TECHNICAL MEMORANDUM

DATE November 24, 2011 **PROJECT No.** Doc 1297-1112210096 1124_11 TM Ver. 0

TO Stéphane Robert
Agnico-Eagle Mines Limited

CC Annie Beaulieu

FROM Paul Beddoes and Nicolas Lauzon **EMAIL** nlauzon@golder.com

DISCHARGE OF DIKE SEEPAGE WATER INTO THIRD PORTAGE LAKE AND SECOND PORTAGE LAKE – MEADOWBANK GOLD PROJECT, NUNAVUT

1.0 INTRODUCTION

Agnico-Eagle Mines Limited (AEM) retained Golder Associates Ltd. (Golder) to evaluate the proposed discharge of dike seepage water from the East Dike and Bay Goose Dike into Second Portage Lake (2PL) and Third Portage Lake (3PL), respectively, at the Meadowbank gold mine in Nunavut. Details of the local bathymetry, lake characteristics and proposed outfall locations have been provided by AEM, or obtained from previous Golder documents.

The development plan for the Meadowbank gold mine includes mining from the Portage Pit and Goose Island Pit, in the East Basin of 3PL and the Northwest Arm of 2PL (Figure 1). The East Dike in 2PL and the Bay Goose Dike in 3PL were constructed to allow mining in these areas, and seepage of lake water through these dikes is expected. AEM has proposed to discharge this seepage water back into the lakes from a discharge outfall along each dike. Figure 1-1 indicates the proposed discharge locations along each dike.

This memorandum summarizes model estimates of mixing of dike seepage water with ambient lake water, based on existing ambient lake data and current understanding of the proposed discharge locations and characteristics. Mixing was modeled using the Cornell Mixing Zone Expert System (CORMIX). The objective of the modelling effort was to determine the maximum allowable concentrations of seepage water to meet regulatory guidelines for drinking water and the protection of aquatic life in 3PL and 2PL, at the edge of a 30 m mixing zone around the discharge outfalls.

This memorandum addresses the following:

- Regulatory requirements applicable to the discharge of seepages into 3PL and 2PL (Section 2);
- Description of the mixing model CORMIX (Section 3);
- Description of ambient water characteristics at 3PL and 2PL (Section 4);
- Description of the outfall characteristics (Section 5);

- Summary of modelling results and estimation of seepage water maximum allowable concentrations (Section 6); and
- Conclusion and recommendations (Section 7).

2.0 REGULATORY REQUIREMENTS

The water quality standards for this work were determined from the following regulatory guidelines:

- Federal and territorial drinking water guidelines (RRNWT 1990); and
- Environmental guidelines for the protection of aquatic life (CCME 2007).

These guidelines were applied to previous mixing studies for the assessment of diffuser outfalls for the Meadowbank project at 3PL and Wally Lake (Golder 2006a and 2007). Table 1 summarizes the comparison of the water quality background concentrations observed in 3PL and 2PL (i.e., ambient waters) together with existing guidelines. For any given constituent with a median concentration lower than the guidelines, which is the case for all constituents at both 2PL and 3PL, the most stringent regulatory guideline applies as the water quality standard for ambient water.

The water quality standards must be met by the mixed seepage discharge at the edge of a mixing zone with a 30 m radius from the discharge outfall, at 2PL and 3PL. The extent of that mixing zone was defined and considered in previous mixing studies for the Meadowbank project (Golder 2006a, 2007 and 2010). The maximum allowable concentrations of seepage water were calculated, based on predicted mixing characteristics in 2PL and 3PL, in order to meet the water quality standards at the edge of the mixing zone.

3.0 MIXING ZONE MODEL

Near-field mixing of discharge water is influenced by buoyancy and velocity of the discharge, while the shape of the resulting plume and transportation within the lake (i.e., far field) is influenced by lake characteristics including current velocity and depth. The CORMIX model (Doneker and Jirka 2007) was used to estimate the near-field mixing of dike seepage waters from both the East Dike and Bay Goose Dike into 2PL and 3PL. This model is widely used for predicting near-field mixing for a variety of loadings (i.e., conservative substances, non-conservative substances, heated discharges, brine and sediment), in a diverse range of water bodies including northern Canadian lakes.

