APPENDIX 7.IV

Peanut Lake Conceptual Diffuser Design

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7.IV.1 INTRODUCTION

Fortune Minerals Limited (Fortune) is proposing to develop the NICO Project a cobalt-gold-copper-bismuth mine, located north of Yellowknife, Northwest Territories (NWT). As part of the proposed NICO Project, Fortune is planning to treat excess mine water in an Effluent Treatment Facility (ETF) during operations and discharge the treated effluent to Peanut Lake, a nearby waterbody. Treated effluent from the Sewage Treatment Plant (STP) would also be discharged in the same location during construction and operations. A submerged outfall is proposed to discharge the effluent year-round.

A conceptual diffuser analysis of a proposed treated effluent release in Peanut Lake was completed to assist with the Developer's Assessment Report (DAR) and to support initial phases of regulatory permitting of the waste water release.

This appendix summarizes diffuser modelling results for various conceptual diffuser configurations and provides conclusions and recommendations for consideration.

7.IV.2 DIFFUSER DESIGN CRITERIA

Proposed site-specific water quality objectives (SSWQOs; Appendix 7.VII) were derived for the protection of aquatic life in the receiving water environment near the NICO Project. The STP effluent is projected to meet SSWQOs at the end of pipe (Appendix 7.II) and was therefore not considered further. Estimates of treated effluent water quality at end of pipe from the ETF were provided to Fortune by Golder (2011) for 5 treatment alternatives. The predicted end of pipe concentrations for the ETF treatment alternative carried forward to the DAR (Appendix 7.I), will require a dilution factor of just less than 2 to meet SSWQOs in the receiving environment within the regulatory mixing zone. Therefore the diffuser must be designed to meet following design criteria:

- diffuser placement in a deep water area which is near to the shoreline to minimize pipeline length from the ETF;
- protect the diffuser port from ice cover; and
- meet the following regulations for treated effluent release:
  - NWT regulatory guidelines for treated effluent state that the maximum size of the regulatory mixing zone in a lake is a diameter of one-third of the width of the lake at the discharge location; and
  - the only chemical constituent in the ETF effluent predicted to be greater than proposed SSWQOs is selenium and the site-specific water quality objective for selenium is 5 micrograms per litre (µg/L), which needs to be met at the edge of the regulatory mixing zone.

Thermal changes in Peanut Lake must also comply with CCME guidelines (1999), which state that:

- thermal additions to receiving waters should be such that thermal stratification and subsequent turnover dates are not altered from those existing prior to the addition of heat from artificial origins;
- thermal additions to receiving waters should be such that the maximum weekly average temperature is not exceeded; and

- thermal additions to receiving waters should be such that the short-term exposures to maximum temperatures are not exceeded. Exposures should not be so lengthy or frequent as to adversely affect the important species.

7.IV.3 DIFFUSER MODELLING

7.IV.3.1 Methodology

The Cornell Mixing Zone Expert System model (CORMIX, developed by the U.S. EPA) was used to examine treated effluent discharge and the effects on water quality in the receiving waterbody of Peanut Lake. The dispersion and dilution of effluent discharge were simulated and predicted in the near field region (NFR) mixing zone. The NFR is defined as the region where the dispersion of the effluent plume is dominated by original discharge momentum and buoyancy force. Key parameters considered include flow and water level in the lake and diffuser configurations (diffuser pipe orientation, port diameter, and exit velocity). The data required for CORMIX modelling included:

- **Ambient data:** lake bathymetry, water level, flow rate, water temperature, water density, wind speed, etc;
- **Effluent data:** flow rate, temperature, concentration, and density at discharge; and
- **Discharge data:** outfall type and the configuration in the lake.

