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TECHNICAL MEMORANDUM

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TO	Ryan Vanengen Agnico Eagle Mines Ltd.	**DOC. No.**	1229 Ver. 0
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EFFLUENT PLUME DELINEATION FROM THE THIRD PORTAGE LAKE DEWATERING SYSTEM OUTFALL, MEADOWBANK GOLD PROJECT, NUNAVUT

1.0 INTRODUCTION

This technical memorandum summarizes results of effluent plume delineation modelling for the Third Portage Lake dewatering system outfall. These results can be used to support the determination of the exposure area for the design of the environmental effect monitoring (EEM) study at the Meadowbank Gold Project, Nunavut. The exposure area is defined as the area of the lake where the effluent plume concentration is 1% or greater of initial concentration at the outfall, reflecting a dilution ratio of no more than 100 to 1 (EC 2003). It is understood that a mine is not required to conduct a fish study if the concentration of the effluent in the exposure area is less than 1% within 250 m of the outfall (EC 2002).

The location of the dewatering system outfall in Third Portage Lake is illustrated in Figure 1. The dewatering system is currently used to discharge non-contact water (*i.e.,* water that is not affected or in contact with mine processes) from Second Portage Lake to Third Portage Lake. This dewatering activity is intended to lower the water surface of Second Portage Lake to a level to permit construction of the Central Dike and the creation of the Portage Attenuation Pond.

The CORMIX model system (Doneker and Jirka 2007) was used to provide numerical simulations of the mixing and dilution behaviour of the dewatering effluent into Third Portage Lake. CORMIX is one of the most extensively used models for predicting plume mixing and dilution of both conservative and non-conservative substances in surface waterbodies. The ambient and effluent water characteristics (*i.e.,* water temperature, density, water depth, lake current and outfall configurations) required by the model for the delineation of the exposure area (*i.e.,* region of the lake with an effluent dilution ratio equal to or lower than 100 to 1) are described in Section 2, which also presents the modelling scenarios that were evaluated. Section 3 summarizes the results of the model, while Section 4 provides the conclusion on the exposure area for the dewatering system.

2.0 AMBIENT AND EFFLUENT WATER CHARACTERISTICS

Ambient water information used in the CORMIX model to characterize the local area surrounding the location of the dewatering system outfall are summarized in Table 1.

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Table 1: Summary of Third Portage Lake Water Characteristics

Characteristic	Lake Current Scenario				Comment/Reference
	Near Stagnant	Average 4-day Low Wind	Average Daily Wind	10-year Peak Hourly Wind	
Water Depth (m)	7.5	7.5	7.5	7.5	From the available bathymetry (Figure 1).
Lake Current (m/s)	0.005	0.05	0.1	0.6	Basis of lake current scenarios.
Manning's Coefficient	0.015	0.015	0.015	0.015	Typical value for lakes.
Water Temperature (°C)	9	9	9	9	Within the range of observed temperature in Cumberland (2005) and monitoring for the mine EEM program (R. Vanengen, AEM, pers. comm., 2010).
Total Dissolved Solids (mg/L)	5	5	5	5	Median of observations in Cumberland (2005).
Total Suspended Solids (mg/L)	0.5	0.5	0.5	0.5	Median of observations from the monitoring for the mine EEM program (R. Vanengen, AEM, pers. comm., 2010).
Density (kg/m^3)	999.8	999.8	999.8	999.8	Calculated based on temperature, and total dissolved and suspended solids.

The water depth used in the model was conservatively selected as that at the location of the dewatering outfall, although the discharge is directed toward deeper portions of the Third Portage Lake. Predictions of effluent dispersion in a lake are not sensitive to the Manning's coefficient; therefore, a typical Manning's coefficient for lakes was selected. Density is a variable calculated as a function of water temperature and the concentration of total dissolved and suspended solids. Values of water temperature and total dissolved and suspended solids concentrations used for the model were determined based on available information for Third Portage Lake.