CORMIX assumes steady-state and generally uniform ambient conditions in receiving water bodies. The model has a specific sub-system for analysing surface discharges from channels or pipes (CORMIX3). The model determines an appropriate hydrodynamic flow pattern for each discharge based on an expert system and solved a corresponding series of simple flow patterns to obtain a complete analysis from the discharge point into the far-field. Predictions of plume geometry and mixing characteristics are based on the determination of this hydrodynamic flow pattern. The CORMIX3 sub-system assumes a cross-flowing lake current. Co-flowing lake currents can be modeled using the CORMIX1 sub-system, creating a single outfall point where discharge orientation is aligned with the ambient lake current.

Table 1: Regulatory Guidelines and Lake Water Quality at Third and Second Portage Lakes

Parameter	Name	Units	Drinking Water Guidelines (RRNWT 1990)	Aquatic Life Guidelines (CCME 2007)	Water Quality at Third Portage Lake (Bay-Goose Dike)					Water Quality at Second Portage Lake (East Dike)				
					Minimum	Median	Maximum	Number of Water Samples	Number of Non-Detectable Concentrations	Minimum	Median	Maximum	Number of Water Samples	Number of Non-Detectable Concentrations
TDS	Total dissolved solids	mg/L	500	-	<5	6.7	40	266	135	<10	16	24	59	8
Ag	Silver	mg/L	0.05	0.0001	<0.00002	<0.00002	0.12	264	261	<0.00002	<0.00002	0.27	61	58
Al	Aluminum	mg/L	-	0.1(b)	<0.005	0.009	0.57	257	51	<0.005	0.03	1.2	62	4
As	Arsenic	mg/L	0.05	0.005	<0.0001	<0.0005	0.0009	257	200	<0.0001	<0.0005	0.0005	62	60
Ba	Barium	mg/L	1	-	<0.01	<0.02	<0.02	250	200	<0.01	<0.02	<0.02	62	61
Cd	Cadmium	mg/L	0.01	0.000017(c)	<0.00001	<0.000017	0.0001	271	264	<0.000017	<0.000017	0.006	62	58
Cl	Chloride	mg/L	250	-	<0.5	<0.5	1.4	258	170	<0.5	0.57	0.83	62	20
Cr	Chromium	mg/L	0.05	0.001	<0.0001	<0.001	0.002	270	255	<0.0005	<0.001	0.004	62	60
Cu	Copper	mg/L	1	0.002(d)	<0.0002	<0.001	0.02	257	202	<0.001	<0.001	0.003	62	57
F	Fluoride	mg/L	1.7	-	0.04	0.06	0.10	246	63	0.05	0.07	0.10	57	0
Fe	Iron	mg/L	0.3	0.3	<0.01	<0.03	0.70	250	166	<0.01	0.04	1.3	62	21
Hg	Mercury	mg/L	-	0.000026	<0.00001	<0.00002	<0.00005	271	271	<0.00001	<0.00002	<0.00005	62	62
Mn	Manganese	mg/L	0.05	-	<0.0003	0.0008	0.03	250	14	<0.005	0.002	0.02	62	2
Mo	Molybdenum	mg/L	-	0.073	<0.00005	<0.001	<0.005	264	226	<0.00005	<0.001	<0.001	62	62
NH4-N	Ammonia	mg/L	-	0.68(e)	<0.005	<0.02	0.08	271	223	<0.005	<0.02	0.09	62	50
Ni	Nickel	mg/L	-	0.025(d)	<0.0002	<0.001	0.007	271	264	<0.001	<0.001	0.003	62	59
NO3-N	Nitrate	mg/L	45	2.9(c),(f)	<0.005	<0.005	0.06	264	195	<0.001	0.007	0.08	62	24
Pb	Lead	mg/L	0.05	0.001(d)	<0.00009	<0.0005	0.009	260	213	<0.00005	<0.0005	0.003	62	58
Se	Selenium	mg/L	0.01	0.001	<0.0005	<0.001	<0.005	264	264	<0.0005	<0.001	<0.001	62	62
SO4	Sulfate	mg/L	250	-	<1	1.5	2.2	243	2	<1	2.2	4.0	62	2
Tl	Thallium	mg/L	-	0.0008	<0.00005	<0.0002	<0.1	271	271	<0.00005	<0.0002	<0.1	62	62
Zn	Zinc	mg/L	5	0.03	<0.0002	<0.005	0.11	271	265	<0.001	<0.005	0.005	62	61