7.IV.3.2 Lake Bathymetry

A bathymetric survey of Peanut Lake was completed as part of an aquatic baseline study (Annex C). Peanut Lake has a maximum length of 1080 metres (m) and mean and maximum widths of 210 m and 380 m, respectively (Figure 7.IV.3-1). The primary inflow into Peanut Lake is from the east, with 2 other small inflows draining the muskeg to the east and a series of small lakes, including Nico Lake, to the north. The north and south ends of Peanut Lake were characterized with shallow sloping bathymetric profiles. One small basin with a maximum depth of 8 m was found in a small embayment along the western shoreline. The main portion of the lake has a maximum depth of approximately 11 m. The water levels in Peanut Lake were variable throughout the baseline study period due to the presence of a beaver impoundment on the lake outflow, but generally varied on the order of 0.5 m higher during spring freshet than at the end of the open water season.

A deep water area of 8.75 m depth (Figure 7.IV.3-1) is proposed for locating a diffuser pipe as it minimizes the length of the pipeline from the ETF while providing a water depth that is both protective against ice and allows mixing to occur through the water column. Mixing analysis was performed to confirm that the regulatory requirements would be met at the proposed location.

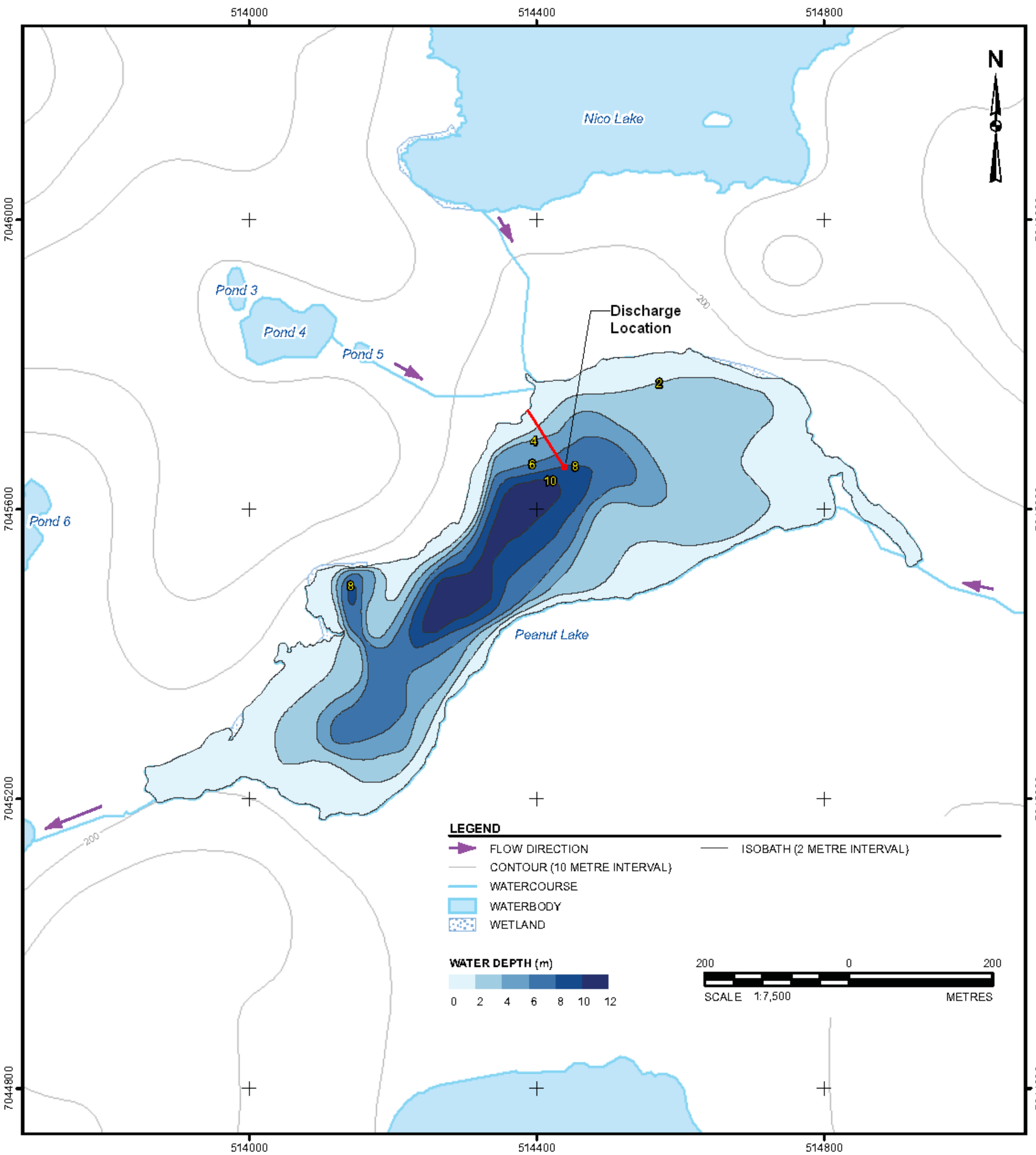


Figure 7.IV.3-1: Peanut Lake Bathymetry and Proposed Effluent Discharge Location

7.IV.3.3 Effluent Discharge

The effluent loading details from the treated effluent treatment plant to Peanut Lake are presented in Table 7.IV.3-1, defined for various design scenarios. Reductions in selenium concentrations at the end of pipe due to concurrent discharge of STP effluent with ETF effluent were not considered in the diffuser evaluation as a conservative assumption.

Table 7.IV.3-1: Effluent Discharge Conditions from NICO Project Site (at End of Pipe)

Parameter	Value			Note
Discharge Rate (m^3/s)[a]	Average Conditions, Early Operations	Average Conditions, Late Operations	Design Basis (25 Year Wet Conditions)	