No measurements of current velocities in Third Portage Lake were available at the time of this analysis. During the open water period, lake currents are expected to be driven by wind, with little or negligible contribution from runoff to the waterbody. Near stagnant conditions are assumed for operation of the dewatering system during the ice cover period, when the wind cannot have an effect on lake currents. Therefore, four scenarios were considered in the model to represent the possible range of current velocities at Third Portage Lake, including:

- Near stagnant current, with a velocity in the order of a few millimetres per second (*i.e.,* 5 mm/s or 0.005 m/s);
- Estimated surface current based on the average 4-day low wind (6.1 km/h, from AMEC 2003 and 2005);
- Estimated surface current based on the average daily wind (17.1 km/h, from AMEC 2003 and 2005); and
- Estimated surface current based on the 10-year peak hourly wind (77 km/h, from Golder 2008).

Shear stress at the air-water interface theoretically leads to near water surface lake currents equal to approximately 3% of wind speed (Cole and Wells 2003). The resulting lake currents for the last three scenarios considered are approximately 0.05, 0.1 and 0.6 m/s, respectively. Simulations with CORMIX tested two directions of lake current, that is, in the direction and across the direction of effluent discharge (*i.e.,* co-flowing and cross-flowing, respectively).

Predictions of effluent mixing are dependent on the difference of density between ambient and effluent waters. Consequently, three scenarios of effluent buoyancy, representing a range of possible effluent water density, were tested:

- Neutrally buoyant effluent: the effluent characteristics (*i.e.,* water temperature and total dissolved and suspended solids concentrations) are similar to those of ambient lake water;
- Positively buoyant effluent: the effluent density is lower than that of the ambient lake water (Second Portage Lake is smaller than Third Portage Lake and therefore may heat more rapidly due to air temperature and solar radiation); and
- Negatively buoyant: the effluent density is higher than that of the ambient lake water (total dissolved solids rise in proportion to total suspended solids, consequently adding mass to effluent water, compared to ambient water).

Effluent water characteristics used in the model are summarized in Table 2. The effluent outfall was considered to be located 95 m into the lake from the shoreline, with the pipeline submerged to a depth of 0.5 m.

Table 2: Summary of Effluent Water Characteristics

Characteristic	Scenarios of Effluent Buoyancy			Comment/Reference
	Neutrally Buoyant	Positively Buoyant	Negatively Buoyant	
Discharge Rate (m^3/s)	0.6	0.6	0.6	Conservatively set higher than the maximum observed discharge (0.524 m^3/s) from the dewatering system in 2010 (R. Vanengen, AEM, pres. Comm., 2010).
Concentration (%)	100	100	100	Effluent concentration at the outfall.
Water Temperature (°C)	9	12	9	Basis of effluent buoyancy scenarios. Within the range of observed lake temperature in Cumberland (2005) and monitoring for the mine EEM program (R. Vanengen, AEM, pres. Comm., 2010) during the open water period. Water temperatures during the open water period were tested in the simulation, since they provide the highest density differential between ambient and effluent waters.
Total Dissolved Solids (mg/L)	5	5	580	Basis of effluent buoyancy scenarios. Consist of 1) median of observations in Cumberland (2005); and 2) calculated from the maximum observed total suspended solids in the effluent (R. Vanengen, AEM, pres. Comm., 2010) and the ratio of dissolved over suspended solids in ambient water (table 1).
Total Suspended Solids (mg/L)	9	9	58	Basis of effluent buoyancy scenarios. Median and maximum values from observed concentrations in dewatering waters (R. Vanengen, AEM, pres. Comm., 2010).
Density (kg/m^3)	999.8	999.5	1000.3	Calculated based on temperature, and total dissolved and suspended solids.

The dewatering system is expected to be in operation year long. However, water temperatures during the open water period (Tables 1 and 2) were tested in the simulation, since they provide the highest density differential between ambient and effluent waters.