(a) Source of data: Cumberland (2005) and AEM (2011)
(b) Guideline based on ambient water pH.
(c) Interim guideline.
(d) Guideline based on ambient water hardness.
(e) Guideline based on ambient water pH and temperature.
(f) Guideline applied to the nitrogen fraction of nitrate (i.e., measured from water samples).

Estimates of discharge mixing and resulting concentrations by CORMIX are generally accurate to within ± 50% (Doneker and Jirka 2007). Therefore, mixing factors reported by CORMIX modelling at (or near) 30 m from the discharge point were halved, to ensure a conservative estimate of seepage water discharge mixing in 3PL and 2PL.

4.0 LAKE AMBIENT CHARACTERISTICS

Inputs required by CORMIX to define lake ambient characteristics at 3PL and 2PL include water temperature and density, current velocity, average depth, and Manning's Coefficient, which are summarized in Table 2. Details on these inputs are provided for each of the lakes in the following sections.

Table 2: Ambient Lake Characteristics as Inputs to the Model

Characteristic	Unit	Third Portage Lake (Bay-Goose Dike)	Second Portage Lake (East-Dike)[(a)]	Notes
Surface area	km^2	33.1	3.9	(b)
Lake volume	$10^6 m^3$	446.2	39.7	(b)
Average depth	m	10 (open water) and 8 (with ice cover)	5 (open water) and 3 (with ice cover)	(b),(c)
Lake velocity	m/s	0.6, 0.1, 0.05, *0.005*	0.6, 0.1, 0.05, *0.005*	(d)
Water temperature	°C	9 (open water) and *2* (with ice cover)	9 (open water) and *2* (with ice cover)	(a),(e)
Current direction relative to seepage discharge direction		Co-flowing and cross-flowing with seepage discharge	Co-flowing and cross-flowing with seepage discharge	
Manning's Coefficient		0.015	0.015	(a),(e)

(a) When unavailable for 2PL, data from 3PL were used.
(b) Values obtained from Golder (2006a).
(c) Ice cover thickness is considered to be 2m during winter conditions.
(d) Italics values denote near stagnant velocity that applies to both open water and ice cover period (other velocities apply to open water period only).
(e) Values obtained from Golder (2007).

4.1 Third Portage Lake (Bay-Goose Dike)

Third Portage Lake has an average water depth of 10 m at the proposed outfall location, based on a lake surface elevation of 134.1 masl, and existing bathymetric data for the area near the proposed discharge location (Golder, 2009). Average summer water temperature is approximately 9ºC; while winter, under ice, water temperature is approximately 2ºC (AEM 2011). Winter ice cover thickness is considered to be 2 m. The lake is sometimes thermally stratified, both in winter and summer, with a temperature difference of 1ºC at approximately 2 m depth (AEM 2011). Both stratified and un-stratified conditions were modeled.

No data on lake currents exist; however, watershed runoff inflows and wind conditions at the lake may induce a general west to east lake current (Golder, 2006b, 2008a, 2008b). Alternatively, since 3PL drains northward into 2PL, a lake current from south to north may be established in 3PL. Both potential current orientations are examined in the modelling of dike seepage discharge: south to north orientation as cross-flowing, and west to east as co-flowing. Four possible open water lake velocities were examined: near stagnant (0.005 m/s); average 4-day low wind (0.05 m/s); average daily wind (0.1 m/s); 10-year peak hourly wind (0.6 m/s) (Golder, 2010). During winter, under-ice lake velocity was assumed to be near stagnant (0.005 m/s). A typical Manning's Coefficient for lakes, a measure of the roughness of a channel, was used (0.015). These are the same lake current and Manning's Coefficient values used in the evaluation of effluent dilution from the Third Portage Lake Diffuser outfall (Golder, 2010).

