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## REPORT ON

### FISH HABITAT DESIGN FOR THE PIT SHELF AREAS AT THE DIAVIK DIAMOND MINE

Submitted to:

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## **EXECUTIVE SUMMARY**

This report presents the detailed design for the creation of fish habitat on the interior of the water retention dikes (dikes) for the Diavik Diamond Mines Inc. diamond mine located on Lac de Gras in the Northwest Territories, Canada. This design was prepared in accordance with the “No Net Loss” plan prepared by Diavik Diamond Mines Inc.

This design is applicable to the A154, A418, and A21 pits; however, since only the A154 dike has been constructed, the majority of the information is based on A154. This design has been prepared by developing criteria for the end result, thus providing flexibility on the part of Diavik Diamond Mines Inc. as to how the end result is achieved.

The fish habitat creation on the interior of the dikes consists of placing material excavated from the open pits in the area between the pit crest and the toe of the dikes, to create an area generally varying from 3 m to 5 m below the mean normal water level for Lac de Gras. During mining operations, the toe of the fill will be set back from the edge of the pit crest for safety. At the completion of mining, the fill will be extended to the pit crest.

Detailed design drawings have been prepared for A154, and construction guidelines have been presented that can be applied to A418 and A21, once the dike location and pit geometry are determined.



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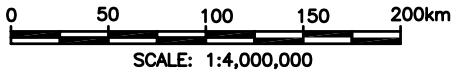
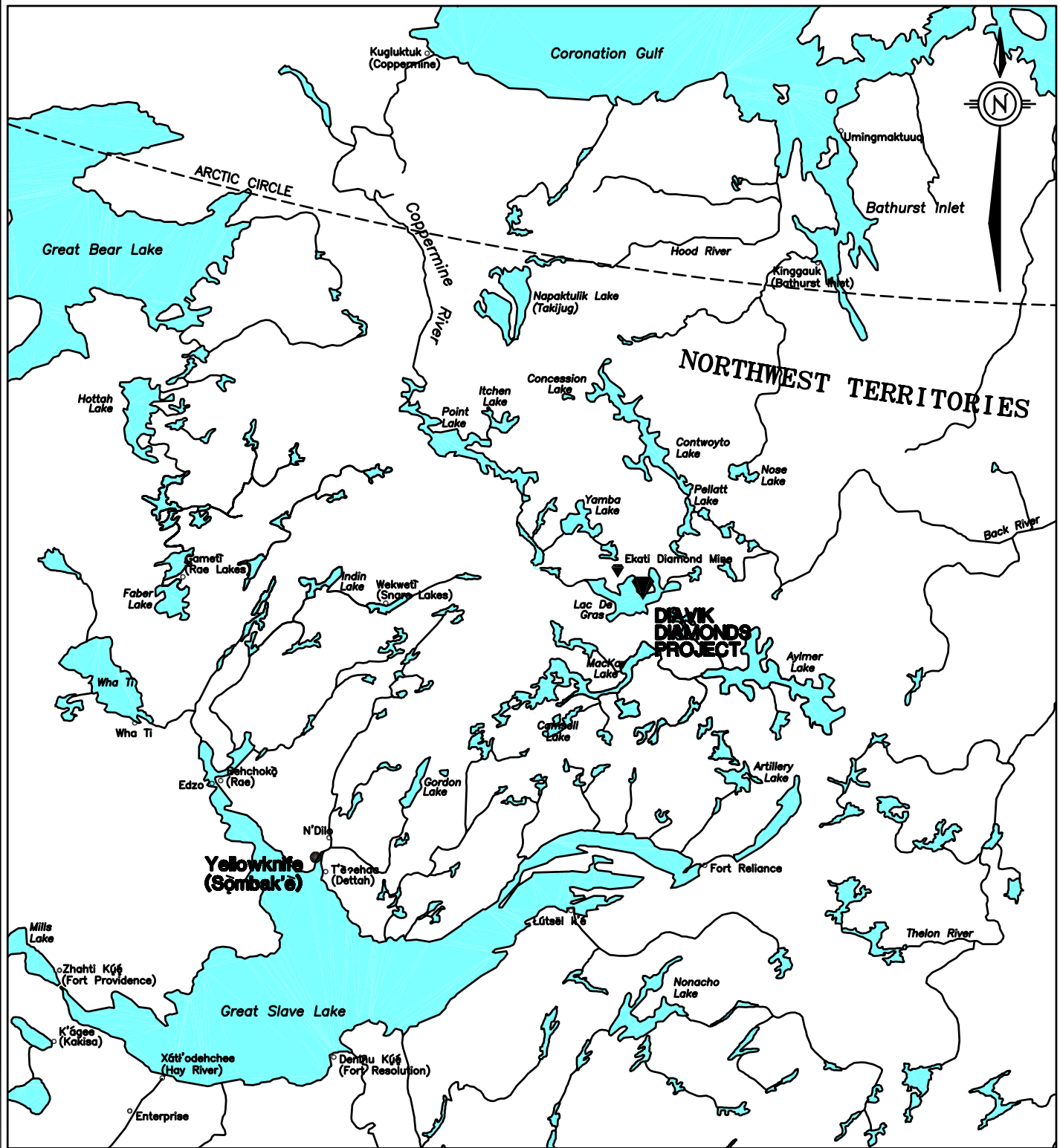
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## 1.0 INTRODUCTION

This report presents the detailed design for the fish habitat compensation plan for the interior of the water retention dikes (*i.e.*, the pit shelf) at the Diavik Diamond Mines Inc. (DDMI) diamond mine in the Northwest Territories. The location of the mine is shown in Figure 1. This detailed design is based on the “No Net Loss” (NNL) Plan (Diavik 1998), and the conceptual fish habitat plan prepared by Golder Associates Ltd. (Golder). The conceptual fish habitat compensation plan for the pit shelf is to construct habitat on the shelf, by filling in the lower elevation (deeper water) areas. The general plan is to fill in the areas on the shelf that are deeper than 5 m of water depth with materials excavated during development of the pits.

As stated, this document provides the detailed design for the fish habitat compensation for the pit shelf; however, it does not provide specifications for construction. Rather, this document provides details for achieving the desired end result, while providing flexibility in how the end result is achieved. The requirement for this flexibility is due to some of the unknowns with respect to material parameters, mine operations (*i.e.*, blasting details, availability of various materials), and construction timing. The habitat design parameters were developed considering fish habitat, surface water runoff, and geotechnical issues. Design details with respect to surface water handling, material selection, construction, and other issues would be addressed by DDMI, to achieve the desired habitat compensation prior to reflooding of the diked areas.

This design applies to the A154, A418, and A21 pits; however, only A154 has been constructed to date. A418 is scheduled for construction in approximately 2007, with A21 currently scheduled for about 2013. Since the water retention dike (dike) locations and pit layouts for A418 and A21 have not been finalized, some of the design details may be modified for these two pits. It is intended that the design details (particularly setback distances and slope angles) be reviewed prior to construction of fish habitat compensation measures for A418 and A21, to incorporate knowledge gained from the construction and performance of A154. Also, it was understood that the pits will be developed in a series of expansion cuts, thus permitting the opportunity to monitor slope stability and pore-pressures in the in-situ materials in each pit well in advance of the excavation of the final pit slopes, and construction of the fish habitat fills.



**LEGEND**

- COMMUNITY
- ◆ DIAMOND MINE/EXPLORATION

**REFERENCE**

SELECTED MINERAL DEPOSITS OF THE NORTHWEST TERRITORIES, DEPARTMENT OF ENERGY, MINES AND RESOURCES, MINERAL INITIATIVES 1991 TO 1996 REVISED OCTOBER, 1996

PROJECT DIAVIK DIAMOND MINES INC.  
FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES

TITLE  
**PROJECT LOCATION**



|         |               |          |                 |
|---------|---------------|----------|-----------------|
| PROJECT | 012-2331.5310 | FILE No. |                 |
| DESIGN  |               | SCALE    | AS SHOWN REV. 0 |
| CADD    | RML 02/17/03  |          |                 |
| CHECK   |               |          |                 |
| REVIEW  |               |          |                 |

**FIGURE: 1**

## 2.0 BACKGROUND

The objective of the fish habitat compensation measures on the interior of the water retention dikes is to provide nursery and rearing habitat similar to the pre-mine habitat in the north inlet. The conceptual design for the fish habitat compensation, as outlined in Golder's report entitled "Conceptual Design and Compensation Workplan for the Fish Habitat Compensation Program, Diavik Diamond Mines Inc., Lac de Gras", dated August 2001 consisted of:

- Re-contouring the pit shelf (area between the interior toe of the water retention dike and the crest of the pit slope) to provide habitat with a water depth of approximately 5 m after the dike is breached. New habitat will only be constructed where the water depth exceeded 5 m, the shallower areas of the shelf will not be excavated, as these areas already provide shallow water habitat. If fill is placed in this area during mine operations, setbacks will be required between the pit crest and the toe of the slope, as well as between the interior toe of the dike and the toe of the fill slope. These areas could be filled near the end of mining, or after completion of mining, if required.
- Constructing long, narrow, rocky reefs extending from the interior slope of the dike to the crest of the open pit. The reefs would be built in areas where the water depth is 5 m and would be approximately 2 m to 3 m high. Areas of granular and soft substrates between the reefs would be based on the conditions that existed in the north inlet.
- Modification of disturbed shoreline areas to establish conditions similar to pre-development. This may include placement of boulders in water depths up to about 5 m.
- Flooding the area after completion of habitat construction.
- Breaching the dikes to create shallow (minimum 2-m depth from low water) entrances, to deter the movement of larger fish into the nursery and feeding habitat, similar to the rearing habitat in the north inlet.

### **3.0 DESIGN PARAMETERS**

#### **3.1 Geotechnical Parameters**

The information that was available to carry out the design consisted of bathymetric contours, till thickness isopachs, sediment thickness isopachs, till and sediment grain size and strength parameters, and earthquake seismic parameters. Production blasts have only recently begun, and thus some assumptions were made, and will be used in conjunction with the observational method to account for the potential of blast-induced instability. The majority of the information provided was specifically for the A154 dike and pit. However, the material parameters and construction guidelines for the fish habitat compensation on the pit shelves are similar for all three proposed open pits.

The till and sediment shear strength parameters used for slope stability analyses were obtained from the final A154 dike design report prepared by Nishi-Kohn/SNC-Lavalin (NKSL). The till and sediment were also observed and sampled to check that the material appeared consistent with the shear strength parameters used for the dike design. The till was also sampled to determine if the grain size of the material sampled was similar to that presented in the dike design report.

The till was sampled at the till dumps, as the active excavation areas were inaccessible at the time of sampling. Inactive excavation areas could not be sampled, as the till was frozen. The till that was sampled at the till dumps is considered representative of the till that was being excavated on October 14 and 15, 2002. It is not considered representative of the till throughout the A154 pit shelf area, as this is a very large area and the till is likely to vary across the shelf, as reflected in the range of grain sizes presented in the dike design report. The results of the grain size analyses are shown in Table 1. The grain size of the till that was sampled generally fall within the range of samples reported in the design report, but on average the samples obtained on October 14 and 15 contain more silt and less sand than the typical samples from the design report. The grain size information from the design report and the October 2002 samples are compared in Table 2.

**Table 1**  
**Grain Size Analysis Results**

| Location     | Moisture Content (%) | Gravel Content (%) | Sand Content (%) | Silt/Clay Content (%) | Clay Content (%) |
|--------------|----------------------|--------------------|------------------|-----------------------|------------------|
| South Dump   | 6.2                  | 52                 | 23               | 25                    | nm               |
| South Dump   | 9.5                  | 23                 | 34               | 43                    | nm               |
| Upper Quarry | 11.0                 | 18                 | 39               | 43                    | 5                |
| Upper Quarry | 19.2                 | 27                 | 37               | 36                    | 4                |
| Batch Plant  | 7.6                  | 33                 | 35               | 32                    | nm               |
| Batch Plant  | 31.2                 | 7                  | 46               | 47                    | nm               |
| Average      | 14.1                 | 26.7               | 35.7             | 37.7                  | NA               |

Notes: nm = not measured.

NA = not applicable, insufficient values measured.

**Table 2**  
**Summary of Grain Size Analyses**

| Material                              | Gravel Content (%) | Sand Content (%) | Silt/Clay Content (%) | Clay Content (%) |
|---------------------------------------|--------------------|------------------|-----------------------|------------------|
| From Dike Design Report               |                    |                  |                       |                  |
| Till (range)                          | 0 to 45            | 40 to 90         | 3 to 50               | 0 to 6           |
| Till (average)                        | 26                 | 51               | 23                    | NA               |
| Sediments (range)                     | 0 to 15            | 0 to 75          | 10 to 100             | 0 to 33          |
| Sediments (average)                   | 2                  | 29               | 63                    | 6                |
| From samples obtained in October 2002 |                    |                  |                       |                  |
| Till (range)                          | 7 to 52            | 23 to 46         | 25 to 47              | 4 to 5           |
| Till (average)                        | 27                 | 36               | 38                    | NA               |

Note: values from dike design report are approximate.

NA = not applicable, insufficient values measured.

The shear strength results reported in the design report are listed in Table 3. The samples were tested in a disturbed state and thus are considered appropriate for the placed material and are conservative for the in-situ material. The design parameters are considered reasonable for the till and sediments, considering the variability of the grain size of these materials.

**Table 3**  
**Shear Strength Parameters (from Final Dike Design Report)**

| <b>Material</b> | <b>Measured Friction Angle (°)</b> | <b>Measured Cohesion (kPa)</b> | <b>Design Friction Angle (°)</b> | <b>Design Cohesion (kPa)</b>      |
|-----------------|------------------------------------|--------------------------------|----------------------------------|-----------------------------------|
| Sediments       | 32 to 38.7<br>(average = 34)       | 0                              | 26                               | 0 to 10<br>(0 used in this study) |
| Till            | 36 to 41.5<br>(average = 39)       | 0                              | 35                               | 0                                 |

Note: Strength parameters are based on effective stresses.  
kPa = kilopascal.

The bathymetric measurements carried out by DDMI prior to dewatering A154 indicate that the maximum water depth was 22 m. The deepest water around the pit crest appears to be approximately 17 m, and the deepest water near the toe of the dike is also approximately 17 m. Consequently, the highest expected long-term face of placed fill for A154 is expected to be 12 m to 14 m, depending on surface water drainage requirements.

Based on available information from exploration boreholes, the lakebed sediments range from 0 m to 7 m thick and are typically less than 2 m thick, except for a few localized pockets. The in-situ till, beneath the sediment, ranges up to 13 m thick and is typically 5-m to 10-m thick. The till is significantly thicker above the pit than on the pit shelf area. The till thickness information is relatively scant on the east side of the A154 pit and thus the till thicknesses could vary from the interpreted values.

### **3.2 Fish Habitat Parameters**

#### **3.2.1 Overview of No Net Loss Requirements related to Insides of Dike Areas**

The Fisheries Authorization identified the requirements for achieving NNL of habitat for all aspects of the DDMI Diamond Project. Specific requirements for the inside of all three dike areas included:

- the development of shallow rearing habitat and shoreline habitat; and,
- ensuring that the habitat features within the dikes areas are modeled after those features found in other productive areas of Lac de Gras, including depth, substrate type, size, and configuration.

Four key zones of habitat were identified in the NNL Plan (Diavik 1998) for the area found inside the constructed dikes during the post closure phase. These included:

1. Inside edge of the dike. The area of water depths from 0 m to 2 m along constructed sections of the dike representing new shoreline habitat.



2. Reclaimed shorelines. Areas of pre-existing shorelines.
3. The pit shelf. The area between the inside edge of the dike, the shorelines, and the pit crest.
4. Deep water. The pit itself as it will have a depth of approximately 250 m.

The NNL Plan provided habitat unit calculations based on the available design information for the dikes and pits at the time. Some modifications to the design dike and pit dimensions were made subsequent to the submission of the NNL plan, and as-built information is now available for the A154 dike. The habitat units calculated as part of the NNL Plan Addendum (DDMI April 1999), along with re-calculated values based on this updated information are presented in Appendix I.

The following sections outline the general principles and criteria to be used in developing the final layout for all three dike areas. As discussed in the NNL, the primary focus for habitat creation inside of all dikes is based on maximizing rearing habitat value. Target species include lake trout (*Salvelinus namaycush*), arctic grayling (*Thymallus arcticus*), burbot (*Lota Lota*), longnose sucker (*Catostomus catostomus*), round whitefish (*Prosopium cylindraceum*), cisco (*Coregonus artedi*), lake whitefish (*Coregonus clupeaformis*), and slimy sculpin (*Cottus cognatus*).

### **3.2.2 Overall Criteria**

Several overall governing criteria can be applied to the habitat creation activities inside the dikes. First of all, areas inside the dike on the pit shelf that are already at a depth of 4 m or less should not be disturbed if possible. This will allow the maintenance of habitat features not easily re-created. In areas where final depth is between 4 m and 5 m, it would be desirable to maintain existing habitat depending upon grading requirements for drainage, or other construction considerations. Existing shoreline features should also be maintained to the extent feasible. Construction crews should avoid driving on, dumping on, scraping, or otherwise impacting these areas. Leaving these areas intact will decrease the amount of work required to restore the shoreline at closure and will speed the recovery process of the altered areas inside the dike as a variety of organic properties, including the possibility that dormant life stages of some plants or animals will be present in the substrate.

The storage and handling of materials, particularly hydrocarbons or other types of contaminants, should be closely monitored on the shorelines, pit shelf, and inside edges of the dike. Heavy equipment in the area should be maintained and fuelled in a manner that avoids the possibility of spills occurring in areas to be reclaimed as fish habitat.

### 3.2.3 Inside Edges of Dike

The inside edge of the dike is intended to provide new shoreline features for foraging and rearing habitat for most species as well as other values, including spawning, for slimy sculpin. The dike itself will resemble existing shoreline and reef habitat and is expected to provide a rocky (boulder/cobble), moderate slope area with low to moderate wind and wave action. The NNL plan habitat evaluation completed for the inside edge the dikes treated this area as shoreline habitat.

Suitable materials for this habitat feature are a mix of primarily large boulder with some smaller cobble. Slopes should also ensure a stable profile and range from gentle to moderate. The range of slopes for existing shorelines should be used as a guideline. The area of habitat predicted in the NNL plan for this habitat type, for all three dikes is provided in Table 4. For A154, based on constructed dike configuration and the design criteria presented in this report, 3.41 ha of new shoreline habitat are expected to be created.

**Table 4**  
**Inside Edge of the Dike Shoreline Habitat Areas**

| Dike | No Net Loss Predicted Area (ha) | Current Predicted Area <sup>1</sup> (ha) |
|------|---------------------------------|--|
| A154 | 1.37                            | 3.41                                     |
| A418 | 0.48                            | n/a                                      |
| A21  | 1.07                            | n/a                                      |

<sup>1</sup> Note: Based on final constructed configuration of dikes, where available.  
ha = hectare.

### 3.2.4 Reclaimed Shorelines

The objectives for the pre-existing shoreline along the edge of the diked area, and around any islands within diked areas, are to:

- minimize change to existing substrates or other features; and,
- re-configure disturbed portions to pre-development conditions as much as possible.

This will allow the shoreline areas to be restored to pre-existing conditions once the dikes are breached. Any areas of disturbed shoreline are to be re-configured to provide fish habitat resembling that which was temporarily lost during the project. This may include placement of boulders in water up to 5 m deep to provide a sloping shoreline. The area of habitat predicted in the NNL plan for this habitat type, for all three dikes, is provided in Table 5. For A154, based on constructed dike configuration and the design criteria

presented in this report, 2.36 ha of shoreline habitat are expected to be reclaimed and includes shoreline areas around one island on the pit shelf.

**Table 5**  
**Reclaimed Shoreline Habitat Areas**

| Dike | No Net Loss Predicted Area (ha) | Current Predicted Area <sup>1</sup> (ha) |
|------|---------------------------------|--|
| A154 | 0.52                            | 2.36                                     |
| A418 | 0.61                            | n/a                                      |
| A21  | 0.82                            | n/a                                      |

<sup>1</sup> Note: Based on final constructed configuration of dikes, where available.  
ha = hectare.

### 3.2.5 Pit Shelf

The pit shelf area extends from the lower inside edges of the dike to the edges of the pit. The reclaimed pit shelf area is intended to provide shallow foraging and rearing habitat for most species of fish present in Lac de Gras. Material excavated from the pit will be used to fill in deeper portions of the pit shelf area. The area of the pit shelf will be covered by water that ranges from 3 m to 5 m deep. As per the *Navigable Waters Protection Act* Permit for the project, no dike breach or constructed shoal features will be less than 2 m from the expected low water level in Lac de Gras.

As indicated in the NNL plan and the Fisheries Authorization, the objectives for the selection of substrate type are based on reflecting physical characteristics of other areas of good foraging and rearing in Lac de Gras. The pit shelf configuration is also to be based on reflecting the physical characteristics of foraging and rearing habitats within Lac de Gras. In order to address these objectives, substrate information from baseline data collections was used and a basic configuration evaluation of the North Arm and two other nearby inlets identified as rearing areas within Lac de Gras was completed. The configuration evaluation was completed through air photo interpretation. Key features identified by assessing other rearing areas included:

- Rocky Shoal Shape – rocky shoals should be somewhat irregular in size and shape and relatively long and narrow. Some may also be constructed like a series of submerged rocky humps like links in a chain. Longer and narrower reefs have more “edge” habitat. Edges are important to fish that feed in one habitat type and rest or seek refuge in another.
- Isolated Pond-like Areas - In some cases it is beneficial to small fish to have the reefs forming a disjointed “ring” to provide pond-like conditions where circulation is limited.

- **Hard to Soft Substrate Ratio** - The hard substrate (shoals areas) to soft substrate (depositional areas) ratio in other nearby rearing areas ranged from 25% to 40% hard with the remainder as soft substrate.
- **Access to Refuge Habitat** – Rocky reefs provide refuge or cover for small fish. It is important for fish to have connectivity between rocky areas and reefs to avoid exposing themselves for extended distances or periods of time to predators. Keeping the distance between rocky reef areas less than 30 m to 40 m will allow fish reasonable access refuge, or hiding places.

### **Shape Configuration**

With regard to water circulation within the diked area, several features should be incorporated to reduce circulation. The shallow nature of the breaches, shallow nature of the pit shelf, and the creation of shoals on the pit shelf will reduce circulation and wind and wave action. The shallow water is expected to warm up quickly in the spring, relative to open areas of the lake, because of the limited water circulation within the enclosed area. As with other rearing habitats in Lac de Gras, warmer water should therefore assist in increasing biological productivity inside the dike by providing a warmer, refuge, and foraging area.

Determining the locations of the reefs should take several factors into consideration. Reefs should have some connectivity to the dikes and other reefs to allow fish to travel throughout the area without being fully exposed to predators for long distances. If the reefs are long, winding, and finger-like, a large amount of “edge” habitat will be created to allow fish to feed in the fine substrate while maintaining close proximity to the cover provided by the rocky reefs. Ideally the reefs will be placed in areas where the final water depth will be 3-m to 5-m deep and the tops of the reefs will remain under at least 2 m of water at all times. This will allow the reef habitat to remain functional even in winter with ice thickness of up to 2 m. Widths of the reefs should vary between 5 m and 30 m, averaging from 10 m to 20 m in width. Distance between the reefs could range from 10 m to 40 m, averaging from 20 m to 30 m apart. Habitat diversity is important and varying the size and shape of the reefs throughout the pit shelf area is expected to improve its value as fish habitat.

### **Substrate Material**

Based on the substrate materials within the North Arm, substrates on the pit shelf should be mostly fine material, primarily sand and silt interspersed with rocky reefs for habitat diversity. The till (existing lake substrate) is primarily sand and silt with some gravel (Tables 1 and 2). The till material will therefore be an appropriate substrate for the

expected biological zone of the sediments (*i.e.*, approximately top 10-cm layer represents the biological zone). The fine substrate areas will support a variety of benthic organisms that will provide forage for small fish.

If till is placed over angular rock to provide the soft substrate zone, it should be a layer deep enough to maintain at least 0.5 m depth of soft substrate after settling, accounting for some migration of fines into the voids in the rock fill.

Reefs should be constructed of granular material of a range of sizes. The primary material should be large boulder size rock with some smaller cobble material. The objective is to create refuge habitat, or hiding areas, among the rocks. Angular, unconsolidated material would provide this benefit. Run of mine blast rock is expected to be acceptable for this purpose.

The area of habitat predicted in the NNL plan for this habitat type, for all three dikes, is provided in Table 6. For A154, based on constructed dike configuration and the design criteria presented in this report, 61.35 ha of shallow rearing and foraging habitat are expected to be created.

**Table 6**  
**Pit Shelf Habitat Areas**

| <b>Dike</b> | <b>No Net Loss Predicted Area (ha)</b> | <b>Current Predicted Area <sup>1</sup> (ha)</b> |
|-------------|--|---|
| A154        | 59.89                                  | 61.35   |
| A418        | 8.68                                   | n/a   |
| A21         | 54.13                                  | n/a   |

<sup>1</sup> Note: Based on final constructed configuration of dikes, where available.  
ha = hectare.

### **3.2.6 Deep Water (Pit Area)**

The deep water habitat created by the project will be located in each of the mine pits near the center of the diked area. The deep water will provide a cooler environment for fishes and was considered a pelagic zone in the NNL plan. This area will likely be used by pelagic feeding fish such as cisco and may provide other benefits. The maximum depth of the pit areas is anticipated to be 250 m. The area of habitat predicted in the NNL plan for this habitat type, for all three dikes is provided in Table 7. For A154, based on constructed dike configuration and the design criteria presented in this report 52.3 ha are actually expected to be created.

**Table 7**  
**Deep Water Habitat Areas**

| Dike | No Net Loss Predicted Area (ha) | Current Predicted Area <sup>1</sup> (ha) |
|------|---------------------------------|--|
| A154 | 55.21                           | 52.3                                     |
| A418 | 41.94                           | n/a                                      |
| A21  | 29.29                           | n/a                                      |

<sup>1</sup> Note: Based on final constructed configuration of dikes, where available.  
ha = hectare.

### 3.3 Construction Considerations

There are a number of construction considerations that arise due to the variabilities in the material parameters, pore-pressure conditions, blasting effects and construction timing. The following construction considerations were evaluated with respect to the detailed design of the fish habitat compensation measures for the pit shelf areas:

- It was understood that flowing artesian conditions were present the southeast portion of the A154 pit shelf. Artesian conditions may cause build-up of porewater pressures within the fill on the pit shelf, depending on drainage conditions and the development of frozen layers.
- The fine-grained lake-bottom sediments are expected to provide poor trafficability, particularly where artesian conditions exist, and when the materials are thawing.
- A berm will be required between the pit crest and the toe of the fish habitat fill to provide safety with respect to equipment travelling too close to the pit crest and to reduce the potential for fill materials spilling into the pit during placement. The berm could also be used as a construction access road prior to pit development adjacent to the berm.
- The majority of the fill volume may consist of either till or rock fill, depending on construction timing and material availability. The final surface of the fill will consist of till, or lake-bottom sediments, to support aquatic life. The thickness of the final till/sediment layer will depend on whether a filter is used between the rock and till. DDMI will be responsible for picking the construction methods, and materials handling such that adequate quantities of till are available for the final fill surface.
- Based on gradation information for the till, summarized in Section 3.1, and predicted blast rock gradations from the feasibility study, it is anticipated that at least two, and possibly three graded aggregate filters would be required. The gradations of the till and blast rock, along with tentative filter gradations are shown in Appendix II.

Production of filter material would be relatively expensive, since it would involve crushing, screening, stockpiling, and double handling of the materials. It has been assumed that use of a filter between the rockfill and the till would not be utilized, due to logistical and economic considerations. As an alternative to using a filter, the thickness of the till cover on a rock fill can be varied as a function of the total fill thickness. The premise for this approach is that a certain portion of the till will migrate into the void spaces in the rock fill, so the thickness of the till cover must be such that a minimum of 0.5 m of till remains on top of the rock. For design purposes, it has been assumed that the porosity of the rock fill would be approximately 30 percent, and that with time, till would migrate into the rock such that 50 percent of the available voids would be filled. Thus, the thickness of till required over the rock is equal to 15 percent of the rock fill thickness, plus 0.5 m. Theoretically, where rocky reefs are to be constructed, till would not be required between the rock fill and reef material.

- Rock fill has the advantages of higher shear strength and better potential for drainage/dissipation of pore-water pressures. Rock fill may require a smaller thickness than till to provide a stable trafficking surface for the initial lifts.
- Rock fill would permit faster infiltration than till, which may provide a more stable trafficking surface after precipitation events and during spring thaw.
- Till will be available earlier in the mining cycle for each pit, since it overlies the bedrock. Materials may be transported between pits, if required.

## 4.0 STABILITY ANALYSES

### 4.1 Overall Pit Stability

The overall pit stability was assessed in Golder's report entitled "Revised A154 Ultimate Pits Stability Review", dated August 16, 2002. The summary of the ultimate pit stability review, and recommendations were as follows:

*The pit slope configurations incorporated into the revised A154 ultimate pit plan are consistent with recommendations previously made by Golder in December 1999, November 2000, and February 2002.*

*Based on the overall slope stability and deformation analyses of the revised A154 pit design, the pit slopes are anticipated to be stable.*

*The haulage ramp crosses the northeast wall at the 190 m elevation, and coincides with the contact between the granitic waste rocks and the A154 north kimberlite pipe. The slope above the ramp on the northeast wall is single benched and consist of kimberlite rocks. The kimberlite is highly fractured, with a low rock mass strength, and ravelling of benches excavated within kimberlite is expected to occur. The bench configuration within the kimberlite should provide adequate catchment for ravelled material. However, the kimberlite exposures must be closely monitored for signs of excessive ravelling on to the haulage ramp.*

*The stability and deformation review of the revised A154 ultimate pit slopes, highlight the following geotechnical considerations:*

- *If localized areas of bench scale toppling are encountered, additional operational considerations such as scaling and installation of ground support in problem areas may be necessary.*
- *The orientation and nature of the structures exposed along the exposed pit slopes should be detailed as excavation of these slopes begins. This can be achieved by continuous geotechnical mapping of new exposures, and comparison of these data with those previously collected through drillcore.*
- *The sensitivity of the northwest wall deformation analyses highlights the need for slope and dike movement monitoring program as outlined in Golder's February 2002 report.*



Analyses indicated that the overall pit stability is not significantly impacted by the presence of the fish habitat fills on the pit shelf.

#### **4.2 Stability of Fish Habitat Fills**

Slope stability analyses were carried out to determine the stability of the face of the fish habitat fills, and the required setback from the pit crest. The impact of the placed material on the stability of the pit was also checked.

Stability analyses were carried out using the computer programs, XSTABL and SLOPE/W. Factors of safety were calculated on the principle of limit equilibrium against potential sliding along a failure surface for each of the selected cross-sections. Factors of safety were computed using both Spencer's method and the Morgenstern-Price method, which satisfy both force and moment equilibrium. Based on the type of soil and the configuration of the habitat, both circular and wedge failure mechanisms were assessed.

DDMI indicated that flowing artesian conditions have been measured in the southeast portion of the A154 pit shelf. It is expected that these conditions would be affected by the development of the pit, but it is not possible/feasible to quantify these conditions until pit development commences. Thus, the factor of safety was assessed for various phreatic levels within the fill. Surface grading towards the sumps along the toe of the dike will help to drain surface water, reducing infiltration of the water into the fill, particularly if the surface of the fill consists of till or lake-bottom sediments.

The effects of blasting in the pit on the stability of the fill were assessed parametrically by using a pseudo-static limit equilibrium analysis with varying levels of pseudo-static loading. As production blasting data is accumulated, the impact of blasting may be reassessed and the design refined.

The results of the stability analyses are summarized in Appendix III. The stability analyses indicate that the critical slip surface impacting both the fish habitat fill and the in-situ till slope in the pit only impacts a small portion of the fish habitat fill. The factor of safety is sensitive to both the phreatic surface and the pseudo-static loading; therefore, a conservative approach with respect to setback distances and slope angles is proposed, combined with monitoring to assess modifications to the proposed design as mining proceeds. The recommended setback from the pit crest (*i.e.*, top of the in-situ till slope to the toe of the fish habitat fill) is 4 times the height of the fill (taken as the difference between the ultimate top of the fill and the elevation of the pit crest), with a minimum of 15 m. The slope of the faces of the fish habitat fill facing the pit and the interior of the dikes should be 3H:1V or flatter. As mining progresses, it may be possible to modify the setback and slope angle parameters.

## 5.0 CONSTRUCTION GUIDELINES

The recommended configuration of the fish habitat on the pit shelves is based on the following guidelines:

- Construct fills with face slopes of 3H:1V during mining, and final slopes at the angle of repose adjacent to the pit crest at the completion of mining.
- Setback from the pit crest to the toe of the fill equal to 4 times the elevation difference between the top of fill and the pit crest, with a minimum of 15 m.
- To the extent feasible, areas of existing shallow habitat (*i.e.*, water depth less than 5 m below mean normal water level) should remain untouched.
- Construction of a berm between the toe of the till slope and the crest of the pit. This berm will help retain material that erodes from the slope away from the pit, and will reduce the potential for any material rolling down the slope and into the pit. A minimum setback of 5 m from the crest of the pit to the toe of the berm has been used. As a minimum, the berm would be approximately 2 m high, with a 2-m crest width and 2H:1V sideslopes. The geometry of this berm may be modified on the basis of construction techniques.
- A setback from the interior toe of the water retention dike, to the upstream toe of the fill may also be required. This setback distance should be determined by DDMI, based on operational requirements and surface water handling requirements.
- Construction in one lift is acceptable.
- The materials used to construct the fill may consist of till, rock fill, or a combination of materials. If rock fill is used to construct the lower portion of the fill, the thickness of till to create the final surface should be equal to 0.15 times the height of rock fill, plus 0.5 m. Alternatively, filter zones could be provided between the rock fill and the till. Details of the filter zones would have to be developed further, once construction techniques and material gradations are determined. Processing of the blast rock will be required to produce filter materials, and is likely to be expensive. If the filter zone approach is taken, it is likely that at least two, and possibly, three filters would be required.
- Grading of the surface of the fill at a nominal grade of 1% is recommended, to direct surface water towards the water collection system at the toe of the dike.

- Final contouring of the surface will be required to establish some relief to provide fish habitat (*i.e.*, some hummocks and hollows, rather than an evenly graded surface).
- Rock ridges or reefs are also required for fish habitat. These reefs should be constructed of non-acid generating country rock, and conform to the parameters discussed in Section 3.2.5.

## **6.0 DETAILED DESIGN DRAWINGS**

A set of detailed design drawings is included in Appendix IV for the A154 pit. Detailed design drawings for the A418 and A21 pits have not been prepared, since the dikes have not been constructed, and the pit layout may change prior to construction. The detailed design guidelines presented in this document are considered sufficient to develop drawings for the A418 and A21 pits once the dike and pit details have been finalized.

## **7.0 MONITORING RECOMMENDATIONS**

Monitoring of various parameters is recommended to confirm the design assumptions, and to provide information for refining the design of the fish habitat on the pit shelves. It is recommended that monitoring consist of:

- Monitoring pore-water pressures in the lake-bottom sediments and till that will form the foundation for the fish habitat fills to assess drainage due to pit development, as well as pore-pressures due to fill placement and blasting.
- Monitor pore-pressures within the fish habitat fills, so that the slope stability analyses can be confirmed.
- Monitor production blasting to assess accelerations and peak particle velocities (PPV) for the fish habitat fills.
- Monitor movements of the fish habitat fills using a series of monitoring prisms, and potentially slope inclinometers. Visual inspections should also be conducted to check for signs of instability, such as bulging, slumping or the development of tension cracks.

Monitoring programs have previously been recommended for the water retention dikes and for monitoring the overall pit stability. It is recommended that the monitoring for the fish habitat fills on the interior of the dikes be integrated into the overall monitoring program, to provide consistency, and improve the efficiency of the monitoring efforts.

## **8.0 CLOSURE**

We trust this report presents the information that you require. Please feel free to call at anytime if you have any questions or concerns.

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**APPENDIX I**  
**HABITAT UNITS**



**Appendix I, Table 1. No Net Loss Habitat Summary "Accounting" Showing Habitat Units Only in the Proposed Areas of Disturbance, from No Net Loss Addendum, 1999**

| Life Stage                 | Species  | North Inlet<br>(2001 - 2023) |             | A418 (2009<br>2023) |              | A154<br>(2001-2023) |              | A21 (2012<br>2018) |              | **Available<br>(pre-1988) | **Available<br>(post-2024) | Net Change   |
|----------------------------|----------|------------------------------|-------------|---------------------|--------------|---------------------|--------------|--------------------|--------------|---------------------------|----------------------------|--------------|
|                            |          | loss                         | gain        | loss                | gain         | loss                | gain         | loss               | gain         |                           |                            |              |
| Spawning                   | LKTR     | 0.32                         | 0.00        | 0.10                | 0.07         | 0.68                | 0.15         | 0.79               | 0.14         | 1.88                      | 0.37                       | -1.51        |
|                            | ARGR     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
|                            | CISC     | 0.31                         | 0.00        | 0.11                | 0.06         | 0.95                | 0.12         | 0.80               | 0.11         | 2.16                      | 0.29                       | -1.87        |
|                            | RNWH     | 0.05                         | 0.00        | 0.02                | 0.05         | 0.18                | 0.29         | 0.14               | 0.26         | 0.39                      | 0.60                       | 0.21         |
|                            | LKWH     | 0.12                         | 0.00        | 0.04                | 0.02         | 0.24                | 0.04         | 0.30               | 0.04         | 0.70                      | 0.11                       | -0.59        |
|                            | LNSC     | 0.07                         | 0.00        | 0.02                | 0.01         | 0.06                | 0.02         | 0.17               | 0.02         | 0.33                      | 0.04                       | -0.29        |
|                            | BURB     | 0.04                         | 0.00        | 0.02                | 0.00         | 0.16                | 0.01         | 0.12               | 0.01         | 0.33                      | 0.02                       | -0.31        |
|                            | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
| SLSC                       | 0.11     | 0.00                         | 0.03        | 0.21                | 0.23         | 0.78                | 0.27         | 0.66               | 0.65         | 1.65                      | 1.01                       |              |
| Rearing                    | LKTR     | 1.60                         | 0.00        | 1.00                | 3.60         | 5.65                | 10.53        | 3.46               | 8.31         | 11.71                     | 22.44                      | 10.73        |
|                            | ARGR     | 0.17                         | 0.00        | 0.17                | 0.26         | 1.03                | 0.76         | 0.44               | 0.60         | 1.81                      | 1.62                       | -0.19        |
|                            | CISC     | 1.06                         | 0.00        | 1.53                | 3.47         | 6.37                | 10.17        | 3.83               | 8.02         | 12.78                     | 21.66                      | 8.87         |
|                            | RNWH     | 0.40                         | 0.00        | 0.26                | 0.61         | 1.21                | 2.06         | 0.72               | 1.69         | 3.90                      | 4.35                       | 0.46         |
|                            | LKWH     | 0.52                         | 0.00        | 0.28                | 0.62         | 1.27                | 2.31         | 1.00               | 1.93         | 3.07                      | 4.85                       | 1.79         |
|                            | LNSC     | 0.34                         | 0.00        | 0.30                | 0.48         | 1.40                | 1.63         | 0.80               | 1.34         | 2.85                      | 3.45                       | 0.60         |
|                            | BURB     | 0.27                         | 0.00        | 0.19                | 0.27         | 0.99                | 0.90         | 0.65               | 0.74         | 2.09                      | 1.91                       | -0.18        |
|                            | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
| SLSC                       | 0.36     | 0.00                         | 0.26        | 0.43                | 1.36         | 1.57                | 0.87         | 1.32               | 2.86         | 3.32                      | 0.47                       |              |
| Foraging                   | LKTR     | 0.70                         | 0.00        | 0.90                | 0.96         | 4.03                | 2.76         | 2.44               | 2.19         | 8.08                      | 5.91                       | -2.17        |
|                            | ARGR     | 0.11                         | 0.00        | 0.10                | 0.13         | 0.54                | 0.39         | 0.27               | 0.31         | 1.01                      | 0.83                       | -0.18        |
|                            | CISC     | 0.77                         | 0.00        | 0.88                | 1.65         | 3.90                | 4.31         | 2.37               | 3.31         | 7.92                      | 9.27                       | 1.35         |
|                            | RNWH     | 0.23                         | 0.00        | 0.17                | 0.28         | 0.88                | 0.80         | 0.51               | 0.63         | 2.37                      | 1.71                       | -0.66        |
|                            | LKWH     | 0.21                         | 0.00        | 0.15                | 0.28         | 0.73                | 0.94         | 0.44               | 0.77         | 1.54                      | 1.99                       | 0.46         |
|                            | LNSC     | 0.18                         | 0.00        | 0.21                | 0.24         | 0.88                | 0.81         | 0.55               | 0.67         | 1.82                      | 1.72                       | -0.10        |
|                            | BURB     | 0.10                         | 0.00        | 0.11                | 0.12         | 0.51                | 0.34         | 0.31               | 0.27         | 1.04                      | 0.73                       | -0.31        |
|                            | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
| SLSC                       | 0.07     | 0.00                         | 0.14        | 0.21                | 0.61         | 0.77                | 0.40         | 0.64               | 1.23         | 1.62                      | 0.39                       |              |
| Nursery                    | LKTR     | 0.32                         | 0.00        | 0.10                | 0.06         | 0.68                | 0.12         | 0.79               | 0.12         | 1.88                      | 0.30                       | -1.58        |
|                            | ARGR     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
|                            | CISC     | 0.31                         | 0.00        | 0.11                | 0.06         | 0.95                | 0.12         | 0.80               | 0.11         | 2.16                      | 0.29                       | -1.87        |
|                            | RNWH     | 0.05                         | 0.00        | 0.02                | 0.05         | 0.18                | 0.29         | 0.14               | 0.26         | 0.39                      | 0.60                       | 0.21         |
|                            | LKWH     | 0.12                         | 0.00        | 0.04                | 0.02         | 0.24                | 0.04         | 0.30               | 0.04         | 0.70                      | 0.11                       | -0.59        |
|                            | LNSC     | 0.07                         | 0.00        | 0.02                | 0.01         | 0.06                | 0.02         | 0.17               | 0.02         | 0.33                      | 0.04                       | -0.29        |
|                            | BURB     | 0.04                         | 0.00        | 0.02                | 0.00         | 0.16                | 0.01         | 0.12               | 0.01         | 0.33                      | 0.02                       | -0.31        |
|                            | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
| SLSC                       | 0.11     | 0.00                         | 0.03        | 0.21                | 0.23         | 0.78                | 0.27         | 0.66               | 0.65         | 1.65                      | 1.01                       |              |
| <b>Total</b>               |          | <b>9.10</b>                  | <b>0.00</b> | <b>7.33</b>         | <b>14.45</b> | <b>36.38</b>        | <b>43.84</b> | <b>24.27</b>       | <b>35.19</b> | <b>78.95</b>              | <b>93.49</b>               | <b>14.54</b> |
| <b>Total by life stage</b> | Spawning | 1.01                         | 0.00        | 0.34                | 0.43         | 2.50                | 1.41         | 2.59               | 1.24         | 6.44                      | 3.09                       | -3.35        |
|                            | Rearing  | 4.71                         | 0.00        | 4.00                | 9.73         | 19.29               | 29.93        | 11.78              | 23.94        | 41.07                     | 63.61                      | 22.54        |
|                            | Foraging | 2.37                         | 0.00        | 2.66                | 3.86         | 12.09               | 11.11        | 7.30               | 8.80         | 25.00                     | 23.77                      | -1.22        |
|                            | Nursery  | 1.01                         | 0.00        | 0.34                | 0.42         | 2.50                | 1.38         | 2.59               | 1.22         | 6.44                      | 3.02                       | -3.42        |
| <b>Total by species</b>    | LKTR     | 2.93                         | 0.00        | 2.11                | 4.69         | 11.04               | 13.56        | 7.48               | 10.76        | 23.55                     | 29.02                      | 5.47         |
|                            | ARGR     | 0.27                         | 0.00        | 0.27                | 0.40         | 1.57                | 1.15         | 0.71               | 0.91         | 2.83                      | 2.45                       | -0.37        |
|                            | CISC     | 2.44                         | 0.00        | 2.62                | 5.23         | 12.18               | 14.72        | 7.80               | 11.55        | 25.03                     | 31.51                      | 6.48         |
|                            | RNWH     | 0.72                         | 0.00        | 0.47                | 0.99         | 2.46                | 3.44         | 1.52               | 2.84         | 7.05                      | 7.26                       | 0.22         |
|                            | LKWH     | 0.97                         | 0.00        | 0.51                | 0.94         | 2.48                | 3.34         | 2.05               | 2.79         | 6.00                      | 7.06                       | 1.06         |
|                            | LNSC     | 0.67                         | 0.00        | 0.55                | 0.74         | 2.40                | 2.48         | 1.69               | 2.03         | 5.31                      | 5.25                       | -0.07        |
|                            | BURB     | 0.45                         | 0.00        | 0.34                | 0.40         | 1.81                | 1.26         | 1.21               | 1.03         | 3.80                      | 2.68                       | -1.12        |
|                            | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
| SLSC                       | 0.65     | 0.00                         | 0.47        | 1.06                | 2.45         | 3.91                | 1.82         | 3.28               | 5.38         | 8.25                      | 2.87                       |              |

Note:  
Minor variation in numbers, when compared with 1999 documentation, due to rounding

\*\* - habitat units available the pre-1988 and post-2024 represent the number of habitat units present on shoals, shorelines, and 'in deep/shallow water areas within the proposed boundaries of the three dikes (A154, A418, A21) and the north inlet.  
LKTR = lake trout; ARGR = Arctic grayling; CISC = cisco; RNWH = round whitefish; LKWH = lake whitefish; LNSC = longnose sucker; BURB = burbot; NRPK = northern pike; SLSC = slimy sculpin.

**Appendix I, Table 2 No Net Loss Habitat Summary "Accounting" Showing Habitat Units Only in the Proposed Areas of Disturbance,  
Recalculated with 2002 Dike A154 Constructed Dimensions**

| Life Stage                         | Species  | North Inlet<br>(2001 - 2023) |             | A418 (2009<br>2023) |              | A154 (2001<br>2023) |              | A21 (2012<br>2018) |              | **Available<br>(pre-1988) | **Available<br>(post-2024) | Net Change   |
|------------------------------------|----------|------------------------------|-------------|---------------------|--------------|---------------------|--------------|--------------------|--------------|---------------------------|----------------------------|--------------|
|                                    |          | loss                         | gain        | loss                | gain         | loss                | gain         | loss               | gain         |                           |                            |              |
| Spawning                           | LKTR     | 0.32                         | 0.00        | 0.10                | 0.07         | 0.68                | 0.24         | 0.79               | 0.14         | 1.88                      | 0.45                       | -1.43        |
|                                    | ARGR     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0            |
|                                    | CISC     | 0.31                         | 0.00        | 0.11                | 0.03         | 0.95                | 0.27         | 0.80               | 0.16         | 2.16                      | 0.37                       | -1.79        |
|                                    | RNWH     | 0.05                         | 0.00        | 0.02                | 0.05         | 0.18                | 0.31         | 0.14               | 0.26         | 0.39                      | 0.63                       | 0.24         |
|                                    | LKWH     | 0.12                         | 0.00        | 0.04                | 0.02         | 0.24                | 0.09         | 0.30               | 0.04         | 0.70                      | 0.15                       | -0.55        |
|                                    | LNSC     | 0.07                         | 0.00        | 0.02                | 0.01         | 0.06                | 0.02         | 0.17               | 0.02         | 0.33                      | 0.05                       | -0.28        |
|                                    | BURB     | 0.04                         | 0.00        | 0.02                | 0.00         | 0.16                | 0.02         | 0.12               | 0.01         | 0.33                      | 0.03                       | -0.30        |
|                                    | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0            |
| SLSC                               | 0.11     | 0.00                         | 0.03        | 0.21                | 0.23         | 0.83                | 0.27         | 0.66               | 0.65         | 1.70                      | 1.05                       |              |
| Rearing                            | LKTR     | 1.60                         | 0.00        | 1.00                | 3.60         | 5.65                | 10.82        | 3.46               | 8.31         | 11.71                     | 22.73                      | 11.01        |
|                                    | ARGR     | 0.17                         | 0.00        | 0.17                | 0.26         | 1.03                | 0.79         | 0.44               | 0.60         | 1.81                      | 1.65                       | -0.16        |
|                                    | CISC     | 1.06                         | 0.00        | 1.53                | 2.48         | 6.37                | 3.42         | 3.83               | 1.86         | 12.78                     | 21.89                      | 9.10         |
|                                    | RNWH     | 0.40                         | 0.00        | 0.26                | 0.61         | 1.21                | 2.14         | 0.72               | 0.31         | 3.90                      | 3.06                       | -0.84        |
|                                    | LKWH     | 0.52                         | 0.00        | 0.28                | 0.62         | 1.27                | 2.42         | 1.00               | 1.93         | 3.07                      | 4.97                       | 1.90         |
|                                    | LNSC     | 0.34                         | 0.00        | 0.30                | 0.48         | 1.40                | 1.69         | 0.80               | 1.34         | 2.85                      | 3.51                       | 0.67         |
|                                    | BURB     | 0.27                         | 0.00        | 0.19                | 0.27         | 0.99                | 0.95         | 0.65               | 0.74         | 2.09                      | 1.95                       | -0.14        |
|                                    | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0            |
| SLSC                               | 0.36     | 0.00                         | 0.26        | 0.43                | 1.36         | 1.66                | 0.87         | 1.32               | 2.86         | 3.41                      | 0.56                       |              |
| Foraging                           | LKTR     | 0.70                         | 0.00        | 0.90                | 0.96         | 4.03                | 2.87         | 2.44               | 2.19         | 8.08                      | 6.03                       | -2.05        |
|                                    | ARGR     | 0.11                         | 0.00        | 0.10                | 0.13         | 0.54                | 0.40         | 0.27               | 0.31         | 1.01                      | 0.85                       | -0.17        |
|                                    | CISC     | 0.77                         | 0.00        | 0.88                | 1.59         | 3.90                | 4.27         | 2.37               | 3.20         | 7.92                      | 9.36                       | 1.43         |
|                                    | RNWH     | 0.23                         | 0.00        | 0.17                | 0.28         | 0.88                | 0.83         | 0.51               | 0.63         | 2.37                      | 1.74                       | -0.62        |
|                                    | LKWH     | 0.21                         | 0.00        | 0.15                | 0.28         | 0.73                | 0.98         | 0.44               | 0.77         | 1.54                      | 2.03                       | 0.49         |
|                                    | LNSC     | 0.18                         | 0.00        | 0.21                | 0.24         | 0.88                | 0.84         | 0.55               | 0.67         | 1.82                      | 1.74                       | -0.08        |
|                                    | BURB     | 0.10                         | 0.00        | 0.11                | 0.12         | 0.51                | 0.36         | 0.31               | 0.27         | 1.04                      | 0.75                       | -0.29        |
|                                    | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0            |
| SLSC                               | 0.07     | 0.00                         | 0.14        | 0.21                | 0.61         | 0.81                | 0.40         | 0.64               | 1.23         | 1.65                      | 0.42                       |              |
| Nursery                            | LKTR     | 0.32                         | 0.00        | 0.10                | 0.06         | 0.68                | 0.21         | 0.79               | 0.12         | 1.88                      | 0.39                       | -1.49        |
|                                    | ARGR     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0            |
|                                    | CISC     | 0.31                         | 0.00        | 0.11                | 0.05         | 0.95                | 0.55         | 0.80               | 0.11         | 2.16                      | 0.37                       | -1.79        |
|                                    | RNWH     | 0.05                         | 0.00        | 0.02                | 0.05         | 0.18                | 0.31         | 0.14               | 0.26         | 0.39                      | 0.62                       | 0.23         |
|                                    | LKWH     | 0.12                         | 0.00        | 0.04                | 0.02         | 0.24                | 0.09         | 0.30               | 0.04         | 0.70                      | 0.15                       | -0.55        |
|                                    | LNSC     | 0.07                         | 0.00        | 0.02                | 0.01         | 0.06                | 0.02         | 0.17               | 0.02         | 0.33                      | 0.05                       | -0.28        |
|                                    | BURB     | 0.04                         | 0.00        | 0.02                | 0.00         | 0.16                | 0.02         | 0.12               | 0.01         | 0.33                      | 0.03                       | -0.30        |
|                                    | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0            |
| SLSC                               | 0.11     | 0.00                         | 0.03        | 0.21                | 0.23         | 0.83                | 0.27         | 0.66               | 0.65         | 1.70                      | 1.05                       |              |
| <b>Total</b>                       |          | <b>9.10</b>                  | <b>0.00</b> | <b>7.33</b>         | <b>13.38</b> | <b>36.38</b>        | <b>39.04</b> | <b>24.27</b>       | <b>27.59</b> | <b>78.95</b>              | <b>94.01</b>               | <b>15.06</b> |
| <b>Total<br/>by life<br/>stage</b> | Spawning | 1.01                         | 0.00        | 0.34                | 0.41         | 2.50                | 1.78         | 2.59               | 1.28         | 6.44                      | 3.39                       | -3.05        |
|                                    | Rearing  | 4.71                         | 0.00        | 4.00                | 8.75         | 19.29               | 23.88        | 11.78              | 16.41        | 41.07                     | 63.16                      | 22.10        |
|                                    | Foraging | 2.37                         | 0.00        | 2.66                | 3.81         | 12.09               | 11.35        | 7.30               | 8.69         | 25.00                     | 24.14                      | -0.86        |
|                                    | Nursery  | 1.01                         | 0.00        | 0.34                | 0.41         | 2.50                | 2.03         | 2.59               | 1.21         | 6.44                      | 3.31                       | -3.12        |
| <b>Total<br/>by specie<br/>s</b>   | LKTR     | 2.93                         | 0.00        | 2.11                | 4.69         | 11.04               | 14.13        | 7.48               | 10.76        | 23.55                     | 29.59                      | 6.04         |
|                                    | ARGR     | 0.27                         | 0.00        | 0.27                | 0.40         | 1.57                | 1.19         | 0.71               | 0.91         | 2.83                      | 2.49                       | -0.33        |
|                                    | CISC     | 2.44                         | 0.00        | 2.62                | 4.16         | 12.18               | 8.50         | 7.80               | 5.32         | 25.03                     | 31.99                      | 6.96         |
|                                    | RNWH     | 0.72                         | 0.00        | 0.47                | 0.99         | 2.46                | 3.60         | 1.52               | 1.47         | 7.05                      | 6.05                       | -0.99        |
|                                    | LKWH     | 0.97                         | 0.00        | 0.51                | 0.94         | 2.48                | 3.57         | 2.05               | 2.79         | 6.00                      | 7.30                       | 1.29         |
|                                    | LNSC     | 0.67                         | 0.00        | 0.55                | 0.74         | 2.40                | 2.58         | 1.69               | 2.03         | 5.31                      | 5.35                       | 0.03         |
|                                    | BURB     | 0.45                         | 0.00        | 0.34                | 0.40         | 1.81                | 1.34         | 1.21               | 1.03         | 3.80                      | 2.76                       | -1.04        |
|                                    | NRPK     | 0.00                         | 0.00        | 0.00                | 0.00         | 0.00                | 0.00         | 0.00               | 0.00         | 0.00                      | 0.00                       | 0.00         |
| SLSC                               | 0.65     | 0.00                         | 0.47        | 1.06                | 2.45         | 4.13                | 1.82         | 3.28               | 5.38         | 8.47                      | 3.09                       |              |

Note:  
Minor variation in numbers, when compared with 1999 documentation, due to rounding

\*\* - habitat units available the pre-1988 and post-2024 represent the number of habitat units present on shoals, shorelines, and in deep/shallow water areas within the proposed boundaries of the three dikes (A154, A418, A21) and the north inlet.  
LKTR = lake trout; ARGR = Arctic grayling; CISC = cisco; RNWH = round whitefish; LKWH = lake whitefish; LNSC = longnose sucker; BURB = burbot; NRPK = northern pike; SLSC = slimy sculpin.

**APPENDIX II**  
**TENTATIVE FILTER GRADATIONS**

**012-2331: DDMI Fish Habitat Compensation - Interior of Dikes**  
**Tentative Filter Gradations**

| Specification Bands | SHT Type 31     |           | SHT Type 33     |            |
|---------------------|-----------------|-----------|-----------------|------------|
|                     | Percent Passing |           | Percent Passing |            |
|                     | Coarse Ra       | Fine Rang | Coarse Ra       | Fine Range |
| Sieve Size<br>mm    |                 |           |                 |            |
| 31.5                | 100%            |           |                 |            |
| 25                  |                 |           |                 |            |
| 18                  | 75%             | 90%       | 100%            |            |
| 12.5                | 65%             | 83%       | 75%             | 100%       |
| 5                   | 40%             | 69%       | 50%             | 75%        |
| 2                   | 26%             | 47%       | 32%             | 52%        |
| 0.9                 | 17%             | 32%       | 20%             | 35%        |
| 0.4                 | 12%             | 22%       | 15%             | 25%        |
| 0.16                | 7%              | 14%       | 8%              | 15%        |
| 0.071               | 6%              | 11%       | 6%              | 11%        |

| Manitoba Highways Class A |           |                 |
|---------------------------|-----------|-----------------|
| Sieve Size                |           | Percent Passing |
| mm                        | Coarse Ra | Fine Range      |
| 19                        | 100%      |                 |
| 16                        | 80%       | 100%            |
| 4.75                      | 40%       | 71%             |
| 2                         | 25%       | 55%             |
| 0.425                     | 15%       | 30%             |
| 0.075                     | 8%        | 15%             |

Mean Till Gradation

| Diam  | % Passing |
|-------|-----------|
| 80    | 100.0%    |
| 50    | 100.0%    |
| 40    | 100.0%    |
| 20    | 97.4%     |
| 10    | 89.3%     |
| 5     | 80.5%     |
| 2.5   | 74.0%     |
| 1.25  | 68.0%     |
| 0.63  | 62.3%     |
| 0.315 | 55.9%     |
| 0.16  | 48.9%     |
| 0.08  | 39.1%     |

D<sub>85</sub>  
7.0

D<sub>15</sub>  
0.08

Filter 1 - Concrete Sand

| Sieve Size | Coarse % Passing | Fine % Passing |
|------------|------------------|----------------|
| 10         | 100%             | 100%           |
| 5          | 95%              | 100%           |
| 2.5        | 80%              | 100%           |
| 1.25       | 50%              | 90%            |
| 0.63       | 25%              | 65%            |
| 0.315      | 10%              | 35%            |
| 0.16       | 2%               | 10%            |

D<sub>85</sub>  
1.9

D<sub>15</sub>  
0.4

Filter 2

| Diam Fine | Diam Coarse | Fine % Passing |
|-----------|-------------|----------------|
|           |             | 100%           |
| 12.5      | 40          | 95%            |
| 8         | 25          | 85%            |
| 3         | 12.5        | 60%            |
| 1.2       | 5           | 15%            |
| 0.9       | 4           | 10%            |

D<sub>85</sub>  
21

D<sub>15</sub>  
3.3

Filter 3

| Diam Fine | Diam Coarse | Fine % Passing |
|-----------|-------------|----------------|
|           |             | 100%           |
| 75        | 200         | 95%            |
| 50        | 150         | 85%            |
| 25        | 75          | 60%            |
| 10        | 25          | 15%            |
| 9         | 22          | 10%            |

Blast Rock

| Diam | % Passing |
|------|-----------|
| 490  | 80%       |
| 280  | 50%       |
| 130  | 20%       |



**Grain Size Analysis**

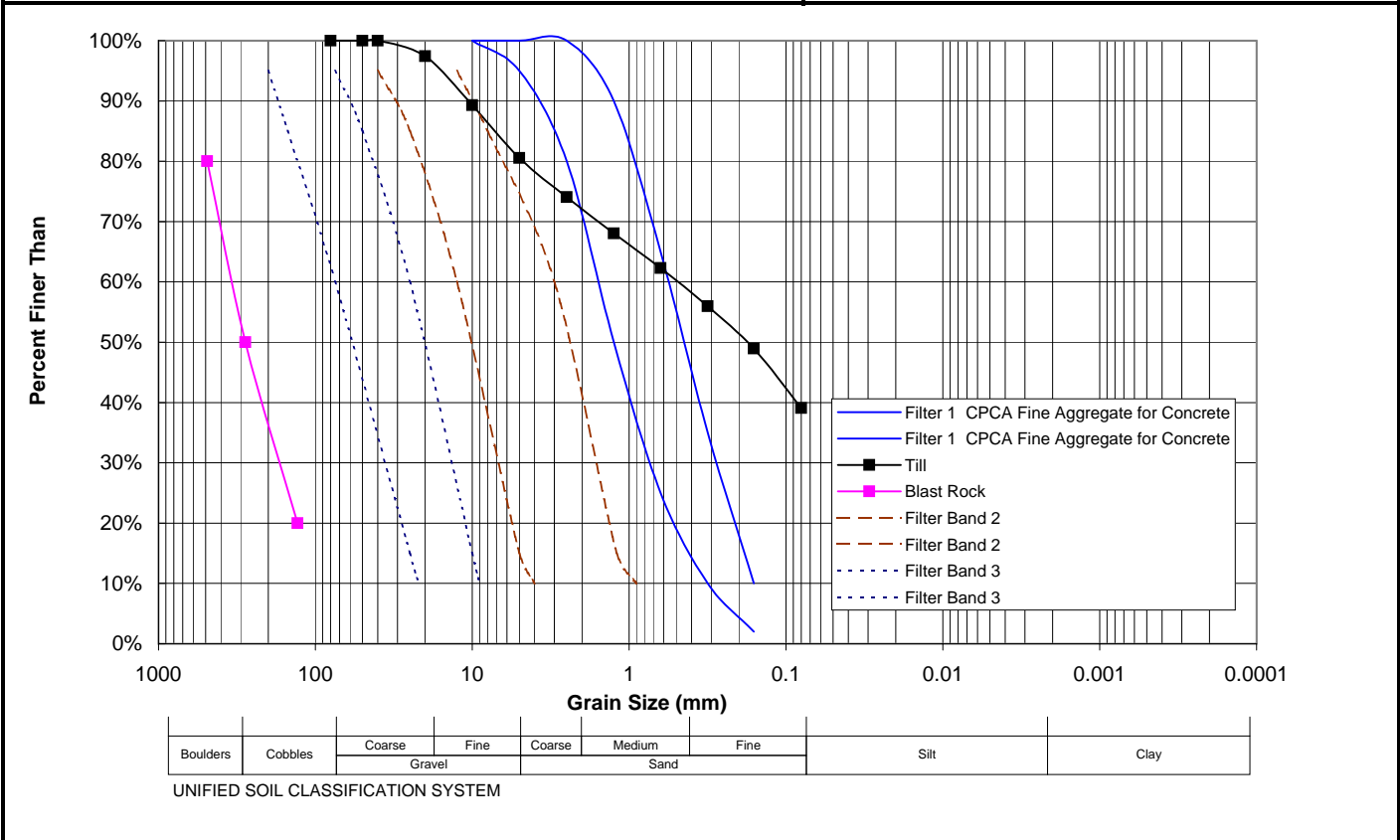
PROJECT No. 012-2331  
 PROJECT: Diavik - Fish Habitat Compensation - Dikes  
 LOCATION: Lac de Gras, NWT  
 SITE:  
 TESTED BY: N/A  
 DATE: March 2003

|                                      | SIEVE No. | Size of Opening |    | WEIGHT RETAINED (grams) |            | Total Weight Finer Than (grams) | Percent Finer Than (%) | % Finer Than Original Sample |
|--------------------------------------|-----------|-----------------|----|-------------------------|------------|---------------------------------|------------------------|------------------------------|
|                                      |           | Inches          | mm | per sieve               | cumulative |                                 |                        |                              |
| Tare Weight (grams) =                | 0         |                 |    |                         |            | 0                               |                        |                              |
| Moist Weight + Tare (grams) =        | 0         |                 |    |                         |            | 0                               |                        |                              |
| Dry Weight + Tare (grams) =          | 0         |                 |    |                         |            | 0                               |                        |                              |
| Washed, Dry Wt. + Tare (grams) =     | 0         |                 |    | 0                       | 0          | 0                               |                        |                              |
|                                      |           |                 |    | 0                       | 0          | 0                               |                        |                              |
| Moisture Content (%) =               | #DIV/0!   |                 |    | 0                       | 0          | 0                               |                        |                              |
| Total Dry Weight of Sample (grams) = | 0         |                 |    | 0                       | 0          | 0                               |                        |                              |
| Passing Total Weight                 |           |                 |    | 0                       | 0          | 0                               |                        |                              |
|                                      |           |                 |    | 0                       | 0          | 0                               |                        |                              |
|                                      |           |                 |    | 0                       | 0          | 0                               |                        |                              |
|                                      |           |                 |    | 0                       | 0          | 0                               |                        |                              |
|                                      |           |                 |    | 0                       | 0          | 0                               |                        |                              |
|                                      |           |                 |    | 0                       | 0          | 0                               |                        |                              |
|                                      |           |                 |    | 0                       | 0          | 0                               |                        |                              |

**Total Retained on Sieves (grams) = 0**

LABORATORY SAMPLE IDENTIFICATION NUMBER:  
 DESCRIPTION OF SAMPLE:

REMARKS:  
**This spreadsheet is being used to illustrate tentative grain-size distributions for filters between rock fill and till for the fish habitat compensation plans on the pit shelf.**



Checked By: \_\_\_\_\_ Reviewed By: \_\_\_\_\_

**APPENDIX III**  
**SUMMARY OF SLOPE STABILITY ANALYSES**

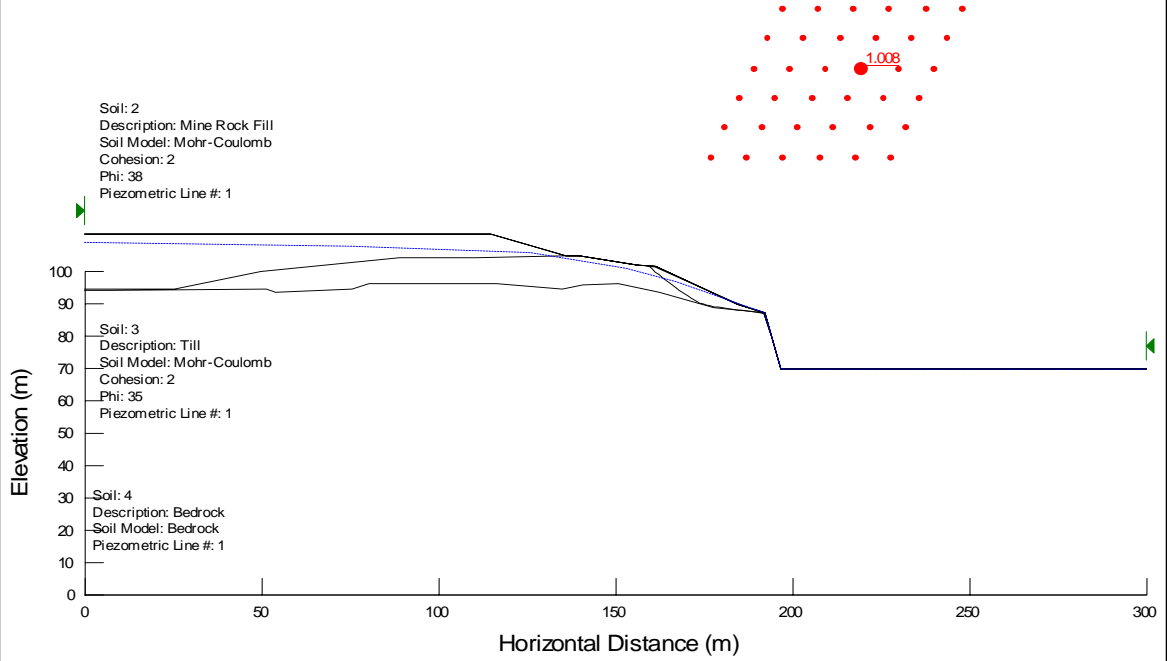
| <b>Section E With 25 m Setback</b> |                                  | <b>With 35 φ Till &amp; 38 Fill</b> |                 | <b>With 35 φ Fill &amp; 35 Till</b> |                 |
|------------------------------------|----------------------------------|-------------------------------------|-----------------|-------------------------------------|-----------------|
| Water Table Elevation              | Seismic Coefficient (horizontal) | F of S (through Till)               | F of S (global) | F of S (through Till)               | F of S (global) |
| Base Case                          | 0                                | 1.50                                | 2.66            |                                     |                 |
| Base Case                          | 0.05                             | 1.33                                | 2.24            |                                     |                 |
| Base Case                          | 0.1                              | 1.19                                | 1.94            |                                     |                 |
| Base Case                          | 0.15                             | 1.07                                | 1.71            |                                     |                 |
| Step 1 Water Table                 | 0                                | 1.34                                | 2.43            |                                     |                 |
| Step 1 Water Table                 | 0.05                             |                                     |                 |                                     |                 |
| Step 1 Water Table                 | 0.1                              |                                     |                 |                                     |                 |
| Step 1 Water Table                 | 0.15                             |                                     |                 |                                     |                 |
| Step 2 Water Table                 | 0                                | 1.19                                | 2.22            |                                     |                 |
| Step 2 Water Table                 | 0.05                             |                                     |                 |                                     |                 |
| Step 2 Water Table                 | 0.1                              |                                     |                 |                                     |                 |
| Step 2 Water Table                 | 0.15                             |                                     |                 |                                     |                 |
| Step 3 Water Table                 | 0                                | 1.18                                | 2.05            | 1.18                                | 2.04            |
| Step 3 Water Table                 | 0.05                             | 1.04                                | 1.76            | 1.04                                | 1.74            |
| Step 3 Water Table                 | 0.1                              | 0.92                                | 1.53            | 0.92                                | 1.52            |
| Step 3 Water Table                 | 0.15                             | 0.82                                | 1.35            | 0.82                                | 1.34            |
| Step 4 Water Table                 | 0                                | 1.01                                | 1.82            | 1.01                                | 1.81            |
| Step 4 Water Table                 | 0.05                             |                                     |                 |                                     |                 |
| Step 4 Water Table                 | 0.1                              |                                     |                 |                                     |                 |
| Step 4 Water Table                 | 0.15                             |                                     |                 |                                     |                 |
| Step 5 Water Table                 | 0                                | 1.01                                | 1.67            | 1.01                                | 1.66            |
| Step 5 Water Table                 | 0.05                             | 0.88                                | 1.43            | 0.88                                | 1.42            |
| Step 5 Water Table                 | 0.1                              | 0.78                                | 1.25            | 0.78                                | 1.24            |
| Step 5 Water Table                 | 0.15                             | 0.69                                | 1.11            | 0.69                                | 1.10            |
| Step 5 Water Table                 |                                  |                                     |                 |                                     |                 |

**Project Number: 012-2331**  
**Project: DDMI - Diavik**  
**Fish Habitat Comp.**

**SUMMARY OF SLOPE STABILITY ANALYSIS**

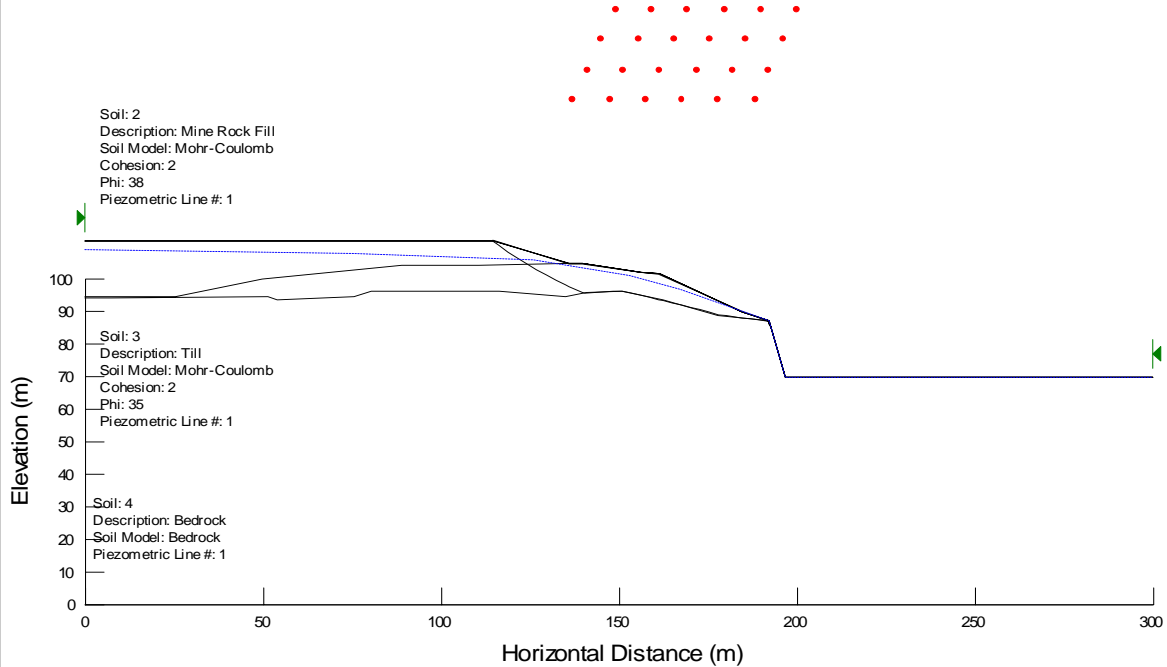
File Name: Section E Step 5.slz  
Analysis Method: Morgenstern-Price  
Seismic Coefficient: (none)  
0.0 g Seismic Load (horizontal)

Step 5 Water Table



File Name: Section E Step 5.slz  
Analysis Method: Morgenstern-Price  
Seismic Coefficient: (none)  
0.0 g Seismic Load (horizontal)

Step 5 Water Table

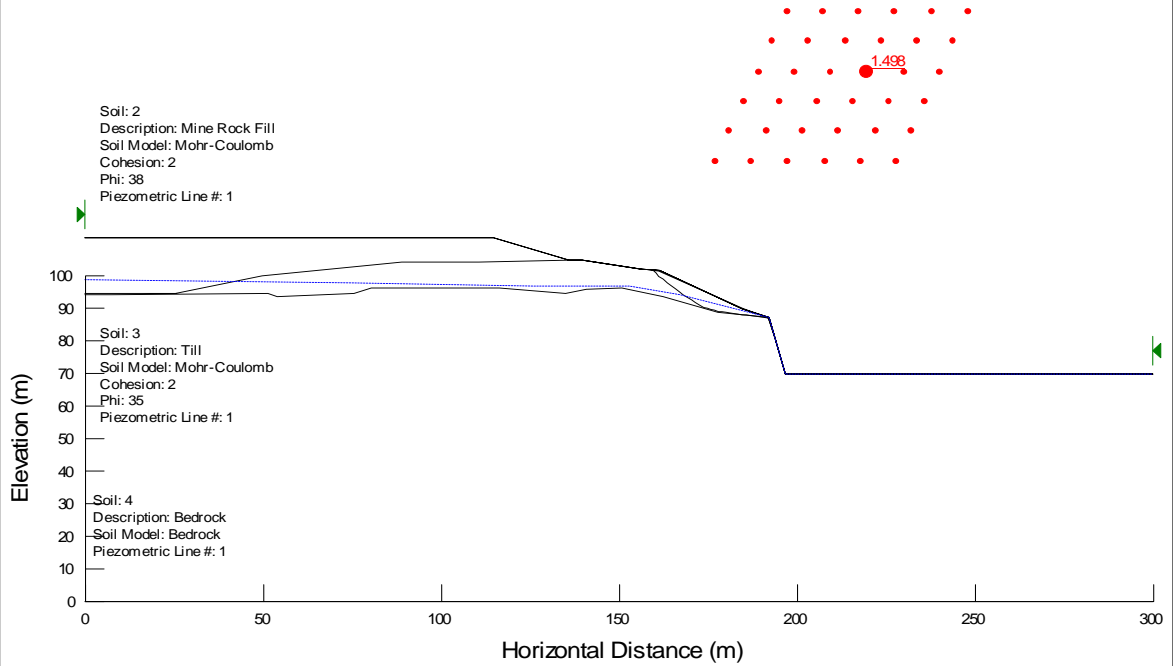




File Name: Section E Base.slz  
Analysis Method: Morgenstern-Price  
Seismic Coefficient: (none)  
0.0 g Seismic Load (horizontal)

Base Case Water Table

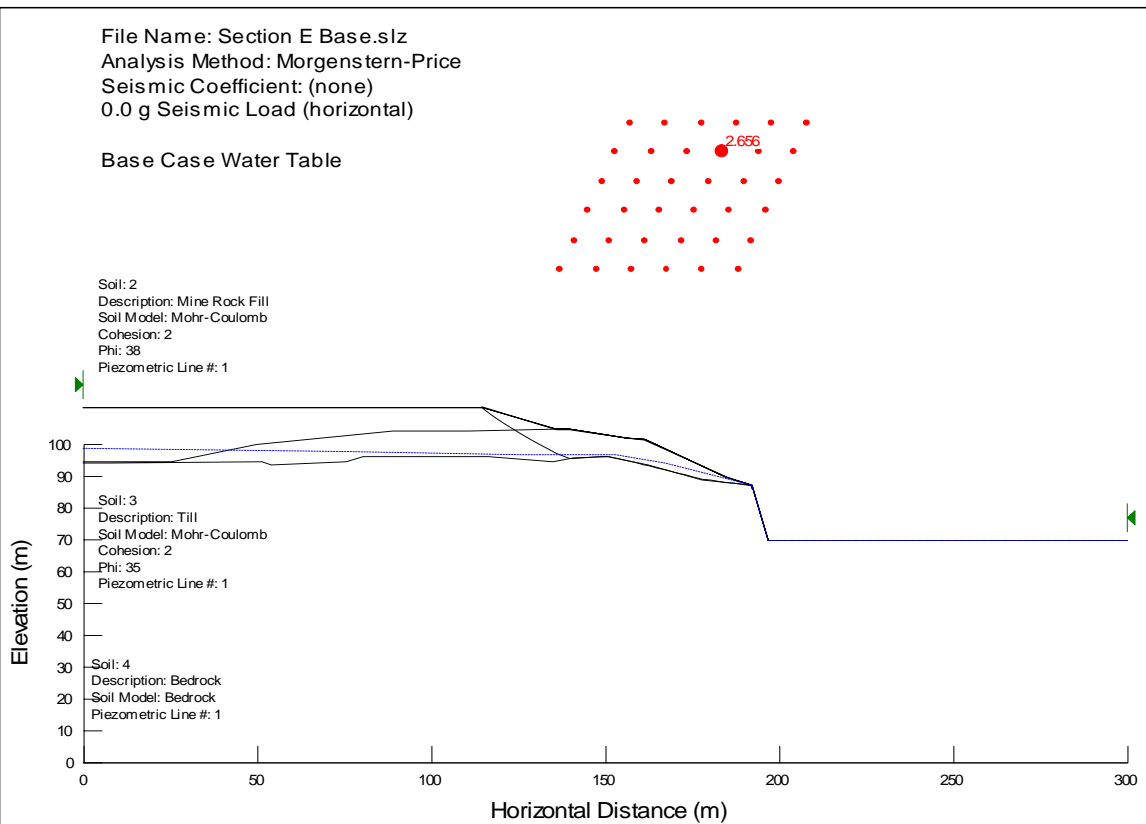
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Description: Mine Rock Fill  
Soil Model: Mohr-Coulomb  
Cohesion: 2  
Phi: 38  
Piezometric Line #: 1



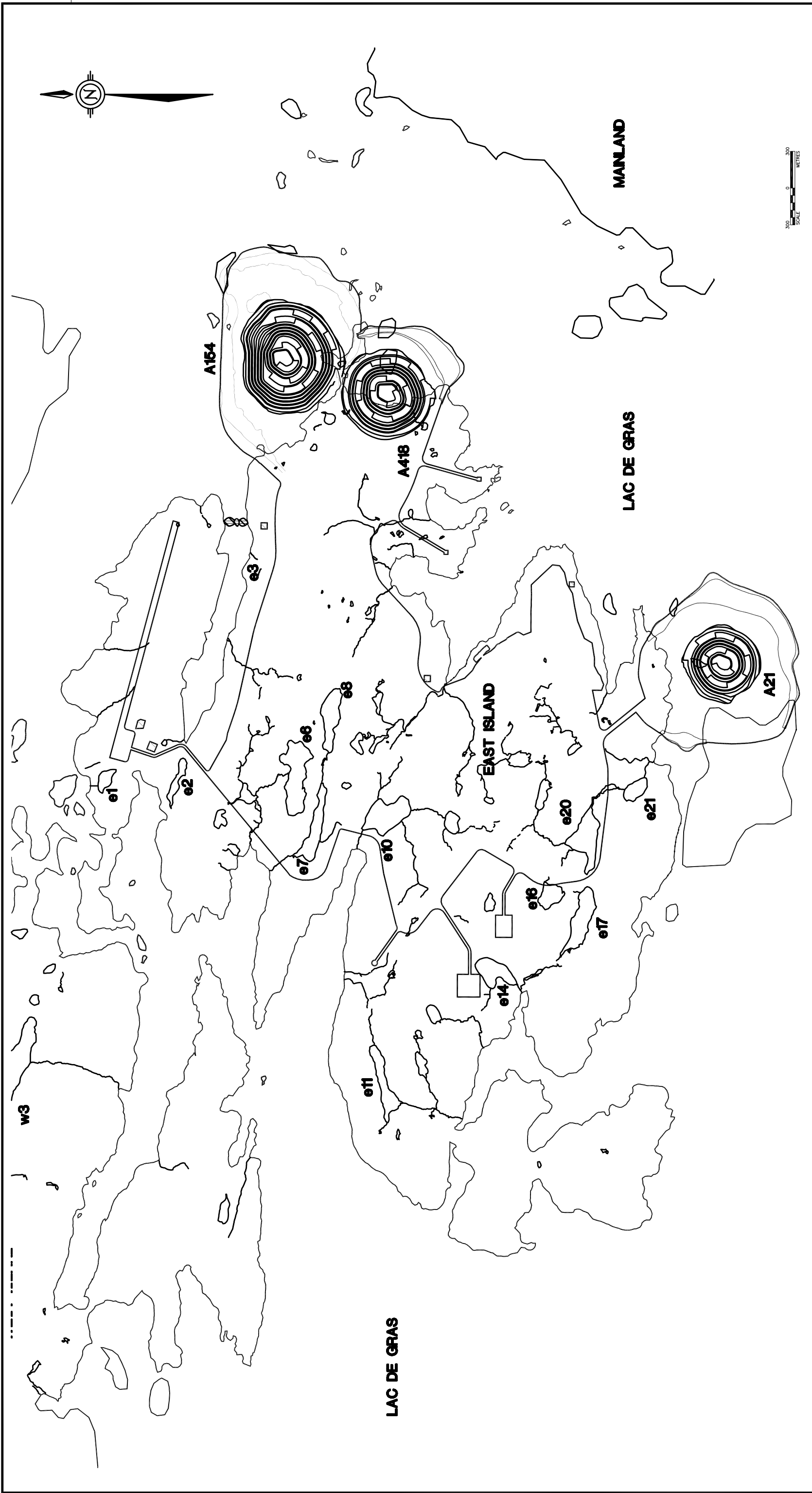
File Name: Section E Base.slz  
Analysis Method: Morgenstern-Price  
Seismic Coefficient: (none)  
0.0 g Seismic Load (horizontal)

Base Case Water Table

Soil: 2  
Description: Mine Rock Fill  
Soil Model: Mohr-Coulomb  
Cohesion: 2  
Phi: 38  
Piezometric Line #: 1



**APPENDIX IV**  
**DETAILED DESIGN DRAWINGS**



PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER  
 RETENTION DIKES, NORTHWEST TERRITORIES

TITLE

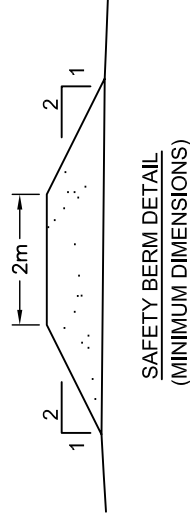
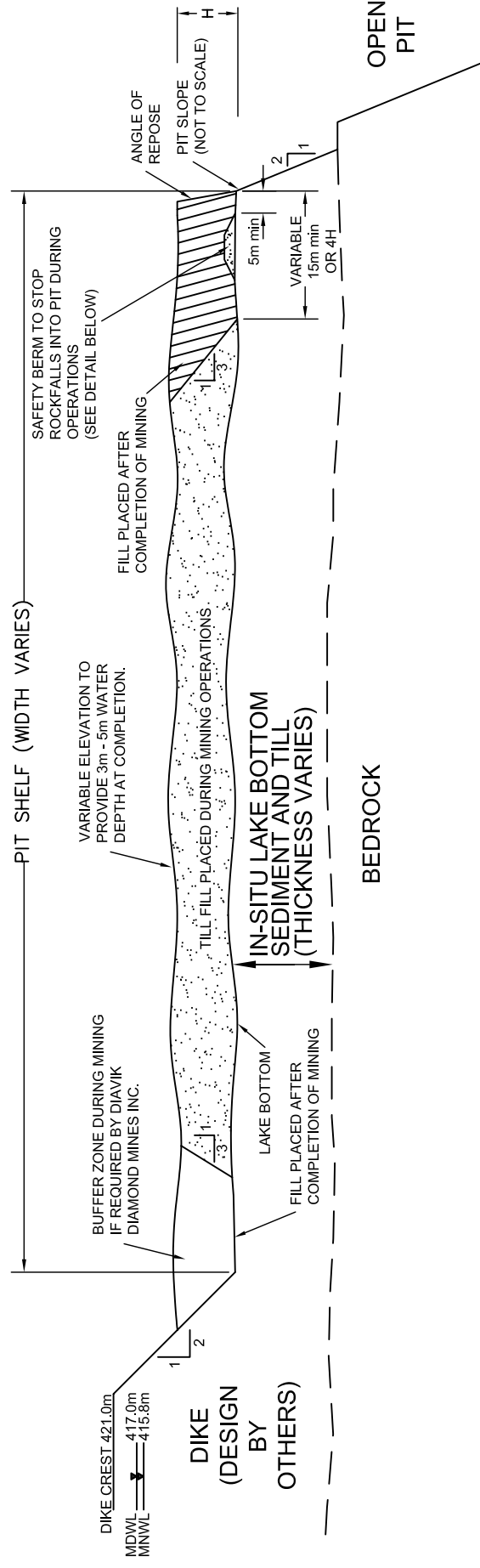
**PROJECT LAYOUT**

|                           |        |          |          |          |      |   |
|---------------------------|--------|----------|----------|----------|------|---|
| PROJECT No. 012-2331.5310 |        | FILE No. | SCALE    | AS SHOWN | REV. | 0 |
| DESIGN                    | CADD   | RML      | 02/17/03 |          |      |   |
| CHECK                     | REVIEW |          |          |          |      |   |

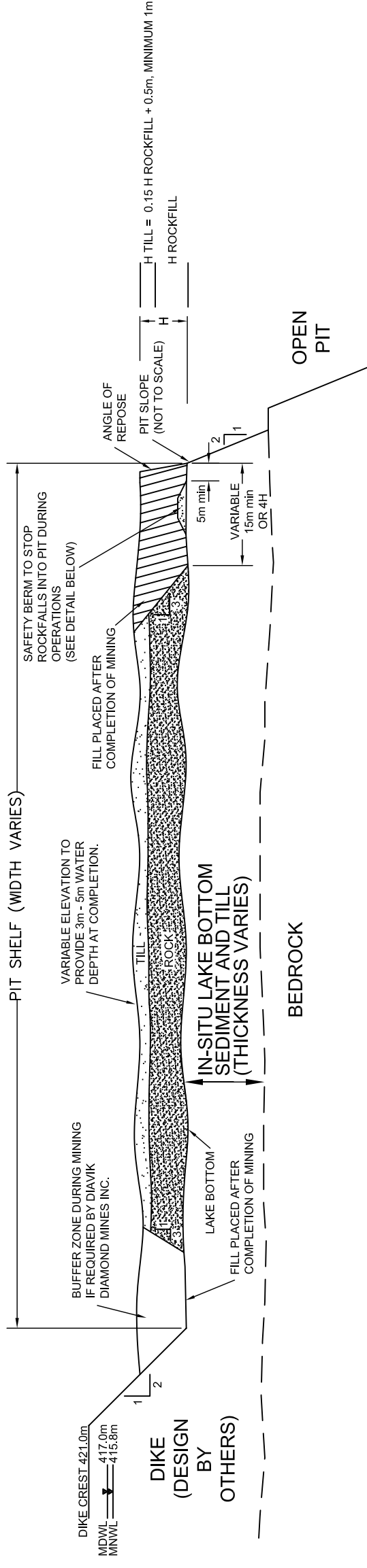
**DRAWING: 1**



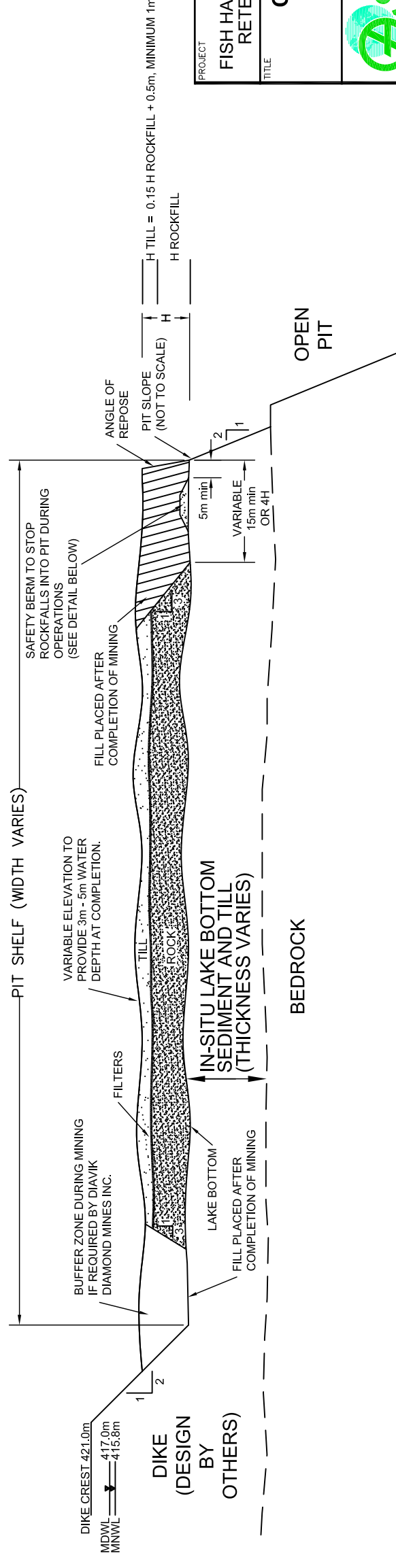
### TILL FILL OPTION



### ROCK/TILL OPTION (NO FILTERS)



### ROCK/TILL OPTION (WITH FILTERS)



PROJECT DIAVIK DIAMOND MINES INC.  
FISH HABITAT COMPENSATION-INTERIOR OF WATER  
RETENTION DIKES, NORTHWEST TERRITORIES

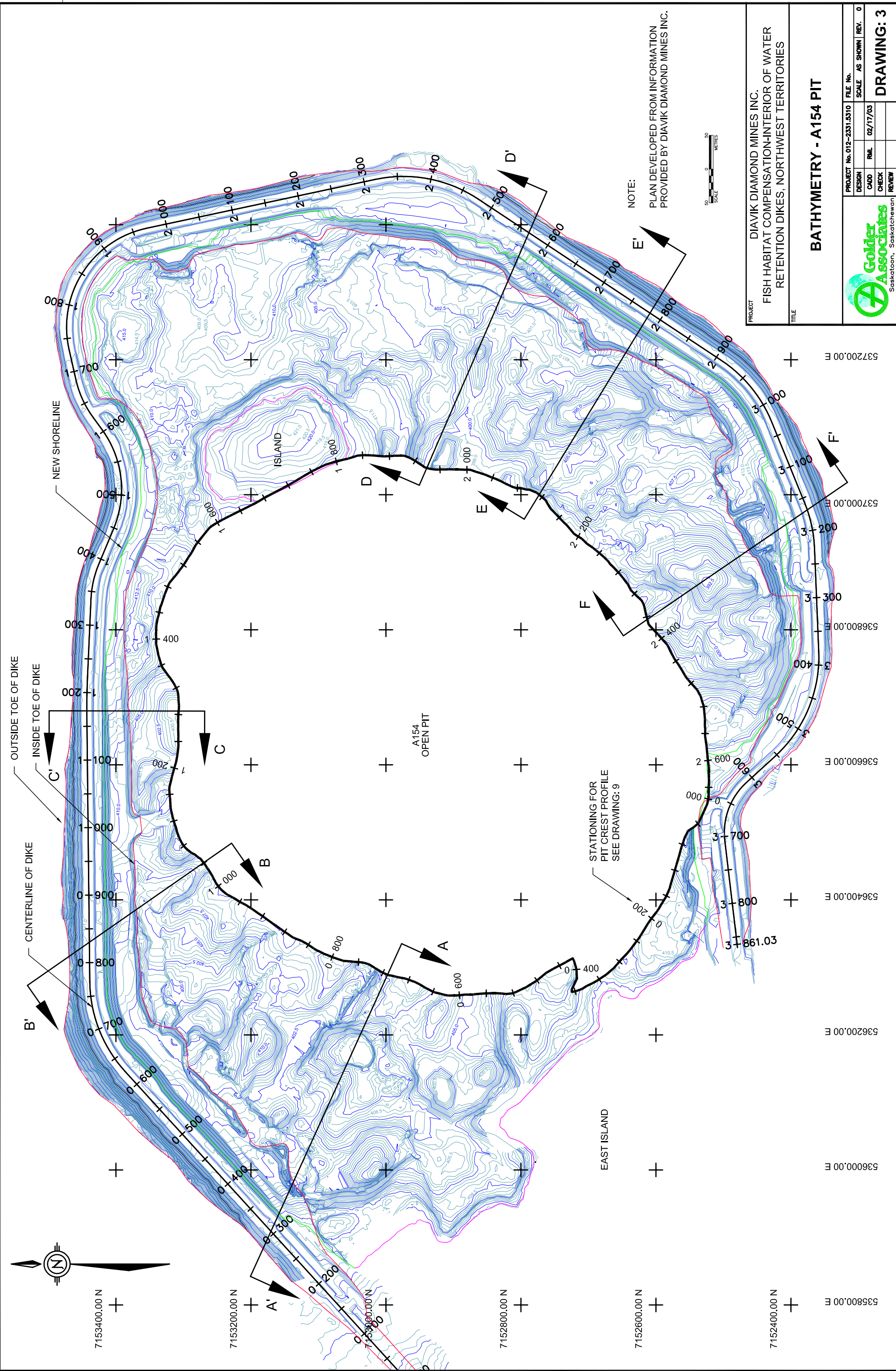
TITLE CROSS-SECTION OPTIONS FOR  
FISH HABITAT  
CREATED INSIDE DIKES

|         |               |          |        |
|---------|---------------|----------|--------|
| PROJECT | 012-2331-5310 | FILE No. |        |
| DESIGN  |               | SCALE    | NTS    |
| CADD    | 02/17/03      | CHECK    | REV. 0 |
| RML     |               | REVIEW   |        |

**Golden Associates**  
Saskatoon, Saskatchewan

**DRAWING: 2**





PROJECT: DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER  
 RETENTION DIKES, NORTHWEST TERRITORIES

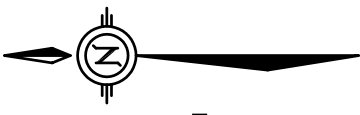
TITLE: **BATHYMETRY - A154 PIT**

|                           |                |
|---------------------------|----------------|
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| DESIGN                    | SCALE AS SHOWN |
| CADD                      | REV. 0         |
| RML                       | 02/17/03       |
| CHECK                     |                |
| REVIEW                    |                |

**Golden Associates**  
 Saskatoon, Saskatchewan


**DRAWING: 3**

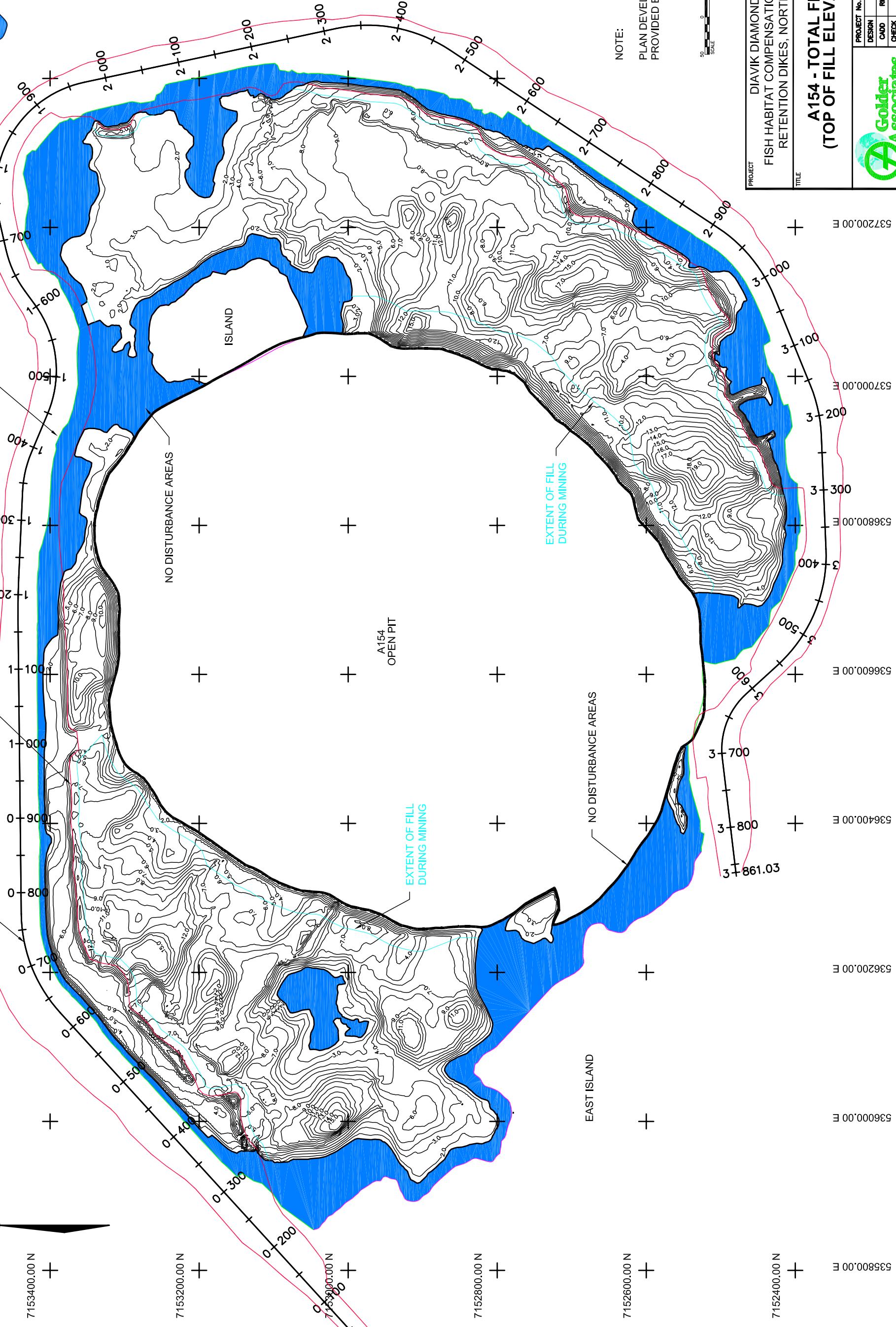




7153400.00 N  
 7153200.00 N  
 7153000.00 N  
 7152800.00 N  
 7152600.00 N  
 7152400.00 N

CENTERLINE OF DIKE  
 INSIDE TOE OF DIKE  
 OUTSIDE TOE OF DIKE

LEGEND:  
  
 MAINTAIN EXISTING HABITAT  
 "NO DISTURBANCE AREA"



NOTE:  
 PLAN DEVELOPED FROM INFORMATION PROVIDED BY DIAVIK DIAMOND MINES INC.