3.0 EFFLUENT MIXING RESULTS

A total of 24 CORMIX simulations were preformed; that is, 4 scenarios of lake current, multiplied by 2 directions of lake current, multiplied by 3 scenarios of effluent buoyancy. For these 24 cases, Table 3 summarizes the dilution ratio achieved from effluent mixing, 250 m from the dewatering outfall, while Table 4 provides the distance from the discharge outfall at which a dilution ratio of 100 to 1 is achieved in the effluent plume.

Table 3: Dilution Ratio at 250 m from the Effluent Discharge Outfall

Lake Current		Effluent Buoyancy		
Velocity	**Direction**	**Neutral**	**Positive**	**Negative**
Near stagnant	Co-flowing	51 to 1	60 to 1	60 to 1
	Cross-flowing	115 to 1	120 to 1	120 to 1
From average 4-day low wind	Co-flowing	65 to 1	63 to 1	63 to 1
	Cross-flowing	75 to 1	96 to 1	95 to 1
From average daily wind	Co-flowing	71 to 1	52 to 1	52 to 1
	Cross-flowing	78 to 1	58 to 1	58 to 1
From 10-year peak hourly wind	Co-flowing	69 to 1	14 to 1	126 to 1
	Cross-flowing	90 to 1	21 to 1	149 to 1

Table 4: Distance from the Discharge Outfall at which an Effluent Dilution Ratio of 100 to 1 is Achieved

Lake Current		Effluent Buoyancy		
Velocity	**Direction**	**Neutral**	**Positive**	**Negative**
Near stagnant	Co-flowing	670 m	660 m	690 m
	Cross-flowing	170 m	150 m	150 m
From average 4-day low wind	Co-flowing	460 m	610 m	620 m
	Cross-flowing	450 m	300 m	300 m
From average daily wind	Co-flowing	400 m	680 m	690 m
	Cross-flowing	370 m	670 m	680 m
From 10-year peak hourly wind	Co-flowing	405 m	1150 m	185 m
	Cross-flowing	300 m	930 m	200 m

Observations from the simulations are as follows:

- For most cases, an effluent dilution of 100 to 1 is not achieved within a distance of 250 m from the dewatering discharge outfall. A fish study would therefore be required as part of an EEM for the assessment of mine effluent at the site.
- In comparison to co-flowing conditions, cross-flowing discharge and lake current is predicted to typically produce greater dilution within a distance of 250 m, and a shorter distance to achieve a dilution ratio of 100 to 1. In this case dilution would be promoted from the turbulences occurring from the merging of ambient and effluent waters, whereas dilution would only be present primarily at the interface between ambient and effluent waters in the co-flowing case.

- For the cases of near stagnant current and currents from the 4-day average low wind and average daily wind, the effect of effluent buoyancy is negligible and the initial discharge is predicted to remain attached to the surface with possible localized recirculation regions. The dilution ratio predictions may vary appreciably between neutrally, positively and negatively buoyant effluents; however the predictions for a select effluent buoyancy are within the same order of magnitude, with predicted differences likely being attributed to modelling uncertainties associated with relatively low ambient velocities.
- Neutrally and negatively buoyant effluents under 10-year peak hourly wind lake current conditions are predicted to mix rapidly with ambient water over the whole column of the lake, resulting in relatively high dilution ratio at 250 m from the discharge point and a comparatively short distance to the 100 to 1 dilution ratio.
- A positively buoyant effluent under 10-year peak hourly wind lake current conditions is predicted to be pushed to the lake surface, providing for limited dilution. Further dilution of the positively buoyant effluent would then occur from gradual erosion of the plume. A positively buoyant effluent (co-flowing and cross-flowing), with a 10-year peak hourly wind lake current is predicted to result in the lowest dilution ratio 250 m from the discharge, and the longest distance to the 100 to 1 dilution ratio, and was therefore considered for the determination of the exposure area in Third Portage Lake.
- As part of a sensitivity analysis on model results, the effluent discharge flow rate was reduced by half for both near stagnant and 10-year peak hourly wind lake currents under co-flowing positively buoyant flow conditions. The resulting predictions indicate that dilution potential is relatively insensitive to a 50% reduction in discharge flow. A reduction in lake depth to 5.5 m was also tested under near stagnant current conditions to assess the dilution potential under the ice cover during winter. The model predictions indicate that the distance to the 100 to 1 dilution ratio for a co-flowing effluent would increase from nearly 700 m (Table 4) to 900 m, but would remain shorter than that predicted for a co-flowing, positively buoyant effluent with current from the 10-year peak hourly wind (*i.e.,* the worst case used to define the exposure area on Figure 1).