The proposed discharge location in 3PL is near the southern most extent of the east-facing portion of the Bay Goose dike. The outfall is oriented east, where lake depth increases quickly and the nearest land fall is a small island located more than 600 m east of the outfall location (Figure 1).

4.2 Second Portage Lake (East-Dike)

Where data were unavailable for 2PL, conditions were assumed to be similar to those in 3PL (Table 2). The depth of 2PL at the proposed discharge location is approximately 5 m, based on a lake surface elevation of 133.1 masl. Ice cover thickness is approximately 2 m. Lake velocity, temperature, stratification and Manning's Coefficient are assumed to be similar to 3PL.

The proposed discharge location in 2PL is approximately halfway along the north-south oriented East Dike. This position directs discharge east towards an unnamed island approximately 110 m east-north-east from the discharge location (Figure 1).

5.0 OUTFALL CHARACTERISTICS

Outfall characteristics required by CORMIX include their geometry and location in the lakes. Furthermore, discharge flow rate, density, and concentration are also needed by the model. Each outfall was considered in this work as a single pipe discharging horizontally, below the lake water surface. Water releases to 3PL and 2PL were respectively estimated at 3000 and 1000 m^3/day (AEM 2011). Mixing potential in the lake of these releases was assessed for three outfall velocities (3 m/s, 6 m/s, and 9 m/s), assuming a discharge over 24 hours on a daily basis. The corresponding discharge pipe diameters for the outfalls at 3PL and 2PL, are as follows:

- Third Portage Lake: 0.12 m (3 m/s), 0.09 m (6 m/s), 0.07 m (9 m/s); and
- Second Portage Lake: 0.07 m (3 m/s), 0.05 m (6 m/s), 0.04 m (9 m/s).

The discharge pipes were also assumed to protrude from the dike by 10 m. The average depths of ambient water in Table 2 were estimated for a protrusion of the discharge pipes of 10 m from the shore.

The discharge characteristics used for CORMIX input are summarized in Table 3. Discharge was examined only from the proposed discharge locations shown in Figure 1.

Table 3: Summary of Modeled Discharge Parameters

	Units	Third Portage Lake (Bay Goose Dike)	Second Portage Lake (East Dike)	Comment
Discharge flow rate	m^3/day	3000	1000	From AEM (2011)
Discharge water temperature	°C	9 (open water) and *2* (with ice cover)	9 (open water) and *2* (with ice cover)	Discharge is assumed to be neutrally buoyant, and therefore of the same temperature as ambient water in Table 2
Discharge concentration	%	100	100	Initial concentration of seepage water
Effluent velocity	m/s	3, 6 and 9	3, 6 and 9	Range of velocities recommended by Doneker and Jirka (2007) for the promotion of mixing from an effluent discharge outfall
Horizontal angle	°	0 (co-flowing) and 90 (cross-flowing)	0 (co-flowing) and 90 (cross-flowing)	Assumed to assess the range of possible current orientations relative to the discharge direction.
Distance protruding from shore	m	10	10	Assumed. The average depths of ambient water in Table 2 were estimated for a protrusion of the discharge pipes of 10 m from the shore.
Pipe diameter	m	0.12, 0.09, 0.06	0.07, 0.05, 0.04	Calculated based on effluent velocity
Discharge depth	m	Ambient minus pipe diameter	Ambient minus pipe diameter	Assumed as a near surface discharge.

6.0 RESULTS

6.1 Mixing Potential

Since lake conditions are not known with certainty and lake characteristics change seasonally, several model cases were simulated to account for different lake velocity and current orientation scenarios, changes in lake depth due to winter ice cover, and temperature stratification within the lake. Additionally, different model cases were simulated to analyse the different discharge velocity scenarios.