	0.0044	0.0111	0.0222	
Selenium Concentration (µg/L)[b]	6.33			Maximum predicted treated effluent concentration
Effluent Temperature (°C)[c]	15			At treatment facility. Some heat loss may occur during winter
TDS Concentration (mg/L)[b]	54 to 108			Early operation and estimated maximum, respectively
Density (kg/m^3)[d]	999.170 to 999.212			Calculated from temperature and TDS

[a] Appendix 7.II.

[b] Appendix 7.I.

[c] Golder 2011.

[d] Compared to ambient density, higher effluent density results in less buoyancy and more conservative dilution factor, and thus the higher value 999.212 kg/m^3 was used for diffuser modelling to be conservative.

TDS = total dissolved solids; m^3/s = cubic metres per second; µg/L = microgram per litre; mg/L = milligram per litre; kg/m^3 = kilogram per cubic metre; °C = degress Celsius

7.IV.3.4 Ambient Conditions

Effluent dispersion was modelled under low flow and low water level conditions to provide a worst case ambient for effluent dispersion. The ambient hydraulic conditions in the vicinity of the proposed diffuser location are summarized in Table 7.IV.3-2.

The average ice thickness for lakes north of Yellowknife is normally 1.2 m, and has been recorded up to 1.5 m or more. The reduction of effective water depth for effluent dispersion was considered.

Table 7.IV.3-2: Ambient Conditions of Receiving Water (Peanut Lake)

Parameter	Value	Note
Water Depth (m)[a]	8.75	Recommended local depth. Water level could be 0.5m higher during spring freshet
Lake Width at Discharge (m)[a]	300	Lake width at point of discharge
Current Velocity (m/s)[b]	1.85×10^{-5} to 3.04×10^{-4}	Varying from low flow in September to freshet flow in June
Wind Speed (m/s)	2	assumed
Selenium Concentration (µg/L)[a]	0.4	Median observed concentration
Water Temperature (°C)[a]	1.6 to 7.0	measured temperature at 8 m depth, varying from winter to summer
Mean TDS (mg/L)[a]	57.5	in the range of 35 to 80
Density (kg/m^3)[c]	999.976 to 1000.000	calculated from temperature and TDS

[a] Annex C.

[b] Derived from baseline flows at the outlet of Peanut Lake (Annex G).