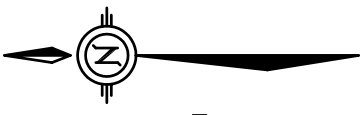
PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES

TITLE  
**A154 - TOTAL FILL ISOPACH (TOP OF FILL ELEVATION = 411.8m)**

|                           |          |       |          |      |   |
|---------------------------|----------|-------|----------|------|---|
| PROJECT No. 012-2331.5310 | FILE No. | SCALE | AS SHOWN | REV. | 0 |
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| CHECK                     | REVIEW   |       |          |      |   |

**Golden Associates**  
 Saskatoon, Saskatchewan

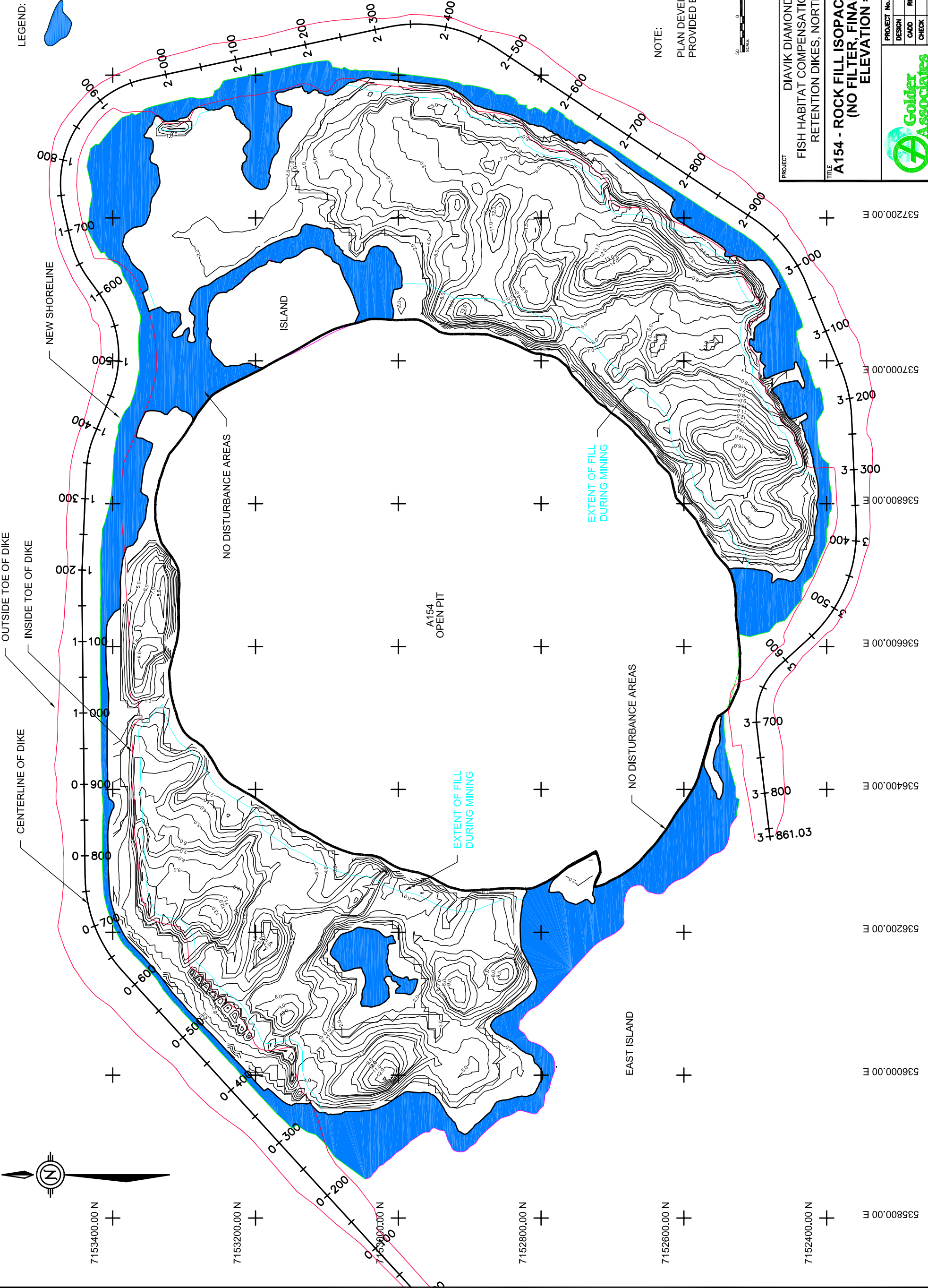
**DRAWING: 4**



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 7152800.00 N  
 7152600.00 N  
 7152400.00 N

CENTERLINE OF DIKE  
 INSIDE TOE OF DIKE  
 OUTSIDE TOE OF DIKE

LEGEND:  
 MAINTAIN EXISTING HABITAT  
 "NO DISTURBANCE AREA"



NOTE:  
 PLAN DEVELOPED FROM INFORMATION PROVIDED BY DIAVIK DIAMOND MINES INC.



PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES  
 TITLE **A154 - ROCK FILL ISOPACH BELOW TILL COVER (NO FILTER, FINAL TOP OF FILL ELEVATION = 411.8m)**

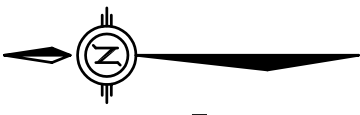
|                           |          |       |          |      |   |
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**Golden Associates**  
 Saskatoon, Saskatchewan

**DRAWING: 5**


537200.00 E  
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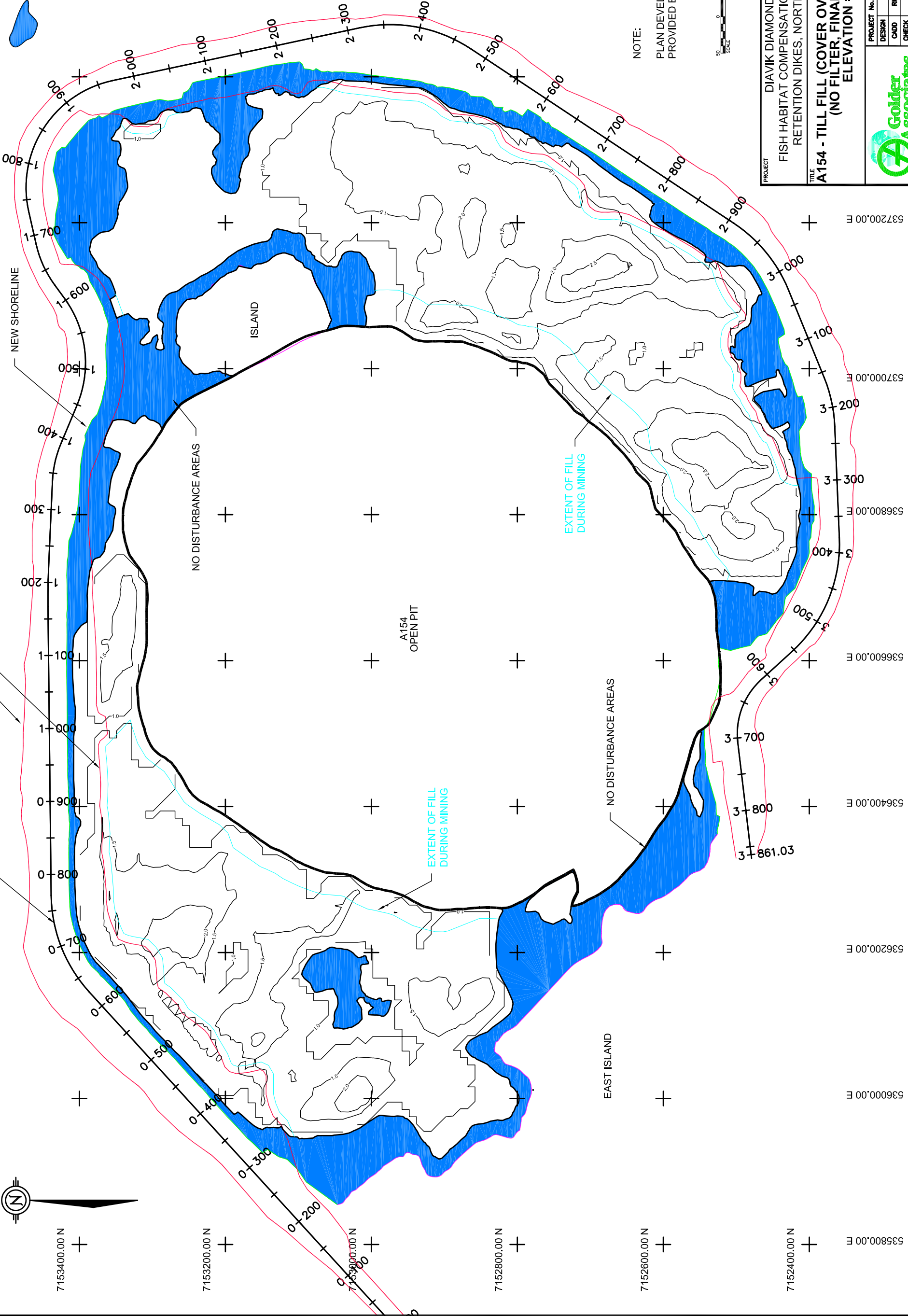




7153400.00 N  
 7153200.00 N  
 7153000.00 N  
 7152800.00 N  
 7152600.00 N  
 7152400.00 N

CENTERLINE OF DIKE  
 INSIDE TOE OF DIKE  
 OUTSIDE TOE OF DIKE

LEGEND:  




NOTE:

PLAN DEVELOPED FROM INFORMATION PROVIDED BY DIAVIK DIAMOND MINES INC.



PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES  
 TITLE A154 - TILL FILL (COVER OVER ROCKFILL) ISOPACH (NO FILTER, FINAL TOP OF FILL ELEVATION = 411.8m)

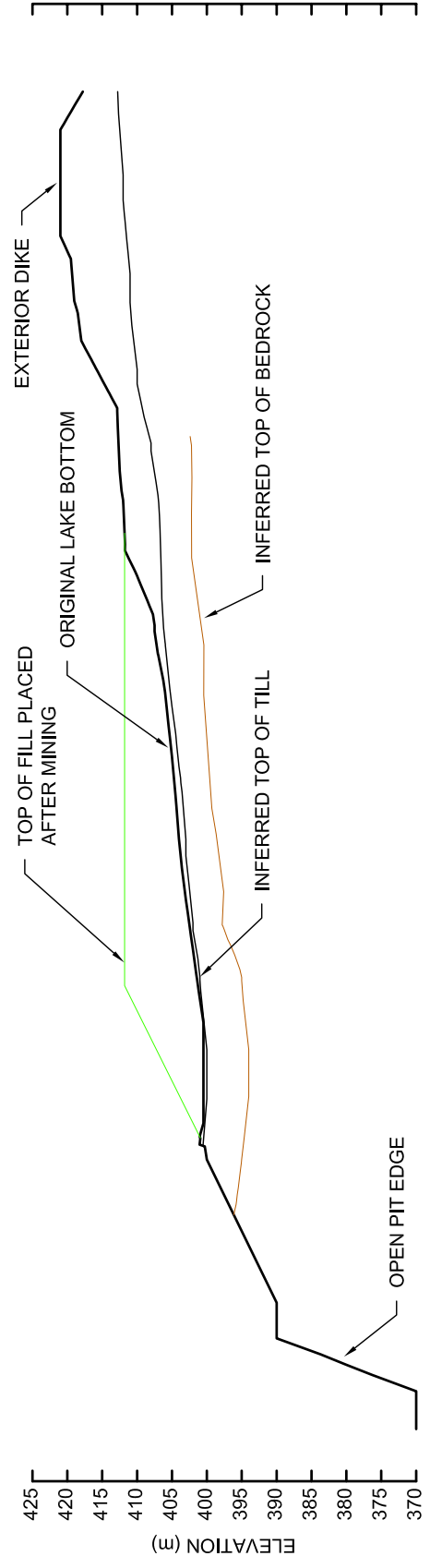
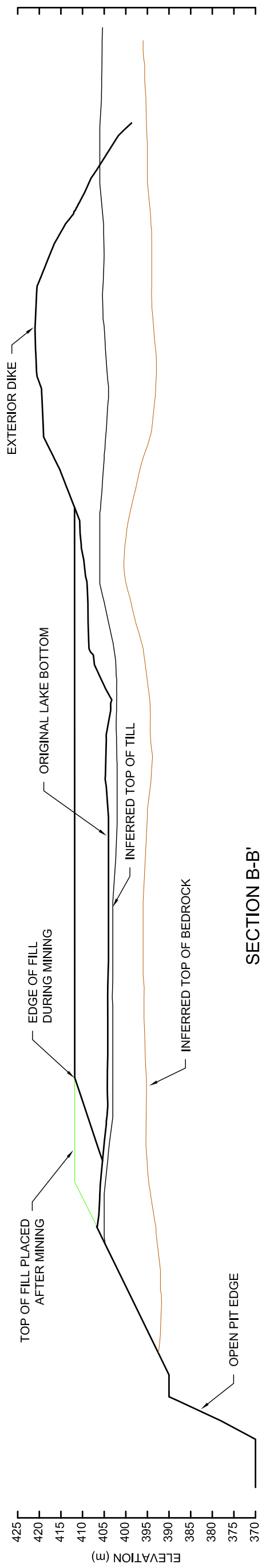
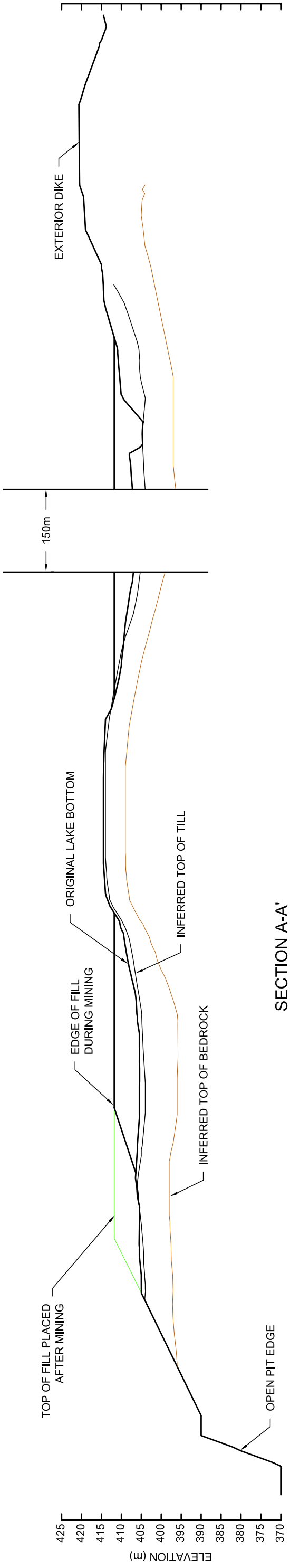
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DRAWING: 6

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NOTE:  
CROSS-SECTIONS MAY NOT BE PERPENDICULAR TO DIKE CENTRELINE



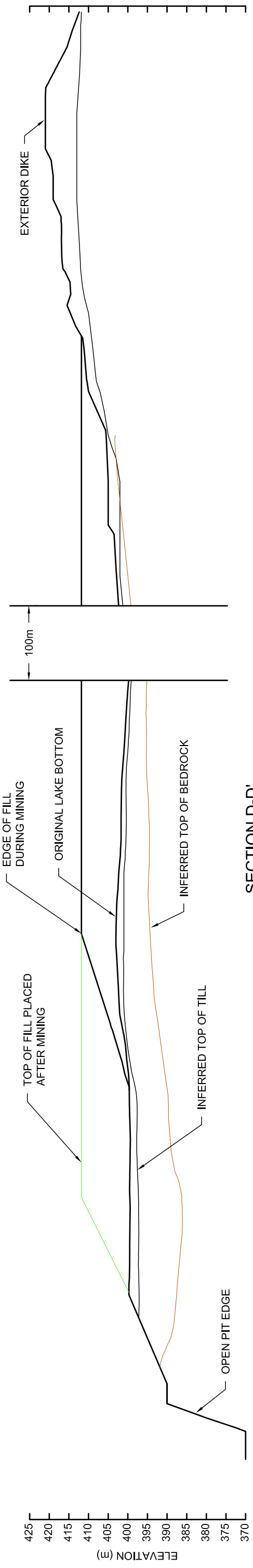
PROJECT DIAVIK DIAMOND MINES INC.  
FISH HABITAT COMPENSATION-INTERIOR OF WATER  
RETENTION DIKES, NORTHWEST TERRITORIES

TITLE **A154 PIT - CROSS SECTIONS OF FISH HABITAT FILL ON EXTERIOR DIKES**

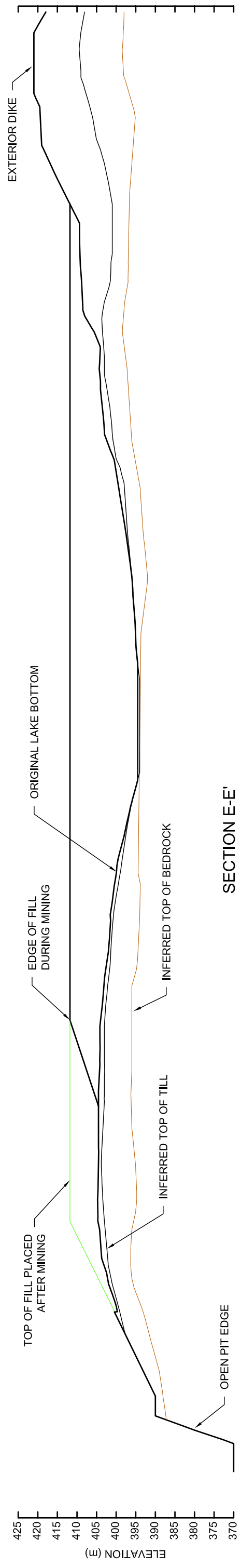
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**Golden Associates**  
Saskatoon, Saskatchewan

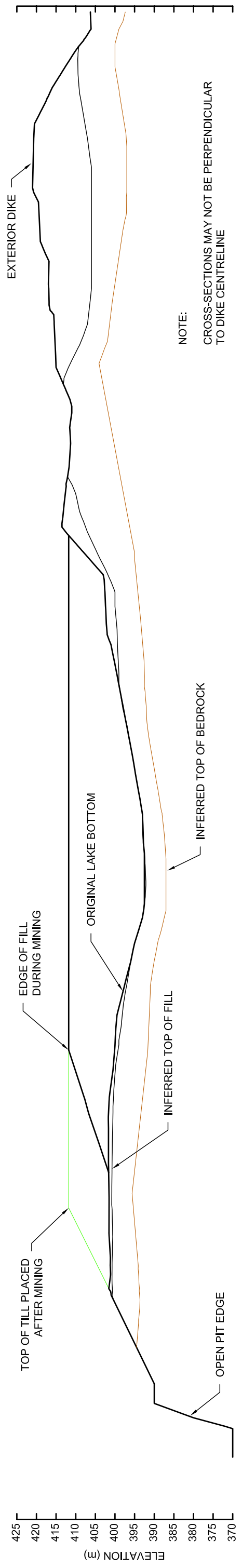
**DRAWING: 7**



SECTION D-D'



SECTION E-E'



SECTION F-F'

NOTE:  
CROSS-SECTIONS MAY NOT BE PERPENDICULAR TO DIKE CENTRELINE

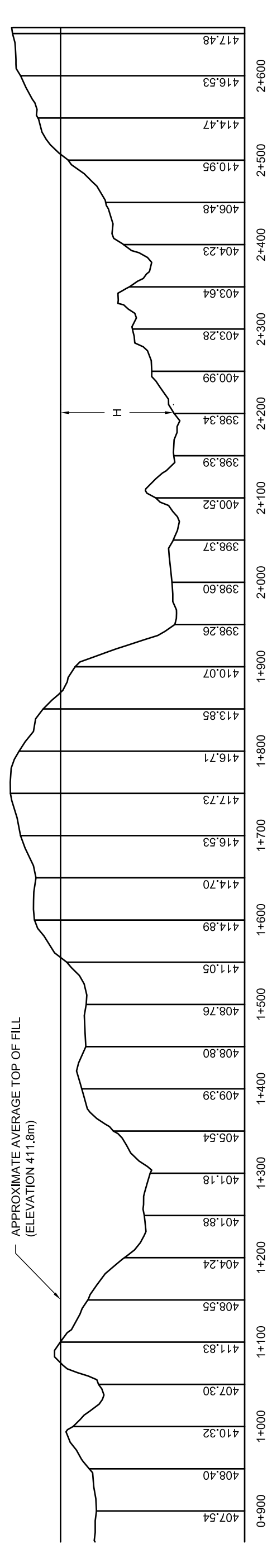
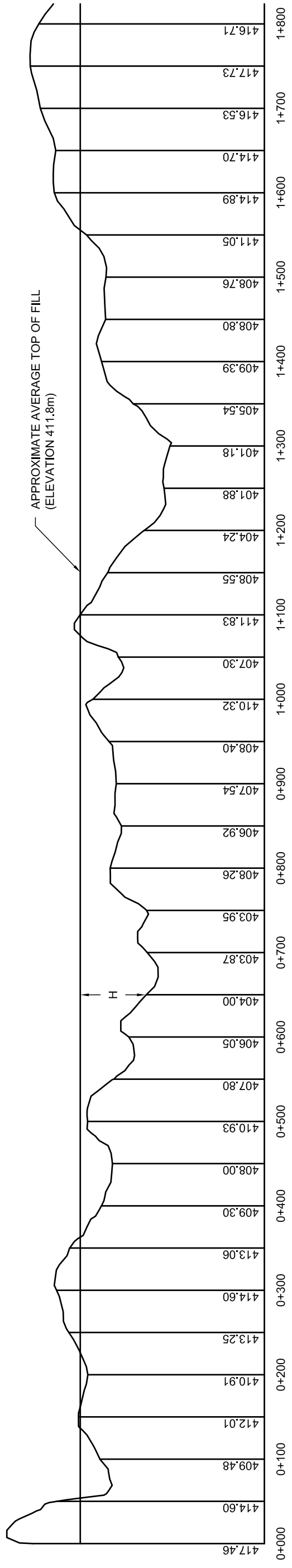


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| TITLE        |               | FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES |          |
| PROJECT No.  | 012-2331.5310 | FILE No.   |          |
| DESIGN SCALE | AS SHOWN      | REV.   | 0        |
| CADD         | RML           | DATE   | 02/17/03 |
| CHECK        |               |  |          |
| REVIEW       |               |  |          |

**Golder Associates**  
Saskatoon, Saskatchewan

**A154 PIT - CROSS SECTIONS OF FISH HABITAT FILL ON EXTERIOR DIKES**

**DRAWING: 8**



50  
SCALE  
0  
METRES

10x VERTICAL EXAGGERATION

NOTES:

1. SEE DRAWING : 3 FOR STATIONING
2. SETBACK FROM PIT CREST TO TOE OF FISH HABITAT FILL (DURING MINING) EQUAL TO 4H WITH A MINIMUM OF 15m.

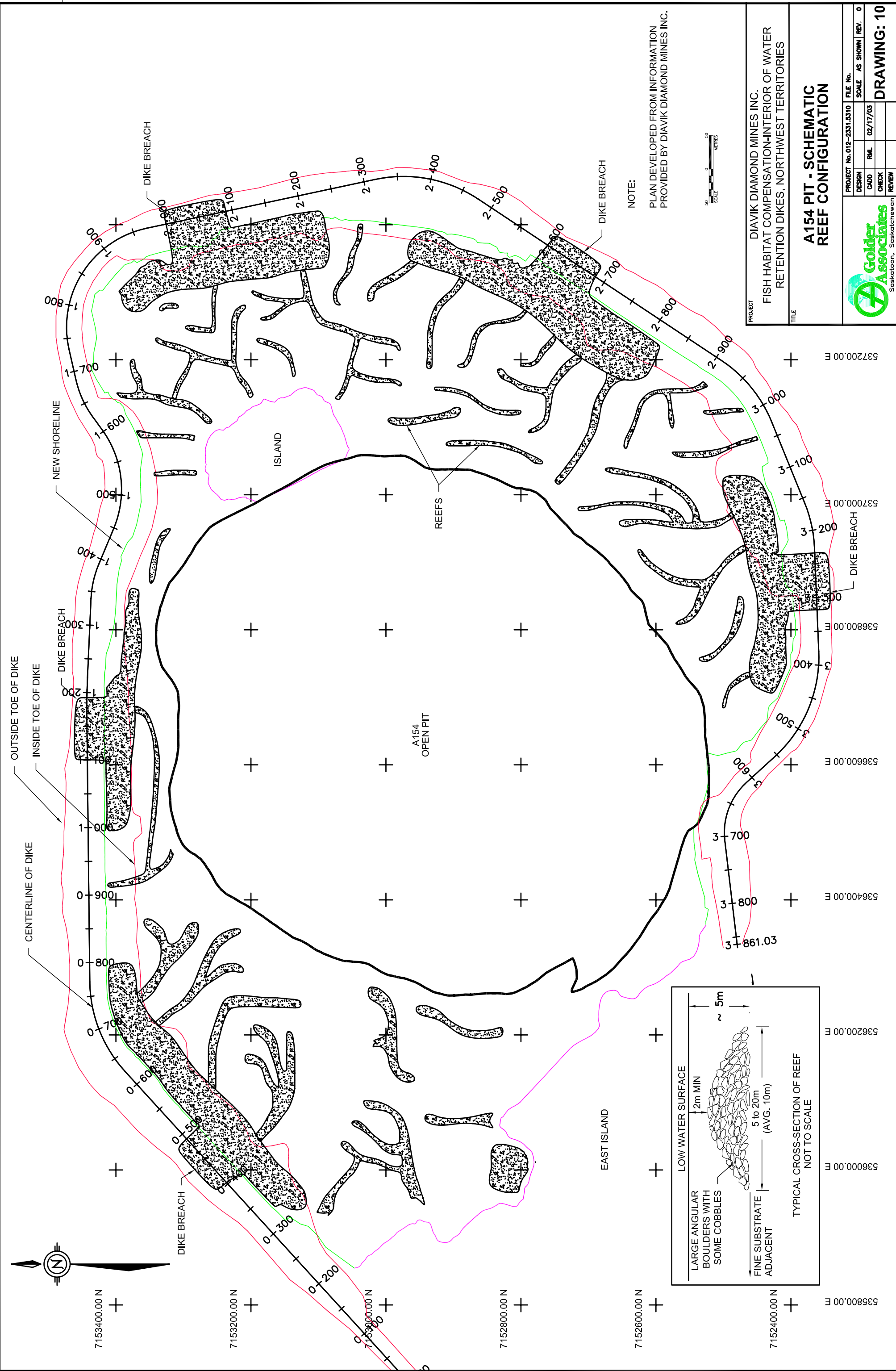
PROJECT: DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER  
 RETENTION DIKES, NORTHWEST TERRITORIES

TITLE: **A154 PIT - PIT CREST PROFILE**

|                           |                |
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| PROJECT No. 012-2331.5310 | FILE No.       |
| DESIGN                    | SCALE AS SHOWN |
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| CHECK                     |                |
| REVIEW                    |                |

**Golden Associates**  
Saskatoon, Saskatchewan

**DRAWING: 9**



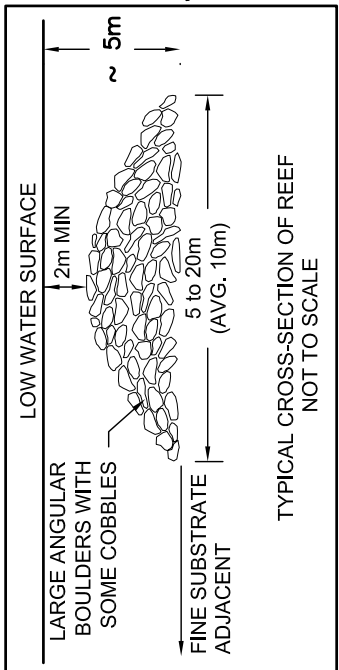
PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER  
 RETENTION DIKES, NORTHWEST TERRITORIES

TITLE **A154 PIT - SCHEMATIC REEF CONFIGURATION**

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| DESIGN                    | RML      | 02/17/03       |        |
| CADD                      | CHECK    |                |        |
|                           | REVIEW   |                |        |

**Golden Associates**  
 Saskatoon, Saskatchewan

**DRAWING: 10**



NOTE:  
 PLAN DEVELOPED FROM INFORMATION  
 PROVIDED BY DIAVIK DIAMOND MINES INC.



**REPORT ON**

**FISH HABITAT DESIGN FOR THE  
A418 PIT SHELF AREA  
AT THE DIAVIK DIAMOND MINE**

Submitted to:

Diavik Diamond Mines Inc.  
P.O. Box 2498  
5007 – 50<sup>th</sup> Avenue  
Yellowknife, Northwest Territories  
1XA 2P8

Attention: Mr. Gord MacDonald

**DISTRIBUTION:**

- 1 Copy - Diavik Diamond Mines Inc., Yellowknife (+1 CD)
- 1 Copy - Golder Associates Ltd., Saskatoon
- 1 Copy - Golder Associates Ltd., Vancouver

December 2008  
07-1328-0001

Doc No. RPT-788 Ver.0 Rev.1

## **EXECUTIVE SUMMARY**

This report presents the detailed design for the creation of fish habitat on the interior of the A418 water retention dike for the Diavik Diamond Mines Inc. diamond mine located on Lac de Gras in the Northwest Territories, Canada. This design was prepared in accordance with the “No Net Loss” plan prepared by Diavik Diamond Mines Inc.

This design is applicable to the A418 pit and has been prepared by developing criteria for the end result. This approach provides flexibility on the part of Diavik Diamond Mines Inc. as to how the end result is achieved.

The fish habitat creation on the interior of the dikes consists of placing material excavated from the open pits in the area between the pit crest and the toe of the dikes, to create an area generally varying from 3 to 5 m below the mean normal water level for Lac de Gras. During mining operations, the toe of the fill will be set back from the edge of the pit crest for safety. At the completion of mining, the fill will be extended to the pit crest.

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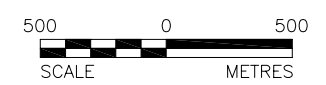
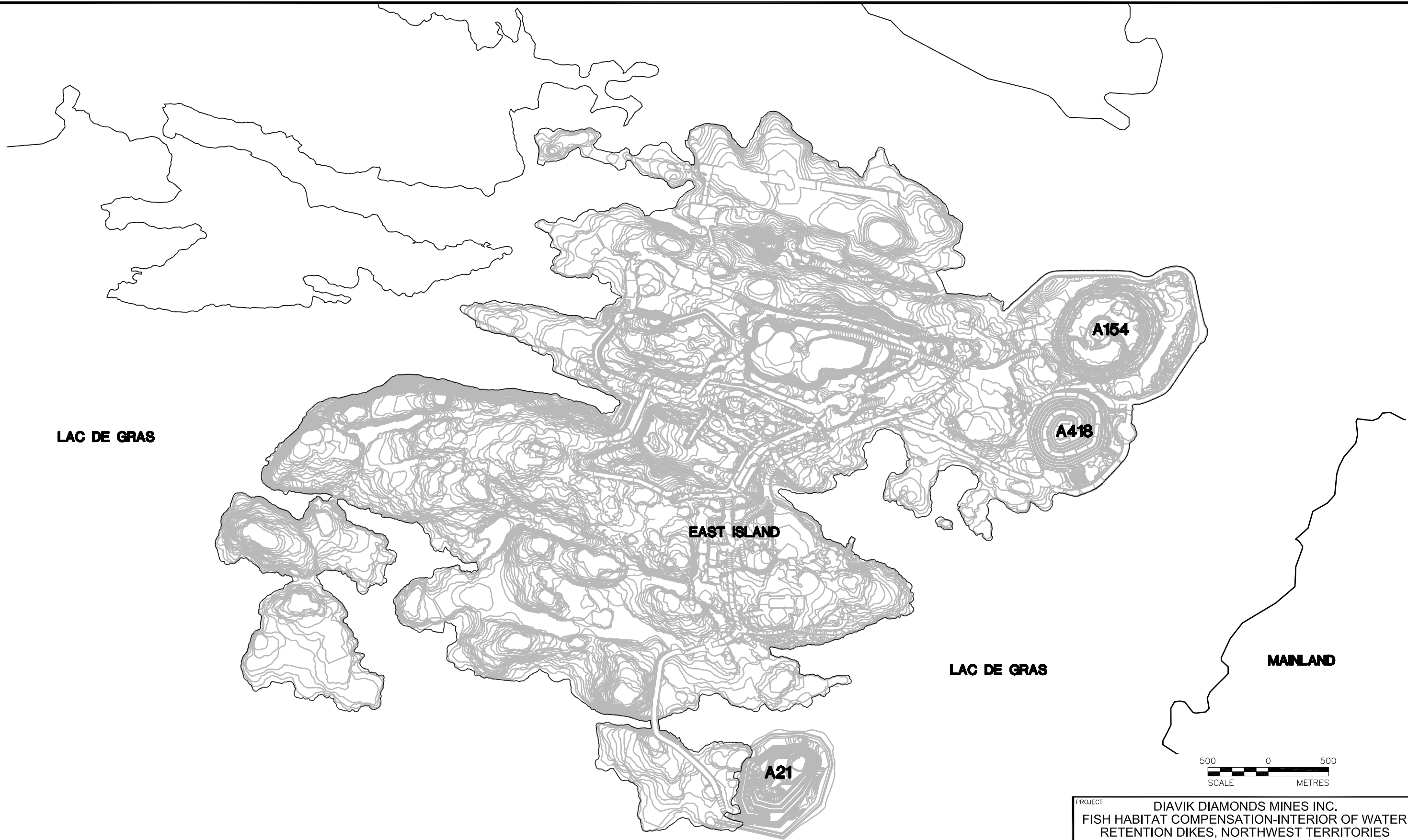
## 1.0 INTRODUCTION


This report presents the detailed design for the fish habitat compensation plan for the interior of the water retention dikes (i.e., the pit shelf) at the Diavik Diamond Mines Inc. (DDMI) diamond mine in the Northwest Territories. The location of the mine is shown in Figure 1. This detailed design is based on the “No Net Loss” (NNL) Plan (Diavik 1998), and the conceptual fish habitat plan prepared by Golder Associates Ltd. (Golder 2001). The conceptual fish habitat compensation plan for the pit shelf is to construct habitat on the shelf, by filling in the lower elevation (deeper water) areas. The general plan is to fill in the areas on the shelf that are deeper than 5 metres (m) of water depth with materials excavated during development of the pits.

As stated, this document provides the detailed design for the fish habitat compensation for the pit shelf; however, it does not provide specifications for construction. Rather, this document provides details for achieving the desired end result, while providing flexibility in how the end result is achieved. The requirement for this flexibility is due to some of the unknowns with respect to material parameters, mine operations (i.e., blasting details, availability of various materials), and construction timing. The habitat design parameters were developed considering fish habitat, surface water runoff, and geotechnical issues. Design details with respect to surface water handling, material selection, construction, and other issues would be addressed by DDMI, to achieve the desired habitat compensation prior to reflooding of the diked areas.

This design applies specifically to the A418 pit; however, it is similar in concept to plans developed for the A154 and A21 pits. Both A154 and A418 have been constructed with the A418 construction completed in 2006. A21 is currently under financial review and has no scheduled construction timeline. The water retention dike (dike) locations and pit layouts for A418 were modified slightly during construction, and have resulted in minor changes in habitat areas when compared with the original NNL Plan predictions. It is intended that the design details (particularly setback distances and slope angles) be reviewed prior to construction of fish habitat compensation measures to incorporate knowledge gained from the construction and performance of A154, as well as any additional studies, investigations and analyses conducted after the preparation of this report. It will also be important to consider mine operations, seepage control measures for the dikes, overall pit stability and instrumentation/monitoring requirements. It was understood that the pits will be developed in a series of expansion cuts, thus permitting the opportunity to monitor slope stability and pore-pressures in the in situ materials in each pit well in advance of the excavation of the final pit slopes, and construction of the fish habitat fills.

G:\2007\1328\07-1328-0001 Diavik\Phase 2000\cad\07-1328-0001 Figure 1.dwg Dec 18, 2008 - 4:43pm



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| PROJECT  |         | DIAVIK DIAMONDS MINES INC.<br>FISH HABITAT COMPENSATION-INTERIOR OF WATER<br>RETENTION DIKES, NORTHWEST TERRITORIES |                  |               |
| TITLE  |         | PROJECT LAYOUT  |                  |               |
| <br>Golder Associates<br>Calgary, Alberta | PROJECT | 07-1328-0001  | FILE No.         |               |
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|  | REVIEW  | PGB 18/12/08  | <b>FIGURE: 1</b> |               |

## 2.0 BACKGROUND

The objective of the fish habitat compensation measures on the interior of the water retention dikes is to provide spawning, nursery, rearing and foraging habitat for lake trout (*Salvelinus namaycush*), cisco (*Coregonus artedi*), round whitefish (*Prosopium cylindraceum*), lake whitefish (*Coregonus clupeaformis*), longnose sucker (*Catostomus catostomus*), burbot (*Lota lota*), northern pike (*Esox lucius*), and slimy sculpin (*Cottus cognatus*), in addition to rearing and foraging habitat for Arctic grayling (*Thymallus arcticus*). The primary gains in habitat are expected to relate to rearing habitat for lake trout, cisco, and slimy sculpin. The habitat on the insides of the dikes was to be designed to be similar to the pre-mine habitat in the north inlet which was considered a shallow, productive area of the lake. The objectives and conceptual design for the fish habitat compensation, were outlined in Golder's report entitled "*Conceptual Design and Compensation Workplan for the Fish Habitat Compensation Program, Diavik Diamond Mines Inc., Lac de Gras*", dated August 2001. The conceptual design consisted of:

- Re-contouring the pit shelf (area between the interior toe of the water retention dike and the crest of the pit slope) to provide habitat with a water depth of approximately 5 m after the dike is breached. New habitat will only be constructed where the pre-mining water depth exceeded 5 m; the shallower areas of the shelf will not be excavated, as these areas already provide shallow water habitat. If fill is placed in this area during mine operations, setbacks will be required between the pit crest and the toe of the slope, as well as between the interior toe of the dike and the toe of the fill slope. These areas could be filled near the end of mining, or after completion of mining, if required.
- Constructing long, narrow, rocky reefs extending from the interior slope of the dike to the crest of the open pit. The reefs would be built in areas where the water depth is 5 m and would be approximately 2 to 3 m high. Areas of granular and soft substrates between the reefs would be based on the conditions that existed in the north inlet.
- Modification of disturbed shoreline areas to establish conditions similar to pre-development. This may include placement of boulders in water depths up to about 5 m.
- Flooding the area after completion of habitat construction.
- Breaching the dikes to create shallow (minimum 2 m depth from low water) entrances, to deter the movement of larger fish into the nursery and feeding habitat, similar to the rearing habitat in the north inlet.

### 3.0 DESIGN PARAMETERS

#### 3.1 Geotechnical Parameters

Geotechnical parameters used were similar to those used in the fish habitat design for pit A154, as the material composition and construction guidelines for the fish habitat compensation on the pit shelves are similar. Bathymetric contours, till thickness isopachs, and sediment thickness isopachs for the A418 pit area were updated in the analysis, as were till strength properties and seismic parameters. During the final design and construction stage, these input parameters can be re-evaluated as necessary if new information becomes available.

Till and sediment samples were characterized as part of the fish habitat design for A154, as described in the Golder report number 012-2331, “*Fish Habitat Design for the Pit Shelf Areas at the Diavik Diamond Mine*”, dated March 2003 (Golder 2003). Since then, additional testing has been conducted on the till; therefore, updated material properties for the till material on site were incorporated into the fish habitat design for the A418 pit. Due to the thickness of the lake sediments and its similarity to the till material, the sediments were modelled as till in the analysis. Material properties used in the stability analysis are summarized in Table 1.

**Table 1**  
**Material Strength Properties Used for Stability Analysis**

| Material | Unit Weight<br>(kN/m <sup>3</sup> ) | Effective Angle of Internal Friction<br>(°) | Effective Cohesion<br>(kPa) |
|----------|-------------------------------------|---|-----------------------------|
| Till     | 22                                  | 34  | 0                           |
| Sediment | 22                                  | 34  | 0                           |

Notes: kN/m<sup>3</sup> = kiloNewtons per cubic metre; ° = degrees; kPa = kilopascal.

The bathymetric information in the A418 area indicated that the maximum water depth was about 22 m. The deepest water around the pit crest appears to be approximately 17 m, and the deepest water near the toe of the dike is also approximately 17 m. The highest expected face of placed aquatic habitat fill over the long-term for A418 is expected to be approximately 11 m.

Based on available information from exploration boreholes, the lakebed sediments range from about 0 to 5 m thick and are typically less than 2 m thick, except for a few localized pockets. The in situ till, beneath the sediment, ranges up to approximately 10 m thick and is typically 5 to 9 m thick.

## **3.2 Fish Habitat Parameters**

### **3.2.1 Overview of No Net Loss Requirements related to Insides of Dike Areas**

The Fisheries Authorization identified the requirements for achieving NNL of habitat for all aspects of the DDMI Diamond Project. Specific requirements for the inside of the A418 dike include:

- the development of shallow rearing habitat, spawning shoals, and shoreline habitat within the dikes areas around the open pits in Lac de Gras upon completion of mining in each open pit; and
- ensuring that the habitat features within the dikes areas are modelled after those features found in other productive areas of Lac de Gras, including depth, substrate type, size, and configuration.

Four key zones of habitat were identified in the NNL Plan (Diavik 1998) for the area found inside the constructed dike during the post closure phase. These included:

1. Inside edge of the dike. The area of water depths from 0 to 2 m along constructed sections of the dike representing new shoreline habitat.
2. Reclaimed shorelines. Areas of pre-existing shorelines.
3. The pit shelf. The area between the inside edge of the dike, the shorelines, and the pit crest.
4. Deep water. The pit itself as it will have a depth of approximately 210 m.

The NNL Plan provided Habitat Unit (HU) calculations based on the available design information for the dikes and pits at the time. Some modifications to the dike design and pit dimensions were made subsequent to the submission of the NNL plan, and the new HU calculations reflect these changes. The HUs calculated as part of the NNL Plan Addendum (DDMI April 1999), along with re-calculated values based on this updated information are presented in Appendix I.

The following sections outline the general principles and criteria to be used in developing the final layout for the A418 dike area. As discussed in the NNL, the primary focus for habitat creation inside of all dikes is based on providing spawning, nursery, rearing and foraging habitat. Target species include lake trout, arctic grayling, burbot, longnose sucker, round whitefish, cisco, lake whitefish, northern pike, and slimy sculpin.

### **3.2.2 Overall Criteria**

Several overall governing criteria can be applied to the habitat creation activities inside the dike. First of all, areas inside the dike on the pit shelf that are already at a depth of 4 m or less should not be disturbed if possible. This will allow the maintenance of habitat features not easily re-created. In areas where final depth is between 4 and 5 m, it would be desirable to maintain existing habitat depending upon grading requirements for drainage, or other construction/operational considerations. Existing shoreline features should also be maintained to the extent feasible. Construction crews should avoid driving on, dumping on, scraping, or otherwise impacting these areas. Leaving these areas intact will decrease the amount of work required to restore the shoreline at closure and will speed the recovery process of the altered areas inside the dike as a variety of organic properties, including the possibility that dormant life stages of some plants or animals will be present in the substrate.

The storage and handling of materials, particularly hydrocarbons or other types of contaminants should be closely monitored on the shorelines, pit shelf, and inside edges of the dike. Heavy equipment in the area should be maintained and fuelled in a manner that avoids the possibility of spills occurring in areas to be reclaimed as fish habitat.

### **3.2.3 Inside Edges of Dike**

The inside edge of the dike is intended to provide new shoreline features for foraging and rearing habitat for most species as well as other values, including spawning, for slimy sculpin. The dike itself will resemble existing shoreline and reef habitat and is expected to provide a rocky (boulder/cobble), moderate slope area with low to moderate wind and wave action. The NNL plan habitat evaluation completed for the inside edge the dike treated this area as shoreline habitat.

Suitable materials for this habitat feature are a mix of primarily large boulder with some smaller cobble. Slopes should also ensure a stable profile and range from gentle to moderate. The range of slopes for existing shorelines should be used as a guideline. The area of habitat gain predicted in the NNL plan as well as the area based on the constructed dike alignment for this habitat type is provided in Table 2. For A418, based on constructed dike configuration and the design criteria presented in this report, 0.34 hectares (ha) of new shoreline habitat are expected to be created.

**Table 2**  
**Inside Edge of the Dike Shoreline Habitat Areas**

| Dike | No Net Loss Predicted Area<br>(ha) | Current Predicted Area <sup>(a)</sup><br>(ha) |
|------|------------------------------------|---|
| A418 | 0.48                               | 0.34  |

Notes: ha = hectare.

(a) = Based on final constructed configuration of the A418 dike.

### 3.2.4 Reclaimed Shorelines

The objectives for the pre-existing shoreline along the edge of the diked area, and around any islands within diked areas, are to:

- minimize change to existing substrates or other features; and
- re-configure disturbed portions to pre-development conditions as much as possible.

This will allow the shoreline areas to be restored to pre-existing conditions once the dike is breached. Any areas of disturbed shoreline are to be re-configured to provide fish habitat resembling that which was temporarily lost during the project. This may include placement of boulders in water up to 5 m deep to provide a sloping shoreline. The area of habitat predicted in the NNL plan for this habitat type is provided in Table 3. For A418, based on the dike configuration and design criteria presented in this report, 1.2 ha of shoreline habitat are expected to be reclaimed and includes shoreline areas around one island on the pit shelf.

**Table 3**  
**Reclaimed Shoreline Habitat Areas**

| Dike | No Net Loss Predicted Area<br>(ha) | Current Predicted Area <sup>(a)</sup><br>(ha) |
|------|------------------------------------|---|
| A418 | 0.61                               | 1.2   |

Notes: ha = hectare.

(a) = Based on final constructed configuration of the A418 dike.

### 3.2.5 Pit Shelf

The pit shelf area extends from the lower inside edges of the dike to the edges of the pit. The reclaimed pit shelf area is intended to provide shallow foraging and rearing habitat for most species of fish present in Lac de Gras. Material excavated from the pit will be used to fill in deeper portions of the pit shelf area. The area of the pit shelf will be covered by water that ranges from 3 to 5 m deep. As per the *Navigable Waters*

*Protection Act* Permit for the project, no dike breach or constructed shoal features will be less than 2 m below the expected low water level in Lac de Gras.

As indicated in the NNL plan and the Fisheries Authorization, the objectives for the selection of substrate type are based on reflecting physical characteristics of other areas of good foraging and rearing in Lac de Gras. The pit shelf configuration is also to be based on reflecting the physical characteristics of other productive habitats within Lac de Gras. In order to address these objectives, substrate information from baseline data collections was used and a basic configuration evaluation of the North Arm and two other nearby inlets identified as rearing areas within Lac de Gras was completed. The configuration evaluation was completed through air photo interpretation. Key features identified by assessing other rearing areas included:

- Rocky Shoal Shape – Rocky shoals should be somewhat irregular in size and shape and relatively long and narrow. Some may also be constructed like a series of submerged rocky humps like links in a chain. Longer and narrower reefs have more “edge” habitat. Edges are important to fish that feed in one habitat type and rest or seek refuge in another.
- Isolated Pond-like Areas - In some cases it is beneficial to small fish to have the reefs forming a disjointed “ring” to provide pond-like conditions where circulation is limited.
- Hard to Soft Substrate Ratio - The hard substrate (shoals areas) to soft substrate (depositional areas) ratio in other nearby rearing areas ranged from 25 to 40% hard with the remainder as soft substrate.
- Access to Refuge Habitat – Rocky reefs provide refuge or cover for small fish. It is important for fish to have connectivity between rocky areas and reefs to avoid exposing themselves for extended distances or periods of time to predators. Keeping the distance between rocky reef areas less than 30 to 40 m will allow fish reasonable access refuge, or hiding places.

### **Shape Configuration**

With regard to water circulation within the diked area, several features should be incorporated to reduce circulation. The shallow nature of the breaches, shallow nature of the pit shelf, and the creation of shoals on the pit shelf will reduce circulation and wind and wave action. The shallow water is expected to warm up quickly in the spring, relative to open areas of the lake, because of the limited water circulation within the enclosed area. As with other rearing habitats in Lac de Gras, warmer water should, therefore, assist in increasing biological productivity inside the dike by providing a warmer refuge, and foraging area.



Determining the locations of the reefs should take several factors into consideration. Reefs should have some connectivity to the dikes and other reefs to allow fish to travel throughout the area without being fully exposed to predators for long distances. If the reefs are long, winding, and finger-like, a large amount of “edge” habitat will be created to allow fish to feed in the fine substrate while maintaining close proximity to the cover provided by the rocky reefs. Ideally, the reefs will be placed in areas where the final water depth will be 3 to 5 m deep and the tops of the reefs will remain under at least 2 m of water at all times. This will allow the reef habitat to remain functional even in winter with ice thickness of up to 2 m. Widths of the reefs should vary between 5 and 30 m, averaging from 10 to 20 m in width. The distance between the reefs could range from 10 to 40 m, averaging from 20 to 30 m apart. Habitat diversity is important and varying the size and shape of the reefs throughout the pit shelf area is expected to improve its value as fish habitat.

### **Substrate Material**

Based on the substrate materials within the North inlet substrates on the pit shelf should be mostly fine material, primarily sand and silt interspersed with rocky reefs for habitat diversity. The till (existing lake substrate) is primarily sand and silt with some gravel. The till material will therefore be an appropriate substrate for the expected biological zone of the sediments (i.e., approximately top 10 centimetre (cm) layer represents the biological zone). The fine substrate areas are expected to support a variety of benthic organisms that will provide forage for small fish.

If till is placed over angular rock to provide the soft substrate zone, it should be a layer deep enough to maintain at least 0.5 m depth of soft substrate after settling, accounting for some migration of fines into the voids in the rock fill.

Reefs should be constructed of granular material of a range of sizes. The primary material should be large boulder size rock with some smaller cobble material. The objective is to create refuge habitat, or hiding areas, among the rocks. Angular, unconsolidated material would provide this benefit. Run of mine blast rock is expected to be acceptable for this purpose.

The area of habitat predicted in the NNL plan for this habitat type is provided in Table 4. For A418, based on constructed dike configuration and the design criteria presented in this report, 9.4 ha of shallow rearing and foraging habitat are expected to be created.

**Table 4**  
**Pit Shelf Habitat Areas**

| <b>Dike</b> | <b>No Net Loss Predicted Area<br/>(ha)</b> | <b>Current Predicted Area<sup>(a)</sup><br/>(ha)</b> |
|-------------|--|--|
| A418        | 8.68                                       | 9.4  |

Notes: ha = hectare.

(a) = Based on final constructed configuration of the A418 dike.

### 3.2.6 Deep Water (Pit Area)

The deep water habitat created by the project will be located in the mine pit, near the center of the diked area. The deep water will provide a cooler environment for fish and was considered a pelagic zone in the NNL plan. This area will likely be used by pelagic feeding fish such as cisco and may provide other benefits (e.g., over wintering habitat). The maximum depth of the pit areas is anticipated to be 210 m. The area of habitat predicted in the NNL plan for this habitat type is provided in Table 5. For A418, based on constructed dike configuration and the design criteria presented in this report, 34.13 ha are actually expected to be created.

**Table 5**  
**Deep Water Habitat Areas**

| <b>Dike</b> | <b>No Net Loss Predicted Area<br/>(ha)</b> | <b>Current Predicted Area<sup>(a)</sup><br/>(ha)</b> |
|-------------|--|--|
| A418        | 41.94                                      | 34.13  |

Notes: ha = hectare.

(a) = Based on final constructed configuration of the A418 dike.

### 3.3 Construction Considerations

There are a number of construction considerations that arise due to the variability in the material parameters, pore-pressure conditions, blasting effects, and construction timing. The following construction considerations were evaluated with respect to the detailed design of the fish habitat compensation measures for the pit shelf areas:

- It was understood that flowing artesian conditions were present in the southeast portion of the A154 pit shelf. Artesian conditions may cause build-up of porewater pressures within the fill on the pit shelf, depending on drainage conditions and the development of frozen layers. It is unknown if similar conditions exist on the A418 pit shelf.

- The fine-grained lake-bottom sediments are expected to provide poor trafficability, particularly where artesian conditions exist, and when the materials are thawing. Portions of the A418 dike are expected to encounter permafrost, which would also present poor trafficability conditions if it thaws.
- A berm will be required between the pit crest and the toe of the fish habitat fill to provide safety with respect to equipment travelling too close to the pit crest and to reduce the potential for fill materials spilling into the pit during placement. The berm could also be used as a construction access road prior to pit development adjacent to the berm.
- The majority of the fill volume may consist of either till or rock fill, depending on construction timing and material availability. The final surface of the fill will consist of till, or lake-bottom sediments, to support aquatic life. The thickness of the final till/sediment layer will depend on whether a filter is used between the rock and till. DDMI will be responsible for picking the construction methods, and materials handling such that adequate quantities of till are available for the final fill surface.
- Based on gradation information for the till from the A154 pit shelf, it is anticipated that at least two, and possibly three graded aggregate filters would be required to prevent the till from migrating into the voids within the rock fill. Production of filter material would likely be relatively expensive, since it would involve crushing, screening, stockpiling, and double handling of the materials. It has been assumed that a filter between the rockfill and the till would not be utilized, due to logistical and economic considerations. As an alternative to using a filter, the thickness of the till cover on a rock fill can be varied as a function of the total fill thickness. The premise for this approach is that a certain portion of the till will migrate into the void spaces in the rock fill, so the thickness of the till cover must be such that a minimum of 0.5 m of till remains on top of the rock. For design purposes, it has been assumed that the porosity of the rock fill would be approximately 30 percent, and that with time, till would migrate into the rock such that 50 percent of the available voids would be filled. Thus, using this approach, the minimum thickness of till required over the rock is equal to 15 percent of the rock fill thickness, plus 0.5 m. If this approach is adopted, some overbuilding of the till layer should be considered to maintain the desired water depths after the till migrates into the rock fill, especially where the till thicknesses are greater. Theoretically, where rocky reefs are to be constructed, till would not be required between the rock fill and reef material.
- Rock fill has the advantages of higher shear strength and better potential for drainage/dissipation of pore-water pressures. Rock fill may require a smaller thickness than till to provide a stable trafficking surface for the initial lifts.
- Rock fill would permit faster infiltration than till, which may provide a more stable trafficking surface after precipitation events and during spring thaw.

- Till will be available earlier in the mining cycle for each pit, since it overlies the bedrock. Materials may be transported between pits, if required.

## **4.0 STABILITY ANALYSES**

### **4.1 Overall Pit Stability**

Golder prepared various reports regarding the stability of the A154 pit (Golder 1999, 2000, 2002, 2002a). The overall pit stability for A418 was assessed in Golder's report entitled, "*A418 Feasibility Pit Slope Design*" (Document No. Rpt-138, dated January 11, 2007). Pertinent items from this report related to the fish habitat compensation fills are as follows:

- Fractured rock zones similar to Dewey's Fault in the vicinity of the A154N/S pipes have not been encountered in the A418 area; however, a bathymetric low, trending a north-south direction, occurs in the south through southeast area of the planned pit. This feature is not fully understood, although while it has been speculated that it could potentially be a zone of high hydraulic conductivity, there is currently no evidence to support this.
- Modelling showed that depressurization will be necessary for Section 130 in order to achieve the required safety factor for the overall slope. Recommendations were provided for piezometer installations to monitor the depressurization of the pit wall.

Construction of the fish habitat compensation fill will require a setback from the crest of the pit to the toe of the fill, such that the overall pit stability is not significantly impacted by the presence of the fish habitat fills on the pit shelf during operations.

### **4.2 Stability of Fish Habitat Fills**

Slope stability analyses were carried out to determine the stability of the fish habitat fills, and the required setback from the pit crest. The impact of the placed material on the stability of the pit was also checked.

Stability analyses were carried out using the computer program, SLOPE/W. Factors of safety were calculated using the principle of limit equilibrium, for potential sliding along assumed failure surfaces for each of the selected cross-sections. Factors of safety were computed using both Spencer's method and the Morgenstern-Price method, which satisfy both force and moment equilibrium. Based on the type of soil and the configuration of the habitat, both circular and wedge failure mechanisms were assessed. The factor of safety was assessed for a phreatic level which was situated at the top of the till/lake sediment surface, simulating saturated conditions in the pit shelf. This is considered conservative due to cut-off measures to be implemented during the dyke construction.

The effects of blasting in the pit on the stability of the fill were assessed by using a pseudo-static limit equilibrium analysis using a 1:2500 year return earthquake value of 0.06 g in the horizontal direction. As production blasting data is accumulated, the impact of blasting may be reassessed and the design refined.

The results of the stability analyses are summarized in Appendix II. The stability analyses indicate that computed factors of safety for the fills are in excess of 1.4 for the conditions during mining. A conservative approach with respect to setback distances and slope angles is proposed, combined with monitoring to assess modifications to the proposed design as mining proceeds, due to the critical importance of maintaining stability during operations. The recommended setback from the pit crest (i.e., top of the in-situ till slope to the toe of the fish habitat fill) is four times the height of the fill (taken as the difference between the ultimate top of the fill and the elevation of the pit crest), with a minimum of 15 m. The slope of the faces of the fish habitat fill facing the pit and the interior of the dikes should be 3H:1V or flatter. As mining progresses, it may be possible to modify the setback and slope angle parameters.

## 5.0 CONSTRUCTION GUIDELINES

The recommended configuration of the fish habitat on the A418 pit shelf is based on the following guidelines:

- Construct fills with face slopes of 3H:1V during mining, and final slopes at the angle of repose adjacent to the pit crest at the completion of mining.
- Setback from the pit crest to the toe of the fill equal to four times the elevation difference between the top of fill and the pit crest, with a minimum distance of 15 m.
- To the extent feasible, areas of existing shallow habitat (i.e., water depth less than 5 m below mean normal water level) should remain untouched.
- A berm should be constructed between the toe of the till slope and the crest of the pit. This berm will help retain material that erodes from the slope of the fish habitat fill and keep it away from the pit, and will also reduce the potential for any material rolling down the slope and into the pit during fill placement. A minimum setback of 5 m from the crest of the pit to the toe of the berm has been used. As a minimum, the berm would be approximately 2 m high, with a 2 m crest width and 2H:1V sideslopes. The geometry of this berm may be modified on the basis of construction techniques.
- A setback from the interior toe of the water retention dike, to the upstream toe of the fill may also be required. This setback distance should be determined by DDMI, based on operational requirements and surface water handling requirements. Construction must also accommodate instrumentation for monitoring seepage through the dike, and overall pit slope stability.
- Construction in one lift is acceptable.
- The materials used to construct the fill may consist of till, rock fill, or a combination of materials. If rock fill is used to construct the lower portion of the fill, the thickness of till to create the final surface should be a minimum of 0.15 times the height of rock fill, plus 0.5 m. Alternatively, filter zones could be provided between the rock fill and the till. Details of the filter zones would have to be developed further, once construction techniques and material gradations are determined. Processing of the blast rock will be required to produce filter materials, and is likely to be expensive. If the filter zone approach is taken, it is likely that at least two, and possibly, three filters would be required.
- Grading of the surface of the fill at a nominal grade of 1% is recommended, to direct surface water towards the water collection system at the toe of the dike.
- Final contouring of the surface will be required to establish some relief to provide fish habitat (i.e., some hummocks and hollows, rather than an evenly graded surface).
- Rock ridges or reefs are also required for fish habitat. These reefs should be constructed of non-acid generating country rock.

## **6.0 DETAILED DESIGN DRAWINGS**

A set of detailed design drawings is included in Appendix III for the A418 pit. The design drawings indicate the desired end results, and provide DDMI with flexibility in regards to construction materials, methods, and timing. Operational considerations and the results of monitoring programs to assess seepage through/below the dike, and overall pit slope stability should be taken into account when planning the construction of the fish habitat fills. At the end of mining, construction of angle of repose slopes adjacent to the pit crest will be required. The exact extent of the fill, placement procedures, and safety protocols should be developed prior to construction.



## **7.0 MONITORING RECOMMENDATIONS**

Monitoring of various parameters is recommended to confirm the design assumptions, and to provide information for refining the design of the fish habitat on the pit shelves. It is recommended that monitoring consist of:

- Monitoring pore-water pressures in the lake-bottom sediments and till that will form the foundation for the fish habitat fills to assess drainage due to pit development, as well as pore-pressures due to fill placement and blasting.
- Monitor pore-pressures within the fish habitat fills, so that the slope stability analyses can be confirmed.
- Monitor movements of the fish habitat fills using a series of monitoring prisms, slope inclinometers or other technologies, consistent with monitoring of the overall pit slopes. Visual inspections should also be conducted to check for signs of instability, such as bulging, slumping, or the development of tension cracks.

Monitoring programs have previously been recommended for the water retention dikes and for monitoring the overall pit stability. It is recommended that the monitoring for the fish habitat fills on the interior of the dikes be integrated into the overall monitoring program, to provide consistency, and improve the efficiency of the monitoring efforts.

## **8.0 CLOSURE**

We trust this report presents the information that you require. Please feel free to call at anytime if you have any questions or concerns.

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**APPENDIX I**

**SUMMARY OF HABITAT UNIT ACCOUNTING FOR A418**

**Table I-1**  
**No Net Loss Habitat Summary "Accounting" Showing Habitat Units for A418,**  
**from No Net Loss Addendum, 1999**

| Life Stage   | Species | A418 (2009-2023) |       | Net Change |
|--------------|---------|------------------|-------|------------|
|              |         | loss             | gain  |            |
| Spawning     | LKTR    | 0.10             | 0.07  | -0.03      |
|              | ARGR    | 0.00             | 0.00  | 0.00       |
|              | CISC    | 0.11             | 0.06  | -0.05      |
|              | RNWH    | 0.02             | 0.05  | 0.03       |
|              | LKWH    | 0.04             | 0.02  | -0.02      |
|              | LNSC    | 0.02             | 0.01  | -0.01      |
|              | BURB    | 0.02             | 0.00  | -0.01      |
|              | NRPK    | 0.00             | 0.00  | 0.00       |
|              | SLSC    | 0.03             | 0.21  | 0.18       |
| Rearing      | LKTR    | 1.00             | 3.60  | 2.60       |
|              | ARGR    | 0.17             | 0.26  | 0.09       |
|              | CISC    | 1.53             | 3.47  | 1.94       |
|              | RNWH    | 0.26             | 0.61  | 0.34       |
|              | LKWH    | 0.28             | 0.62  | 0.34       |
|              | LNSC    | 0.30             | 0.48  | 0.19       |
|              | BURB    | 0.19             | 0.27  | 0.08       |
|              | NRPK    | 0.00             | 0.00  | 0.00       |
|              | SLSC    | 0.26             | 0.43  | 0.17       |
| Foraging     | LKTR    | 0.90             | 0.96  | 0.06       |
|              | ARGR    | 0.10             | 0.13  | 0.04       |
|              | CISC    | 0.88             | 1.65  | 0.77       |
|              | RNWH    | 0.17             | 0.28  | 0.11       |
|              | LKWH    | 0.15             | 0.28  | 0.13       |
|              | LNSC    | 0.21             | 0.24  | 0.03       |
|              | BURB    | 0.11             | 0.12  | 0.00       |
|              | NRPK    | 0.00             | 0.00  | 0.00       |
|              | SLSC    | 0.14             | 0.21  | 0.06       |
| Nursery      | LKTR    | 0.10             | 0.06  | -0.04      |
|              | ARGR    | 0.00             | 0.00  | 0.00       |
|              | CISC    | 0.11             | 0.06  | -0.05      |
|              | RNWH    | 0.02             | 0.05  | 0.03       |
|              | LKWH    | 0.04             | 0.02  | -0.02      |
|              | LNSC    | 0.02             | 0.01  | -0.01      |
|              | BURB    | 0.02             | 0.00  | -0.01      |
|              | NRPK    | 0.00             | 0.00  | 0.00       |
|              | SLSC    | 0.03             | 0.21  | 0.18       |
| <b>Total</b> |         | 7.33             | 14.45 | 7.12       |

**Table I-1**  
**No Net Loss Habitat Summary "Accounting" Showing Habitat Units for A418,**  
**from No Net Loss Addendum, 1999 (continued)**

| Life Stage                 | Species  | A418 (2009-2023) |      | Net Change |
|----------------------------|----------|------------------|------|------------|
|                            |          | loss             | gain |            |
| <b>Total by life stage</b> | Spawning | 0.34             | 0.43 | 0.10       |
|                            | Rearing  | 4.00             | 9.73 | 5.74       |
|                            | Foraging | 2.66             | 3.86 | 1.20       |
|                            | Nursery  | 0.34             | 0.42 | 0.08       |
| <b>Total by species</b>    | LKTR     | 2.11             | 4.69 | 2.59       |
|                            | ARGR     | 0.27             | 0.40 | 0.13       |
|                            | CISC     | 2.62             | 5.23 | 2.61       |
|                            | RNWH     | 0.47             | 0.99 | 0.51       |
|                            | LKWH     | 0.51             | 0.94 | 0.43       |
|                            | LNSC     | 0.55             | 0.74 | 0.19       |
|                            | BURB     | 0.34             | 0.40 | 0.06       |
|                            | NRPK     | 0.00             | 0.00 | 0.00       |
| SLSC                       | 0.47     | 1.06             | 0.60 |            |

Notes: LKTR = lake trout; ARGR = Arctic grayling; CISC = cisco; RNWH = round whitefish;  
 LKWH = lake whitefish; LNSC = longnose sucker; BURB = burbot; NRPK = northern pike;  
 SLSC = slimy sculpin.

**Table I-2**  
**No Net Loss Habitat Summary "Accounting" Showing Habitat Units for A418,**  
**Recalculated with Constructed Dimensions for A418 Dike**

| Life Stage | Species | A418 (2009-2023) |      | Net Change |
|------------|---------|------------------|------|------------|
|            |         | loss             | gain |            |
| Spawning   | LKTR    | 0.10             | 0.09 | -0.01      |
|            | ARGR    | 0.00             | 0.00 | 0.00       |
|            | CISC    | 0.11             | 0.07 | -0.03      |
|            | RNWH    | 0.02             | 0.06 | 0.04       |
|            | LKWH    | 0.04             | 0.03 | -0.01      |
|            | LNSC    | 0.02             | 0.01 | -0.02      |
|            | BURB    | 0.02             | 0.01 | -0.01      |
|            | NRPK    | 0.00             | 0.00 | 0.00       |
|            | SLSC    | 0.03             | 0.21 | 0.17       |
| Rearing    | LKTR    | 1.00             | 3.25 | 2.24       |
|            | ARGR    | 0.17             | 0.24 | 0.06       |
|            | CISC    | 1.53             | 3.11 | 1.58       |
|            | RNWH    | 0.26             | 0.56 | 0.30       |
|            | LKWH    | 0.28             | 0.59 | 0.31       |
|            | LNSC    | 0.30             | 0.45 | 0.15       |

**Table I-2**  
**No Net Loss Habitat Summary "Accounting" Showing Habitat Units for A418,**  
**Recalculated with Constructed Dimensions for A418 Dike (continued)**

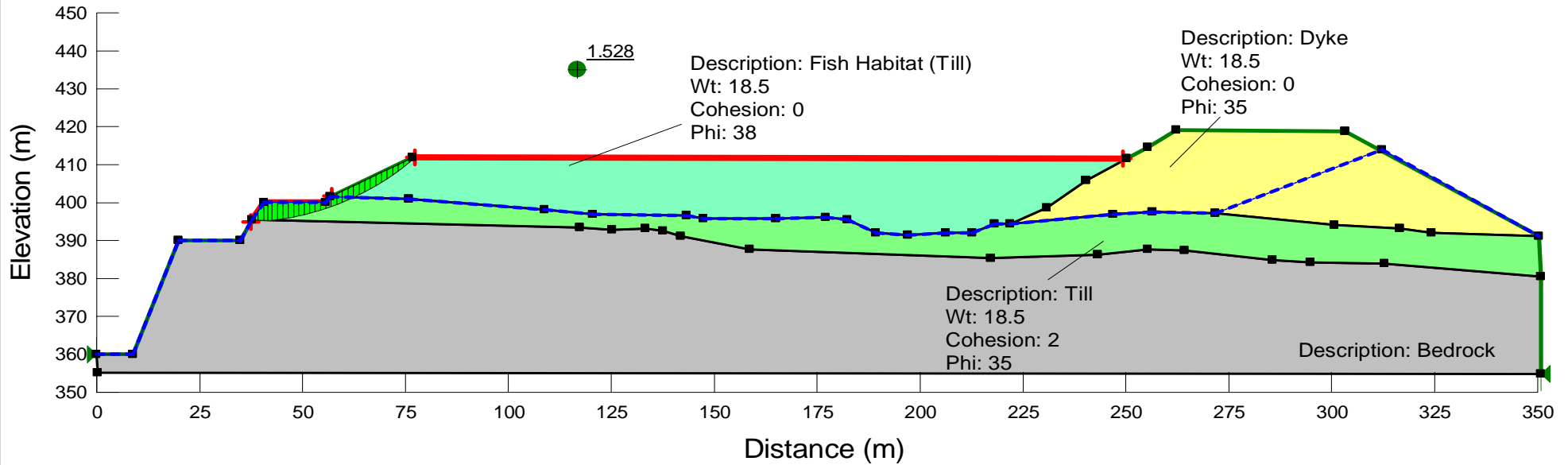
| Life Stage                 | Species  | A418 (2009-2023) |              | Net Change  |
|----------------------------|----------|------------------|--------------|-------------|
|                            |          | loss             | gain         |             |
| Rearing (continued)        | BURB     | 0.19             | 0.25         | 0.06        |
|                            | NRPK     | 0.00             | 0.00         | 0.00        |
|                            | SLSC     | 0.26             | 0.41         | 0.16        |
| Foraging                   | LKTR     | 0.90             | 0.88         | -0.03       |
|                            | ARGR     | 0.10             | 0.12         | 0.03        |
|                            | CISC     | 0.88             | 1.47         | 0.59        |
|                            | RNWH     | 0.17             | 0.25         | 0.09        |
|                            | LKWH     | 0.15             | 0.26         | 0.11        |
|                            | LNSC     | 0.21             | 0.22         | 0.02        |
|                            | BURB     | 0.11             | 0.11         | -0.01       |
|                            | NRPK     | 0.00             | 0.00         | 0.00        |
|                            | SLSC     | 0.14             | 0.19         | 0.05        |
|                            | Nursery  | LKTR             | 0.10         | 0.08        |
| ARGR                       |          | 0.00             | 0.00         | 0.00        |
| CISC                       |          | 0.11             | 0.07         | -0.03       |
| RNWH                       |          | 0.02             | 0.06         | 0.04        |
| LKWH                       |          | 0.04             | 0.03         | -0.01       |
| LNSC                       |          | 0.02             | 0.01         | -0.02       |
| BURB                       |          | 0.02             | 0.01         | -0.01       |
| NRPK                       |          | 0.00             | 0.00         | 0.00        |
| SLSC                       |          | 0.03             | 0.21         | 0.18        |
| <b>Total</b>               |          | <b>7.33</b>      | <b>13.28</b> | <b>5.95</b> |
| <b>Total by life stage</b> | Spawning | 0.34             | 0.46         | 0.13        |
|                            | Rearing  | 4.00             | 8.85         | 4.86        |
|                            | Foraging | 2.66             | 3.51         | 0.85        |
|                            | Nursery  | 0.34             | 0.45         | 0.12        |
| <b>Total by species</b>    | LKTR     | 2.11             | 4.29         | 2.18        |
|                            | ARGR     | 0.27             | 0.36         | 0.09        |
|                            | CISC     | 2.62             | 4.72         | 2.10        |
|                            | RNWH     | 0.47             | 0.93         | 0.45        |
|                            | LKWH     | 0.51             | 0.90         | 0.40        |
|                            | LNSC     | 0.55             | 0.69         | 0.14        |
|                            | BURB     | 0.34             | 0.38         | 0.04        |
|                            | NRPK     | 0.00             | 0.00         | 0.00        |
| SLSC                       | 0.47     | 1.02             | 0.56         |             |


Notes: LKTR = lake trout; ARGR = Arctic grayling; CISC = cisco; RNWH = round whitefish; LKWH = lake whitefish; LNSC = longnose sucker; BURB = burbot; NRPK = northern pike; SLSC = slimy sculpin.