Figures 2 and 3, respectively, illustrate the 100 to 1 effluent plume dilution ratio iso-contour for the co-flowing and cross-flowing, positively buoyant effluent under 10-year peak hourly wind lake current conditions. The dilution ratio of the effluent within the iso contour shown on the figures is less than 100 to 1 (the 50 to 1 dilution ratio iso-contour is provided as an example in Figures 2 and 3). As indicated on the figures, the predicted width of the effluent plume is relatively small compared to the length. However, as lake current direction can vary with time, the exposure area within Third Portage Lake is more appropriately considered to be an ellipsoid centered at the dewatering discharge outfall, with radii defined by the length of plume at the 100 to 1 dilution ratio (*i.e.,* 930 and 1150 m for cross- and co-flowing effluent, see Table 4).

It is noted that the resulting exposure area for the dewatering discharge outfall is within that determined for the planned diffuser outfall within Third Portage Lake (Golder 2010; Figure 1). This is mainly due to the dewatering outfall discharge rate being significantly less than that used in the design of the diffuser.

4.0 CONCLUSION

Several cases of effluent plume dilution from the dewatering discharge outfall were tested. These cases were intended to define the range of possible lake current conditions (*i.e.,* velocity, and either co-flowing or cross-flowing) and effluent buoyancy (neutral, positive and negative). The exposure area in Third Portage Lake was then defined based on the case with the longest model predicted distance to the 100 to 1 dilution ratio.

The exposure area applicable to the dewatering discharge outfall is within that determined for the planned diffuser outfall within Third Portage Lake. The limited exposure area of the dewatering system is mainly due to an observed discharge flow that is significantly smaller than that used for the design of the diffuser.

We trust the information contained in this memorandum meets your requirements at this time. Should you have any questions regarding the information contained here in please do not hesitate to contact the undersigned.

GOLDER ASSOCIATES LTD.

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ORIGINAL SIGNED AND SEALED

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Associate, Senior Water Resources Engineer