A total of 96 different model cases were run for seepage discharges from both the East Dike and Bay Goose Dike. Predicted mixing factors at 30 m from all scenarios are presented in Table 4. The mixing factor represents the reduction in concentration of seepage water in the lake, 30 m from the discharge outfall, from its initial concentration at the outfall. For example, a mixing factor of 20 indicates that seepage concentration 30 m from the outfall has been reduced from its initial concentration at the outfall by a factor of 20 to 1. Observations made from the results of Table 4 are as follows:

- High discharge velocity promotes mixing of seepage water in the ambient water column, resulting in higher mixing factors as discharge velocity is higher.

- The stratification observed in the lakes is relatively weak (i.e., approximately 1°C). This stratification was predicted to have little impact on mixing. The mixing factors for modelled stratified and non-stratified scenarios were similar in almost all scenarios in both lakes.
- Co-flowing scenarios were predicted to have smaller mixing factors than those of the cross-flowing scenarios.
- Mixing factors for cross-flowing scenarios are smaller with increasing ambient velocity. A higher ambient velocity would impose a greater deflection of the discharge plume that limit mixing.

Table 4: Summary of Dilution Ratio at 30 m from discharge from all CORMIX Model Scenarios

Flow condition		**Cross-flowing**			**Co-flowing**		
Discharge velocity (m/s)		**3**	**6**	**9**	**3**	**6**	**9**
Non-stratified Second Portage lake (East Dike)							
Open water period ambient velocities (m/s)	0.005	58	93	113	20	27	32
	0.05	55	76	83	20	30	32
	0.1	43	69	90	19	32	39
	0.6	**15**[(a)]	32	38	20	**23**[(a)]	**26**[(a)]
Ice cover period ambient velocity (m/s)	0.005	49	77	94	25	35	40
Stratified Second Portage lake (East Dike)							
Open water period ambient velocities (m/s)	0.005	61	94	114	21	29	33
	0.05	56	76	81	25	36	41
	0.1	43	69	89	21	30	46
	0.6	15	32	38	5	7	8
Ice cover period ambient velocity (m/s)	0.005	49	77	94	28	35	41
Non-stratified Third Portage lake (Bay-Goose Dike)							
Open water period ambient velocities (m/s)	0.005	49	79	101	12	16	19
	0.05	41	53	82	18	18	23
	0.1	33	47	62	14	**15**[(a)]	21
	0.6	**12**[(a)]	24	31	14	16	**18**[(a)]
Ice cover period ambient velocity (m/s)	0.005	47	74	95	12	17	20
Stratified Third Portage lake (Bay-Goose Dike)							
Open water period ambient velocities (m/s)	0.005	64	82	103	12	16	19
	0.05	41	62	82	15	20	22
	0.1	33	48	62	16	20	28
	0.6	12	24	31	3	4	20
Ice cover period ambient velocity (m/s)	0.005	47	74	95	12	16	25

(a) For the estimation of seepage water maximum allowable concentrations, the most stringent mixing factors (highlighted in bold in the table) of the valid scenarios were considered for each discharge velocity, for each lake.

- Mixing factors at 3PL are lower than those at 2PL due to the higher volume of seepage expected to be discharge at 3PL than at 2PL.
- The lowest mixing factors occur at both lakes for scenarios of a stratified water column and ambient velocity generated by a 10-year peak hourly wind (0.6 m/s). These scenarios are however considered unlikely to occur, since a high ambient velocity from a high wind is likely to create mixing conditions in lakes that would negate or prevent stratification. The mixing factors for these scenarios were therefore not considered further.
- For the estimation of seepage water maximum allowable concentrations, the most stringent (i.e., lowest) mixing factors of the valid scenarios were considered for each discharge velocity, for each lake. These stringent factors are highlighted in bold in Table 4.

6.2 Seepage Water Maximum Allowable Concentration

Seepage water maximum allowable concentrations were calculated using the following equation:

$$MAC = (C_G - C_{BG}) * D + C_G \quad \text{Eq. 1}$$

Where:

- MAC is the Maximum Effluent Concentration
- C_G is the most stringent guideline concentration
- C_{BG} is the median background concentration
- D is the mixing factor at 30 m, calculated using CORMIX.