**APPENDIX II**  
**SUMMARY OF SLOPE STABILITY ANALYSES**



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 Comments: Final Configuration

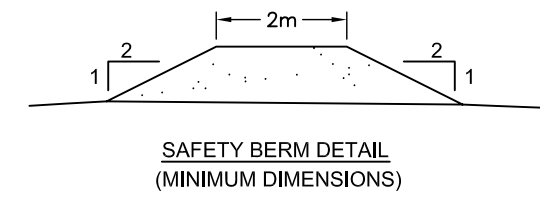
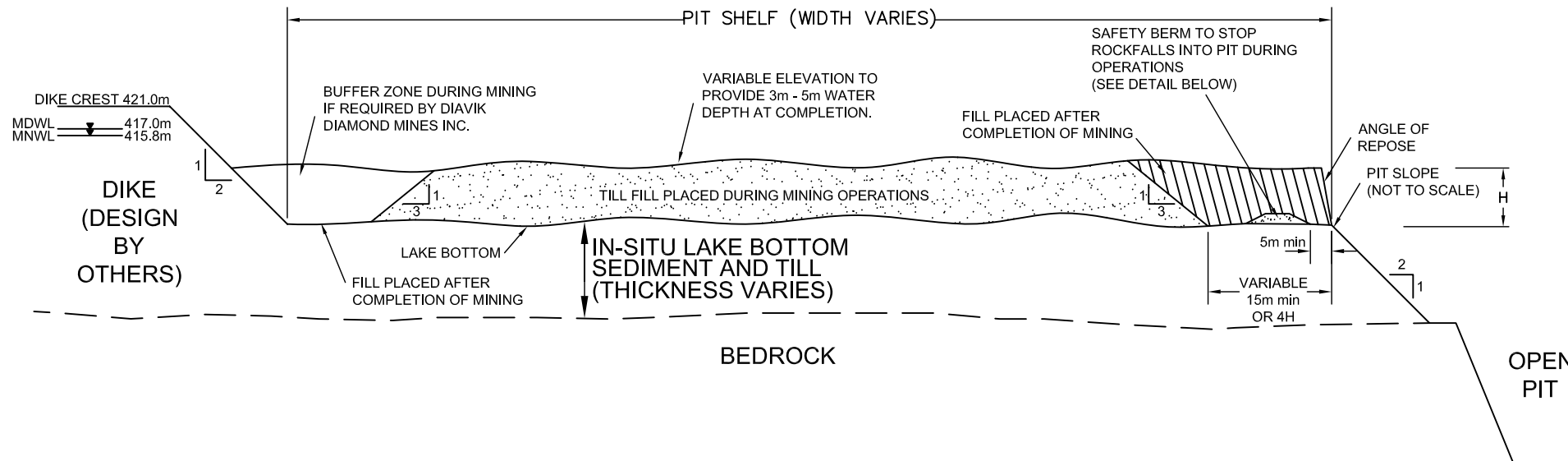


|  |  |     |  |              |  |   |  |     |  |      |  |
|--|--|-----|--|--------------|--|---|--|-----|--|------|--|
| PROJECT  |  |     |  |              |  | DIAVIK DIAMONDS MINES INC.<br>FISH HABITAT COMPENSATION-INTERIOR OF WATER<br>RETENTION DIKES, NORTHWEST TERRITORIES |  |     |  |      |  |
| TITLE  |  |     |  |              |  |   |  |     |  |      |  |
| A418 STABILITY ANALYSIS RESULTS  |  |     |  |              |  |   |  |     |  |      |  |
| PROJECT  |  |     |  | 07-1328-0001 |  | FILE No.  |  |     |  |      |  |
| DESIGN   |  | EAM |  | 23/09/08     |  | SCALE   |  | N/A |  | REV. |  |
| CADD   |  |     |  |              |  |   |  |     |  |      |  |
| CHECK  |  | RML |  | 18/12/08     |  |   |  |     |  |      |  |
| REVIEW   |  | PGB |  | 18/12/08     |  |   |  |     |  |      |  |
| <br><b>Golder Associates</b><br>Saskatoon, Saskatchewan |  |     |  |              |  | <b>FIGURE:II-1</b>  |  |     |  |      |  |

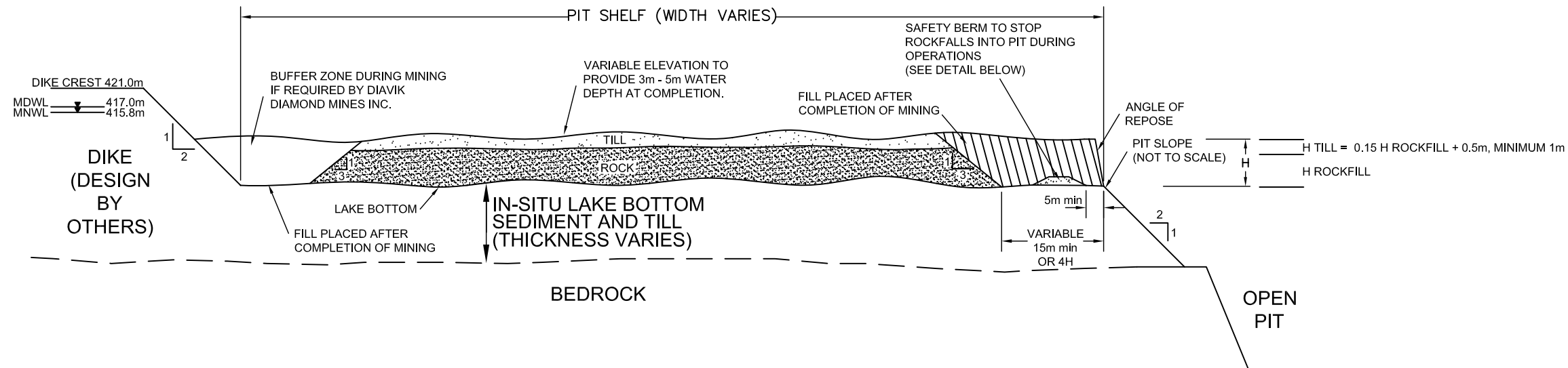
**APPENDIX III**  
**DETAILED DESIGN DRAWINGS**

C:\2007\1328\07-1328-001 Diavik\Phase 2000\cod\ Drawing file: CONCEPTUAL\_XSECTION.dwg Dec 18, 2008 - 4:48pm

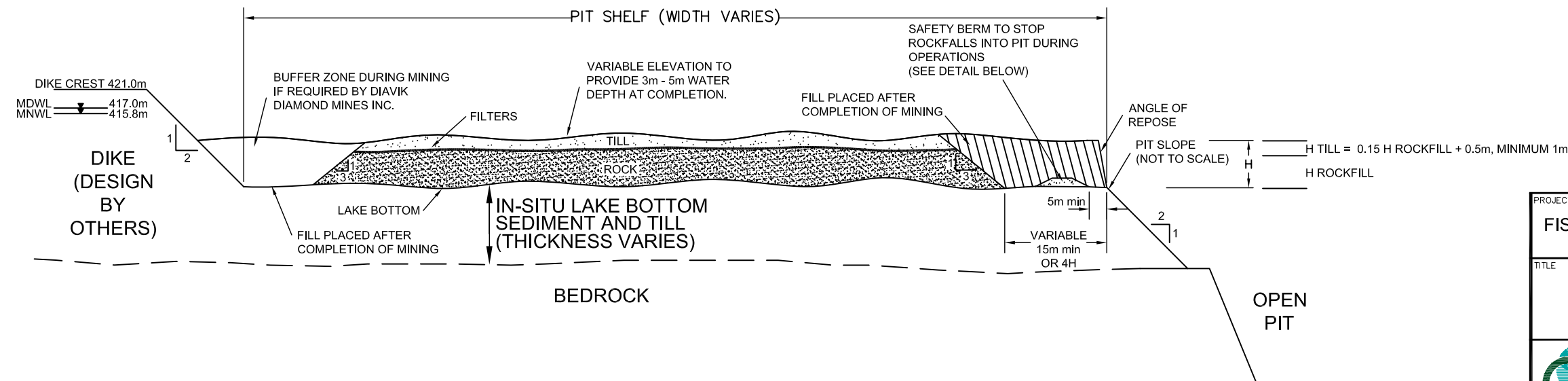
### TILL FILL OPTION



### ROCK/TILL OPTION (NO FILTERS)



### ROCK/TILL OPTION (WITH FILTERS)

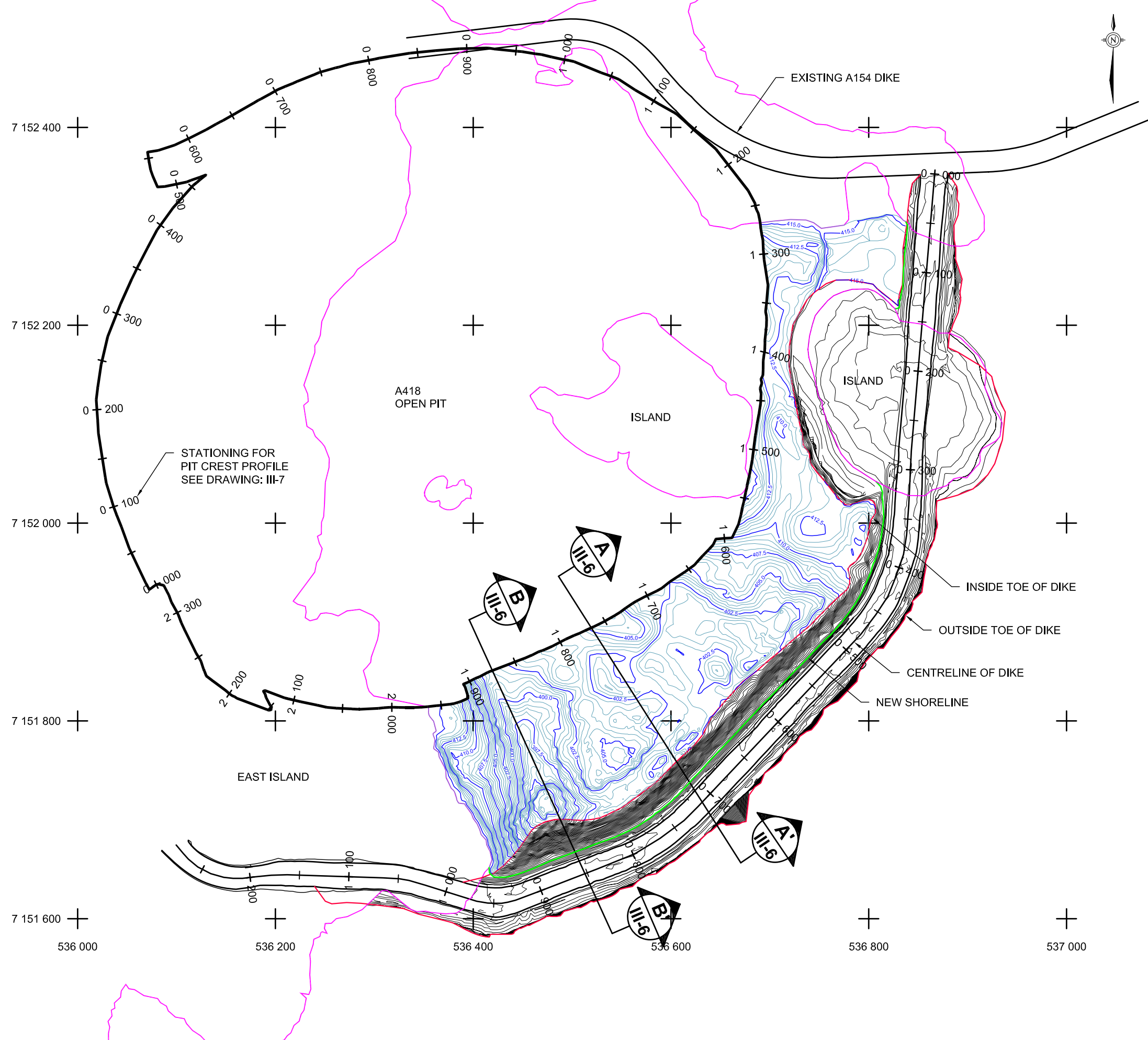


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|---------|--|----------|------------|
| PROJECT | DIAVIK DIAMOND MINES INC.<br>FISH HABITAT COMPENSATION-INTERIOR OF WATER<br>RETENTION DIKES, NORTHWEST TERRITORIES |          |            |
| TITLE   | <b>CROSS-SECTION OPTIONS FOR<br/>FISH HABITAT<br/>CREATED INSIDE DIKES</b>   |          |            |
| PROJECT | 07-1328-0001   | FILE No. |            |
| DESIGN  |  | SCALE    | NTS REV. 0 |
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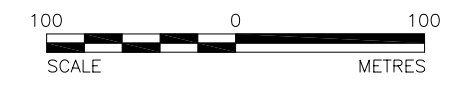


**FIGURE: III-1**

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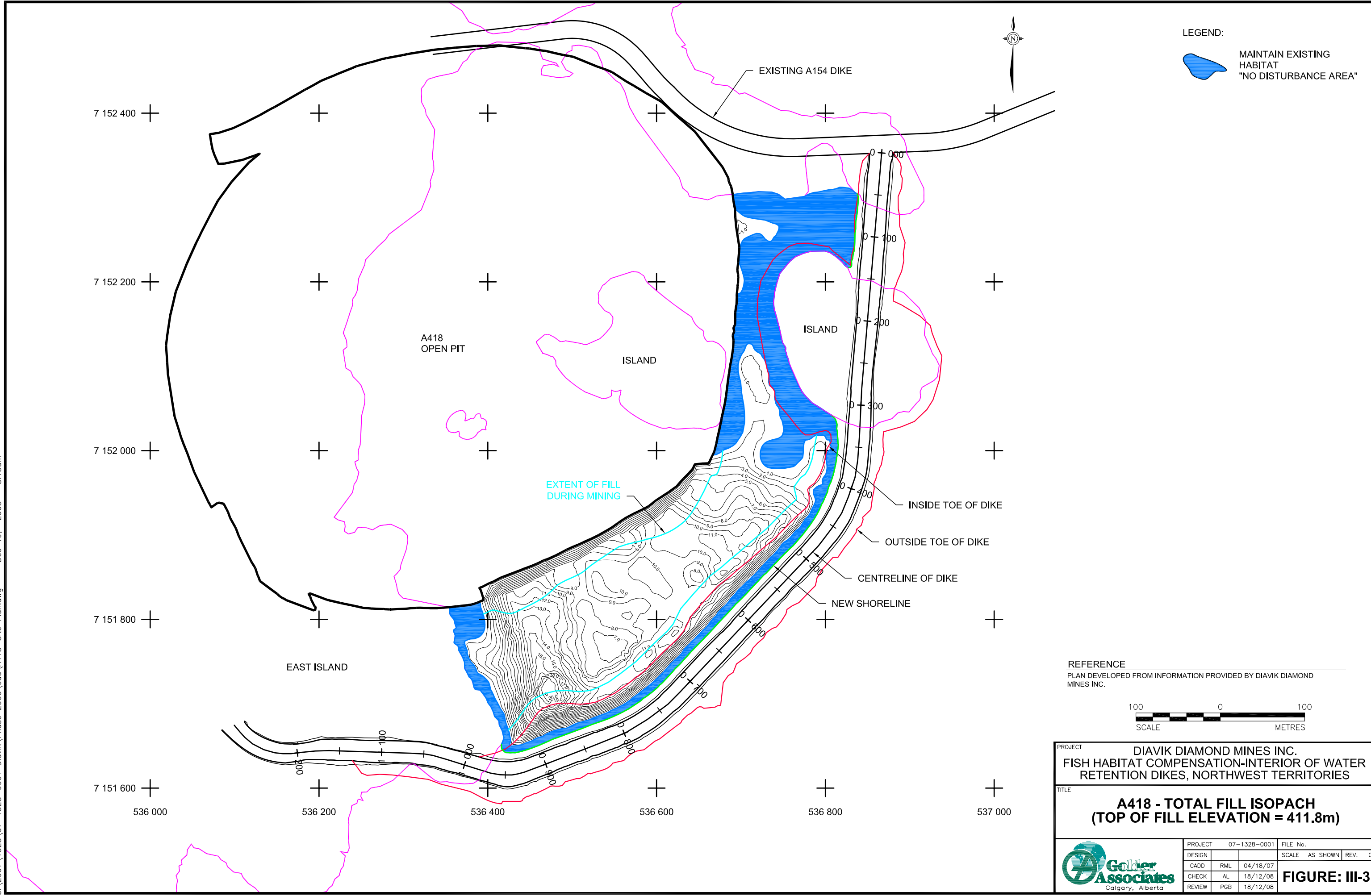
REFERENCE  
 PLAN DEVELOPED FROM INFORMATION PROVIDED BY DIAVIK DIAMOND MINES INC.



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|         |              | FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES |          |
| TITLE   |              | <b>BATHYMETRY - A418 PIT</b>   |          |
| PROJECT | 07-1328-0001 | FILE No.   |          |
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| CHECK   | AL 18/12/08  | <b>FIGURE: III-2</b>   |          |
| REVIEW  | PGB 18/12/08 |  |          |




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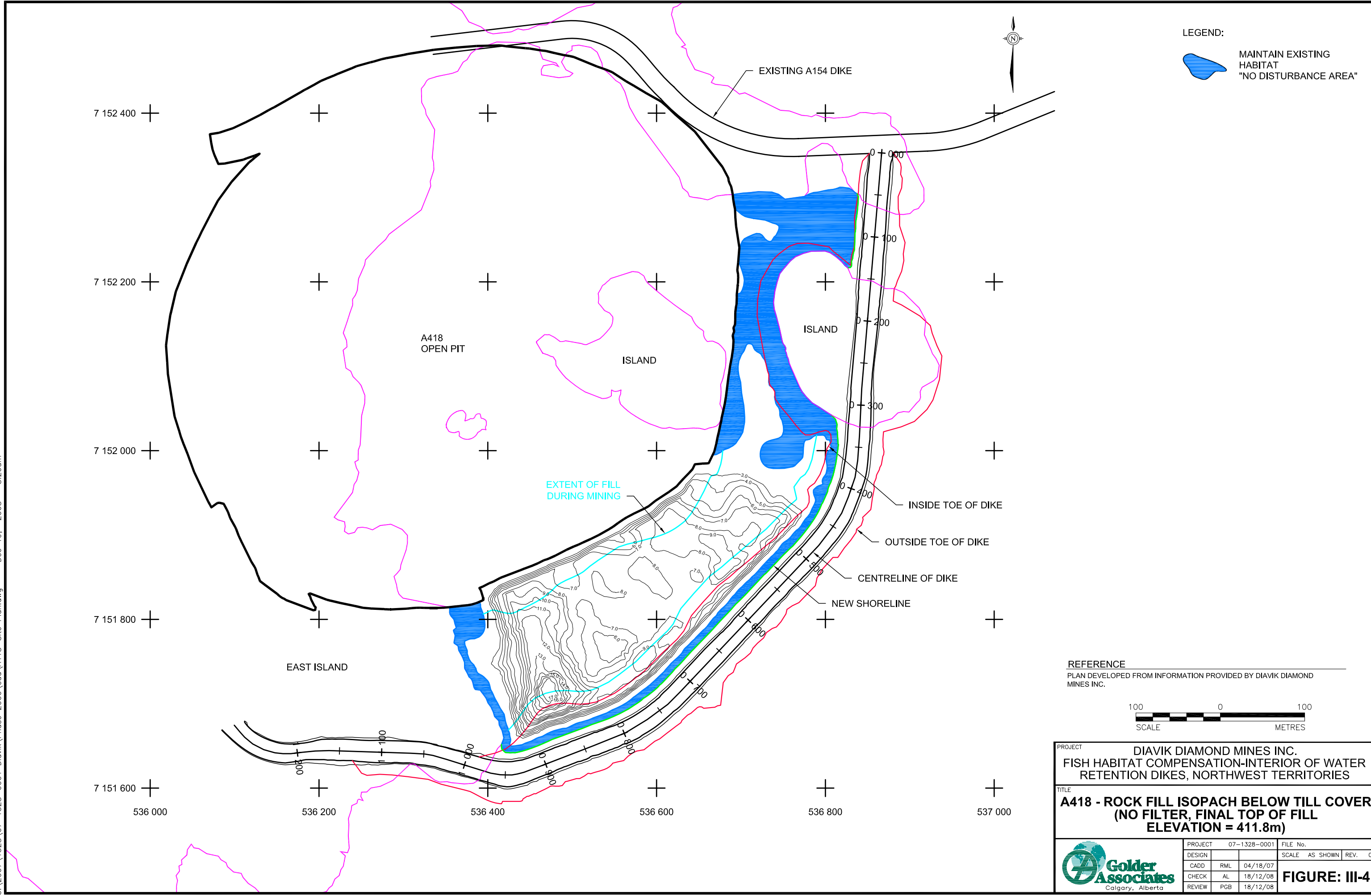
PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES

TITLE  
**A418 - TOTAL FILL ISOPACH  
 (TOP OF FILL ELEVATION = 411.8m)**

|   |              |              |                      |          |
|---|--------------|--------------|----------------------|----------|
|  <p><b>Golder Associates</b><br/>         Calgary, Alberta</p> | PROJECT      | 07-1328-0001 | FILE No.             |          |
|   | DESIGN       |              | SCALE                | AS SHOWN |
|   | CADD         | RML 04/18/07 | REV.                 | 0        |
|   | CHECK        | AL 18/12/08  | <b>FIGURE: III-3</b> |          |
| REVIEW  | PGB 18/12/08 |              |                      |          |




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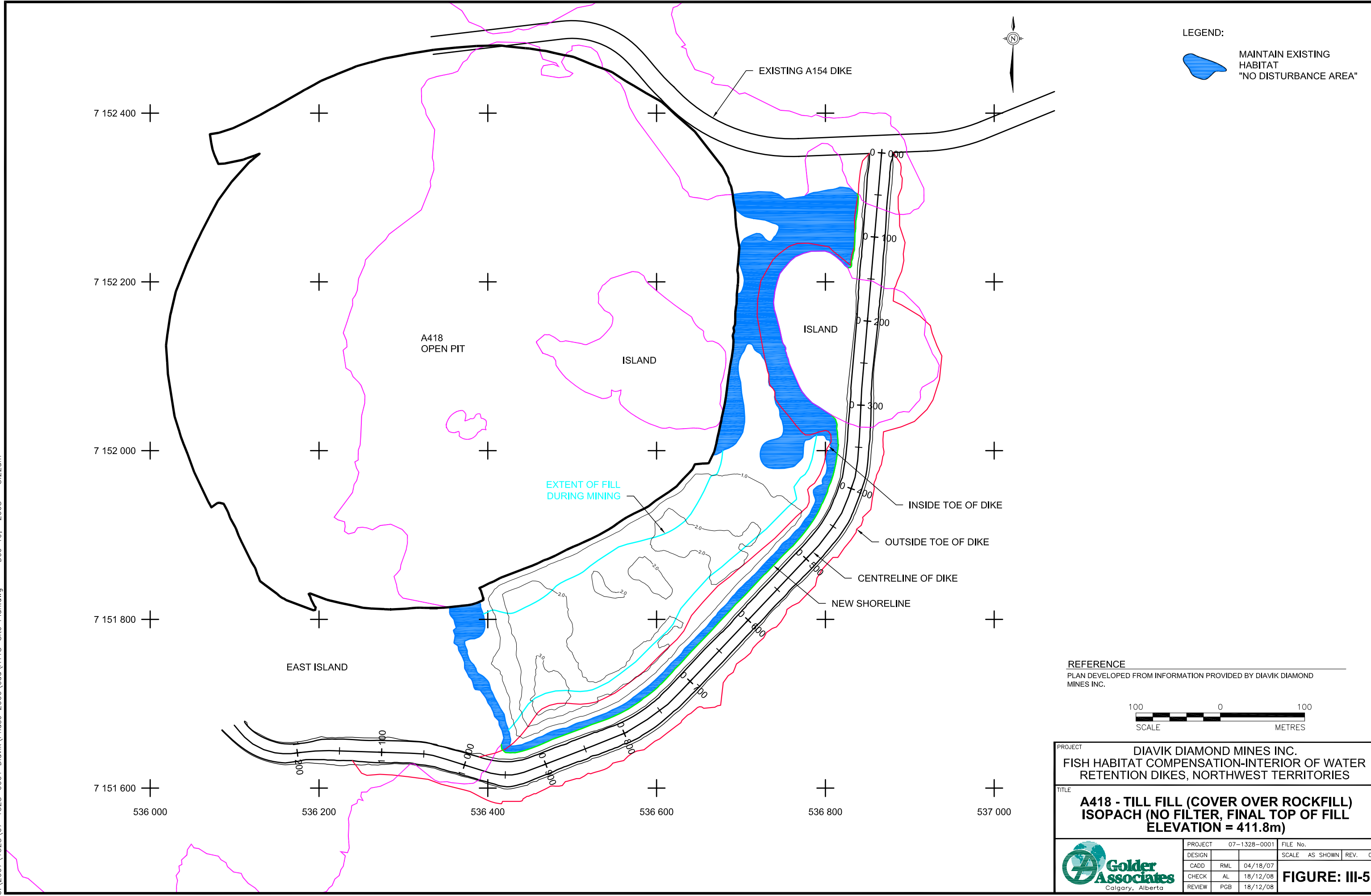
**REFERENCE**  
 PLAN DEVELOPED FROM INFORMATION PROVIDED BY DIAVIK DIAMOND MINES INC.


**PROJECT** DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES

**TITLE**  
**A418 - ROCK FILL ISOPACH BELOW TILL COVER (NO FILTER, FINAL TOP OF FILL ELEVATION = 411.8m)**

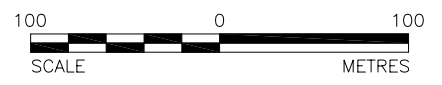
|   |         |              |          |                      |
|---|---------|--------------|----------|----------------------|
|  <p><b>Golder Associates</b><br/>         Calgary, Alberta</p> | PROJECT | 07-1328-0001 | FILE No. |                      |
|   | DESIGN  |              | SCALE    | AS SHOWN             |
|   | CADD    | RML          | 04/18/07 | REV. 0               |
|   | CHECK   | AL           | 18/12/08 | <b>FIGURE: III-4</b> |
| REVIEW  | PGB     | 18/12/08     |          |                      |

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LEGEND:  
 MAINTAIN EXISTING HABITAT  
 "NO DISTURBANCE AREA"

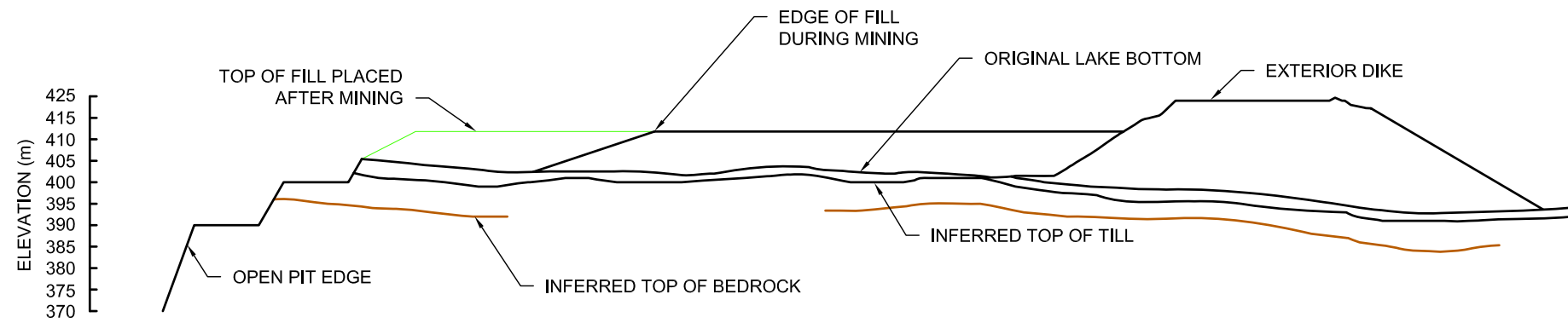
REFERENCE  
 PLAN DEVELOPED FROM INFORMATION PROVIDED BY DIAVIK DIAMOND MINES INC.



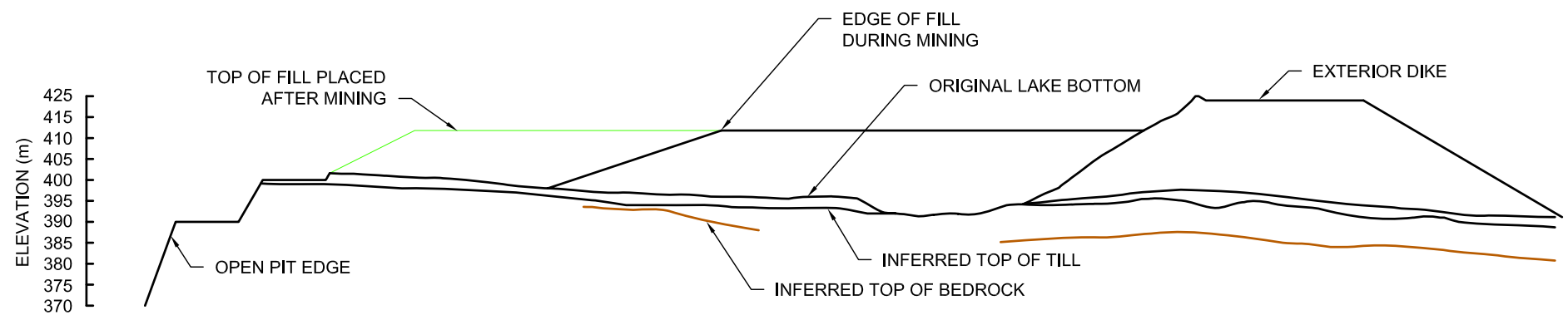
PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES  
 TITLE  
**A418 - TILL FILL (COVER OVER ROCKFILL) ISOPACH (NO FILTER, FINAL TOP OF FILL ELEVATION = 411.8m)**

|         |     |              |                      |          |
|---------|-----|--------------|----------------------|----------|
| PROJECT |     | 07-1328-0001 | FILE No.             |          |
| DESIGN  |     |              | SCALE                | AS SHOWN |
| CADD    | RML | 04/18/07     | REV.                 | 0        |
| CHECK   | AL  | 18/12/08     | <b>FIGURE: III-5</b> |          |
| REVIEW  | PGB | 18/12/08     |                      |          |



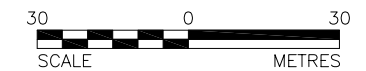


**A**  
III-2 **CROSS SECTION A-A'**



**B**  
III-2 **CROSS SECTION B-B'**

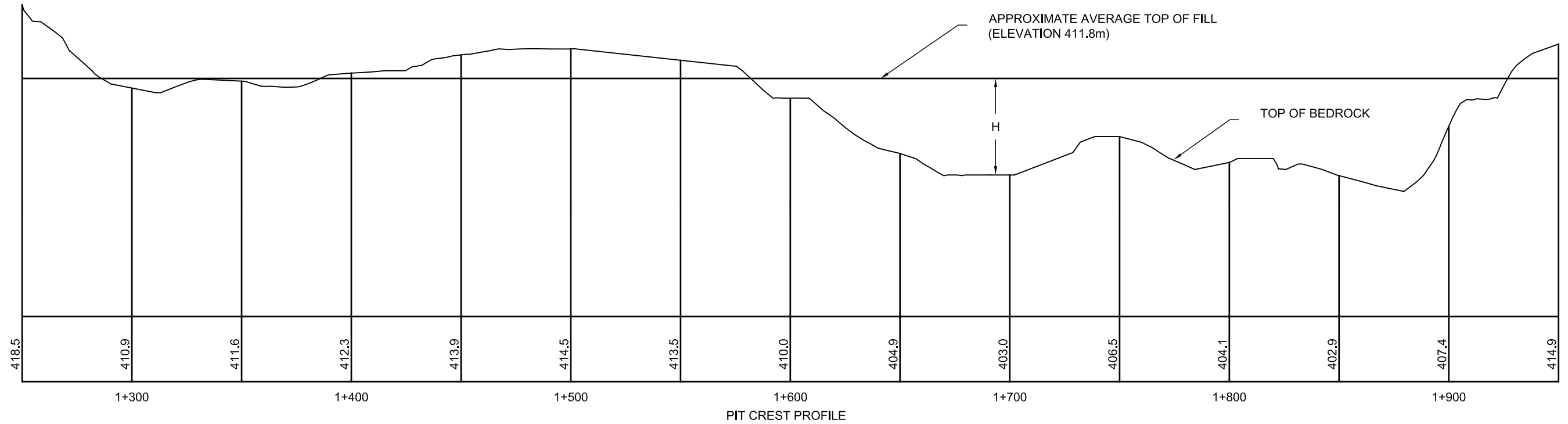
NOTE:  
CROSS-SECTIONS MAY NOT BE PERPENDICULAR TO DIKE CENTRELINE.



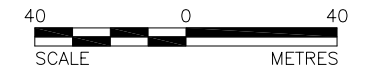
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|---------|--------------|--|----------|
| PROJECT |              | DIAVIK DIAMOND MINES INC.  |          |
|         |              | FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES |          |
| TITLE   |              | <b>A418 - CROSS SECTIONS OF FISH HABITAT FILL ON EXTERIOR DIKES</b>                |          |
| PROJECT | 07-1328-0001 | FILE No.   |          |
| DESIGN  |              | SCALE  | AS SHOWN |
| CADD    | RML 04/18/07 | REV.   | 0        |
| CHECK   | AL 18/12/08  | <b>FIGURE: III-6</b>   |          |
| REVIEW  | PGB 18/12/08 |  |          |







PIT CREST PROFILE



5x VERTICAL EXAGGERATION

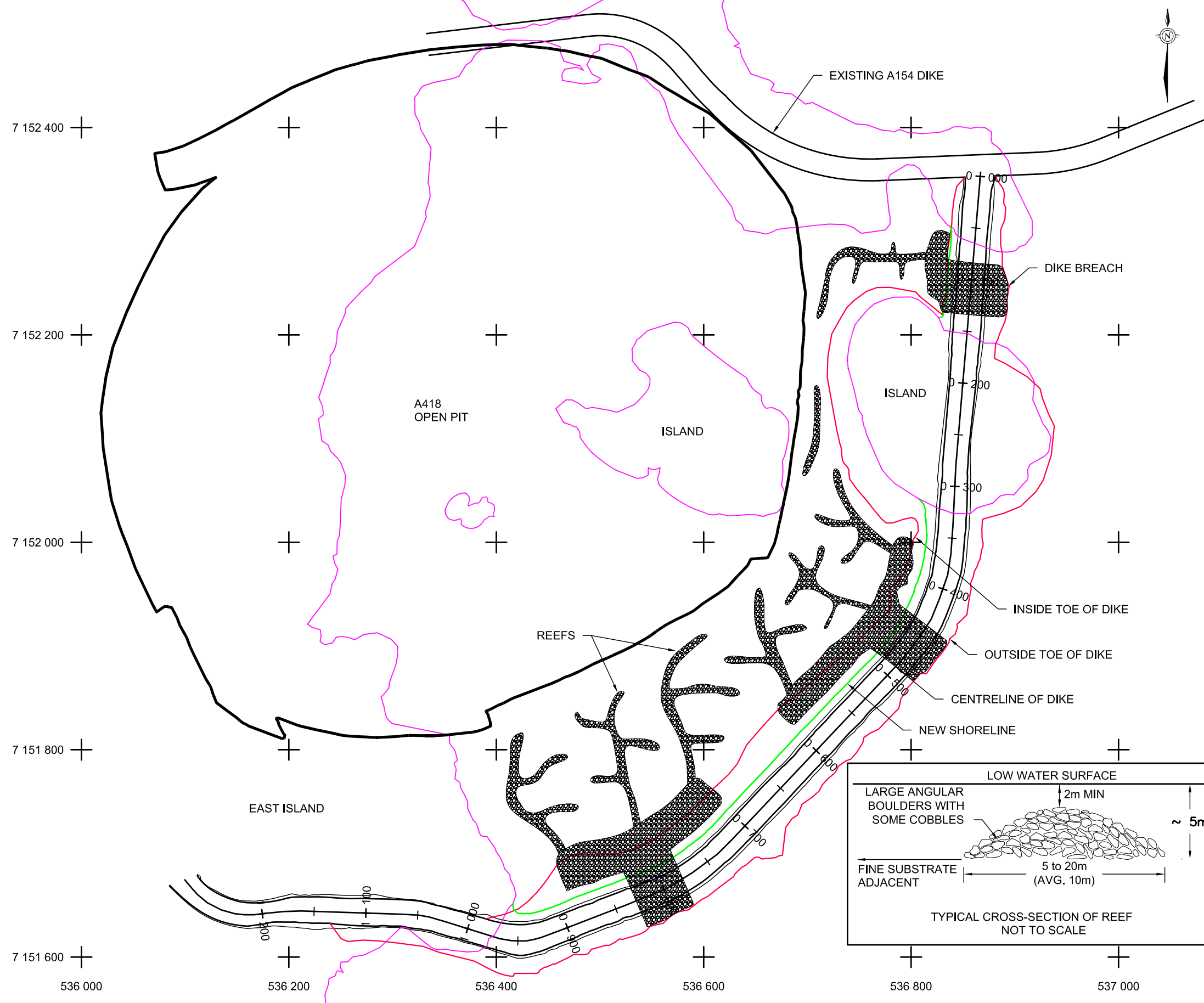
NOTES:

1. SEE FIGURE : III-2 FOR STATIONING
2. SETBACK FROM PIT CREST TO TOE OF FISH HABITAT FILL (DURING MINING) EQUAL TO 4H WITH A MINIMUM OF 15m.

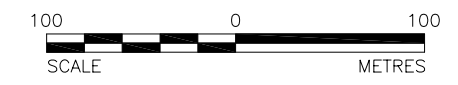
|                                 |     |  |                      |
|---------------------------------|-----|--|----------------------|
| PROJECT                         |     | DIAVIK DIAMOND MINES INC.  |                      |
|                                 |     | FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES |                      |
| TITLE                           |     |  |                      |
| <b>A418 - PIT CREST PROFILE</b> |     |  |                      |
| PROJECT                         |     | 07-1328-0001   | FILE No.             |
| DESIGN                          |     |  | SCALE AS SHOWN       |
| CADD                            | RML | 04/18/07   | REV. 0               |
| CHECK                           | AL  | 18/12/08   | <b>FIGURE: III-7</b> |
| REVIEW                          | PGB | 18/12/08   |                      |



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REFERENCE  
 PLAN DEVELOPED FROM INFORMATION PROVIDED BY DIAVIK DIAMOND MINES INC.



PROJECT DIAVIK DIAMOND MINES INC.  
 FISH HABITAT COMPENSATION-INTERIOR OF WATER RETENTION DIKES, NORTHWEST TERRITORIES

TITLE  
**A418 PIT - SCHEMATIC REEF CONFIGURATION**

|         |     |              |                       |
|---------|-----|--------------|-----------------------|
| PROJECT |     | 07-1328-0001 | FILE No.              |
| DESIGN  |     |              | SCALE AS SHOWN REV. 0 |
| CADD    | RML | 04/18/07     | <b>FIGURE: III-8</b>  |
| CHECK   | AL  | 18/12/08     |                       |
| REVIEW  | PGB | 18/12/08     |                       |



**DATE** December 9, 2010**PROJECT No.** 10-1328-0028 / 9000**TO** Gord Macdonald  
Diavik Diamond Mines Inc.**DOC. No.** 1016 Ver. 0  
**PO No.** D01479 line1**FROM** J.P. Bechtold and Dinesh Pokhrel**EMAIL** jp\_bechtold@golder.com;  
dinesh\_pokhrel@golder.com**PRELIMINARY PIT LAKE MIXING STUDY****1.0 INTRODUCTION****1.1 Background**

Based on current plans, Diavik Diamond Mines Inc. (Diavik) will be creating two pit lakes at its Lac de Gras mine site as part of final closure and reclamation activity. One pit lake will be created in each of the two existing, active mining areas, with a third pit lake possibly being created in the A21 mine pit (if open-pit mining proceeds). Each pit lake will be created by filling the empty, inactive pits with groundwater that naturally seeps into each mine area and water pumped in from Lac de Gras.

Once each lake is full, the existing dikes that separate the mine pits from Lac de Gras will be breached to allow fish access to the pit lakes, which will be designed to include some sheltered bay areas. Sheltered bays are not a common feature in Lac de Gras, and their presence in the pit lakes may enhance the spawning and rearing success of some of the key fish species found in Lac de Gras. Breaching of the dikes will also allow for the free exchange of the pit lake waters with those in Lac de Gras.

The quality of the water that is likely to occur within the upper portion of each pit lake is of interest to Diavik and local and regulatory stakeholders. The mixing characteristics of each lake are also of interest, because vertical turnover could affect the quality of the upper pit lake waters that will be open to exchange with Lac de Gras and in which most aquatic life that establishes within the pit lakes will be located. Golder Associates Ltd. (Golder) was contracted by Diavik to examine each of these areas of interest through the completion of a preliminary pit lake mixing study.

**1.2 Study Objectives**

The objectives of the preliminary pit lake mixing study were as follows:

- to examine how different approaches to filling the pit lakes may influence their mixing and turnover characteristics;
- to evaluate how those mixing characteristics may vary with changes in wind speed, salinity levels in the incoming groundwater and degree of connectivity with Lac de Gras; and
- to assess how water quality in the upper portion of the pit lakes may be affected by the different rates of internal mixing and exchange with Lac de Gras, using salinity as an indicator.



## 1.3 Scope

The preliminary pit lake mixing study was completed with a focus on the potential performance of the A154 pit lake, which will be formed by the flooding of the A154 mine pit once mining is complete. Although the A154 and A418 mine pits will share joint underground workings, the underground mining component of the Lac de Gras operation was ignored, and the A154 mine pit was treated as an isolated structure with a solid foundation.

Water quality in the A154 pit lake was evaluated with reference to predicted levels of total dissolved solids (TDS) and water temperature, and conditions in the pit lake were examined over a 10 year time period, beginning once the lake was initially filled. Where dynamic water quality models were used, they were run using default rate constants and coefficients, without detailed calibration to existing conditions. A detailed calibration was not required at this time, because the purpose of the study was to provide a general understanding of potential pit lake performance, rather than detailed estimates of projected parameter concentrations over time.

## 1.4 Organization

The general approach used to complete the preliminary pit lake mixing study is outlined in Section 2, followed by a description of the study methods in Section 3. The results of the study are discussed in Section 4, and study conclusions are presented in Section 5.

## 2.0 GENERAL APPROACH

Potential mixing conditions in the A154 pit lake were evaluated using a two dimensional (2-D), laterally-averaged water quality model in combination with empirical formulas developed to describe the likelihood of complete mixing within a given waterbody. The 2-D, CE-QUAL-W2 software package originally developed by the U.S. Army Corps of Engineers (Cole and Wells 2008) was used to predict water temperatures and TDS levels in the A154 pit lake during filling and in the 10-year period that would immediately follow lake filling and connection of the pit lake to Lac de Gras. Plots of predicted water temperatures and TDS levels at different depths in the pit lake were generated and reviewed to determine the degree to which vertical mixing was occurring under several different filling scenarios and a limited range of wind and influent flow conditions. The empirical Lake Number relationship developed by Imberger and Patterson (1990) was then used to evaluate the potential for turnover to occur in the A154 pit lake over a wider range of wind conditions and varying salinity levels in the groundwater that would enter the pit lake during filling.

## 3.0 METHODS

### 3.1 Dynamic Water Quality Modelling

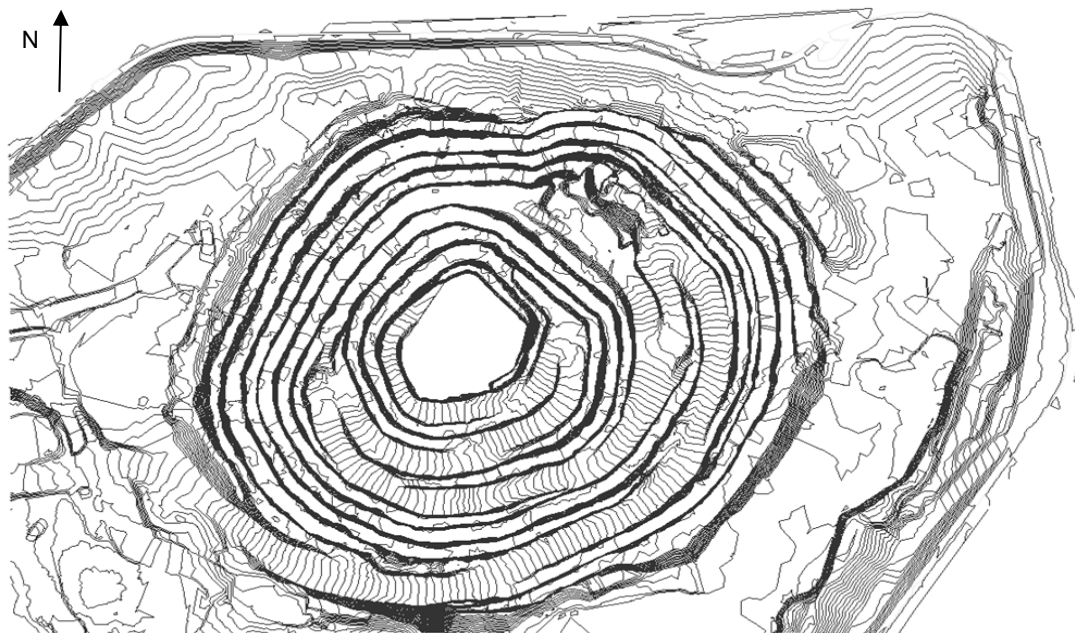
#### 3.1.1 General Model Set-up and Configuration

As previously noted, the 2-D, CE-QUAL-W2 software package originally developed by the U.S. Army Corps of Engineers was used to predict water temperatures and TDS levels in the A154 pit lake. The top of the A154 mine pit has a surface area of approximately 0.98 km<sup>2</sup>, which declines gradually over a depth of about 7 m to about 0.84 km<sup>2</sup> (Figures 1 and 2). Between approximately 7 and 8 m, the pit narrows to approximately 0.63 km<sup>2</sup>, and it continues to narrow over its remaining 249 m depth to a final bottom surface area of 0.025 km<sup>2</sup>. The top and bottom of the mine pit are located at surface elevations of 416 and 160 meters above sea level (masl), respectively.

Figure 1: Graphical Representation of the A154 Mine Pit Based on a Southwest to Northeast View Point



Figure 2: Contour Plot of the A154 Mine Pit (Plan View)

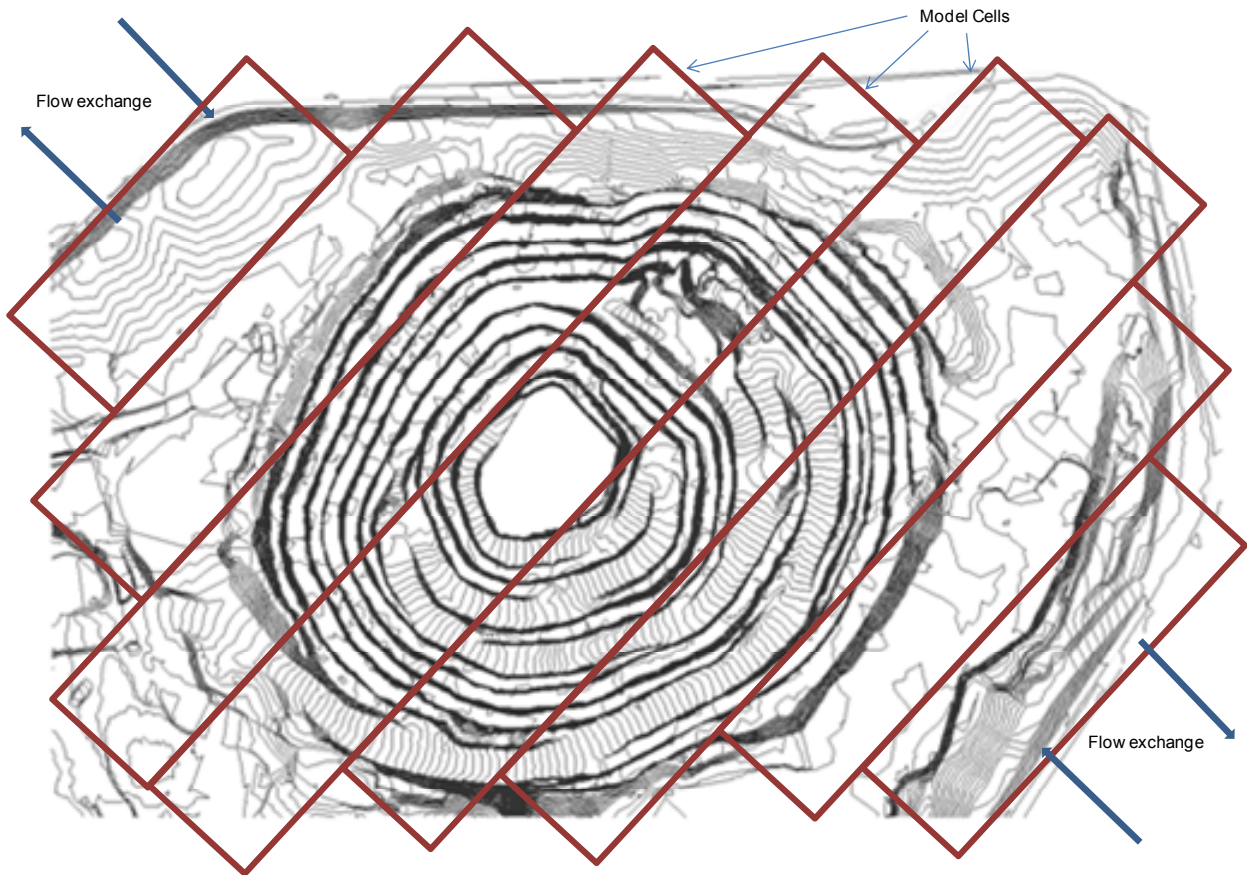


A total of 453 model cells were used to create a model grid that resembled the shape of the A154 mine pit, with the model cells varying in width from 100 to 750 m and in height from 1 to 3 m (Figure 3). The model was oriented such that it extended laterally along the longest axis of the pit, and flow exchange with Lac de Gras was assumed to exclusively occur through the outer model cells, perpendicular to this axis (as shown in Figure 4). The total volume of the A154 mine pit, as represented in the CE-QUAL-W2 model, was approximately 59.3 Mm<sup>3</sup> (Figure 3).





Figure 4: Model Orientation and Flow Direction



Although the CE-QUAL-W2 software package is designed to simulate nutrient levels, dissolved oxygen conditions and the behaviour of other parameters, these functions were not activated. The A154 pit lake model was focused on the simulation of TDS levels and water temperature. TDS was treated as a conservative parameter. It was not susceptible to settling, partitioning or other forms of transformation. In contrast, water temperature predictions were developed taking into account incoming water temperatures, changing atmospheric conditions and heat loss that can occur through the boundaries of the A154 mine pit. Model coefficients and rate constants included in the CE-QUAL-W2 model that were relevant to the current study are listed in the attached table (Table A-1), together with the values assigned to each of these variables.

In general, the values assigned to the model coefficients and rate constants corresponded to the default values recommended by the model developers (Cole and Wells 2008), although, in some cases, the default values were replaced with those previously used by Golder to examine the performance of constructed waterbodies in northern climates. A detailed calibration to existing conditions was not undertaken, because the objective of the preliminary mixing study was to provide a general understanding of potential pit lake performance, rather than detailed estimates of projected parameter concentrations over time.

### 3.1.2 Input Information

Input information required by the A154 pit lake model included the following:

- TDS levels and water temperatures in Lac de Gras in the area surrounding the A154 mine pit and in the groundwater that would likely report to the A154 mine pit during lake filling;
- estimates of surface water pumping rates and groundwater inflow rates during filling;
- surface water exchange rates between Lac de Gras and the A154 pit lake following the completion of lake filling and breaching of the existing A154 perimeter dike; and
- local climate data to define air temperature, wind speed and direction, solar radiation, cloud cover and dew point temperature.

TDS levels and water temperatures in Lac de Gras were defined using data obtained from Diavik's Aquatic Effects Monitoring Program (AEMP) (Diavik 2008, 2009, 2010). Based on this information, TDS levels in surface water inflows to the pit lake were set to vary between 16 and 25 mg/L, with a median concentration of 18.5 mg/L. Water temperatures in these same waters were set to vary between near zero during the winter period up to 14.5°C in the peak of summer.

TDS levels and water temperatures in the influent groundwater were defined using baseline data collected on-site prior to mining. More specifically, they were set to 375 mg/L and 3.7°C, respectively, to be reflective of average conditions encountered in the deeper boreholes established around the A154 mine site.

The groundwater inflow rate was estimated based on a linear relationship developed from historical pit dewatering rates and pit depths. Based on this relationship, the groundwater inflow rate at the start of filling was set to 28,300 m<sup>3</sup>/day. It was then assumed to decline over the filling period as water levels in the pit increased, ultimately reaching a value of zero when the pit was full of water.

Surface water pumping rates during the filling period were set such that the A154 pit lake could be filled with water within one open-water season, as per the direction received from Diavik. This approach resulted in the use of a pumping rate of approximately 4.4 m<sup>3</sup>/s or 379,000 m<sup>3</sup>/day. Filling was initiated at the beginning of May, and it was completed by mid to late September.

After filling was complete, surface water flow rates between Lac de Gras and the A154 pit lake were defined for both the open-water (May to September) and winter (October to April) periods, based on current velocities in Lac de Gras around the A154 mine pit (as outlined in Diavik [1998]) and an assumed exchange area of approximately 90 m<sup>2</sup> between the pit lake and Lac de Gras. The exchange area corresponds to the cross-section area formed by creating two breaches within the A154 perimeter dike. Each breach was assumed to be 30 m in length and 3 m in height, and flows traveling into the pit lake through one breach were assumed to displace an equivalent amount of water through the second breach. In other words, pit lake inflows and outflows were set equal to one another to maintain a stable water surface elevation. This approach resulted in open-water and winter flow rates of approximately 4.5 and 0.76 m<sup>3</sup>/s, respectively.

Climate data were obtained from an on-site monitoring station. Complete data records containing the information required for the A154 pit lake were available over a four year period, from 2000 to 2003. These data were repeated as necessary to create a 10-year climate record, which was incorporated into the model.



### 3.1.3 Scenarios Considered

Eight scenarios were evaluated using the configured A154 pit lake model. As outlined in Table 1, they included a two-part “Base Case” scenario that was designed to represent the likely method by which the pit lake will be filled and the general climatic conditions that the lake may be exposed to. This scenario included an examination of lake dynamics during the filling period (Base Case Part 1) and over the following 10 years (Base Case Part 2). The filling period was assumed, as previously noted, to span one open-water season with pumping rates from Lac de Gras set to achieve this goal. During the filling period, inflows to the A154 mine pit consisted of the pumped Lac de Gras water and natural groundwater seepage. Once filled, pumping was assumed to cease, groundwater inflow rates were assumed to drop to zero, and the A154 pit lake was assumed to be in open communication with Lac de Gras.

The remaining seven scenarios were developed around alternative filling schemes that involved an initial accumulation of saline<sup>1</sup> groundwater in the A154 mine pit prior to the addition of surface water from Lac de Gras. In these latter scenarios, the filling period was not specifically modelled. Instead, the characteristics of the pit lake when initially filled were simply defined and used as the starting point for the 10-year post-fill simulations. In addition, wind speeds and surface inflow rates were altered in some of the scenarios to evaluate how these changes could affect mixing conditions in the pit lake. In all cases, groundwater seepage rates were assumed to be zero, as were pumping rates from Lac de Gras (consistent with the approach used in the Base Case Part 2 simulation).

A general description of each of the eight scenarios considered in the A154 pit lake assessment is provided in Table 1. Table 2 contains a summary of how key model input variables were defined for each of the eight scenarios. In all cases, the post-filling simulations were run for a 10-year period. The start date of each simulation was set to September 14, 2010, based on the idea that pit lake filling would be complete near the end of an open-water season regardless of when it started or how long it took to complete. The resulting TDS and water temperature predictions were then plotted and reviewed to evaluate the degree of vertical mixing that could be expected in the A154 pit lake and how it may influence water quality conditions in the upper portion of the lake.

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<sup>1</sup> In the context of this report, the term saline is being used to describe waters containing TDS levels  $\geq 300$  mg/L. Although waters containing 300 mg/L of TDS can still be considered freshwater, they are being characterized herein as saline in acknowledgement of the low levels of TDS (i.e.,  $<30$  mg/L) that can be commonly observed in surface waters of Lac de Gras.

**Table 1: Scenarios Evaluated using the A154 Pit Lake Model**

| Number | Short Title       | Description  |
|--------|-------------------|--|
| 1a     | Base Case Part 1  | <ul style="list-style-type: none"> <li>Simulation period spanned one open-water season; it began with the mined out A154 pit, which was subsequently filled over the course of the simulation with natural groundwater inflow and water pumped in from Lac de Gras.</li> <li>All input variables were set to the values outlined in Section 3.1.2.</li> </ul>      |
| 1b     | Base Case Part 2  | <ul style="list-style-type: none"> <li>Continuation of the Base Case scenario, focused on an examination of conditions in the A154 pit lake over a 10 year time period, beginning after it had been filled and connected to Lac de Gras.</li> <li>Initial conditions in the pit lake were defined using the output from the Base Case Part 1 model run.</li> </ul> |
| 2      | GW to 195         | <ul style="list-style-type: none"> <li>10 year simulation that began with the A154 pit lake having been initially filled with saline groundwater to an elevation of 195 masl, followed by water pumped slowly in from Lac de Gras.</li> <li>Climate conditions and influent flow rates matched those used in the Base Case</li> </ul>                              |
| 3      | GW to 195 W2      | <ul style="list-style-type: none"> <li>Identical set-up to Scenario GW to 195, except that wind speeds were doubled</li> </ul>   |
| 4      | GW to 295         | <ul style="list-style-type: none"> <li>10 year simulation that began with the A154 pit lake having been initially filled with saline groundwater to an elevation of 295 masl, followed by water pumped slowly in from Lac de Gras.</li> <li>Climate conditions and influent flow rates matched those used in the Base Case</li> </ul>                              |
| 5      | GW to 295 W2      | <ul style="list-style-type: none"> <li>Identical set-up to Scenario GW to 295, except that wind speeds were doubled</li> </ul>   |
| 6      | GW to 295 W2 RedQ | <ul style="list-style-type: none"> <li>Identical set-up to Scenario GW to 295, except that wind speeds were doubled and open-water inflow rates were reduced by 60%</li> </ul>   |
| 7      | GW to 411         | <ul style="list-style-type: none"> <li>10 year simulation that began with the A154 pit lake having been initially filled with saline groundwater to an elevation of 411 masl, followed by water pumped slowly in from Lac de Gras.</li> <li>Climate conditions and influent flow rates matched those used in the Base Case</li> </ul>                              |
| 8      | GW to 411 W2      | <ul style="list-style-type: none"> <li>Identical set-up to Scenario GW to 411, except that wind speeds were doubled</li> </ul>   |

**Table 2: General Configuration of the Eight Scenarios Evaluated using the A154 Pit Lake Model**

| Attribute   | Scenario                 |              |                    |                    |                    |                    |                    |                    |                    |
|---|--------------------------|--------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
|   | Base Case                |              | GW to 195          | GW to 195 W2       | GW to 295          | GW to 295 W2       | GW to 295 W2 RedQ  | GW to 411          | GW to 411 W2       |
|   | Part 1                   | Part 2       |                    |                    |                    |                    |                    |                    |                    |
| <b>Initial Conditions</b>   |                          |              |                    |                    |                    |                    |                    |                    |                    |
| Elevation of initial chemocline (masl)                              | _(a)                     | _(a)         | 195                | 195                | 295                | 295                | 295                | 411                | 411                |
| TDS level above the chemocline (mg/L)                               | _(a)                     | _(a)         | 18.5               | 18.5               | 18.5               | 18.5               | 18.5               | 18.5               | 18.5               |
| TDS level below the chemocline (mg/L)                               | _(a)                     | _(a)         | 375                | 375                | 375                | 375                | 375                | 375                | 375                |
| Elevation of initial thermocline                                    | _(a)                     | _(a)         | 360 <sup>(e)</sup> | 360 <sup>(e)</sup> | 360 <sup>(e)</sup> | 360 <sup>(e)</sup> | 360 <sup>(e)</sup> | 360 <sup>(e)</sup> | 360 <sup>(e)</sup> |
| Temperature above the thermocline (°C)                              | _(a)                     | _(a)         | 8                  | 8                  | 8                  | 8                  | 8                  | 8                  | 8                  |
| Temperature below the thermocline (°C)                              | _(a)                     | _(a)         | 3.7                | 3.7                | 3.7                | 3.7                | 3.7                | 3.7                | 3.7                |
| <b>Surface inflow</b>   |                          |              |                    |                    |                    |                    |                    |                    |                    |
| Average open-water flow rate (May to September) (m <sup>3</sup> /s) | 4.4                      | 4.5          | 4.5                | 4.5                | 4.5                | 4.5                | 1.4                | 4.5                | 4.5                |
| Average winter flow rate (October to April) (m <sup>3</sup> /s)     | _(b)                     | 0.76         | 0.76               | 0.76               | 0.76               | 0.76               | 0.76               | 0.76               | 0.76               |
| TDS level (mg/L)  | 18.5                     | 16.7 to 25.2 | 16.7 to 25.2       | 16.7 to 25.2       | 16.7 to 25.2       | 16.7 to 25.2       | 16.7 to 25.2       | 16.7 to 25.2       | 16.7 to 25.2       |
| Temperature (°C)  | 6                        | -0.4 to 14.5 | -0.4 to 14.5       | -0.4 to 14.5       | -0.4 to 14.5       | -0.4 to 14.5       | -0.4 to 14.5       | -0.4 to 14.5       | -0.4 to 14.5       |
| <b>Groundwater inflow</b>   |                          |              |                    |                    |                    |                    |                    |                    |                    |
| Flow rate (m <sup>3</sup> /s)                                       | 0.33 to 0 <sup>(c)</sup> | 0            | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  | 0                  |
| TDS level (mg/L)  | 375                      | _(d)         | _(d)               | _(d)               | _(d)               | _(d)               | _(d)               | _(d)               | _(d)               |
| Temperature (°C)  | 3.7                      | _(d)         | _(d)               | _(d)               | _(d)               | _(d)               | _(d)               | _(d)               | _(d)               |
| Wind speed  | observed                 | observed     | observed           | 2 x observed       | observed           | 2 x observed       | 2 x observed       | observed           | 2 x observed       |
| Duration of the simulation  | 153 days                 | 10 years     | 10 years           | 10 years           | 10 years           | 10 years           | 10 years           | 10 years           | 10 years           |
| Start date  | May 1                    | September 14 | September 14       | September 14       | September 14       | September 14       | September 14       | September 14       | September 14       |

<sup>(a)</sup> Assumptions about the location of an initial thermocline or chemocline are not applicable to the Base Case scenario, because it began with an empty mine pit.

<sup>(b)</sup> Not applicable to the Base Case Part 1 scenario, because this scenario was focused on conditions in the A154 pit lake during filling over a single open-water period; the simulation run did not extend into the winter season.

<sup>(c)</sup> Groundwater inflow rates are shown as a range, because they were assumed to decrease as water levels in the A154 pit lake increased during filling; groundwater inflows were assumed to cease once the lake was full.

<sup>(d)</sup> Not applicable to the noted scenarios, because groundwater flow rates were assumed to be zero once the A154 pit lake was full.

<sup>(e)</sup> The initial elevation of the thermocline was set to 360 masl based on a review of the results of some initial model simulations, which suggested that water temperatures in the A154 pit lake are likely to remain reasonably stable at or below this elevation.

### 3.2 Empirical Analysis

Imberger and Patterson (1990) developed an empirical equation to calculate a single, dimensionless Lake Number ( $L_N$ ) that can be used to define the dynamic stability of a lake and the expected extent of deep mixing. It is a quantitative index that is defined as the ratio of the stabilizing force of gravity that prevents turnover and/or extensive vertical mixing to the destabilizing forces that encourage them to occur, such as wind and incoming and outgoing water flow. The stabilizing force of gravity in a lake is mainly due to density stratification, and the destabilizing effects of wind generally far exceed those of incoming and outgoing flows. As a result, it is the balance of the stabilizing force of gravity versus the destabilizing force of wind that forms the basis of the Imberger and Patterson (1990) relationship, which takes the following form:

$$L_N = \frac{g * S_t * \left(1 - \frac{Z_p}{Z_m}\right)}{\rho_m * u_*^2 * A_m^{0.5} * \left(1 - \frac{Z_g}{Z_m}\right)} \quad \text{Equation 1}$$

where:  $g$  = acceleration due to gravity ( $9.8 \text{ m/s}^2$ );

$S_t$  = amount of work that is required to mix the waterbody in question to a uniform density, which is referred to as the Schmidt Number ( $\text{g-cm/cm}^2$ );

$Z_p$  = thermocline or chemocline depth (m);

$Z_m$  = maximum depth (m);

$\rho_m$  = water density at surface ( $\text{kg/m}^3$ );

$u_*$  = water friction velocity as a function of wind stress (m/s);

$A_m$  = surface area of the lake ( $\text{m}^2$ ); and

$Z_g$  = center of the lake water volume (m).

This equation provides a relatively rapid means of evaluating the potential for deep vertical mixing and turnover, and it was used in the present study to evaluate the potential for turnover in the A154 pit lake over a wider range of wind conditions than was included in the scenarios examining using the dynamic CE-QUAL-W2 model. This equation was also used to examine how mixing rates in the A154 pit lake may change with different levels of TDS being present in the groundwater that would enter the pit lake during filling.

The empirical analysis was completed with a focus on the GW to 195 and GW to 295 scenarios outlined in Table 2, because they represent filling schemes that could potentially result in prolonged stratification within the A154 pit lake. For each scenario, Lake Numbers were developed over wind speeds ranging from 5 to 50 m/s and TDS levels in the lower portion of the A154 pit lake ranging from 25 to 575 mg/L. The calculations were also completed for water temperatures in the top portion of the lake set to 6 and 8°C to reflect the general range of conditions predicted to occur in this region of the lake, as defined using the dynamic CE-QUAL-W2 model.

Consistent with the guidance provided by Imberger and Patterson (1990), Lake Numbers equal to or less than one (i.e.,  $L_N \leq 1$ ) were identified as situations where the force of the wind travelling over the A154 pit lake would likely be sufficient to destabilize any internal stratification and trigger deep vertical mixing. In contrast, Lake Numbers in excess of one (i.e.,  $L_N > 1$ ) were used to identify situations where internal stratification would likely persist and inhibit large scale vertical mixing.

When completing the empirical analysis, the values of the terms  $u_*$  and  $S_t$  were calculated using Equation 2 (Robertson and Imberger 1994) and Equation 3 (Idso 1973), which took the following form:

$$u_*^2 = \frac{\rho_a}{\rho_m} C_D * U_{10}^2 \quad \text{Equation 2}$$

$$S_t = \frac{1}{A_0} \int_{Z_0}^{Z_m} (\rho_z - \bar{\rho}) * A_z * (Z - Z_p) * dZ \quad \text{Equation 3}$$

where:  $\rho_a$  = density of air (1.209 kg/m<sup>3</sup>);  
 $C_D$  = drag coefficient (0.0013) (unitless);  
 $U_{10}$  = wind speed at 10 m above the water surface (m/s);  
 $A_0$  = top surface area (m<sup>2</sup>);  
 $Z_0$  = surface or zero depth (m);  
 $\rho_z$  = density at depth Z (kg/m<sup>3</sup>);  
 $\bar{\rho}$  = average lake density (kg/m<sup>3</sup>); and  
 $A_z$  = surface area at depth Z (m<sup>2</sup>).

The GW to 411 scenario was not considered in the empirical analysis, because it represents an extreme situation that is unlikely to occur given the large volume of saline groundwater involved in this filling scheme (i.e., 55 Mm<sup>3</sup> of groundwater would be require to fill the A154 pit to an elevation of 411 masl). The Base Case filling scheme was not explicitly included in the empirical analysis, because the results of the Base Case dynamic modelling indicated that (1) extensive mixing would occur during the filling process and (2) the resultant variations that may develop between temperature and salinity levels in the upper and lower portions of the A154 pit lake would be suitably represented by the range of conditions considered in the calculations completed using the GW to 195 and GW to 295 scenarios.

## 4.0 RESULTS AND DISCUSSION

### 4.1 Dynamic Water Quality Modelling

#### 4.1.1 Base Case

Results from the Base Case scenario suggest that the parallel input of pumped surface water from Lac de Gras and natural groundwater seepage is likely to encourage a high degree of mixing between the two water sources during the filling period. The mixing would likely occur regardless of whether the pumped water from Lac de Gras is released at the base of the A154 mine pit or is allowed to flow down the pit walls. If the water is allowed to flow down the pit walls, as was assumed in the model simulation, then some vertical variations in TDS levels and water temperatures may develop towards the end of the filling period as water levels approach the top of the A154 mine pit (Figure 5). The variations develop, because the incoming surface water no longer has sufficient energy to mix the large volume of water that has accumulated within the A154 mine pit and the influence of the groundwater that enters the lake primarily along its base and lower pit walls becomes more apparent.

At the end of the filling period, the model results indicate that the A154 pit lake may experience a fall turnover event prior to freeze-up (Figure 6). The predicted turnover event occurred when water temperatures in the upper portion of the lake decreased to 4°C (Figure 7), the point at which water reaches its maximum density. The heavier surface waters subsequently sank into the lower portion of the lake and displaced the slightly warmer, less dense waters that were residing in this area.

No other full turnover events were observed over the remainder of the 10 year simulation (Figure 6). The lack of full turnover events after initial freeze-up is likely attributable to the establishment of stable water temperatures in the lower portion of the pit lake at around 4°C (Figure 7). Although full turnover events were not observed, vertical mixing was still predicted to occur, albeit at a slower rate than what would otherwise occur during a full turnover event. As shown in Figure 6, TDS levels in the lower portion of the lake gradually declined with time as the groundwater that originally seeped into the A154 mine pit during the filling period was slowly flushed from the system and replaced with the lower TDS content water flowing in from Lac de Gras.

The degree to which TDS levels in the lower portion of the A154 pit lake decline over time and the speed at which this occurs may be lower than suggested by the model results outlined herein, because the modelling was completed without consideration of a diffusive salt flux from the surrounding groundwater system. In other words, although groundwater inflow rates are likely to become negligible once the A154 pit lake is full, materials may still be released from the surrounding groundwater into the pit lake as a result of diffusion across the concentration gradients that are likely to become established between the two systems. This diffusive process was not included in the CE-QUAL-W2 model, and its inclusion may have resulted in a slower rate of decline in TDS levels in the lower portion of the A154 pit lake.

Figure 5: Predicted Concentrations of Total Dissolved Solids and Water Temperature in the A154 Pit Lake at the End of the Filling Period under the Base Case Scenario

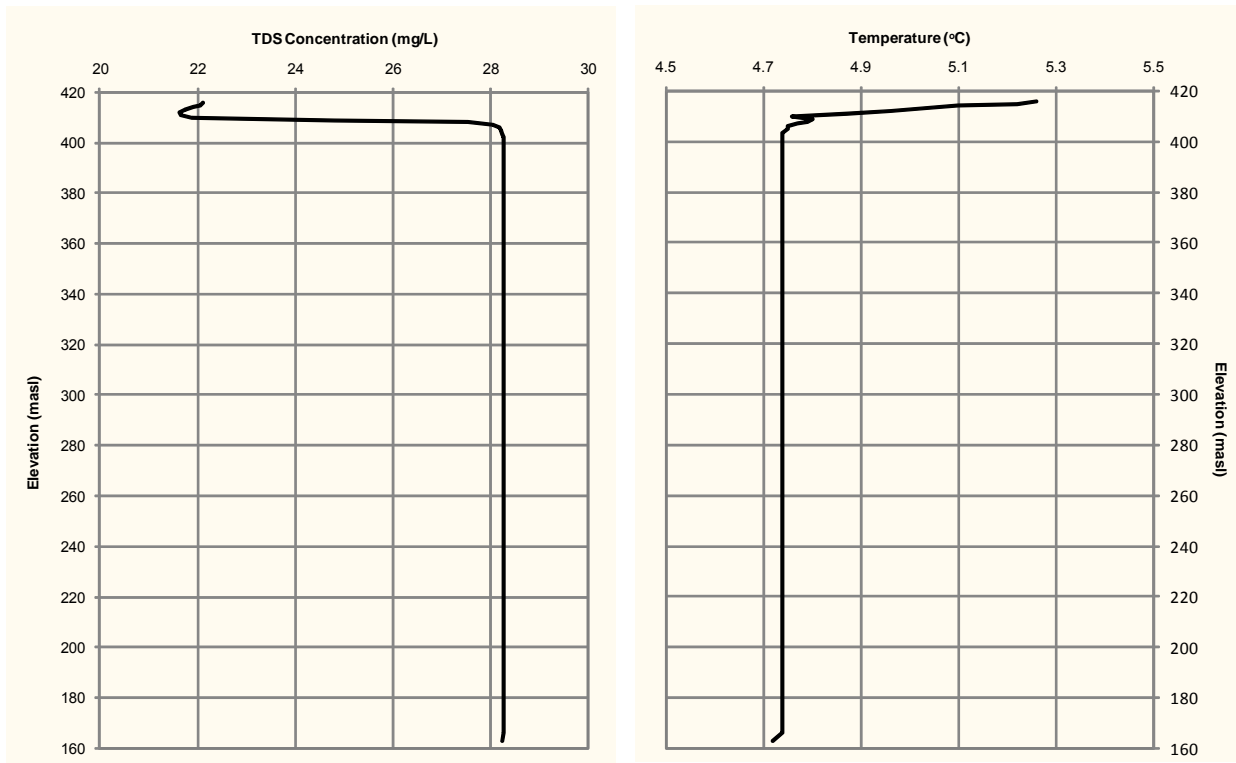
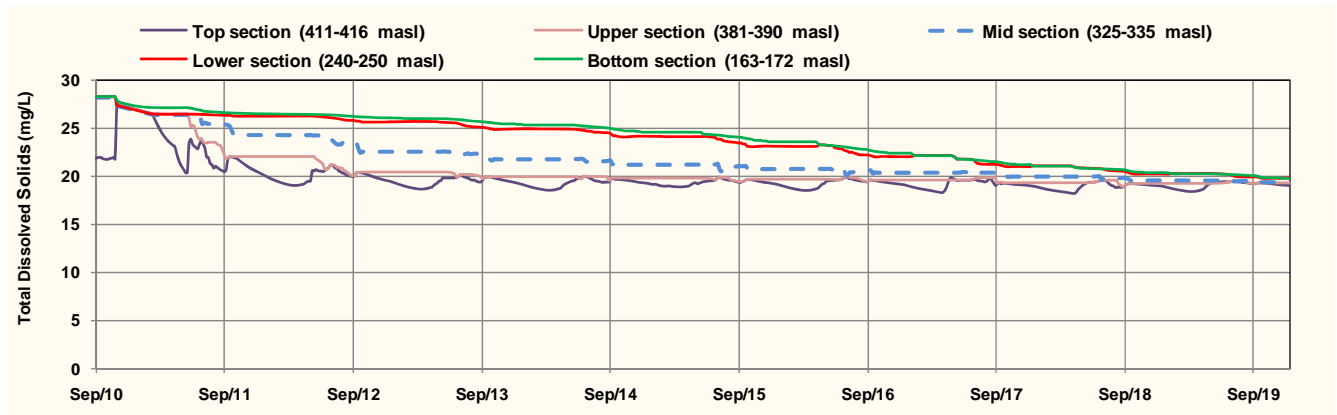
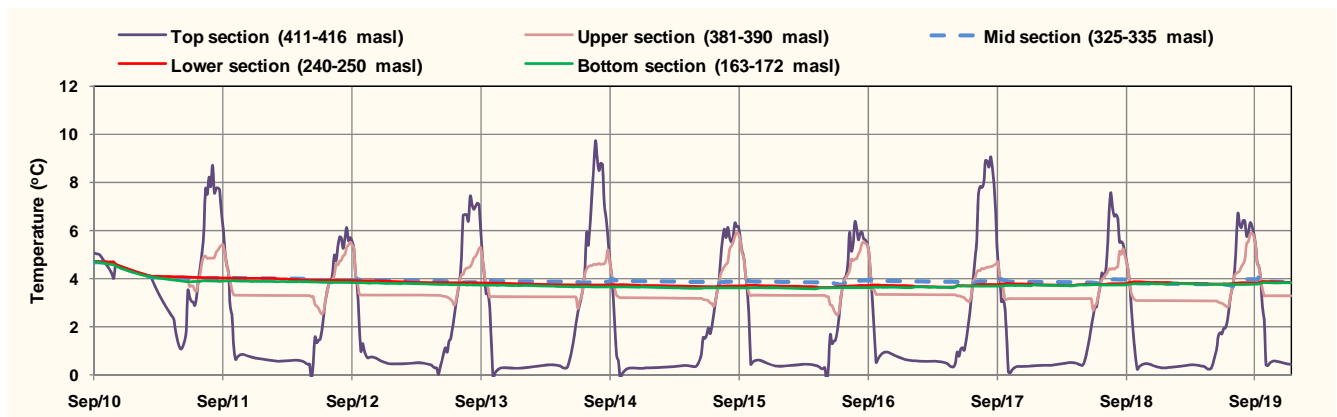


Figure 6: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the Base Case Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010

Figure 7: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the Base Case Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010; predicted water temperatures in the mid, lower and bottom sections of the A154 pit lake are difficult to distinguish from one another, because of extensive overlap.

#### 4.1.2 Alternative Scenarios

##### Scenario GW to 195

The GW to 195 simulation began with the A154 pit lake having been initially filled with saline groundwater to an elevation of 195 masl, followed by water pumped slowly in from Lac de Gras. Based on this filling scheme, the starting TDS level in the portion of the pit lake above 195 masl was 18.5 mg/L, and it was 375 mg/L in the bottom portion of the lake below 195 masl.

TDS levels in the upper portion of the lake remained stable at 18.5 mg/L over the course of the 10 year simulation, and no turnover events were predicted (Figure 8). TDS levels in the bottom section of the pit lake below 195 masl remained high throughout the simulation, indicating that the bottom portion of the lake was largely isolated from the upper portion of the lake. However, TDS levels in the bottom portion of the lake were predicted to slowly decline over time, which is indicative of a small rate of exchange between the upper and

lower portions of the lake. In other words, although large scale vertical mixing was not observed, material from the bottom of the lake was moving into the upper portion of the lake through small scale mixing and diffusion.

Water temperatures in the top and upper portions of the A154 pit lake were virtually unchanged in the GW to 195 scenario in comparison to those predicted to occur under the Base Case (Figures 7 and 9). They continued to vary in reflection of season changes in air temperature and the presence or absence of ice (Figure 9). Water temperatures in the mid and lower sections of the pit lake above 195 masl were also consistent with Base Case predictions; water temperatures in this region of the lake were predicted to rapidly approach 4°C and remain around this point through the duration of the simulation.

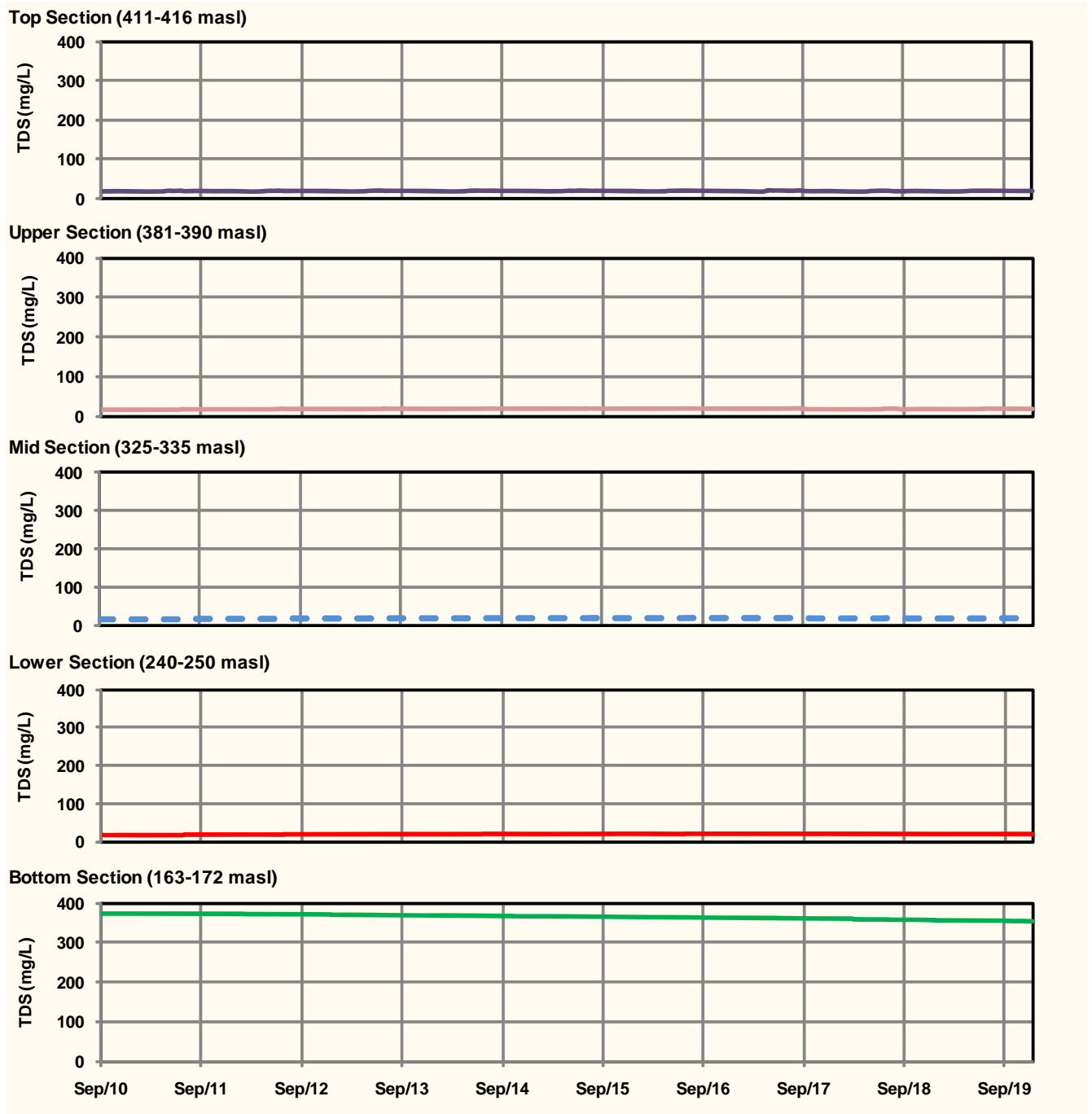
Below 195 masl, in the area of the lake filled with saline groundwater, water temperatures were predicted to decline over time from the initial groundwater temperature of 3.7°C to just under 2°C at the end of the 10 year simulation. The predicted decline is likely due to the loss of heat from this portion of the lake to the surrounding soils. This trend was not observed in the Base Case, because the bottom of the lake was not as isolated in that scenario as it was in the GW to 195 scenario. In the Base Case, heat lost from the bottom section of the lake was replaced at an equivalent rate as waters slowly mixed over the entire depth of the lake over time. Although predicted TDS level suggest that some level mixing and diffusion also occurred under the GW to 195 set-up (Figure 8), it was more limited than that which occurred under the Base Case; hence, the net loss of heat from this section of the pit lake.

### ***Scenario GW to 195 W2***

Repeating the GW to 195 simulation with wind speeds increased by a factor of two resulted in a greater level of exchange between the portions of the A154 pit lake situated above and below 195 masl, as suggested by the more rapid decline in TDS levels observed at the bottom of the lake (Figures 8 and 10). Water temperatures in the lower portion of the lake were also slightly warmer at the end of the simulation than observed in the GW to 195 simulation (Figures 9 and 11), indicating that the predicted heat losses identified in the GW to 195 scenario were mitigated to some extent through the greater exchange of water between the upper and lower portions of the lake. However, at no point in the simulation was turnover observed; the A154 pit lake remained stratified despite a doubling in the speed of the wind passing over the lake.

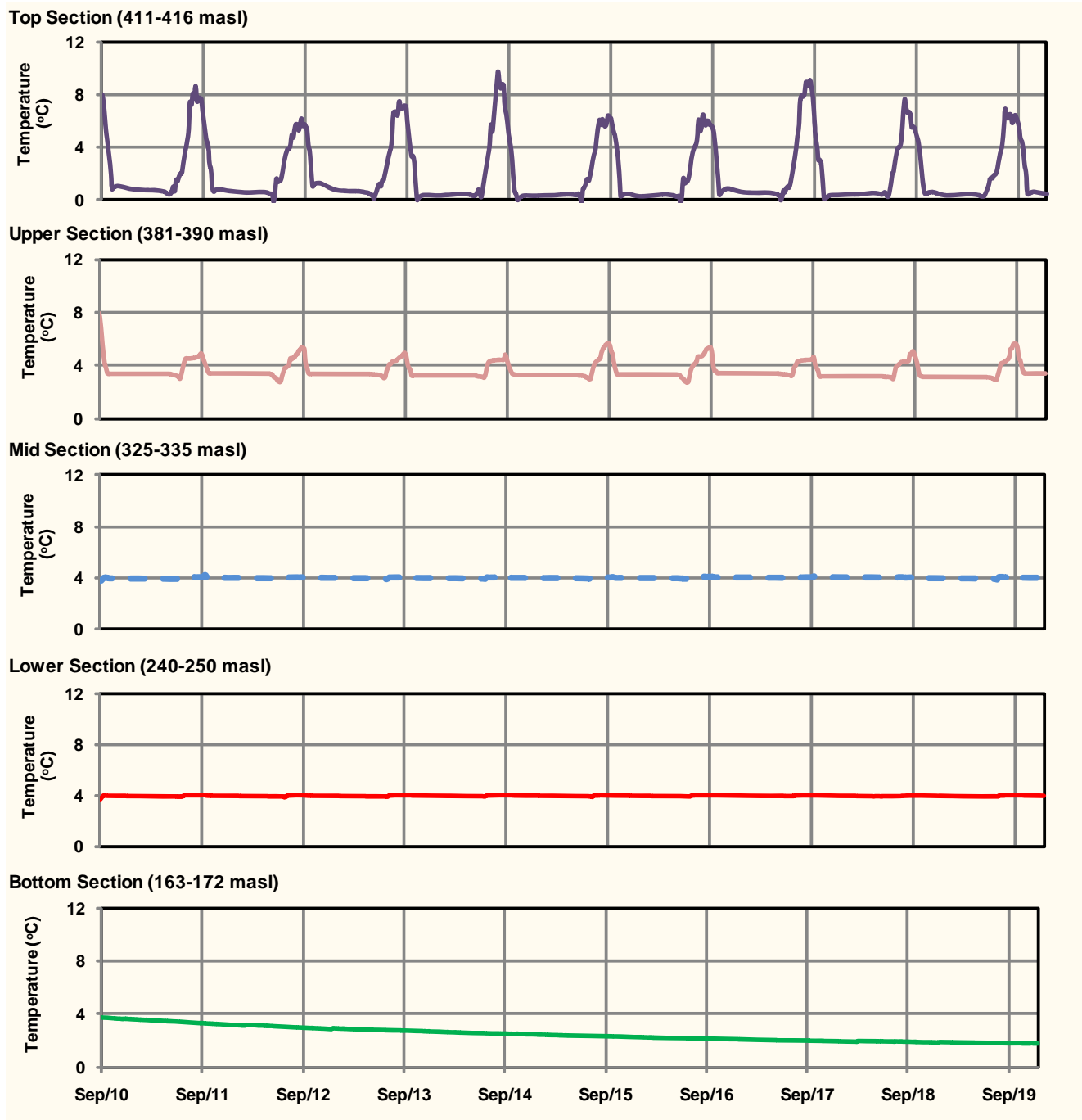


Figure 8: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 195 Scenario



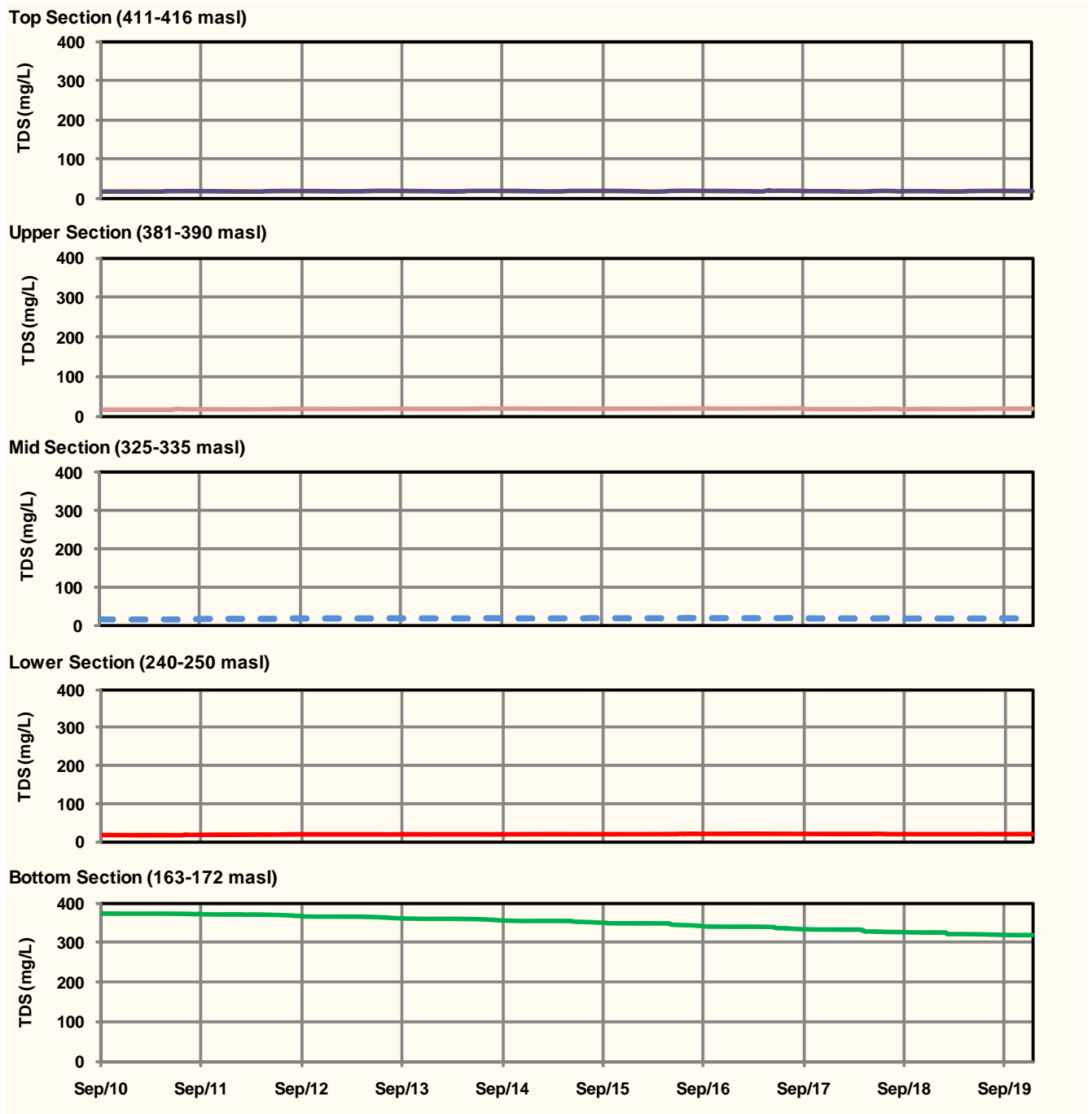
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 9: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 195 Scenario



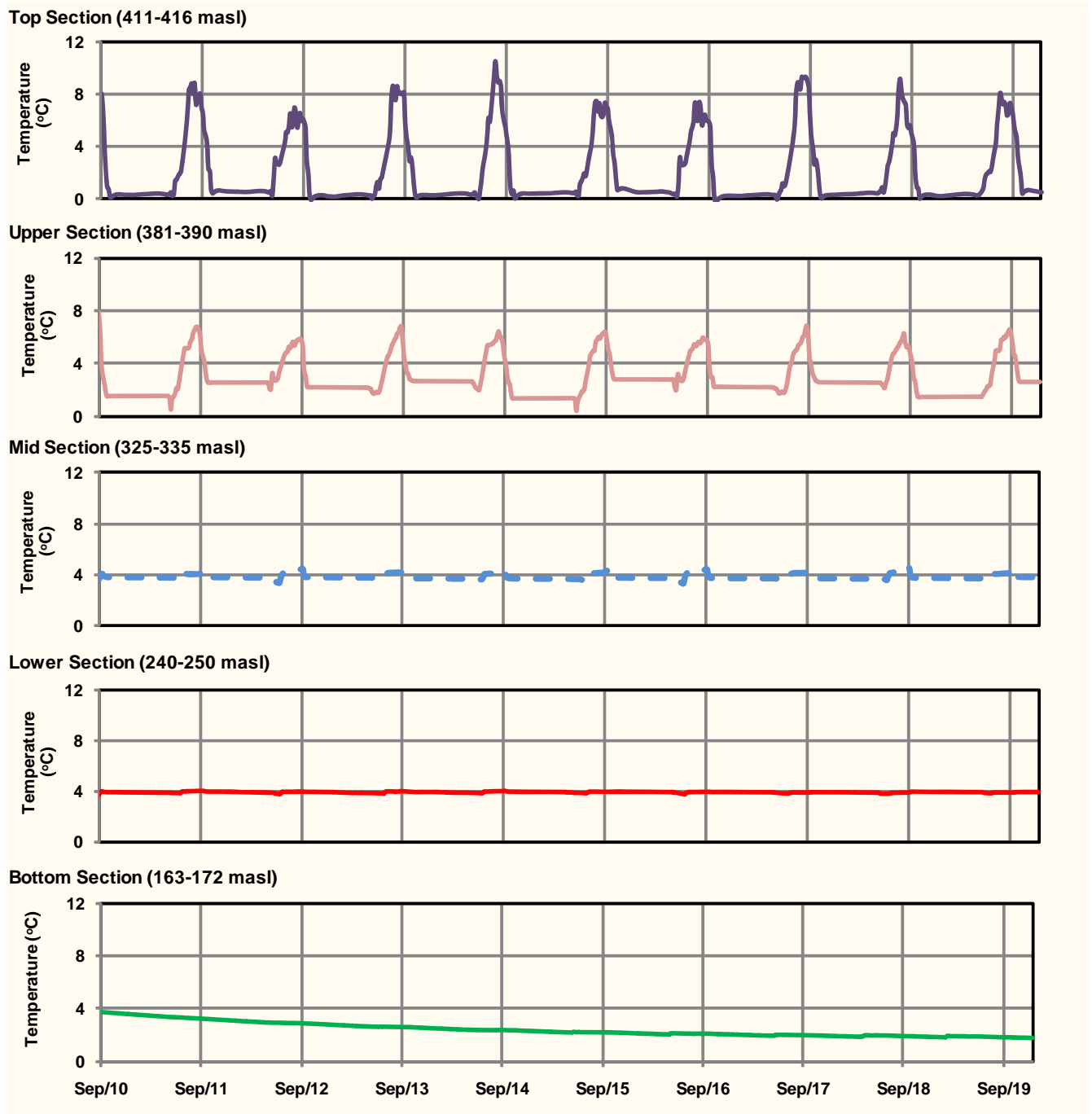
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 10: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 195 W2 Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 11: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 195 W2 Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

### **Scenarios GW to 295, GW to 295 W2 and GW to 295 W2 RedQ**

In the GW to 295 simulation, the volume of groundwater initially contained in the A154 pit lake was increased such that it filled the lake to an elevation of 295 masl. The remaining portion of the lake was filled with water pumped in from Lac de Gras. Consequently, a larger proportion of the A154 pit lake had the characteristics of the saline groundwater in comparison to both the Base Case and GW to 195 scenarios.

