperature is 9.1°C and it is observed in August when average ambient lake temperature is 18.6°C and the minimum mixed effluent temperature is 9.5°C.

Figure 2: Summary of Thermal Sources Forming the Extent of Mixing Zone



A 2°C differential between the average ambient lake temperature and the treated effluent temperature was selected for assessing potential effects on the aquatic environment. This differential is well below the Provincial Water Quality Objectives of 10°C for effluent in a receiving environment. Assuming the temperature differential occurs during the more intense daylight hours of summer, from 10:00 to 16:00 (6 hours), at the maximum design treated effluent flow rate of 141 litres per second (L/s), the maximum extent of the mixing zone is approximately 37 m from the treated effluent discharge location to meet a differential of 2°C.

POTENTIAL EFFECTS

Ice Formation and Thickness

Ice formation may be delayed or inhibited during the early part of the winter and the ice may melt or thin prematurely within the mixing zone in comparison to the surrounding areas in some years as a result of discharges from the ETP during the operational life of the Project.

Reference: Assessment of Potential Thermal Effect of Effluent Treatment Plant Discharge on the Southwest Arm

Treated effluent flow rates may also inhibit ice formation due to increased water velocity and turbulence at the lake surface near the outfall. Ice formation is typically inhibited at surface velocities exceeding 0.2 m/s (Environment Canada 2011). Taking into account the maximum design discharge rate and orientation of diffuser nozzles it is concluded that ice formation may be inhibited around the treated effluent discharge location. It is recommended that the treated effluent discharge location be clearly marked as a potential thin ice hazard for users of Kenogamisis Lake during the winter season. This mitigation is common at northern mine sites.

Fish Habitat

The maximum differential between the treated effluent and lake temperature is 9.1°C and it is observed in August. The treated effluent temperature will equilibrate with ambient lake temperature (up to 2 °C differential) within approximately 37 m of the treated effluent discharge location. The area of fish habitat potentially affected by the temperature differential in the mixing zone consists of a cylinder that is 3 m deep and 74 m in diameter.

Given the natural temperature variability within the receiver and relatively small size of the mixing zone compared to the size of the Southwest Arm of Kenogamisis Lake, it is unlikely that the temperature differential could affect fish. Fish may be attracted to or avoid the thermal plume in the summer. However, given the small size of the thermal mixing zone relative to the size of the lake, and given the ubiquity of the habitat within the mixing zone, effects are not anticipated. Temperature changes within the thermal mixing zone are not anticipated to occur rapidly, due to the attenuation times in pond M1. Therefore, fish will not be subject to sudden changes in temperature. As a result, it is anticipated that the range of temperature differentials within the mixing zone will not cause an adverse effect on fish or fish habitat.

STANTEC CONSULTING LTD.

<Original signed by>

Igor Iskra, P.Eng. Ph.D. (Eng.)
Water Resources Engineer
Phone: (905) 415-6371
Fax: (905) 474-9889
Igor.Iskra@stantec.com

Attachment: Tables

References:

Environment Canada. 2011. *New Brunswick River Ice Manual.* Prepared by The New Brunswick Subcommittee on River Ice, Inland Waters Directorate, Environment Canada, August 1989 (republished in 2011), New Brunswick. The New Brunswick Subcommittee on River Ice, 2011.

Stantec Consulting Ltd. (Stantec). 2015. *Environmental Baseline Data Report – Hardrock Project: Hydrogeology*. Prepared for Premier Gold Mines Hardrock Inc., March 6, 2015.

Stantec Consulting Ltd. (Stantec). 2016a. *Environmental Baseline Data Report (Combined 2014 and 2015) – Hardrock Project: Hydrology*. Prepared for Greenstone Gold Mines GP Inc., January 2016.

Stantec Consulting Ltd. (Stantec). 2016b. Supplemental 2015 Hydrogeology Characterization Data Report – Hardrock Project. Prepared for Greenstone Gold Mines GP Inc., January 2016.

Stantec Consulting Ltd. (Stantec). 2017a. *Hardrock Project: Final Environmental Impact Statement / Environmental Assessment*. Prepared for Greenstone Gold Mines GP Inc., April 2017.

Stantec Consulting Ltd. (Stantec). 2017b. *Technical Data Report: Hardrock Project - Assimilative Capacity Study of Southwest Arm of Kenogamisis Lake*. Prepared for Greenstone Gold Mines GP Inc., April 2017.

Stantec Consulting Ltd. (Stantec). 2017c. *Technical Data Report: Hardrock Project - Water Balance and Water Quality Model*. Prepared for Greenstone Gold Mines GP Inc., April 2017.

Williams, G. P. 1963. *Heat transfer coefficients for natural water surfaces*, International Association of Scientific Hydrology, Vol 62. pp. 203-212, November 1963.

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Table 1: Monthly Water Balance of Pond M1 (m^3/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Surface Water from WRSA to Pond M1												
Max	536	845	1,069	4,915	7,666	4,793	8,688	6,899	6,786	7,859	4,030	3,157
Ave	419	686	873	4,116	6,080	3,936	6,600	5,692	5,668	6,315	3,406	2,642
Min	27	79	129	812	1,480	707	1,652	1,309	2,139	2,932	1,299	962
Groundwater from Open Pit Dewatering to Pond M1												
Max	11,560	11,251	11,027	7,181	5,834	7,303	5,784	5,760	5,849	6,064	8,066	8,939
Ave	9,754	9,206	9,124	6,075	4,399	6,197	3,985	4,737	4,804	4,352	6,804	7,481
Min	5,706	5,507	5,718	5,040	3,276	5,257	2,978	3,773	3,941	3,226	5,891	5,845
Outflow from Pond M1/ETP to Kenogamisis Lake												
Max	8,059	8,064	8,068	8,151	8,045	7,897	8,644	8,156	8,393	8,331	5,907	5,887
Ave	4,172	3,957	4,202	4,853	4,900	4,280	5,100	4,854	4,962	5,372	4,420	4,239
Min	157	251	223	1,307	569	553	1,590	1,251	2,154	3,106	1,456	1,077

Table 2: Estimated Minimum Monthly Flows in the Southwest Arm of Kenogamisis Lake (m3/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	75,686	51,926	53,482	341,280	491,616	344,736	127,872	81,648	56,160	81,562	145,152	110,592

Table 3: Observed Groundwater Temperatures (°C)

Well Completion	Minimum	Median	Mean	Maximum	Standard Deviation	Number of Wells
Overburden	3.6	5.07	5.31	9.9	1.48	26
Bedrock	2.72	4.56	4.55	6	1.07	11

Table 4: Geraldton Airport Weather Station (ID 6042716) Climate Normals (1981-2010)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Daily Ave	-18.6	-15.8	-8.9	0.6	8.5	14.3	17.2	16	10.5	3.3	-5.4	-14.2

Table 5: Average Water Temperature in Southwest Arm of Kenogamisis Lake (2013-2016)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Ave	0.1	0.2	0.7	3.8	12.9	18.2	18.9	18.6	14.2	5.6	3.2	0.7