[c] Lower ambient density results in less bouyancy and more conservative dilution factor, and thus 999.976 kg/m^3 was used for diffuser modelling

m = metres; m/s = metres per second; µg/L = micrograms per litre; mg/L = milligrams per litre; kg/m^3 = kilograms per cubic metre; °C = degress Celsius; TDS = total dissolved solids

7.IV.3.5 Modelling Results

CORMIX modelling was performed to optimize the diffuser and port configuration by maximizing the dilution factor for effluent dispersion. The recommended diffuser port configuration for a single port is shown in Table 7.IV.3-3, based on a port diameter that would result in a discharge velocity of 8.0 metres per second (m/s) at the maximum discharge rate expected from the ETF (i.e., the design basis discharge rate). This corresponds to the upper end of the exit velocity recommended within the CORMIX model system (i.e., from 3.0 to 8.0 m/s). Compared to the ambient water density (Table 7.IV.3-2), the effluent density (Table 7.IV.3-1) is generally smaller and results in slightly buoyant dispersion. To optimize the dilution factor for the recommended port size, a series of modelling scenarios were completed as shown in Table 7.IV.3-4.

Table 7.IV.3-3: Diffuser Port Configuration (Single Port)

Scenarios	Early Operations	Late Operations	Design Basis (25 Year Wet)
Discharge Rate (m^3/s)	0.0044	0.0111	0.0222
Discharge Velocity (m/s)	1.60	4.00	8.00
Port Area (m^2)	0.003	0.003	0.003
Port Diameter (m)	0.059	0.059	0.059

m = metre; m^2 = square metres; m/s = metres per second; m^3/s = cubic metres per seond

Table 7.IV.3-4: Modelling Scenarios

Release Depth (m)	8.75 (Open Water) and 7.25 (Under Ice Cover)
Height of Discharge Ports above Lake Bed (m)	1.0
Port Vertical Angle (°)	30, 45, 60, 90

m = metre; °=degrees

Modelling predictions of concentration and dilution factor are presented in Table 7.IV.3-5 for effluent dispersion during the open water season, with an assumed water depth of 8.75 m. The dispersion characteristics and distance to the edge of the NFR are provided. For Scenario A (discharge rate 0.0044 cubic metres per second [m^3/s]), the extent of the near-field mixing zone is within 9 m of the port due to a low exit velocity. Under each of the 3 discharge scenarios, a port vertical angle of 30° provides the highest dilution factors and thus is the recommended port angle.

During the winter, the water surface is covered by ice which results in a reduction of effective water depth for effluent dispersion. Table 7.IV.3-6 summarizes the predictions of concentration and dilution at a water depth of 7.25 m assuming that the surface is covered by a 1.5 m thick of ice, and the modeling was conducted for a vertical port angle of 30° only. Prediction results are presented in Figure 7.IV.3-2 for Scenario A, as this is the lowest dilution scenario.

The water quality objective of selenium concentration is set at 5 µg/L, which gives an objective dilution factor of 1.27 for selenium in the effluent (at concentration of 6.33 µg/L). The dilution factors for all scenarios meet this requirement.

Table 7.IV.3-5: CORMIX Modelling Results for Discharge at 8.75 m Water Depth During Open Water Season (Port Height 1.0 m)