Based on the model predictions, the increased groundwater content provided the pit lake with a greater level of internal stability, in comparison to that observed under the GW to 195 scenario. TDS levels in the lower portion of the pit lake remained virtually unchanged over the 10-year simulation (Figure 12), in contrast to the small rate of decline observed under the GW to 195 scenario (Figure 8). This pattern suggests that mixing rates between the freshwater and saline portions of the pit lake were lower than those that occurred in the GW to 195 scenario when a smaller portion of the pit lake was initially filled with groundwater.

Predicted water temperature trends in the upper portion of A154 pit lake under the GW to 295 scenario were similar to those observed in the GW to 195 scenario, while water temperatures in the lower portion of the pit lake declined to a lesser extent (Figures 9 and 13). The slower observed rate of decline is likely attributable to the large volume of groundwater residing in the bottom of the lake as a connected entity, which provided a greater buffer to the heat lost that was occurring along the bottom and sides of the lower portion of the pit lake.

When wind speeds were doubled, this connectedness within the lower portion of the pit lake was disrupted, because of increased vertical mixing across the 295 masl divide. Although the mixing energy was insufficient to result in complete turnover events, it did produce vertical variations in water temperatures and TDS levels over the lower portion of the pit lake, below 295 masl. TDS levels near the 295 masl divide declined by approximately 40 mg/L over the 10-year simulation, whereas those near the lake bottom declined by only 10 mg/L (Figure 14). Similarly, water temperatures closer to the 295 masl divide were warmer than those predicted at depth, where heat losses were no longer buffered to the same extent as they were under normal wind conditions (Figure 15).

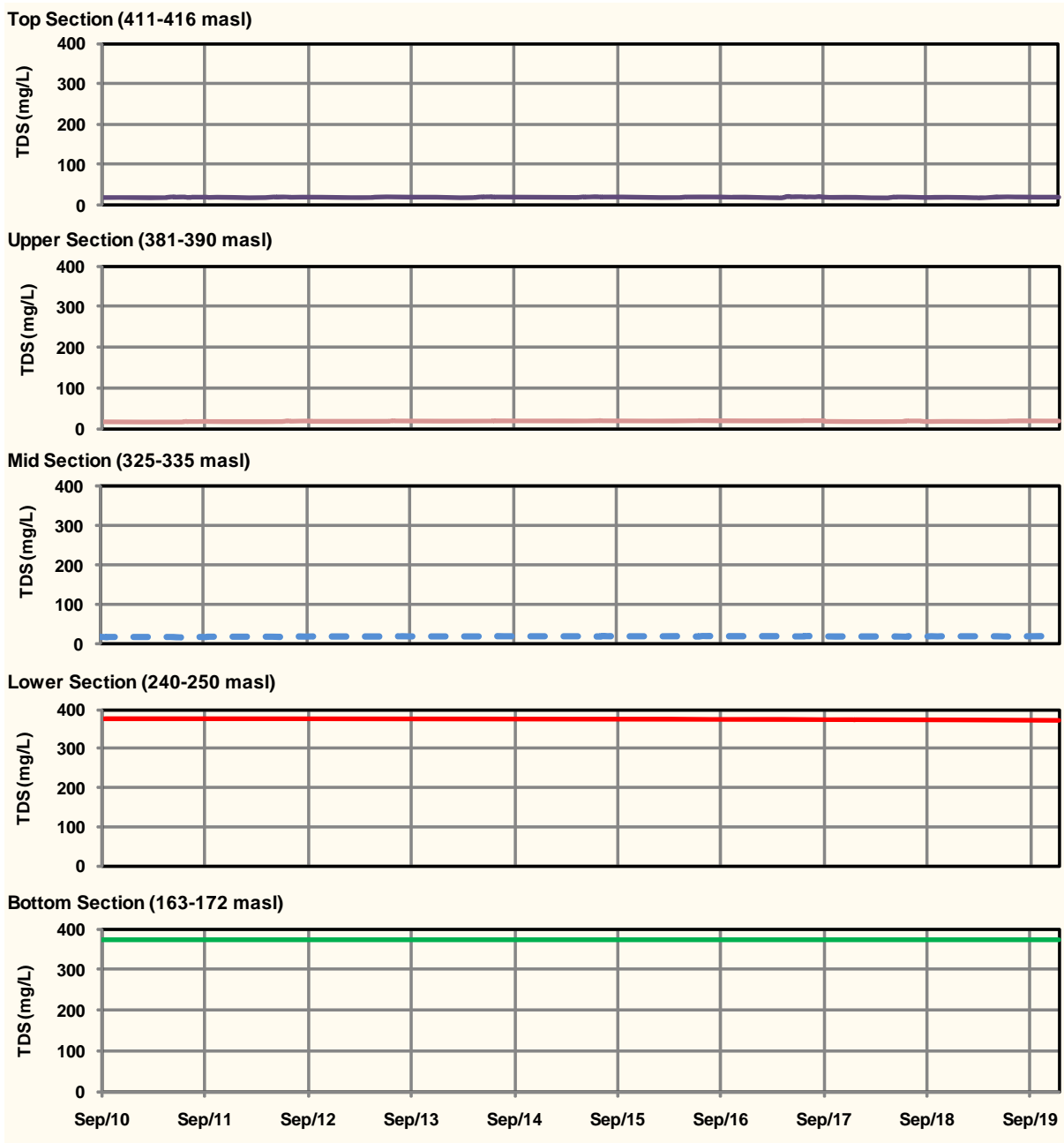
In the upper portion of the A154 pit lake, the increased wind speed resulted in a smaller increase in open-water temperatures (Figure 15), consistent with the changes observed in the GW to 195 W2 scenario (Figure 11). Water temperatures at mid-depth remained around 4°C (Figure 15), consistent with the patterns observed under normal wind conditions (Figure 13) and in the Base Case and GW to 195 simulations (Figures 7, 9 and 11).

TDS levels in the upper lake waters were virtually unchanged from those predicted to occur under normal wind conditions (Figures 12 and 14). However, TDS levels at mid-depth were predicted to increase slightly over the course of the simulation (increasing from 18.5 to 28 mg/L) (Figures 14). Under normal wind conditions (i.e., under the GW to 295 set-up) and under the GW to 195 W2 scenario, no such increase was predicted to occur. These contrasting patterns suggest that, although increased groundwater content can provide a greater level of internal stability under typical wind conditions, it can also lead to detectable changes in water quality in the upper portion of the water column near the groundwater – surface water divide under more extreme wind conditions. Detectable changes can occur, because the volume of freshwater available for mixing declines in proportion to the volume of groundwater initially placed in the lake.

Reducing the rate of surface water exchange between the A154 pit lake and Lac de Gras in the open-water season (Scenario GW to 295 W2 Red Q) had little effect on TDS levels in the pit lake; they remained consistent with the predictions developed under higher exchange rates (Figures 14 and 16). It also had little effect on water temperatures through the lower portion of the pit lake (Figures 15 and 17). The reduction in open-water surface inflow rates produced a noticeable change in predicted water temperatures in the upper portion of the pit lake.

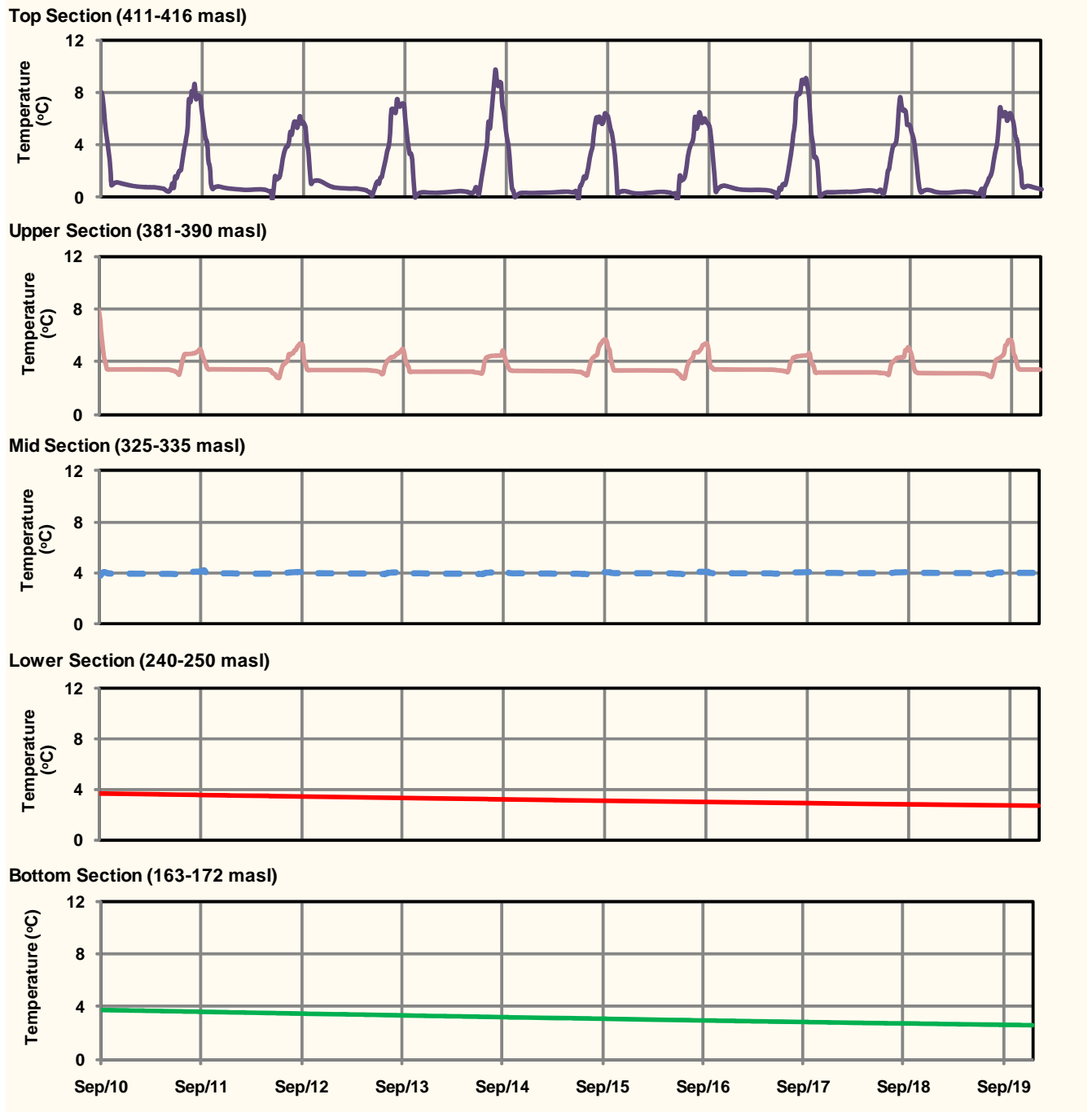
Water temperatures in this portion of the pit lake tended to be cooler than under the higher exchange rate included in the GW to 295 W2 scenario, because of the reduced input of warmer water from Lac de Gras. These trends support the findings of Imberger and Patterson (1990), who suggest that the destabilizing effects of wind generally far exceed those of incoming and outgoing flows. That said, the rate at which water can travel between the A154 pit lake and Lac de Gras will have an influence on water quality in the upper portion of the pit lake, because it determines the residence time of the lake and, more importantly, the degree to which the upper waters are flushed each year.

Figure 12: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 295 Scenario



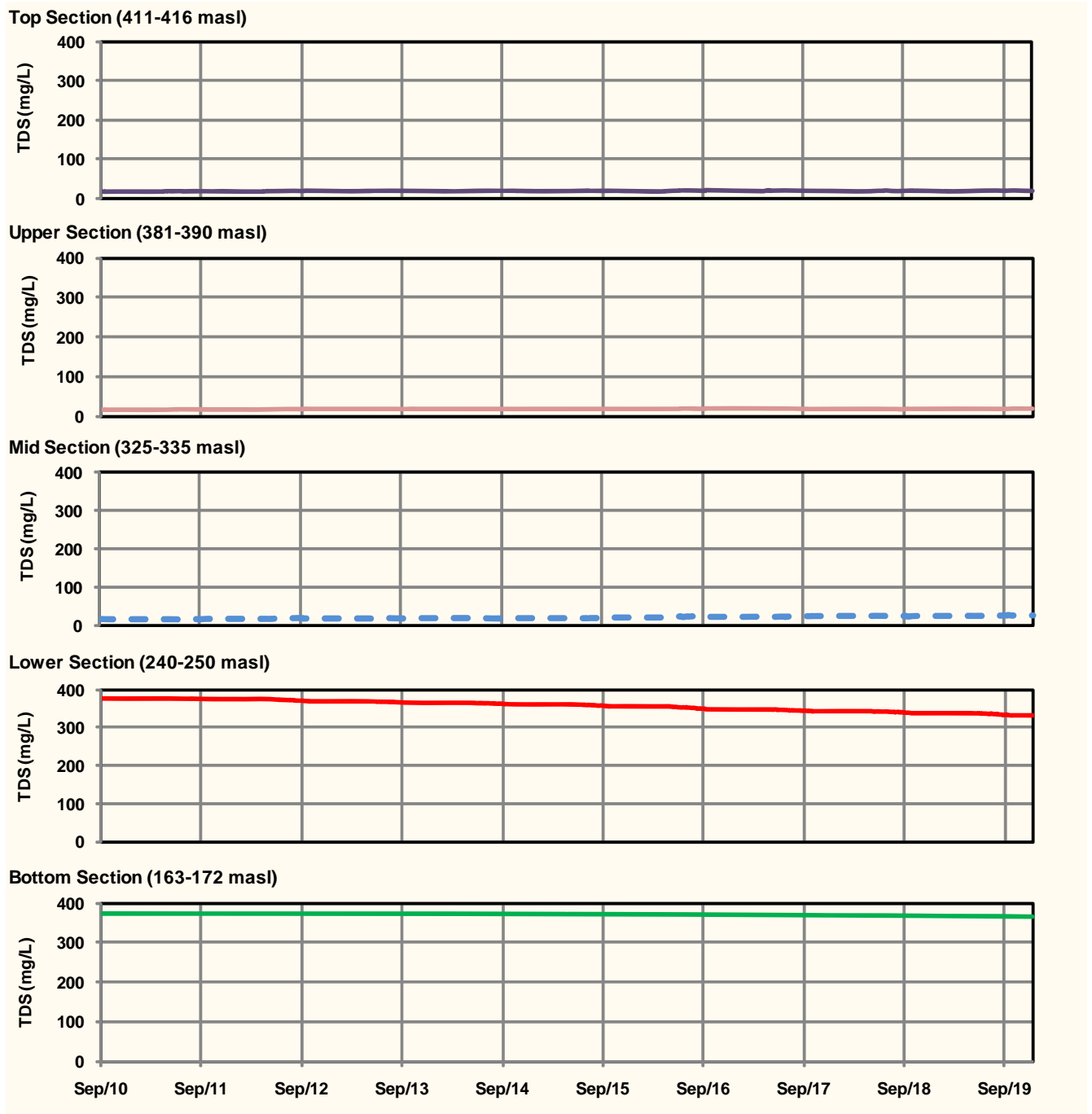
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 13: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 295 Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

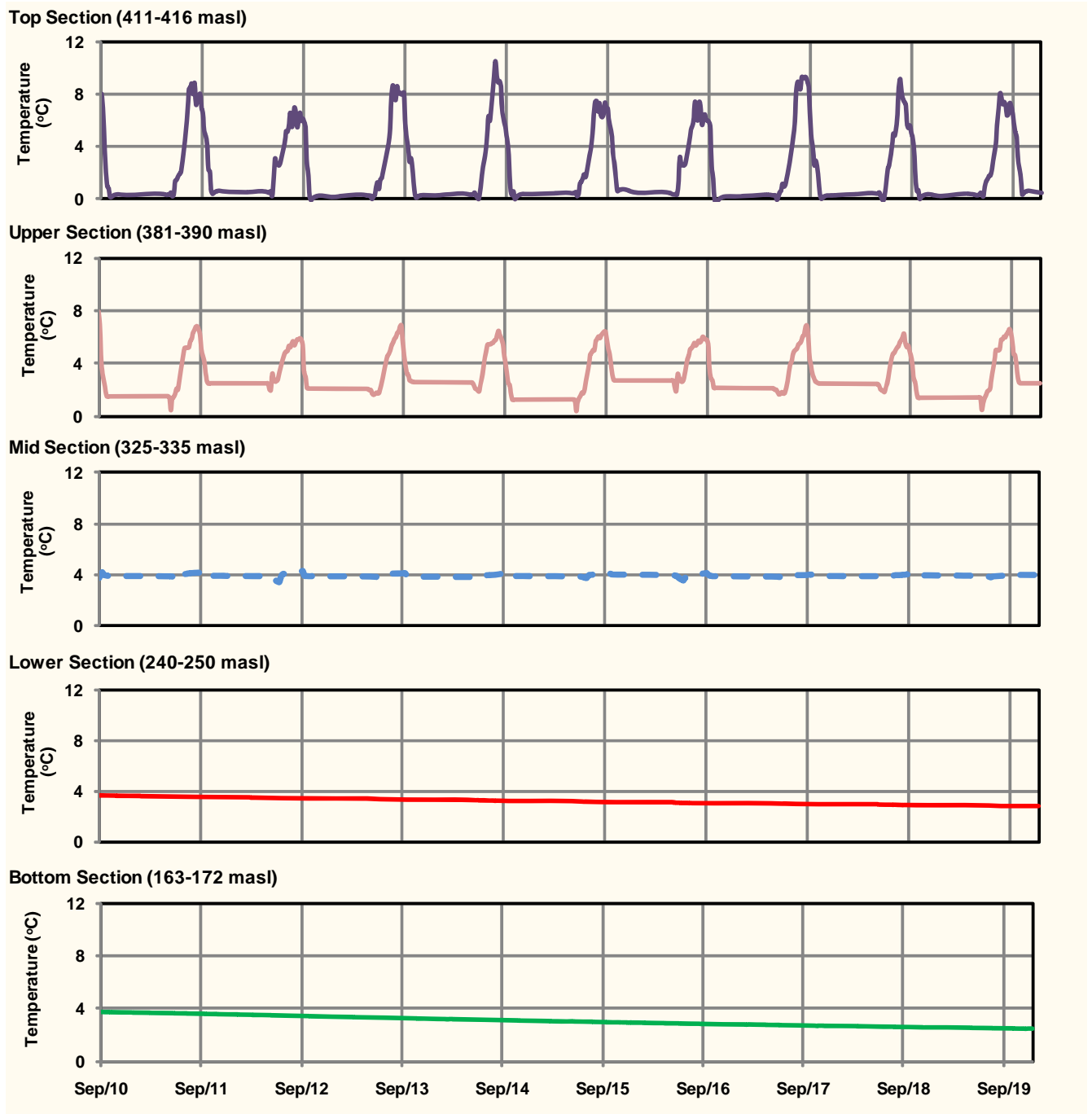
Figure 14: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 295 W2 Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

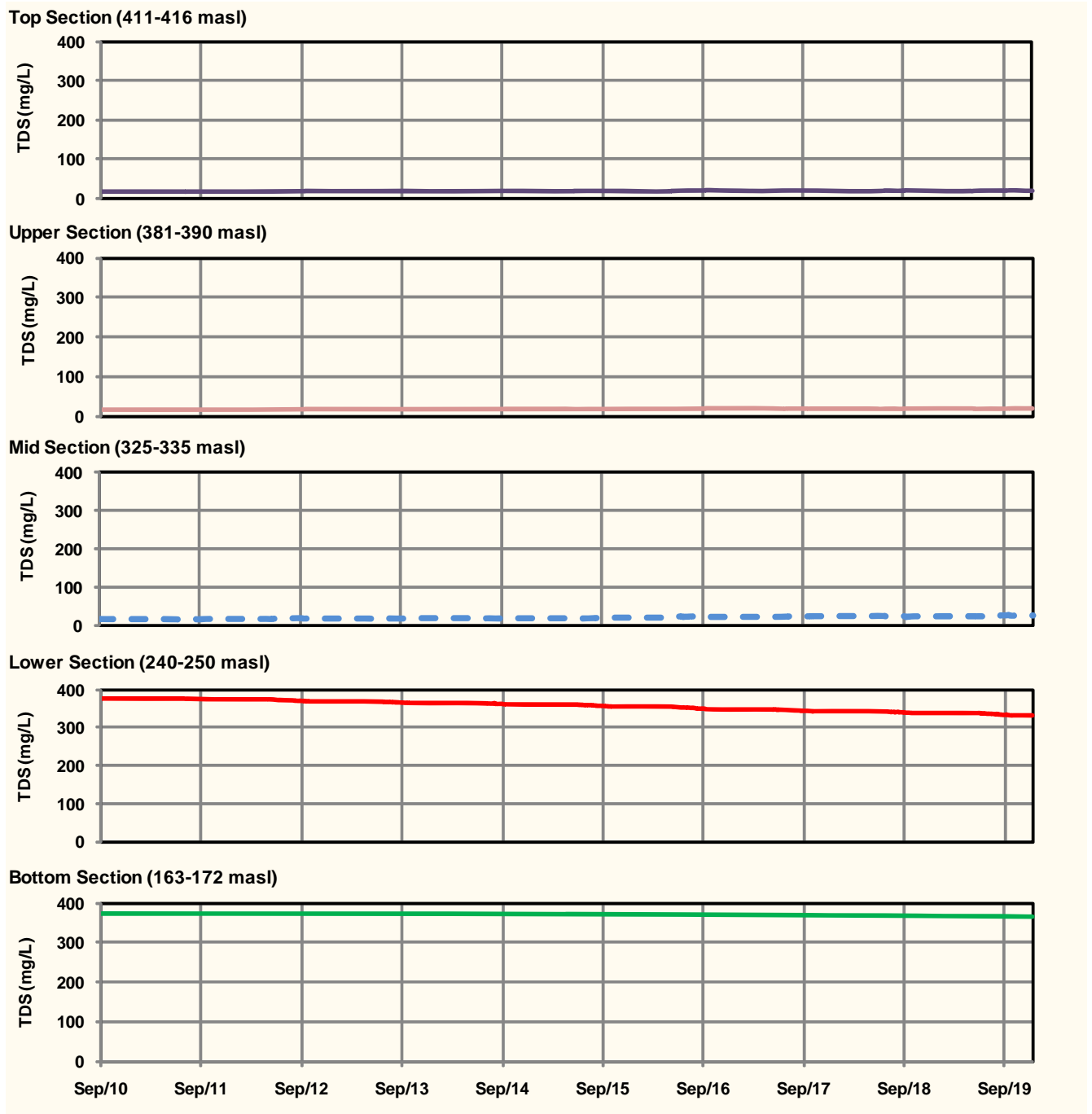


Figure 15: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 295 W2 Scenario



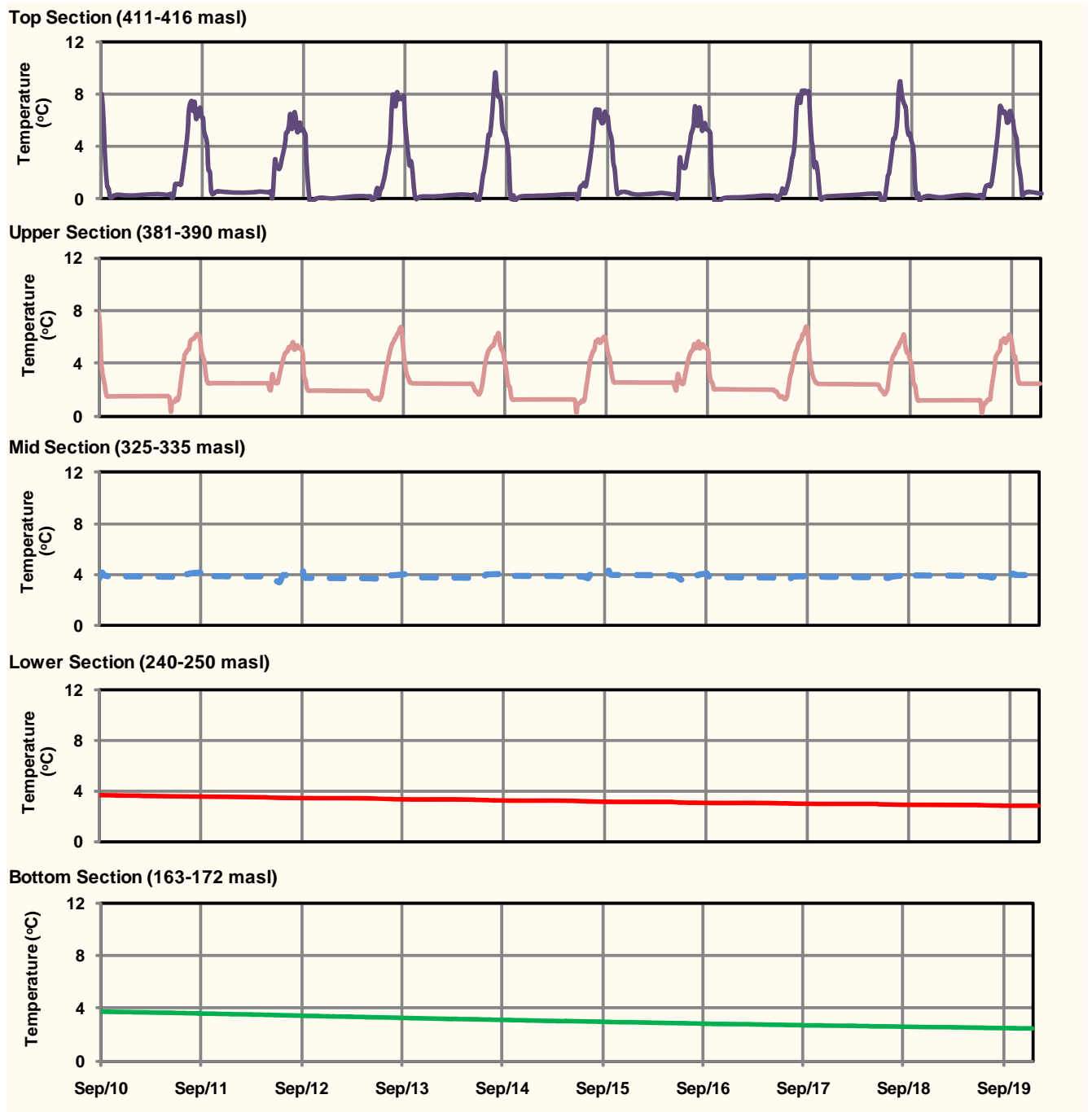
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 16: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 295 W2 RedQ Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 17: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 295 W2 RedQ Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

## **Scenarios GW to 411 and GW to 411 W2**

The GW to 411 and GW to 411 W2 scenarios involved filling the majority of the A154 pit lake with groundwater, up to an elevation of 411 masl, and then using surface water from Lac de Gras to fill the remaining space. The GW to 411 scenario was completed using observed wind speed data, which were then doubled in the GW to 411 W2 simulation.

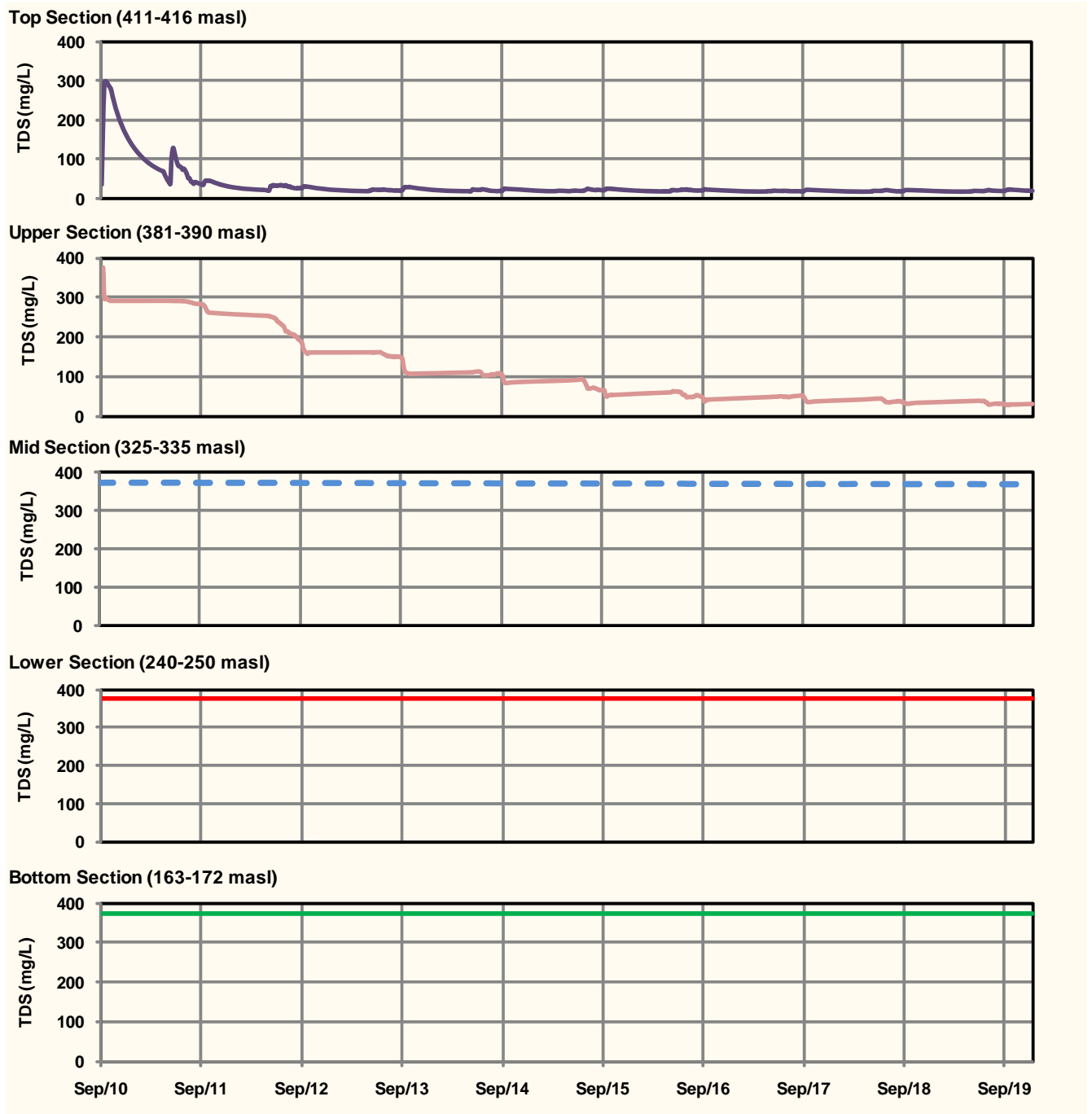
Predicted TDS levels from the GW to 411 simulation indicate that a groundwater – surface water divide at 411 masl cannot be maintained. Although full mixing of the pit lake did not occur at any point in the 10-year simulation, TDS levels in the upper portion of the pit lake (i.e., above 360 to 380 masl) gradually declined, suggesting a slow downward migration of the chemocline to a depth between 335 and 360 masl (Figure 18). Below 335 masl, TDS levels were typically consistent and stable at around 375 mg/L, although a small, slow rate of decline in TDS levels was observed at mid-depth, between 325 and 335 masl. This small decline is suggestive of some limited vertical mixing and diffusion across the chemocline, consistent with the predictions generated from the GW to 195 and GW to 295 simulations. However, TDS levels at depth changed to a lesser extent under the GW to 411 scenario than under GW to 295 scenario, in which TDS levels at depth changed to a lesser extent than under the GW to 195. This pattern was observed under normal wind conditions (Figures 8, 12 and 18) and when wind speeds across the surface of the pit lake were doubled (Figures 10, 14 and 19). Together, these observations support the concept that increased groundwater content up to approximately 360 masl would likely provide the A154 pit lake with a greater level of internal stability than would otherwise occur with less groundwater content.

Doubling the speed of the wind travelling across the surface of the A154 pit lake resulted in a more rapid downward migration of the chemocline and a greater level of exchange across the chemocline, as illustrated by the changes in TDS levels predicted to occur over the duration of the GW to 411 W2 simulation (Figure 19), relative to those predicted to occur under the GW to 411 scenario (Figure 18).

Predicted water temperatures in the upper portion of the pit lake were similar to those predicted to occur under the GW to 195 and GW to 295 scenarios, with respect to normal wind conditions (Figures 9, 13 and 20) and to more extreme wind conditions (Figures 11, 15 and 21). These results suggest that initial groundwater content in the A154 pit lake is unlikely to appreciably affect water temperatures in the upper portion of the lake. Instead, they are likely to be controlled to a much greater degree by climate conditions and, to a lesser extent, the rate of exchange between the pit lake and Lac de Gras.

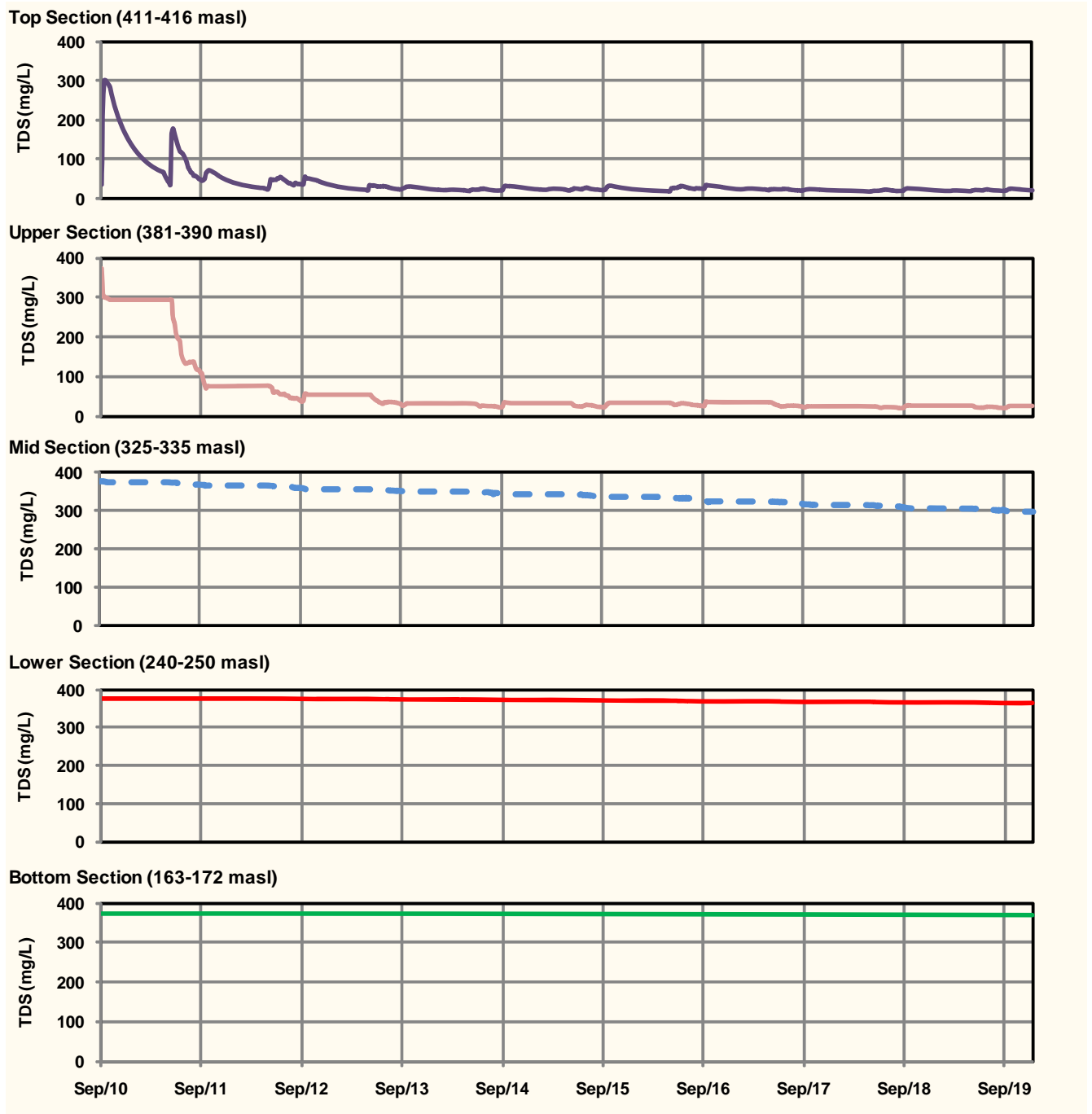
The amount of groundwater initially placed in the A154 pit lake could exert some influence on water temperatures at the bottom of the lake, since model predictions suggest that slightly cooler temperatures may occur with smaller groundwater volumes than with larger initial volumes. However, the predicted differences are small in magnitude and may be of limited ecological relevance, given the depth at which they occur.

Figure 18: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 411 Scenario



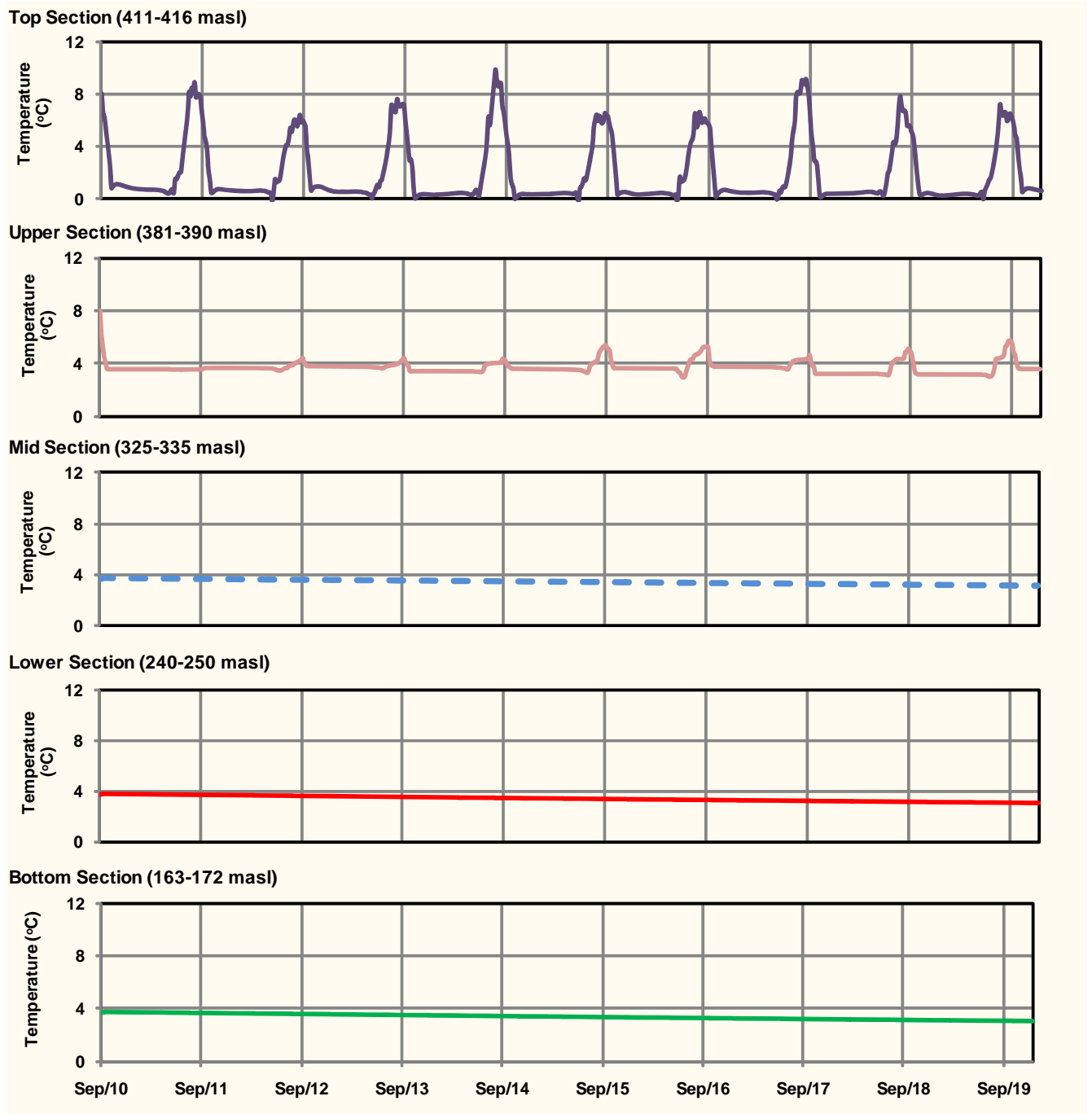
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 19: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 411 W2 Scenario



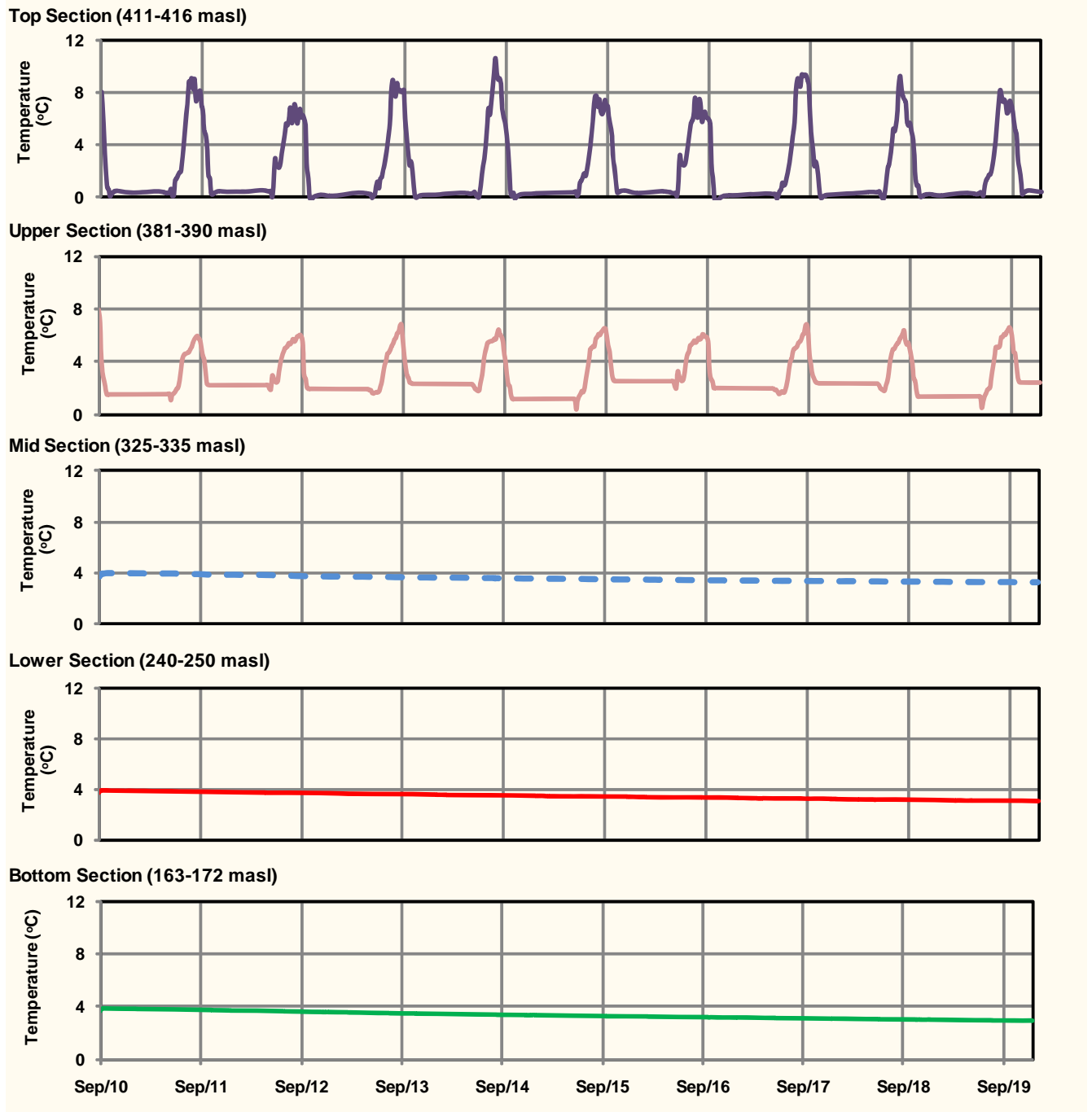
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 20: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 411 Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

Figure 21: Predicted Water Temperatures at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the GW to 411 W2 Scenario



Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.



## 4.2 Empirical Analysis

As noted in Section 3.2, the empirical analysis consisted of calculating Lake Numbers for the A154 pit lake for a range of wind speeds and varying TDS levels in the lower portion of the lake. These calculations were completed for two different water temperatures in the upper portion of the lake (i.e., 6 and 8°C), and with the chemocline placed at two different elevations (i.e., 195 and 295 masl).

General trends observed in the data produced from the empirical analysis were as follows (Tables 3 to 6):

- Lake Numbers for a given set of water temperatures, wind speeds and TDS levels were almost always higher when the chemocline was set to 295 masl rather than 195 masl.
- Lake Numbers typically increased as TDS levels in the lower portion of the lake increased, although the effect was more pronounced when the chemocline was set to 295 masl relative to when it was set to 195 masl.
- Increased wind speeds resulted in lower Lake Numbers for a given set-up, reflective of the increased destabilizing force it exerts on the lake.
- Lake Numbers were also typically lower for a given set-up when water temperatures in the upper portion of the lake were set to 6 rather than 8°C, although the effect was less pronounced when the chemocline was set to 295 masl than when it was set to 195 masl.

These results suggest that the internal stability of the A154 pit lake will likely be higher with greater groundwater content (particularly if TDS levels in the groundwater exceed 175 mg/L), provided the groundwater is placed into the lake first and then capped with surface water.

The results of the empirical analysis were consistent with those produced using the dynamic water quality model in all four cases where similar set-ups involving an initial groundwater elevation of 295 masl were evaluated. Lake Numbers greater than one were produced for all four cases (Tables 3 and 4), which is indicative of a stable system that is resistant to turnover. As outlined in Section 4.1.2, turnover was not observed in either of the GW to 295 or GW to 295 W2 scenarios.

**Table 3: Lake Numbers for the A154 Pit Lake when Filled with Groundwater to an Elevation of 295 masl, Having a Water Temperature of 8°C in the Upper Portion of the Lake**

| Wind Speed (m/s) | Concentration of Total Dissolved Solids in Groundwater (mg/L) <sup>(a)</sup> |     |     |     |     |     |     |     |     |
|------------------|--|-----|-----|-----|-----|-----|-----|-----|-----|
|                  | 25   | 50  | 75  | 125 | 175 | 275 | 375 | 475 | 575 |
| 5                | 28   | 32  | 36  | 44  | 51  | 67  | 176 | 209 | 241 |
| 10               | 7.0  | 8.0 | 9.0 | 11  | 13  | 17  | 44  | 52  | 60  |
| 15               | 3.1  | 3.6 | 4.0 | 4.8 | 5.7 | 7.4 | 20  | 23  | 27  |
| 20               | 1.8  | 2.0 | 2.2 | 2.7 | 3.2 | 4.2 | 11  | 13  | 15  |
| 25               | 1.1  | 1.3 | 1.4 | 1.7 | 2.1 | 2.7 | 7.0 | 8.3 | 10  |
| 30               | 0.8  | 0.9 | 1.0 | 1.2 | 1.4 | 1.9 | 4.9 | 5.8 | 6.7 |
| 35               | 0.6  | 0.7 | 0.7 | 0.9 | 1.0 | 1.4 | 3.6 | 4.3 | 4.9 |
| 40               | 0.4  | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 2.7 | 3.3 | 3.8 |
| 45               | 0.3  | 0.4 | 0.4 | 0.5 | 0.6 | 0.8 | 2.2 | 2.6 | 3.0 |
| 50               | 0.3  | 0.3 | 0.4 | 0.4 | 0.5 | 0.7 | 1.8 | 2.1 | 2.4 |

<sup>(a)</sup> Lake Numbers >1 are shaded and indicate limited potential for turnover; cross-hatched cells represent cases that mirror the conditions examined using the dynamic CE-QUAL-W2 model, based on peak wind speeds as defined in Table 7.

The same level of consistency was not observed in the common cases involving an initial groundwater elevation of 195 masl. Although Lake Numbers greater than one were calculated under normal wind conditions (i.e., peak velocities of ~15 m/s) (Tables 5 and 6), Lake Numbers less than one were produced under more extreme wind conditions, which is indicative of the potential for full turnover. However, full turnover was not predicted to occur by the dynamic water quality model for these situations, as outlined in Section 4.1.2. This discrepancy suggests that the empirical analysis completed as part of this preliminary study may result in conservative estimates of turnover potential.

**Table 4: Lake Numbers for the A154 Pit Lake when Filled with Groundwater to an Elevation of 295 masl, Having a Water Temperature of 6°C in the Upper Portion of the Lake**

| Wind Speed (m/s) | Concentration of Total Dissolved Solids in Groundwater (mg/L) <sup>(a)</sup> |     |     |     |     |     |     |     |     |
|------------------|--|-----|-----|-----|-----|-----|-----|-----|-----|
|                  | 25   | 50  | 75  | 125 | 175 | 275 | 375 | 475 | 575 |
| 5                | 8  | 12  | 16  | 50  | 66  | 99  | 132 | 165 | 198 |
| 10               | 2.0  | 2.9 | 3.9 | 12  | 17  | 25  | 33  | 41  | 49  |
| 15               | 0.9  | 1.3 | 1.7 | 5.5 | 7.4 | 11  | 15  | 18  | 22  |
| 20               | 0.5  | 0.7 | 1.0 | 3.1 | 4.1 | 6.2 | 8.3 | 10  | 12  |
| 25               | 0.3  | 0.5 | 0.6 | 2.0 | 2.7 | 4.0 | 5.3 | 6.6 | 7.9 |
| 30               | 0.2  | 0.3 | 0.4 | 1.4 | 1.8 | 2.8 | 3.7 | 4.6 | 5.5 |
| 35               | 0.2  | 0.2 | 0.3 | 1.0 | 1.4 | 2.0 | 2.7 | 3.4 | 4.0 |
| 40               | 0.1  | 0.2 | 0.2 | 0.8 | 1.0 | 1.6 | 2.1 | 2.6 | 3.1 |
| 45               | 0.1  | 0.1 | 0.2 | 0.6 | 0.8 | 1.2 | 1.6 | 2.0 | 2.4 |
| 50               | 0.1  | 0.1 | 0.2 | 0.5 | 0.7 | 1.0 | 1.3 | 1.7 | 2.0 |

<sup>(a)</sup> Lake Numbers >1 are shaded and indicate limited potential for turnover; circled numbers represent cases that mirror the conditions examined using the dynamic CE-QUAL-W2 model, based on peak wind speeds as defined in Table 7.

**Table 5: Lake Numbers for the A154 Pit Lake when Filled with Groundwater to an Elevation of 195 masl, Having a Water Temperature of 8°C in the Upper Portion of the Lake**

| Wind Speed (m/s) | Concentration of Total Dissolved Solids in Groundwater (mg/L) <sup>(a)</sup> |     |     |     |     |     |     |     |     |
|------------------|--|-----|-----|-----|-----|-----|-----|-----|-----|
|                  | 25   | 50  | 75  | 125 | 175 | 275 | 375 | 475 | 575 |
| 5                | 27   | 28  | 28  | 30  | 31  | 33  | 35  | 38  | 40  |
| 10               | 6.8  | 7.0 | 7.1 | 7.4 | 7.7 | 8.3 | 8.8 | 9.4 | 10  |
| 15               | 3.0  | 3.1 | 3.2 | 3.3 | 3.4 | 3.7 | 3.9 | 4.2 | 4.4 |
| 20               | 1.7  | 1.7 | 1.8 | 1.9 | 1.9 | 2.1 | 2.2 | 2.3 | 2.5 |
| 25               | 1.1  | 1.1 | 1.1 | 1.2 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 |
| 30               | 0.8  | 0.8 | 0.8 | 0.8 | 0.9 | 0.9 | 1.0 | 1.0 | 1.1 |
| 35               | 0.6  | 0.6 | 0.6 | 0.6 | 0.6 | 0.7 | 0.7 | 0.8 | 0.8 |
| 40               | 0.4  | 0.4 | 0.4 | 0.5 | 0.5 | 0.5 | 0.6 | 0.6 | 0.6 |
| 45               | 0.3  | 0.3 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.5 |
| 50               | 0.3  | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.4 | 0.4 | 0.4 |

<sup>(a)</sup> Lake Numbers >1 are shaded and indicate limited potential for turnover; circled numbers represent cases that mirror the conditions examined using the dynamic CE-QUAL-W2 model, based on peak wind speeds as defined in Table 7.

**Table 6: Lake Numbers for the A154 Pit Lake when Filled with Groundwater to an Elevation of 195 masl, Having a Water Temperature of 6°C in the Upper Portion of the Lake**

| Wind Speed (m/s) | Concentration of Total Dissolved Solids in Groundwater (mg/L) <sup>(a)</sup> |     |     |     |     |     |     |     |     |
|------------------|--|-----|-----|-----|-----|-----|-----|-----|-----|
|                  | 25   | 50  | 75  | 125 | 175 | 275 | 375 | 475 | 575 |
| 5                | 7  | 8   | 8   | 9   | 10  | 13  | 15  | 17  | 20  |
| 10               | 1.8  | 1.9 | 2.0 | 2.3 | 2.6 | 3.2 | 3.8 | 4.3 | 5   |
| 15               | 0.8  | 0.8 | 0.9 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | 2.2 |
| 20               | 0.4  | 0.5 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.1 | 1.2 |
| 25               | 0.3  | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
| 30               | 0.2  | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.5 |
| 35               | 0.1  | 0.2 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 | 0.4 | 0.4 |
| 40               | 0.1  | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.3 |
| 45               | 0.1  | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.2 |
| 50               | 0.1  | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 |

<sup>(a)</sup> Lake Numbers >1 are shaded and indicate limited potential for turnover; circled numbers represent cases that mirror the conditions examined using the dynamic CE-QUAL-W2 model, based on peak wind speeds as defined in Table 7.

**Table 7: Characteristics of the Wind Speed Profile Included as Input to the Dynamic A154 Pit Lake Model**

| Statistic                          | Wind Speed (m/s) |
|------------------------------------|------------------|
| Median                             | 4.6              |
| 75 <sup>th</sup> Percentile        | 6.9              |
| 95 <sup>th</sup> Percentile        | 11.0             |
| 99 <sup>th</sup> Percentile / Peak | 13.9             |
| Maximum                            | 19.8             |

## 5.0 CONCLUSIONS

Conclusions that can be drawn from the results of the initial pit lake mixing study are as follows:

- The simultaneous introduction of surface water and groundwater into the A154 mine pit is likely to lead to a high degree of mixing as the pit fills, although some minor variations in water quality may develop over the depth of the lake near the end of the filling period. Over time, these variations would be expected to disappear as a consequence of slow vertical mixing. The depth of the A154 mine pit relative to its surface dimensions minimizes the opportunities for rapid, full turnover events, except perhaps just after the lake is filled before the lower section has cooled to around 4°C.
- Initially filling a portion of the A154 mine pit with saline groundwater, which is then carefully covered with surface water from Lac de Gras, is likely to result in a stratified system that will persist for some time. Although the system will be stratified and turnover events would not be expected, a small amount of vertical mixing and diffusion is likely to occur across the groundwater – surface water divide. However, the rate of transfer across this interface appears to be negatively correlated with the volume of groundwater placed in the lake. In other words, the internal stability of the pit lake appears to increase as its groundwater content

increases up to an elevation of approximately 360 masl. Groundwater placed above this elevation is likely to be mixed into to the overlying surface water.

- The initial groundwater content of the A154 pit lake is unlikely to appreciably affect water temperatures in the upper portion of the lake. Instead, they are likely to be controlled to a much greater degree by climate conditions and, to a lesser extent, the rate of exchange between the pit lake and Lac de Gras.
- The amount of groundwater initially placed in the A154 pit lake could exert some influence on water temperatures at the bottom of the lake, since model predictions suggest that slightly cooler temperatures may occur with smaller groundwater volumes than with larger initial volumes. However, the predicted differences are small in magnitude and may be of limited ecological relevance, given the depth at which they occur.
- Finally, the Lake Number estimates produced using the empirical relationships outlined herein appear to be conservative in their prediction of full lake turnover, because those expected to occur under certain conditions were not observed in the results produced using the dynamic A154 pit lake model.

These conclusions are put forth with the understanding that they are based on preliminary modelling. The focus of the initial mixing study was to provide a general understanding of potential mixing conditions in the A154 pit lake. It was not intended to provide a definitive description of water quality in the pit lake over time, and the results outlined herein should be interpreted and used with this limitation in mind.

## 6.0 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned at (403) 299-5600.

Yours truly,

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Water Quality Modeller

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Associate, Senior Water Quality Specialist

JPB/kl/aw

Attachment: Table A-1, Values Assigned to Model Coefficients and Rate Constants

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**Table A-1: Values Assigned to Model Coefficients and Rate Constants**

| Category                | Parameter Definition                                       | Parameter Code | Unit                 | Value <sup>(a)</sup> |
|-------------------------|--|----------------|----------------------|----------------------|
| Heat exchange           | heat exchange method                                       | [SLHTC]        | -                    | term-by-term         |
|                         | wind speed coefficients                                    | a [AFW]        | -                    | 9.2                  |
|                         |  | b [BFW]        | -                    | 0.46                 |
|                         |  | c [CFW]        | -                    | 2                    |
|                         | bottom heat exchange coefficient                           | [CBHE]         | W/m <sup>2</sup> sec | 0.3                  |
| sediment temperature    | [TSED]   | °C             | 0.6 <sup>(b)</sup>   |                      |
| Ice module coefficients | ice method   | [SLICEC]       | -                    | Detail               |
|                         | ice albedo   | [ALBEDO]       | [fraction]           | 0.8 <sup>(b)</sup>   |
|                         | water-ice heat exchange coefficient                        | [HWI]          | W/m <sup>2</sup> sec | 0.1 <sup>(b)</sup>   |
|                         | fraction of solar radiation absorbed by ice                | [BETA]         | -                    | 0.6                  |
|                         | solar radiation extinction coefficient                     | [GAMMA]        | m <sup>-1</sup>      | 0.1                  |
|                         | minimum ice thickness before formation                     | [ICEMIN]       | M                    | 0.05                 |
|                         | water temperature above which ice formation is not allowed | [ICET2]        | bn                   | 4 <sup>(b)</sup>     |
| Hydraulic coefficients  | transportation scheme                                      | [SLTRC]        | -                    | ultimate             |
|                         | time-weighting for vertical advection scheme               | [THETA]        | -                    | 0.55                 |
|                         | longitudinal eddy viscosity                                | [AX]           | m <sup>2</sup> /sec  | 1                    |
|                         | longitudinal eddy diffusivity                              | [DX]           | m <sup>2</sup> /sec  | 1                    |
|                         | interfacial friction factor                                | [FI]           | -                    | 0.01                 |
|                         | Manning's n  | [FRICTC]       | -                    | 0.025 <sup>(b)</sup> |
|                         | vertical turbulence closure algorithm                      | [AZC]          | -                    | W2N <sup>(d)</sup>   |
|                         | treatment of vertical eddy viscosity                       | [AZSLC]        | -                    | Implicit             |
|                         | maximum value of eddy viscosity                            | [AZMAX]        | m <sup>2</sup> /sec  | 0.001 <sup>(e)</sup> |
| Light extinction        | light extinction for pure water                            | [EXH2O]        | m <sup>-1</sup>      | 0.35                 |
|                         | light extinction due to suspended sediments                | [EXSS]         | m <sup>-1</sup>      | 0.1                  |
|                         | fraction of solar radiation absorbed at surface            | [BETA]         | m <sup>-1</sup>      | 0.45                 |

<sup>(a)</sup> Shaded values differ from default values recommended by Cole and Wells (2008).

<sup>(b)</sup> Selected value has been used in other northern lake modelling studies.

<sup>(c)</sup> The W2N algorithm provides a lower estimate of the turbulent eddy viscosity; as such, it provides a more conservative estimate of the degree of potential stratification in the lake.

<sup>(d)</sup> The maximum eddy viscosity was changed from the default value of 1.0. A value of 1.0 is recommended for rivers and estuaries, but values as low as 0.001 are acceptable for lakes (Cole and Wells 2008).

**DATE** December 10, 2010**PROJECT No.** 10-1328-0031/4000**TO** Mr. Gord Macdonald  
Diavik Diamond Mines Inc.**DOC No.** 1011 Ver. 0**DIAVIK PO No.** C09400**GOLDER CONTRACT No.** D01510**FROM** John Cunning**EMAIL** jccunning@golder.com**INITIAL SCREENING ASSESSMENT OF OPTIONS FOR DISPOSAL OF INERT BUILDING MATERIALS AT CLOSURE – DIAVIK MINE SITE****1.0 INTRODUCTION**

Diavik Diamond Mines Inc. (DDMI) requested that Golder Associates Ltd. (Golder) prepare an assessment to review options for the disposal of inert building materials arising from the decommissioning and closure at the Diavik site.

This technical memorandum presents a conceptual estimate of the potential inert building material waste to be generated during decommissioning and closure, an initial screening evaluation of on-site versus off-site disposal options for the inert building material waste at closure, and recommendation for further building material waste disposal studies.

**2.0 CONCEPTUAL ESTIMATE OF POTENTIAL WASTE GENERATED**

An estimate of the potential inert building material waste has been prepared based on a desktop assessment of the building's dimensions provided by DDMI and Golder's knowledge of mine site building structures. The inventory of buildings currently at the Diavik site as provided by DDMI is presented in Appendix I, Table AI-1.

The potential inert building material waste likely to be generated from the existing Diavik site buildings were considered to be:

- Steel Elements: columns, beams, open mesh flooring and pipes;
- Concrete: base slabs, floor slabs, internal walls and inner skins; and
- Various: wall and sheet panels, insulation and cladding, plasterboard and fittings.

As-built drawings for the existing buildings were not reviewed as part of this work. The estimate is limited to the building structures and does not include any contained equipment or structures supporting this equipment. The estimates developed have been based on the anticipated steel frame type structures with concrete slabs and steel open mesh flooring or trailer type structures. Specific interior distribution of buildings (number of floors or internal wall divisions) was not available for this conceptual estimate and have been estimated based on pre-existing knowledge of mine site structures.

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Building foundations and base slabs were not included in the quantity estimate as these have been assumed to remain in place at closure.

The estimate has assumed that hazardous materials will have been identified and removed prior to decommissioning. At this stage, it has been assumed that the buildings have no residual value and cannot be salvaged and re-sold.

For each building in the inventory list (Appendix I, Table AI-1), estimated volumes have been prepared based on assumed sizing for each buildings components. To obtain the bulk volume for disposal, a conservative bulking factor of 2.2 was applied, with the bulking factor based on previous building demolition estimates. The weight for building components in the inventory list has been determined from the volume and typical material bulk density. To obtain the total weight for disposal a contingency of 35% has been applied to the estimated weight, with the contingency used to accounts for some of the uncertainty in assumed building components at this preliminary stage of the estimate.

Appendix I Table AI-2 presents a summary of the estimated bulk volume and weight quantity of inert building material waste by building and includes some key assumptions used in the estimate. Table 1 presents a summary of the total quantity of waste inert building materials by material type which is estimated to be generated at closure based on the inventory of buildings provided. The results of this estimate indicate a potential total waste inert building materials bulk volume of some 53,000 m<sup>3</sup> and total weight of some 58,000 tonnes.

**Table 1: Summary of the Estimated Quantity of Inert Building Material Waste**

| <b>Material</b>                         | <b>Bulk Volume for Disposal (m<sup>3</sup>)</b> | <b>Total Weight for Disposal (tonne)</b> |
|---|---|--|
| Steel                                   | 6,000   | 8,000                                    |
| Concrete                                | 27,000  | 36,000                                   |
| Wall and sheet panels                   | 1,000   | 4,500                                    |
| Insulation                              | 14,000  | 3,500                                    |
| Others (plasterboard, fittings, cables) | 5,000   | 6,000                                    |
| Total Estimated                         | ~53,000   | ~58,000                                  |

### **3.0 ASSESSMENT OF OPTIONS FOR WASTE DISPOSAL**

The first phase of the evaluation of disposal options for the inert building material waste was considered to be an initial screening assessment of on-site and off-site waste disposal options. An initial screening of these two options has been carried out using a weighted ranking matrix analysis. The analysis uses a set of indicators which are scored based on anticipated conditions and performance.

The waste disposal options indicators that were utilized for this evaluation were grouped under three categories:

- Environmental factors;
- Social factors; and
- Economic factors.



For this evaluation, each indicator within a category was considered equally important and the scores assigned to each indicator were summed and normalized to a percentage of the maximum possible score of the category to allow for a direct comparison. The relative scores were assigned based on considerations of risk, reliability and cost.

No specific off-site waste management facility has been identified for this evaluation. For this assessment, it has been assumed that a suitable facility in Yellowknife could be available for this waste. For the on-site option, disposal of inert building materials within the currently disturbed main areas (open pit, waste dumps, underground mine, etc.) has been considered feasible. The estimated quantity of potential waste inert building materials presented in this document has been utilized for this evaluation.

Table 2 presents a summary of the initial screening assessment ranking the on-site and off-site waste disposal options. The evaluation indicates that an on-site waste disposal results in a higher score and thus more favourable option for each of the three categories considered when compared to an off-site waste disposal option.

On the environmental factors, off-site disposal requires a significant use of fuel just to transport the material from the mine site to a landfill in Yellowknife. This is estimated to produce over 350 tonnes of CO<sub>2</sub> equivalent green house gas emissions which results in the lowest relative ranking for the off-site option. The on-site is anticipated to generate a lower risk of release of waste or spills in to the environment.

On the social factors, the construction of an on-site waste disposal facility is expected to have a lower impact on worker's safety. Both on-site and off-site disposal are expected to have about the same impact on public safety.

On the economic factors, there is a significant cost advantage to on-site disposal, as high waste tipping fees would be incurred for off-site. However, off-site is at an advantage as once tipped, there is no long term monitoring required. On-site disposal requires monitoring as part of the overall site decommissioning.

**Table 2: Initial Screening Assessment for Disposal of Inert Building Materials at Closure**

| Theme                      | Indicator                                     | Indicator Description  | Ranking Description  | Score     |          | Comments   |
|----------------------------|---|--|--|-----------|----------|--|
|                            |   |  |  | On-Site   | Off-Site |  |
| <b>Environmental</b>       |   |  |  |           |          |  |
| Use of Natural Resources   | Energy Consumption                            | Direct and/or indirect energy consumption (fuel, electricity, etc.) during disposal operations including transportation.   | A score from 1 (high energy) to 5 (low energy) is assigned based on the relative energy usage.   | 5         | 1        | On-site waste disposal: low energy consumed during disposal operations.<br><br>Off-site waste disposal: very high energy consumption required for transporting some 58,000 tonnes to Yellowknife. Trucking alone would require about 150,000 litres of diesel fuel and create over 350 tonnes of equivalent CO <sub>2</sub> green house gas emissions. |
|                            | Use of Natural Resources                      | Quantity of natural resources required for the implementation of the options excluding energy and water (e.g., Quarried material)  | A score from 1 (high) to 5 (low) is assigned based on the relative quantity of construction materials required.                          | 2         | 3        | On-site waste disposal: reasonable use of natural resources if constructed within disturbed areas.<br><br>Off-site waste disposal: minimal or low use of natural resources (excluding transport energy).   |
| Hazards                    | Release of waste, spills or Related Solutions | Potential for release of waste, leachate or spills into the environment.   | 1 = high risk<br>2, 3, 4 = relative ranking<br>5 = low risk  | 4         | 2        | On-site waste disposal: relatively low risk based on small work area, shorter material handling time, disposal within disturbed mine area.<br><br>Off-site waste disposal: relatively high based on longer handling time with more equipment.  |
| Ecological Integrity       | Impacts on Biodiversity, Species and Habitat  | Direct and indirect short-term impacts during the construction and operation of the option on species diversity (health, growth, interactions, density, composition and distribution) with an emphasis on rare and endangered flora and fauna. | 1 = permanent impact<br>2 = persisting impact<br>3 = partial recovery<br>4 = full recovery<br>5 = Improvement by implementing the option | 3         | 3        | On-site waste disposal: disposed within disturbed area.<br><br>Off-site waste disposal: disposed on existing facility, similar impacts.  |
| <b>Total Environmental</b> |   |  |  | 14<br>70% | 9<br>45% |  |

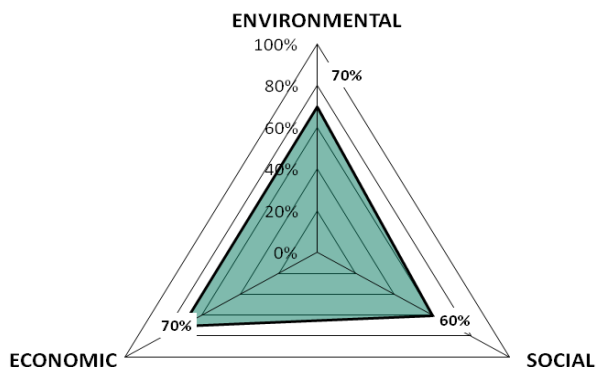
**Table 2: Initial Screening Assessment for Disposal of Inert Building Materials at Closure**

| Theme              | Indicator                              | Indicator Description  | Ranking Description   | Score    |          | Comments  |
|--------------------|--|--|---|----------|----------|---|
|                    |  |  |   | On-Site  | Off-Site |   |
| <b>Social</b>      |  |  |   |          |          |   |
| Health and Safety  | Public Safety                          | Potential adverse impacts on public safety arising from the implementation of the option.  | 1 = significant impact<br>2 = moderate impact<br>3 = low impact<br>4 = no impact<br>5 = potential benefit   | 3        | 2        | On-site waste disposal: low impact on existing industrial site with trained work force and limited or no access by the public.<br><br>Off-site waste disposal: moderate impact due to transportation some 800 loads during winter conditions to Yellowknife.  |
|                    | Workers' Safety                        | Potential adverse impacts for the safety of the Corporation and contractor staff (accidents, time off, illness, etc.) from the implementation of the option. | 1 = significant impact<br>2 = moderate impact<br>3 = low impact<br>4 = no impact<br>5 = potential benefit   | 3        | 2        | On-site waste disposal: low impact, familiar construction and operation activities within the mine site. Safety procedures and supervision can be easily implemented.<br><br>Off-site waste disposal: moderate impact of transportation during winter conditions to Yellowknife. Supervision and monitoring is more difficult to implement. |
| Social Environment | Use for the Public / Cultural Heritage | Overall impacts on the socio-economic and cultural attributes of the site (land use, historical, preservation, archaeological, etc.)                         | 1 = significant impact/restriction<br>2 = moderate impact/restriction<br>3 = low impact/restriction<br>4 = no impact/restriction<br>5 = potential benefit | 3        | 3        | On site waste disposal: facility within currently disturbed areas.<br><br>Off-site waste disposal: existing facility, similar impacts.  |
|                    |  |  | <b>Total Social</b>   | 9<br>60% | 7<br>47% |   |

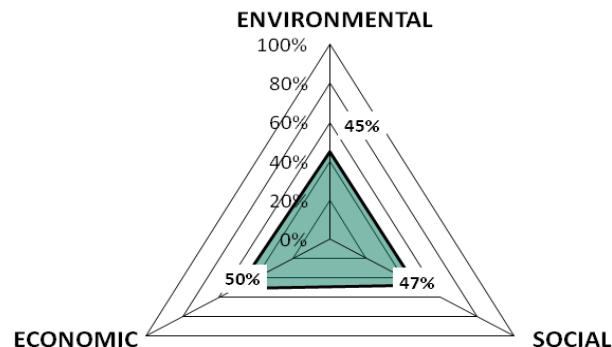
| Theme           | Indicator             | Indicator Description  | Ranking Description   | Score     |           | Comments  |
|-----------------|-----------------------|--|---|-----------|-----------|---|
|                 |                       |  |   | On Site   | Off Site  |   |
| <b>Economic</b> |                       |  |   |           |           |   |
| Costs           | Tipping fee for waste | Value of construction and capital costs of the option.                                     | A relative score from 1 (high cost) to 5 (low cost) is assigned based on the relative capital cost of the option.   | 5         | 1         | On-site waste disposal: low cost with the construction of a waste management facility within disturbed mine area.<br><br>Off-site waste disposal: high cost due to transporting 58,000 tonnes to Yellowknife and high tipping fee for over 58,000 tonnes. |
|                 | Operating Costs       | Present value of operation and maintenance costs over the operating horizon of the option. | A relative score from 1 (high cost) to 5 (low cost) is assigned based on the relative operating cost of the option. | 2         | 4         | On-site waste disposal: higher cost of monitoring the waste management facility.<br><br>Off-site waste disposal: low cost as limited long term operating cost   |
|                 |                       |  | <b>Total Economic</b>   | 7<br>70%  | 5<br>50%  |   |
|                 |                       |  | <b>TOTAL</b>  | 30<br>67% | 21<br>47% |   |

**On-site**

**Off-site**



**Preferred Option**



## 4.0 RECOMMENDATIONS

Based on the building inventory and dimensions provided by DDMI, an estimate of the inert building material waste arising from the decommissioning and closure of the Diavik site has been prepared and used to compare the options of on-site versus off-site disposal of this waste at closure.

It is recommended to review the list of buildings considered for decommissioning and closure of the Diavik site for completeness. As closure planning is advanced, further refinements to the estimate should be undertaken through a review of the as-built drawings for each building (if available), and detailed inventory of building materials, to support more detailed waste disposal designs. The preliminary estimate assumed that the buildings have no residual or salvage value at closure, and it is recommended to review this assumption prior to final planning for closure activities.

Based on the initial screening assessment ranking of the on-site and off-site waste disposal options, the results indicate that the on-site disposal option is preferred.

A preliminary review of the options for locations of on-site waste disposal should be undertaken and conceptual design for an on-site disposal facility for the estimated volume of inert building material waste.

## 5.0 CLOSURE

We trust the information provided to you in this technical memorandum is sufficient for your needs at this time. Should you have any questions, please contact us.

**GOLDER ASSOCIATES LTD.**

**ORIGINAL SIGNED**

German Pizarro  
Junior Geotechnical Consultant

GP/JCC/aw/rs

**ORIGINAL SIGNED**

John Cunning, P.Eng. (BC, NWT, NU)  
Associate

Attachments: Appendix I: Tables AI-1 and AI-2

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**APPENDIX I**  
**Tables AI-1 and AI-2**

Table AI-1: Summary of Diavik Site Building Inventory and Dimension Provided By DDMI

| Building Name                         | Building Dimensions |                       |                        |
|---------------------------------------|---------------------|-----------------------|------------------------|
|                                       | Perimeter (m)       | Height (m)            | Area (m <sup>2</sup> ) |
| Process Plant                         | 573                 | 36                    | 8,525                  |
| Main Accommodation Complex            | 750                 | 11                    | 6,981                  |
| Maintenance Building                  | 374                 | 20.9                  | 6,527                  |
| Paste Plant                           | 262                 | 35.6                  | 2,912                  |
| Ammonia Nitrate Building              | 272                 | 16                    | 2,894                  |
| Power House #1                        | 247                 | 14                    | 2,638                  |
| Power House #2                        | 213                 | 14                    | 2,451                  |
| (NEW) Mine Dry                        | 195                 | 8.8                   | 1,851                  |
| Boiler House                          | 196                 | 11.5                  | 1,548                  |
| Lube Oil Storage                      | 171                 | 10                    | 1,457                  |
| NIWTP Acid Storage                    | 152                 | 13.5                  | 1,372                  |
| MAC E Wing                            | 268                 | ATCO Trailer (Single) | 1,283                  |
| North Inlet Water Treatment Plant     | 140                 | 14                    | 1,125                  |
| North Inlet Water treatment Expansion | 129                 | 14                    | 999                    |
| LDG Offices                           | 260                 | ATCO Trailer (Single) | 993                    |
| Sewage Treatment Plant                | 132                 | 7.6                   | 968                    |
| UG Mine Dry                           | 138                 | ATCO Trailer (Double) | 954                    |
| Emulsion Plant                        | 132                 | 7.5                   | 942                    |
| Crusher Building                      | 137                 | 27.03                 | 857                    |
| Surface Operations Welding Shop       | 117                 | 7.5                   | 732                    |
| Surface Operations Building           | 116                 | 7.5                   | 718                    |
| Dorm 2                                | 111                 | 10.9                  | 621                    |
| Dorm 1                                | 111                 | 10.9                  | 614                    |
| North Construction Offices            | 158                 | ATCO Trailer (Single) | 547                    |
| Pit Muster                            | 95                  | ATCO Trailer (Single) | 485                    |
| Mine Rescue Fire Hall                 | 79                  | 6.1                   | 368                    |
| LDG Muster                            | 72                  | ATCO Trailer (Single) | 328                    |
| LDG Offices                           | 75                  | ATCO Trailer (Single) | 273                    |
| A21 Offices                           | 62                  | ATCO Trailer (Single) | 238                    |
| Tank 4                                | 141                 | 14.63                 | 1,590                  |
| Tank 5                                | 141                 | 14.63                 | 1,590                  |
| Tank 3                                | 141                 | 14.63                 | 1,590                  |
| Tank 2                                | 141                 | 14.63                 | 1,590                  |
| Tank 1                                | 141                 | 14.63                 | 1,590                  |

**Table AI-2: Summary of Estimated Quantity of Inert Building Material Waste and Summary of Key Assumptions**

| Building Name                         | Building Dimensions |                       |           | Estimated Volume* (m3) | Estimated Weight^ (tonne) | Information   | Key Assumptions  |
|---------------------------------------|---------------------|-----------------------|-----------|------------------------|---------------------------|---|--|
|                                       | Perimeter (m)       | Height (m)            | Area (m2) |                        |                           |   |  |
| Process Plant                         | 573                 | 36                    | 8,525     | 12,718                 | 13,346                    |   | Steel frame structures have been assumed for all buildings (except ATCO trailer structures identified on list provided by DDMI). The size and configuration of columns and beams has been assumed.                                 |
| Main Accommodation Complex            | 750                 | 11                    | 6,981     | 6,844                  | 8,427                     |   |  |
| Maintenance Building                  | 374                 | 20.9                  | 6,527     | 5,679                  | 5,356                     |   |  |
| Paste Plant                           | 262                 | 35.6                  | 2,912     | 3,907                  | 3,398                     |   |  |
| Ammonia Nitrate Building              | 272                 | 16                    | 2,894     | 3,266                  | 3,701                     |   |  |
| Power House #1                        | 247                 | 14                    | 2,638     | 2,946                  | 2,987                     |   |  |
| Power House #2                        | 213                 | 14                    | 2,451     | 2,677                  | 2,731                     |   |  |
| (NEW) Mine Dry                        | 195                 | 8.8                   | 1,851     | 2,281                  | 2,809                     | Values taken from Main Accommodation divided by 3   |  |
| Boiler House                          | 196                 | 11.5                  | 1,548     | 893                    | 586                       |   |  |
| Lube Oil Storage                      | 171                 | 10                    | 1,457     | 1,018                  | 864                       |   |  |
| NIWTP Acid Storage                    | 152                 | 13.5                  | 1,372     | 1,229                  | 1,170                     |   | Base slabs of each structure are assumed to be staying in place.   |
| MAC E Wing                            | 268                 | ATCO Trailer (Single) | 1,283     | 97                     | 117                       |   |  |
| North Inlet Water Treatment Plant     | 140                 | 14                    | 1,125     | 1,762                  | 1,846                     |   | It has been assumed that the buildings do not have underground structures (except for the Paste Plant). The number of floors of each building has been assumed. Floor concrete slabs and steel mesh flooring have been considered. |
| North Inlet Water treatment Expansion | 129                 | 14                    | 999       | 1,586                  | 1,662                     | Same as NIWTP * 0.9   |  |
| LDG Offices                           | 260                 | ATCO Trailer (Single) | 993       | 86                     | 107                       |   | Only building structures have been considered. No structures supporting equipment or equipment has been considered on this estimation.   |
| Sewage Treatment Plant                | 132                 | 7.6                   | 968       | 523                    | 366                       |   |  |
| UG Mine Dry                           | 138                 | ATCO Trailer (Double) | 954       | 82                     | 92                        |   |  |
| Emulsion Plant                        | 132                 | 7.5                   | 942       | 612                    | 653                       |   | The internal distribution of each building has been assumed. Internal partition walls (plasterboard) and internal concrete walls have been assumed based on the function and perimeter of each building.                           |
| Crusher Building                      | 137                 | 27.03                 | 857       | 1,341                  | 1,160                     |   |  |
| Surface Operations Welding Shop       | 117                 | 7.5                   | 732       | 282                    | 243                       |   |  |
| Surface Operations Building           | 116                 | 7.5                   | 718       | 1,011                  | 1,101                     |   |  |
| Dorm 2                                | 111                 | 10.9                  | 621       | 472                    | 513                       | Same as Dorm 1  | Insulation of all exterior walls and roof has been assumed for all buildings.<br><br>An exterior concrete wall along the perimeter of buildings has been assumed.  |
| Dorm 1                                | 111                 | 10.9                  | 614       | 472                    | 513                       |   |  |
| North Construction Offices            | 158                 | ATCO Trailer (Single) | 547       | 50                     | 78                        |   |  |
| Pit Muster                            | 95                  | ATCO Trailer (Single) | 485       | 36                     | 45                        |   |  |
| Mine Rescue Fire Hall                 | 79                  | 6.1                   | 368       | 36                     | 44                        |   |  |
| LDG Muster                            | 72                  | ATCO Trailer (Single) | 328       | 26                     | 31                        |   |  |
| LDG Offices                           | 75                  | ATCO Trailer (Single) | 273       | 26                     | 31                        | Same as LDG Muster  |  |
| A21 Offices                           | 62                  | ATCO Trailer (Single) | 238       | 26                     | 31                        | Same as LDG Muster  |  |
| Tank 4                                | 141                 | 14.63                 | 1,590     | 148                    | 713                       | Same as Tank 1  |  |
| Tank 5                                | 141                 | 14.63                 | 1,590     | 148                    | 713                       | Same as Tank 1  |  |
| Tank 3                                | 141                 | 14.63                 | 1,590     | 148                    | 713                       | Same as Tank 1  |  |
| Tank 2                                | 141                 | 14.63                 | 1,590     | 148                    | 713                       | Same as Tank 1  |  |
| Tank 1                                | 141                 | 14.63                 | 1,590     | 148                    | 713                       |   |  |
| <b>TOTAL~</b>                         |                     |                       |           | <b>53,000</b>          | <b>58,000</b>             | * Estimated Bulk Volume includes 2.2 bulk factor<br>^ Estimated weight includes 35% contingency |  |

|   |        |        |
|---|--------|--------|
| Total Steel                                   | 6,000  | 8,000  |
| Total Concrete                                | 27,000 | 36,000 |
| Total External Sheet Panels                   | 1,000  | 4,500  |
| Total Insulation                              | 14,000 | 3,500  |
| Total Others (plasterboard, fittings, cables) | 5,000  | 6,000  |



**DATE** December 8, 2010**PROJECT No.** 10-1328-0028/7000/7400**TO** Gord Macdonald  
Diavik Diamond Mines Inc.**DOC. No.** 1015 Ver. 0**DIAVIK PO No.** D01474 line 1**GOLDER CONTRACT No.** C09400**FROM** John Cunning and Peter M. Chapman**EMAIL** jcunning@golder.com;  
pmchapman@golder.com**DISPOSAL ALTERNATIVES FOR NORTH INLET WATER TREATMENT PLANT SLUDGE****1.0 INTRODUCTION**

Diavik Diamond Mines Inc. (DDMI) requested Golder Associates Ltd. (Golder) to explore alternative options for the disposal of the clarifier extraction water (sludge) from the North Inlet water treatment plant (NIWTP) at the Diavik Mine site. Golder is currently involved in a scope of work for DDMI as defined in Work Plan 261 – Support to North Inlet Closure Planning. As part of this work plan, Golder is preparing a report which presents a summary of sampling and characterization of the sludge and the sediments collected from the North Inlet area. Independent of the finding of this report, Golder has prepared the following technical memorandum which presents an overview of the current NIWTP sludge disposal, estimated quantity of sludge to be disposed of over the remaining life of mine, and an initial discussion of alternative disposal options for this sludge.

**2.0 BACKGROUND****2.1 NIWTP**

The North Inlet is located on the East Island in Lac de Gras between the site airport (to the north) and the A154 and A418 mine workings (to the southeast). The North Inlet is approximately 1.75 km in length and ranges from approximately 50 to 150 m in width. The North Inlet was closed off from Lac de Gras in 2001 by construction of the East Dike at its eastern extent and the West Dike at its western extent. Mine inflows and excess PKC Facility pond water are collected and directed by pipeline to the North Inlet. The North Inlet has a holding capacity of about 4 million cubic metres. The process plant has the ability to draw water from the North Inlet. Excess North Inlet water is treated and released into Lac de Gras.