This equation is valid when median background concentration in the lakes is smaller than the most stringent guideline, which is the case for all constituent (Table 1). When the median background concentration is a non detectable concentration the following rule applied for the implementation of Equation 1:

- The median background concentration C_{BG} is equal to half the detection limit if some of the samples in Table 1 for a given constituent produced observable concentration; and
- The median background concentration C_{BG} is equal to zero if all samples in Table 1 for a given constituent were non-detectable concentrations

Table 5 summarizes the maximum allowable concentrations calculated from Equation 1, as a function of the most stringent dilution factors of Table 4, and the water quality standards and background concentration provided in Table 1. Table 5 therefore gives the maximum allowable concentrations of seepage water to meet regulatory guidelines for drinking water and the protection of aquatic life in 3PL and 2PL, at the edge of the 30 m mixing zone around the discharge outfalls. The results are separated for each lake and divided according to the seepage discharge velocities. Observations made on these results are as follows:

- Maximum allowable concentration should not be higher than the thresholds set in the Metal Mining Effluent Regulations (MMER 2002). Therefore nickel and zinc maximum allowable concentration must not be higher than 0.5 mg/L.
- While feasible according to Equation 1, the resulting maximum allowable concentrations calculated for TDS and chloride (Cl) would be considered as unusually high. It is recommended that the TDS maximum allowable concentration be limited to 1500 mg/L, which is a threshold used in other industrial developments for the assessment of aquatic health. The maximum allowable concentration for Cl should be set at 1000 mg/L, which corresponds to the maximum average concentration of effluent discharged from the Portage Attenuation Pond into Third Portage Lake, as set in the mine water license for that parameter (NWB 2008).
- Maximum allowable concentrations at 2PL are higher than those at 3PL, due to the lower volume of seepage discharged into that first waterbody.
- While maximum allowable concentrations are the highest for discharge velocity of 9 m/s, these high values remains only incremental compared to concentrations for a discharge velocity of 6 m/s. It is therefore recommended that discharge velocity not exceed 6 m/s to further minimize the potential for lake bottom erosion.

Table 5: Estimated Seepage Water Maximum Allowable Concentrations

Parameter	Unit	Most stringent guideline [(a)] (Table 1)	MMER Guidelines (MMER 2002)	Seepage Water Maximum Allowable Concentration[(b)] for Discharge at Third Portage Lake (Bay-Goose Dike) at velocity of			Seepage Water Maximum Allowable Concentration[(b)] for Discharge at Second Portage Lake (East Dike) at velocity of		
				3 m/s	6 m/s	9 m/s	3 m/s	6 m/s	9 m/s
TDS	mg/L	500[(c)]	-	6600	7900	9400	7700	11000	13000
Ag	mg/L	0.0001[(d)]	-	0.001	0.001	0.002	0.001	0.002	0.002
Al	mg/L	0.1[(d)]	-	1.2	1.5	1.7	1.1	1.6	1.8
As	mg/L	0.005[(d)]	0.5	0.06	0.08	0.09	0.08	0.11	0.13
Ba	mg/L	1[(c)]	-	13	16	19	16	24	27
Cd	mg/L	0.000017[(d)]	-	0.0001	0.0001	0.0002	0.0001	0.0002	0.0002
Cl	mg/L	250[(c)]	-	3300	4000	4700	3900	6000	6700
Cr	mg/L	0.001[(d)]	-	0.007	0.009	0.01	0.008	0.013	0.014
Cu	mg/L	0.002[(d)]	0.3	0.02	0.02	0.03	0.02	0.04	0.04
F	mg/L	1.7[(c)]	-	22	26	31	26	39	44
Fe	mg/L	0.3[(d)]	-	3.8	4.6	5.4	4.1	6.3	7.1
Hg	mg/L	0.000026[(d)]	-	0.0003	0.0004	0.0005	0.0004	0.0006	0.0007
Mn	mg/L	0.05[(c)]	-	0.66	0.79	0.94	0.77	1.2	1.3
Mo	mg/L	0.073[(d)]	-	0.96	1.2	1.4	1.2	1.8	2
NH4-N	mg/L	0.68[(d)]	-	8.9	11	13	11	16	18
Ni	mg/L	0.025[(d)]	0.5	0.33	0.39	0.47	0.39	0.59	0.66
NO3-N	mg/L	2.9[(d)]	-	39	46	55	46	69	78
Pb	mg/L	0.001[(d)]	0.2	0.01	0.01	0.01	0.01	0.02	0.02
Se	mg/L	0.001[(d)]	-	0.01	0.02	0.02	0.02	0.02	0.03
SO4	mg/L	250[(c)]	-	3300	4000	4700	3900	6000	6700
Tl	mg/L	0.0008[(d)]	-	0.01	0.01	0.02	0.01	0.02	0.02
Zn	mg/L	0.03[(d)]	0.5	0.37	0.44	0.53	0.44	0.66	0.75