Parameters		Scenario A: Average Year 2				Scenario B: Average Year 18				Scenario C: Design Basis (25 Year Wet)			
Discharge Rate (m^3/s)		0.0044				0.0111				0.0222			
Port Discharge Velocity (m/s)		1.6				4				8			
Port Diameter (m)		0.059				0.059				0.059			
Port Vertical Angle (°)		30	45	60	90	30	45	60	90	30	45	60	90
Near Field Region (NFR) Conditions	Dilution Factor at NFR Edge [a] (lower and upper uncertainty limits)	59 (29, 88)	50 (25, 75)	46 (23, 69)	25 (13, 38)	49 (25, 74)	42 (21, 63)	39 (20, 59)	22 (11, 34)	47 (24, 71)	40 (20, 61)	38 (19, 57)	23 (11 to 33)
	Concentration at NFR Edge (µg/L)[b] (upper and lower uncertainty limits)	0.51 (0.62, 0.47)	0.53 (0.65, 0.48)	0.54 (0.68, 0.49)	0.65 (0.90, 0.57)	0.53 (0.66, 0.49)	0.55 (0.70, 0.50)	0.56 (0.72, 0.51)	0.68 (0.97, 0.59)	0.53 (0.67, 0.49)	0.56 (0.71, 0.50)	0.57 (0.73, 0.51)	0.69 (0.98, 0.59)
	Temperature at NFR Edge (°C)[c] (upper and lower uncertainty limits)	7.3 (7.5, 7.2)	7.3 (7.6, 7.2)	7.3 (7.7, 7.2)	7.6 (8.2, 7.4)	7.3 (7.6, 7.2)	7.4 (7.7, 7.2)	7.4 (7.8, 7.3)	7.7 (8.3, 7.4)	7.3 (7.6, 7.2)	7.4 (7.7, 7.2)	7.4 (7.8, 7.3)	7.7 (8.4, 7.5)
	NFR Location (Downstream Dist.) (m)	9.7	7.2	5.0	0.0	12.4	8.4	5.6	0.0	13.4	8.7	5.7	0.0
Location to Meet Water Quality Objective (5 µg/L)		X= 0.33m; Z= 0.44m	X= 0.27m; Z= 0.52m	X= 0.20m; Z= 0.59m	X= 0.00m; Z= 0.64m	X= 0.33m; Z= 0.44m	X= 0.27m; Z= 0.52m	X= 0.19m; Z= 0.59m	X= 0.00m; Z= 0.64m	X= 0.33m; Z= 0.44m	X= 0.27m; Z= 0.52m	X= 0.19m; Z= 0.59m	X= 0.00m; Z= 0.64m

[a] Accuracy of estimated dilution factor is at ±50%.

[b] Concentration at discharge is assumed 6.33 µg/L.

[c] Based on ambient temperature of 7.0 °C at diffuser depth.

m = metre; m/s = metres per second; m^3/s = cubic metres per second; µg/L = micrograms per litre; °C = degree Celsius

Table 7.IV.3-6: CORMIX Modelling Results for Discharge at 7.25 m Water Depth Under Ice Cover (Port Height 1.0 m)

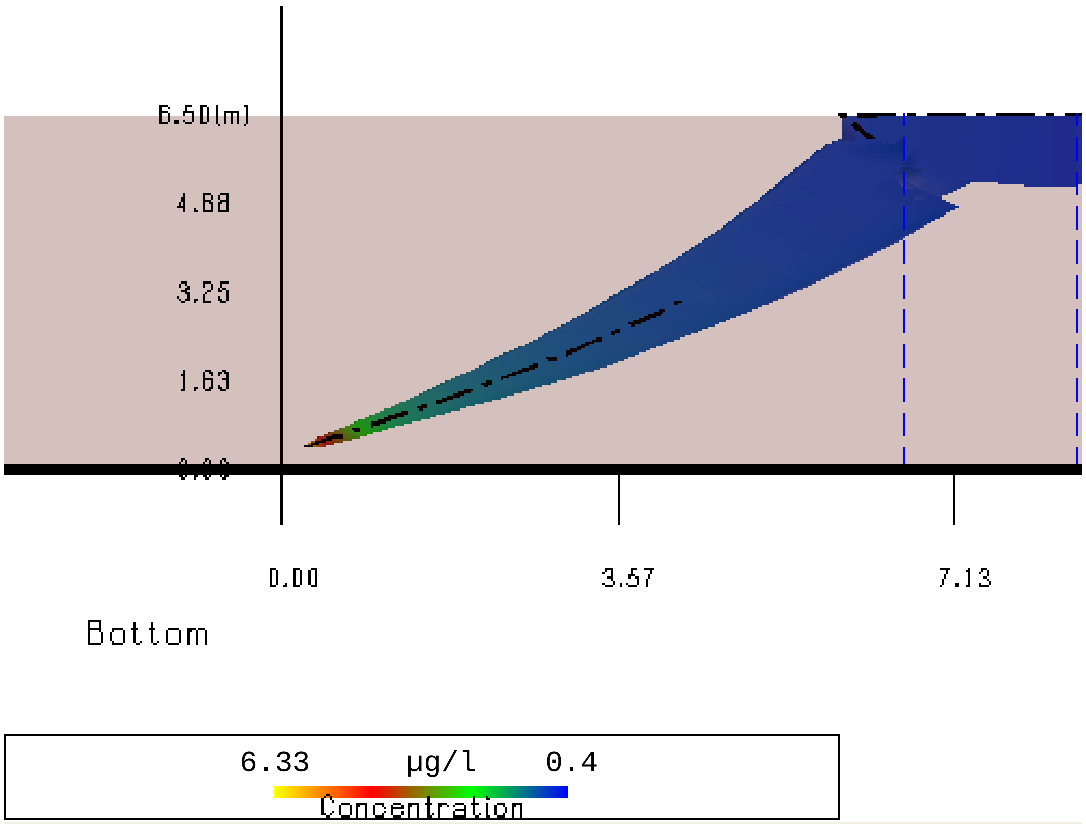
Parameters		Scenario A Average Year 2	Scenario B Average Year 18	Scenario C Design Basis (25 Year Wet)
Discharge Rate (m^3/s)		**0.0044**	**0.0111**	**0.0222**
Port Discharge Velocity (m/s)		**1.6**	**4**	**8**
Port Diameter (m)		**0.059**	**0.059**	**0.059**
Port Vertical Angle (°)		**30**	**30**	**30**
Near Field Region (NFR) Conditions	Dilution Factor at NFR Edge[a] (lower and upper uncertainty limits)	45 (22, 67)	39 (19, 58)	38 (19, 57)
	Concentration at NFR Edge (mg/L)[b] (upper and lower uncertainty limits)	0.54 (0.68, 0.49)	0.56 (0.73, 0.51)	0.57 (0.73, 0.51)
	Temperature at NFR Edge (°C)[c] (upper and lower uncertainty limits)	2.0 (2.4, 1.9)	2.1 (2.5, 2.0)	2.1 (2.5, 2.0)
	NFR Location (Downstream Dist.) (m)	8.5	10.3	13.9
Location to Meet Water Quality Objective (5 µg/L)		X= 0.33m; Z= 0.44m	X= 0.33m; Z= 0.44m	X= 0.33m; Z= 0.44m