NL/DRW/rs

Attachments: Figures 1 to 3

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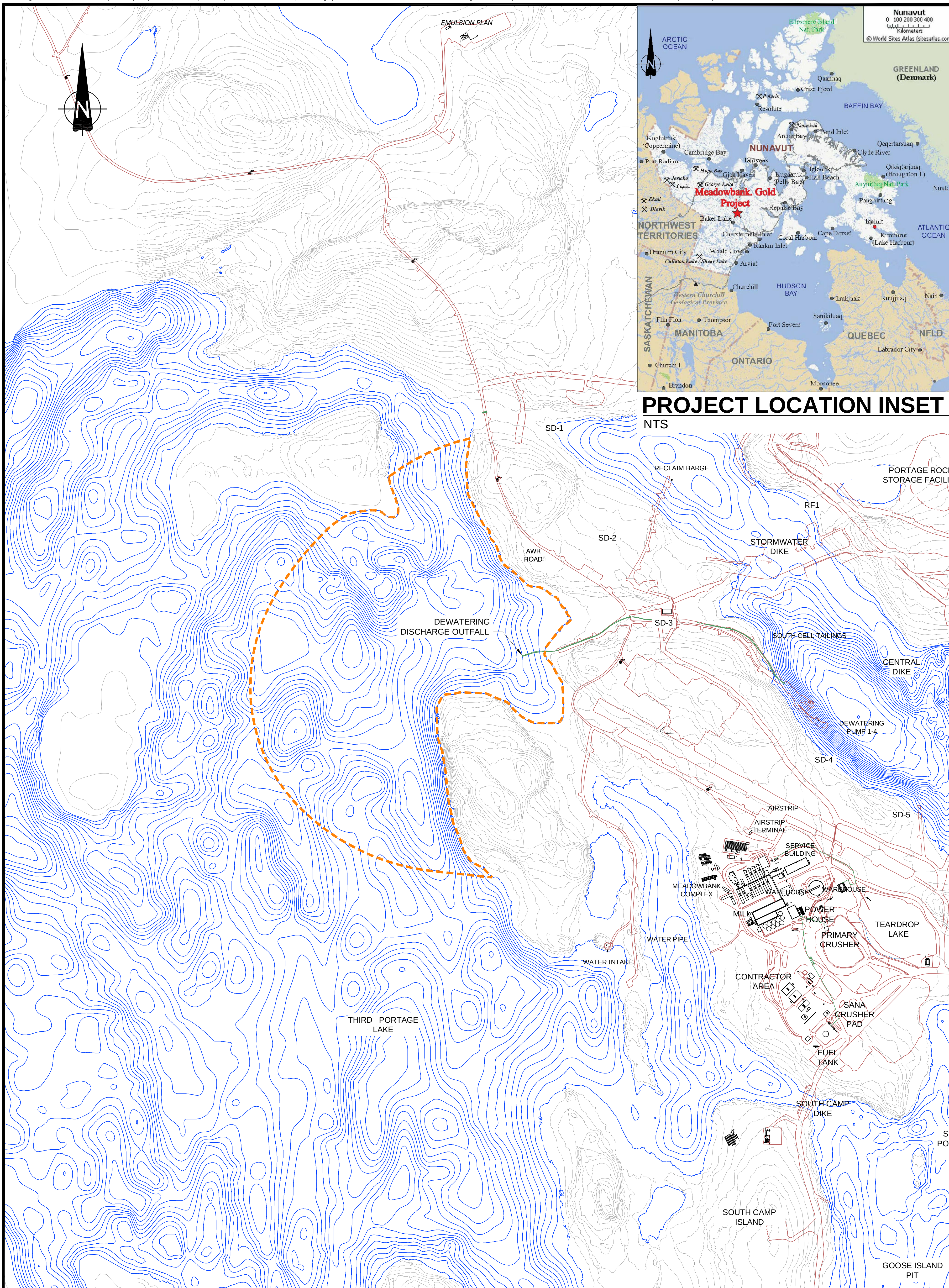

0 150 300 450 600 750

SCALE IN METRES

LEGEND

- BATHYMETRY CONTOURS (2m)
- TOPOGRAPHY CONTOURS (2m)
- ROAD
- PIPE
- EXPOSURE AREA (DILUTION RATIO OF 100 TO 1 OR LESS)