The NIWTP is located at the east end of the North Inlet adjacent to the East Dike and has been in operation since 2002, treating excess water from North Inlet prior to discharge to Lac de Gras. Treatment at the NIWTP includes both flocculation and coagulation. Alum (a water treatment coagulant composed of potassium aluminum sulphate hydrate) and an organic polymer flocculant are used to reduce suspended solids in North Inlet water. Typical annual use is 500 tonnes alum and 5 tonnes flocculant. A by-product of the water treatment process is clarifier thickener underflow or sludge material. Sludge is pulled from the bottom of the thickeners and is hydraulically transported in one of two pipelines to the west end and/or middle of the North Inlet where it is discharged into the Inlet.



Figure 1, which is based on operational data provided by DDMI for the NIWTP, presents a summary of the annual volume of water treated and the annual volume of sludge produced during treatment by the NIWTP between 2003 and 2010. The annual values for 2010 are estimated based on operational data provided up to December 1, 2010.

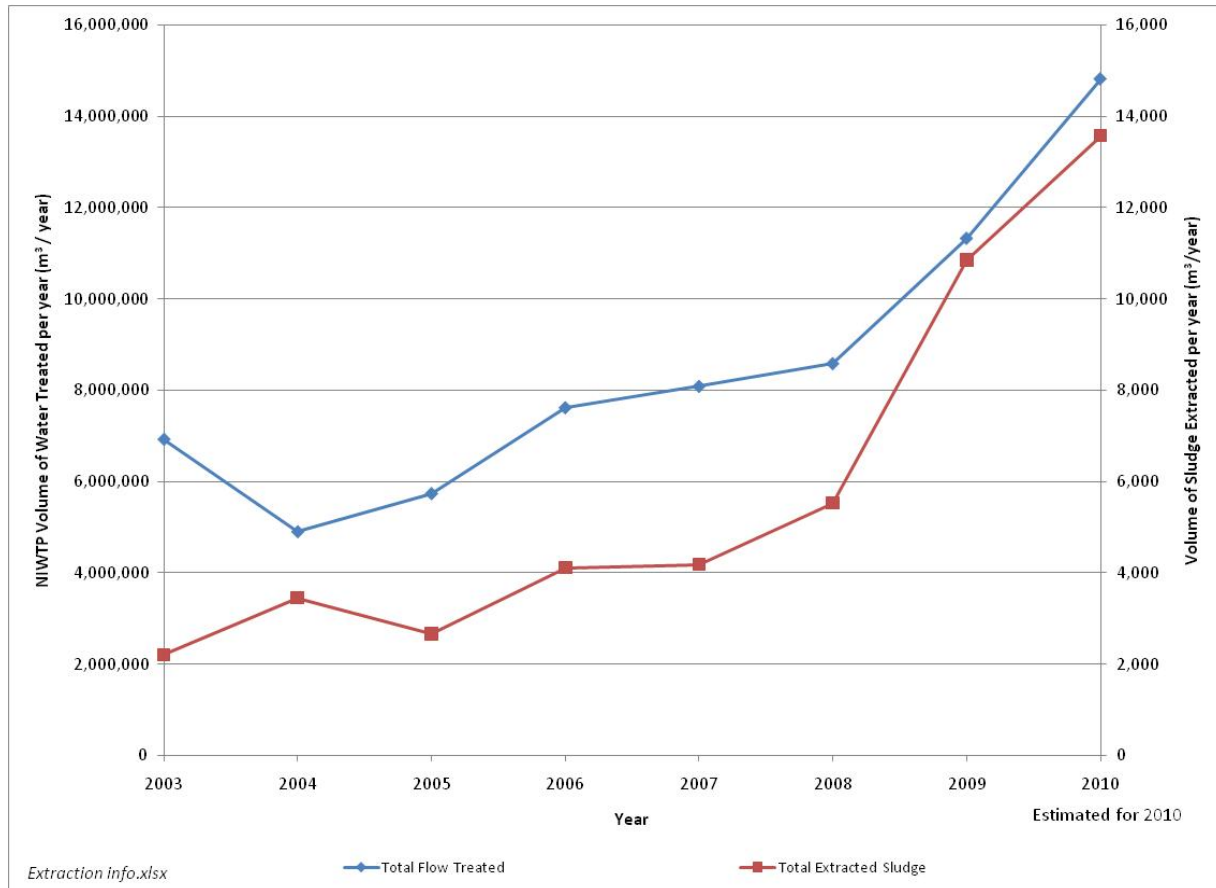


Figure 1: Annual NIWTP quantity of water treated and sludge produced.

The quantity of water directed to the North Inlet and the quantity of water treated by the NIWTP increased with start of underground mining activities through 2009 and 2010. The total volume of water treated in 2009 and 2010 averaged some 13 million m<sup>3</sup> per year. The total sludge extracted in 2009 and 2010 averaged some 12,250 m<sup>3</sup>. For the purpose of this memorandum, it is assumed that the NIWTP will treat an average of 14 million m<sup>3</sup> of water per year, and produce an average of 13,000 m<sup>3</sup> of sludge per year.

Between start up in 2003 and June 2010, the NIWTP has treated a total of 68 M m<sup>3</sup> of water and produced about 46,500 m<sup>3</sup> of sludge. For the remaining life of mine, which has been assumed to be 2011 through to 2024 (14 years), it is estimated that the NIWTP will be required to treat about 196 million m<sup>3</sup> of water, and assuming conditions do not change, it is estimated that this will create over 182,000 m<sup>3</sup> of sludge to be disposed of. The current frequency of sludge production is between 30 and 37 m<sup>3</sup> per day.

## 2.2 Sludge Characteristics

A sample of the sludge material obtained direct from the clarifier was collected as part of the North Inlet sampling program undertaken by Golder in September 2010. Results of testing carried out on this sample will be summarized in a forthcoming technical memorandum.

Sediment chemistry testing indicates that the sludge sample collected contained some 76% sand size particles and 24% silt and clay size particles, with a 97% moisture content (approximate slurry density of 50%). In situ density measurements were not part of the sampling scope of work, but based on these material properties it is estimated that the sludge deposit from the hydraulic deposition would result in a very loose consistency material.

## 3.0 DISPOSAL ALTERNATIVES

### 3.1 Current Sludge Disposal System

Our understanding of the current sludge disposal system is as follows. Alum and an organic polymer are used to reduce suspended solids in a clarifier thickener and periodically the thickener underflow or sludge material is cleaned out. The current sludge disposal method is to pull the sludge from the bottom of the thickener and hydraulically transport the sludge slurry through existing pipelines for discharge into the North Inlet pond. This current sludge disposal system is understood to work well from an operational and economic point of view. The environmental issues related to the continued deposit of the sludge into the North Inlet and the impacts of this deposition on closure are being addressed in another Golder report.

With no change to the sludge disposal, the sludge would continue to accumulate over the North Inlet lakebed. Based on the anticipated sludge production to year 2024, it is estimated that an additional 2 m layer of sludge would deposit over the lakebed, which would be thickest near the pipe outlets and thinner to the east towards the East Dike.

### 3.2 Alternative Options for Sludge Disposal

The following alternative options are technically feasible for the disposal of the NIWTP sludge. A brief description of each alternative and its advantages and disadvantages as compared to the current method are provided.

#### ***Disposal within the Type 3 Waste Rock Pile***

This option considers deposition of the sludge into the existing inert materials landfill area that is contained within the Type 3 waste rock pile. By design, runoff from the Type 3 waste rock pile is directed to Pond 3 where runoff water quality can be monitored through to closure. The sludge would be transported as a hydraulic slurry in a pipeline to this disposal area. Overflow slurry transport water would report to Pond 3. Excess Pond 3 water would be pumped to the North Inlet Pond, using the existing pipeline. The available volume within the inert material landfill would readily accommodate the anticipated volume of sludge. The inert landfill area is also being used for farmed hydrocarbon contaminated soils and is being considered for inert building waste deposit at closure.

No additional containment facility infrastructure would be required to support this option. A slurry pipeline from the NIWTP (about El. 420 m) to the inert material landfill area (about El. 465 m) would be required. Additional pumps would be required to lift the slurry the approximate 45 m in elevation, over a distance of about 3 km.

The deposited sludge would be covered within the waste rock pile and would need to be considered in the Type 3 waste rock pile closure plan.

The impact on water quality of placing the sludge and additional water into the Type 3 waste rock pile would need to be evaluated. Additional pumping from Pond 3 to the North Inlet would be required to handle return of the excess sludge slurry transport water.

Advantages of this option are:

- Removes sludge from disposal in the North Inlet; and,
- Combines this waste material with Type 3 rock and inert landfill materials, which has an existing runoff collection facility (Pond 3) so no additional containment facility would be required.

Disadvantages of this option are:

- Potential to impact or complicate the long term water quality coming from the Type 3 waste rock pile;
- Requires high capital and operational costs, (slurry pipeline and pumps, and permanent return water pumps); and,
- Pumping intermittent slurry flows (flushing once per day) up in elevation would likely be difficult to manage in a pipeline that is required to operate most of the year in the cold Diavik climate.

***Disposal Within the PKC Facility***

This option considers depositing the sludge into the Process Kimberlite Containment (PKC) Facility along with the process kimberlite (PK) materials. The sludge would be transported in a pipeline as a hydraulic slurry, with overflow water reporting to the PKC Pond. The PKC pond waster is re-used by the process plant and about once per year excess water is pumped from the PKC Pond to the North Inlet.

A slurry line from the NIWTP (about El. 420 m) to the PKC Facility (current crest El. 460 m) would be required. The sludge deposition would need to be incorporated into the PKC Facility deposition plan. The slurry line would be required to be raised with the PKC Dam crests, currently estimated to be raised to between El. 470 and 475 m. Additional pumps would be required to lift the slurry the approximate 45 to 60 m in elevation, over a distance of about 2 km.

The deposited sludge would be part of the PKC facility closure plan. The impact of the sludge on the PKC pond water during operation and closure would need to be evaluated.

Advantages of this option are:

- Removes sludge from disposal in the North Inlet; and,
- Combines this waste material with process kimberlite materials (co-disposal) so no additional containment facility would be required.

Disadvantages of this option are:

- Potential to impact operational water quality in the PKC pond;
- Potential to impact or complicate the long term water quality coming from the PKC Facility;
- Requires high capital and operational costs (slurry pipeline and pumps);
- Pumping intermittent slurry flows (flushing once per day) up in elevation would likely be difficult to manage in a pipeline that is required to operate most of the year in the cold Diavik climate; and,
- The PKC Facility available volume for PK would be reduced by about 180,000 m<sup>3</sup>.

***Disposal within a New On-Land Facility***

A new on-land containment facility could be constructed, near the NIWTP, to allow for deposition and storage of the sludge. The facility would require a liner system to retain the sludge and manage the overflow slurry transport water. The sludge could be deposited as hydraulic slurry; however, it is anticipated that the sludge would require additional dewatering to form a higher density material. The use of a rotary filter press could be considered for sludge dewatering. Any overflow water would be collected within the lined facility and pumped back to the North Inlet pond as required.

The new on-land containment facility could be accommodated on the North or South side of the North Inlet Pond. The feasibility of building the new containment facility would need to be evaluated. A pipeline from the NIWTP to the facility would be required.

A closure plan for the sludge facility would be required.

Advantages of this option are:

- Removes sludge from disposal in the North Inlet; and,
- Makes the sludge material available for use in reclamation or hydrocarbon treatment options.

Disadvantages of this option are:

- Potential water quality issues associated with this new facility;
- Requires high capital cost to construct a new on-land containment facility plus capital and operational costs for pipelines, pumps and possibly filter press equipment;
- Pumping intermittent slurry flows (flushing once per day) up in elevation would likely be difficult to manage in a pipeline that is required to operate most of the year in the cold Diavik climate; and,
- Would require a Water Board approval and a closure plan.

### ***Disposal by Mixing with Cover Soils or Mixing with the Hydrocarbon Contaminated Soils***

This option considers mixing the sludge with soil or till material that would then be used as cover for the waste rock pile or other facilities as required as part of the site closure and reclamation activities. The sludge could potentially also be used in the land farm for treatment of hydrocarbon contaminated soils.

This option assumes either an on land storage facility to dewater the sludge, or the addition of a mechanical dewatering system to reduce the sludge water content for mixing purposes.

The effects of the slurry on the hydrocarbon contaminated soils and the final material state would need to be evaluated. It is understood that treated hydrocarbon contaminated soils are deposited in the Type 3 waste rock pile, and the impact of adding sludge to this pile would need to be evaluated.

At closure, the sludge would be part of the till material used for reclamation. The impact of the sludge mixed with till on surface runoff would need to be evaluated.

#### Advantages of this option are:

- Removes sludge from disposal in the North Inlet; and,
- Makes use of the sludge material to enhance available reclamation materials and/or in hydrocarbon soil treatment/reclamation.

#### Disadvantages of this option are:

- Requires either an on land storage facility for dewatering or a mechanical dewatering system;
- Requires capital and operational costs (slurry pipeline, pumps and possibly filter press equipment);
- Potential effects of using the sludge would need to be evaluated; and,
- Requires update to closure and reclamation plan, and approval.

### ***Disposal within the Underground Mine Backfill Mix***

This option considers mixing the sludge with the underground mine backfill mixes which are used throughout underground mine operations. The feasibility of mixing slurry with backfill would need to be evaluated to confirm it did not result in reduced backfill strengths. The sludge could be transported as hydraulic slurry to the paste plant where a mixing methodology would need to be developed.

#### Advantages of this option are:

- Removes sludge from disposal in the North Inlet; and,
- At closure, the sludge would be part of the underground backfill, which will ultimately be flooded.

Disadvantages of this option are:

- Requires capital and operational costs to transport the slurry (pipeline and pumps) and to mix with the backfill; and,
- Need to confirm that this would not affect backfill strength.

***Disposal into the North Inlet Pond followed by Selective Dredging***

This option considers the continuing deposition of the sludge into the North Inlet Pond throughout the remaining mine life. If the North Inlet cannot support the final quantity of sludge at closure, an option would be to consider dredging some quantity of the sludge from the North Inlet and depositing it into either the mined out open pit or underground areas. The feasibility of effectively dredging the sludge would need to be evaluated; however it is expected that the dredge material could be easily transported as hydraulic slurry to the pit area.

At closure, the sludge would be part of the open pit or underground area which are flooded.

Advantages of this option are:

- Allows the current operation for sludge disposal to continue through to the end of mine life; and,
- If appropriate, removes sludge from disposal in the shallow North Inlet part of the lake and places it deep in the flooded mine out area.

Disadvantages of this option are:

- Requires high capital costs at closure to dredge and to transport the dredged material to the mine out areas; and,
- Could be difficult to effectively dredge the sludge deposit from the North Inlet Pond.

We trust that this Technical Memorandum provides you with the information you require. However, if you have any questions or require additional information, please do not hesitate to contact the undersigned.

**GOLDER ASSOCIATES LTD.**

**ORIGINAL SIGNED**

John Cunning, P.Eng. (BC, NWT, NU)  
Associate

Attachment: Study Limitations

JCC/PMC/rs/aw

**ORIGINAL SIGNED**

Peter M. Chapman, Ph.D., R.P.Bio.  
Principal, Sr. Environmental Scientist

## STUDY LIMITATIONS

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# DIAVIK WASTE-ROCK RESEARCH PROGRAM

2009 Progress Report

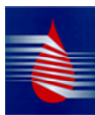
for

Diavik Diamond Mines Inc.  
International Network for Acid Prevention  
Mine Environment Neutral Drainage

Research Partners

University of Waterloo  
University of British Columbia  
University of Alberta

**Diavik Diamond Mine**



MEND



## **Acknowledgements**

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## Executive Summary

The Diavik Waste Rock Project is designed to evaluate the benefits of the proposed reclamation concepts for the Diavik Country Rock Stockpiles, and to evaluate techniques used to scale the results of laboratory studies to predict the environmental impacts of full-scale rock stockpiles. The Diavik Project includes laboratory testing of rock from the Diavik site, field lysimeters containing each rock type and three large-scale test piles. The test piles have been instrumented in detail and monitoring is underway. This report provides a brief update of progress over the 2009 field season. Results and interpretation presented in this report are preliminary and will be updated as new data are collected and more comprehensive quality control and data analysis are performed.

Gas transport studies of the Diavik test piles include gas pressure measurements in the Type III pile and oxygen and carbon dioxide measurements in the Type I, Type III and Covered piles. In the Type III pile gas pressure measurements indicate that pressures within the pile respond to observed changes in wind speed and wind direction exterior to the pile, suggesting that the wind is a major driver for gas transport in this pile. Gas concentration measurements in the Type I and Type III pile show no deviation from atmospheric concentrations suggesting that the rate of gas transport is fast relative to the rate of oxidation reactions. In the Covered pile modest depletions in O<sub>2</sub> concentrations have been observed below the till layer, indicating that the till layer provides a barrier to gas transport. O<sub>2</sub> depletion rates through the summer of 2008 are used to calculate a rate of sulfide oxidation. The calculated rate ranges from  $1.7 \times 10^{-11}$  to  $4.1 \times 10^{-11}$  kg O<sub>2</sub> m<sup>-3</sup> s<sup>-1</sup>. In comparison, humidity cell experiments on Type III rock from the Diavik site give average oxidation rates of approximately  $2 \times 10^{-12}$  kg O<sub>2</sub> m<sup>-3</sup> s<sup>-1</sup>.

Thermal data collected from 2007 to 2009 show freezing of the Type I and Type III piles each winter with a progressive decrease in observed winter temperatures. This trend suggests cooling of the piles. In the summer months the internal temperature throughout the piles continues to rise above 0 °C. The high permeability of the piles combined with the influence of the wind on gas transport led to these large temperature fluctuations. In the covered pile internal temperatures below the till cover remain near zero throughout the year, suggesting that the till layer moderates thermal transport. Above the till layer temperatures fluctuate in response to external temperatures, whereas within the till layer the temperatures drop below 0 °C in the

winter months but remain at 0 °C through the summer, suggesting that frozen water within the till layer is thawing.

Since construction of the test piles, two years have been well below average for rainfall totals (2007, 2009), whereas 2008 was slightly wetter than average. For the Type I and Type III piles outflow in 2009 was lower than in 2008; likely reflecting the much lower infiltration rate in 2009. Outflow for the Type III pile is much higher than the Type I pile, likely due to the artificial rainfall events conducted on the Type III pile in 2007. Covered pile outflow in 2009 also is much lower than 2008. Flow is reporting to a subset of the basal lysimeters in each of Type I and Type III piles. This behaviour is significant because it now provides the opportunity of examining trends in water chemistry for a flow path across the full height of the Type I and Type III test piles. A large scale field permeameter was constructed in 2009 (4 m x 4 m x 2 m). Estimates of matrix porosity as a proportion of total porosity are 5%, with a macroporosity of 22%. These estimates are consistent with the tests carried out in 2007 on a 1 m high permeameter. The saturated hydraulic conductivity for the 2 m high permeameter was approximately  $6 \times 10^{-3}$  m/s.

Effluent from the Type I and Type III basal drains contains high concentrations of ammonia, nitrite and nitrate, which are likely derived from residuals of blasting agents. The irregular concentrations and gradual dissipation of these by-products likely represents flushing along different flow paths. In both the Type I and Type III piles the pH rises and falls each year, possibly as a result of changes in the rates of sulfide oxidation reactions, and declines to below neutral for each pile. Sulfide oxidation in Type III rock is indicated by increased sulfate, release of acidity, depletion of alkalinity, and an increase in dissolved aluminum concentrations associated with dissolution of aluminosilicate minerals. Dissolved metal concentrations from the Type III basal drain effluent increase as the pH declines. Concentrations observed in 2009 are higher than observed in earlier years as the pH declines further each year. In the Type I basal drain effluent dissolved metal concentrations are significantly lower than in the Type III pile. Flow in the upper collection lysimeters is restricted to a few months in summer season. Effluent water quality from the upper collection lysimeters illustrates the difference in the Type I and Type III rock. Type I effluent has remained neutral since construction, whereas the Type III effluent annually falls below pH 4. Sulphate concentrations observed in Type III effluent are higher than the Type I, and alkalinity remains in Type I lysimeter but is completely depleted in

Type III. In the Covered pile, flow to the basal drains occurs throughout the winter, because the pile does not experience the same seasonal temperature cycle as the uncovered piles. As a consequence the pH remains low throughout the year, alkalinity remains low, sulfate concentrations consistently exceed  $2000 \text{ mg L}^{-1}$ , and dissolved metal concentrations are consistently high. In 2008, microbial populations in Type I and Type III test piles effluent were completely dominated by neutrophilic bacteria, *T. thioparus* and related species (Figure 2-25). In June 2009, increased numbers of acidophilic sulfur oxidizing bacteria were observed in all piles, and by September 2009 increased predominance of acidophilic iron oxidizers in the Covered and Type III piles was observed.

Instrumentation of the Type III full-scale waste rock dump will provide important information with respect closure planning at Diavik as well as provide the information necessary to complete the scale up characterization. Due to financial constraints drilling was postponed in 2009 and is tentatively planned for March 2010. Instrumentation is planned to include thermistors, gas sampling lines, tensiometers, soil moisture probes, and permeability instruments. Three attempts were made in 2009 to install instrumentation without drilling. The first two attempts were unsuccessful as the instrumentation was damaged during burial. The third attempt was made at the beginning of December 2009 by stringing a 150 m long instrument bundle horizontally at the base of the 50 m lift. This bundle includes gas lines and permeability samplers and was covered with approximately 0.5 m of crush to protect it during burial. Instrument survival will be assessed in the spring of 2010.

Preliminary scaling calculations based on time weighted load estimates, and volume and time based concentration estimates have been completed. Time weighted load estimates compare yearly geochemical loadings from the Type III humidity cell experiments to the Type III upper collection lysimeters and the Type III basal drains. Sulfur loadings calculated from the Type III humidity cells, based on mass of rock, surface area of rock, and mass of sulfur, are higher for the Type III upper collection lysimeters and the Type III test pile. Estimates based on the surface area of exposed sulfur provide a better estimate for the field-scale installations. Concentration values based on the time dependent loading rates derived from Type III humidity cells were used to estimate sulfur and metal concentrations for the Type III upper collection lysimeters. Initial calculations assume a constant residence time and a constant temperature. Estimates scaled on the basis of the mass of the rock and the mass of sulfur overestimate the dissolved concentration

observed in the field. Concentration estimates for sulfate and nickel scaled based on the surface area of exposed sulfur provide reasonable estimates of measured values, suggesting that scale-up calculations can provide reasonable estimates of sulfur and metal loadings in the field provided that the rock is adequately characterized at both scales.

Results from the Diavik Waste Rock Project have been presented at numerous Canadian and international conferences and published in various conference proceedings. One article has been published in a peer reviewed journal and several more are near completion and will be submitted in early 2010. The project has involved 11 graduate students from the three participating universities, including two that graduated in 2009, and has involved over 25 undergraduate students.

The Diavik Waste Rock Project research team is proposing to extend the research program for an addition 5 years beginning in 2010. A significant investment in research infrastructure at Diavik was made by the research partners including, Diavik, The Natural Science and Engineering Council of Canada, The Canadian Foundation for Innovation, INAP and MEND. This infrastructure represents a tremendous opportunity to continue to gain further insights into behaviour of the waste rock piles as the hydrology, thermal regime, and geochemistry evolve. Continuation of the project will; allow for a longer, richer data set to form the basis of scale up comparisons; provide additional full-scale data to be included in scale-up comparisons; further strengthen linkages between thermal, gas and water transport, and geochemical reactive transport aspects of the project; provide stronger support for closure planning for northern operations; and provide the opportunity to apply and evaluate sophisticated data interpretation and analysis techniques. Diavik has committed funding for the project extension and funding has been requested from INAP and MEND. It is anticipated that matching funding from NSERC will be requested in early 2010.

# 1 Introduction

## 1.1 *Diavik Waste Rock Project*

The Diavik Waste Rock Project is designed to evaluate the benefits of the proposed reclamation concepts for the Diavik Country Rock Stockpiles, and to evaluate techniques used to scale the results of laboratory studies to predict the environmental impacts of full-scale waste rock stockpiles. The Diavik Project includes laboratory testing of rock from the Diavik site using established, standardized testing procedures. Field lysimeters containing each rock type, constructed in duplicate, were installed at the Diavik site and are being monitored. Three large-scale test piles have been constructed. The test piles have been instrumented in detail and monitoring is underway.

The large-scale test piles consist of:

Type I pile: Type I rock with no cover ('best case' or baseline)

Type III pile: Type III rock with no cover

Covered pile: Type III rock with till (low permeability) and Type I rock (thermal) cover.

The Type I and Type III rock lysimeters and test piles simulate the extremes of the geochemical behaviour of the Diavik country rock, and provide valuable information to evaluate the approaches presently used to estimate solute loadings from waste rock stockpiles using small-scale testing procedures. The covered lysimeters and the covered test pile simulate the cover design proposed for the full-scale Country Rock Stockpiles.

This report provides an update of progress over the 2009 field season. Results and interpretations presented in this report are preliminary and will be updated as new data are collected and more comprehensive quality control and data analysis are performed. For more in-depth information on construction of field lysimeters and test-piles, and results from the experiments, the reader is referred to the Diavik Waste-Rock Research Project 2008 Progress report and a series of papers presented at the 2009 ICARD meeting. The publications are listed at the end of this report and have been made available on a CD distributed to the research partners.

## 2 Summary of Research Progress

### 2.1 Gas Transport

In 2007, an automated datalogging system was installed to measure gas pressures at 49 locations within, and 14 locations around, the Type III waste rock pile at 1 minute intervals (Figure 2-1; Amos et al; 2009). In addition, O<sub>2</sub>/CO<sub>2</sub> concentrations are measured daily at 27 locations within the pile and wind speed and wind direction are recorded at 10 minute intervals using a wind monitor mounted approximately 7 m above the Type III pile. To facilitate frequent measurements (bi-weekly to monthly) of O<sub>2</sub>/CO<sub>2</sub> concentrations at all sampling points in all three piles, a 22-port portable gas sampler, constructed at the University of Waterloo, is employed (Figure 2-2). Key features of this instrument are the AMI model 65 O<sub>2</sub> sensor, which is less sensitive to temperature fluctuations than previous instruments, and the automated two-point calibration of both the CO<sub>2</sub> and O<sub>2</sub>. These features allow for small changes in gas concentrations to be detected.

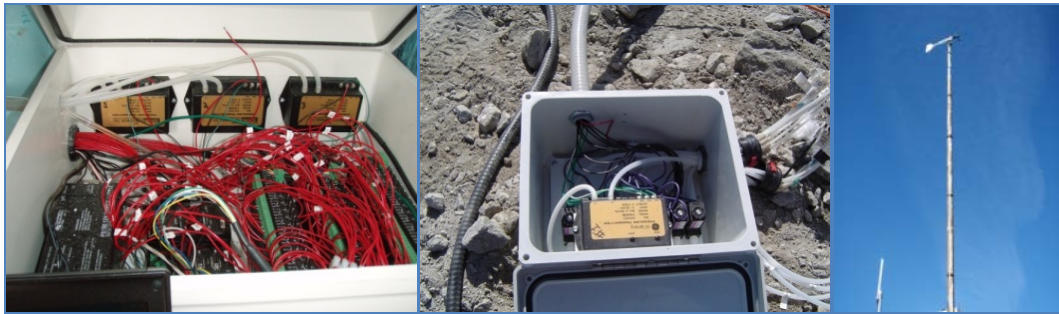


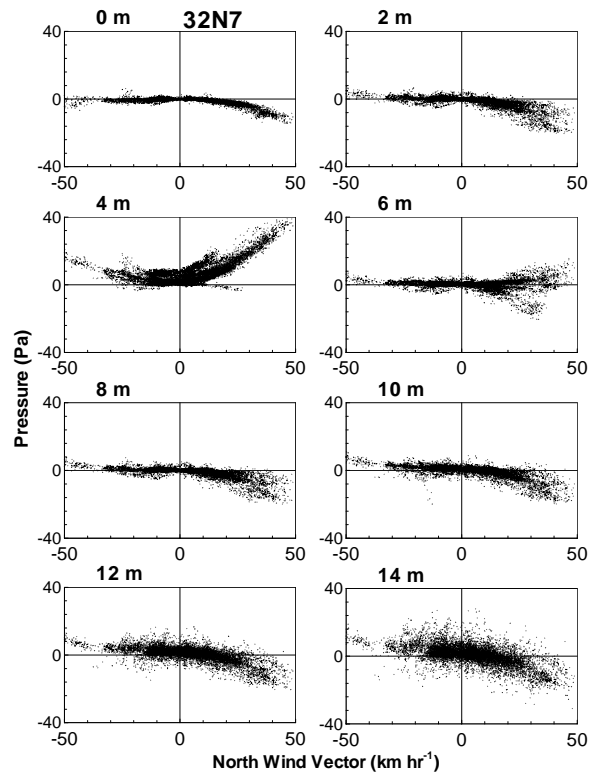
Figure 2-1. Continuous gas pressure sampling system.



Figure 2-2. Portable 22 port O<sub>2</sub>/CO<sub>2</sub> sampler and gas sample tubing bundle.



Measured differential gas pressures for gas sampling bundle 32N7 are shown in Figure 2-3. The data are shown as the differential pressure between the sampling point and the reference point on the top surface of the pile (32N2-0) and are plotted against the north wind vector. The pressure response at a given sampling point is a function of both wind speed and wind direction so that plotting the data against the wind vector provides a better understanding of the pressure response. Although the sampling points within sampling bundle 32N7 show a varied response to the wind, the general observation is that increases in wind speed result in greater pressures within the pile, particularly with the wind from the north (Figure 2-3). Sampling bundle 32N7 is located closer to the northern face of the pile.



**Figure 2-3. Measured differential pressures plotted against the north wind vector for the Diavik Type III test pile. Pressures are shown as the differential pressure between the sampling point and the reference point 32N2-0.**

Figure 2-4 shows 2-D cross-sections of the differential pressure measurements along the north-south and east-west sampling transects on September 24 at 9:00 am with the winds speed at over 40 km/hr from the north. Although this is a relatively high wind speed, it is not uncommon at the Diavik site. With this strong wind from the north, high pressures develop along

the northern face of the pile, as is expected, although a low pressure zone at the toe of the northern face also develops. This anomaly is likely a result of a berm built close to the toe of the northern slope or other structural features around the test piles. Similarly, pressure gradients develop within the pile, although the irregularity of the pressure gradients suggests that the physical characteristics of the pile, and particularly the permeability distribution, may be major factors controlling the pressure distribution and air flow.

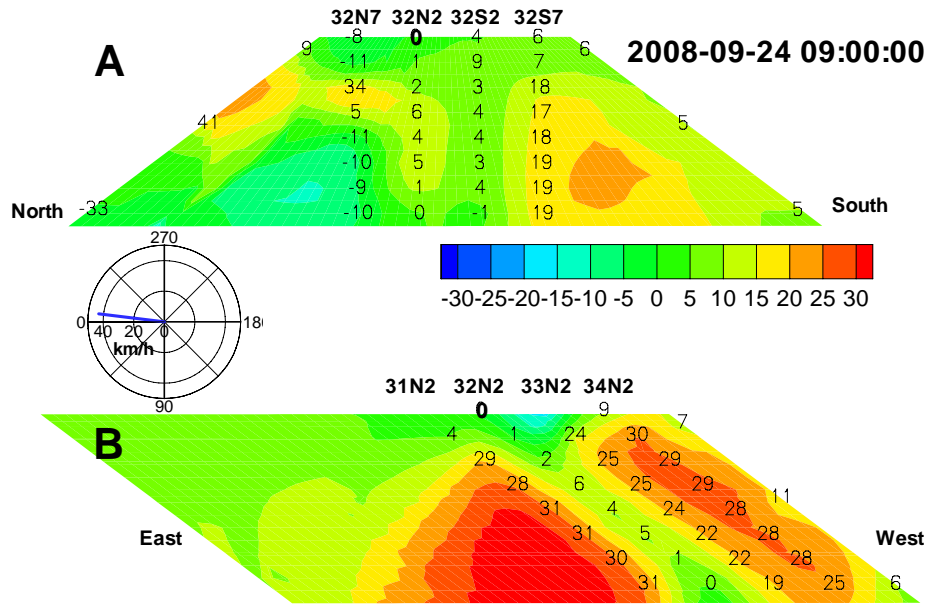


Figure 2-4. 2-D spatial profiles of differential pressure within and around the Type III test pile along with the prevailing wind conditions on September 24, 2008 at 9:00 am. Numbers on the contour plots represent measured data points spaced 2 m vertically. All differential pressures are referenced to point 32N2-0 (shown in bold). 2-D contours are obtained from 3-D kriging of all available data points. 2-D profiles shown are along North-South (A) East-West (B) sampling transects. Radial diagrams show wind direction in degrees plus wind speed along the radius in km/h.

In the Type I and Type III uncovered piles,  $O_2$  and  $CO_2$  concentrations have been measured monthly from May to November since the completion of the piles in September 2006. As of November, 2009, no deviation from atmospheric concentrations has been observed in either of the piles. This observation suggests that the rate of  $O_2$  consumption through sulfide oxidation is slower than the  $O_2$  transport rates.

In the Covered pile, gas concentrations were measured approximately monthly from June through October 2007, and twice per month from June to mid-November in 2008 and 2009. In most measured locations, gas concentrations remain near atmospheric; however, in a few

locations, the concentrations of O<sub>2</sub> are below atmospheric levels and the concentrations of CO<sub>2</sub> are elevated. An example of gas concentrations along sampling bundle C3W2 is shown in Figure 2-5. Gas concentrations remain near atmospheric from the surface to just below the till layer. At 7 to 8 m depth, O<sub>2</sub> concentrations decrease and CO<sub>2</sub> concentrations increase. Furthermore, at 7-8 m depth, the O<sub>2</sub> concentrations decrease with time and CO<sub>2</sub> concentrations increase with time. The observed changes in gas concentrations suggest that in certain locations within the pile, the rate of O<sub>2</sub> consumption through sulfide oxidation and the rate of CO<sub>2</sub> production through carbonate dissolution exceed the rate of gas transport.

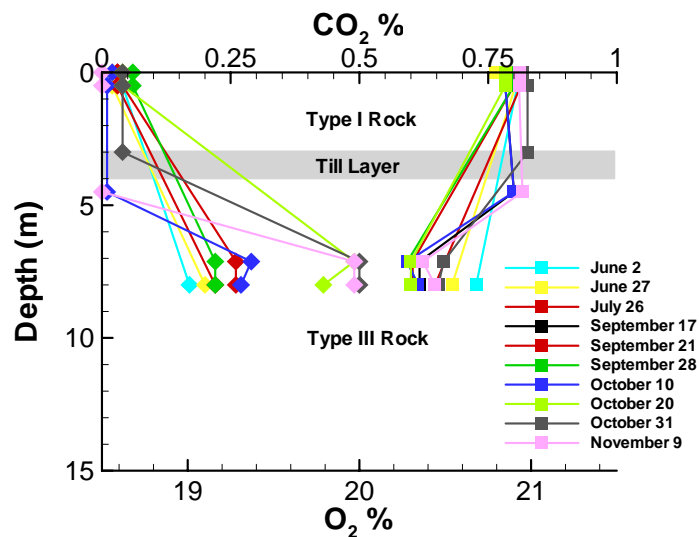


Figure 2-5. O<sub>2</sub> (squares) and CO<sub>2</sub> (diamonds) concentrations along sampling bundle C3W2 for June to November, 2008.

The temporal trends in O<sub>2</sub> concentrations are shown in greater detail for the three sampling locations within the Covered pile Type III core that showed depletions in O<sub>2</sub> concentrations and increases in CO<sub>2</sub> concentrations (Figure 2-6). For each of these locations, there is a period of decreasing O<sub>2</sub> concentrations starting in early June ( $\approx$ day 0) and going to late August ( $\approx$ day 110). Assuming a linear decrease in O<sub>2</sub> concentrations during this period, the rate of O<sub>2</sub> depletion ranges from  $9.1 \times 10^{-11}$  to  $3.8 \times 10^{-10}$  kg O<sub>2</sub> m<sup>-3</sup> s<sup>-1</sup> (Table 2-1). Assuming that diffusion is the dominant O<sub>2</sub> transport mechanism, the maximum O<sub>2</sub> transport rates can be estimated based on the lowest observed concentrations. Diffusion rates range from  $2.2 \times 10^{-12}$  to  $7.7 \times 10^{-12}$  kg O<sub>2</sub> m<sup>-2</sup> s<sup>-1</sup>. Therefore, for the period with the lowest observed O<sub>2</sub> concentrations, the total oxidation rate, equal to the sum of O<sub>2</sub> depletion rates and the influx of O<sub>2</sub> through

diffusion, range from  $9.9 \times 10^{-11}$  to  $3.9 \times 10^{-10}$   $\text{kg O}_2 \text{ m}^{-3} \text{ s}^{-1}$  for the three sampling points analyzed. Humidity cell experiments on Type III rock from the Diavik site give average oxidation rates of approximately  $3 \times 10^{-11}$   $\text{kg O}_2 \text{ m}^{-3} \text{ s}^{-1}$ . Further analysis is required to investigate the relationship between the lab measured rates and those determined from the gas concentration measurements.

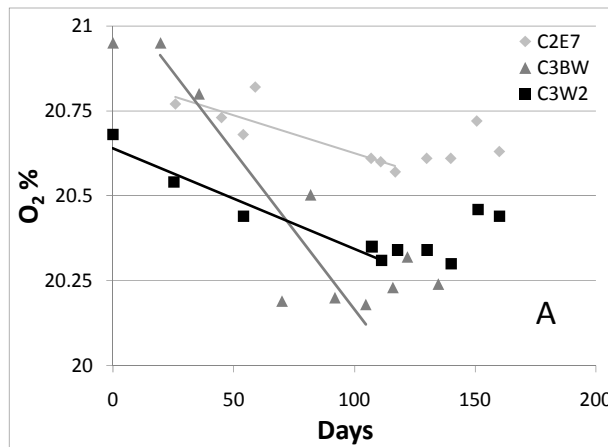
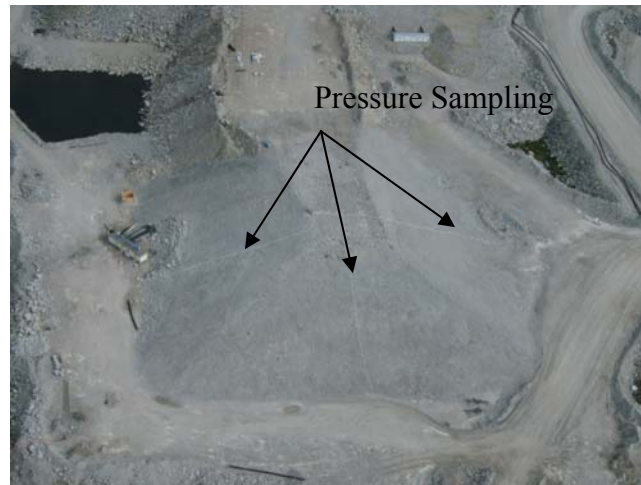


Figure 2-6.  $\text{O}_2$  concentrations with time for selected sampling locations C2E7-4.5, C3BW-24, and C3W2-8. Lines are linear regressions of data points during the period of decreasing  $\text{O}_2$  concentrations. Day '0' is June 2, 2008.

Table 2-1. Oxidation rate calculation results from Covered pile  $\text{O}_2$  data.

|   | C2E7                  | C3BW                  | C3W2                  |
|---|-----------------------|-----------------------|-----------------------|
| $\text{O}_2$ depletion rate ( $\text{kg O}_2 \text{ m}^{-3} \text{ s}^{-1}$ )         | $9.1 \times 10^{-11}$ | $3.8 \times 10^{-10}$ | $1.2 \times 10^{-10}$ |
| Maximum $\text{O}_2$ diffusion rate ( $\text{kg O}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) | $7.7 \times 10^{-12}$ | $2.2 \times 10^{-12}$ | $4.6 \times 10^{-12}$ |
| Total oxidation rate ( $\text{kg O}_2 \text{ m}^{-3} \text{ s}^{-1}$ )                | $9.9 \times 10^{-11}$ | $3.9 \times 10^{-10}$ | $1.3 \times 10^{-10}$ |

In 2009 an automated gas pressure and gas concentration sampling system was installed on the Covered pile (Figure 2-7). This system is similar to that previously installed on the Type III pile and includes gas pressure measurements at 105 sample locations within the pile and 14 locations on the surface of the pile at 1 minute intervals. Gas concentration measurements are taken at all 105 internal locations daily. The extensive data set collected from this system is currently being evaluated.



**Figure 2-7. Aerial view of Covered test pile showing surface pressure sampling conduit; part of the automated pressure and gas sampling system installed in 2009.**

## **2.2 Thermal Regime**

Internal temperatures in the uncovered test piles show a cooling trend. This is demonstrated for Face 4 of the Type III pile in Figure 2-8. These plots show progressively lower temperatures in January of each year. Figure 2-9 shows temperature versus time plots for individual thermistor strings on Face 1 of the Type I and Type III piles. These plots show that temperatures from 1 to 12 m depth drop well below 0 °C in the winter of each year and also demonstrate the cooling trend, with lower temperatures observed each year. In the summer months temperatures along the length of the thermistor string exceed 0 °C, demonstrating that the piles continue to thaw each year. The continued annual freezing and thawing of the piles is due to the high rate of thermal transport in the pile, as a result of the high permeability and gas transport rates observed.

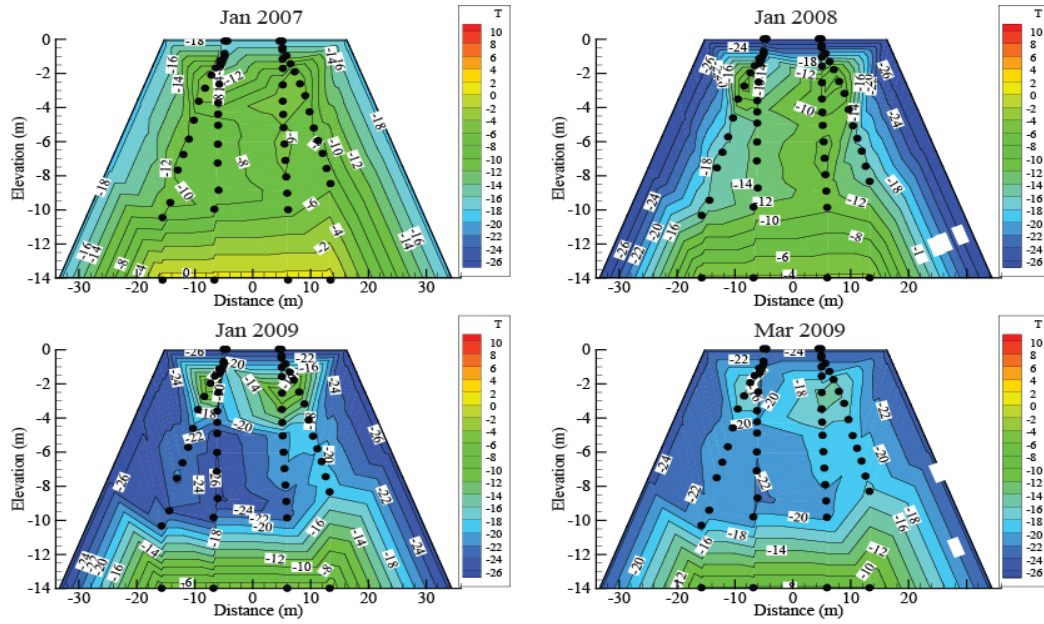


Figure 2-8. Contour temperature in Jan at face 4 type III pile since 2007.

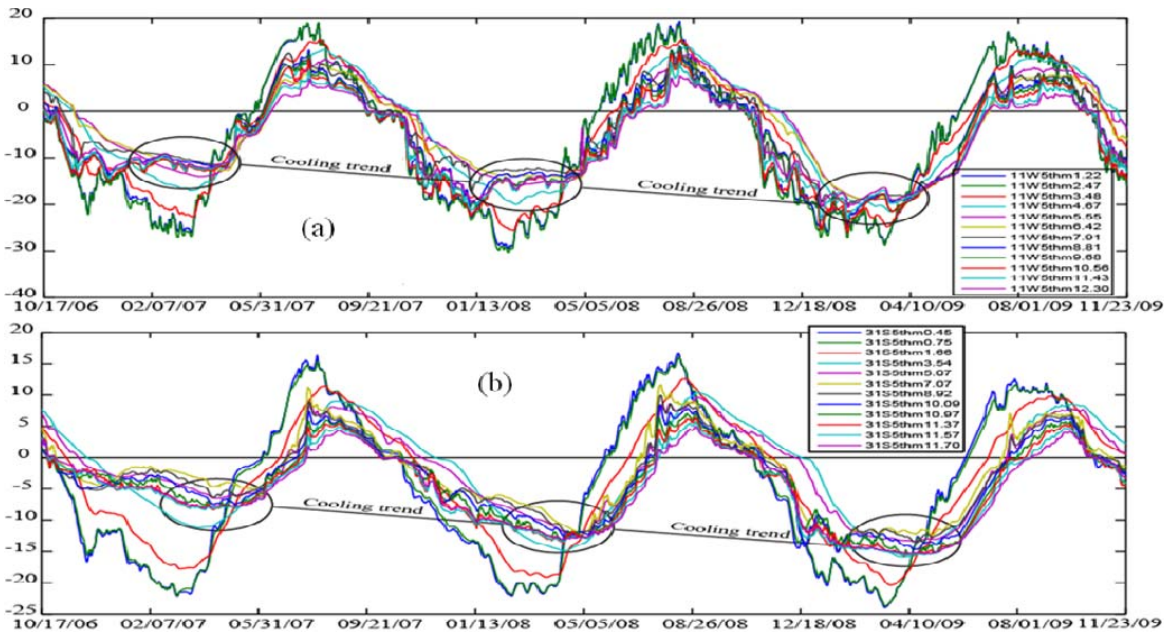


Figure 2-9. Thermistor string at face 1 Type I (a) and Type III (b) pile shows cooling trend.

In the covered pile a cooling trend has not been observed (Figure 2-10). Below the till layer temperatures remain relatively constant throughout the year as the till layer limits gas and thermal transport. Above the till layer temperatures cycle annually under the influence of the external temperature (Figure 2-11). Within the till layer the temperatures drop below 0 °C in the winter months but remain at 0 °C through the summer suggesting that frozen water within the till layer is thawing.

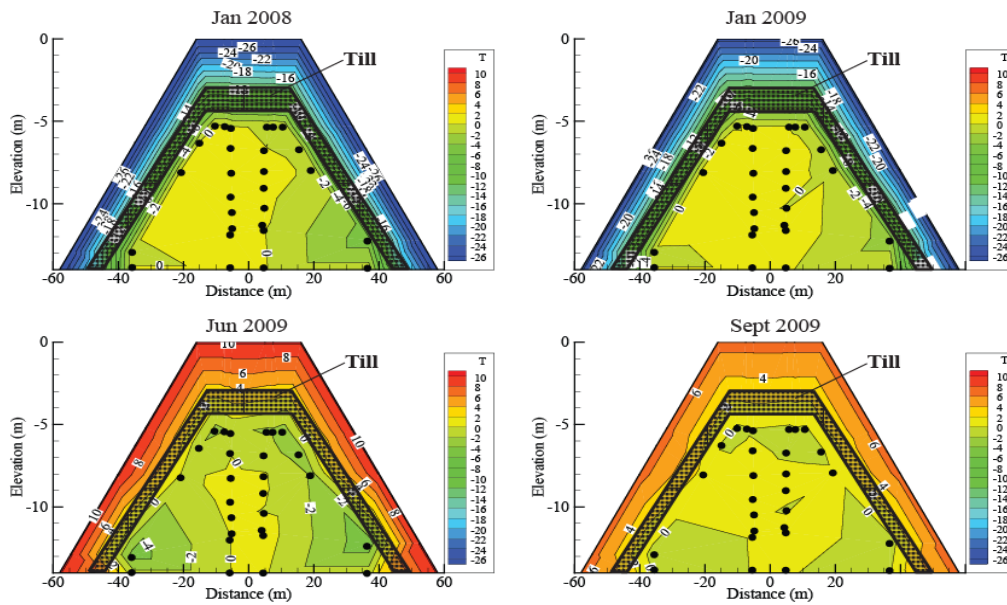


Figure 2-10. Contour temperature at face 4 covered pile since 2007.

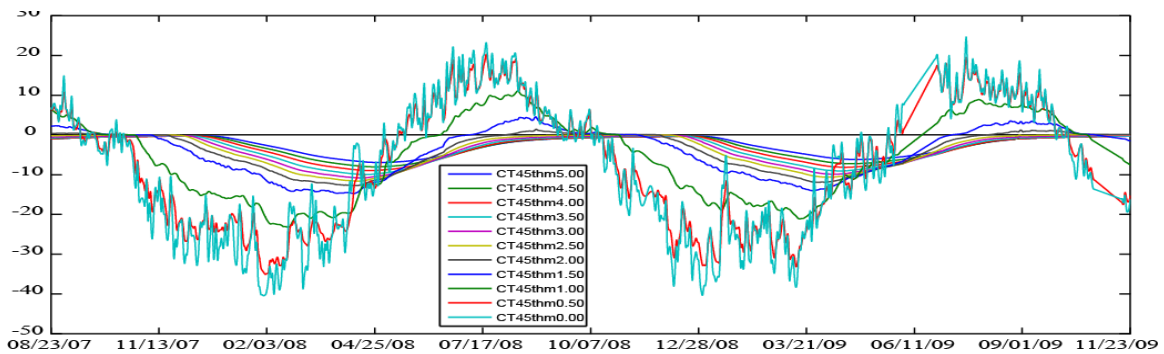


Figure 2-11. Thermistor string drilled from the top of covered pile shows an active layer of 3m at this string since 2008.



### 2.3 Hydrology

Precipitation in 2009 (excluding snowfall) was approximately one half of the average annual rainfall at Diavik (81 mm versus 154 mm; Figure 2-12). Since construction of the test piles, two years have been well below average for rainfall totals (2007, 2009), while 2008 was slightly wetter than average. Although there were frequent small rainfall events in 2009, no large events occurred in 2009 (unlike the pattern in 2008).

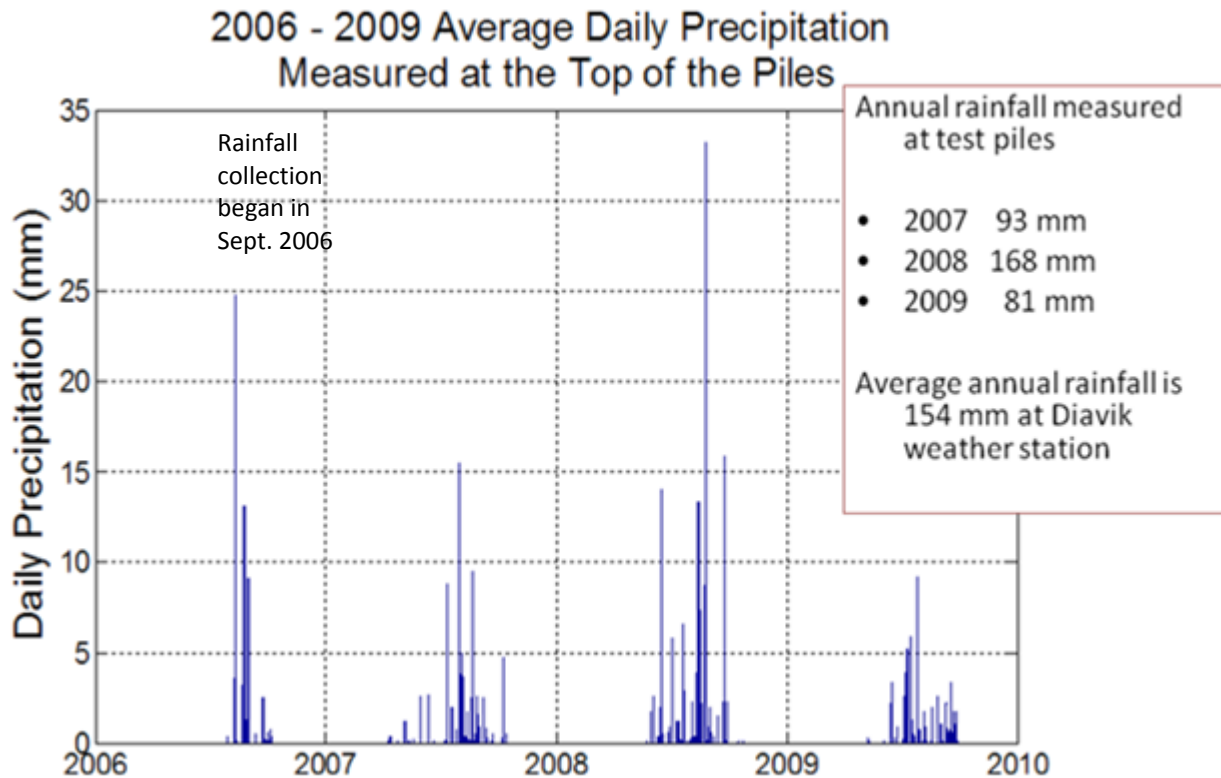


Figure 2-12. Average daily precipitation at top of test piles.

There was outflow from the basal drains in each of the three test piles (Figure 2-13, Figure 2-14). For the Type I pile, which has experienced only natural rainfall events, the outflow in 2009 (10,000 L) was substantially lower than that in 2008 (70,000 L); likely reflecting a much lower to negligible infiltration rate at the top surface of the test pile in 2009. For the Type III pile, the outflow was also smaller in comparison to the previous year (110,000 L versus 130,000 L), but still much higher than the Type I pile, likely reflecting a residual drain down effect from the artificial rainfall events applied on this pile in September 2007. At the Covered pile, outflow



in the late summer and fall of 2009 was also much lower than that which occurred in 2008 (Figure 2-14).

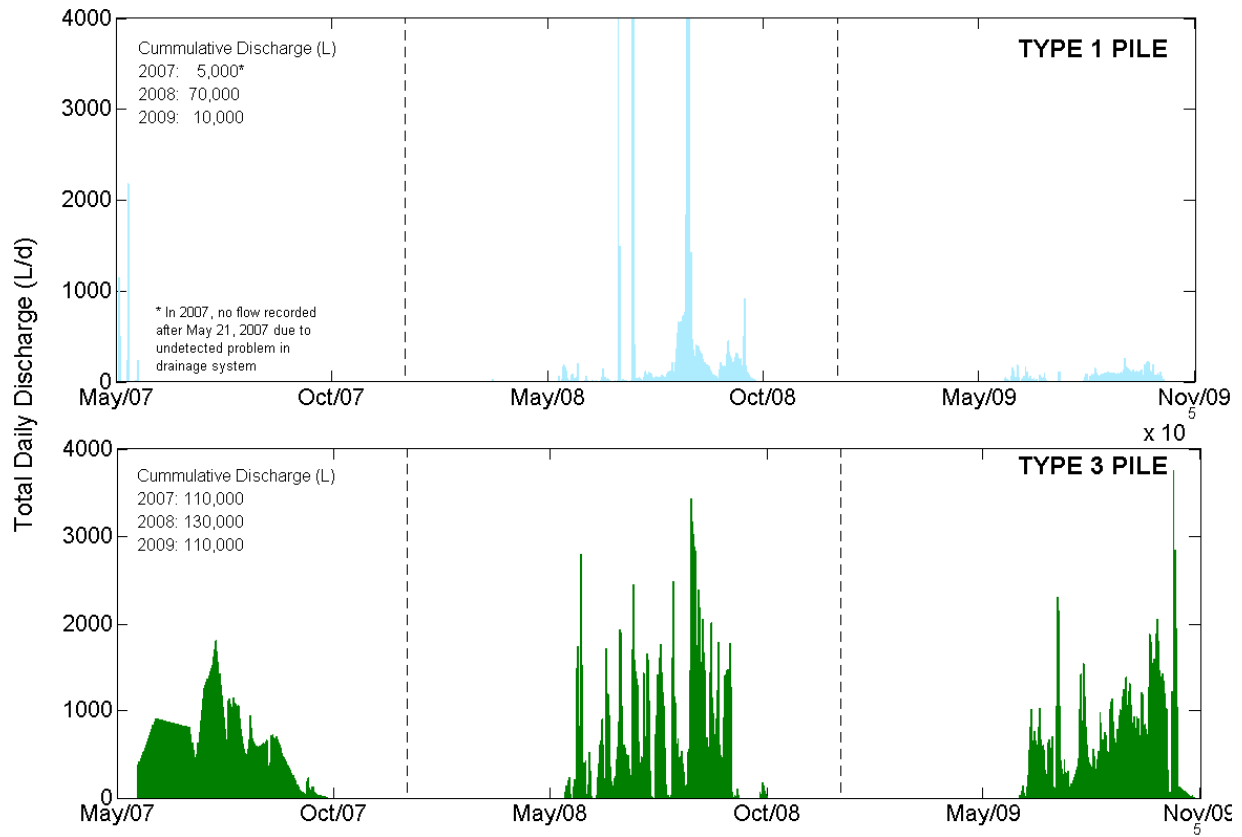


Figure 2-13. Total daily outflow volume at Type I and Type III basal drains.

Flow is reporting to a subset of the basal lysimeters in each of Type I and Type III piles (Figure 2-15; Figure 2-16). At the Type III pile, flow from the central basal lysimeters in 2009 (250 L) was much less than the reporting to the central lysimeters in 2008 (2200 L), however, flow did initiate in 2009 in a subset of the basal lysimeters under the batter of the Type III pile. Small amounts of flow also reported to the basal lysimeters located beneath the Type I pile (150 L in the central zone, 60 L in a batter lysimeters). This behaviour is significant because it now provides the opportunity of examining trends in water chemistry for a flow path across the full height of the Type I and Type III test piles.

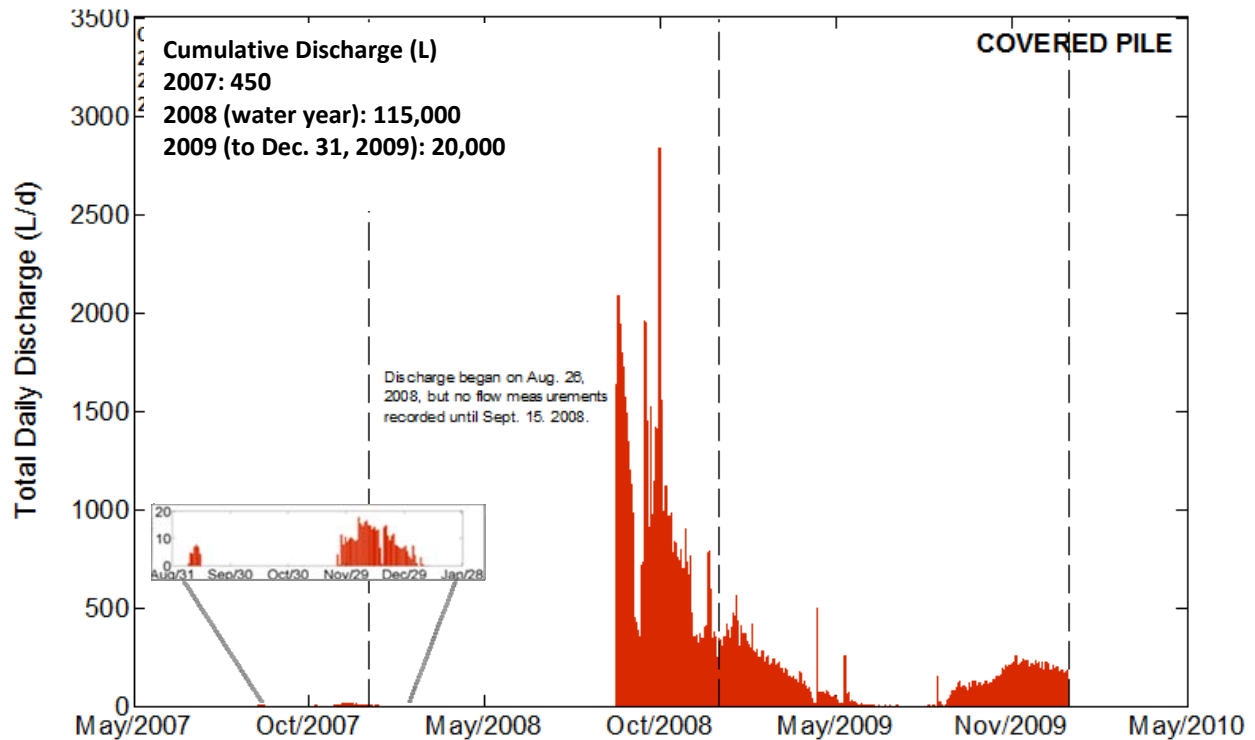


Figure 2-14. Total daily outflow volume at Covered pile basal drain.

TDR data has been collected and processed to document the seasonal variation in moisture content within each of the test piles. Results are qualitatively similar to the previous two years. Moisture content data for 2009 for the till layer within the covered pile has recently been processed and is now being evaluated to examine the movement of wetting fronts across the till layer.

A large scale field permeameter (Figure 2-17) was constructed in 2009 (4 m x 4 m x 2 m) to obtain a comparison to the hydraulic properties of waste rock obtained in 2007 in a permeameter with the same lateral dimensions, but a height of 1 m. Estimates of matrix porosity (Figure 2-18) as a proportion of total porosity are 5%, with a macroporosity of 22% (total porosity of 27%). These estimates are consistent with the tests carried out in 2007. The saturated hydraulic conductivity for the 2 m high permeameter was approximately  $6 \times 10^{-3}$  m/s. The field permeameter, filled with Type I rock, will now be used as another collection lysimeter to focus on water chemistry questions.

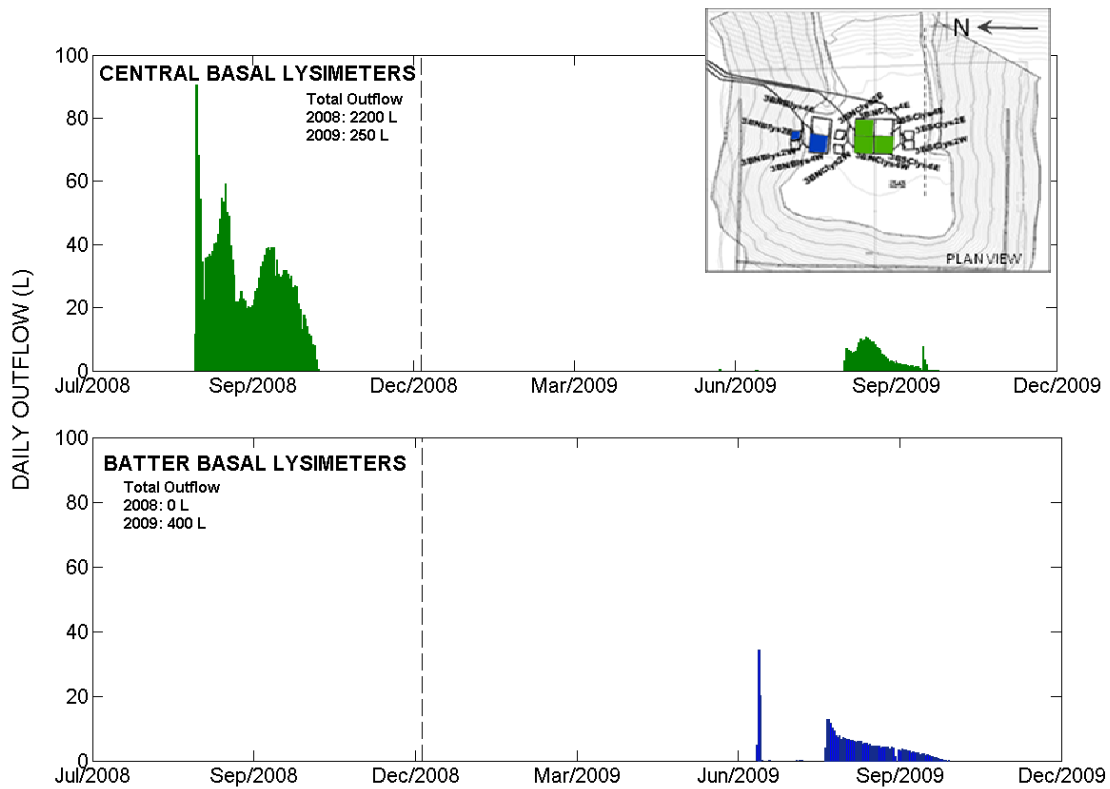


Figure 2-15. Total daily outflow volume at Type III basal lysimeters.

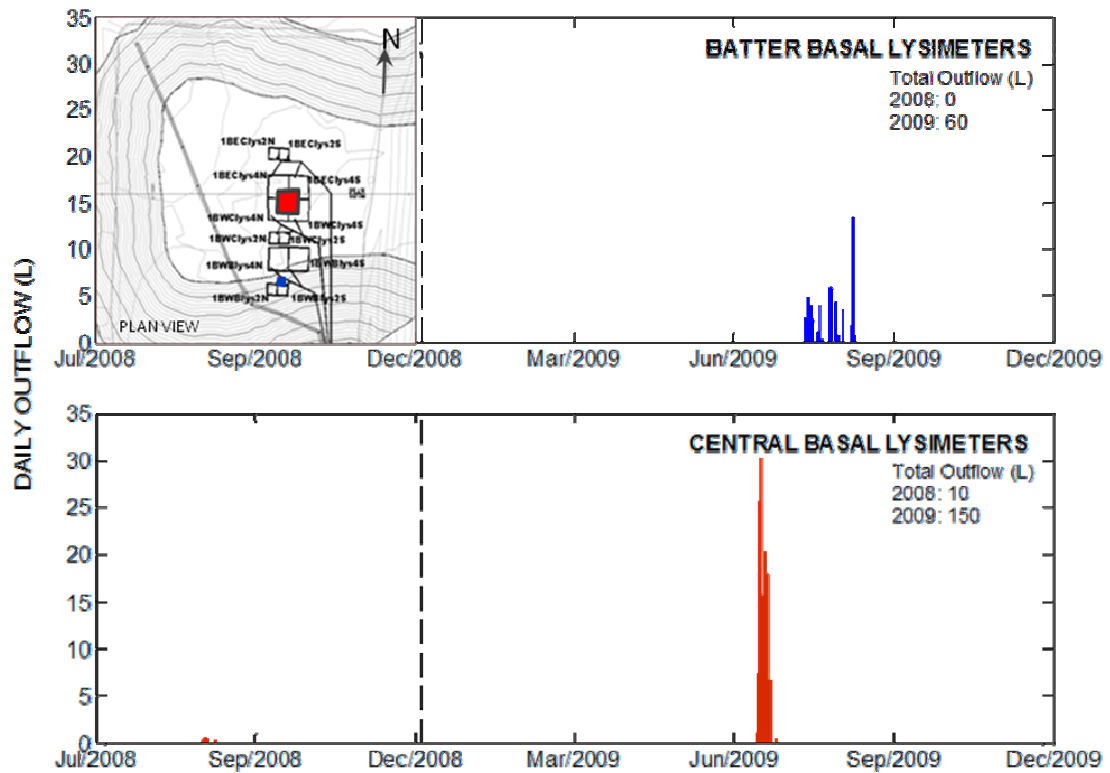


Figure 2-16. Total daily outflow volume at Type I basal lysimeters.



Figure 2-17. Construction of 32 m<sup>3</sup> field permeameter experiment.

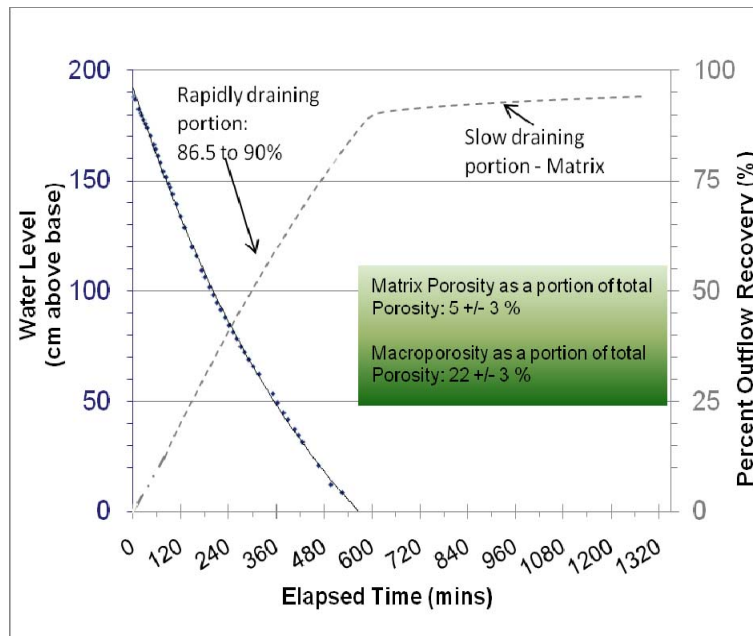


Figure 2-18. Results of 32 m<sup>3</sup> field permeameter experiment.

Monitoring continued to record the movement of tracers released onto the surface of the Type III test pile in September 2007 (Figure 2-19). A definitive tracer arrival in the basal drain was detected in September 2009 (chloride and bromide). Data are being processed to estimate

solute velocities, using the TDR and temperature data to determine the time window under which free water can move downward through the pile. Note the tracer was first detected in several of the basal lysimeters in 2008, and again in 2009 (Figure 2-20). Tracer arrival at the bottom of the Type III pile is currently being correlated with tracer concentrations recorded in the soil water solution samplers internal to the test pile.

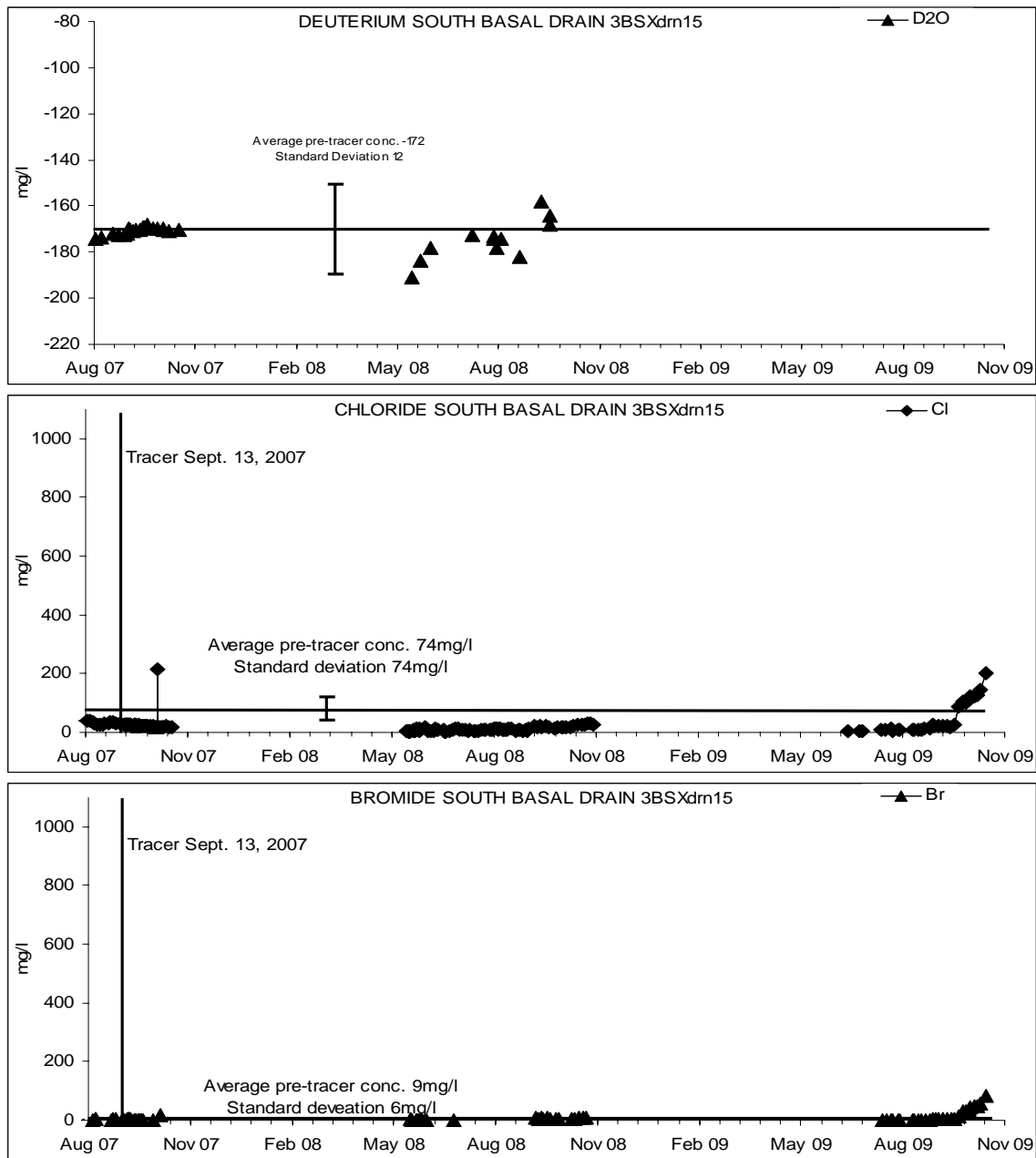


Figure 2-19. Tracer breakthrough at Type III basal drain.

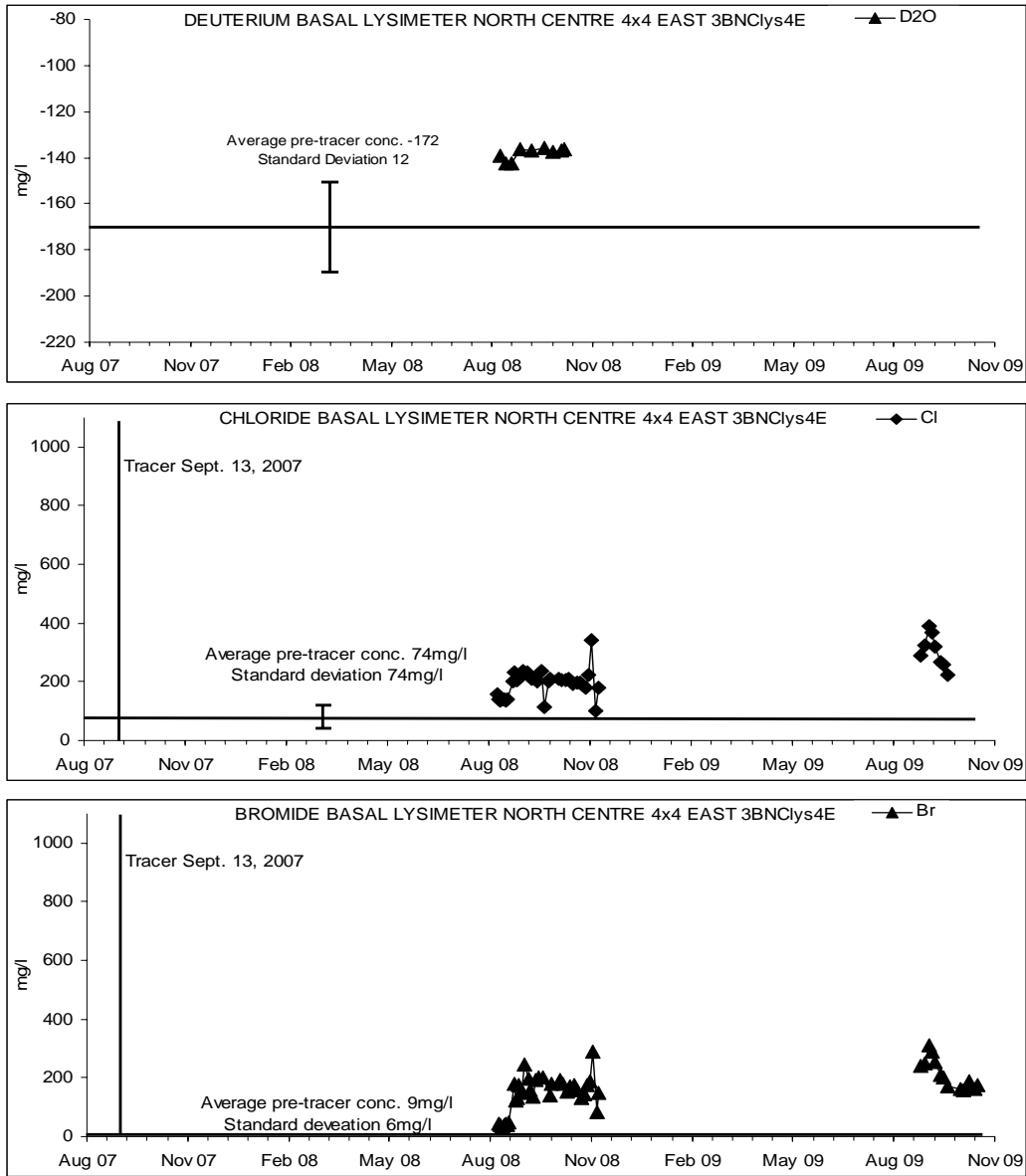


Figure 2-20. Tracer Breakthrough at Type III north centre 4 m by 4 m lysimeter.

## 2.4 Geochemistry and Microbiology

Effluent from the Type I and Type III basal drains contains high concentrations of ammonia, nitrite and nitrate, which are derived from residuals of blasting agents (Figure 2-21). Other by-products of blasting are chloride, derived from perchlorate, which is used as an accelerant in blasting materials, and sulfate, derived from oxidation of sulfide minerals during

blasting. The release of blasting by-products can be used as an indicator of the first flush of water through the pile, while irregular concentrations and gradual dissipation of these by-products likely represents flushing along different flow paths.

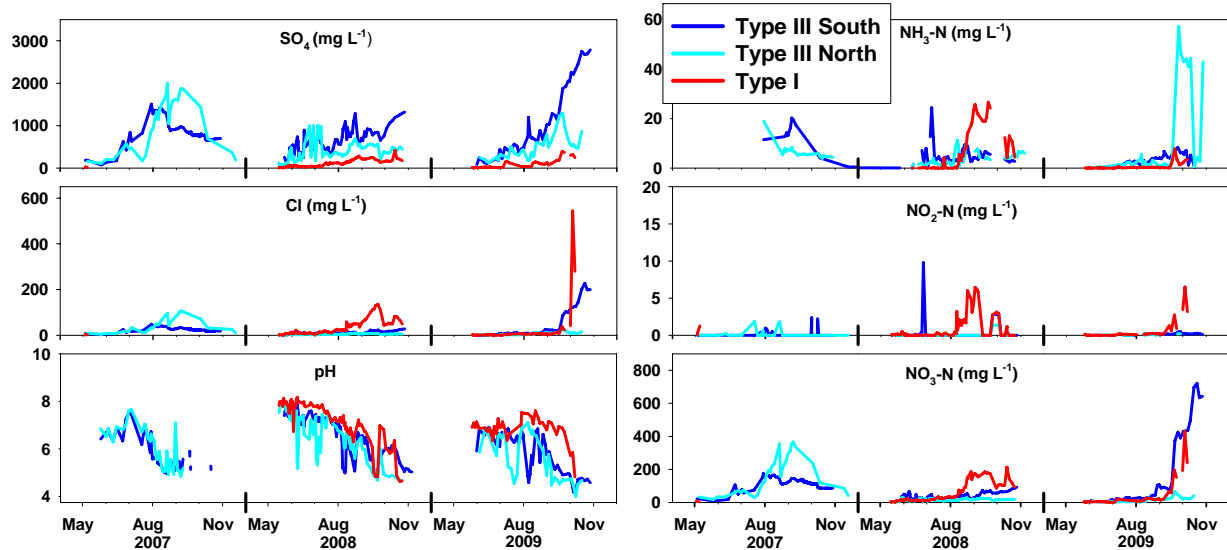


Figure 2-21. Type I and Type III basal drains general geochemistry and blasting residuals.

In both the Type I and Type III piles pH rises and falls each year, likely as a result of changes in the sulfide oxidation reaction rates (Figure 2-21). The pH falls more rapidly and to lower values in the Type III pile than in the Type I pile, however, by the end of the season the pH in both piles has declined below neutral. Sulfide oxidation in Type III rock is indicated by increased sulfate concentrations, exceeding  $1000 \text{ mg L}^{-1}$  each year. Sulfate in the north and south drains are similar, although slightly higher in south drain. As a result of sulfide oxidation, effluent from the Type III north and south drains become acidic early each year. The release of acidic water is accompanied by the depletion of alkalinity and an increase in dissolved aluminum concentrations, exceeding  $5 \text{ mg L}^{-1}$  in 2009 (Figure 2-22). This increase is associated with the dissolution of aluminosilicate minerals, which is enhanced at low pH. Aluminosilicate dissolution also releases cations such as K, Mg, Ca.

Dissolved metal concentrations in the Type III basal drain effluent increase as the pH declines, with high concentrations of nickel, exceeding  $3 \text{ mg L}^{-1}$ , cobalt reaching  $0.5 \text{ mg L}^{-1}$ , zinc up to  $1 \text{ mg L}^{-1}$ , and cadmium exceeding  $5 \text{ } \mu\text{g L}^{-1}$ , observed each year. Concentrations observed in 2009 are higher than observed in previous years. The dissolved metal concentrations in the

Type I basal drain effluent were significantly lower than in the Type III with concentrations of nickel less than 1.4 mg L<sup>-1</sup>, cobalt less than 0.3 mg L<sup>-1</sup>, cadmium less than 0.01 µg L<sup>-1</sup>, and zinc below 1.5 mg L<sup>-1</sup> (Figure 2-22).

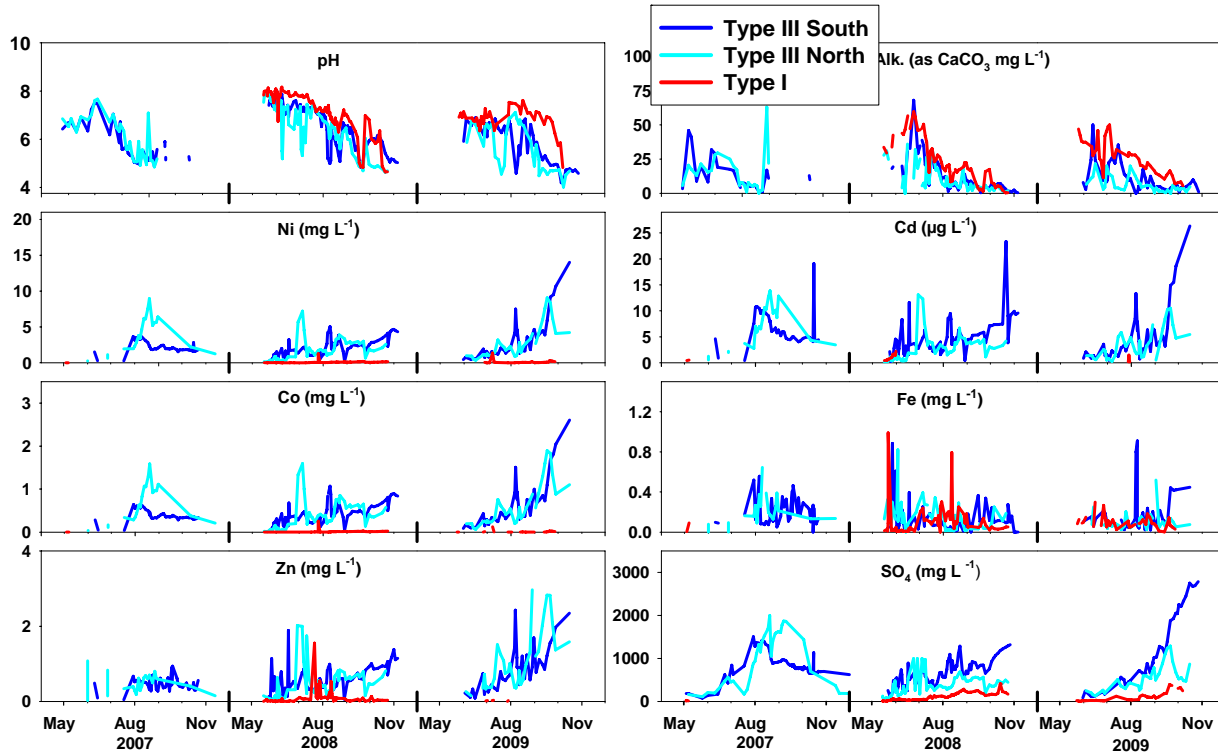


Figure 2-22. Type I and Type III basal drains geochemistry including major ion and metals.

The Covered pile does not experience the same amplitude in the temperature cycles, in contrast to the seasonal cycles observed in the uncovered piles Type I and Type III piles. As a result the Covered pile basal drain flows throughout the year (Figure 2-23). Alkalinity was depleted in late 2007 and has remained low since then. The pH remains below 5, sulfate concentrations consistently exceed 2000 mg L<sup>-1</sup>, and increased concentrations of dissolved metals persist, including nickel above 5 mg L<sup>-1</sup>, zinc exceeding 2 mg L<sup>-1</sup>, cobalt in excess of 1 mg L<sup>-1</sup>, and cadmium above 20 µg L<sup>-1</sup> (Figure 2-23).



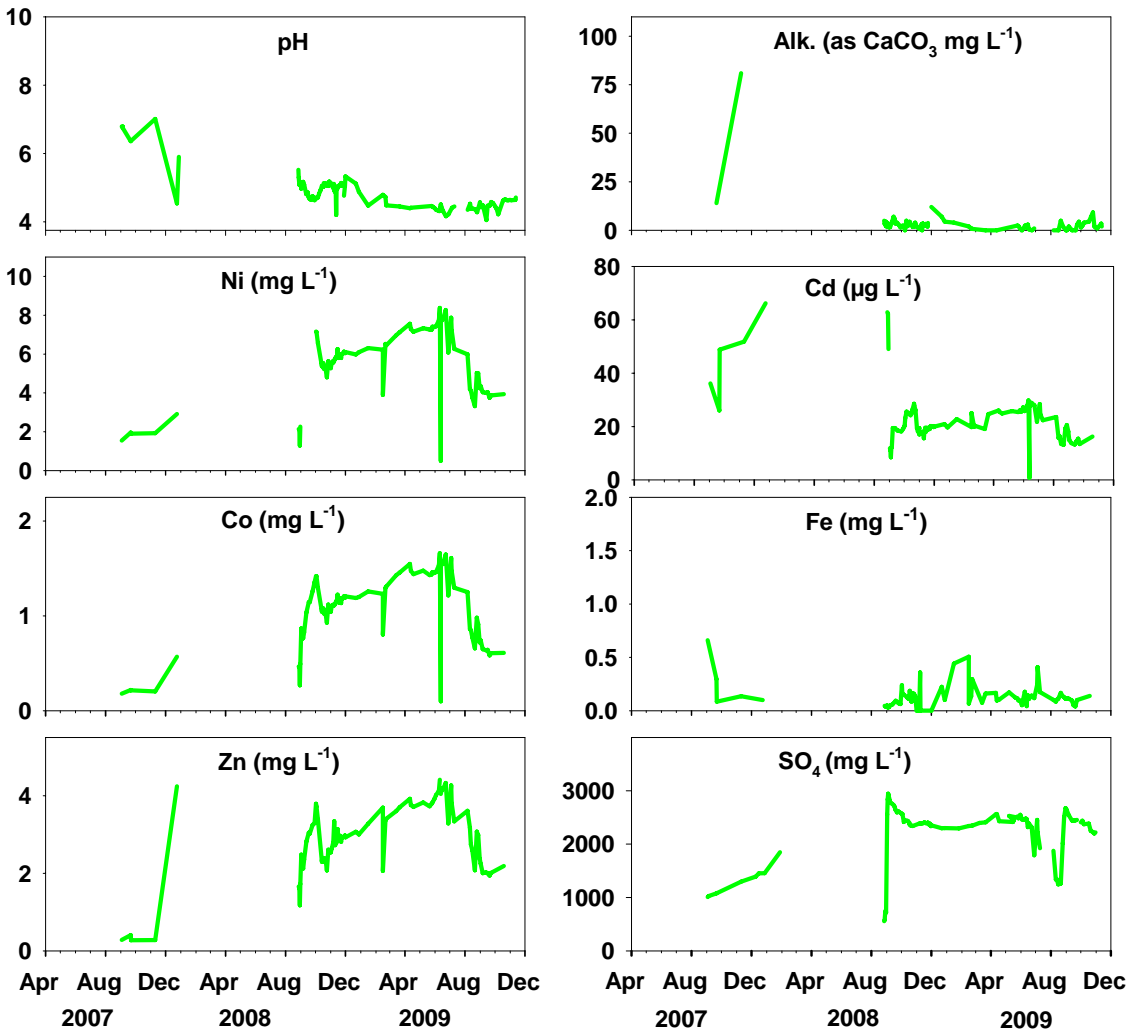


Figure 2-23. Covered pile basal drain geochemistry.