[a] Accuracy of estimated dilution factor is at ±50%.

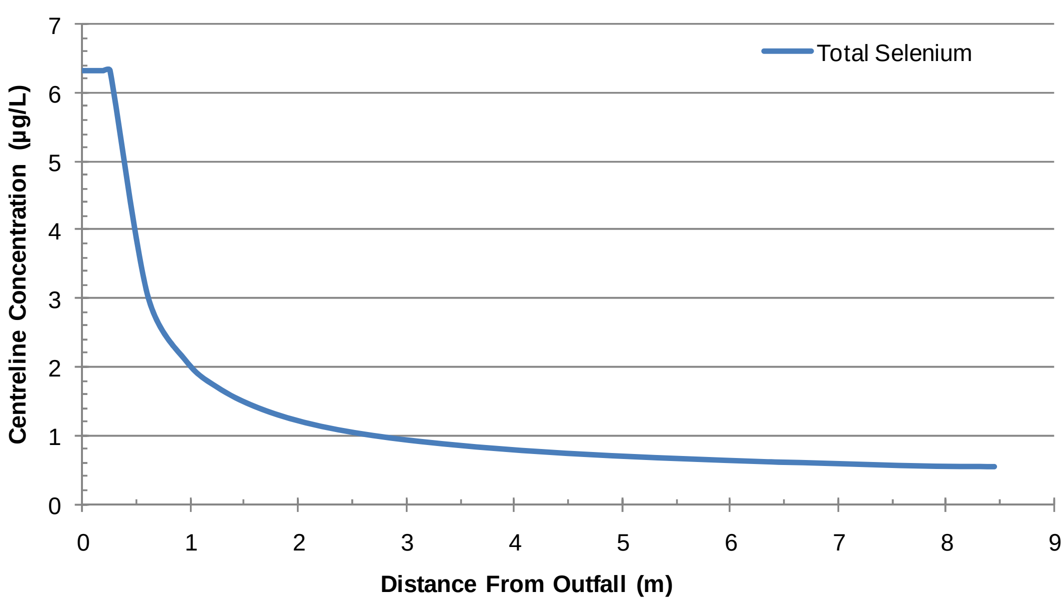
[b] Concentration at discharge is assumed 6.33 µg/L.