REFERENCES

1. BASE PLAN PROVIDED BY AEM
   CAD FILE: MEADOWBANK PLANNING.DWG
   DATED: 03 MARCH 2010

PROJECT

AEM

AGNICO-EAGLE MINES LIMITED
MEADOWBANK GOLD PROJECT
NUNAVUT

TITLE

DEWATERING DISCHARGE OUTFALL AND EXPOSURE AREA

Golder Associates
Greater Vancouver Office, BC

PROJECT No. 10-1428-0004			PHASE No.	2000
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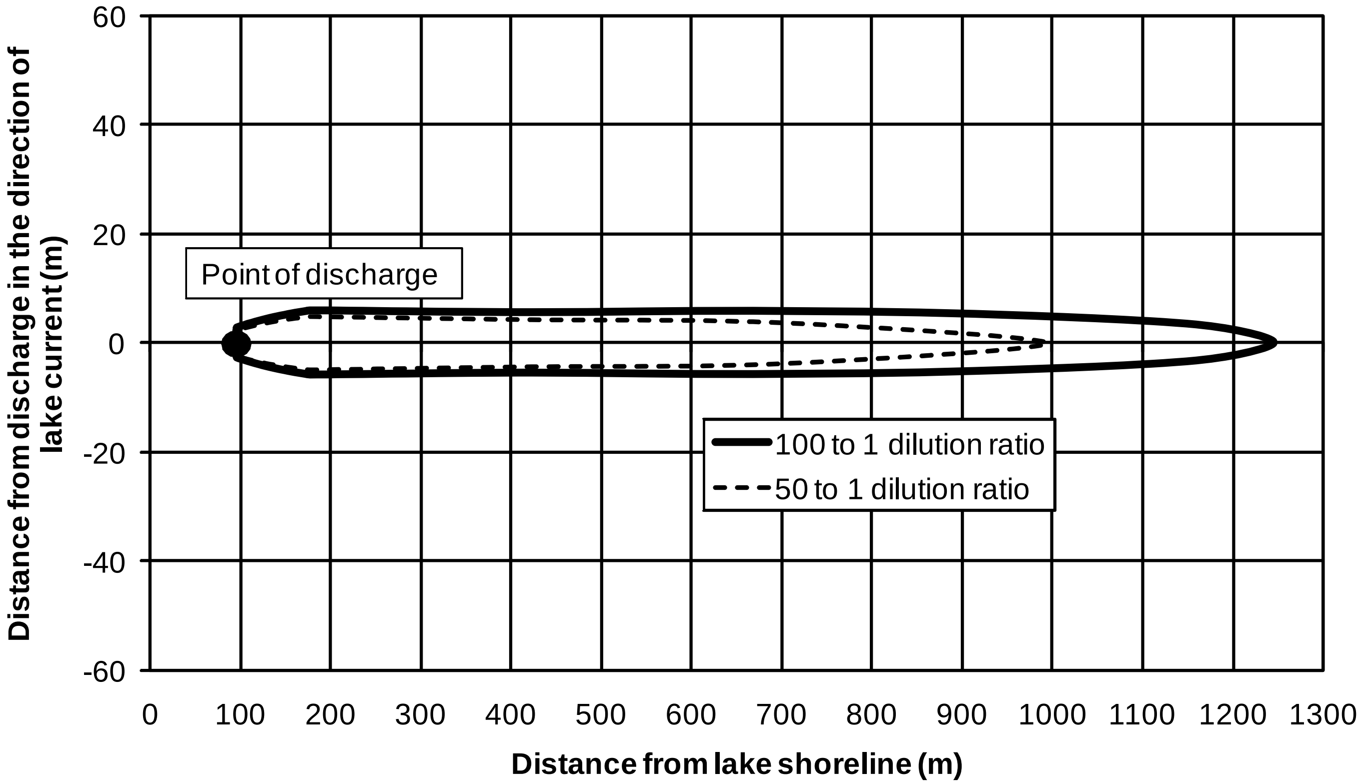
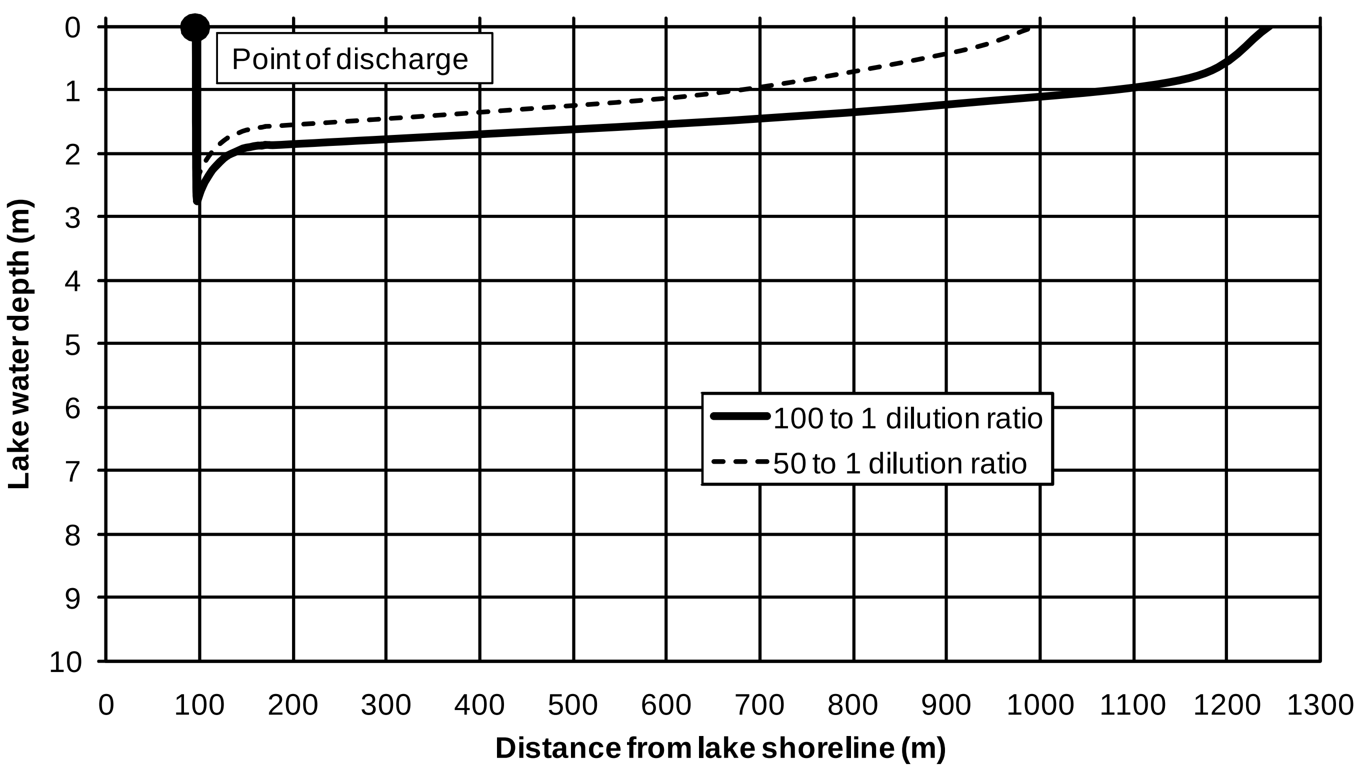
CADD	SRR	09DEC10	FIGURE 1	
CHECK				
REVIEW				