Flow in the upper collection lysimeters is more episodic than the basal drains in the test piles, with most flow occurring in a few months in summer season (Figure 2-24). Effluent water quality from the upper collection lysimeters illustrates the difference in the Type I and Type III waste rock. Type I effluent has remained neutral since construction, whereas the Type III effluent annually falls below pH 4. In addition, increased sulfate concentrations associated with sulfide oxidation are observed in Type III effluent compared to the Type I effluent, and alkalinity remains in the Type I lysimeter but is completely depleted in the Type III lysimeter.

Microbial enumerations conducted on samples collected in 2008 indicated that microbial populations in Type I and Type III test piles were dominated by neutrophilic bacteria, *T. thioparus* and related species (Figure 2-25). No significant populations of acidophilic sulfur

oxidizers or acidophilic iron oxidizers were detected. Succession of bacterial species was evident in 2009, with increased numbers of acidophilic sulfur oxidizing bacteria observed in all piles in June, and increased predominance of acidophilic iron oxidizers in the Covered and Type III piles by September of 2009 (Figure 2-26).

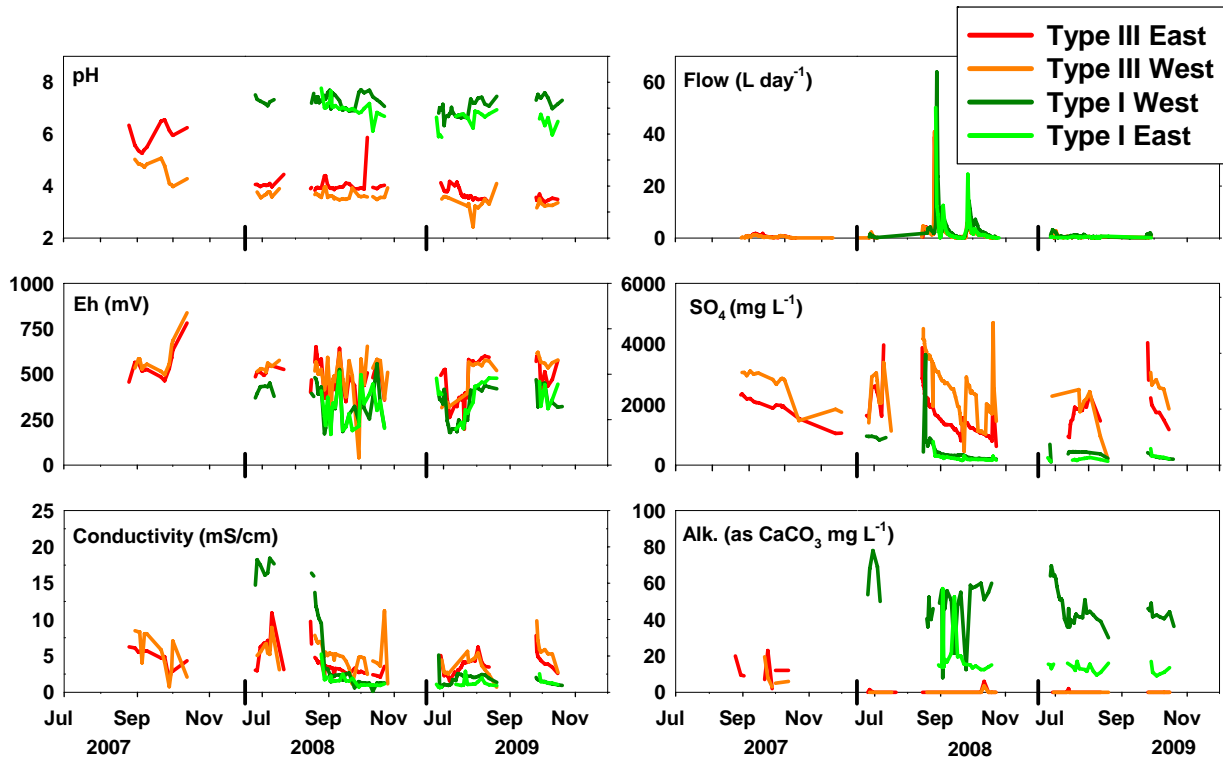


Figure 2-24. Upper collection lysimeter geochemical parameters and flow data.

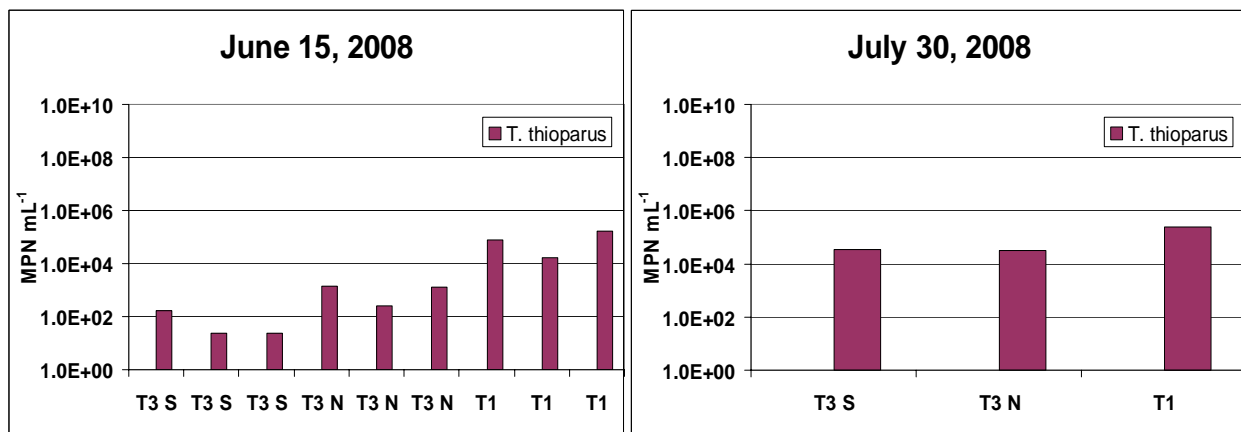


Figure 2-25. Type I and Type III pile microbial enumerations for 2008 – effluent water samples.

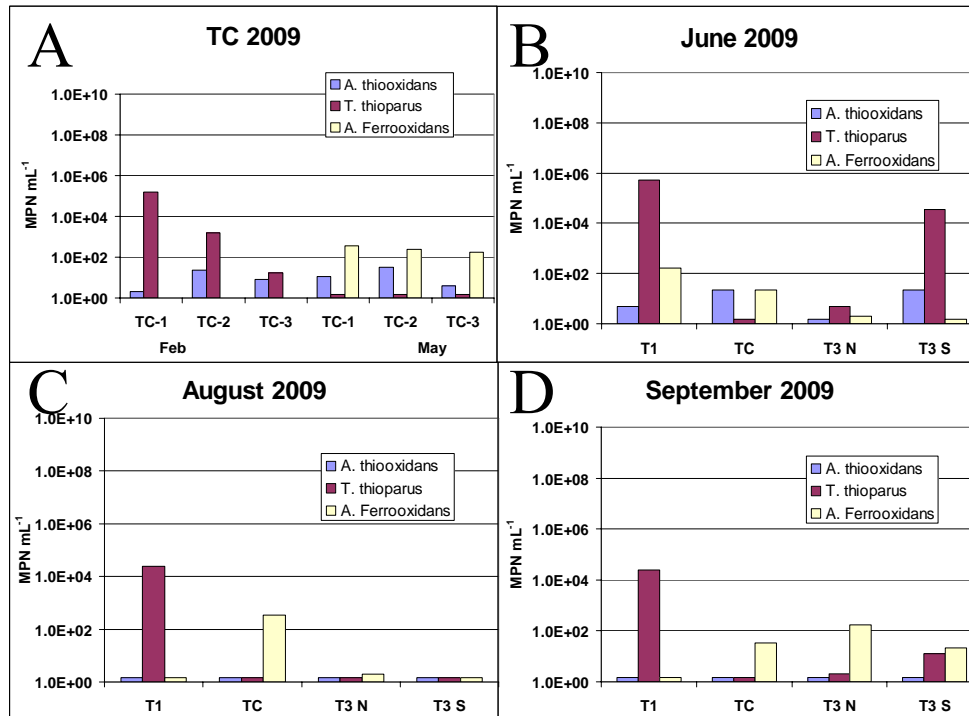


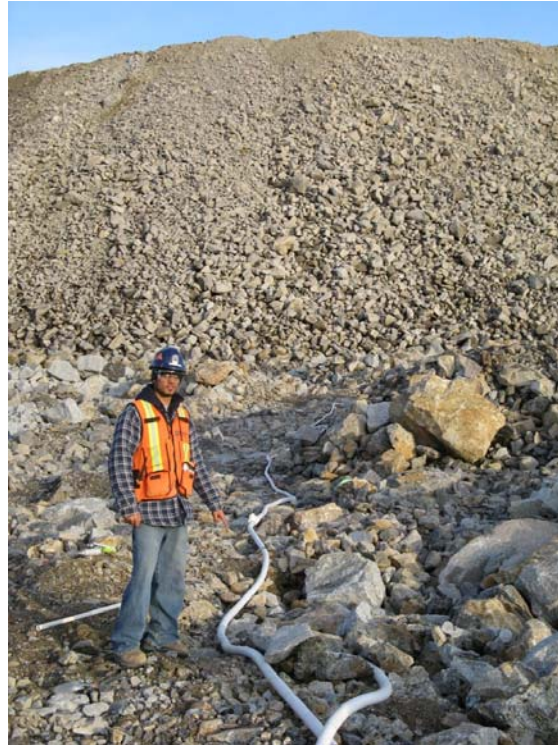
Figure 2-26. A: Covered pile microbial enumerations in 2009. B-D: Type I, Type III and Covered pile microbial enumerations in June (B), August (C) and September (D) 2009 – effluent water samples.

## 2.5 Full Scale Installations

Instrumentation of the Type III full-scale waste rock dump will provide important information with respect closure planning at Diavik as well as provide the information necessary to complete the scale up characterization from small (< 1 kg) samples to the full-scale pile. Due to financial constraints drilling was postponed in 2009 and is currently tentatively planned for March 2010. Instrumentation is planned to include thermistors, gas sampling lines, tensiometers, soil moisture probes, and permeability instruments.

In 2009, three attempts were made to install instrumentation in the full-scale Type III waste rock pile without drilling. The first attempt was along a 50 m high tip face of the Type III dump. Due to difficulties in stringing the instrument lines down the 50 m high slope, damage sustained during burial of the instruments, and subsequent damage by working mining equipment, no instruments survived this installation. A second attempt was made by stringing a 120 m long instrument bundle horizontally extending from the base of a 50 m lift in the Type III dump (Figure 2-27). These instruments were left uncovered and buried when end dumping

resumed from the top of the dump. This method proved to be too harsh for the instruments and none survived.



**Figure 2-27. Horizontal instrument installation in full-scale Type III dump.**

A third attempt was made at the beginning of December 2009 by stringing a 150 m long instrument bundle horizontally at the base of the 50 m lift. The length of the bundle includes an 80 m long lead to clear the planned roadway so that approximately 70 m of the bundle will be buried within the dump. This bundle includes only gas lines and permeability samplers and was covered with approximately 0.5 m of crush to protect it during burial. Burial of this line is in progress and instrument survival will be assessed in the spring.

### **3 Scale-up Calculations**

Several methods can be used to scale geochemical loading rates from small-scale laboratory experiments to large-scale field experiments and ultimately to full-scale waste rock piles. Here we present preliminary scaling results based on time weighted load estimates, and volume and time based concentration estimates. Future concentration estimates will include more

refined estimates of water flow and temperature. In addition, reactive transport models will be used to simulate spatially and temporally distributed loadings with temperature corrections and gas transport constraints.

### **3.1 Time Weighted Load Estimates**

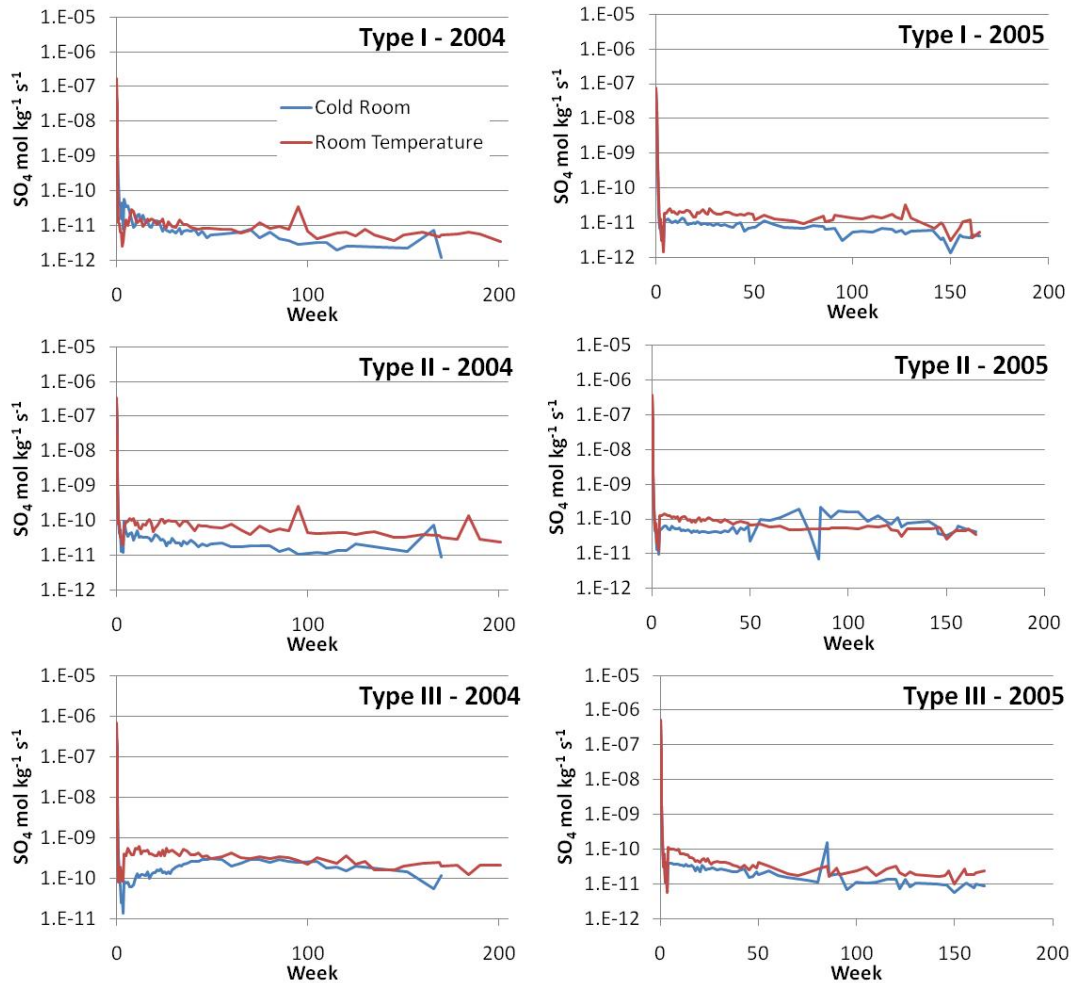
Several humidity cell experiments have been underway, in both room temperature and cold room environments and for each of the Type I, Type II, and Type III rock classifications, for more than 3 years (Figure 3-1). Geochemical loading estimates derived from these experiments, including sulfate release rates and metal release rates, form the basis of the scale-up calculations (Figure 3-2). Material properties, including sulfur content and grain size, have been determined to provide a basis of comparison to field experiments.



**Figure 3-1. Room temperature humidity Cell Experiments**

For both the upper collection lysimeter experiments and the test piles the Type III installations provide the best data sets for scale-up comparisons. This is because of the additional volume of water applied to these experiments through artificial rainfall. For each of the Type III humidity cells, the Type III upper collection lysimeters, the Type III basal drains, and the Type III basal lysimeters, yearly sulfur loads are calculated using the measured sulfur concentrations and the measured water volumes from each of the experiments. The sulfur loads are then normalized to the mass of the rock, the surface area of the rock, the mass of sulfur in the rock, and estimated surface area of the sulfur (Table 3 1). For the field installations, rock masses are

estimated based on as-built drawings. For the Type III basal drains two loading estimates are provided; one uses the rock mass of the entire pile and the second uses the rock mass of only the batters of the pile. This difference reflects the assumption that flow to the basal drains is from the entire pile *versus* the assumption that flow is only derived from the batters of the piles.



**Figure 3-2. Average sulfate release rates from Type I, II and III rock collected in 2004 and 2005 for both cold room and room temperature experiments.**

The surface area of the rock is estimated based on surface area measurements performed on humidity cell charges and comparison of grain-size analysis of both humidity cells and field scale experiments. Comparison of the grain-size results from the humidity cells and the material from the Type III test pile indicate that the grain-size distribution of the material in the humidity cells is representative of the fine fraction in the Type III pile. In addition, this comparison

indicates that the size fraction used in the humidity cells (< ¼ inch) represents approximately 16 % of the material in the Type III pile. Since the fine fraction of a rock sample contains the vast majority of the surface area, it is assumed that the surface area of the field installations is 16 % of that measured in the humidity cells on a per mass basis.

Sulfur content of the Type III material was measured on multiple samples during construction of the Type III pile. Material from the Type III upper collection lysimeter has not yet been analyzed so it is assumed here to be the same as the Type III test pile. Surface area of the sulfur is calculated assuming that the ratio of surface area of the sulfur to the surface area of the rock is proportional to the sulfur content of the rock.

**Table 3-1. Preliminary Yearly Load Estimates**

| Type III Rock    |                        | g S<br>( kg rock) <sup>-1</sup> | g S<br>( m <sup>2</sup> rock) <sup>-1</sup> | g S<br>(Kg S) <sup>-1</sup> | g S<br>(m <sup>2</sup> S) <sup>-1</sup> |
|------------------|------------------------|---------------------------------|---|-----------------------------|---|
| Humidity Cells   | 2004 Room Temperature  | 0.44                            | 2.7E-04                                     | 273                         | 0.17                                    |
|                  | 2005 Room Temperature  | 0.18                            | 3.0E-05                                     | 294                         | 0.05                                    |
|                  | 2004 Cold Room         | 0.23                            | 1.4E-04                                     | 144                         | 0.09                                    |
|                  | 2005 Cold Room         | 0.14                            | 2.4E-05                                     | 241                         | 0.04                                    |
| Upper Collection |                        |                                 |   |                             |   |
| Lysimeters       | West                   | 0.0062                          | 3.5E-05                                     | 9.89                        | 0.06                                    |
|                  | East                   | 0.0042                          | 2.3E-05                                     | 6.66                        | 0.04                                    |
| Test Pile        | Basal Drain            | 0.00038                         | 2.1E-06                                     | 0.61                        | 0.003                                   |
|                  | Basal Drain - Batters  | 0.00064                         | 3.6E-06                                     | 1.02                        | 0.006                                   |
|                  | Basal Lysimeter -      |                                 |   |                             |   |
|                  | 3BNCl <sub>ys</sub> 4E | 0.0018                          | 9.9E-06                                     | 2.83                        | 0.02                                    |
|                  | 3BNCl <sub>ys</sub> 4W | 0.0017                          | 9.3E-06                                     | 2.64                        | 0.01                                    |
|                  | 3BSCl <sub>ys</sub> 4E | 0.00044                         | 2.5E-06                                     | 0.70                        | 0.004                                   |

In general, the sulfur loadings calculated from the Type III humidity cells based on mass of rock, surface area of rock, and mass of sulfur, are much higher than for the Type III upper collection lysimeters and the Type III test pile. For estimates based on the surface area of the

sulfur the sulfur loading rates derived from the humidity cells provide a better estimate of loading rates from the field-scale installations (Table 3 1).

### **3.2 Concentration Estimates**

Time dependent loading rates from Type III humidity cells (Figure 3-2) are used to estimate sulfur and metal concentrations for the Type III upper collection lysimeters and estimated concentrations are compared to measured concentrations (Figure 3-3). Calculations are based on a specific date, corresponding to a certain elapsed time since the upper collection lysimeters were installed. Taking this and an estimated residence time of 400 days (based on observed water flow and tracer breakthrough), release rates based on the mass of rock are determined from the humidity cells corresponding to the same elapsed time. A total sulfur loading is calculated based on the residence time and a concentration estimate is calculated by estimating the volume of water within the rock mass. Concentrations are then corrected for mass of sulfur and surface area of sulfur in a similar manner as in section 3.1.

Estimates based on the mass of the rock and the mass of sulfur overestimate the dissolved concentrations observed in the field. However, concentration estimates for sulfate and nickel based on the surface area of the exposed sulfur are in reasonable agreement compared to values measured in the field. For iron the estimated concentrations are well above the measured concentrations, likely indicating a solubility control on iron in the system. The good agreement between estimated and observed concentrations shows that scale-up calculation can provide reasonable estimates of sulfur and metal loadings in the field provided that the rock is adequately characterized at both scales, particularly with respect to grain size and sulfur content.

These estimates assume a constant residence time and utilize room temperature rate estimates. Better predictions should be achievable by applying correction for the dependence of reaction rate on temperature and the variations in residence times actually observed in the field. The concentration estimates presented here provide scale-up estimates from lab-scale experiments to the 2 m-scale upper collection lysimeters. Ongoing work includes scaling to the 15 m-scale test piles.



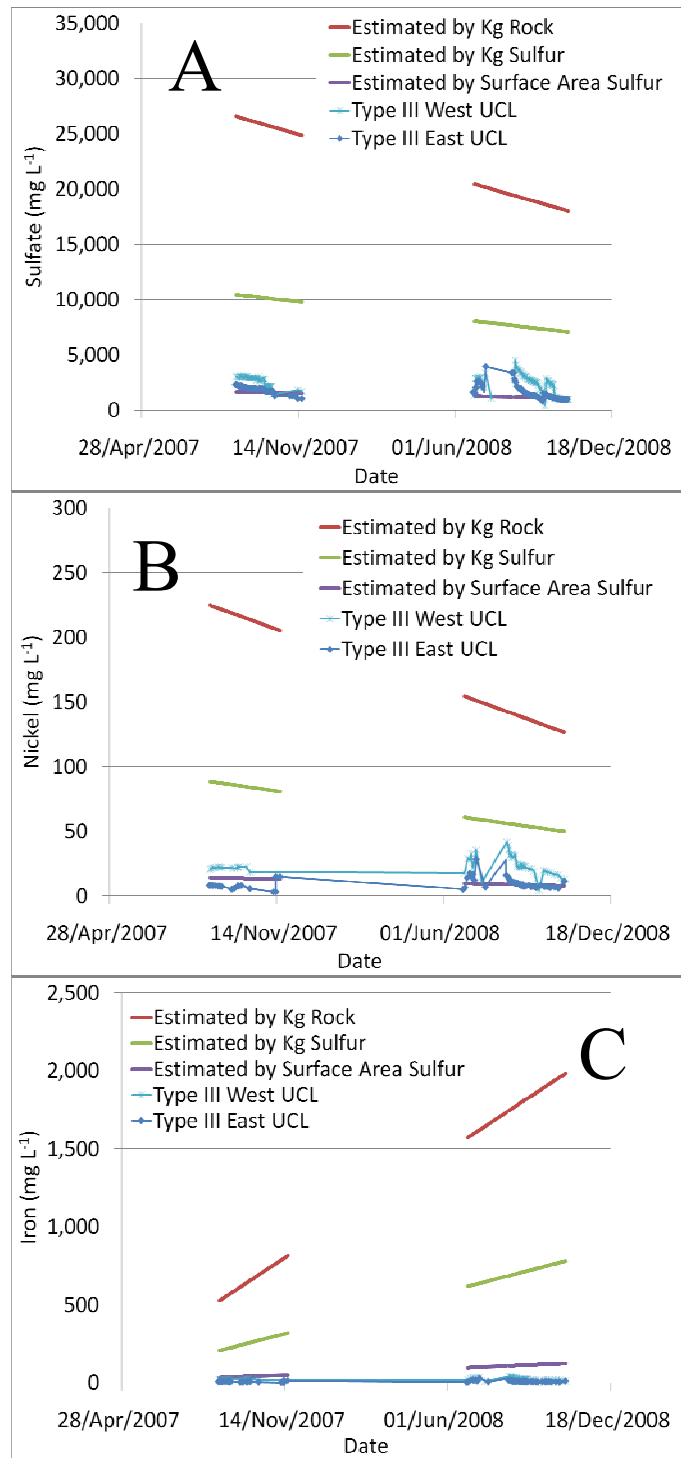


Figure 3-3. Concentration estimates for A: sulfate, B: nickel and C: iron for Type III upper collection lysimeters based on release rates derived from room temperature humidity cell experiments.

## 4 Results and Reporting

Results from the Diavik Waste Rock Project have been presented at numerous Canadian and international conferences and published in various conference proceedings (Table 4-1). These presentations and publications cover construction, hydrological, thermal, gas transport, and geochemical aspects of the project. In 2009, initial results from the gas transport studies were published in the Vadose Zone Journal, a highly regarded journal published by the Soil Science Society of America. This article was featured on the cover of the journal and was also featured in the society's monthly newsletter, providing a broader exposure for the research project. The project has involved 11 graduate students from the three participating universities, including two that graduated in 2009, and has involved over 25 undergraduate students (Table 4-2).

**Table 4-1. Diavik Waste Rock Project Publication and Presentations**

| Publications   |
|--|
| Blowes et al., Proceedings of the Sea to Sky Geotechnique, 2006.                           |
| Blowes et al., ICARD, 2006.  |
| Blowes et al., IMWA Symposium 2007.  |
| Arenson et al., Proceeding of the 60 <sup>th</sup> Canadian Geotechnical Conference, 2007. |
| Blowes et al., Proceedings of the CIM Symposium 2008.                                      |
| Pham et al., Ninth International Conference on Permafrost, 2008                            |
| Pham et al., Proceeding of the 61 <sup>th</sup> Canadian Geotechnical, 2008                |
| Amos et al., Vadose Zone Journal, November 2009  |
| Amos et al., Proceedings of Securing the Future and 8th ICARD, 2009                        |
| Bailey et al., Proceedings of Securing the Future and 8th ICARD, 2009                      |
| Neuner et al., Proceedings of Securing the Future and 8th ICARD, 2009                      |
| Pham et al., Proceedings of Securing the Future and 8th ICARD, 2009                        |
| Smith et al., Proceedings of Securing the Future and 8th ICARD, 2009                       |
| Theses   |
| Neuner, M., MSc. Thesis, University of British Columbia, 2009                              |
| Smith, L.J.D., MSc. Thesis, University of Waterloo, 2009                                   |

|  |
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| Reports  |
| Diavik Waste Rock Project Annual Update – 2005, 2006, 2007, 2009 |
| INAP test piles site tour and update - August 2008               |
| Diavik Waste Rock Project Comprehensive Progress Report - 2008   |
| Conference Presentations   |
| Canadian Geotechnical Conference 2006, 2007, 2008                |
| ICARD 2006, 2009 – 6 Presentations                               |
| Yellowknife Geoscience Forum 2006, 2008, 2009 - 5 Presentations  |
| Sudbury 2007   |
| AGU 2007   |
| IMWA 2008  |
| Goldschmidt 2008 - 2 Presentations                               |

**Table 4-2. Graduate Student Participation in Diavik Waste Rock Project**

| Student        | Project Description   | Graduation Year |
|----------------|---|-----------------|
| Mandy Moore    | Humidity cells – years 1 to 4                                     | 2010            |
| Matt Neuner    | Hydrology years 1 and 2   | 2009*           |
| Lianna Smith   | Pile Construction, characterization and early geochemical results | 2009*           |
| Renata Klassen | Thermal Modelling   | 2010            |
| Mike Gupton    | Tracer tests and hydrology  | 2010            |
| Nam Pham       | Thermal characterization and modelling                            | 2010            |
| Steve Momeyer  | Hydrology years 3 and 4   | 2010            |
| Brenda Bailey  | Geochemistry and Microbiology                                     | 2011            |
| Sheldon Chi    | Gas Transport analysis and modelling                              | 2011            |
| Ashley Stanton | Humidity cells years 4 to 6, database management                  | 2012            |
| Stacey Hannam  | Mineralogy  | 2012            |

\* Graduated

## **5 Summary of Progress and Future Outlook**

The objectives of the Diavik Waste Rock Research Program are to evaluate the benefits of the proposed reclamation concepts for the Diavik Country Rock Stockpiles, and to evaluate techniques used to scale the results of laboratory studies to predict the environmental impacts of full-scale rock stockpiles. Laboratory experiments have been underway for more than 3 years to evaluate leaching rates from Diavik waste rock. Data collection from the field experiments has been underway for 3 full field seasons from 2007 to 2009. The extensive data sets reveal clear hydrological, thermal and geochemical trends and demonstrate that the hydrology, geochemistry and thermal states of the test piles continue to evolve. The data sets have allowed for preliminary scaling calculations to be completed. These calculations suggest that small-scale experiments can give reasonable estimates of field scale leaching rates provided that the material properties are well characterized at each scale. In 2009, instrumentation of the full scale Type III waste rock type at Diavik was attempted; although the success of the installation is unknown to date.

The Diavik Waste Rock Project Research Team is proposing to extend the research program for an addition 5 years beginning in 2010. A significant investment in research infrastructure at Diavik was made by the research partners including, Diavik, The Natural Science and Engineering Council of Canada (NSERC), The Canadian Foundation for Innovation (CFI), INAP and MEND. This infrastructure represents a tremendous opportunity to continue to gain further insights into behaviour of the waste rock piles as the hydrology, thermal regime, and geochemistry evolve toward steady state conditions. Continuation of the project will; allow for a longer, richer data set to form the basis of scale up comparisons; provide additional full-scale data to be included in scale-up comparison; further strengthen linkages between thermal, gas and water transport, and geochemical reactive transport aspects of the project; provide stronger support for closure planning for northern operations; and provide the opportunity to apply and evaluate sophisticated data interpretation and analysis techniques. Diavik has committed funding for the project extension and funding has been requested from INAP and MEND. Matching funding from NSERC will be request in March, 2010.

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**TECHNICAL MEMORANDUM  
DIAVIK DIMOND MINES INC. PROJECT**

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TO: Erik Madsen, Murray Swyripa, File

DATE: 1/17/97  
PROJECT: 962-2309-5551

AUTHOR(S): Tim R. Bossenberry

**FINAL REPORT**

TITLE: Technical Memorandum #4-revision #1  
Reclamation Materials Inventory and Mapping  
1996 Environmental Baseline Program

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**OBJECTIVES**

The objectives of the 1996 terrain and soils programme for the Diavik Diamond Mines Inc. Project were to:

- describe the terrain of the east island.
- inventory and classify the surficial deposits and soils of the east island.
- identify the surficial materials on the east island that would be suitable for reclaiming the areas disturbed by mining activities.
- interpretation of surficial materials on the mainland and west island, based on the investigations and mapping completed for the east island.

**INTRODUCTION**

The field component of the terrain and soils programme was carried out from July 29 through August 3, 1996. Personnel involved in the field programme included Tim R. Bossenberry (Golder) and Phoebe Ann Wetrade, an assistant provided by the camp. Field work was confined to the east island (a portion of the Local Study Area), since at that time, that was where the majority of the disturbance was to occur. Interpretation of the surficial materials on the



mainland and west island (remainder of the Local Study Area) will be forthcoming (end of November, 1996), and will be based on the investigations and mapping completed for the east island.

- A total of 47 sites were investigated on the east island to determine local terrain and soils characteristics (Figure 14).
- Numerous photographs were taken at various locations on the east island, including the soil inspection sites, to fully characterise the terrain conditions and the extent of surficial materials (Plates 1 through 80).
- Surficial materials mapping was done on a series of 1:10,000 colour aerial photographs of the east island (Figures 2 through 13). The aerial photographs were interpreted and provided a base for defining the surficial materials polygons.
- Orientation of the twelve (12) aerial photographs is included on Figure 1.
- Each of the eighty (80) photographs taken from the ground on the east island and the direction in which these photos were taken are indicated on Figures 2 through 13.

## **METHODS**

Technical Procedure 8-11-0 (Soil Investigation and Sampling) was followed for the investigation of terrain and soils on the east island of the Diavik Dimond Mines Inc. Project. Specific Work Instructions SWI-15.0 were also followed for this investigation. There were no deviations to the Technical Procedure or the Specific Work Instructions. Technical Procedure TP 8-11-0 and Specific Work Instructions SWI-15.0 are included at the end of this Technical Memorandum.

## **RESULTS**

### **Terrain**

The landscape conditions on the east island are described in Table 1 (Landscape and Soil Profile Characteristics) for the 47 Soil Investigation Sites, and visually by the 80 photographic plates included at the end of this Technical Memorandum.

The project area is a glaciated landscape characterised by:

- steep sided bedrock ridges (examples on Plates 18, 21, 26 and 32);
- undulating to strongly rolling (2% to 30% slopes) morainal deposits (examples on Plates 4, 6, 25 and 80);
- ridged (eskers) and hummocky (kames) glaciofluvial deposits (examples on Plates 51, 52 and 73); and
- level to depressional glaciolacustrine (examples on Plates 7, 18, 24, 32, 34, 50, 58, 60 and 61) and organic deposits (examples on Plates 1, 22, 23, 42, 44, 48, 50, 54, 65, 69 and 76).

There are numerous solifluction lobes on the east island (examples on Plates 13, 14 and 16). These lobes are most defined on slopes ranging from 10% to 25%, however, may occur on slopes as shallow as 2%.

There are a few small creeks that dissect the east island (examples on Plates 11 and 36). The creeks are not incised, therefore, do not affect the condition of the landscape.

Most of the terrain features on the east island are controlled by shallow bedrock (examples on Plates 4, 40 and 48). There are veneers (<one metre thick) and blankets (one to three metres thick) of morainal and glaciolacustrine deposits overlying the bedrock. There are also veneers and blankets of glaciolacustrine deposits overlying morainal deposits on the east island.

## Surficial Geology

Parent materials on the east island consist of morainal, glaciolacustrine, glaciofluvial and organic deposits. The spatial distribution of surficial deposits on the east island is illustrated on Figures 2 through 13.

- Morainal (material deposited by glaciers) deposits overlie most of the bedrock in the area. These deposits are: moderately coarse (sandy loam) to coarse (loamy sand, sand) textured; moderately well to imperfectly drained on undulating to strongly rolling topography (2% to 30% slopes); and moderately to exceedingly stony.
- Glaciolacustrine (material deposited by glacial lakes) deposits occupy most of the lowland areas that are within 10 metres of the current level of Lac de Gras. These deposits are: medium (silt loam, loam) to moderately coarse (sandy loam) textured; imperfectly to poorly drained on level to gentle slopes (0% to 5% slopes); and nonstony to slightly stony. Glaciolacustrine deposits overlie bedrock and morainal deposits on the east island.
- Glaciofluvial (material deposited by glacial rivers) deposits are generally in the form of eskers and kames. These deposits are: coarse (sand, loamy sand) textured; well to rapidly drained on moderate to strong slopes (6% to 30% slopes); and generally nonstony. Glaciofluvial deposits in this area may have lenses of fine gravel throughout their profiles.
- Organic deposits are: poorly to very poorly drained on level to depressional topography; and nonstony. Most of the shallow (<1 metre) organic deposits have large remanant stones (bedrock or glacial till) exposed at the surface.

## Regional Soils

The east island lies within the continuous permafrost zone of the North West Territories. Soils in this zone are of the Cryosolic order. Cryosolic soils are formed in either mineral or organic materials under the influence of cryoturbation, or frost boiling, and are characterised by disrupted, mixed or broken horizons. Cryosolic soils form where permafrost occurs within 2 metres of the ground surface.

The Cryosolic order is divided into:

- Turbic Cryosols, where there is marked cryoturbation in mineral material, as evidenced by patterned ground (circles, polygons) or surface frost boils (earth hummocks);
- Static Cryosols, where there is no visible evidence of patterned ground or surface frost boils in mineral material; and
- Organic Cryosols, which occur in organic material.

There is a high risk of mass movement (solifluction) in Cryosolic soils on slopes greater than 2%. Solifluction occurs when thaw water:

- infiltrates to the permafrost layer, which;
- saturates the thaw layer, which;
- increases the materials weight, which;
- lubricates the thawed/frozen interface, which;
- decreases the shear strength of the material, which;
- results in a slow, downslope movement of the material.

Solifluction, like cryoturbation, causes soil horizons to become mixed together.

Areas of the east island that have been significantly cryoturbated and soliflucted are indicated on Figures 2 through 11 by the symbols C and S, respectively. Most of the soils on the east island have been cryoturbated to a certain extent, and if on a slope greater than 2%, soliflucted.

A soil investigation was completed for the east island, the results of which are included on Table 1 at the end of this Technical Memorandum. This information was used as part of the baseline map created for the Local Study Area.

### **Materials Suitable for Reclamation**

The suitability of the morainal, glaciolacustrine and glaciofluvial materials on the east island for reclamation purposes are indicated on Table 1. Suitability for reclamation is rated based primarily on soil texture, soil consistence, and stone content.

All of the organic materials on the east island are particularly suitable for reclamation, since they:

- have a very high moisture retention capacity; and

- contain an abundant reserve of native seeds and stolons.

The glaciolacustrine materials on the east island are suitable for reclamation, since they generally:

- have a fine sandy loam to silty loam texture;
- have a friable to very friable consistence; and
- have less than a 10% stone content.

The glaciofluvial materials (eskers and kames) on the east island are marginally suitable for reclamation, since they:

- have a sand to loamy sand texture;
- have a loose consistence; and
- may contain a significant content of gravel.

The morainal materials on the east island are marginally suitable for reclamation, since they:

- have a sand to gravelly sandy loam texture;
- have a friable to loose consistence; and
- have a stone content generally exceeding 20% and a very (stones 1 to 2 metres apart) to exceedingly (stones 0.1 to 0.5 metres apart) stony surface.

The frost boiled materials (Turbic Cryosols), particularly those developed in thin organic over glaciolacustrine or glaciofluvial deposits, on the east island are suitable for reclamation, since they:

- have had organic and mineral materials naturally mixed together;
- have had only the finer mineral fractions boiled to the surface, with large stones being left at depth; and
- have a noncompacted consistency, due to the constant frost boiling.

The soliflucted materials on the east island are suitable for reclamation, since they:

- have had organic and mineral material naturally mixed together, similar to the Turbic Cryosols; and
- have a noncompacted consistency, due to the slow downslope movement of the material.

Overall, there appears to be an abundant supply of materials suitable for reclamation on the east island.

- Most of the organic, organic over glaciolacustrine, and glaciolacustrine deposits occur on large level plains and could be easily salvaged for stockpiling.
- Other materials suitable for reclamation occur in small, sometimes confined areas, and will need to be selectively salvaged from the less suitable reclamation materials, such as the stony morainal deposits and bedrock.
- The reclamation plan for the mine should include a detailed salvage and stockpiling procedure to ensure that these valuable reclamation materials are not lost by lack of effort during salvage, inappropriate stockpiling, or sterilisation by stockpiling granite over this resource.

## TABLE 1



TABLE 1 LANDSCAPE AND SOIL PROFILE CHARACTERISTICS

| SITE | LANDSCAPE   | HOR  | DEPTH (cm)                               | COLOUR                                   | TEXT                 | RECL RATING                  | STRUCT               | CONS                   | RECL RATING                  | ROCKS (%)            | RECL RATING                  |
|------|---|--|--|--|----------------------|------------------------------|----------------------|------------------------|------------------------------|----------------------|------------------------------|
| 1    | Topography: Depressional<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Poor<br>Parent Material: Glaciolacustrine<br>UTM Coordinates: E530000<br>N7150242                              | Om<br>smooth<br>Bm<br>wavy<br>Cg                 | 0 - 6<br>6 - 20<br>20 - 99+              | 10YR4/3<br>10YR5/3                       | fSL<br>fSL           | good<br>good                 | GR<br>MA             | MVFR<br>MFR            | good<br>good                 | 0<br>10<br>10        | good<br>good                 |
| 2    | Topography: Depressional<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E529902<br>N7150375                      | Of<br>wavy<br>Om<br>wavy<br>Cg<br>wavy<br>Cz     | 0 - 33<br>33 - 41<br>41 - 53<br>53 - 99+ | 10YR4/4<br>10YR4/4                       | SiL<br>SiL           | good<br>good                 | MA<br>MA             | MFR<br>frozen          | good<br>n/a                  | 0<br>0<br>0<br>0     | good<br>good                 |
| 3    | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E529992<br>N7150393                       | Om<br>wavy<br>Cg                                 | 0 - 20<br>20 - 99+                       | 10YR5/1                                  | fSL                  | good                         | MA                   | MVFR                   | good                         | 0<br>10              | good                         |
| 4    | Topography: Moderately Rolling<br>Slope: 14%<br>Slope Position: Lower<br>Surface Stoniness: Exceedingly Stony<br>Drainage: Moderately Well to Well<br>Parent Material: Morainal<br>UTM Coordinates: E529620<br>N7151500 | Ah<br>irreg.<br>Bm<br>irreg.<br>C1<br>wavy<br>C2 | 0 - 4<br>4 - 24<br>24 - 35<br>35 - 99+   | 10YR3/3<br>10YR4/4<br>10YR5/3<br>10YR5/3 | SL<br>SL<br>SL<br>SL | good<br>good<br>good<br>good | GR<br>GR<br>MA<br>MA | DS<br>MFR<br>MFR<br>ML | good<br>good<br>good<br>fair | 10<br>30<br>30<br>60 | good<br>fair<br>fair<br>poor |

| SITE | LANDSCAPE  | HOR  | DEPTH (cm)                             | COLOUR                                   | TEXT                | RECL RATING                  | STRUCT               | CONS                    | RECL RATING                  | ROCKS (%)           | RECL RATING                  |  |
|------|--|--|--|--|---------------------|------------------------------|----------------------|-------------------------|------------------------------|---------------------|------------------------------|--|
| 5    | Topography: Gently Sloping<br>Slope: 5%<br>Slope Position: Middle<br>Surface Stoniness: Nonstony<br>Drainage: Moderately Well<br>Parent Material: Glaciolacustrine<br>UTM Coordinates: E530146<br>N7151481       | Ah<br>irreg.<br>Bm<br>irreg.<br>C1<br>wavy<br>C2 | 0 - 4<br>4 - 26<br>26 - 45<br>45 - 99+ | 10YR3/3<br>10YR4/4<br>10YR5/3<br>10YR3/2 | SL<br>SL<br>SL<br>L | good<br>good<br>good<br>good | GR<br>GR<br>MA<br>MA | DS<br>MFR<br>MFR<br>MFR | good<br>good<br>good<br>good | 10<br>10<br>10<br>5 | good<br>good<br>good<br>good |  |
| 6    | Topography: Moderately Rolling<br>Slope: 17%<br>Slope Position: Middle<br>Surface Stoniness: Exceedingly Stony<br>Drainage: Moderately Well<br>Parent Material: Morainal<br>UTM Coordinates: E529738<br>N7151752 | Of<br>irreg.<br>Oh<br>irreg.<br>C1<br>wavy<br>C2 | 0 - 6<br>6 - 12<br>12 - 43<br>43 - 99+ |  |                     |                              |                      |                         |                              | 0<br>0<br>40<br>80  |                              |  |
| 7    | Topography: Moderately Sloping<br>Slope: 8%<br>Slope Position: Lower<br>Surface Stoniness: Slightly Stony<br>Drainage: Moderately Well<br>Parent Material: Colluvial<br>UTM Coordinates: E530159<br>7152293      | Of<br>irreg.<br>C                                | 0 - 13<br>13 - 99+                     | 10YR3/3                                  | grLS<br>grSL        | poor<br>good<br>good         | SGR<br>MA<br>MA      | ML<br>MVFR<br>MVFR      | fair<br>good<br>good         | 0<br>10             | good                         |  |
| 8    | Topography: Strongly Sloping<br>Slope: 14%<br>Slope Position: Lower<br>Surface Stoniness: Nonstony<br>Drainage: Moderately Well<br>Parent Material: Organic/Colluvial<br>UTM Coordinates: E530528<br>N7152393    | Of<br>wavy<br>Om<br>irreg.<br>Cz                 | 0 - 14<br>14 - 34<br>34 - 99+          | 10YR4/3                                  | SL                  | good                         | MA                   | frozen                  | n/a                          | 0<br>0<br>20        | fair                         |  |

| SITE | LANDSCAPE   | HQR  | DEPTH (cm)                             | COLOUR                        | TEXT        | RECL RATING          | STRUCT            | CONS               | RECL RATING         | ROCKS (%)        | RECL RATING          |
|------|---|--|--|-------------------------------|-------------|----------------------|-------------------|--------------------|---------------------|------------------|----------------------|
| 9    | Topography: Steeply Sloping<br>Slope: 18%<br>Slope Position: Middle<br>Surface Stoniness: Slightly Stony<br>Drainage: Well<br>Parent Material: Colluvial<br>UTM Coordinates: E530948<br>N7152459      | Ahy<br>irreg.<br>Cy                          | 0 - 33<br>33 - 99+                     | 10YR3/1<br>10YR4/4            | SiL<br>SL   | good<br>good         | GR<br>MA          | DS<br>DL           | good<br>fair        | 10<br>40         | good<br>poor         |
| 10   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Imperfect<br>Parent Material: Glaciolacustrine<br>UTM Coordinates: E533232<br>N7151987              | Oh<br>irreg.<br>Cg                           | 0 - 8<br>8 - 99+                       | 10YR6/2                       | fSL         | good                 | MA                | DS                 | good                | 0<br>0           | good                 |
| 11   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Poor<br>Parent Material: Glaciolacustrine<br>UTM Coordinates: E531349<br>N7150545                   | Of<br>wavy<br>Bm<br>wavy<br>Cg<br>wavy<br>Cz | 0 - 7<br>7 - 30<br>30 - 95<br>95 - 99+ | 10YR6/3<br>10YR6/1<br>10YR6/1 | S<br>S<br>S | poor<br>poor<br>poor | SGR<br>SGR<br>SGR | ML<br>ML<br>frozen | fair<br>fair<br>n/a | 0<br>0<br>0<br>0 | good<br>good<br>good |
| 12   | Topography: Depressional<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Very Poor<br>Parent Material: Organic/Morainal<br>UTM Coordinates: E531742<br>N7150638 | Of<br>irreg.<br>Cg                           | 0 - 38<br>38 - 99+                     | 10YR6/1                       | grS         | poor                 | SGR               | WNS                | good                | 0<br>90          | unsuit               |

| SITE | LANDSCAPE  | HOR  | DEPTH (cm)                               | COLOUR                        | TEXT                 | RECL RATING          | STRUCT           | CONS                 | RECL RATING         | ROCKS (%)           | RECL RATING          |
|------|--|--|--|-------------------------------|----------------------|----------------------|------------------|----------------------|---------------------|---------------------|----------------------|
| 13   | Topography: Undulating<br>Slope: 5%<br>Slope Position: Lower<br>Surface Stoniness: Slightly Stony<br>Drainage: Moderately Well<br>Parent Material: Morainal<br>UTM Coordinates: E531621<br>N7151022                      | Om<br>wavy<br>Bm<br>irreg.<br>Cgy                    | 0 - 2<br>2 - 9<br>9 - 99+                | 10YR4/4<br>10YR5/2            | SiL<br>grSiL         | good<br>good         | GR<br>MA         | DS<br>MFR            | good<br>good        | 0<br>5<br>30        | good<br>fair         |
| 14   | Topography: Gently Undulating<br>Slope: 2%<br>Slope Position: Upper<br>Surface Stoniness: Very Stony<br>Drainage: Moderately Well<br>Parent Material: Morainal<br>UTM Coordinates: E532387<br>N7150469                   | Om<br>wavy<br>Cgy                                    | 0 - 4<br>4 - 99+                         | 10YR6/3                       | grfSL                | good                 | GR               | MVFR                 | good                | 0<br>40             | poor                 |
| 15   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Imperfect to Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E532629<br>N7150681                 | Of<br>wavy<br>Bm<br>irreg.<br>Cgy<br>wavy<br>Cz      | 0 - 20<br>20 - 46<br>46 - 60<br>60 - 99+ | 10YR4/4<br>10YR5/2<br>10YR5/2 | fSL<br>grLS<br>grLS  | good<br>poor<br>poor | GR<br>SGR<br>SGR | MFR<br>ML<br>frozen  | good<br>fair<br>n/a | 0<br>0<br>10<br>10  | good<br>good<br>good |
| 16   | Topography: Gently Undulating<br>Slope: 2%<br>Slope Position: Middle<br>Surface Stoniness: Very Stony<br>Drainage: Moderately Well<br>Parent Material: Glaciolacustrine/Morainal<br>UTM Coordinates: E533373<br>N7150301 | Of<br>irreg.<br>Bmy<br>irreg.<br>Cgy<br>irreg.<br>Cz | 0 - 2<br>2 - 24<br>24 - 88<br>88 - 99+   | 10YR4/4<br>10YR6/3<br>10YR6/3 | grSL<br>grSL<br>grSL | good<br>good<br>good | MA<br>MA<br>MA   | MFR<br>MFR<br>frozen | good<br>good<br>n/a | 0<br>10<br>30<br>30 | good<br>fair<br>fair |

| SITE | LANDSCAPE  | HOR   | DEPTH (cm)                               | COLOUR                        | TEXT            | RECL RATING          | STRUCT         | CONS                 | RECL RATING         | ROCKS (%)        | RECL RATING          |
|------|--|---|--|-------------------------------|-----------------|----------------------|----------------|----------------------|---------------------|------------------|----------------------|
| 17   | Topography: Level<br>Slope: 0.5%<br>Slope Position: Middle<br>Surface Stoniness: Nonstony<br>Drainage: Imperfect to Poor<br>Parent Material: Glaciolacustrine<br>UTM Coordinates: E533884<br>N7150213              | Of wavy<br>Bmy<br>irreg.<br>Cgy<br>irreg.<br>Cz | 0 - 10<br>10 - 18<br>18 - 86<br>86 - 99+ | 10YR4/4<br>10YR6/2<br>10YR6/2 | fSL<br>SL<br>SL | good<br>good<br>good | GR<br>MA<br>MA | MFR<br>MFR<br>frozen | good<br>good<br>n/a | 0<br>0<br>0<br>0 | good<br>good<br>good |
| 18   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Poor<br>Parent Material: Organic/Bedrock<br>UTM Coordinates: E533740<br>N7150822                           | Of wavy<br>Om<br>irreg.<br>R                    | 0 - 39<br>39 - 53<br>53 - 99+            |                               |                 |                      |                |                      |                     |                  |                      |
| 19   | Topography: Very Gently Sloping<br>Slope: 1.5%<br>Slope Position: Middle<br>Surface Stoniness: Very Stony<br>Drainage: Imperfect<br>Parent Material: Colluvial<br>UTM Coordinates: E534179<br>N7151165             | Of irreg.<br>Cgy                                | 0 - 3<br>3 - 99+                         | 10YR5/3                       | fSL             | good                 | MA             | MFR                  | good                | 0<br>5           | good<br>good         |
| 20   | Topography: Very Gently Sloping<br>Slope: 1.5%<br>Slope Position: Middle<br>Surface Stoniness: Slightly Stony<br>Drainage: Imperfect<br>Parent Material: Organic/Colluvial<br>UTM Coordinates: E533657<br>N7151393 | Of irreg.<br>Cz                                 | 0 - 45<br>45 - 99+                       | 10YR4/4                       | SL              | good                 | MA             | frozen               | n/a                 | 0<br>10          | good<br>good         |

| SITE | LANDSCAPE  | HGR                             | DEPTH (cm)                    | COLOUR             | TEXT       | RECL RATING  | STRUCT     | CONS          | RECL RATING | ROCKS (%)   | RECL RATING  |
|------|--|---------------------------------|-------------------------------|--------------------|------------|--------------|------------|---------------|-------------|-------------|--------------|
| 21   | Topography: Gently Sloping<br>Slope: 4%<br>Slope Position: Middle<br>Surface Stoniness: Nonstony<br>Drainage: Imperfect<br>Parent Material: Colluvial/Glaciolacustrine<br>UTM Coordinates: E533714<br>N7151625 | Of<br>wavy<br>Cgy<br>wavy<br>Cz | 0 - 2<br>2 - 76<br>76 - 99+   | 10YR6/3<br>10YR6/3 | fSL<br>fSL | good<br>good | MA<br>MA   | MFR<br>frozen | good<br>n/a | 0<br>5<br>5 | good<br>good |
| 22   | Topography: Level<br>Slope: 0.5%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Imperfect<br>Parent Material: Glaciolacustrine<br>UTM Coordinates: E533845<br>N7151751                     | Of<br>wavy<br>Cgy<br>wavy<br>Cz | 0 - 23<br>23 - 42<br>42 - 99+ | 10YR6/3<br>10YR6/3 | fSL<br>fSL | good<br>good | MA<br>MA   | MFR<br>frozen | good<br>n/a | 0<br>5<br>5 | good<br>good |
| 23   | Topography: Depressional<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E532147<br>N7153737             | Of<br>wavy<br>Cz                | 0 - 35<br>35 - 99+            | 10YR4/4            | LS         | poor         | SGR        | frozen        | n/a         | 0<br>0      | good         |
| 24   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Poor to Very Poor<br>Parent Material: Organic/Glaciofluvial<br>UTM Coordinates: E532937<br>N7153414          | Of<br>wavy<br>Cgy<br>wavy<br>Cz | 0 - 37<br>37 - 62<br>62 - 99+ | 10YR4/4<br>10YR4/4 | S<br>S     | poor<br>poor | SGR<br>SGR | ML<br>frozen  | fair<br>n/a | 0<br>0<br>0 | good<br>good |

| SITE | LANDSCAPE  | HGR   | DEPTH (cm)                             | COLOUR                        | TEXT                 | RECL RATING          | STRUCT           | CONS               | RECL RATING         | ROCKS (%)           | RECL RATING          |
|------|--|---|--|-------------------------------|----------------------|----------------------|------------------|--------------------|---------------------|---------------------|----------------------|
| 25   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Moderately Stony<br>Drainage: Imperfect<br>Parent Material: Organic/Morainal<br>UTM Coordinates: E532257<br>N7152978                               | Of<br>irreg.<br>Cgy                             | 0 - 26<br>26 - 35+                     | 10YR4/4                       | grSL                 | good                 | GR               | MFR                | good                | 0<br>60             | unsuit               |
| 26   | Topography: Gently Sloping<br>Slope: 4%<br>Slope Position: Middle<br>Surface Stoniness: Nonstony<br>Drainage: Imperfect<br>Parent Material: Colluvial/Glaciolacustrine<br>UTM Coordinates: E532626<br>N7152654                 | Of<br>wavy<br>Cgy<br>wavy<br>Cz                 | 0 - 4<br>4 - 75<br>75 - 99+            | 10YR5/3<br>10YR5/3            | fSL<br>fSL           | good<br>good         | MA<br>MA         | MFR<br>frozen      | good<br>n/a         | 0<br>0<br>0         | good<br>good         |
| 27   | Topography: Very Gently Sloping<br>Slope: 2%<br>Slope Position: Middle<br>Surface Stoniness: Moderately Stony<br>Drainage: Moderately Well<br>Parent Material: Colluvial/Glaciofluvial<br>UTM Coordinates: E533717<br>N7152857 | Of<br>irreg.<br>Bmy<br>wavy<br>Cy<br>wavy<br>Cz | 0 - 4<br>4 - 30<br>30 - 87<br>87 - 99+ | 10YR4/3<br>10YR5/3<br>10YR5/3 | grLS<br>grLS<br>grSL | poor<br>poor<br>good | SGR<br>SGR<br>MA | ML<br>ML<br>frozen | fair<br>fair<br>n/a | 0<br>30<br>30<br>30 | fair<br>fair<br>fair |
| 28   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E534269<br>N7152503                                    | Of<br>irreg.<br>Om<br>wavy<br>Cz                | 0 - 12<br>12 - 50<br>50 - 99+          | 10YR4/3                       | LS                   | poor                 | SGR              | frozen             | n/a                 | 0<br>0<br>5         | good                 |





| SITE | LANDSCAPE  | HOR   | DEPTH (cm)                             | COLOUR                        | TEXT                 | RECL RATING          | STRUCT         | CONS                 | RECL RATING         | ROCKS (%)           | RECL RATING          |
|------|--|---|--|-------------------------------|----------------------|----------------------|----------------|----------------------|---------------------|---------------------|----------------------|
| 33   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Imperfect<br>Parent Material: Organic/Glaciofluvial<br>UTM Coordinates: E535092<br>N7153858                  | Of<br>irreg.<br>Cgy<br>wavy<br>Cz             | 0 - 32<br>32 - 95<br>95 - 99+          | 10YR6/2<br>10YR6/2            | grSL<br>grSL         | good<br>good         | MA<br>MA       | MFR<br>frozen        | good<br>n/a         | 0<br>10<br>10       | good<br>good         |
| 34   | Topography: Gently Sloping<br>Slope: 3%<br>Slope Position: Middle<br>Surface Stoniness: Slightly Stony<br>Drainage: Imperfect<br>Parent Material: Organic/Colluvial<br>UTM Coordinates: E534692<br>N7154000          | Of<br>irreg.<br>Cgy<br>wavy<br>Cz             | 0 - 32<br>32 - 39<br>39 - 99+          | 10YR5/2<br>10YR5/2            | SiL<br>SiL           | good<br>good         | MA<br>MA       | WSS<br>frozen        | good<br>n/a         | 0<br>5<br>5         | good<br>good         |
| 35   | Topography: Gently Sloping<br>Slope: 2%<br>Slope Position: Middle<br>Surface Stoniness: Moderately Stony<br>Drainage: Moderately Well<br>Parent Material: Colluvial/Morainal<br>UTM Coordinates: E534590<br>N7153767 | Om<br>wavy<br>Bmy<br>wavy<br>Cy<br>wavy<br>Cz | 0 - 5<br>5 - 26<br>26 - 77<br>77 - 99+ | 10YR4/3<br>10YR5/3<br>10YR5/3 | grSL<br>grSL<br>grSL | good<br>good<br>good | GR<br>MA<br>MA | MFR<br>MFR<br>frozen | good<br>good<br>n/a | 0<br>40<br>20<br>20 | poor<br>fair<br>fair |
| 36   | Topography: Level<br>Slope: 0.5%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E534137<br>N7153956                  | Of<br>wavy<br>Om<br>wavy<br>Cz                | 0 - 18<br>18 - 33<br>33 - 99+          | 10YR4/3                       | SL                   | good                 | MA             | frozen               | n/a                 | 0<br>0<br>10        | good                 |

| SITE | LANDSCAPE  | HOR  | DEPTH (cm)                               | COLOUR                        | TEXT                 | RECL RATING          | STRUCT          | CONS                  | HECL RATING         | ROCKS (%)           | RECL RATING            |
|------|--|--|--|-------------------------------|----------------------|----------------------|-----------------|-----------------------|---------------------|---------------------|------------------------|
| 37   | Topography: Gently Sloping<br>Slope: 3%<br>Slope Position: Lower<br>Surface Stoniness: Moderately Stony<br>Drainage: Moderately Well to Imperfect<br>Parent Material: Colluvial/Glaciolacustrine<br>UTM Coordinates: E534253<br>N7154355 | Of<br>wavy<br>Cgy<br>wavy<br>Cz                    | 0 - 3<br>3 - 98<br>98 - 99+              | 10YR6/2<br>10YR6/2            | fSL<br>fSL           | good<br>good         | MA<br>MA        | MFR<br>frozen         | good<br>n/a         | 0<br>5<br>5         | good<br>good           |
| 38   | Topography: Gently Sloping<br>Slope: 2.5%<br>Slope Position: Middle<br>Surface Stoniness: Slightly Stony<br>Drainage: Imperfect<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E533917<br>N7154544                     | Of<br>wavy<br>Om<br>wavy<br>Cz                     | 0 - 15<br>15 - 43<br>43 - 99+            | 10YR6/2                       | fSL                  | good                 | MA              | frozen                | n/a                 | 0<br>0<br>5         | good                   |
| 39   | Topography: Gently Sloping<br>Slope: 3%<br>Slope Position: Lower<br>Surface Stoniness: Slightly Stony<br>Drainage: Moderately Well to Imperfect<br>Parent Material: Colluvial/Morainal<br>UTM Coordinates: E533475<br>N7154571           | Of<br>wavy<br>Bmy<br>irreg.<br>Cgy<br>irreg.<br>Cz | 0 - 14<br>14 - 22<br>22 - 68<br>68 - 99+ | 10YR5/3<br>10YR6/2<br>10YR6/2 | grSL<br>grSL<br>grSL | good<br>good<br>good | SGR<br>MA<br>MA | MVFR<br>MFR<br>frozen | good<br>good<br>n/a | 0<br>80<br>20<br>20 | unsuit<br>fair<br>fair |
| 40   | Topography: Gently Sloping<br>Slope: 4%<br>Slope Position: Middle<br>Surface Stoniness: Very Stony<br>Drainage: Moderately Well<br>Parent Material: Organic/Colluvial<br>UTM Coordinates: E533195<br>N7154265                            | Of<br>irreg.<br>Om<br>irreg.<br>Cy<br>wavy<br>Cz   | 0 - 10<br>10 - 18<br>18 - 68<br>68 - 99+ | 10YR5/3<br>10YR5/3            | grSL<br>grSL         | good<br>good         | MA<br>MA        | MFR<br>frozen         | good<br>n/a         | 0<br>0<br>40<br>40  | poor<br>poor           |

| SITE | LANDSCAPE  | HOR  | DEPTH (cm)                               | COLOUR                        | TEXT                 | RECL RATING          | STRUCT            | CONS               | RECL RATING         | ROCKS (%)           | RECL RATING            |
|------|--|--|--|-------------------------------|----------------------|----------------------|-------------------|--------------------|---------------------|---------------------|------------------------|
| 41   | Topography: Depressional<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Poor<br>Parent Material: Organic/Morainal<br>UTM Coordinates: E533410<br>N7153277         | Of<br>irreg.<br>Om<br>irreg.<br>Cz               | 0 - 13<br>13 - 45<br>45 - 99+            | 10YR4/3                       | grSL                 | good                 | MA                | frozen             | n/a                 | 0<br>0<br>20        | fair                   |
| 42   | Topography: Level<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Nonstony<br>Drainage: Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E534116<br>N7153338              | Of<br>wavy<br>Om<br>irreg.<br>Cz                 | 0 - 17<br>17 - 38<br>38 - 99+            | 10YR4/3                       | fSL                  | good                 | MA                | frozen             | n/a                 | 0<br>0<br>5         | good                   |
| 43   | Topography: Depressional<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E534207<br>N7153351 | Of<br>irreg.<br>Om<br>irreg.<br>Cy<br>wavy<br>Cz | 0 - 13<br>13 - 29<br>29 - 68<br>68 - 99+ | 7.5YR4/2<br>7.5YR4/2          | fSL<br>fSL           | good<br>good         | MA<br>MA          | MFR<br>frozen      | n/a                 | 0<br>0<br>5<br>5    | good<br>good           |
| 44   | Topography: Strongly Sloping<br>Slope: 15%<br>Slope Position: Middle<br>Surface Stoniness: Very Stony<br>Drainage: Well<br>Parent Material: Colluvial/Morainal<br>UTM Coordinates: E534924<br>N7153054   | Of<br>wavy<br>Bmy<br>wavy<br>Cy<br>wavy<br>Cz    | 0 - 9<br>9 - 22<br>22 - 59<br>59 - 99+   | 10YR4/3<br>10YR5/3<br>10YR5/3 | grSL<br>grLS<br>grLS | good<br>poor<br>poor | SGR<br>SGR<br>SGR | DS<br>ML<br>frozen | good<br>fair<br>n/a | 0<br>80<br>40<br>40 | unsuit<br>poor<br>poor |

| SITE | LANDSCAPE  | HOR  | DEPTH (cm)  | COLOUR                        | TEXT            | NECL RATING          | STRUCT            | CONS                  | HEEL RATING         | ROCKS (%)             | HEEL RATING                          |
|------|--|--|---|-------------------------------|-----------------|----------------------|-------------------|-----------------------|---------------------|-----------------------|--------------------------------------|
| 45   | Topography: Very Gently Sloping<br>Slope: 2%<br>Slope Position: Upper<br>Surface Stoniness: Nonstony<br>Drainage: Imperfect<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E535308<br>N7152559 | Of<br>wavy<br>Om<br>wavy<br>Bmy<br>wavy<br>Cgy<br>wavy<br>Cz     | 0 - 10<br>10 - 19<br>19 - 26<br>26 - 58<br>58 - 99+ | 10YR4/4<br>10YR6/2<br>10YR6/2 | LS<br>LS<br>LS  | poor<br>poor<br>poor | SGR<br>SGR<br>SGR | MVFR<br>WSS<br>frozen | good<br>good<br>n/a | 0<br>0<br>0<br>0<br>0 | good<br>good<br>good                 |
| 46   | Topography: Depressional<br>Slope: 0%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Very Poor<br>Parent Material: Organic/Glaciolacustrine<br>UTM Coordinates: E535921<br>N7151929    | Of<br>irreg.<br>Om<br>wavy<br>Cg<br>wavy<br>Cz                   | 0 - 12<br>12 - 35<br>35 - 58<br>58 - 99+            | 10YR5/2<br>10YR5/2            | SL<br>SL        | good<br>good         | MA<br>MA          | WSS<br>frozen         | good<br>n/a         | 5<br>5                | good<br>good                         |
| 47   | Topography: Very Gently Sloping<br>Slope: 1%<br>Slope Position: n/a<br>Surface Stoniness: Slightly Stony<br>Drainage: Imperfect<br>Parent Material: Glaciolacustrine<br>UTM Coordinates: E535521<br>N7151989     | Of<br>irreg.<br>Om<br>irreg.<br>Bmy<br>wavy<br>Cgy<br>wavy<br>Cz | 0 - 7<br>7 - 14<br>14 - 30<br>30 - 90<br>90 - 99+   | 10YR4/4<br>10YR6/2<br>10YR6/2 | S<br>fLS<br>fLS | poor<br>fair<br>fair | SGR<br>SGR<br>SGR | ML<br>ML<br>frozen    | fair<br>fair<br>n/a | 0<br>0<br>5<br>5<br>5 | good<br>good<br>good<br>good<br>good |

**TABLE 1 LEGEND:**

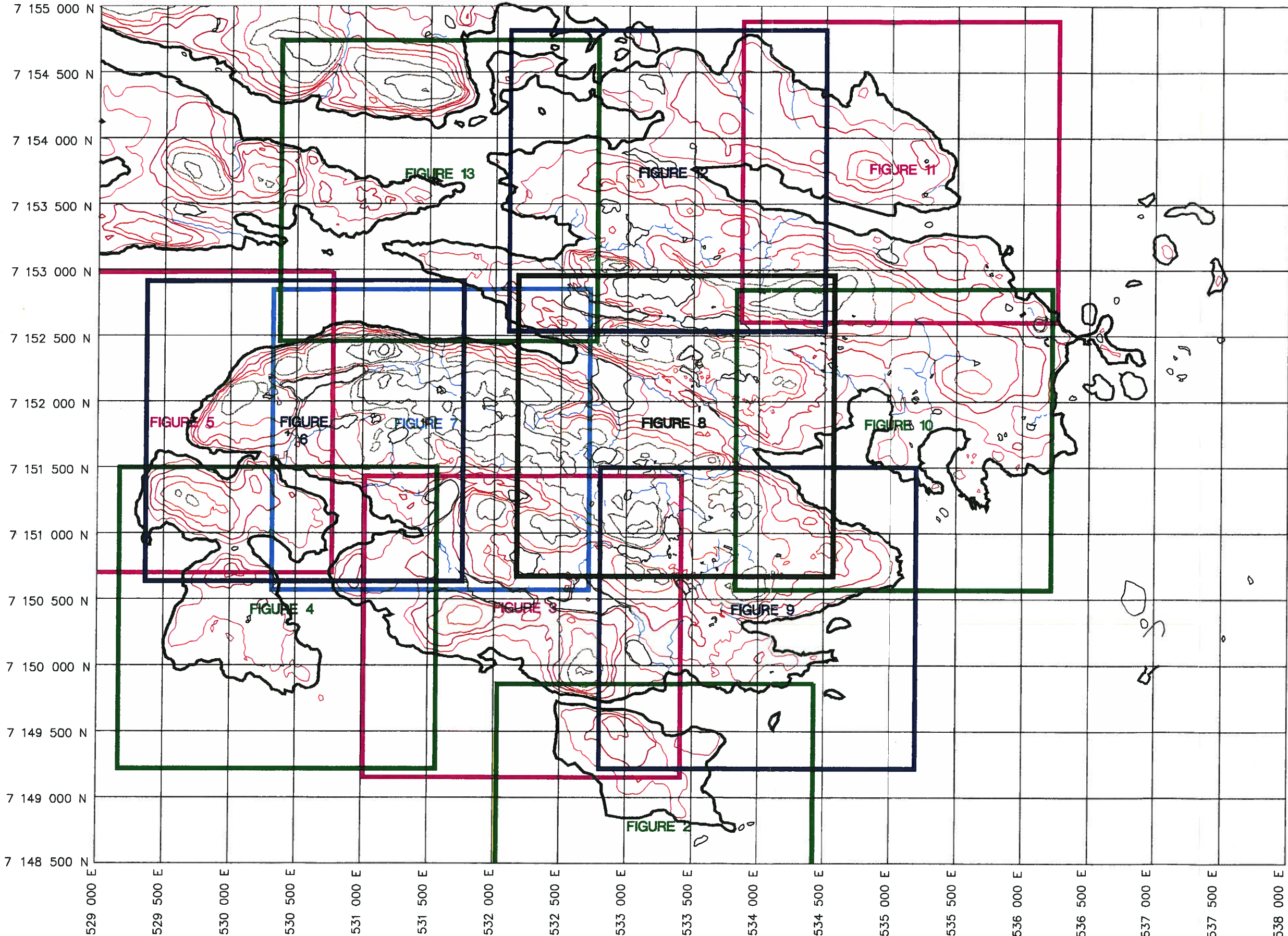
| <u>Texture</u> |                     | <u>Structure</u> |                | <u>Consistence</u> |                     |
|----------------|---------------------|------------------|----------------|--------------------|---------------------|
| SL             | sandy loam          | GR               | granular       | MVFR               | moist very friable  |
| fSL            | fine sandy loam     | SGR              | single grained | MFR                | moist friable       |
| grSL           | gravelly sandy loam | MA               | massive        | ML                 | moist loose         |
| SiL            | silt loam           |                  |                | DS                 | dry soft            |
| grSiL          | gravelly silt loam  |                  |                | DL                 | dry loose           |
| LS             | loamy sand          |                  |                | WNS                | wet nonsticky       |
| grLS           | gravelly loamy sand |                  |                | WSS                | wet slightly sticky |
| L              | loam                |                  |                |                    |                     |
| S              | sand                |                  |                |                    |                     |
| grS            | gravelly sand       |                  |                |                    |                     |
| fS             | fine sand           |                  |                |                    |                     |

**Reclamation Ratings**

|                      |            |   |
|----------------------|------------|---|
| <b>Texture</b>       | Good       | fine Sandy Loam, very fine Sandy Loam, Loam, Silty Loam, Sandy Loam |
|                      | Fair       | Clay Loam, Sandy Clay Loam, Silty Clay Loam                         |
|                      | Poor       | Sand, Loamy Sand, Silty Clay, Clay, Heavy Clay                      |
|                      | Unsuitable | Bedrock   |
| <b>Consistence</b>   | Good       | Very Friable, Friable   |
|                      | Fair       | Loose, Firm   |
|                      | Poor       | Very Firm   |
|                      | Unsuitable | Extremely Firm  |
| <b>Stone Content</b> | Good       | <11%  |
|                      | Fair       | 11 to 30%   |
|                      | Poor       | 31 to 60%   |
|                      | Unsuitable | >60%  |

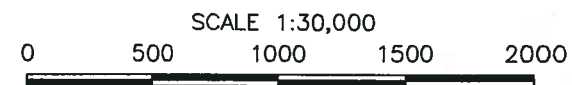
## FIGURES





**LEGEND**

- CONTOUR ELEVATION 420m
- CONTOUR ELEVATION 425m
- CONTOUR ELEVATION 430m
- CONTOUR ELEVATION 435m
- CONTOUR ELEVATION 440m
- CONTOUR ELEVATION 445m
- CONTOUR ELEVATION 450m
- CONTOUR ELEVATION 455m
- CONTOUR ELEVATION 460m
- CONTOUR ELEVATION 465m



|    |        |          |  |  |    |      |
|----|--------|----------|--|--|----|------|
| A  | 97/X/X | X        |  |  | X  | X    |
| NO | DATE   | REVISION |  |  | BY | CHK. |

**DIAMOND MINES INC.** 

**SURFICIAL MATERIALS  
EAST ISLAND**

|           |           |            |                              |              |          |
|-----------|-----------|------------|------------------------------|--------------|----------|
| DRAWN:    | RFM       | DATE:      | 17 JAN 97                    | SCALE:       | AS SHOWN |
| CHECKED:  | TB        | ACAD FILE: |                              | DRAWING No.: | REV      |
| REVIEWED: | <b>TB</b> | FILE:      | \\1995\2309\5551\FIGLOC5.dwg | <b>1</b>     | <b>A</b> |





G9508039-11-17



**LEGEND**

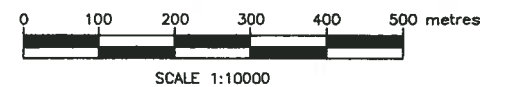
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gi Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 2  
REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR  
PHOTO G9508039-11-17  
ORIGINAL SCALE 1:10,000



|    |        |          |  |    |      |
|----|--------|----------|--|----|------|
| A  | 97/X/X | X        |  | X  | X    |
| NO | DATE   | REVISION |  | BY | CHK. |

**DIAMOND  
MINES INC.**



**SURFICIAL MATERIALS  
EAST ISLAND**

|          |     |                             |           |             |          |
|----------|-----|-----------------------------|-----------|-------------|----------|
| DRAWN    | RFM | DATE                        | 17 JAN 97 | SCALE       | AS SHOWN |
| CHECKED  | TB  | ACAD FILE                   |           | DRAWING No. | REV      |
| REVIEWED | TB  | d:\1996\2309\5551\SURF1.dwg |           | 2           | A        |





**LEGEND**

P31 Photo Location and Direction

- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gl Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 3 REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-10-211 ORIGINAL SCALE 1:10,000



SCALE 1:10000

G9508038-10-211

|  |        |            |                             |             |          |      |          |
|--|--------|------------|-----------------------------|-------------|----------|------|----------|
|  |        |            |                             |             |          |      |          |
| A  | 97/X/X | X          |                             |             | X        | X    |          |
| NO   | DATE   | REVISION   |                             |             | BY       | CHK. |          |
| <b>DIAMOND MINES INC.</b>                  |        |            |                             |             |          |      |          |
| <b>SURFICIAL MATERIALS<br/>EAST ISLAND</b> |        |            |                             |             |          |      |          |
| DRAWN:                                     | RFM    | DATE:      | 17 JAN 97                   | SCALE:      | AS SHOWN |      |          |
| CHECKED:                                   | TB     | ACAD FILE: |                             | DRAWING No. |          | REV  |          |
| REVIEWED:                                  | TB     | FILE:      | z:\1996\2309\5551\SURFI.dwg |             | <b>3</b> |      | <b>A</b> |





G9508038-10-209

**LEGEND**

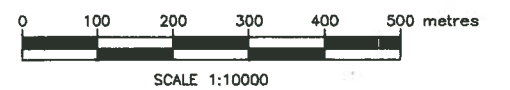
- P1 Photo Location and Direction
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- GI Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 4 REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-10-209 ORIGINAL SCALE 1:10,000



|  |      |             |                             |
|--|------|-------------|-----------------------------|
| A 97/X/X                               |      | X           | X                           |
| NO                                     | DATE | REVISION    | BY                          |
| <b>DIAMOND MINES INC.</b>              |      |             |                             |
| <b>SURFICIAL MATERIALS EAST ISLAND</b> |      |             |                             |
| DRAWN:                                 | RFM  | DATE:       | 17 JAN 97                   |
| CHECKED:                               | TB   | SCALE:      | AS SHOWN                    |
| REVIEWED:                              | TB   | ACAD FILE:  | d:\1996\2309\5551\SURF1.dwg |
|  |      | DRAWING No. | 4                           |
|  |      | REV         | A                           |





G9508038-9-160

**LEGEND**

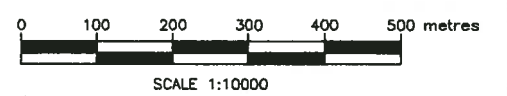
- Photo Location and Direction
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gl Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 5 REFER TO FIGURE 1.

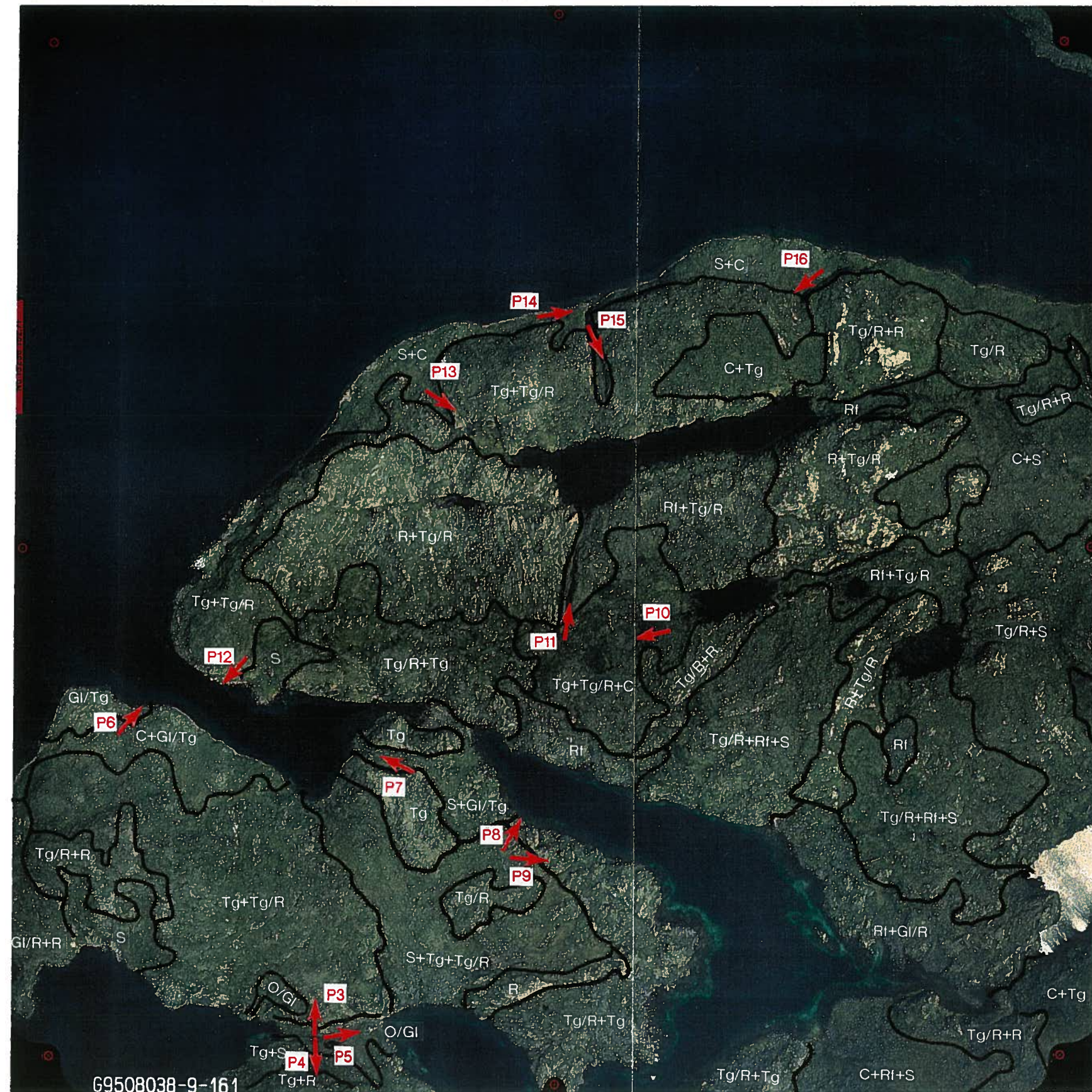
**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-9-160 ORIGINAL SCALE 1:10,000



|  |      |                            |           |                 |
|--|------|----------------------------|-----------|-----------------|
| A 97/X/X                               |      | X                          | X         | X               |
| NO                                     | DATE | REVISION                   | BY        | CHK.            |
| <b>DIAMOND MINES INC.</b>              |      |                            |           |                 |
| <b>SURFICIAL MATERIALS EAST ISLAND</b> |      |                            |           |                 |
| DRAWN                                  | RFM  | DATE                       | 17 JAN 97 | SCALE: AS SHOWN |
| CHECKED                                | TB   | ACAD FILE                  |           | DRAWING No.     |
| REVIEWED                               | TB   | Δ 1996/2201/5551/SURF1.dwg |           | 5               |
|  |      |                            |           | REV             |
|  |      |                            |           | A               |





**LEGEND**

P12 Photo Location and Direction

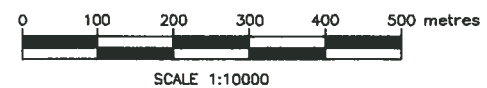
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gl Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 6 REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-9-161 ORIGINAL SCALE 1:10,000



|    |        |          |    |      |
|----|--------|----------|----|------|
| NO | DATE   | REVISION | BY | CHK. |
| A  | 97/x/x | x        | x  | x    |

**DAVIK DIAMOND MINES INC.**



**SURFICIAL MATERIALS EAST ISLAND**

|          |           |                             |           |             |          |
|----------|-----------|-----------------------------|-----------|-------------|----------|
| DRAWN    | RFM       | DATE                        | 17 JAN 97 | SCALE       | AS SHOWN |
| CHECKED  | TB        | ACAD FILE                   |           | DRAWING No. | REV      |
| REVIEWED | <b>TB</b> | d:\1996\2309\5551\SURF1.dwg |           | <b>6</b>    | <b>A</b> |

G9508038-9-161





**LEGEND**

P17 Photo Location and Direction

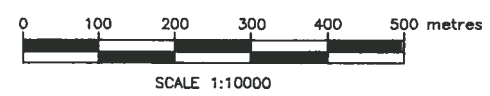
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gl Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 7 REFER TO FIGURE 1.

**REFERENCE**

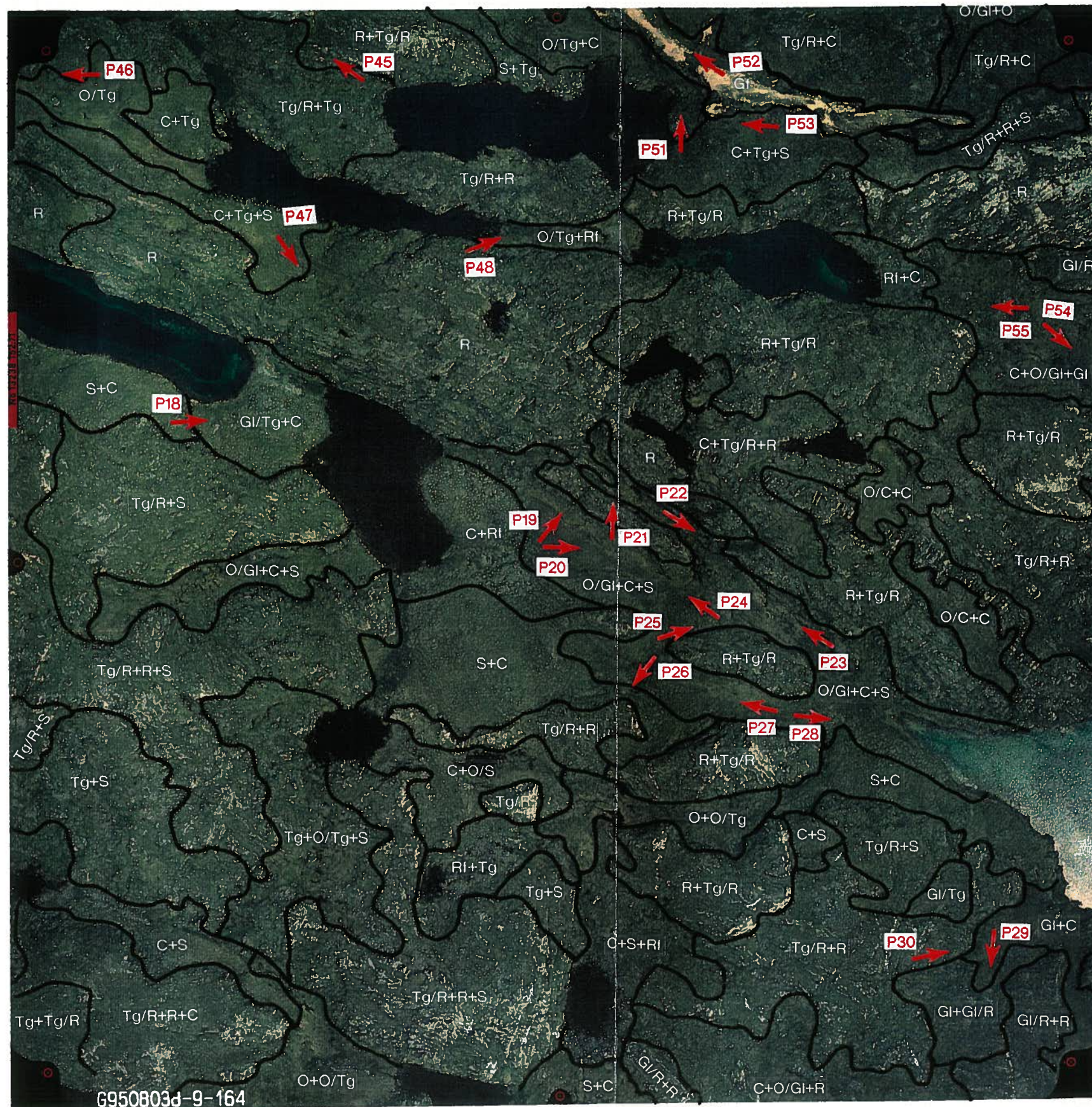
GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-9-162 ORIGINAL SCALE 1:10,000



G9508038-9-162

|   |   |                                  |         |
|---|---|----------------------------------|---------|
| A 97/X/X X                                |   | X                                | X       |
| NO  | DATE  | REVISION                         | BY CHK. |
| <b>DIAMOND MINES INC.</b>                 |   |                                  |         |
| <b>SURFICIAL MATERIALS EAST ISLAND</b>    |   |                                  |         |
| DRAWN: RFM<br>CHECKED: TB<br>REVIEWED: TB | DATE: 17 JAN 97<br>ACAD FILE: \\1996\2309\555\9URF1.dwg | SCALE: AS SHOWN<br>DRAWING No. 7 | REV A   |





**LEGEND**

P20 Photo Location and Direction

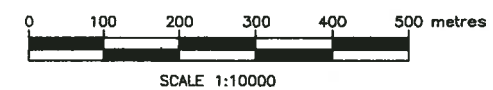
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- GI Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 8 REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-9-164 ORIGINAL SCALE 1:10,000



|    |        |          |    |      |   |   |
|----|--------|----------|----|------|---|---|
| A  | 97/X/X | X        |    |      | X | X |
| NO | DATE   | REVISION | BY | CHK. |   |   |

DAVIK DIAMOND MINES INC.