[c] Based on ambient temperature of 1.7 °C at diffuser depth.

m = metre; m/s = metres per second; m^3/s = cubic metres per second; µg/L = micrograms per litre; °C = degree Celsius



(a) Dispersion Plume Side View



(b) Concentration vs. Downstream Distance

Figure 7.IV.3-2: CORMIX Modelling Prediction of Effluent Dispersion Characteristics for Scenario A (Discharge Rate at 0.004 m^3/s) Under Ice Cover

7.IV.4 CONCLUSIONS AND RECOMMENDATIONS

7.IV.4.1 Conclusions

Preliminary diffuser modelling was conducted using conservative conditions. As a result, the following diffuser/port configurations are recommended:

- a single diffuser port located in Peanut Lake near the ETF at a depth of 8.75 m;
- port depth of 7.75 m (i.e., 1 m above the substrate);
- port diameter of 0.059 m, which provides a maximum exit velocity of 8.0 m/s at the ETF design discharge rate of 0.0222 m3/s; and
- port angle of 30 ° from horizontal, directed toward the lake outlet (i.e., downstream to the southwest).

Achieved effluent characteristics at the edge of the NFR are:

- Near Field Region Location: less than 14 m (downstream);
- Dilution Factor: higher than 19; and
- Temperature: increase of less than +0.8 °C

Achieved dilution factors at the boundary of the regulatory mixing zone (50 m radius from discharge) are not able to be directly predicted using CORMIX as the dilution outside the NFR is dominated by wind shear stress and other lake mixing processes. However, the high dilution achieved in the NFR gives some confidence that dilution in the lake will be acceptable. This can be confirmed through further analysis including review of site conditions, such as wind data, and flow and mass balance modelling (i.e., as being conducted for the DAR) to examine potential for accumulation of effluent discharge in the receiving environment.

The most conservative prediction of temperature changes indicates that the highest expected temperature change at the edge of the NFR is less than 0.8 °C. This is unlikely to alter thermal stratification and subsequent turnover dates, result in exceedance of maximum weekly average temperature, or alter the frequency and duration of short-term exposures to maximum temperatures.

The thermal input during the winter months may result in areas of weak ice cover that might be a concern for local stakeholders or wildlife. If this is a concern, higher diultion ratios could be achived through use of a mutiport diffuser or increasing the diffuser depth. Alternatively, recovery of heat from the treated effluent during winter months could be used to reduce the potential for this to occur.

7.IV.4.2 Recommendations

The practical aspects of the proposed diffuser should be investigated to confirm the assumed configuration including: geotechnical conditions at the lake bed (bearing capacity, loose sediments that could be entrained), and information on local ice thicknesses.

The use of batch pumping (i.e., intermittent discharge) is recommended in place of continuous low rate of discharge during early operations, such that the discharge rate results in an exit velocity of no less than 3 m/s, and preferably closer to 6 m/s, to encourage near field mixing in a larger area. Exit velocities less than 3 m/s are expected to produce sufficient near field mixing, but may be subject to higher variations in dilution effectiveness.

Due to the small size of Peanut Lake, treated effluent discharges during the ice cover season may result in changes in lake level if discharge-driven flows at the outlet freeze and accumulate to form an ice dam. Water levels in Peanut Lake could increase by up to 1.5 m over a 6 month period (at maximum design discharge rates) if outflow cannot occur. It is therefore recommended that periodic monitoring be performed during the ice cover season while the outfall is operating to determine whether the treated effluent release is creating lake level changes that could impact the shoreline, and that water management contingencies be in place to limit effluent discharge to Peanut Lake should this occur.

7.IV.5 REFERENCES

Golder Associates Ltd. (Golder). 2011. Water Treatment Options Evaluation (DOC 117-REV 3). Technical memorandum submitted to Fortune Minerals Limited. February 2011.