(a) At the edge of a 30 m mixing zone around the discharge outfalls
(b) At the discharge outfalls
(c) Drinking water guidelines (RRNWT 1990).
(d) Aquatic life guidelines (CCME 2007).

7.0 CONCLUSIONS AND RECOMMENDATIONS

It is understood that seepages from 3PL and 2PL, through the Bay-Goose and East dikes, would be collected during mining operations. It is proposed that these seepages be returned as discharges into 3PL and 2PL. The objective of this work was to determine the seepage water maximum allowable concentrations to allow discharge into 3PL and 2PL that meet the guidelines for drinking water and the protection of aquatic life at the edge of a 30 m mixing zone around the discharge outfalls. Mixing of seepage within 3PL and 2PL were modelled under the possible ranges of ambient and seepage water characteristics. The most stringent mixing factors obtained from the modelling effort were then used for the estimation of seepage water maximum allowable concentrations.

Recommendations from this work would be as follow:

- Modelling predictions are valid for discharge rates of 1000 m^3/day at 2PL and 3000 m^3/day at 3PL, or lower when discharge velocities between 3 and 9 m/s are maintained. Higher discharge rates would require a re-assessment of mixing characteristics at 2PL and 3PL.
- Estimated maximum allowable concentrations are summarized in Table 5; however these estimate must not be higher than the MMER (2002) threshold (*e.g.,* nickel and zinc). Estimated concentrations for TDS and chloride were unusually high and should be limited to 1500 and 250 mg/L, respectively.
- It is anticipated that seepage discharges may be implemented year-round, during open water and ice cover conditions.
- The discharge locations shown in Figure 1 can be used for the release of seepages from East and Bay-Goose dikes. The discharge outfalls should not be directed directly toward an island or a bay. The direction of discharge should allow conveyance of mixed seepages toward the main body of 2PL and 3PL. From the dikes, it is expected that the discharge outfalls would be directed in a south-east direction in 2PL (East Dike) and a north-east direction in 3PL (Bay-Goose Dike).
- The discharge outfalls should be directed to minimize erosion of the lake bottom or the dike walls (i.e., horizontal with the water surface and away from the dikes). The outfall has been assessed for a near surface discharge from a pipe protruding by 10 m from the lake shoreline. The protrusion of the pipe into the lakes may be adjusted depending on field conditions; however the final locations of the outfall must provide a minimum ambient water depth shown in Table 2 (10 m at 3PL and 5 m at 2PL during the open water period).
- Discharge velocity should be between 3 and 6 m/s to promote mixing of seepage in 2PL and 3PL. The design of the discharge systems must consider anchoring of the outfall to prevent its movement as a result of these discharge velocity and ambient currents in 2PL and 3PL.
- It is anticipated that the design of the discharge system will include the sizing of pumps and discharge pipelines that minimize energy requirements from the pumps and energy loss to friction in the pipelines. The downstream end of the pipelines, which shall constitute the discharge outfall must however be sized with a diameter that produce a discharge velocity between 3 and 6 m/s. The sizing of a diameter reducer fitting must therefore be included in the design of the discharge systems.