**SURFICIAL MATERIALS EAST ISLAND**

|              |                           |                 |
|--------------|---------------------------|-----------------|
| DRAWN: RFM   | DATE: 17 JAN 97           | SCALE: AS SHOWN |
| CHECKED: TB  | ACAD FILE:                | DRAWING No. 8   |
| REVIEWED: TB | \\1998\2309\555\SURF1.dwg | REV A           |





G9508038-10-213



**LEGEND**

P32 Photo Location and Direction

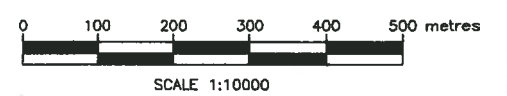
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- GI Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 9 REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-10-213 ORIGINAL SCALE 1:10,000



|    |        |          |  |    |      |  |  |   |   |
|----|--------|----------|--|----|------|--|--|---|---|
|    |        |          |  |    |      |  |  |   |   |
| A  | 97/X/X | X        |  |    |      |  |  | X | X |
| NO | DATE   | REVISION |  | BY | CHK. |  |  |   |   |

|                                  |  |
|----------------------------------|--|
| <p><b>DIAMOND MINES INC.</b></p> |  |
|----------------------------------|--|

**SURFICIAL MATERIALS EAST ISLAND**

|                     |                              |                 |          |  |
|---------------------|------------------------------|-----------------|----------|--|
| DRAWN: RFM          | DATE: 17 JAN 97              | SCALE: AS SHOWN |          |  |
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**LEGEND**

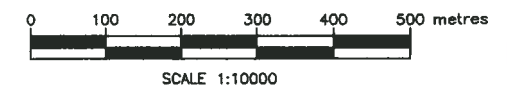
- ➔ P59 Photo Location and Direction
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gl Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 10 REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-9-166 ORIGINAL SCALE 1:10,000



G9508038-9-166

|  |      |                             |                      |
|--|------|-----------------------------|----------------------|
| A 97/X/X                               |      | X                           | X                    |
| NO                                     | DATE | REVISION                    | BY CHK.              |
| <b>DIAMIK DIAMOND MINES INC.</b>       |      |                             |                      |
| <b>SURFICIAL MATERIALS EAST ISLAND</b> |      |                             |                      |
| DRAWN:                                 | RFM  | DATE: 17 JAN 97             | SCALE: AS SHOWN      |
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| REVIEWED:                              | TB   | J:\1996\2309\5551\SURFL.dwg |                      |





**LEGEND**

P78 Photo Location and Direction

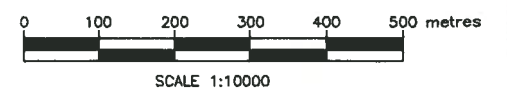
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gl Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 11 REFER TO FIGURE 1.

**REFERENCE**

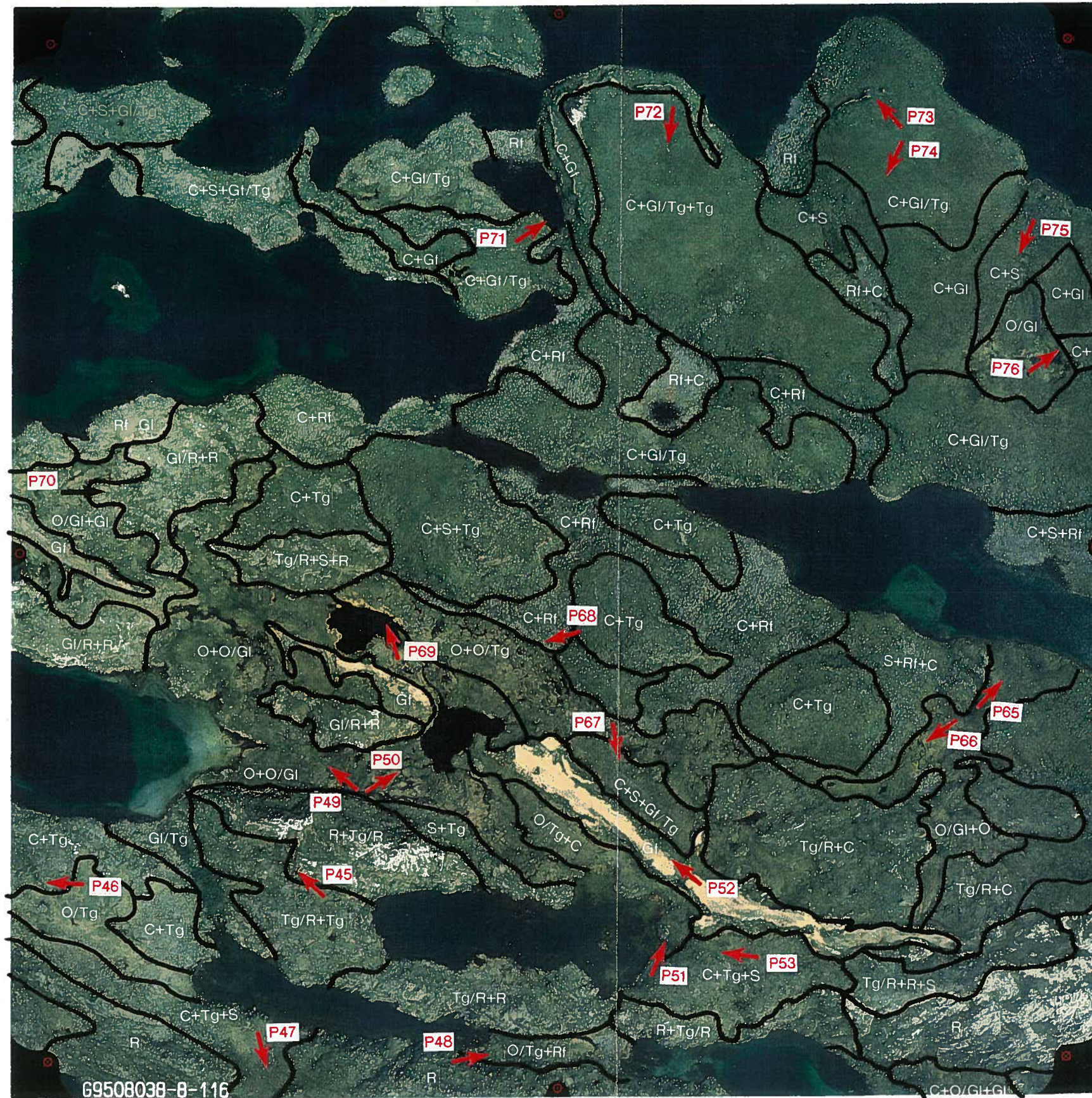
GEOGRAPHIC AIR SURVEY LTD. AIR PHOTO G9508038-8-118 ORIGINAL SCALE 1:10,000



G9508038-8-118

|  |           |                            |           |             |          |     |      |
|--|-----------|----------------------------|-----------|-------------|----------|-----|------|
|  |           |                            |           |             |          |     |      |
| A                                      | 97/X/X    | X                          |           |             |          | X   | X    |
| NO                                     | DATE      | REVISION                   |           |             |          | BY  | CHK. |
| <b>DIAVIK DIAMOND MINES INC.</b>       |           |                            |           |             |          |     |      |
| <b>SURFICIAL MATERIALS EAST ISLAND</b> |           |                            |           |             |          |     |      |
| DRAWN:                                 | RFM       | DATE:                      | 17 JAN 97 | SCALE:      | AS SHOWN |     |      |
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| REVIEWED:                              | <b>TB</b> | d:\1996\2309\555\SURF1.dwg |           |             |          |     |      |





**LEGEND**

P74 Photo Location and Direction

- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- Gf Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 12  
REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR  
PHOTO G9508038-8-116  
ORIGINAL SCALE 1:10,000



G9508038-8-116

|  |                 |
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|  |                 |
| <b>SURFICIAL MATERIALS<br/>EAST ISLAND</b> |                 |
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**LEGEND**

P70 Photo Location and Direction

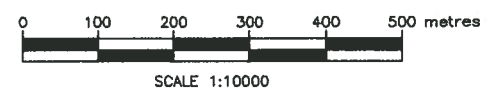
- R Bedrock
- Rf Felsenmeer
- Tg Glacial Till
- GI Glaciolacustrine
- Gf Glaciofluvial
- O Organic
- S Solifluction
- C Cryoturbation

**NOTE**

FOR LOCATION OF FIGURE 13  
REFER TO FIGURE 1.

**REFERENCE**

GEOGRAPHIC AIR SURVEY LTD. AIR  
PHOTO G9508038-8-114  
ORIGINAL SCALE 1:10,000



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| NO | DATE   | REVISION | BY | CHK. |   |   |

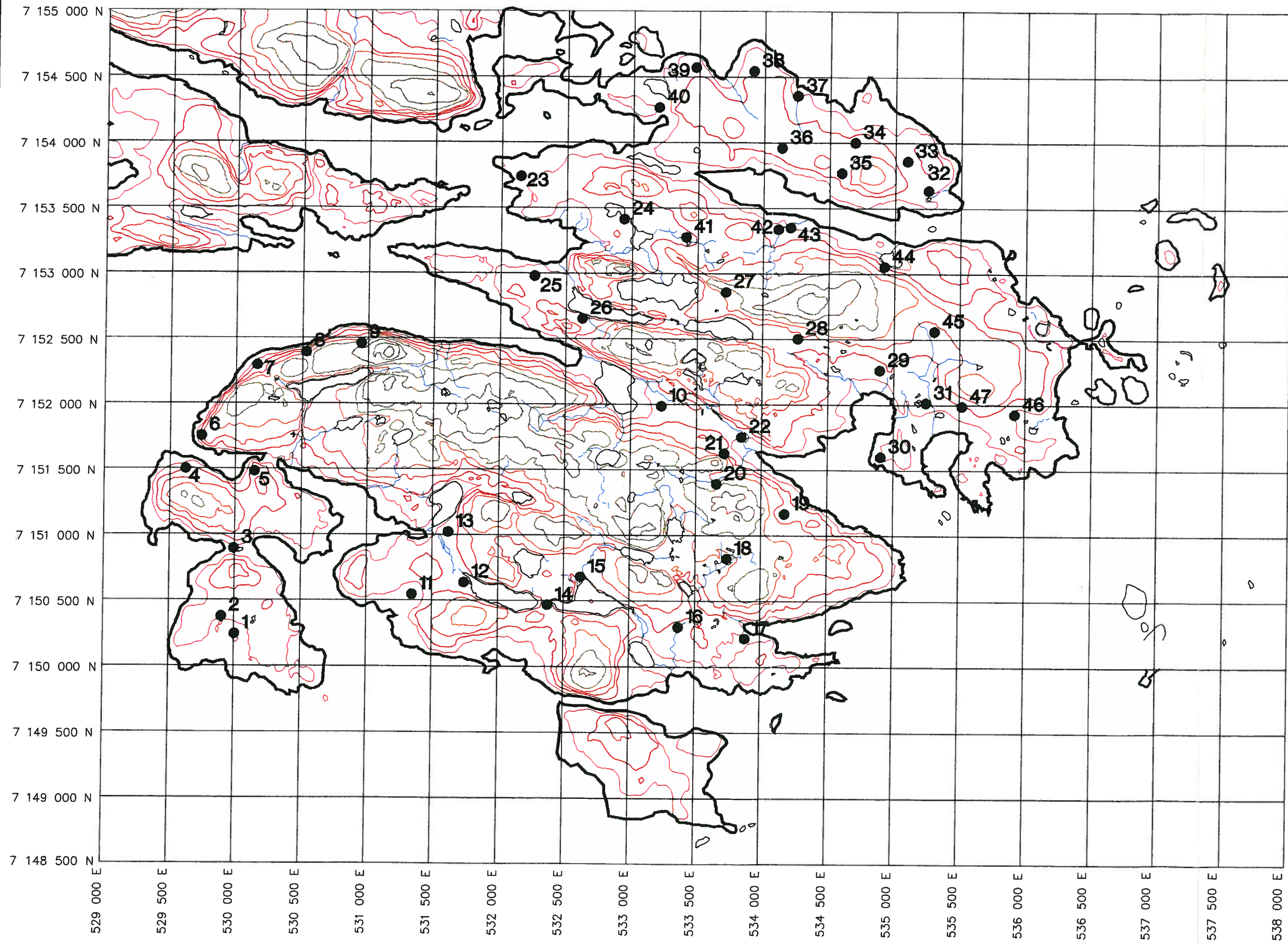
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| <b>DIAMOND<br/>MINES INC.</b> | <br><b>Golder<br/>Associates</b> |
|-------------------------------|----------------------------------|

**SURFICIAL MATERIALS  
EAST ISLAND**

|                     |                             |                 |
|---------------------|-----------------------------|-----------------|
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| REVIEWED: <b>TB</b> | J:\1996\2309\5551\SURF1.dwg | REV A           |

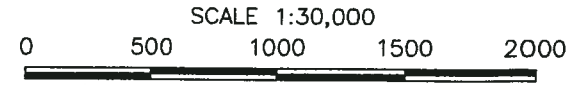
G9508038-8-114





**LEGEND**

- 11 SOIL INSPECTION SITE
- CONTOUR ELEVATION 420m
- CONTOUR ELEVATION 425m
- CONTOUR ELEVATION 430m
- CONTOUR ELEVATION 435m
- CONTOUR ELEVATION 440m
- CONTOUR ELEVATION 445m
- CONTOUR ELEVATION 450m
- CONTOUR ELEVATION 455m
- CONTOUR ELEVATION 460m
- CONTOUR ELEVATION 465m



|    |        |          |  |  |    |     |
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| A  | 97/x/x | X        |  |  | X  | X   |
| NO | DATE   | REVISION |  |  | BY | CHK |

**DIAMOND MINES INC.**

**SOIL INSPECTION SITES  
EAST ISLAND**

|              |                                |                 |
|--------------|--------------------------------|-----------------|
| DRAWN: RFM   | DATE: 17 JAN 97                | SCALE: AS SHOWN |
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| REVIEWED: TB | \\1996\2309\5551\SOIL.PLOT.dwg | 14 A            |

# PLATES





Plate 1 Looking north from Soil Inspection Site #1. Organic over glaciolacustrine in the foreground, and glacial till and glacial till over bedrock in the background.



Plate 2 Looking north-west from Soil Inspection Site #2. Organic over glaciolacustrine in foreground and extending to lake, and glacial till on each side of photo.





Plate 3 Looking north from Soil Inspection Site #3. Organic over glaciolacustrine in foreground, and very stony glacial till over bedrock in background. Note vegetation in areas protected from the wind on leeward slope, and where snow would accumulate.



Plate 4 Looking south from Soil Inspection Site #3. Very stony glacial till, with some areas of exposed bedrock.





Plate 5 Looking east from Soil Inspection Site #3. Organic over glaciolacustrine. These types of areas are the best source of materials for reclamation.



Plate 6 Looking north-east from Soil Inspection Site #4. Glaciolacustrine over glacial till in foreground, and glacial till and bedrock in background. Note frost boils in foreground. These features provide a good source of materials for reclamation.





Plate 7 Looking north-west towards Soil Inspection Site #5. Glaciolacustrine over glacial till in middle of photo, and very stony glacial till in foreground and background.



Plate 8 Looking north-east at a south aspect (leeward) slope. Shrubs are protected from the wind. Frost boils (foreground) provide a good source of reclamation materials.





Plate 9 Looking east at an area of extensive frost boiling and solifluction. These materials should be salvaged and stockpiled for later use during reclamation.



Plate 10 Looking west from small inland lake at an area of frost boiling. These areas are valuable sources for reclamation materials and should be selectively salvaged prior to stockpiling of the granite.





Plate 11 Looking north at a narrow canyon. The reclamation of the granite stockpile should include features such as this to add diversity to the landscape, as well as promoting proper surface drainage.



Plate 12 Looking south-west towards Soil Inspection Site #4. Note lower density of surface stones on lower slope (glaciolacustrine) compared to upper slope and foreground of photo (glacial till).





Plate 13 Looking south-south-east from Soil Inspection Site #7. The soils are frost boiled (cryoturbated) and slowly moving downslope (soliflucted). These types of materials should be salvaged for reclamation purposes.



Plate 14 Looking east towards Soil Inspection Site #8. Toe of solifluction lobe.





Plate 15 Looking south-south-east from Soil Inspection Site #8 (toe of solifluction lobe). These materials should be salvaged for reclamation purposes prior to stockpiling of the granite.



Plate 16 Looking south-south-west towards Soil Inspection Site #9. This is a relatively recent solifluction lobe, judging from the lack of vegetation cover. This is a good source of reclamation material.





Plate 17 Looking south from shore of lake inlet. Most of the material is moving slowly downslope (solifluction), with some frost boils (foreground).



Plate 18 Looking east at glaciolacustrine deposit at end of lake inlet. This material should be selectively removed for use during reclamation. Bedrock ridge in background.





Plate 19 Looking north-north-east from Soil Inspection Site #10. Organic over glaciolacustrine, with some frost boils. This is the best type of material for reclamation, since it contains organic material and moderately fine-textured mineral material.



Plate 20 Looking east-south-east from Soil Inspection Site #10. This is an extensive deposit of organic over glaciolacustrine material.





Plate 21 Looking north from a bedrock ridge at an organic over glaciolacustrine deposit. This material is of value for reclamation.



Plate 22 Looking south-east at an extensive deposit of organic over glaciolacustrine. A lot of the area is frost boiled.





Plate 23 Looking west-north-west from Soil Inspection Site #22 at an extensive deposit of organic over glaciolacustrine. The organics are between 20 to 40 cm thick in this area.



Plate 24 Looking west-north-west from Soil Inspection Site #21 at an extensive glaciolacustrine deposit. These deposits have been extensively frost boiled.





Plate 25 Looking east-north-east down a frost boiled, soliflucted slope towards Soil Inspection Site #21. Bedrock and very stony glacial till over bedrock in background.



Plate 26 Looking south-west at an organic over glaciolacustrine deposit. Bedrock ridge in background.





Plate 27 Looking west from Soil Inspection Site #20. Organic over frost boiled glaciolacustrine material. This material should be salvaged prior to stockpiling the granite, so as not to sterilise this valuable reclamation material.



Plate 28 Looking east from Soil Inspection Site #20. Organic over glaciolacustrine material right to shore of lake. Glacial till over bedrock in background. Note camp on horizon.





Plate 29 Looking south from Soil Inspection Site #19. Primarily frost boiled glaciolacustrine material. These types of areas are important sources for reclamation materials.



Plate 30 Looking east-north-east toward Soil Inspection Site #19. Glaciolacustrine over glacial till in foreground and glaciolacustrine in middle of photo. Note camp on horizon.





Plate 31 Looking south from Soil Inspection Site #18. Frost boiled glaciolacustrine material in foreground, and glacial till over bedrock in background.



Plate 32 Looking west-north-west from Soil Inspection Site #17. Glaciolacustrine in foreground, and bedrock ridge in background.





Plate 33 Looking east-north-east from Soil Inspection Site #16. Glaciolacustrine and organic over glaciolacustrine deposits. Most of this area is frost boiled. Bedrock ridge in background.



Plate 34 Looking south-east from Soil Inspection Site #16. The frost boiled glaciolacustrine material should be salvaged prior to granite stockpiling, for later use during reclamation.





Plate 35 Looking south-west from Soil Inspection Site #16. Frost boiled glaciolacustrine material in foreground, and bedrock ridge in right background. Note solifluction lobes on ridge.



Plate 36 Looking south-east across small creek at organic area. Surface drainage channels, similar to this one, will need to be established on the reclaimed surface.





Plate 37 Looking north-east towards Soil Inspection Site #15. Organic over glacial till deposit. These materials should be salvaged prior to granite stockpiling, for later use during reclamation. Bedrock ridge in background.



Plate 38 Looking north-west at a small organic deposit. Even these small deposits should be salvaged prior to granite stockpiling, so as not to sterilise them from use during reclamation.





Plate 39 Looking south-west from Soil Inspection Site #14. Mainly frost boiled glacial till in this area. Even though the material has numerous stones (40%) throughout the profile, it may still be worth salvaging for reclamation.



Plate 40 Looking west-south-west at organic area (light green tone). Bedrock in immediate foreground, and glacial till over bedrock in foreground to shore of lake.





Plate 41 Looking south-east (upslope) from Soil Inspection Site 13. Frost boiled glacial till. This material may have some value for reclamation.



Plate 42 Looking north-west from Soil Inspection Site #12. Organic and organic over glacial till deposits. This area is an important source of reclamation materials.





Plate 43 Looking east-north-east from Soil Inspection Site #11. Organic over glaciolacustrine deposits in foreground, and frost boiled glaciolacustrine deposits in background. Note absence of surface stones in glaciolacustrine deposit.



Plate 44 Looking south-west from Soil Inspection Site #11. These organic and glaciolacustrine materials are valuable for reclamation and should be salvaged prior to granite stockpiling.





Plate 45 Looking west-north-west toward Soil Inspection Site #25. Mainly glacial till, however, numerous small patches of organic over glacial till (light green areas). These small deposits should be selectively salvaged for later use during reclamation.



Plate 46 Looking west from Soil Inspection Site #25. Organic over glacial till. Most of the materials in these depressional areas are suitable for reclamation purposes.





Plate 47 Looking south-south-east from Soil Inspection Site #26. Frost boiled glaciolacustrine on lower slopes and frost boiled glacial till on upper slopes. The glaciolacustrine deposits are slightly stony to nonstony and are valuable reclamation materials.



Plate 48 Looking east-north-east at an organic over glacial till deposit between two inland lakes. Although small in area, it contains an abundant supply of good quality reclamation material.





Plate 49 Looking north-west from bedrock ridge at a large organic and glaciolacustrine deposit. This area is an important source of reclamation materials.



Plate 50 Looking northeast at a large organic and glaciolacustrine deposit. Note glaciofluvial feature (esker) in upper right of photo.





Plate 51 Looking north at a major glaciofluvial feature (esker). The esker is primarily sand and fine gravel and would be of limited use for reclamation.



Plate 52 Looking north-west from esker at a large organic and frost boiled deposit. These materials would be a valuable resource for reclamation.





Plate 53 Looking west from Soil Inspection Site #27. Primarily frost boiled glacial till.



Plate 54 Looking east-south-east from Soil Inspection Site #28. Organic over glaciolacustrine deposits. This is an excellent source of good quality reclamation materials.





Plate 55 Looking west from Soil Inspection Site #28 at organic over glaciolacustrine deposit.



Plate 56 Looking east-south-east at organic (light green tones), glaciolacustrine and glaciofluvial (light tan tones) deposits. This is an excellent source area for reclamation materials.





Plate 57 Looking east at organic (light green tones) and glaciolacustrine deposits. Note camp on horizon.



Plate 58 Looking north from Soil Inspection Site #29. This glaciolacustrine deposit is an excellent source of good quality reclamation material.





Plate 59 Looking north from Soil Inspection Site #31. Frost boiled glaciolacustrine material. This material could be used for reclamation. The surface organic layer is an important source of native seed and stolons.



Plate 60 Looking south-east toward Soil Inspection Site #46. The organic and glaciolacustrine deposits, and frost boiled materials in this area can be selectively salvaged from the stony glacial tills for use as reclamation materials.





Plate 61 Looking south from Soil Inspection Site #45. Frost boiled and soliflucted glaciolacustrine material. This slightly stony to nonstony material is very suitable for reclamation.



Plate 62 Looking north from Soil Inspection Site #45. Organic over glaciolacustrine in foreground, and frost boiled and soliflucted material in background.



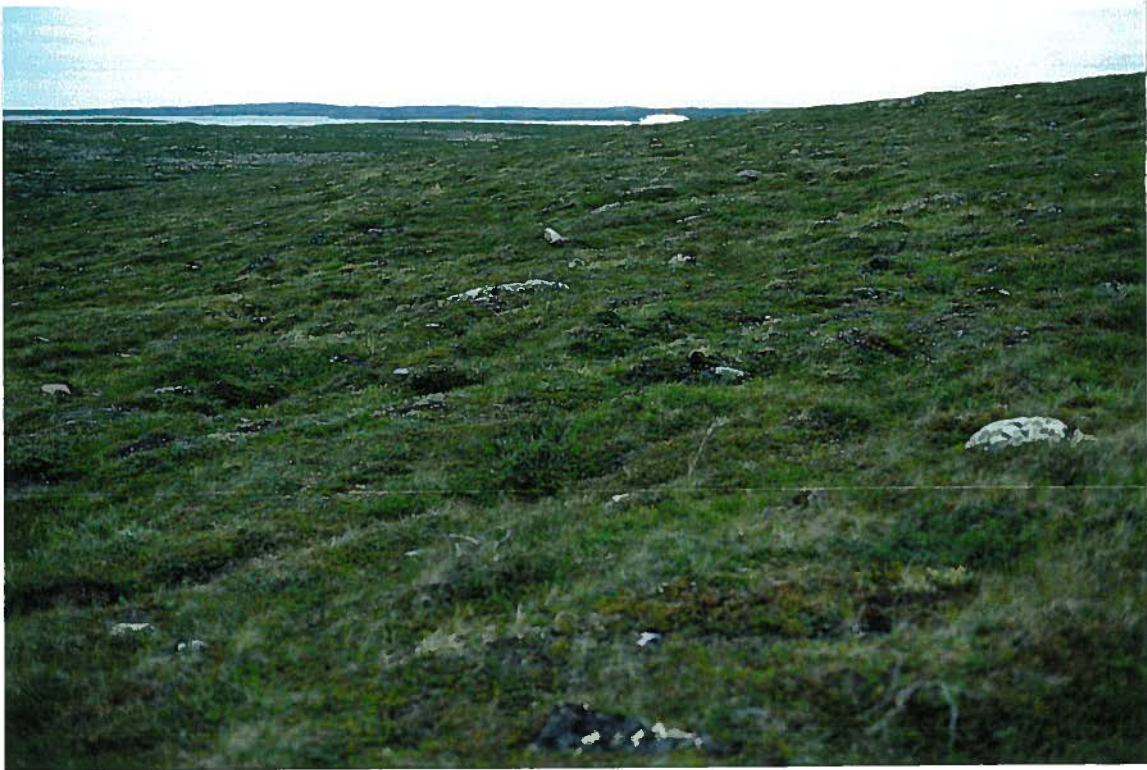


Plate 63 Looking east-south-east from Soil Inspection Site #44. Frosted boiled and soliflucted glacial till on this 15% slope. This material is of little to no value for reclamation.



Plate 64 Looking north-west at glaciolacustrine deposit (lower slope). This material is a valuable resource for reclamation.





Plate 65 Looking north-east from Soil Inspection Site #42. Organic over glaciolacustrine.



Plate 66 Looking south-west from Soil Inspection Site #42. Organic over glaciolacustrine.





Plate 67 Looking south-east from Soil Inspection Site #41. Organic and organic over glacial till. The organic materials should be salvaged from the stony glacial tills for use during reclamation. Note esker in background.



Plate 68 Looking west towards large organic deposit (light green tone). Note esker beyond organic deposit.





Plate 69 Looking north-north-west from Soil Inspection Site #24. Organic over glaciofluvial. The organic material contains a reserve of native seeds and stolons, and is therefore of value for reclamation.



Plate 70 Looking east from Soil Inspection Site #23. Organic over glaciolacustrine. These deposits are a valuable source for reclamation materials.





Plate 71 Looking north-east from Soil Inspection Site #40. Frost boiled glaciofluvial. This material is of limited value for reclamation.



Plate 72 Looking south-south-west from Soil Inspection Site #39. Frost boiled glaciolacustrine over glacial till on lower slopes and frost boiled glacial till on upper slopes. This material would be of limited value for reclamation.





Plate 73 Looking north-west from Soil Inspection Site #38. Knobs are part of an outwash (esker) complex. Organic over glaciolacustrine.



Plate 74 Looking south-south-west from Soil Inspection Site #38. Frost boiled glaciolacustrine on lower slopes, and frost boiled glacial till on upper slopes.





Plate 75 Looking south-south-west from Soil Inspection Site #37. Frost boiled glaciolacustrine on lower slopes and frost boiled glacial till on upper slopes.



Plate 76 Looking north-east from Soil Inspection Site #36. Organic and organic over glaciolacustrine. This area is a valuable source for reclamation materials.





Plate 77 Looking north-east from Soil Inspection Site #35. Frost boiled glacial till. This material is of limited value for reclamation.



Plate 78 Looking north from Soil Inspection Site #34. Organic over frost boiled glacial till. The organic material is of value for reclamation as it contains a reserve of native seeds and stolons.





Plate 79 Looking north-west from Soil Inspection Site #33. Organic over glaciofluvial.



Plate 80 Looking south from Soil Inspection Site #32. Frost boiled glacial till. This material is of limited value for reclamation.

**TP-8-11-0**

## **1. PURPOSE**

This technical procedure describes the methodology to be used for the investigation and sampling of surficial soils. Contained within are detailed investigation and sampling instructions.

## **2. APPLICABILITY**

This technical procedure is applicable to any person involved in the investigation and manual sampling of surficial soils.

## **3. DEFINITIONS**

### **3.1 Chain-of Custody Forms**

Standardised forms are used as a means of keeping close track of soil samples taken from the field and transported to laboratories for analysis. Whenever the samples are transported from the field, the custody is relinquished from the delivery person to the receiver by signatures on the forms. These forms substantially decrease the risk of losing samples because they provide a clear record of the chain of transport and handling of the samples.

### **3.2 Surficial Soil**

Refers to the unconsolidated material on the ground surface that serves as a natural medium for the growth of plants, and that has been subjected to or influenced by parent material, climate, macro and microorganisms, and topography over time producing a material that differs physically, chemically, biologically and morphologically from the material from which it was derived.

## **4. REFERENCES AND SUGGESTED READING**

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian System of Soil Classification. 2nd ed. Agric. Can. Publ. 1646. 164pp.



## **5. DISCUSSION**

### **5.1 General Safety**

Refer to Golder Associates Ltd. Safety Manual.

### **5.2 Methods**

Soils will be investigated based on a visual examination of excavated pits, with information gathered being recorded on Soil Inspection Sheets (see attached example). Certain soils are sampled from the various horizons identified during the soil investigation. Samples are taken using a shovel, trowel, or auger. Each sample is individually bagged and labeled to location and analysis to be performed. Each sample is also indicated on the appropriate soil inspection sheet as a cross reference.

### **5.3 Site Location**

Samples are taken from the various soil horizons exposed in the excavated pits used for soil characterisation. Sites will be pinpointed on air photos and maps in the field, and marked using the global positioning system.

### **5.4 Sample Handling**

Soil samples are placed in ziploc type plastic bags. The bagged soil samples are stored in cardboard boxes to protect the plastic bags from ripping during transport to the lab.

### **5.5 Cleaning Sampling Equipment**

The shovel, trowel, or auger used to take each sample is wiped clean of any soil residue after each sample is taken to minimise contamination of other samples.

## **5.6 Field Records and Logbook**

For proper interpretation of field survey results, thorough documentation of all field investigation and sample collection activities is required. All logbooks should be perfect-bound and waterproof, forms should be preprinted on waterproof paper, and only indelible ink and pencil (if form or paper is wet) should be used.

Characteristics of the soils being investigated are recorded on Soil Inspection Sheets (see attached example). Soil samples are also recorded on these sheets. Basic information from each site investigated or sampled, such as site number and GPS location, will be recorded in a logbook.

All pertinent information on field activities and sampling must be recorded in an appropriate (i.e. waterproof) bound logbook. The field crew leader is responsible for ensuring that sufficient detail is recorded in the logbook. The logbook must be complete enough to enable someone unfamiliar with the project to completely reconstruct field activity without relying on the memory of the field crew. All entries must be made in indelible ink, with each page numbered, signed and dated by the author, and a line drawn through the remainder of any partly used page. All corrections are made by a single-line cross-out of the error, entering the correct information, dating and initialing the change. Upon return to the office, all field notes must be photocopied and placed in the appropriate project files.

Entries in the field logbook must include:

- Purpose of proposed sampling effort
- Date and time (24 hour clock) of sampling
- Names of field crew leader and team members
- Description of each sampling site, including information on any photographs that may be taken.
- Location of each sampling site, name and number, applicable navigational coordinates, waterbody name/segment numbers.
- Details of sampling method and effort, particularly deviations from Specific Work Instructions.
- Clear identification of site names and sample numbers.
- Field observations.
- Field measurements taken ( recorded on Soil Inspection Sheets)

Sample shipping information.

The field logbook should also be used to document any additional information on sample collection activities or any unusual activities observed or problems encountered that would be useful to the project manager when evaluating the quality of the soil and terrain data.

To document field activities, sample identification labels, Chain-of-Custody forms, field logbooks, field record sheets (Appendix A) should be used. This will serve as an overall "Chain-of-Custody" documenting all field samples and field events beginning with sample collection through, preservation and shipment to the laboratory.

## **6. EQUIPMENT**

### **6.1 Sampling and Investigation Equipment**

Soils will be investigated and sampled with a shovel, trowel and auger.

### **6.2 Field Location Equipment and Logs**

The following pieces of equipment are required to properly investigate and sample soils.

- perfect bound, water-proof field logbook
- soil inspection sheets (sample attached)
- maps and aerial photographs of the site
- indelible ink pens and felt tip markers, and pencils
- munsell colour chart
- 12 metre tape measure
- bottle of clean water
- bottle of 10% hydrochloric acid
- clean rags
- clinometre

- compass
- shovel
- trowel
- soil auger
- penetrometer
- plastic ziploc type storage bags
- pH meter
- metre wheel



**SWI-150**

## SOIL INSPECTION SHEET

### Diavik Diamond Mines Inc. Project

Project # 962-2309 (Task 5551) SITE \_\_\_\_\_

Inspectors: \_\_\_\_\_ GPS # \_\_\_\_\_

Inspection Date: \_\_\_\_\_ (day), \_\_\_\_\_ (month), \_\_\_\_\_ (year)

Inspection Time: \_\_\_\_\_ (24 hour clock)

Slope: \_\_\_\_\_ Aspect: \_\_\_\_\_ Topography: \_\_\_\_\_

Drainage: \_\_\_\_\_ Surface Stoniness: \_\_\_\_\_

Slope Position: \_\_\_\_\_ Parent Material: \_\_\_\_\_

| HORIZON | DEPTH<br>(cm) | BDY | COLOUR | TEXTURE | STRUCTURE | STONES<br>(%) | CONS | EFF | SAMPLE<br># |
|---------|---------------|-----|--------|---------|-----------|---------------|------|-----|-------------|
|         | -             |     |        |         |           |               |      |     |             |
|         | -             |     |        |         |           |               |      |     |             |
|         | -             |     |        |         |           |               |      |     |             |
|         | -             |     |        |         |           |               |      |     |             |
|         | -             |     |        |         |           |               |      |     |             |

### NOTES

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Photographs: Numbers \_\_\_\_\_ Roll \_\_\_\_\_

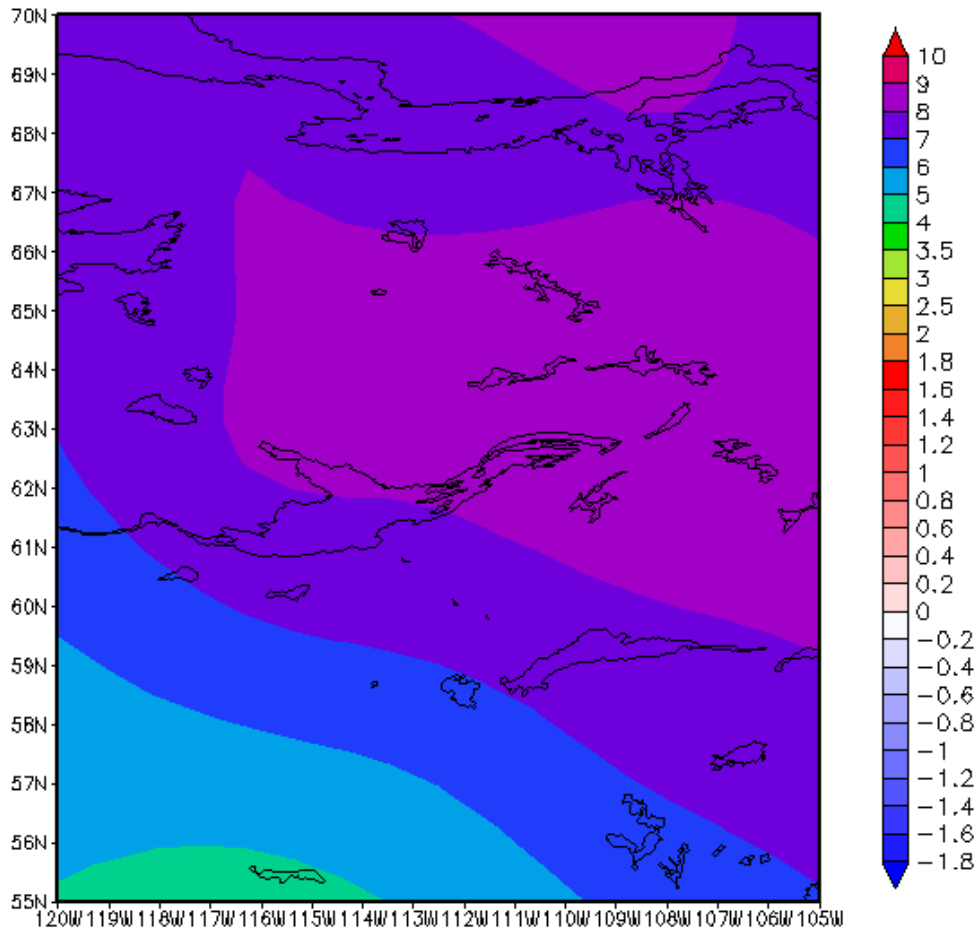
## SPECIFIC WORK INSTRUCTIONS

|   |  |                                    |  |
|---|--|------------------------------------|--|
| <b>SPECIFIC WORK INSTRUCTIONS</b>   |  | <b>SWI No.: SWI-15.0</b>           |  |
| <b>Project:</b> Diavik Dimond Mines Inc. Baseline Summer Survey (SOIL INVESTIGATION AND SAMPLING)   |  |                                    |  |
| <b>Date:</b> JULY 11 1996   |  |                                    |  |
| <b>Author:</b>  |  |                                    |  |
| <b>To:</b>  |  |                                    |  |
| <b>cc:</b> Kym Holley   |  | <b>File No.:</b>                   |  |
| <b>Subject:</b> SUMMER 1996 SOIL INVESTIGATION AND SAMPLING   |  | <b>Job/Task No.:</b> 962-2309/5551 |  |
| <b>Scope of Work/Specific Instructions:</b>   |  |                                    |  |
| <p>Soil Investigation: Soil investigation sites will be located using maps and aerial photographs of the local study area. The location and number of sites may be relocated or increased/decreased to ensure all soil types are represented. Each site will be pinpointed using a global positioning system, with the location being recorded. A photographic record will be kept of the existing terrain at each site. Terrain characteristics will also be recorded. At each site a soil pit will be excavated using a track shovel, trowel and auger. Soil profile characteristics (including drainage and parent material) will be investigated based on a visual examination of the excavated pits. Information will be recorded on Soil Inspection Sheets (see attached). Certain soils will be sampled from the various horizons identified during the soil investigation. Samples will be taken using the shovel or trowel. Each sample will be individually bagged and labeled with site location for analysis.</p> |  |                                    |  |
| <p>All health and safety procedures for Golder and Kennecott must be strictly adhered to during the work period.</p>  |  |                                    |  |
| <p>Crew is to telephone the Golder office in Calgary a minimum of once every three days. If problems in the field arise, phone the project manager at once.</p>   |  |                                    |  |
| <p>Technician: n/a</p>  |  |                                    |  |
| <p>Discipline Leader: Tim Bossenberry</p>   |  |                                    |  |
| <p>Technical Supervisor: David Kerr</p>   |  |                                    |  |
| <p>Project Manager: Gordon Macdonald</p>  |  |                                    |  |
| <b>Work Product(s) Due By:</b> 03 September 1996  |  |                                    |  |
| <b>Allocated Man-hours:</b> Task 5551   |  |                                    |  |
| <b>Subcontractor (as applicable):</b> n/a   |  |                                    |  |
| <b>Special Handling Requirements:</b> Forms to use: Soil Inspection Sheets (see attached), Chain of Custody Forms, Analytical Request Forms.  |  |                                    |  |
| <b>Applicable Specs. and Procedures:</b> Golder T.P. 8.10-0   |  |                                    |  |
| <b>Project Manager Approval/Date:</b>   |  | <b>QA Manager/Date:</b>            |  |

# Climate Change Adaptation Project

## Rio Tinto

### Climate Change Impacts in the Diavik Region of Northern Canada



Future climate mean minimum temperature change predictions for Diavik for December 2060-2069

4 July 2008

Not for general distribution.

Produced by Environmental Modelling and Prediction P/L Australia exclusively for the internal use of Rio Tinto



## Executive Summary

Caveat: Climate modelling is still an emerging science with practical constraints imposed by limitations on supercomputing and data processing of terabytes of data. Although the analyses that follow are based upon the best currently available science, there are inherent limitations on the skill of the techniques used. Due care should be exercised when interpreting these results.

Future climate analyses, spanning the period out to 2060, were conducted for Rio Tinto's Diavik Diamond Mine Incorporated (DDMI) operations in the Northwest Territories Province of northern Canada. The mine site at Diavik (latitude 64° 30'N, longitude 110° 20' W), is located approximately 300 km northeast of Yellowknife and is connected to this location by a 350km long ice road that is constructed annually, 75% of which is built over frozen lakes. The analyses and data provided can be used to assess what the future climate impacts are likely to be upon this ice road, as well as at the mine site itself.

The data for the analyses was from a suite of climate models especially configured and run to meet Rio Tinto's global climate change requirements which was completed in May 2007. The northern Canadian region has high resolution data (notionally a grid box size 20km x 20km, although the narrowing of the longitudes at these locations improves the effective resolution closer to 15km) available across the entire region and for the offshore waters from a suite of 12 individual century-long Coupled Ocean – Atmosphere Climate Model runs from the Oklahoma University. The numerical scheme used in the climate models means that meteorological features are able to be resolved down to an effective resolution of close to 12km.

The future climate models used a mix of mathematical and physical climate model schemes as used in the leading climate modeling centres of the world, including the Hadley Centre in the United Kingdom, and the National Center for Atmospheric Research in the USA, combined with refined versions developed by Prof. Lance Leslie at the Oklahoma University. These models have been used and verified extensively in other climate studies focused upon future climate severe weather in widely separated parts of the world for the insurance and mining industries, and have very high long term atmospheric energy stability, a critical feature of climate models.

The climate models were run in two sets of six model members, one set of which simulated the historical climate of the world, and the other set simulated the future climate using an up-to-date adjustment, valid as at early 2007 to the IPCC's A2 scenario, making the prediction most closely resembling the A1B greenhouse gas/aerosol forcing scenario (referred to as the future greenhouse gas climate, or simply "future climate" throughout this report). This approach is undertaken to identify the best performing climate model and to allow the mean of all six model members to be calculated, thereby providing future climate predictions that possess a higher level of confidence than can be achieved from a single climate model run. An analysis of all of the ensemble model runs demonstrated that the ensemble mean of the six member future Coupled Global Climate Model runs is most likely to be the best predictor of the future climate for the northern Canadian region. The analyses that are provided in the detailed report contain a mix of results from the average of the six ensemble model members and the more detailed results from the model closest to the ensemble mean.

The preliminary investigations of the future climate impacts on the northern Canadian region, under what is currently considered to be the most likely IPCC future greenhouse gas / aerosol emission scenario for the period from the present out to the year 2060, are summarized in the following paragraphs.

## **Temperature**

The ensemble mean climate model predictions of minimum, mean and maximum temperatures were validated against those observed at Environment Canada's weather stations at Lupin A and Ekati and the limited Rio Tinto Canada data from the Diavik mine site for the period through to 2007. There are warm model biases evident for the period from January through to June, greatest in April for Diavik, Ekati and Lupin A data but not for the longer period Fort Reliance data. These biases are not thought to affect the predicted trends and bias corrections were applied to the future climate predictions to account for these differences. There are also warming trends through the model validation period (1970 to 2007) that fit the overall trends observed in the various observational data, although some months in the observational dataset were subject to

multi-decadal oscillations that have the effect of producing transient cooling trends when viewed in isolation and over a limited period of record. Attachments 4a and b North that show the spatial distributions of minimum and maximum temperature across the northern Canadian region should be consulted for further information.

Using the bias corrected linear trends, the predicted annual temperature rises for Diavik, from 1970 to 2060, were as follows:

- Maxima: from  $-8.3^{\circ}\text{C}$  to  $-2.8^{\circ}\text{C}$ , a rise of  $5.5^{\circ}\text{C}$  over the 90 year period. This equates to an annual maximum temperature increase of  $0.061^{\circ}\text{C}$ .
- Mean temperature: from  $-11.0^{\circ}\text{C}$  to  $-6.0^{\circ}\text{C}$ , a rise of  $5.0^{\circ}\text{C}$  over the 90-year period. This equates to an annual mean temperature increase of approximately  $0.056^{\circ}\text{C}$ .
- Minima: from  $-14.7^{\circ}\text{C}$  to  $-9.3^{\circ}\text{C}$ , a rise of  $5.4^{\circ}\text{C}$  over the 90-year period. This equates to an annual minimum temperature increase of approximately  $0.060^{\circ}\text{C}$ .

The predicted temperature changes can be applied to the historical daily air temperature data to determine likely changes to the Freezing Index at any given time through the future climate period. The predicted changes in surface temperature can also be applied in the same way to historical surface temperature data to determine expected changes in the Surface Freezing Index into the future. Although it is outside the scope of this project to determine the Freezing Index, the future climate model predictions clearly show a marked reduction in the number of below-freezing days are to be expected in the future climate, with this reduction accelerating through the future climate period.

Other changes identified were:

- The greatest predicted warming is through the winter to spring period, meaning the length of the snow season, and hence the duration when the ice road is likely to be viable, are likely to be greatly shortened in the future climate period.
- The greatest predicted warming was forecast for January minima with the forecast bias-corrected change from  $-33.6^{\circ}\text{C}$  in 1970 up to  $-25.4^{\circ}\text{C}$  by the year 2060, a very large rise of  $8.2^{\circ}\text{C}$  over the 90-year period.
- The predicted warming through the summer months, typified by those for the month of July, were much smaller with rises of around  $2^{\circ}\text{C}$  predicted for the

minimum, mean and maximum temperatures out to the year 2060. However, the hottest of the climate models indicated one-off much warmer years could be expected with the potential for temperature jumps in the future of up to 5°C for individual summer months. This should also apply to the maximum temperatures at Diavik.

- July is predicted to remain the hottest month.
- By the year 2060, the average monthly temperatures are very likely to be hotter than the hottest months recorded in the historic record for most months of the year.
- Maximum temperatures were predicted to rise fastest through the winter and spring months.
- The predicted warming was forecast to continue well beyond the end of the analysis period.

## **Precipitation**

It must be noted that the climate modelling technique produces rainfall predictions across a 20km x 20km grid, or an area of 400km<sup>2</sup>, whereas the observations from Diavik are from point locations with the diameter of the precipitation gauges used being typically around 10cm. The precipitation received is inherently highly variable in space and time and snow is a particularly difficult phenomenon to accurately measure. It is almost impossible to separate wind driven snow from freshly fallen snow. There are also strong topographic influences that affect the distributions and intensities of the precipitation producing weather systems. Hence the uncertainty in future climate predictions for precipitation must be considered to be higher than those for temperature. The climate models are less likely to predict extremely heavy or light precipitation events that would completely match the observed extreme spot snow and rainfalls. There are also strong multi-decadal signals evident in the precipitation record with trends over the full length of the observational record being markedly different to those over the shorter validation period. It was also discovered that the way in which the historically measured snowfall was converted into equivalent liquid precipitation changed from month to month and year to year at Ekati, producing spurious trends and biases for many of the months



in which snowfall dominates the precipitation record. Therefore there are inherent uncertainties in the observational records to consider.

The predicted trends in precipitation were more complex than for temperature. For most months of the year the climate models predicted increases in precipitation, although the magnitudes of these increases varied markedly from month to month. The predicted annual increase in precipitation went from an average of near 310mm in 1970 to near 360mm by 2060, which equates to a rise of around 16% over 90 years.

In the winter months the quantity of precipitation received at Diavik is relatively small due to the very cold conditions. The climate model predictions for the mean monthly December precipitation ranges from around 18mm in 1970 up to 25.5mm by the year 2060, an increase of 7.5mm, which equates to a very large, in percentage terms, rise of near 42% for the month. A large increase in precipitation, in percentage terms, was predicted for the mid winter month of January with an increase of 24% forecast. The actual quantity of snow involved is small, being only 4mm in liquid precipitation terms, or roughly 4cm of snow. The intensity of the heavier snowfalls are also expected to increase for many of the coolest months of the year with most of the months, but not all, expected to also experience an increase in the frequency of these heavier precipitation events.

Looking at the summer precipitation, the ensemble mean model prediction for Diavik varies from month to month. In June the predictions are for no appreciable change through the future climate period although the wettest months are forecast to increase from around 65mm up to 83mm. For July the climate models predict a slight decline in rainfall, from an average of near 38mm in 1970 to near 35mm by 2060, or a decline of approximately 8%. The climate model predictions indicate a decreasing frequency of extreme heavy rainfall events, although the two heaviest July rainfall predictions lie in the future climate period, indicating new extremes of heavy rainfall are possible in the future climate period, even if the heaviest falls become less frequent than they currently are. In August the climate models return to predicting increases in precipitation, a trend that continues through the remainder of the year.

There is a marked multi-decadal oscillation in the future climate predictions, indicating these changes will not be steady increases but rather a general increasing trend interrupted by large excursions from the mean. There is a marked leveling off of the precipitation increases indicated through the future climate period beyond around model year 2025. The predictions indicate there will be fewer dry years in the future and a trend towards gradually increasing extremely wet years, by Diavik standards, although this region will still only have relatively modest precipitation through the future climate period in comparison to warmer regions of the world. The wettest years tend to occur as lone events, as are the predicted driest years.

### **Extreme Precipitation Events**

The climate model predictions for Diavik vary from month to month. In general the predictions favour increases in both the intensity and frequency of heavy precipitation events through the future climate period. December was predicted to have a particularly large increase in extreme precipitation, jumping from 45mm for the year through the validation period to 65mm in the future climate. Although heavy by local standards, the climate models do not predict falls through the future climate period as great as for other parts of Canada.

The predictions at the lowest end of the precipitation spectrum (the dry years) are for either no change through the future climate period or for a gradual increase in the quantities of precipitation to be expected in the driest months and years.

### **Snowfall and Accumulation**

A set of four attachments have been prepared that show the decadal monthly average snow cover, snow cover anomaly, snow depth and snow depth anomaly charts for the northern Canadian region (Attachments 3b, c, d and e North) and these should be consulted for details on the changes in the amount and depth of snowfall through the Diavik to Yellowknife region. There are also monthly decadal surface temperature average and anomaly charts that map the changes in the temperature of the ground across this

region through the future climate period (Attachments 4, 4a North), which help to quantify the changes in the ground surface that affect snow and ice accumulations.

The anomaly charts for the month of January, representative of the mid winter months, show an interesting transition in the predicted snow cover. The initial predictions show an increase in snow cover over most of the region with the greatest increases centred over and southeast of the Great Slave Lake, reaching a peak of around 7.5% in the 2020-2029 decade. This anomaly pattern then generally changes to one where decreasing snow cover dominates from the decades from 2040 onwards and particularly the 2060-2069 decade. For the onset period of the snow season, the November predictions for Diavik it is likely the snow cover would vary significantly along the access road to Diavik from year to year in the expected future climate. Although this would be positive in some years, the model tends to slightly favour the years of reduced snow cover overall.

The month of April is one where the snow cover is still relatively high in the Diavik region but is rapidly declining in the Great Slave Lake region. The climate model predictions show a very interesting and unusual sequence of anomaly charts. For the first three decades – from 2010 out to 2039, the climate models predict a general increasing trend for snow cover with a strong increase predicted for the 2030-2039 decade over the north and east of the Great Slave Lake, including an area where the snow cover is predicted to increase by over 25%. The increases in cover over the Diavik region during this period are slight, given that this region has a high snow cover to begin with. However, the climate models then predict a sudden and strong reversal in this trend, particularly in the region just north of the Great Slave Lake where snow cover is predicted to decline by over 15% in the 2040-2049 decade increasing to over 22.5% by the 2060-2069 decade. The changes in snow cover at Diavik itself are not shown to be great being within +/- 2.5% for all the decades apart from the 2050-2059 decade when a 7.5% decline in coverage is predicted.

Overall the predictions show a shortening of the length of the season which has snow accumulations on the ground with a general reduction of the depth of the snow, particularly during the months of onset and cessation of the snowfall.

## Wind Speeds and Directions

Attachments 5 and 5a North provides analyses of the expected average monthly wind speeds and directions and the corresponding anomalies across northern Canada out to 2060 relative to the 1970-1999 reference period. The future changes in winds are quite variable from season to season and decade to decade. Strong multi-decadal oscillations are evident in the wind anomaly predictions for each month, indicating the changes will not be simple progressions of a trend, but rather complex changes to the weather patterns throughout the future climate period.

For the mid winter month of January the climate model predictions are for initial reversals of the wind anomalies, starting with a southeasterly wind anomaly in the 2000-2009 decade but turning to a northwesterly anomaly for the following one. Then the trend is for a progressive clockwise swing in the wind anomalies. Initially in the 2010-2019 decade the wind anomalies are predicted to be from the northwest. By the 2020-2029 decade the model predicts a swing back to the north to northeast, continuing around to the northeast by the 2030-2039 decade. Then there is an abrupt reversal of the wind anomalies predicted for the 2040-2049 decade with wind anomalies forecast to change to a south southwesterly. Speeds throughout this period of time are generally within the 0.5 to 1.0m/s range for most of the region. This then settles in as the dominant wind anomaly through the remainder of the future climate analysis period, strengthening through the 2060-2069 decade.

During April the predictions are for a general increase in the easterly wind anomalies, which would serve to increase the wind speeds to the north of Diavik and decrease them to the south of the Great Slave Lake.

In July there is a predominant trend towards a strengthening of the westerly wind anomalies across much of the region to the north of the Great Slave Lake with the strength of the anomalies increasing northwards and reaching close to 1m/s in regions near the Coronation Gulf. There is a more erratic increase in the westerlies to the south of the Great Slave Lake.



During October the climate model predictions highlight a move into a future climate regime with growing variability of the weather patterns, with these variations having signatures that last a decade or more at a time.

With increased energy predicted in the summer time wind regimes and marked multi-decadal oscillations predicted in the weather systems throughout the future climate period, it is likely there will be an intensification of some of the associated weather systems. Although a detailed investigation of individual weather systems is required to quantify this, it is likely that some of these systems will have the potential to increase the severe wind storm risk for the Diavik region.

### **Relative Humidity**

Attachment 6 North provides an analysis of the expected changes in the relative humidity over the northern Canadian region, including the Diavik to Yellowknife area. During the cold winter months there are only small changes in relative humidity predicted. The relative humidity anomalies begin to increase as temperatures rise in April. For this month a band of decreased relative humidity, mostly in the 1-2% range but with a small area of over 2%, develops with an orientation from the west northwest towards the east southeast, centred just north of the Great Slave Lake and hence across the region between Yellowknife and Diavik. Bands of increasing relative humidity, mostly only around 1%, simultaneously form over the eastern parts of the Coronation Gulf and to the southwest of the Great Slave Lake. Diavik itself tends to remain in a region of little change in relative humidity.

In the mid summer month of July the predicted changes in relative humidity become relatively large with a reasonably significant amount of variability from decade to decade. During this time of the year a region of decreasing relative humidity can be seen to become established in a west to east oriented band roughly centred over or along the northern shore-line of the Great Slave Lake. For most of the future climate decades this decrease peaks around 3% although through the 2060-2069 a decrease of over 8% is predicted, including the Yellowknife region. There tends to be a countering increase in

relative humidity across the northern parts of the region, particularly near Coronation Gulf where the humidity is predicted to rise by 4-5% for several of the future climate decades, and further north. Diavik itself tends to experience little change or slight increases in humidity through to the end of the 2050-2059 decade. After this the relative humidity starts to decline.

In October the changes in relative humidity become insignificant once more.

## **Evaporation**

Attachments 7 and 7a North provides analyses of the expected changes in the environmental evaporation for the northern Canadian region, including the Diavik to Yellowknife region. This is a measure of the actual quantity of water evaporated from the environment and not potential evaporation, which only applies to open water surfaces. The evaporation anomalies are derived based upon changes relative to the current decade (2000-2009). For the mid winter months, typified by January, the change in the evaporation rates remain low due to the continuing very cold temperatures at this time of the year. The evaporation anomaly rates remain low until the warmer months of the year, particularly north of the Great Slave Lake.

The trends in evaporation become far more significant as temperatures rise from May through to August. The trends are bimodal in nature with decreases in evaporation rates predicted across the northern parts of this region with a corresponding increase in evaporation rates to the south. There is a marked increase in evaporation rate through the central region in a band that lies across the Great Slave Lake through the 2020-2029 decade with a corresponding decrease in evaporation through the Coronation Gulf and further northwards. The 2030-2039 decade marks a transition period with the evaporation rates then accelerating over the Great Slave Lake and areas southwards, particularly to the southeast near Lake Athabasca where evaporation rates climb to over 0.4mm/day. Diavik remains in a region of slightly reduced evaporation through this period of time although at Yellowknife the evaporation rates are predicted to start to increase. Through the 2050-2059 and 2060-2069 decades the strengths of the evaporation rate anomalies tends to increase with greatest increases over and southeast

of the Great Slave Lake, again peaking to the southeast over and beyond Lake Athabasca. There are opposing decreases in evaporation across the north of this region. Diavik is predicted to remain in a region where slight decreases in evaporation rate dominate, although the Yellowknife region is predicted to experience increases of around 0.25mm/day by the 2060-2069 decade.

The evaporation anomaly rates again become small from October onwards as temperatures fall.

### **Solar Radiation**

Attachments 8 and 8a North provides analyses of the expected changes in solar radiation across northern Canada out to 2060 relative to the 1970-1999 reference period. Given there is little incident solar radiation during the winter months the anomalies are small through out the region for these months, although what trend there is indicates a reduction in incoming solar radiation due to increased cloud cover. For the mid spring month of April, both Diavik and Yellowknife tend to lie close to the no change line through the future climate period and fluctuate between increases and decreases in solar radiation through the future climate period in the order of 6 Watts/m<sup>2</sup>.

During the mid summer month of July very strong decreases in solar radiation, in excess of 30 Watts/m<sup>2</sup>, are predicted for the northern part of the northern Canadian domain for the period beyond 2050, as well as slightly lower reductions in solar radiation over the regions south of Lake Athabasca. However, in the area from Diavik down to Yellowknife tends to be in an area where the solar radiation anomalies oscillate from increases to decreases with the size of the anomalies remaining generally below 6 Watts/m<sup>2</sup>.

Overall the larger solar radiation anomalies are predicted to occur during the warmer months of the year and reach a peak during the months of June and July. Although the solar radiation anomaly patterns show considerable variability from decade to decade, there is a marked move towards decreases in solar radiation across this region as a whole, although Diavik and Yellowknife are expected to remain away from the largest changes.

# Climate Change Impacts in the Diavik Region of Northern Canada

## 1. The Current Climate

This report covers the key location of Diavik and its' access road to Yellowknife, both of which form a part of Rio Tinto's DDMI operations. The mine site at Diavik (64° 30'N, 110° 20'W) is located in the Northwest Territories of northern Canada, approximately 300km to the northeast of Yellowknife. A 350km long ice road connects the two locations that is constructed annually, with 75% built over frozen lakes. The future response of the frozen lakes to a changing climate is therefore a key concern. Although the authors of this report do not have a sufficient understanding of the response rates of these ice lakes to changing weather conditions, it is hoped that the data and analyses provided here will enable those with this knowledge to be able to determine how the ice lakes will fare in the future.

The Google Earth image in Figure 1 shows the relative positions of Diavik and Yellowknife and the general topography of the region. The climate data used to validate the climate models' performance near Diavik is from a combination of the data measured near the Diavik mine site and from the Environment Canada weather stations at Ekati and Lupin A. Obviously it is preferable to have historical climate data from the same location as the climate model data but the length of the climate data for Diavik is too short for proper climate analysis. This is the reason why historical data from relatively climate stations is also included.

Diavik's inland location protects it from the more extreme stormy weather conditions that affect coastal parts of Canada, although the intense polar low pressure systems bring recurring blizzards during the cooler months of the year. Its' northern latitude and high elevation (Ekati is at an elevation of 470m and it is assumed Diavik has a similar elevation) means it has very cold winters with minima having dropped as low as -47.0°C, although the average winter temperature during the coldest month of January is -33.4°C (both figures for Ekati). The high elevation and northern latitude of the Diavik to



Yellowknife region also allows its snow pack to last well through the spring months. The mean monthly temperatures climb through the 0°C during the month of May (average temperature -3.7°C) then drop below zero again early in the month of October (average temperature -9.1°C). The summers are cool to mild with temperatures rising to an average minimum of 10.2°C during its warmest month, July, with a mean monthly temperature near 14.2°C and an average maximum a mild 18.2°C. Infrequent relatively warm days can occur in this location with the all time record maximum temperature reaching 28.0°C. Being very cold through winter, little precipitation falls through the winter months, almost all of it falling as snow. The precipitation rapidly increases during the warmer months, August being the wettest month of the year with an average of 64mm. The precipitation is almost entirely rain at this time of the year.

The prevailing wind regime across the Diavik to Yellowknife region tends to be westerly winds through much of the year. However they do become quite changeable through certain months and particularly during the April to June period. At this time of the year the centres of the polar lows that dominate the regions weather tend to track eastwards between Diavik and Yellowknife. The complete set of long term average wind speed and direction charts are to be found in the report entitled “Wind average charts Canada – 2”.

The weather tends to be dominated by the passage of sometimes intense polar low pressure systems separated by transient highs. As a result of this there can be very abrupt changes in the weather from mild and sunny conditions to heavy rain or snow within a short space of time. The passage of warm and cold fronts brings the heaviest rain and snow falls. There are few thunderstorms at this high latitude and any that do occur are likely to be experienced in summer.

Diavik’s temperature and precipitation climate will be discussed in more detail in the following sections.



**Figure 1: Location map showing Rio Tinto DDMI's Diavik operations and Yellowknife with the location of the climate model data extraction location shown as the Diavik yellow marker. Map courtesy of Google Earth.**

## 1.1 Precipitation

The available climate data is from the Diavik mine site supplemented by the Ekati and Lupin A data from Environment Canada's records. Some long term data is also used for Fort Reliance, although this is a little further away from Diavik than is desirable. The

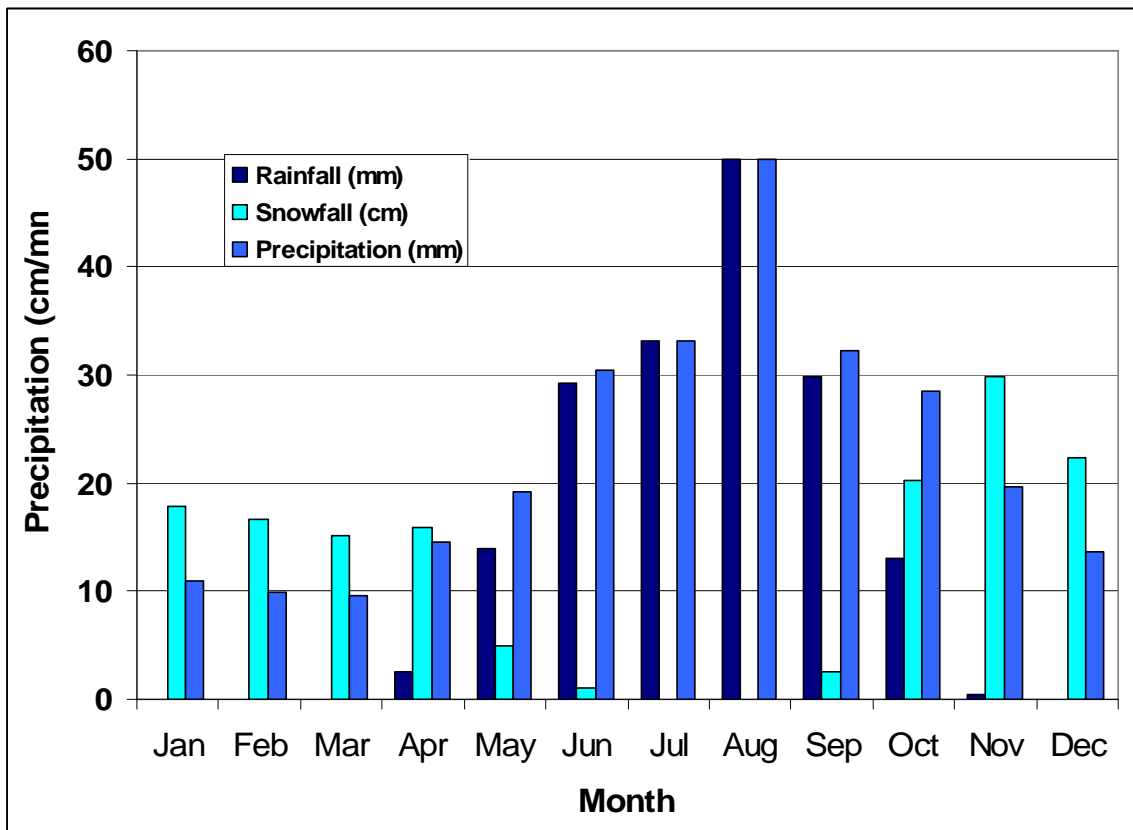
Environment Canada climate records are relatively complete, although there are small numbers of missing months or months when the data is estimated. The historical records can be considered comparatively good quality datasets, although there appear to be problems with the Ekati total precipitation data for months when snow falls. Diavik's precipitation is summarized in Figures 2a and b and in Table 1, although the data is actually from nearby stations. The total precipitation refers to the sum of melted snow together with any rainfall that occurred during the same month. It should be noted at this point that it is very difficult to accurately measure snowfall as the catch efficiency of snow gauges decreases rapidly with increasing exposure to wind, and it is also virtually impossible to separate out wind-driven snow that fell elsewhere and then was blown across the snow gauge from freshly fallen snow. The broader climate records shows the Diavik region has moderate to fresh average wind speeds throughout the year but with bouts of very strong winds. Hence it is to be assumed there is a large degree of uncertainty in the underlying accuracy of the snowfall records at all of the locations used in this study caused by the difficulty in measuring snowfall, not by the quality of the underlying observations program. The measurement of liquid rainfall should be considered more accurate, although the efficiency of rain gauges also declines significantly with increasing wind speed.

Diavik, being an elevated inland location with a northerly latitude, has an Arctic-type of precipitation climate with relatively low quantities of snow falling during the very cold winter months but relatively good falls of rain being received through the few warmer months of the year. There are no long term Climate Normals available for Diavik, Ekati or Lupin A from Environment Canada and so, as a general guide to the long term climate of the region, data from the nearest station with long term data, Fort Reliance (62° 34'N, 109° 10'W), is shown in Table 1, and graphically in Figure 2a. As Table 1 shows, from November through to March the precipitation falls almost entirely as snow. Then there is a rapid transition in the snow/rain mix from April, when snow still dominates, to May when most of the precipitation falls in liquid form. The period from June to August inclusive is almost all rain with the reverse transition occurring during the months of October and November. The greatest amount of snow is shown to fall in the month of November (29.9cm) with the greatest amount of rainfall (50mm) falling in August, which also has the greatest total precipitation. The driest month is March with around 9.6mm of

total precipitation, followed closely by February with 9.9mm. The annual total precipitation is a modest 272mm, concentrated in the warmer months of the year from June to October.

|                    | Jan  | Feb  | Mar  | Apr  | May  | Jun  | Jul  | Aug | Sep  | Oct  | Nov  | Dec  | Year  |
|--------------------|------|------|------|------|------|------|------|-----|------|------|------|------|-------|
| Rainfall (mm)      | 0    | 0    | 0    | 2.5  | 13.9 | 29.3 | 33.2 | 50  | 29.9 | 13.1 | 0.4  | 0    | 172.3 |
| Snowfall (cm)      | 17.8 | 16.6 | 15.2 | 15.9 | 5    | 1.1  | 0    | 0   | 2.6  | 20.3 | 29.9 | 22.4 | 146.8 |
| Precipitation (mm) | 11   | 9.9  | 9.6  | 14.5 | 19.2 | 30.5 | 33.2 | 50  | 32.2 | 28.5 | 19.7 | 13.7 | 272   |
| Ave Snow Depth     | 32   | 38   | 41   | 36   | 9    | 0    | 0    | 0   | 0    | 2    | 14   | 25   | 16    |
| Median Snow Depth  | 31   | 38   | 41   | 37   | 7    | 0    | 0    | 0   | 0    | 1    | 15   | 25   | 16    |
| Snow Depth End Mth | 36   | 40   | 42   | 25   | 0    | 0    | 0    | 0   | 0    | 6    | 19   | 29   | N/A   |

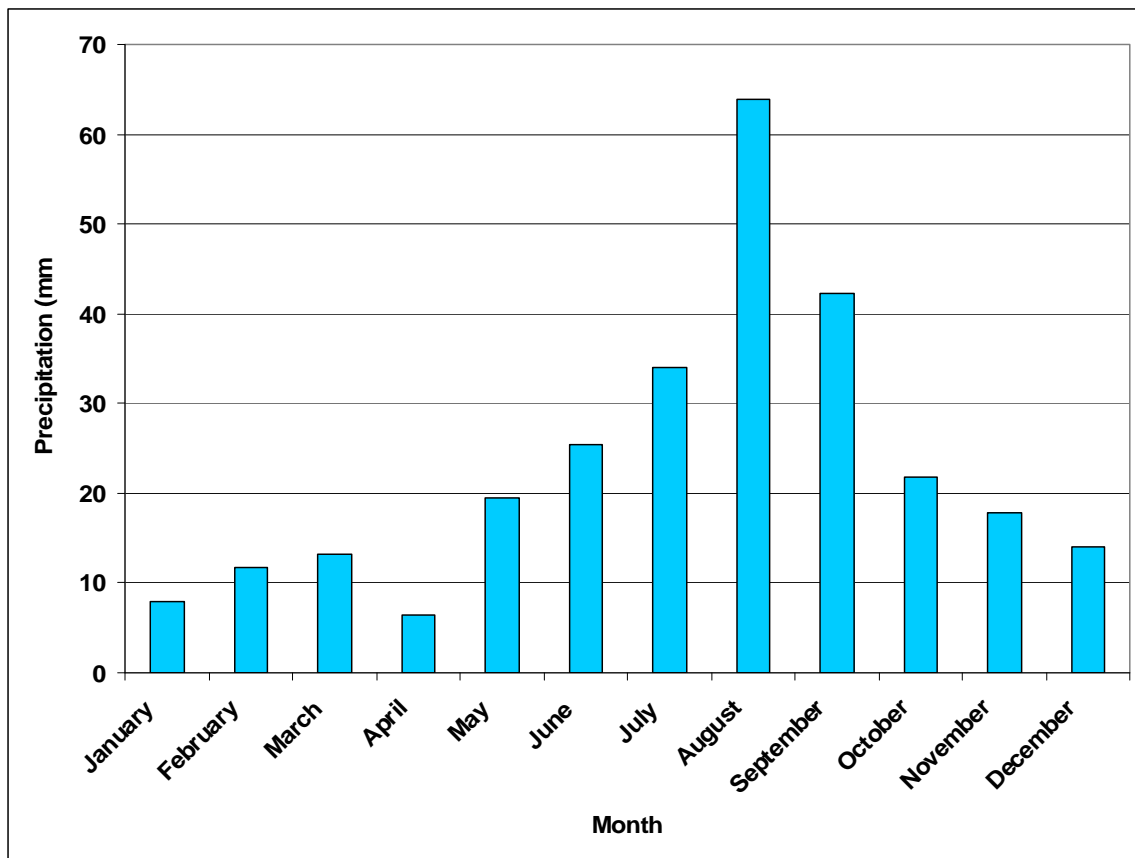
**Table 1: Average monthly rainfall (mm), snowfall (cm), total precipitation (mm), average snow depth, median snow depth and snow depth at end of month (cm) for Fort Reliance from 1971 to 2000. Data courtesy of Environment Canada.**



**Figure 2a: Average monthly rainfall, snowfall and total precipitation graph for Fort Reliance. Data courtesy of Environment Canada.**



Although the mix of snow and rainfall for the Fort Reliance area is generally indicative of that to be expected at Diavik, there are localised differences from one place to another across this region. This can be seen by comparing the longer term data in Figure 2a with the shorter length of total precipitation data from Ekati in Figure 2b. August is still the wettest month although Ekati has a larger average rainfall. The driest month shifts to April followed by January at Ekati, rather than March, although the late winter to early spring period is still the driest time of the year. The shorter period of records for Ekati means the individual months are likely to have been biased by anomalously wet and dry months within the available period of record and hence they should not be considered true long term averages. The conversion of snowfall into liquid precipitation is also an issue here. None-the-less, they do provide a useful guide of the likely climate at Diavik.



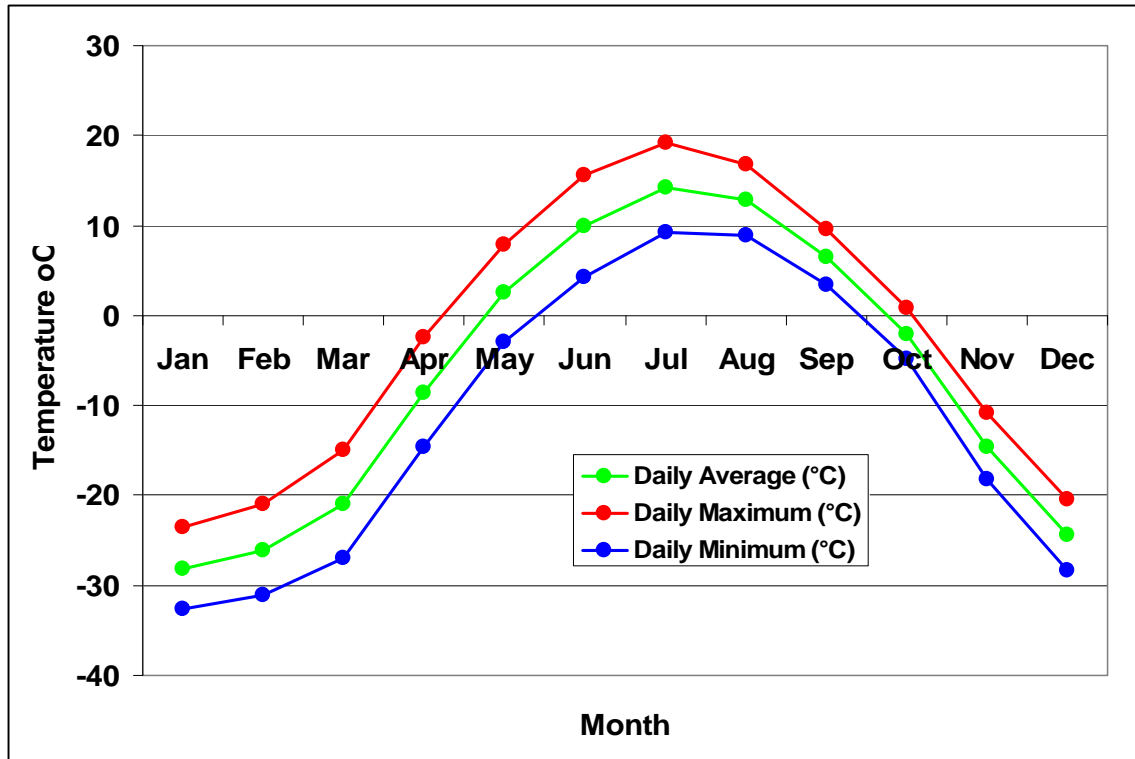
**Figure 2b: Average monthly total precipitation graph for Ekati. Data courtesy of Environment Canada.**

There is, unfortunately, insufficient length of observations from Diavik or Ekati to prepare a long term trend analysis. Some indications of the trends in the climate variables can be gained from viewing the time series data plotted in the model validation section that follows, although it must be noted that the trends in the observational data must be treated with extreme caution as they are prone to be heavily affected by naturally occurring multi-decadal climate variability.

The original rainfall records show the annual totals are significantly affected by one-off heavy rainfall or snowfall events in only one or two months of the year, highlighting the fact that the rainfall regime in this part of Canada are quite variable from month to month and year to year. It can be concluded that the magnitude of any long term changes in precipitation at Diavik are smaller than the magnitude of the naturally occurring multi-decadal oscillations.

## **1.2. Temperature**

The temperature regime for the Diavik region is characterized by relatively mild summers and very cold winter days and nights, as can be seen in Table 2 and Figure 3 where the historical minimum, mean and maximum temperature records for Fort Reliance, in lieu of the limited data available for Diavik, for the period from 1971 to 2000 are shown on a monthly basis. The diurnal range ranges from around 12.1°C in the spring months of March and April to a small 5.6°C in the mid-fall month of October. January is the coldest month for both maximum and minimum temperatures with a rapid rise in temperatures during the March to May period. July is the warmest month, again for both maximum and minimum temperatures, with the decline in temperatures during the October to December period being more rapid than the rate of the transition out of the winter period.



**Figure 3: Average monthly maximum, mean and minimum temperature graph for Fort Reliance, in lieu of Diavik. Data courtesy of Environment Canada.**

|                | Jan   | Feb   | Mar   | Apr   | May  | Jun  | Jul  | Aug  | Sep | Oct  | Nov   | Dec   | Year  |
|----------------|-------|-------|-------|-------|------|------|------|------|-----|------|-------|-------|-------|
| Daily Ave (°C) | -28.1 | -26.1 | -21   | -8.6  | 2.5  | 9.9  | 14.3 | 12.9 | 6.5 | -2   | -14.6 | -24.4 | -6.6  |
| Std Devn       | 4     | 5.3   | 3.4   | 3.6   | 3.4  | 1.6  | 1.5  | 1.8  | 1.8 | 2.1  | 3.3   | 4.1   | 5.2   |
| Daily Max (°C) | -23.5 | -21   | -14.9 | -2.5  | 7.9  | 15.6 | 19.2 | 16.8 | 9.6 | 0.8  | -10.9 | -20.4 | -2    |
| Daily Min (°C) | -32.7 | -31.1 | -27   | -14.6 | -2.9 | 4.2  | 9.3  | 8.9  | 3.4 | -4.8 | -18.2 | -28.4 | -11.2 |

**Table 2: Monthly maximum, mean and minimum temperature (°C), together with the standard deviation for the mean daily temperature for Fort Reliance, in lieu of data for Diavik, from 1971 to 2000. Data courtesy of Environment Canada.**

In Diavik Attachment 2 in Figures DT1a, b and c the time series of minimum, mean and maximum temperatures are shown for the very limited period of record from 1997 through to 2008. From the data it can be seen that there is typically a variation in the monthly temperatures of around +/-1.5°C from the mean monthly values from one year to the next, although there are one-off large variations of up to 10°C for individual months, notably February. It is not possible to determine whether these larger

excursions from the mean are true or errors in the dataset. The winter time temperatures, both maximum and minimum, can be seen to experience the greatest inter-annual variations with February being the most variable month of all. The summer months, in contrast to this, have a relatively stable temperature regime from year to year. The trends will be discussed in the model comparison section that follows.

## **2. Future Climate Simulations of the Diavik Region of Northern Canada**

The analysis that follows utilizes the results from a suite of 12 ensemble Coupled Atmosphere-Ocean Climate model runs. The modeling procedure used is described in simple terms earlier in this report. Six of the ensemble model members were run with the observed historical greenhouse gas forcing through to 2000, after which time the greenhouse gas and aerosol concentrations were held at a constant level. This represents the historical climate. The other six model members were subject to a modified IPCC A2 scenario, similar to the A1B scenario, greenhouse gas / aerosol forcing from 2000 onwards. The ensemble means were then calculated for each suite of model runs and these are considered most likely to provide the most reliable information on future climate trends. The model member closest to the ensemble mean was then selected as being the model with both the greatest likelihood of representing the future climate and as the model that is likely to provide the most accurate detailed information on variability associated with climate change. The fields from either of the ensemble mean or of the model closest to the ensemble mean, form the basis of most of the analyses that follow, with all ensemble members used for some of the analyses.

### ***2.1 Future Temperature Changes***

In the following section the modelled changes in mean monthly air temperatures for the Diavik region will be discussed. Firstly the model validation will be discussed, followed by the future climate predictions. The model validation data is available for each month of the year. However, in order to reduce the size of the report, the comparisons between the historical observations of air temperature and the climate model predictions are discussed primarily for the middle month for each of the four seasons, namely January,



April, July and October, as well as annually, although interesting aspects of the other months are also covered..

### **2.1.1 Model Validation**

In Figures DT2a, b and c, the mean of the six climate model member predictions, the predictions from the warmest climate model member and the predictions from the coldest climate model member for the period from 1970 through to 2007 are shown for the coldest month of the year, January, against the available observations from Diavik, Ekati and Lupin A for the minimum, mean and maximum temperatures. Linear trend lines are included for the ensemble mean of the models for maximum, mean and minimum temperatures and also for the coldest of the model members. It must be remembered that the climate model predictions are for the air temperature at 2m above the ground for the 20km square grid point centred upon Diavik, whereas the comparison observations are from the temperatures measured inside a temperature screen at a point location. Hence the two datasets are not exactly the same, but are as close as the current state of the science will allow.

From the comparisons it can be seen that the ensemble mean modelled maximum, minimum and mean temperatures have a warm bias of approximately 2-3°C against the observed Diavik minimum temperature data, based upon observations from Lupin A, Ekati and Diavik, which grows to around 4°C for the maximum temperatures. This bias is much smaller if the long term Fort Reliance data is used (see Table 2). The coldest of the model members is, in general able to reproduce the observed temperature records best. It is likely this is also the model that is best able to predict snowfall and hence is the most skillful at these latitudes at this time of the year. The observed, ensemble mean model and coldest ensemble model member trends are very close to each other, with the linear trend lines showing very similar rates of warming through the 1970 to 2007 model validation period. This warming is predicted to affect both minimum and maximum temperatures. The observed mean temperatures show greater year to year variability, which is to be expected as the ensemble mean is an average of six models, which reduces the amount of inter-annual variability. The variability in the coldest of the model members is quite similar to that of the observations showing the individual climate model

members are able to replicate the prevailing weather conditions at this location quite well.

The observed maximum temperatures, shown in Figure DT2c, tend have mean values close to those of the coldest ensemble model. The variability of maximum temperatures is greater than the climate model mean but similar to the coldest model member's variability. The hottest observed maxima remain within the envelope described by the hottest of the climate model members throughout the validation period and generally lie in the region between the ensemble mean and the coldest model member. The observed extreme low monthly maximum temperatures are very close to the coldest of the climate model member's predictions. This means that the coldest model member replicates the observed mean maxima well, with the observed extremes of temperature lying within the bounds of the range of predictions from the ensemble of model predictions. Overall the mean model bias is around 4°C and this should be considered when the future climate model predictions are being considered.

The observed minimum temperatures, shown in Figure DT2b, tend have mean values mid way between those of the ensemble mean model and the coldest of the model members. The variability of observed minimum temperatures is greater than the climate model mean but is similar to that of the coldest model member. The warmest observed minima remain within the envelope described by the warmest of the climate model members throughout the validation period and, for the most part, lie below the predicted values of the ensemble mean of the models. The coldest minimum temperatures tend to be very similar to the coldest minima predicted by the coldest of the ensemble of model members. It can be concluded that the climate model predictions are quite well calibrated for minimum temperatures at Diavik for this time of the year, although the ensemble mean model has a warm bias of approximately 2°C at this time of the year.

The comparisons for Diavik for February similar skill with the climate model again having a similar warm bias. It is noted the observed mean temperatures for February for Diavik and Ekati are too short to be able to identify any trend. However the longer period of record from Lupin A does show a rising trend similar o that of the climate models. Once

again the observed temperatures generally sit within the envelope of predictions provided by the climate model members.

In Figures DT5a, b and c the mid-spring month of April temperature comparisons are shown for Diavik. For this month the observed temperatures from Diavik, Ekati and Lupin A continue to be cooler than the ensemble mean of the climate models with the warm bias growing to around 6°C. This bias is greater than preferred but it should be noted that in complex terrain such as that around Diavik, naturally occurring variations over short distances can be of this magnitude. It should be noted that the longer term record for Fort Reliance matches the ensemble mean model values almost exactly with a monthly mean value of -8.6°C. The same applies to both the maximum and minimum data with Fort Reliance matching the ensemble model mean data very well.

These local biases can be exacerbated by differential accumulations of snow and ice that can dramatically affect the temperatures over small distances. As the climate model is providing an average over an area while the observations are for point locations, differences are inevitable. Bias corrections need to be applied to the future climate model temperature predictions at Diavik to account for this warm bias, although it should also be noted that no bias correction at all is required if the Fort Reliance data is considered representative. As was the case for the preceding months, the longer period of record from Lupin A shows a warming trend comparable to that of the ensemble mean of the climate models. The observed minimum and maximum temperatures tend to show similar warm model biases with the coldest of the model members being most similar to the coldest of the climate model members. At this time of the year the observed coldest minima and maxima are lower than the lowest modelled minima and maxima and so this needs to be borne in mind when the future climate model predictions are interpreted.

In Figures DT8a, b and c the same comparisons are made for Diavik for the mid summer month of July, which is the warmest month of the year for this location. It can be seen that the climate model has a reduced warm bias for this month of the year with the warm bias for the mean temperature being around 2°C. The trend for Lupin A's observational record shows a rise of similar magnitude to the climate models mean. The observed minima and maxima for Diavik also show a similar bias of around 2°C. The coldest of the

observed minimum temperatures is only marginally below the coldest predictions from the coldest model member for this month with the coldest maxima being similar to the model predicted coldest maxima. The warmest of the observed temperatures are all below the highest predicted temperatures from the warmest model member.

In Figures DT11a, b and c the comparisons for the mid-fall month of October are shown for the climate models and the available observations for the Diavik region. For this month the observed minimum, mean and maximum temperature matches the climate model extremely well, with the observations being almost identical to the modelled values in both magnitude and trend. No bias correction is required at this time of the year. The minimum and maximum temperatures again sit well inside the envelope of predictions of the climate model. Hence there can be a high level of confidence in the ability of the climate model to represent the temperature regime for the Diavik region at this rapidly changing time of the year.

It should be noted that the ensemble mean model predictions require very little in the way of bias corrections for the months from August through to December inclusive. Hence the warm bias of the ensemble mean models is a seasonal feature of the climate model that applies to the period from mid winter through to mid summer, peaking in mid spring.

The annual comparisons between the climate models and the Diavik observations are shown in Figure DT14. The maximum, minimum and mean temperatures, at an annual level, are between 2 and 2.5°C cooler than the ensemble mean climate model, which is considered good for an Arctic location in complex terrain such as Diavik. The modelled trend over the 38 years of this comparison for the annual data shows a 2.5°C increase for the mean temperature, which is comparable to the observed warming trend at Lupin A of 2°C over the period since 1982. The trend lines show that this increase is a fairly constant feature throughout the 38 years of the validation period, although there are multi-decadal oscillations present, more obvious in individual model runs. From all of the comparisons it can be concluded that the ensemble mean model temperature data recreates the observed Diavik temperature record to an acceptable degree with the application of bias corrections thought to be a suitable way of adjusting for the



differences between model and observations as the trends and observed variability are similar between the datasets.

### **2.1.2 Future Climate Model Predictions**

Next the future climate temperature predictions are analyzed for the grid box centred upon Diavik. The model predictions for Diavik for all twelve months are shown in Diavik Attachment D2 as Figures DT15 a, b and c (mean, minimum and maximum temperatures respectively) through to DT26 a, b and c with the annual predictions shown in DT27a (ensemble mean of the climate models) and DT27b (the model closest to the ensemble mean). The predictions from the hottest and the coldest of the six climate model predictions are also shown for maximum and minimum temperatures. These serve to provide an estimate of the range of possibilities for the more extreme hot or cold periods. The ensemble mean of the six models will, in general, provide the best estimate of the long term trends in the minimum, mean and maximum temperatures. The future climate temperature prediction discussions that follow are based upon the ensemble mean of the climate models. Comments on inter-annual and decadal scale oscillations, and likely changes in the frequency of more extreme events, will generally be based upon the results of the model closest to the ensemble mean. For brevity, only the months in the middle of the four seasons and the annual trends will be discussed in any detail.

The predicted temperature changes can be applied to the historical daily air temperature data to determine likely changes to the Freezing Index at any given time through the future climate period. The predicted changes in surface temperature can also be applied in the same way to historical surface temperature data to determine expected changes in the Surface Freezing Index into the future. Although it is outside the scope of this project to determine the Freezing Index, the future climate model predictions clearly show a marked reduction in the number of below-freezing days are to be expected in the future climate, with this reduction accelerating through the future climate period.