PROJECT

AEM

AGNICO-EAGLE MINES LIMITED
MEADOWBANK GOLD PROJECT
NUNAVUT

TITLE

EFFLUENT PLUME - CO-FLOWING, POSITIVELY BUOYANT PLUME UNDER A 10-YEAR PEAK HOURLY WIND INDUCED CURRENT

Golder Associates
Greater Vancouver Office, BC

PROJECT No. 10-1428-0004			PHASE No.		2000
DESIGN	NL	10DEC10	SCALE AS SHOWN	REV.	–
CADD	SRR	10DEC10			
CHECK			**FIGURE 2**		
REVIEW					

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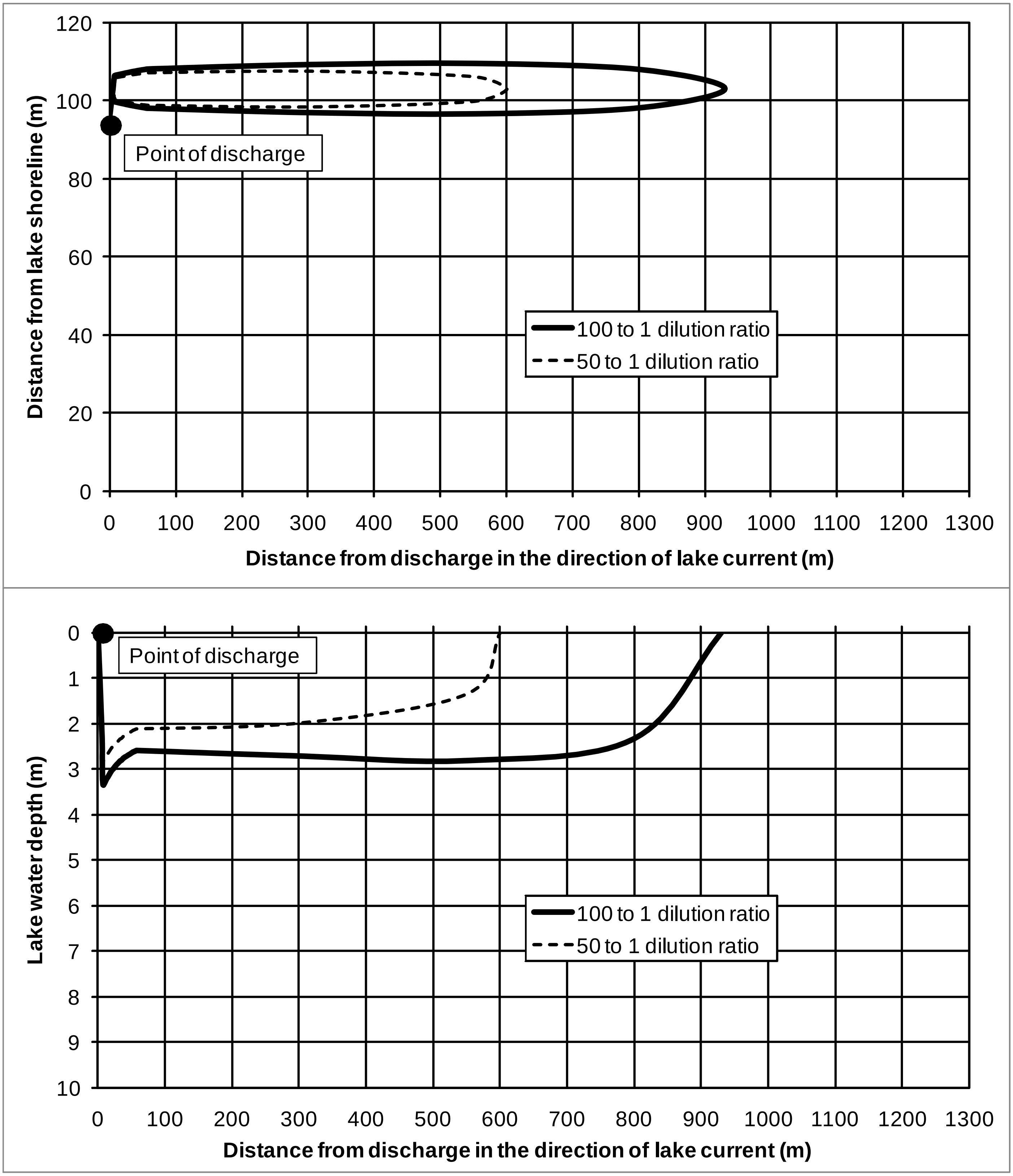

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PROJECT

AEM

AGNICO-EAGLE MINES LIMITED
MEADOWBANK GOLD PROJECT
NUNAVUT

TITLE

EFFLUENT PLUME - CROSS-FLOWING, POSITIVELY BUOYANT PLUME UNDER A 10-YEAR PEAK HOURLY WIND INDUCED CURRENT

Golder Associates
Greater Vancouver Office, BC

PROJECT No. 10-1428-0004		
DESIGN	NL	10DEC10
CADD	SRR	10DEC10
CHECK		
REVIEW		

PHASE No.	2000		
SCALE	AS SHOWN	REV.	–

FIGURE 3