8.0 CLOSURE

Should you have any questions or concerns regarding the information presented herein, please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED

Paul Beddoes
Environmental Scientist

ORIGINAL SIGNED AND SEALED

Nicolas Lauzon, Ph.D., P.Eng. (BC)
Associate, Water Resources Engineer

PB/NL/AB/lw/ja/aw

Attachment: Figure 1 - Discharge Proposed Location Meadowbank

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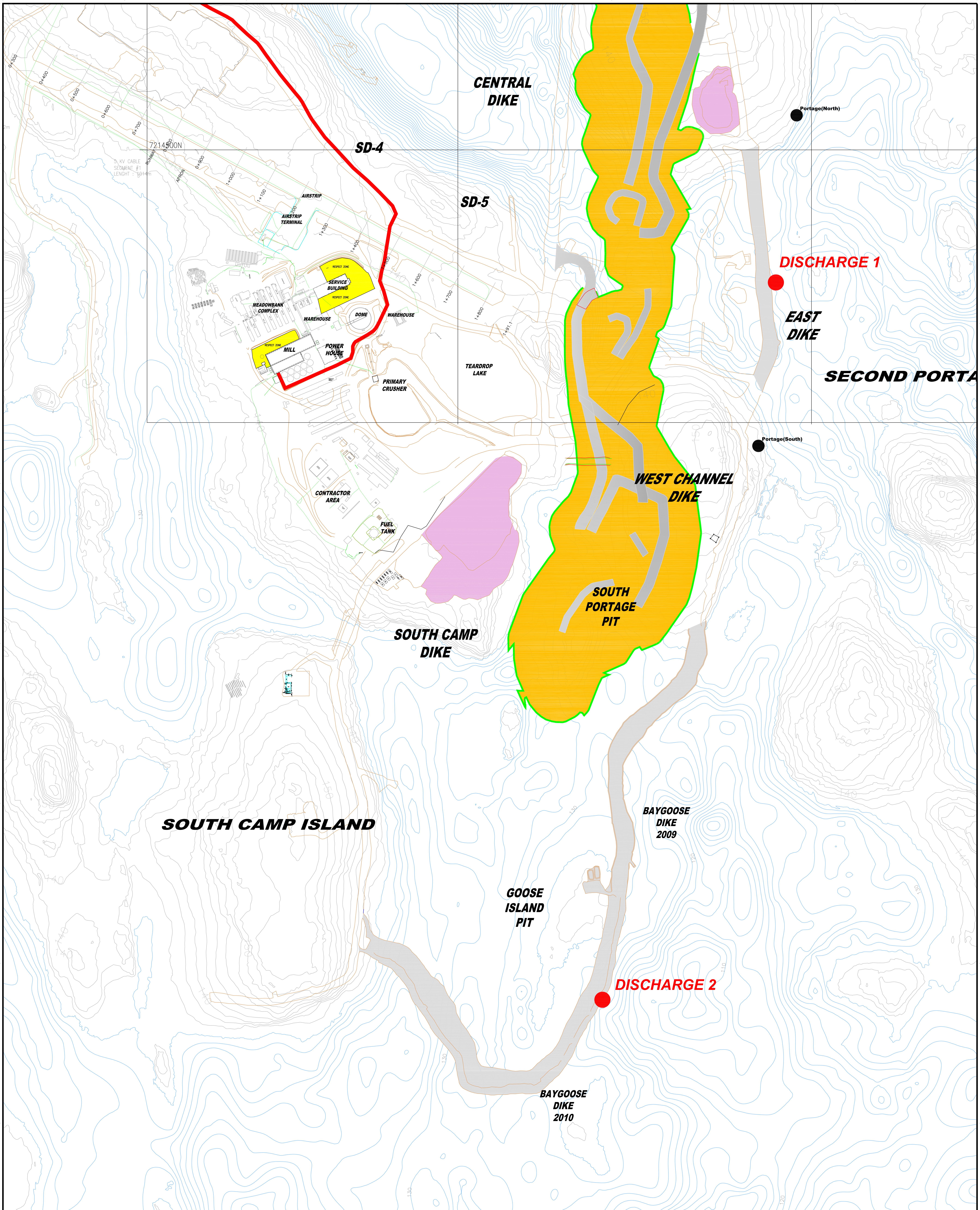

GENERAL NOTES

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PLANNING
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