## **January**

In Figures DT15a, b and c the ensemble mean model predictions of minimum, mean and maximum temperatures for Diavik are shown from 1970 through to 2060 for the mid-winter month of January, together with linear trend lines for the ensemble mean of the model predictions. The climate models show an ongoing, almost linear increasing trend in the minimum, mean and maximum temperatures through to at least 2060, although there is a definite multi-decadal signal in the rate at which the temperatures rise. This can be seen as a series of steps in the graphs of temperature with the temperatures remaining relatively constant for a decade or more followed by a sudden rise, then another period of relatively constant temperature before the next rapid rise occurs. The warming trends are quite significant for both minima and maxima, with the rate of rise of minimum temperatures predicted to be slightly greater than for maximum temperatures. Both are predicted to warm relatively rapidly.

Using the linear trend lines as the reference, the predicted temperature changes, from 1970 to 2060, are as follows:

- Maxima: from  $-23.4^{\circ}\text{C}$  to  $-15.8^{\circ}\text{C}$ , a rise of  $7.6^{\circ}\text{C}$  over the 90-year period. This equates to an annual maximum temperature increase of  $0.084^{\circ}\text{C}$ .
- Mean temperatures: from  $-27.3^{\circ}\text{C}$  to  $-19.6^{\circ}\text{C}$ , a rise of  $7.7^{\circ}\text{C}$  over the 90-year period. This equates to an annual mean temperature increase of  $0.086^{\circ}\text{C}$ .
- Minima: from  $-31.6^{\circ}\text{C}$  to  $-23.4^{\circ}\text{C}$ , a rise of  $8.2^{\circ}\text{C}$  over the 90-year period. This equates to an annual minimum temperature increase of  $0.091^{\circ}\text{C}$ .

Applying bias corrections to these datasets based upon the observations shown in Figures DT2a, b and c, adjusts the predicted temperature changes for the month of January for the period from 1970 to 2060 to the following values (bias correction not required for Fort Reliance data):

- Maxima: from  $-27.4^{\circ}\text{C}$  to  $-19.8^{\circ}\text{C}$ , a rise of  $7.6^{\circ}\text{C}$  over the 90-year period.
- Mean temperatures: from  $-30.3^{\circ}\text{C}$  to  $-22.6^{\circ}\text{C}$ , a rise of  $7.7^{\circ}\text{C}$  over the 90-year period.
- Minima: from  $-33.6^{\circ}\text{C}$  to  $-25.4^{\circ}\text{C}$ , a rise of  $8.2^{\circ}\text{C}$  over the 90-year period.

Looking at the variability of the year to year temperature variations at Diavik it can be seen that there are likely to be decades in the future when the temperature rise plateaus for a period of time, followed by an accelerated rise. Also there are predictions of one-off years when there are spikes in the temperatures predicted – either hot or cool spikes, One key thing to note concerns the transition into a consistently warmer climate beyond the 1990-1999 decade. In the period from 1970 through to around 2000 there are occasional years when there are relatively cold years – when the January minima drop to around  $-32^{\circ}\text{C}$ , well below the long term average. However, beyond 2015 these colder years become less frequent or severe, with the coldest of the years predicted to drop only as far as  $-27^{\circ}\text{C}$ . The minimum temperatures predicted for the period from 2050-2060 are all shown to be higher than the warmest minimum temperature during the 1970s and 1980s.

### ***April***

For the spring month of April, the predicted changes in maximum, mean and minimum temperatures for Diavik are shown in Figures DT18a, b and c. The future climate predictions are based upon the mean of the ensemble of models. However, it must be noted that the ensemble mean model has a warm bias of approximately  $4\text{-}5^{\circ}\text{C}$  at this time of the year, based upon the Diavik, Ekati and Lupin A data but not the Fort Reliance data, and this bias correction can be applied to better match the available Diavik observations. The coldest of the model members appears to replicate Diavik's temperature regime more closely during this month. Again there are multi-decadal oscillations in the temperature predictions for both maximum and minimum evident. However, over the full 90 years of the climate model predictions the linear trend line provides a good estimate of the predicted long term trend in the temperatures.

Using the linear trend lines for the analysis, the predicted temperature changes, from 1970 to 2060, are as follows:

- Maxima: from  $-4.5^{\circ}\text{C}$  to  $-0.9^{\circ}\text{C}$ , a rise of  $3.6^{\circ}\text{C}$  over the 90-year period. This equates to an annual maximum temperature increase of  $0.040^{\circ}\text{C}$ .
- Mean temperatures: from  $-9.7^{\circ}\text{C}$  to  $-5.0^{\circ}\text{C}$ , a rise of  $4.7^{\circ}\text{C}$  over the 90-year period. This equates to an annual mean temperature increase of  $0.052^{\circ}\text{C}$ .

- Minima: from  $-14.8^{\circ}\text{C}$  to  $-9.2^{\circ}\text{C}$ , a rise of  $5.6^{\circ}\text{C}$  over the 90-year period. This equates to an annual minimum temperature increase of  $0.062^{\circ}\text{C}$ .

Applying bias corrections to these datasets based upon the observations, which are at their greatest at this time of the year and are shown in Figures DT5a, b and c, adjusts the predicted temperature changes for the month of January for the period from 1970 to 2060 to the following values (bias correction not required for Fort Reliance data):

- Maxima: from  $-11.5^{\circ}\text{C}$  to  $-7.9^{\circ}\text{C}$ , a rise of  $3.6^{\circ}\text{C}$  over the 90-year period.
- Mean temperatures: from  $-15.7^{\circ}\text{C}$  to  $-11.0^{\circ}\text{C}$ , a rise of  $4.7^{\circ}\text{C}$  over the 90-year period.
- Minima: from  $-19.3^{\circ}\text{C}$  to  $-13.7^{\circ}\text{C}$ , a rise of  $5.6^{\circ}\text{C}$  over the 90-year period.

These predictions show the April period to have a slightly slower rate of warming but still one that is considered rapid in a global context. The minima are expected to rise at a faster rate than for the maxima, although this rate is a slightly slower rate than for the mid winter months. The climate model predictions for both the minimum and maximum temperatures show a relatively large amount of variability from one year to another, indicating there can be expected to be abrupt jumps in the temperature followed by equally rapid falls the following year. The rise in mean temperature of  $4.7^{\circ}\text{C}$  over the period of the future climate predictions would amount to a much earlier and more rapid thaw of the accumulated snow in the future climate regime. With a similar rate of warming predicted for the month of May, this would also mean the ice road connecting Diavik and Yellowknife would be expected to disintegrate much earlier in the future climate regime. The climate model predictions still show outlying abnormally cool and warm years but there is clear evidence in these predictions for a move into a consistently significantly warmer climate.

## **July**

The predicted changes in maximum, mean and minimum temperatures for the warmest time of the year at Diavik, July, are shown in Figures DT21a, b and c. The ensemble mean of the model predictions can be seen to go through cycles of increased then decreased inter-annual variability through the future climate period, indicating the nature



of the climate variability is not expected to be uniform through the future climate period. This variability appears to affect both maximum and minimum temperature predictions. There are also marked multi-decadal signals in the temperature predictions, as illustrated by the series of step-like increases in temperature predicted through to the year 2060.

Using the linear trend lines for the analysis, the predicted temperature changes, from 1970 to 2060, are as follows:

- Maxima: from 18.2°C to 20.0°C, a rise of 1.8°C over the 90-year period. This equates to an annual maximum temperature increase of 0.020°C.
- Mean temperatures: from 13.6°C to 15.7°C, a rise of 2.1°C over the 90-year period. This equates to an annual mean temperature increase of 0.023°C.
- Minima: from 9.0°C to 10.9°C, a rise of 1.9°C over the 90-year period. This equates to an annual minimum temperature increase of 0.021°C.

Again applying bias corrections to these datasets based upon the observations, which have reduced to a modest 1.5°C (minimum) to 2.5°C (maximum) for this month, as shown in Figures DT8a, b and c, adjusts the predicted temperature changes for the month of January for the period from 1970 to 2060 to the following values:

- Maxima: from 15.7°C to 17.5°C, a rise of 1.8°C over the 90-year period.
- Mean temperatures: from 11.6°C to 13.7°C, a rise of 2.1°C over the 90-year period.
- Minima: from 7.5°C to 9.4°C, a rise of 1.9°C over the 90-year period.

From these predictions it can be seen that the ensemble mean climate model forecasts a relatively uniform increase in maximum and minimum temperatures through the summer period, although the rate of increase in temperatures are predicted to be very slow in comparison to the winter and spring months. Although the predictions are for ongoing warming, there continue to be a reasonably number of years, sometimes several years in succession as for the period from 2022-2025, when there are Julys with maximum temperatures a couple of degrees cooler than the long term average trend would indicate as being the normal conditions. The variability is predicted to similar for both maximum and minimum temperatures.

## **October**

The predicted changes in maximum, mean and minimum temperatures for Diavik for the central month of fall, October, are shown in Figures DT24a, b and c. October represents the start of the transition from the mild to warm season into the time of year when snowfalls become more frequent. Hence it is an inherently changeable time of the year and one when the accumulation of snow on the ground can be expected to commence as the mean daily temperatures historically drops below freezing during this month.

Once again the linear trend lines are used to quantify the expected changes in the temperature for this time of the year. On this basis, the predicted temperature changes, from 1970 to 2060, are as follows:

- Maxima: from  $-3.8^{\circ}\text{C}$  to  $0.4^{\circ}\text{C}$ , a rise of  $4.2^{\circ}\text{C}$  over the 90-year period. This equates to an annual maximum temperature increase of  $0.047^{\circ}\text{C}$ .
- Mean temperatures: from  $-6.9^{\circ}\text{C}$  to  $-2.0^{\circ}\text{C}$ , a rise of  $4.9^{\circ}\text{C}$  over the 90-year period. This equates to an annual mean temperature increase of  $0.054^{\circ}\text{C}$ .
- Minima: from  $-9.9^{\circ}\text{C}$  to  $-4.4^{\circ}\text{C}$ , a rise of  $5.5^{\circ}\text{C}$  over the 90-year period. This equates to an annual minimum temperature increase of  $0.061^{\circ}\text{C}$ .

Again applying bias corrections to these datasets based upon the observations, which have reduced to very small values of zero  $^{\circ}\text{C}$  (minimum) to  $1.0^{\circ}\text{C}$  (maximum) for this month, as shown in Figures DT11a, b and c, adjusts the predicted temperature changes for the month of January for the period from 1970 to 2060 to the following values:

- Maxima: from  $-4.8^{\circ}\text{C}$  to  $-0.6^{\circ}\text{C}$ , a rise of  $4.2^{\circ}\text{C}$  over the 90-year period.
- Mean temperatures: from  $-7.4^{\circ}\text{C}$  to  $-2.5^{\circ}\text{C}$ , a rise of  $4.9^{\circ}\text{C}$  over the 90-year period.
- Minima: from  $-9.9^{\circ}\text{C}$  to  $-4.4^{\circ}\text{C}$ , a rise of  $5.5^{\circ}\text{C}$  over the 90-year period.

The climate models show an important shift in the temperature regime at this time of the year as the warming becomes significantly faster than for the summer months. The climate model indicates there would be significant delays in the starting time for snow accumulations and for the lakes to start to freeze. Although the modelling does show

there will still be some years in the future when the mean monthly temperature is close to the current values, they become increasingly less common. By around the year 2020 there are indications that the mean monthly temperature could be within 1°C of freezing, which is a significant warming within only just over a decade. It would become increasingly likely that less snow would accumulate on the ground during this month through the future climate period due to these rapid rises in temperature. The predicted rises in minimum temperature are also faster than those forecast for the maximum temperatures which would exacerbate this effect. Towards the end of the future climate period, mean monthly temperatures are no longer expected to drop below -3°C and are likely to start to be above zero for some years.

Based upon the predicted temperature rises, the expectation would be for fewer snow events with more precipitation falling as rain, which is also harmful for snow and ice formation.

### ***Annual***

Finally, the trends in the annual minimum, mean and maximum temperatures for Diavik are shown in Figure DT27a for the ensemble mean of the models and in Figure DT27b for the model closest to the ensemble mean. Both of these approaches give very similar trends for this location. These are the trends normally used to quantify, in the simplest of terms, the effects of climate change at a given location. Smoothed over an entire year, the predictions show a relatively constant rate of increase in temperature over the coming decades, although periods of climate variability are evident throughout the climate predictions. The inter-annual and multi-decadal oscillations are not as pronounced as they are for the individual months as they are not aligned throughout the entire year and tend to cancel each other out over time. On almost all occasions the annual temperatures (maximum, mean and minimum) lie within 2°C of the expected temperature, as indicated by the linear trend line.

The linear trend line provides a good estimate of the long-term warming trend. Using this trend line, the predicted temperature changes, from 1970 to 2060, can be quantified as follows:

- Maxima: from  $-4.8^{\circ}\text{C}$  to  $0.7^{\circ}\text{C}$ , a rise of  $5.5^{\circ}\text{C}$  over the 90-year period. This equates to an annual maximum temperature increase of  $0.061^{\circ}\text{C}$ .
- Mean temperatures: from  $-8.0^{\circ}\text{C}$  to  $-3.0^{\circ}\text{C}$ , a rise of  $5.0^{\circ}\text{C}$  over the 90-year period. This equates to an annual mean temperature increase of approximately  $0.056^{\circ}\text{C}$ .
- Minima: from  $-12.2^{\circ}\text{C}$  to  $-6.8^{\circ}\text{C}$ , a rise of  $5.4^{\circ}\text{C}$  over the 90-year period. This equates to an annual minimum temperature increase of approximately  $0.060^{\circ}\text{C}$ .

Applying the annualized bias corrections to these dataset, again based upon the observations, shown in Figures DT14a, b and c, adjusts the predicted temperature changes for the month of January for the period from 1970 to 2060 to the following values:

- Maxima: from  $-8.3^{\circ}\text{C}$  to  $-2.8^{\circ}\text{C}$ , a rise of  $5.5^{\circ}\text{C}$  over the 90-year period.
- Mean temperatures: from  $-11.0^{\circ}\text{C}$  to  $-6.0^{\circ}\text{C}$ , a rise of  $5.0^{\circ}\text{C}$  over the 90-year period.
- Minima: from  $-14.7^{\circ}\text{C}$  to  $-9.3^{\circ}\text{C}$ , a rise of  $5.4^{\circ}\text{C}$  over the 90-year period.

These temperature rises are likely to have a significant impact upon the way of life and ecology of the Diavik Yellowknife region as this still amounts to a significant warming, one of the highest in the world, and one that would greatly reduce the length of the very cold snow season. The length of time that the lakes would be frozen to sufficient depth to be used as ice roads would almost certainly be greatly reduced. Someone more familiar with ice roads should be consulted to quantify the extent of these reductions based upon the data provided here.

It should be emphasized that, as marked as these temperature rises are, these are not the end points of climate change. Beyond this period of time, the temperatures would be expected to continue to rise, although the rate at which they rise will be determined, to a large extent, by what happens to the global rate of greenhouse gas and aerosol emissions over the next couple of decades. For the future climate scenario used in this series of climate predictions, which is the one considered to be the most likely future climate outcome, the region surrounding Diavik are showing a marked trend towards



increasing temperatures, particularly for minimum temperatures, with sustained and increasing impacts to be expected upon the communities and ecology of the region.

### ***Climate Periodicities – Wavelet Analysis***

The periodicities and oscillations in the temperature record for Diavik have been analyzed through the use of wavelet analyses. These analyses and their interpretations are to be found in the document entitled Diavik Wavelet (Appendix A).

## ***2.2 Future Precipitation Changes***

In the following sections the results of a series of analyses using data from all six of the ensemble members are presented, covering precipitation predictions from 1970 through to 2060. In the first section the results of the models are validated against the observed rainfalls for the Diavik area using Environment Canada's climatological data for the Ekati and Lupin A weather stations, and the limited Rio Tinto Diavik weather station data. In the following section the future climate predictions are presented.

### ***2.2.1 Precipitation Validation***

In this section the ensemble control mean rainfall for the period 1970-2006 for the Diavik grid box is used as the principle reference precipitation for trend analysis purposes. The precipitation used is the total precipitation from liquid rainfall and the water equivalent of snow fall and is the values obtained from across the grid box, rather than being a point measurement, which is the observed precipitation. Results from all six of the model members are also shown in the form of the driest and the wettest of the climate model predictions in order to provide an indication of the variability of the rainfall at this location and the potential extreme precipitation events, both wet and dry, on monthly time scales.

The lowest line shows the predictions from the driest of the six models for each of the model validation years with one graph for every month of the year. The lowest predicted precipitation for any given year could come from any one of the six models and is almost certain to change from one model to another from one year to the next. The lowest

precipitation, labeled “Driest Model” on the graphs, therefore identifies what is likely to be the lower bounds for the rainfall regime for that month in any given year. It can be seen from the plots that there can be a large separation between the highest and lowest precipitation for many of the model years, indicating the Diavik area experiences a quite variable precipitation regime with very large fluctuations possible from one year to the next. The highest line on the graphs, labeled “Wettest Model”, shows the heaviest predicted precipitation for that month and year from the six ensemble model members. Again the highest precipitation could be from any one of the six climate models and the highest predictions could and does vary from one model member to another from one year to the next and from one month to the next. A detailed analysis of the model outputs shows that some of the climate model members are better able to predict the precipitation climate of this region than the others. The heaviest precipitation is normally predicted best by those models with the cloud physics that is best able to simulate frontal precipitation processes that produce the heaviest precipitation at this location. Conversely, the models that predict the lightest rainfall (for example drizzle, snow and ice crystals) would be from a different set of climate models. The area between the highest and lowest model predictions is shaded light blue in order to show the model spread of the rainfall predictions.

In the earlier section on observed precipitation for the Diavik area, the precipitation regime was shown to be highly seasonal with considerable variability from month to month and year to year. The difficulty in accurately measuring snowfall in a location exposed to wind was also noted. The mean values of the models and the spread of the six model members are used to quantify the rainfall regime throughout the validation periods. Ideally the observed precipitation would lie within the envelope of predictions from the wettest to the driest of the climate model members and the mean of the two distributions would be identical. Precipitation is a highly variable quantity in both space and time, subject to geographically-produced very localised enhancements or reductions (rain shadow and lake snow enhancement effects). Hence it is to be expected that the simplified physics employed within the climate model would not be able to replicate the finer detail of the precipitation climate. However, the trends identified by the climate model predictions should serve as a useful guide as to the likely future nature of the

precipitation regime in this region, with bias corrections applied to the model data where these can be identified with confidence.

In Figures D2 to D14 comparisons are presented in graphical form between the modelled precipitations for the 20km square grid box surrounding Diavik against the corresponding observed precipitation, where there are sufficient observational records available, for each of the twelve months of the year and annually. The Ekati precipitation data is shown as the red dots connected by red lines, Lupin A as the purple lines and dots and the Ekati data as orange lines and dots. The ensemble mean model data represented in dark green dots on the graph. The spread between the highest and lowest model predictions is coloured pale blue. Linear trend lines are also included for both the observed Lupin A precipitation, being the only station of the three with a reasonable length of climate record, and the data from the ensemble mean of the climate model runs.

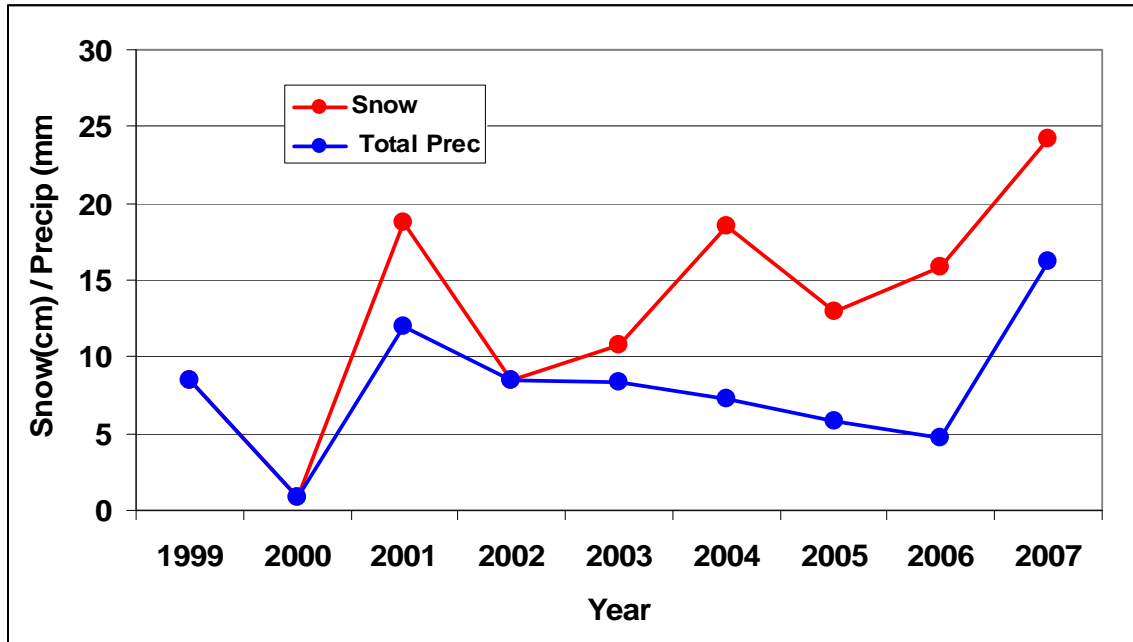
The heaviest observed precipitation at Diavik would be expected to generally lie below a curve connecting the highest points from the wettest of the climate models, with the exception that the one or two most extreme precipitation events could be expected to lie above this curve. This is because the precipitation measured at the three observation stations used in this comparison are from point locations whereas the model produces rainfall across a region 20km x 20km, or over approximately 400km<sup>2</sup>. Running the model at very high horizontal resolution (e.g. 500m) and with complex cloud physics would better define the true nature of the potential rainfall extremes but this is computationally too expensive at the present time.

The best way to quantify the model predictions of precipitation is through the use of the ensemble mean rainfall or, in cases where one of the climate model members is very well configured to represent the precipitation regime experienced at Diavik, the model closest to the ensemble mean. The ensemble mean precipitation is the average precipitation from the six climate models, calculated on a monthly basis throughout the entire period of the climate model runs. Although the ensemble means smoothes out the variability caused by the heavy and light precipitation events that are a feature of the climate of this region, experience has shown that it normally provides a very good

estimate of the typical precipitation of the region under investigation on monthly and annual bases. The middle month of each season will now be discussed in detail, although there will be a little discussion of some of the intermediate months as well.

In January, the comparisons between the climate models and the Diavik region (i.e. Ekati, Diavik and Lupin A) precipitation observations are shown in Figure D2. From the graph it can be seen that the ensemble mean quantity of total precipitation tends to be above the Lupin A and Ekati precipitation records but is closer to the limited data available for Diavik itself. Of the 8 Januarys of data available there are three years above the average and five below. The lowest Diavik precipitation record is similar to the lowest precipitation of the driest climate model and the highest precipitation matches the wettest model well. Lupin A tends to be consistently drier, as does Ekati. This could be a feature of the precipitation regime of the area or it could be related to the catch efficiency of the snow gauges at this time of the year. The trend line for Lupin A shows a decline although with heavier rainfalls indicated in the Diavik data for 2007 and 2008 (no data available for Lupin A for these two years) the trend line would most likely flatten out and possibly increase if there was a corresponding increase in precipitation. There is also a change from rapidly fluctuating relatively high then low then high precipitation values at Lupin A through to 1993 after which time the plot changes to one of remarkably small year to year fluctuations. This is often a sign of changing instrumentation exposure or a site change rather than a true climate change. However, the siting and exposure history for these stations are unknown and hence this cannot be confirmed. There is insufficient data for Ekati and Diavik for any form of trend analysis, although it is interesting to note Diavik has had a run of relatively wet Januarys in recent years, noting that this is a very dry month overall. The climate model predicts a gradual increase in precipitation from near 17mm in 1970 up to 19mm in 2008, a rise of 10.5%, with similar increases for both the wettest and driest of the climate models. The observed total precipitation in the graph, which is the recorded quantity of melted snow from the Environment Canada records, needs to be treated with caution, partially for the reasons mentioned previously, but also due to the way in which recorded snow fall is converted into equivalent precipitation.





*Figure 5: Observed snow and the corresponding melted snow (total precipitation) for January for Ekati from 1999 to 2007. Data courtesy of Environment Canada.*

At Ekati, for example, this conversion has been handled differently from month to month and year to year, as the graph in Figure 5 and the data in Table 3 shows. Although the technique could make allowances for changes in snow density, it is more likely there have been a variety of techniques used in the way the snow is gathered and melted through the observational record through to the current time. The original snow measurements show a marked increasing trend in snowfall whereas the snow converted into liquid precipitation shows a much lower trend. The snow to liquid precipitation ratio has a remarkably large range, from 1.0 up to 3.4 (in January 2006). The same issues were noted at some other locations across Canada and for other months. It should be noted the climate model does not suffer from altered observational practices as do the original observations. Hence the trends and model biases based upon precipitation measurements which include a snowfall component have to be treated very cautiously. From this information it would be concluded the climate model replicates the Diavik January total precipitation very well.

| Year | Snow | Total<br>Precipitation | Ratio |
|------|------|------------------------|-------|
| 1999 | 8.5  | 8.5                    | 1.0   |
| 2000 | 0.8  | 0.8                    | 1.0   |
| 2001 | 18.7 | 12                     | 1.6   |
| 2002 | 8.5  | 8.5                    | 1.0   |
| 2003 | 10.8 | 8.4                    | 1.3   |
| 2004 | 18.5 | 7.2                    | 2.6   |
| 2005 | 13   | 5.8                    | 2.2   |
| 2006 | 15.9 | 4.7                    | 3.4   |
| 2007 | 24.2 | 16.2                   | 1.5   |

**Table 3: Observed snowfall and subsequently derived total liquid precipitation for Ekati for January, together with the snow to liquid precipitation ratio. Data courtesy of Environment Canada.**

For the month of February the limited Diavik total precipitation record fits in well with the ensemble mean modelled precipitation with the wettest and driest months also fitting within the range of ensemble model predictions. It is apparent that Lupin A tends to have more dry months than the other two locations. The Ekati data continues to be affected by an inconsistent approach to the conversion of snow into liquid precipitation. For this month, arguably the driest time of the year, the climate model predicts a smaller increase in precipitation, being a rise of just under 1 mm over the 38 years of the validation period. The reliability of the trend from Lupin A is still subject to an insufficient length of good quality data as the trend is reversed for the following month of March. Diavik data is again well calibrated to the model mean data for the month of March. The heaviest recorded precipitation events for Lupin A and Ekati appear to match the predictions from the wettest climate model well.

The same issues affect the Ekati comparisons for April with most of the precipitation falling as snow. Table 4 shows how great the variations are in the conversion of snow into liquid precipitation for this month, which makes the Ekati plot in the graph open to question as a conversion rate close to 1.0 would have removed the apparent low bias in this dataset. The limited Diavik data fits in well with the ensemble mean and spread once more. For this month the trend for the Lupin A data is almost identical to that of the driest

of the climate model members, indicating there could be a believable trend starting to emerge from the observational data at this time of the year. The heaviest Lupin A and Diavik falls also match those of the wettest climate model well.

| Year | Snow | Total Precipitation | Ratio |
|------|------|---------------------|-------|
| 1999 | 11.8 | 11.8                | 1.0   |
| 2000 | 5.4  | 5.1*                | 1.1   |
| 2001 | 8.7  | 2.4                 | 3.6   |
| 2002 | 5.0  | 4.4                 | 1.1   |
| 2003 | 21.1 | 8.8                 | 2.4   |
| 2004 | 9.2  | 2.5                 | 3.7   |
| 2005 | 10.7 | 9.9*                | 1.1   |
| 2006 | 17.5 | 7.3*                | 2.4   |
| 2007 | 10.9 | 9.2*                | 1.2   |

**Table 4: Observed snowfall and subsequently derived total liquid precipitation for Ekati for April, together with the snow to liquid precipitation ratio. Data courtesy of Environment Canada. \* indicates rain has been added to this total for consistency purposes.**

For the month of May the precipitation at Diavik is becoming dominated by liquid rainfall with the problems associated with snowfall becoming less of an issue. The Diavik observations show a high level of year to year variability, including one fall heavier than anything recorded at Ekati and Lupin A for this month. It is also slightly higher, around 4mm, than the highest precipitation predicted by the wettest of the climate model members. The Lupin A data continues to be consistently drier than Diavik and the ensemble mean model with little trend through the future climate period. Of significance are the large variations between the observed precipitations for the three stations at times when there is an overlap of their observations, confirming the inherently variable nature of the precipitation in the Diavik region at this time of the year. Overall the ensemble mean provides a realistic representation of the likely precipitation for this area, although probably with a slight wet bias.

For June the available Lupin A data more closely matches the ensemble mean, wettest and driest rainfall data and shows a similar trend of little change in precipitation over the

available length of record. In contrast to the Lupin A data, the limited Diavik rainfall record indicates the development of a dry bias with Ekati also generally being drier than the ensemble mean model, apart from a lone very heavy rainfall event. If the Diavik data is considered a true indication of the long term average then a bias correction should be applied to the ensemble mean model data. However, the ensemble mean average precipitation is relatively close to that of Lupin A (30mm) and Fort Reliance (30.5mm) and so the difference between the two datasets could be a function of natural climate variability or a localised micro-climatic effect at Diavik.

For the mid summer month of July the ensemble mean of the climate models appears to be quite close to the mean of the observed Diavik rainfall with the wettest and driest models also matching the available observations well. The Lupin A mean rainfall also agrees well with the model data although the linear trend line is unrealistic, biased by the combination of three wet years near the start of the observational record and three dry ones at the end. This trend is markedly different to that seen in June and August. The Ekati data also seems close to both the Diavik and model data for this month, one in which snowfall plays no role.

In August the model data appears to have a dry bias of approximately 15mm when compared to the Diavik rainfall data. Lupin A appears to be even wetter, although it is interesting to note that the Lupin A data appears to be markedly different to both Diavik and Ekati for many of the years where the datasets overlap, indicating this location may not truly represent the Diavik region's precipitation regime.

There is a reduced dry bias in the model data for the month of September, down to around 10mm for the three observation stations. The observations also show greater variability than the wettest and driest climate models, indicating the model is likely to underestimate the magnitude of extreme precipitation events at this time of the year. Both the model and Lupin A data show an almost horizontal trend, or no change in the rainfall regime for this month through the validation period.

October is the month when snowfall once again dominates the precipitation figures. The model bias appears to vanish at this time of the year with the ensemble mean



precipitation close to that of the observed Diavik precipitation, slightly below that of Lupin A and above that of Ekati, which appears to have problems with conversion into liquid precipitation for months when snowfall is a significant part of the record. The Lupin A trend is again almost flat, although it shows an increase in November. The ensemble mean model data indicates a gradually increasing trend, primarily due to greater amounts of precipitation predicted through the 2000's. This trend returns to one of little change in November, indicating this could be a function of natural climate variability rather than a true long term rise.

It is difficult to determine if there is a model bias at Diavik for the month of November. The limited observations at Diavik show good agreement with the ensemble mean precipitation until three wet years appear from 2005 through to 2007. Ekati and Lupin A remain well below Diavik for months where there is data and either match or are below the ensemble mean model data, raising a question as to whether these were atypical very heavy falls, local effects or a true reflection of the Diavik climate. These extremes of rainfall do not appear in the Diavik December precipitation record with all three observing stations tending to be around 5mm drier than the modelled precipitation. This could be considered a wet model bias for this month of the year. The trends and the observed extremes in precipitation match those of the climate models to a pleasing extent. The problems associated with increasing quantities of snowfall have to be considered at this time of the year, of course.

The annual climate model predictions of total precipitation for Diavik and the observed rainfalls for the three observing stations are shown in Figure D14, together with linear trend lines for the model and Lupin A data. The climate model predictions are for very slightly increasing precipitation, in good agreement with the annual trend for Lupin A. The limited Diavik data is in very good agreement with the ensemble mean model data with a minor dry bias evident in the Lupin A data. Ekati appears drier than the model but this could be attributed to the inconsistent conversion procedure used for snowfall.

So it can be concluded that, provided the observational record is treated correctly and with appropriate caution, the historical precipitation data and the climate model data agree to a satisfying degree. Bias corrections improve the correlations between the

climate model data and individual months, although these bias corrections change in sign and magnitude from month to month with several months requiring no bias correction at all. The level of agreement between the observations and the climate models is best when viewed on seasonal and annual time scales as the effects of natural climate variability on time scales as short as a month can provide misleading trends, even when twenty five years of records are used.

### ***2.2.2 Future Climate Precipitation Predictions***

Next the future climate rainfall predictions out to the year 2060 are analyzed. Once again the data from the six ensemble models and the ensemble mean were used. The time series of modelled monthly rainfalls from 1970 through to 2060 are shown in Figures D15a (model closest to the ensemble mean) and D15b (ensemble mean, wettest and driest of the climate models) through to D27 for Diavik. Both sets of graphs have linear and polynomial trend lines included for the model mean data. The same colour schemes are used for these future climate predictions as were used for the validation period. No bias corrections have been applied to these datasets to adjust them to match the observed data precisely as some of the values to use for the bias corrections are subject to interpretation and also it is the trends that are important.

The data shows strong evidence of inter-annual and decadal variability with the sixth order polynomial trend line highlighting the multi-decadal oscillations in the rainfall climate. The wavelet analysis discussions for Diavik should also be consulted when looking at trends in the climate oscillations. Overall, despite the presence of these oscillations, the linear trend line appears to represent the long-term changes in the monthly total precipitation well, even though the linear trend lines have been shown to be misleading even over periods of close to 40 years duration in some circumstances. The climate model predictions for all twelve months are shown in the Attachments and spreadsheets. For brevity, the discussions that follow will again focus on the middle month of each season, with references to the other months where these illustrate a point of particular interest.

## **January**

The climate model predictions for Diavik show a continuation of a highly variable, though relatively low, rainfall regime for the winter months with an identifiable multi-decadal signal, illustrated by the polynomial trend line. This oscillation continues through to the end of the future climate prediction period and is super-imposed upon the linear trend. The linear trend line from the ensemble mean model shows an increasing trend although the polynomial trend line shows a plateauing of the precipitation from around 2020 onwards with a very minor decline towards the end of the prediction. The ensemble minimum rainfall predictions show a slight upwards trend as well with the largest change indicated by the wettest of the model members with more frequent heavier falls predicted. The driest year of all is a predicted fall of near 5mm in climate model year 1970 and it is not until model year 2026 when this low precipitation prediction is approached with a fall of 5.5mm forecast.

Using the linear trend line as the reference for the long-term trend in precipitation, it can be seen that the mean monthly precipitation is predicted to be around 17 mm in the year 1970, increasing to around 21 mm by the year 2060. This represents a rise of 4 mm per January by the year 2060, which equates to an increase in the mean precipitation by the year 2060 of close to 24%, compared to that of the years near 1970. In average terms this is a very slow increase of around 0.04mm for each successive January. The climate models show an increase in the quantity of the heaviest precipitation events through the future climate period from around 32mm for the validation period out to 2007 up to 41mm for the future climate period. There is also a predicted increase in their frequency. For example, looking at the events where 30mm or more precipitation is predicted by the wettest of the climate models, only three events are indicated for the first 30 years of the predictions, nine events are predicted for the next 30 years and ten events of 30mm or more are predicted from 2030 onwards. The differences in their magnitudes are considered to be modest in modelling terms but with some confidence in the increasing trend. This indicates the future climate regime will support heavier snowfalls than does the current climate regime for January, with an increasing frequency of these heavier snowfalls in the future climate.

For the month of February, the predicted increases in Diavik's mean and extreme precipitation is similar to that for January whereas in March the slight increasing trend continues for the mean precipitation but the changes in the extreme snowfalls are less compelling.

### ***April***

April is still in a precipitation regime dominated by snowfall but one where rainfall starts to become more important for the Diavik region. With the predicted warming of the temperatures through the future climate period rainfall can be expected to increase in frequency and intensity as time progresses. The driest of the climate model members indicates little change in the lowest of the precipitation events with predictions in the future equal to, even slightly less than, those for the validation period. The linear trend line for the ensemble mean model predictions shows a gradual increase from around 19.5 mm in the year 1970 to around 22.5 mm by the year 2060. This represents a rise of 3 mm per April by the year 2060, which, due to the low precipitation quantities involved, equates to an increase in the mean precipitation by the year 2060 of close to 15%, compared to that of the years near 1970. The wettest of the ensemble model members does predict a heavier precipitation event in the future (44mm) than those for the model validation period (37mm) with a slight increase in the frequency of these more extreme events.

These trends appear to accelerate for May, the first month there liquid precipitation dominates at Diavik with the climate models predicting a future climate of gradually increasing mean and extreme precipitation totals. The mean precipitation is predicted to rise from near 26mm in 1970 up to around 34mm in 2060, an increase of 8mm or 31% over the length of the climate prediction. The extreme monthly rainfall is predicted to climb from around 57mm through the validation period to around 65mm in the future climate environment with a corresponding increase in frequency.

For June the long term mean is not predicted to change significantly through the future climate period although the wettest months are forecast to increase from around 65mm up to 83mm into the future.



## ***July***

The future climate model predictions for July for Diavik reverse the trends of the earlier months with a gradual decline in mean precipitation forecast. The climate model predictions are for a decrease in rainfall from an average of near 38mm in 1970 to near 35mm by 2060. This 3mm decrease in rainfall amounts to an 8% decline in precipitation over 90 years, an annual rate of decrease of a very small 0.03mm/year. The climate model predictions indicate a decreasing frequency of extreme heavy rainfall events, although the two heaviest July rainfall predictions lie in the future climate period, indicating new extremes of heavy rainfall are possible in the future climate period. The wettest of the climate models predicts a fall of near 95mm in the future climate period near model year 2052 compared to 84mm in the validation period. Although not a major trend, the driest of the climate model predictions tend to indicate dry months slightly drier than those of the historical past are likely in the future climate regime.

This reduction in future rainfall appears to be confined to the month of July as in August the ensemble mean model predictions return to one of increasing mean and heavier rainfalls.

## ***October***

October is one of the transition months back into a regime where snowfall becomes increasingly important. At Diavik the driest of the climate models predicts a gradual increase in the lowest rainfalls, indicating extremely dry Octobers are likely to become less frequent than those experienced in the past. The linear trend is for a gradual increase in total precipitation with the average rising from near 30mm in 1970 to around 40mm by the year 2060. This 10mm increase amounts to a significant 33% change in mean monthly precipitation over 90 years, or an annual rise of 0.11mm/year. The wettest of the climate models predicts an increase in the frequency of the wettest Octobers in the future although the quantity of precipitation is not shown to rise. The change in driest Octobers is predicted to be slight through the future climate period.

In November a similar increasing trend is predicted with the extreme wet years also forecast to increase in both frequency and intensity.

December is predicted to have one of the greatest change with the ensemble mean precipitation forecast to rise from around 18mm in 1970 up to 25.5mm by the year 2060, an increase of 7.5mm, which equates to a very large, in percentage terms, rise of near 42% for the month. The wettest December is also predicted to jump from around 45mm through the validation period up to around 65mm in the future climate.

### ***Annual Precipitation***

The Diavik annual precipitation trends from the ensemble mean of the climate models is shown in Figure D27. The ensemble mean model prediction is for an increase in precipitation from around 310mm in the year 1970 up to around 360mm by the year 2060, an increase in annual precipitation of around 50mm, or approximately 16%. There is a marked multi-decadal oscillation in the future climate predictions, indicating this change will not be a steady increase but rather one interrupted by large excursions from the mean. There is a marked leveling off of the precipitation increases indicated through the future climate period beyond around model year 2025. The predictions indicate there will be fewer dry years in the future and a trend towards gradually increasing extremely wet years, by Diavik standards, although this region will still only have relatively modest precipitation through the future climate period in comparison to warmer regions of the world. The wettest years tend to occur as lone events, as are the predicted driest years.

### ***2.2.3 Precipitation Periodicities***

A separate appendix has been prepared that summarizes the periodicities in the precipitation climate record for Diavik. This should be referred to in order to identify climate model predicted changes to the variability of this record.

### **3.0 Conclusions**

An ensemble of six future Coupled Global Climate Model runs were analyzed and the mean used for determining likely future trends in the climate for the northern Canadian region, specifically Diavik and the ice road connecting it to the Great Slave Lake. The results of these analyses are detailed in the body of this report and its' attachments. The Executive Summary contains a summary of the more important findings of these analyses.

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October 8, 2010

**Re: Diavik Underground Backfill**

Diavik Diamond Mines Inc. (DDMI) would like to advise you of our immediate plans for underground backfilling. As you are aware different underground mining methods and different kimberlite pipes have different geotechnical requirements for backfilling mine openings in the kimberlite ore. The specific composition of each type of backfill will be determined based on the specific geotechnical requirements. A large component of backfill is mine wasterock.

For the next 12-18 months DDMI is planning to use the wasterock, from underground development work, to prepare a cemented rock fill (CRF). DDMI has identified possible concerns with cement curing when mixed with low temperature wasterock. To eliminate the need to warm the wasterock from the open-pit or wasterock pile, and the associated energy consumption, use of wasterock from underground that is already above 0°C has been proposed. To meet the tonnage requirements both Type I and Type III underground wasterock will be required.

DDMI has previously evaluated the geochemical implications of using Type III wasterock in underground backfill. These evaluations were conducted because over the long term it is preferable geochemically to encapsulate Type III material in cement and place it underground as compared with having it exposed on the surface. However, DDMI also wanted to ensure there would not be any significant impacts on operational water quality.

The evaluation consisted of two phases; a) geochemical testing, and b) water quality modeling.

*Geochemical Testing*

Wasterock samples were taken from the Type I and Type III dump areas, crushed to < 2" diameter and mixed with 5% cement. After 28 days of curing the samples were sent to CEMI in Vancouver B.C for the following analysis:

- Acid-Base Accounting (ABA)



- Whole rock and Bulk metal Analysis on Solids
- Short Term Leach Testing
- Mineralogical Analysis

The short term leach testing results were used in the water quality modeling.

*Water Quality Modeling*

A mass-balance geochemical model was used to estimate the mine water quality once the seepage water from underground workings and the water from the open pit sumps have been mixed to produce a final mine water. The model consists of a number of source components (i.e. underground seepage, open-pit sumps, etc.) that are linked together to define a mass transport system. Each source component was assigned a flow (based on flow modeling) and water chemistries that together define the load contribution from each component.

The following Tables provide the model inputs used to define each source component. These inputs remained constant in all model scenarios.

- Table 2 – Flow rates assumed for open-pits, ramps, vents and drainage drifts and the water origin (groundwater versus lake water).
- Table 3C – Groundwater quality assumed for groundwater inflows.
- Table 3D – Lake water quality assumed for lake water inflows.
- Table 4 – Pit sump water quality assumed for open-pit sump inputs

Numerous scenarios were run using the inputs as defined above but varying the quality of the leach water from the backfill material. Table 1 lists all the backfill scenarios that were modeled. Several different types of backfill were modeled using both a high seepage rate from the backfill and a low seepage rate. Of relevance here are Scenarios 2, 9, and 18. Scenarios 9 and 18 use the leaching rates from the geochemical testing of the cemented rock fills (CRF) made with material from the Type I and Type III stockpiles respectively (see above) and the higher seepage rates (worst-case).

As it turns out, results of the out whole rock testing of the samples collected from the Type I and Type III stockpiles both had sulphur contents of 0.06%S meaning they are both actually representative of Type II rock using DDMI’s classification. However, they are ideal for the purpose of evaluating implications of the plan to use a mixture of Type I and Type III wasterock from underground as 0.06%S would likely be a reasonable estimate of the bulk sulphur content for the underground waste material.

Scenario 2 is a worst-case geochemical scenario. It assumes a backfill leach quality estimated from the baseline long-term kinetic tests run on biotite schist with a sulphur content of 0.16%S. It is included to both illustrate a worst-case condition but also the relative insensitivity of the final water quality to the backfill leach quality. Table 5 lists the actual backfill leach water quality used to represent each of the backfill material types.

Table 6 shows the predicted mine water quality for each of the backfill options modeled. Despite differences in backfill leach water quality, the final mine water quality is unchanged because the final chemistry is dominated by the groundwater reporting to the drainage galleries.

*Conclusion*

There are environmental benefits to including Type III wasterock from underground to prepare backfill material for underground. This includes both the reduction in potential for poor quality surface runoff from surface exposure of Type III rock and elimination of short-term energy required to warm rock for use in underground. No impact on operational mine water quality has been predicted.

Please let me know if you require any further information.

Regards,



Gord Macdonald

Attachments:

- Table 1 – Description of Backfill Scenarios Modeled
- Table 2 – Flow rates assumed for open-pits, ramps, vents and drainage drifts.
- Table 3C – Groundwater quality assumed for groundwater inflows.
- Table 3D – Lake water quality assumed for lake water inflows.
- Table 4 – Pit sump water quality assumed for open-pit sump inputs
- Table 5 – Backfill leach water quality assumed for modeling.
- Table 6 – Modeling results for various backfill materials.

**TABLE 1****SCENARIOS MODELED: BACKFILL TYPES AND PERCENTAGE OF BACKFILL SEEPAGE  
DIAVIK DIAMOND MINE**

| <b>Backfill Type</b>                                     | <b>Percentage of Water from Backfill <sup>(1)</sup></b> | <b>Scenario Number</b>     |
|--|---|----------------------------|
| Acid Generating (AG) Rock - Sulphide-rich Biotite Schist | 0.1%  | Scenario 1                 |
|  | 10%   | Scenario 2                 |
| Type I Stockpile - Coarse Rock                           | 0.1%  | Scenario 3                 |
|  | 10%   | Scenario 4                 |
| Type I Stockpile - Paste Fill w/ 5% Cement               | 0.1%  | Scenario 5                 |
|  | 10%   | Scenario 6                 |
| Type I Stockpile - Paste Fill w/ 5% Intercem             | 0.1%  | Scenario 7                 |
|  | 10%   | Scenario 8                 |
| Type I Stockpile - Rock Fill                             | 0.1%  | Scenario 9                 |
|  | 10%   | Scenario 10                |
| Type III Stockpile - Coarse Rock                         | 0.1%  | Scenario 11                |
|  | 10%   | Scenario 12                |
| Type III Stockpile - Paste Fill w/ 5% Cement             | 0.1%  | Scenario 13                |
|  | 10%   | Scenario 14                |
| Type III Stockpile - Paste Fill w/ 5% Intercem           | 0.1%  | Scenario 15                |
|  | 10%   | Scenario 16                |
| Type III Stockpile - Rock Fill                           | 0.1%  | Scenario 17                |
|  | 10%   | Scenario 18 <sup>(2)</sup> |

**Notes:**

(1) Percentage of water from backfill:

(i) 0.1% Low flow – assumes that consolidation of backfill seepage will result in release of 0.1% of the total flow reporting to the drainage galleries.

(ii) 10% High flow – assumes that consolidation of backfill seepage will result in release of 10% of the total flow reporting to the drainage galleries.

(2) Scenario 18 was also simulated with the effect of upwelling of saline groundwater to the drainage galleries.

**TABLE 2**  
**FLOW RATE SCHEDULE FOR OPEN PITS, RAMPS, VENTS AND DRAINAGE DRIFTS**  
**DIAMIK DIAMOND MINE**

| Flow Source                | Annual Average Flow Rates (m <sup>3</sup> /d) |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
|----------------------------|---|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                            | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  | 2020  | 2021  | 2022  |
| A154 Pit                   | 16000   | 1600  | 1200  | 1100  | 1100  | 1100  | 1000  | 1000  | 1000  | 1000  | 900   | 900   | 1000  | 900   | 900   |
| A418 Pit                   | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  | 1000  |
| Ramps                      | 1500  | 1600  | 1500  | 1400  | 1400  | 1800  | 2300  | 2200  | 2600  | 2500  | 2400  | 2400  | 2400  | 2500  | 2500  |
| Vents                      | 1800  | 1700  | 1300  | 1200  | 1100  | 1000  | 900   | 700   | 600   | 500   | 500   | 500   | 600   | 500   | 500   |
| <b>A154N Drifts</b>        |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 9225 m                     | 500   | 1700  | 1000  | 800   | 700   | 700   | 700   | 700   | 700   | 600   | 600   | 600   | 700   | 700   | 700   |
| 9150 m                     | 900   | 15900 | 15200 | 11600 | 11500 | 11500 | 11400 | 11300 | 11300 | 11200 | 11200 | 11200 | 11300 | 11300 | 11300 |
| 9075 m                     | 300   | 400   | 1000  | 8900  | 9000  | 9000  | 8900  | 8900  | 8800  | 8800  | 8800  | 8800  | 8900  | 8900  | 8900  |
| 9000 m                     | 0   | 900   | 1000  | 700   | 700   | 700   | 700   | 600   | 600   | 600   | 600   | 600   | 600   | 600   | 600   |
| 8925 m                     | 0   | 0     | 0     | 5900  | 5400  | 5100  | 3900  | 1700  | 1600  | 1400  | 1300  | 1400  | 2400  | 2900  | 2800  |
| 8850 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 1200  | 1900  | 1800  | 800   | 1000  | 1100  | 1500  | 1600  | 1600  |
| 8775 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 0     | 500   | 600   | 900   | 900   | 1200  | 2100  | 2100  | 2200  |
| 8700 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 0     | 1300  | 1200  | 1300  | 1300  | 2700  | 1100  | 1200  | 1200  |
| 8685 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 4300  | 4000  | 0     | 0     | 0     | 0     |
| <b>A154S Drifts</b>        |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 9075 m                     | 100   | 600   | 400   | 400   | 400   | 300   | 300   | 200   | 200   | 200   | 200   | 200   | 0     | 0     | 0     |
| 9000 m                     | 100   | 9000  | 7800  | 700   | 600   | 600   | 400   | 300   | 200   | 300   | 300   | 300   | 0     | 0     | 0     |
| 8925 m                     | 0   | 0     | 0     | 300   | 500   | 500   | 400   | 400   | 300   | 300   | 600   | 900   | 0     | 0     | 0     |
| 8850 m                     | 0   | 0     | 0     | 0     | 0     | 100   | 900   | 1100  | 1000  | 1300  | 300   | 300   | 0     | 0     | 0     |
| 8835 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 0     | 2000  | 1800  | 0     | 0     | 0     | 0     | 0     | 0     |
| <b>A418 Drifts</b>         |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| 9165 m                     | 1200  | 1200  | 800   | 700   | 700   | 700   | 600   | 600   | 600   | 500   | 500   | 500   | 500   | 500   | 500   |
| 9105 m                     | 1800  | 1800  | 1500  | 1500  | 1500  | 1500  | 1300  | 1200  | 1200  | 1200  | 1200  | 1200  | 1200  | 1200  | 1200  |
| 9045 m                     | 2700  | 2700  | 2300  | 2200  | 2200  | 2000  | 700   | 700   | 700   | 700   | 700   | 600   | 600   | 600   | 600   |
| 8980 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 1700  | 1200  | 500   | 500   | 500   | 500   | 500   | 500   | 500   |
| 8915 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 300   | 300   | 1000  | 900   | 900   | 900   | 900   | 900   | 900   |
| 8850 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 0     | 600   | 700   | 400   | 400   | 400   | 400   | 300   | 300   |
| 8785 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 700   | 700   | 700   | 600   | 300   | 300   | 300   |
| 8760 m                     | 0   | 0     | 0     | 0     | 0     | 0     | 0     | 0     | 100   | 100   | 100   | 0     | 900   | 800   | 800   |
| <b>Underground Sources</b> |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Total Flow                 | 10900   | 37500 | 33800 | 36300 | 35700 | 35500 | 36600 | 38400 | 38800 | 40000 | 39000 | 36900 | 36900 | 37400 | 37400 |
| % Lake Water               | 73  | 75    | 86    | 88    | 90    | 91    | 90    | 86    | 88    | 84    | 89    | 92    | 93    | 93    | 94    |
| <b>All Sources</b>         |   |       |       |       |       |       |       |       |       |       |       |       |       |       |       |
| Total Flow                 | 27900   | 40100 | 36000 | 38400 | 37800 | 37600 | 38600 | 40400 | 40800 | 42000 | 40900 | 38800 | 38900 | 39300 | 39300 |
| % Underground              | 39  | 94    | 94    | 95    | 94    | 94    | 95    | 95    | 95    | 95    | 95    | 95    | 95    | 95    | 95    |

**Note:**

- Flow rates are derived from the July 2007 hydrogeologic numerical model.



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**TABLE 3C**  
**SUMMARY OF MODEL INPUT WATER QUALITY:**  
**GROUNDWATER**  
**DIAVIK DIAMOND MINE**

| Parameter  | Units       | Groundwater Quality <sup>(1)</sup> |
|--|-------------|------------------------------------|
| <b>Total Dissolved Solids (TDS) <sup>(2)</sup></b> | <b>mg/L</b> | <b>500–2800</b>                    |
| <b>Total Dissolved Solids (TDS) <sup>(3)</sup></b> | <b>mg/L</b> | <b>271–2313</b>                    |
| Aluminum (Al)                                      | mg/L        | 0.03                               |
| Ammonia (NH <sub>4</sub> +NH <sub>3</sub> )        | mg/L as N   | 0.06                               |
| Arsenic (As)                                       | mg/L        | 0.005                              |
| Chromium (Cr)                                      | mg/L        | <i>0.005</i>                       |
| Cobalt (Co)  | mg/L        | <i>0.0002</i>                      |
| Copper (Cu)  | mg/L        | <i>0.0008</i>                      |
| Iron (Fe)  | mg/L        | 0.2                                |
| Lead (Pb)  | mg/L        | <i>0.00008</i>                     |
| Manganese (Mn)                                     | mg/L        | 0.09                               |
| Molybdenum (Mo)                                    | mg/L        | 0.009                              |
| Nickel (Ni)  | mg/L        | 0.002                              |
| Nitrate (NO <sub>3</sub> )                         | mg/L as N   | 0.01                               |
| Nitrite (NO <sub>2</sub> )                         | mg/L as N   | <i>0.002</i>                       |
| Phosphorus (P) <sup>(4)</sup>                      | mg/L        | 0.00005–0.2                        |
| Sulphate (SO <sub>4</sub> )                        | mg/L        | 5                                  |
| Uranium (U)  | mg/L        | 0.0002                             |
| Vanadium (V)                                       | mg/L        | 0.0008                             |
| Zinc (Zn)  | mg/L        | 0.007                              |

**Notes:**

*0.0025* – denotes a value that is one half of the detection limit. Concentrations below detection were input into the model as one half of the detection limit.

(1) Groundwater Quality– taken from monitoring data collected from a depth of about 150 mbsl during a pumping test in 2006.

(2) Total Dissolved Solids– determined from the numerical hydrogeological model and considers the effect of upwelling of saline groundwater (Table 3B).

(3) Total Dissolved Solids– determined from the relationship between TDS and depth at Diavik and Lupin Mine sites (Table 3A; Figure 1).

(4) Phosphorous – determined from the relationship between P and depth (Table 3A; Figure 2).

**TABLE 3D**  
**SUMMARY OF MODEL INPUT WATER QUALITY:**  
**LAKE WATER**  
**DIAVIK DIAMOND MINE**

| Parameter                                   | Units       | Lake Water Quality <sup>(1)</sup> |
|---|-------------|-----------------------------------|
| <b>Total Dissolved Solids (TDS)</b>         | <b>mg/L</b> | <b>30</b>                         |
| Aluminum (Al)                               | mg/L        | 0.02                              |
| Ammonia (NH <sub>4</sub> +NH <sub>3</sub> ) | mg/L as N   | 0.05                              |
| Arsenic (As)                                | mg/L        | 0.0003                            |
| Chromium (Cr)                               | mg/L        | 0.0001                            |
| Cobalt (Co)                                 | mg/L        | 0.0003                            |
| Copper (Cu)                                 | mg/L        | 0.001                             |
| Iron (Fe)                                   | mg/L        | 0.01                              |
| Lead (Pb)                                   | mg/L        | 0.0004                            |
| Manganese (Mn)                              | mg/L        | 0.004                             |
| Molybdenum (Mo)                             | mg/L        | 0.001                             |
| Nickel (Ni)                                 | mg/L        | 0.002                             |
| Nitrate (NO <sub>3</sub> )                  | mg/L as N   | 0.03                              |
| Nitrite (NO <sub>2</sub> )                  | mg/L as N   | 0.01                              |
| Phosphorus (P)                              | mg/L        | 0.6 <sup>(2)</sup>                |
| Sulphate (SO <sub>4</sub> )                 | mg/L        | 1                                 |
| Uranium (U)                                 | mg/L        | 0.0004                            |
| Vanadium (V)                                | mg/L        | 0.0004                            |
| Zinc (Zn)                                   | mg/L        | 0.005                             |

**Notes:**

(1) Lake Water Quality – taken from Table 6-16 in DDMI (1998).

(2) Concentration of phosphorous assumed to be 0.6 mg/L. This assumption is based on observations of concentrations of phosphorous from previous pumping test data.

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**TABLE 4**  
**SUMMARY OF MODEL INPUT WATER QUALITY:**  
**OPEN PIT SUMPS**  
**DIAMOND MINE**

| Parameter                                   | Units     | Water Quality Monitoring Data |             |             |                      |                      |                       | Average Open Pit Sump Water Quality <sup>(1)</sup> |
|---|-----------|-------------------------------|-------------|-------------|----------------------|----------------------|-----------------------|--|
|   |           | SUMP 1 2003                   | SUMP 1 2004 | SUMP 1 2005 | NEW SUMP 1 8/26/2006 | NEW SUMP 2 8/28/2006 | NEW SUMP 2B 8/28/2006 |  |
| Total Dissolved Solids (TDS)                | mg/L      | 360                           | 360         | 270         | –                    | –                    | –                     | 330  |
| Aluminum (Al)                               | mg/L      | 7                             | 7           | 0.3         | 0.6                  | 1                    | 1                     | 3  |
| Ammonia (NH <sub>4</sub> +NH <sub>3</sub> ) | mg/L as N | –                             | –           | 3           | 5                    | 9                    | 9                     | 7  |
| Arsenic (As)                                | mg/L      | 0.003                         | 0.003       | 0.003       | 0.003                | 0.004                | 0.004                 | 0.003  |
| Chromium (Cr)                               | mg/L      | 0.02                          | 0.02        | 0.003       | 0.01                 | 0.03                 | 0.03                  | 0.02   |
| Cobalt (Co)                                 | mg/L      | 0.005                         | 0.005       | 0.001       | 0.003                | 0.007                | 0.007                 | 0.005  |
| Copper (Cu)                                 | mg/L      | 0.04                          | 0.04        | 0.003       | 0.007                | 0.009                | 0.009                 | 0.02   |
| Iron (Fe)                                   | mg/L      | 7                             | 7           | 0.5         | 1                    | 3                    | 3                     | 4  |
| Lead (Pb)                                   | mg/L      | 0.003                         | 0.003       | 0.0005      | 0.004                | 0.001                | 0.001                 | 0.002  |
| Manganese (Mn)                              | mg/L      | 0.4                           | 0.4         | 0.1         | 0.04                 | 0.1                  | 0.1                   | 0.2  |
| Molybdenum (Mo)                             | mg/L      | 0.03                          | 0.03        | 0.02        | 0.05                 | 0.03                 | 0.04                  | 0.03   |
| Nickel (Ni)                                 | mg/L      | 0.03                          | 0.03        | 0.02        | 0.06                 | 0.1                  | 0.1                   | 0.07   |
| Nitrate (NO <sub>3</sub> )                  | mg/L as N | 9                             | 9           | 5           | 12                   | 16                   | 17                    | 11   |
| Nitrite (NO <sub>2</sub> )                  | mg/L as N | 0.2                           | 0.2         | 0.1         | 0.8                  | 1.0                  | 0.9                   | 0.5  |
| Phosphorus (P)                              | mg/L      | –                             | –           | 0.4         | 0.3                  | 0.2                  | 0.2                   | 0.3  |
| Sulphate (SO <sub>4</sub> )                 | mg/L      | 8                             | 8           | 6           | 22                   | 19                   | 19                    | 14   |
| Uranium (U)                                 | mg/L      | 0.03                          | 0.03        | 0.01        | 0.005                | 0.007                | 0.007                 | 0.02   |
| Vanadium (V)                                | mg/L      | 0.02                          | 0.02        | 0.003       | 0.003                | 0.005                | 0.006                 | 0.008  |
| Zinc (Zn)                                   | mg/L      | 0.02                          | 0.02        | 0.02        | 0.02                 | 0.006                | 0.008                 | 0.02   |

**Notes:**

0.0025 – denotes a value that is one half of the detection limit. Concentrations below detection were input into the model as one half of the detection limit.

(1) Average Open Pit Sump Water Quality – calculated from monitoring data collected from the open pit sumps from 2003 to 2006. Assumed to represent the water quality of the mixed water from the sumps in A154 and A418 pits.

**TABLE 5**  
**SUMMARY OF MODEL INPUT WATER QUALITY:**  
**BACKFILL LEACH**  
**DIAVIK DIAMOND MINE**

| Parameter                                   | Units       | Acid Generating Rock                        | Type I Stockpile Samples |                      |                        |             | Type III Stockpile Samples |                      |                        |             |
|---|-------------|---|--------------------------|----------------------|------------------------|-------------|----------------------------|----------------------|------------------------|-------------|
|   |             | Sulphide-rich Biotite Schist <sup>(2)</sup> | Coarse Rock              | Paste Fill 5% Cement | Paste Fill 5% Intercem | Rock Fill   | Coarse Rock                | Paste Fill 5% Cement | Paste Fill 5% Intercem | Rock Fill   |
| <b>Total Dissolved Solids (TDS)</b>         | <b>mg/L</b> | <b>536</b>                                  | <b>96</b>                | <b>473</b>           | <b>230</b>             | <b>1518</b> | <b>102</b>                 | <b>348</b>           | <b>243</b>             | <b>1665</b> |
| Aluminum (Al)                               | mg/L        | 19  | 1                        | 2                    | 0.7                    | 0.6         | 1                          | 2                    | 1.0                    | 0.4         |
| Ammonia (NH <sub>4</sub> +NH <sub>3</sub> ) | mg/L as N   | 0.005                                       | -                        | -                    | -                      | -           | -                          | -                    | -                      | -           |
| Arsenic (As)                                | mg/L        | 0.0001                                      | 0.0008                   | 0.0003               | 0.001                  | 0.00005     | 0.0008                     | 0.0004               | 0.001                  | 0.00005     |
| Chromium (Cr)                               | mg/L        | 0.007                                       | 0.004                    | 0.05                 | 0.01                   | 0.07        | 0.003                      | 0.01                 | 0.003                  | 0.04        |
| Cobalt (Co)                                 | mg/L        | 0.4   | 0.00001                  | 0.0008               | 0.00002                | 0.001       | 0.00001                    | 0.0002               | 0.00001                | 0.001       |
| Copper (Cu)                                 | mg/L        | 2   | 0.0006                   | 0.005                | 0.001                  | 0.007       | 0.0003                     | 0.003                | 0.0004                 | 0.007       |
| Iron (Fe)                                   | mg/L        | 3   | 0.006                    | 0.01                 | 0.0025                 | 0.0025      | 0.0025                     | 0.01                 | 0.0025                 | 0.0025      |
| Lead (Pb)                                   | mg/L        | 0.02  | 0.00001                  | 0.0003               | 0.0002                 | 0.0002      | 0.00001                    | 0.002                | 0.00001                | 0.0003      |
| Manganese (Mn)                              | mg/L        | 0.6   | 0.00008                  | 0.00005              | 0.0002                 | 0.00004     | 0.00003                    | 0.0001               | 0.00003                | 0.00007     |
| Molybdenum (Mo)                             | mg/L        | 0.010                                       | 0.001                    | 0.007                | 0.006                  | 0.009       | 0.01                       | 0.02                 | 0.02                   | 0.02        |
| Nickel (Ni)                                 | mg/L        | 2   | 0.00025                  | 0.004                | 0.0008                 | 0.006       | 0.00025                    | 0.003                | 0.00025                | 0.008       |
| Nitrate (NO <sub>3</sub> )                  | mg/L as N   | 0.005                                       | -                        | -                    | -                      | -           | -                          | -                    | -                      | -           |
| Nitrite (NO <sub>2</sub> )                  | mg/L as N   | 0.01  | -                        | -                    | -                      | -           | -                          | -                    | -                      | -           |
| Phosphorus (P)                              | mg/L        | 0.05  | 0.05                     | 0.05                 | 0.05                   | 0.05        | 0.05                       | 0.05                 | 0.05                   | 0.05        |
| Sulphate (SO <sub>4</sub> )                 | mg/L        | 451   | 17                       | 69                   | 83                     | 208         | 21                         | 90                   | 97                     | 6           |
| Uranium (U)                                 | mg/L        | 0.02  | 0.0002                   | 0.000005             | 0.000005               | 0.000005    | 0.00007                    | 0.000005             | 0.000005               | 0.000005    |
| Vanadium (V)                                | mg/L        | 0.003                                       | 0.009                    | 0.003                | 0.004                  | 0.001       | 0.009                      | 0.01                 | 0.007                  | 0.0006      |
| Zinc (Zn)                                   | mg/L        | 2   | 0.00025                  | 0.00025              | 0.00025                | 0.00025     | 0.00025                    | 0.00025              | 0.00025                | 0.00025     |

**Notes:**

0.0025 - denotes a value that is one half of the detection limit. Concentrations below detection were input into the model as one half of the detection limit.

(1) Backfill Leachate Water Quality - SPLP leach testing results conducted on samples of Type I and Type III coarse rock, rock fill and paste fill. The leach testing results are described in detail in Golder (2007).

(2) Biotite Schist - represents the acid generating rock material with relatively high concentrations of metals. These concentrations are an average of the last five weeks of kinetic testing of sample VR17699A as reported in the geochemistry baseline study by Sala/Geochimica (1998).



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**TABLE 6**  
**SIMULATION RESULTS:**  
**AVERAGE CONCENTRATIONS OVER LOM**  
**DIAMOND MINE**

| Parameter                                   | Units | Simulated Concentrations for Mine Discharge Water (Underground Sump Water + Open Pit Sump Water) |            |                            |            |                         |            |                           |            |            |            |                              |            |                         |            |                           |            |            |            | DDMI Water License Criteria <sup>(1)</sup> |                  |
|---|-------|--|------------|----------------------------|------------|-------------------------|------------|---------------------------|------------|------------|------------|------------------------------|------------|-------------------------|------------|---------------------------|------------|------------|------------|--|------------------|
|   |       | Simulation Scenarios   |            |                            |            |                         |            |                           |            |            |            |                              |            |                         |            |                           |            |            |            |  |                  |
|   |       | Acid Generating Rock   |            | Type I - Stockpile Samples |            |                         |            |                           |            |            |            | Type III - Stockpile Samples |            |                         |            |                           |            |            |            |  |                  |
|   |       | Sulphide-rich Biotite Schist   |            | Coarse Rock                |            | Paste Fill w/ 5% Cement |            | Paste Fill w/ 5% Intercem |            | Rock Fill  |            | Coarse Rock                  |            | Paste Fill w/ 5% Cement |            | Paste Fill w/ 5% Intercem |            | Rock Fill  |            |  |                  |
|   |       | 0.1%   | 10%        | 0.1%                       | 10%        | 0.1%                    | 10%        | 0.1%                      | 10%        | 0.1%       | 10%        | 0.1%                         | 10%        | 0.1%                    | 10%        | 0.1%                      | 10%        | 0.1%       | 10%        |  |                  |
| <b>Total Dissolved Solids (TDS)</b>         | mg/L  | <b>174</b>   | <b>174</b> | <b>174</b>                 | <b>174</b> | <b>174</b>              | <b>174</b> | <b>174</b>                | <b>174</b> | <b>174</b> | <b>175</b> | <b>174</b>                   | <b>174</b> | <b>174</b>              | <b>174</b> | <b>174</b>                | <b>174</b> | <b>174</b> | <b>175</b> | -  |                  |
| Aluminum (Al)                               | mg/L  | 0.3  | 0.3        | 0.3                        | 0.3        | 0.3                     | 0.3        | 0.3                       | 0.3        | 0.3        | 0.3        | 0.3                          | 0.3        | 0.3                     | 0.3        | 0.3                       | 0.3        | 0.3        | 0.3        | 0.3  | 1.5              |
| Ammonia (NH <sub>4</sub> +NH <sub>3</sub> ) | mg/L  | 1.3  | 1.3        | 1.3                        | 1.3        | 1.3                     | 1.3        | 1.3                       | 1.3        | 1.3        | 1.3        | 1.3                          | 1.3        | 1.3                     | 1.3        | 1.3                       | 1.3        | 1.3        | 1.3        | 1.3  | 10               |
| Arsenic (As)                                | mg/L  | 0.001  | 0.001      | 0.001                      | 0.001      | 0.001                   | 0.001      | 0.001                     | 0.001      | 0.001      | 0.001      | 0.001                        | 0.001      | 0.001                   | 0.001      | 0.001                     | 0.001      | 0.001      | 0.001      | 0.001                                      | 0.05             |
| Chromium (Cr)                               | mg/L  | 0.002  | 0.002      | 0.002                      | 0.002      | 0.002                   | 0.002      | 0.002                     | 0.002      | 0.002      | 0.002      | 0.002                        | 0.002      | 0.002                   | 0.002      | 0.002                     | 0.002      | 0.002      | 0.002      | 0.002                                      | 0.02             |
| Cobalt (Co)                                 | mg/L  | 0.001  | 0.001      | 0.001                      | 0.001      | 0.001                   | 0.001      | 0.001                     | 0.001      | 0.001      | 0.001      | 0.001                        | 0.001      | 0.001                   | 0.001      | 0.001                     | 0.001      | 0.001      | 0.001      | 0.001                                      | -                |
| Copper (Cu)                                 | mg/L  | 0.003  | 0.005      | 0.003                      | 0.003      | 0.003                   | 0.003      | 0.003                     | 0.003      | 0.003      | 0.003      | 0.003                        | 0.003      | 0.003                   | 0.003      | 0.003                     | 0.003      | 0.003      | 0.003      | 0.003                                      | 0.02             |
| Iron (Fe)                                   | mg/L  | 0.4  | 0.4        | 0.4                        | 0.4        | 0.4                     | 0.4        | 0.4                       | 0.4        | 0.4        | 0.4        | 0.4                          | 0.4        | 0.4                     | 0.4        | 0.4                       | 0.4        | 0.4        | 0.4        | 0.4  | -                |
| Lead (Pb)                                   | mg/L  | 0.0005   | 0.0005     | 0.0005                     | 0.0005     | 0.0005                  | 0.0005     | 0.0005                    | 0.0005     | 0.0005     | 0.0005     | 0.0005                       | 0.0005     | 0.0005                  | 0.0005     | 0.0005                    | 0.0005     | 0.0005     | 0.0005     | 0.0005                                     | 0.01             |
| Manganese (Mn)                              | mg/L  | 0.03   | 0.03       | 0.03                       | 0.03       | 0.03                    | 0.03       | 0.03                      | 0.03       | 0.03       | 0.03       | 0.03                         | 0.03       | 0.03                    | 0.03       | 0.03                      | 0.03       | 0.03       | 0.03       | 0.03                                       | -                |
| Molybdenum (Mo)                             | mg/L  | 0.004  | 0.004      | 0.004                      | 0.004      | 0.004                   | 0.004      | 0.004                     | 0.004      | 0.004      | 0.004      | 0.004                        | 0.004      | 0.004                   | 0.004      | 0.004                     | 0.004      | 0.004      | 0.004      | 0.004                                      | -                |
| Nickel (Ni)                                 | mg/L  | 0.008  | 0.009      | 0.008                      | 0.008      | 0.008                   | 0.008      | 0.008                     | 0.008      | 0.008      | 0.008      | 0.008                        | 0.008      | 0.008                   | 0.008      | 0.008                     | 0.008      | 0.008      | 0.008      | 0.008                                      | 0.05             |
| Nitrate (NO <sub>3</sub> )                  | mg/L  | 1.6  | 1.6        | 1.6                        | 1.6        | 1.6                     | 1.6        | 1.6                       | 1.6        | 1.6        | 1.6        | 1.6                          | 1.6        | 1.6                     | 1.6        | 1.6                       | 1.6        | 1.6        | 1.6        | 1.6  | -                |
| Nitrite (NO <sub>2</sub> )                  | mg/L  | 0.05   | 0.05       | 0.05                       | 0.05       | 0.05                    | 0.05       | 0.05                      | 0.05       | 0.05       | 0.05       | 0.05                         | 0.05       | 0.05                    | 0.05       | 0.05                      | 0.05       | 0.05       | 0.05       | 0.05                                       | 1                |
| Phosphorous (P)                             | mg/L  | 0.52   | 0.52       | 0.52                       | 0.52       | 0.52                    | 0.52       | 0.52                      | 0.52       | 0.52       | 0.52       | 0.52                         | 0.52       | 0.52                    | 0.52       | 0.52                      | 0.52       | 0.52       | 0.52       | 0.52                                       | - <sup>(2)</sup> |
| Sulphate (SO <sub>4</sub> )                 | mg/L  | 3  | 3          | 3                          | 3          | 3                       | 3          | 3                         | 3          | 3          | 3          | 3                            | 3          | 3                       | 3          | 3                         | 3          | 3          | 3          | 3  | -                |
| Uranium (U)                                 | mg/L  | 0.002  | 0.002      | 0.002                      | 0.002      | 0.002                   | 0.002      | 0.002                     | 0.002      | 0.002      | 0.002      | 0.002                        | 0.002      | 0.002                   | 0.002      | 0.002                     | 0.002      | 0.002      | 0.002      | 0.002                                      | -                |
| Vanadium (V)                                | mg/L  | 0.001  | 0.001      | 0.001                      | 0.001      | 0.001                   | 0.001      | 0.001                     | 0.001      | 0.001      | 0.001      | 0.001                        | 0.001      | 0.001                   | 0.001      | 0.001                     | 0.001      | 0.001      | 0.001      | 0.001                                      | -                |
| Zinc (Zn)                                   | mg/L  | 0.006  | 0.009      | 0.006                      | 0.006      | 0.006                   | 0.006      | 0.006                     | 0.006      | 0.006      | 0.006      | 0.006                        | 0.006      | 0.006                   | 0.006      | 0.006                     | 0.006      | 0.006      | 0.006      | 0.006                                      | 0.01             |

**Notes:**

- All 18 scenarios are presented, including 9 different backfill types that were modeled using two backfill flow rates (0.1% and 10% of the total flow reporting to the drainage galleries).

(1) DDMI Water License Criteria are compliance limits outlined in the site water license N7L2-1645.

(2) Water license criteria for total phosphorous is defined as a load, not a concentration, at 1000 kg/year.

**APPENDIX XI**

**DEVIATIONS FROM WEK'ÈEZHÌI LAND AND WATER BOARD TEMPLATE**





## Appendix XI – Deviations from WLWB Report Outline

As directed by the WLWB, this ICRP was developed to conform with a new *Annotated Outline for Interim and Final Closure and Reclamation Plans*. This reporting template was developed by the Mackenzie Valley Land and Water Board (MVLWB) Standard Procedures and Consistency Working Group. Although it has not been approved by the MVLWB it has been reviewed by the WLWB and meets their expectations for this Interim Closure and Reclamation Plan (WLWB 2009).

In some areas this ICRP has deviated from the outline to improve readability. The deviations of note are:

1. The template uses “reclamation” and “closure” interchangeably. To avoid any confusion we will identify in the introduction that we will use “closure” to mean closure, reclamation or closure and reclamation.
2. *5.2.3 Alternative Closure Options, Identified Risks and Contingencies* – was changed to *Preferred and Alternative Closure Options* it is important to let the reader know where to find the preferred closure option.
3. *Risks* have been moved from 5.2.3 to 5.2.6 and renamed *5.2.6 Uncertainties, Risks and Research Plans*. While risks are discussed in 5.2.3 they are in relation to advantages/disadvantages of closure options. Whereas 5.2.6 is specific to risks associated with the preferred closure option.
4. *Contingencies* have been moved from 5.2.3 to 5.2.9 which is already titled *Contingencies*. In 5.2.3 the contingencies are effectively the options. In 5.2.9 specific contingencies are identified that could be applied if the preferred option is not successful.
5. In section 5.2.5 *Residual Effects* the expected environmental effects that would remain post-closure for that specific closure area are listed. In Section 9 we provide an overall assessment of the combined environmental effects from all mine components.





**APPENDIX XII**  
**CONFORMANCE TABLES**





**Table XII-1 Conformance Table with Class “A” Water Licence W2007L2-0003 Requirements. Part L, Conditions Applying to Closure and Reclamation**

| Water License Item # | Requirement(s) of the Interim Closure and Reclamation Plan   | December 2009 ICRP Update    |
|----------------------|--|------------------------------|
| 1 a)                 | Specific closure and restoration objectives and criteria and an evaluation of alternatives for the closure of each mine component, including, but not limited to: i) open pits, water retention dikes, and related structures; ii) underground workings; iii) Processed Kimberlite Containment Facility, including the placement of coarse kimberlite material over PKC slimes, and water handling during placement; iv) Waste Rock Storage Facilities and the Drainage Control and Collection System; v) water management structures (dams, intake and delivery systems, treatment plants); vi) Dredged Sediment Containment Facility; vii) North Inlet Facility including, sediment containment, and water management; viii) borrow pits, ore storage stockpiles, and other disturbed areas; ix) surface infrastructure (Process Plant, camp, roads, and airstrip); x) all petroleum and chemical storage areas; xi) any other areas potentially contaminated with hazardous materials; xii) any facilities or areas, which may have been affected by development such that a potential pollution problem exists; xiii) contingencies for pit water treatment during closure; xiv) dike breach locations and sizes; and xv) restoration of aquatic habitat in all areas. | S. 2, S. 5 and Appendix V    |
| 1 b)                 | A description of the detailed plans for reclamation, measures required, or actions to be taken, to achieve the objectives stated in the Board’s Guidelines and Part L, Item 1 for each mine component.   | S. 5,                        |
| 1 c)                 | A detailed description, including maps and other visual representation, of the pre-disturbance conditions for each site, accompanied by a detailed description of the proposed final landscape, with emphasis on the restoration of surface drainage over the restored units.  | S. 5                         |
| 1 d)                 | A comprehensive assessment of materials suitability, including geochemical and physical characterization, and schedule of availability for restoration needs, with attention to top-dressing materials, including maps where appropriate, showing sources and stockpile locations of all reclamation construction materials.   | S. 4, S. 5                   |
| 1 e)                 | A description of the procedure to be employed for progressive reclamation, including details of restoration scheduling and procedures for coordinating restoration activities within the overall mining sequence and materials balance.  | S. 6                         |
| 1 f)                 | A description of any post-closure treatment that may be required for drainage water that is not acceptable for discharge from any of the reclaimed mine components including a description for handling and disposing of post-closure treatment facility sludges.  | S. 5.2, S. 5.2.4.3           |
| 1 g)                 | A description of the plan to assess and monitor any ground water contamination during post-closure.  | S.5 and S 9                  |
| 1 h)                 | An evaluation of the potential to re-vegetate disturbed sites that includes the identification of criteria to be used to determine technical feasibility and alternative restoration options.  | S 5.2.5 and Appendix VIII-10 |



| Water License Item # | Requirement(s) of the Interim Closure and Reclamation Plan  | December 2009 ICRP Update |
|----------------------|---|---------------------------|
| 1 i)                 | An identification of the research needs for restoration.  | S. 5 and Appendix VIII    |
| 1 j)                 | A description of how progressive reclamation will be monitored throughout the life of the mine, including an evaluation of the effectiveness of any reclaimed areas.          | S.5 and S.6               |
| 1 k)                 | Details of closure measures proposed in the event of a premature or temporary shutdown at any time throughout mine life.  | Ch. 7                     |
| 1 l)                 | A description of proposed means to provide long term maintenance of collection system and treatment plant.  | S. 5                      |
| 6                    | A restoration monitoring program to evaluate the effectiveness of all progressive reclamation and to identify any modifications required to facilitate landscape restoration. | S.5 and Appendix VIII     |

**Table XII-2 Conformance table: Water Licence Requirements Not Met in the 2006 Version of the ICRP (according to WL N7L2-1645)**

| #  | Deficiencies in 2006 ICRP  | Location Addressed in 2009 ICRP Update |
|----|--|--|
| 1  | There are no criteria presented that would indicate and/or measure the success or failure of closure for each mine component.  | Appendix V                             |
| 2  | DDMI has not provided evidence of ongoing community engagement with respect to the development of the ICRP   | S.2.4                                  |
| 3  | Include contingency plan for re-sloping of country rock and till storage   | S. 5.2.2.9                             |
| 4  | Address North Inlet rehabilitation potential for fish habitat and how backwash sediments from NIWTP may impact on NI use of fish habitat   | S. 5.2.4.3 and Appendix VIII-9         |
| 5  | Address how much backwash sediments from NIWTP might impact the quality of discharges from NI to Lac de Gras   | S. 5.2.4.3 and Appendix VIII-9         |
| 6  | Include alternatives for storage for NI backwash sediments   | S. 5.2.4.3                             |
| 7  | In chapter 8 of DDMI's 2006 ICRP, each mine component has "closure strategies" which touch on the goals for closure for that component but lacks a clear and explicit objective  | S. 5.2 and Appendix V                  |
| 8  | There are no evaluations of alternatives discussed for the closure of each mine component, only a "Closure Strategy" and the "Proposed Closure Method" in chapters 7 and 8 of the 2006 ICRP  | S. 5.2                                 |
| 9  | There are no detailed reclamation plans presented. DDMI has produced "Closure Factors" and "Closure Strategies" within the 2006 ICRP but they lack a focused objective which may attribute to the lack of a clear link between what action will be taken to fulfill which objective.   | S 5.2 and Appendix V                   |
| 10 | A map which illustrates the pre and post operational condition at a general level (Figure 2-1 and 9-1) is present in the 2006 ICRP, but does not show surface drainage throughout the site or the final landscape for each altered site.   | S 5.2                                  |
| 11 | A schedule of major operational activities has been included in Table 11-2, and some general reclamation events are listed in Figures 2-2 and 2-3, however there is no detailed schedule or description which outlines the dates for the commencement, completion and evaluation of all progressive reclamation studies and activities   | S 5.2 and S.8                          |
| 12 | A description of the processes that will be used during closure to treat unsafe water for each mine component has been provided. However, no contingency has been provided in the event that the remaining water does not meet discharge criteria post-closure. These details should be included in the ICRP. Also, additional detail is needed regarding the process for specific handling and disposal of facility sludges during closure and post-closure | S.5.2                                  |
| 13 | How will contaminated groundwater be assessed after closure? Plan not found.   | S. 9                                   |

| #  | Deficiencies in 2006 ICRP  | Location Addressed in 2009 ICRP Update |
|----|--|--|
| 14 | Objectives of revegetation have been listed in 10.3-3 and alternative strategies for revegetation are listed in 3.2.1, however, no indication of the criteria that will be used to evaluate the success of the studies have been discussed. Much more investigation and detail is needed in section 3.2.   | Appendix V and Appendix VIII-10        |
| 15 | Some areas of necessary research have been identified but it is not clear if it was with the participation of outside parties. DDMI has not provided evidence that parties have given input into the development of research gaps and requirements that will be investigated   | S. 2.4 and Appendix IX-4               |
| 16 | In section 10.3, DDMI explains the current monitoring that is taking place within each mine component. However, no description of how reclamation activities will be monitored or evaluated during or after mine operations has been discussed   | S.5.2, S.9 and Appendix VI             |
| 17 | DFO are concerned that no specific habitat thresholds and criteria have been identified within the plan so how can reviewers be confident that the proposed restored aquatic habitat will support fish populations and components of the aquatic ecosystem.  | Appendix V                             |
| 18 | LKDFN are concerned that Aboriginal Parties were not consulted on either version of the reclamation plan and the development of closure criteria. They also believe that EKATI and Diavik should collaborate on closure programs and develop consistent closure criteria to address the cumulative effects on the Lac de Gras ecosystem.   | S.2.4                                  |
| 19 | The NSMA strongly encourage a public review process so interveners are given the opportunity to participate, whereas some of their compensation claim allows for funding to specifically be part of such a process.  | S.2.4                                  |
| 20 | The Tlicho observed that the 'PKC Monitoring Plan' has never been carried out and submitted and thus relevant monitoring activities might not fulfil requirements set out in Schedule 2 of the Licence. Additional research needs and monitoring details have not been addressed and include areas such as: PKC Cover (technical feasibility of this strategy has not been assessed), Water Quality in the flooded pits (the impact of soluble metals on the pits walls has not been studied for this issue) and the breaching of dikes to meet water quality objectives | S.5.2, Appendix VIII-1, and VIII-5     |
| 21 | EMAB identified several uncertainties within the 2006 ICRP, most of which were not adequately addressed throughout the plan. This observation of remaining uncertainties is consistent with other reviewers conclusions.   | S.5.2                                  |

## APPENDIX XIII

### EXCERPTS FROM:

**ENVIRONMENT CANADA. 2009. ENVIRONMENT CANADA CODE OF PRACTICE FOR METAL MINES. PRS, 1/MM/17 E. APRIL 2009.**

AND

**INAC (INDIAN AND NORTHERN AFFAIRS CANADA). 2007. *MINE SITE RECLAMATION GUIDELINES FOR THE NORTHWEST TERRITORIES*. JANUARY 2007.**

Table 1-A. General guidance on closure objectives relevant to the open-pit and underground areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 1-B. Recommendations for decommissioning of underground and open-pit mine workings from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

Table 1-C. Guidance for generic options for closure of open-pits and underground mine workings from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 1-D. General guidance on post-closure monitoring of the open-pit and underground areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 2A. General guidance on closure objectives relevant to waste rock and till areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 2B. Recommendations for decommissioning of waste rock piles from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

Table 2C. Guidance for generic options for closure of waste rock and overburden areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 2-D. General guidance on post-closure monitoring of the waste rock and till areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 3A. General guidance on closure objectives relevant to the processed kimberlite containment area from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 3B. Recommendations for decommissioning of the processed kimberlite containment from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

Table 3C. Guidance for generic options for closure of the processed kimberlite containment area from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

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Table 3-D. General guidance on post-closure monitoring of the processed kimberlite containment facility from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 4A. General guidance on closure objectives relevant to the North Inlet areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 4B. Recommendations for decommissioning of water management and treatment systems from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

Table 4C. Guidance for generic options for closure of water management facilities from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 4-D. General guidance on post-closure monitoring of the North Inlet from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 5A. General guidance on closure objectives relevant to mine infrastructure areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 5B. Recommendations for decommissioning of mine infrastructure from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

Table 5C. Guidance for generic options for closure of mine infrastructure areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

Table 5-D. General guidance on post-closure monitoring of the Infrastructure Areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

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Table 1-A. General guidance on closure objectives relevant to the open-pit and underground areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Minimize access to open-pits to protect human and wildlife safety
- Allow emergency access and escape routes from flooded pits
- Implement water management strategies to minimize and control migration and discharge of contaminated drainage, and if required, collect and treat contaminated water
- Meet water quality objectives for any discharge from pits
- Stabilize slopes to minimize erosion and slumping
- Meet end land use target for resulting surface expression
- Establish original or desired new surface drainage patterns
- Establish in-pit water habitat where feasible for flooded pits
- Minimize access to underground workings and surface openings to protect human and wildlife safety
- Maximize the stability of underground workings so that there is no surface expression of underground failure
- Prevent collapse, stress transfer and flooding of adjacent mines
- Ensure that underground workings do not become a source of contamination to the surface environment
- Minimize potential for contamination and, if required, collect and treat
- Resurface, re-slope and contour surface disturbance as required to blend with surrounding topography or desired end land-use targets
- Minimize erosion, thaw settlement, slope failure, collapse or the release of contaminants or sediment
- Build to blend in with current topography, be compatible with wildlife use, and/or meet future land use targets
- Build to minimize the overall project footprint

Table 1-B. Recommendations for decommissioning of underground and open-pit mine workings from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

- R506: If it is technically and economically feasible to do so, underground or in-pit infrastructure (e.g. crushers, rails, metal structures, water and air pipes) and equipment (e.g. fans and pumps) should be removed from the site. Any equipment to be left underground or in pit should be inspected and remediated as appropriate to ensure that there is no risk of leakage of any contaminants.
- R507: During the decommissioning of underground and open pit mines, any contamination associated with vehicles and equipment operations and maintenance should be identified and remediated, as appropriate.
- R508: Underground mine workings should be secured and signs should be posted warning the public of potential dangers associated with the facility.
- R509: The risk of subsidence in underground mines should be assessed. Appropriate measures should be taken to prevent subsidence in cases where the risk of subsidence is determined to be significant. The primary measure used to prevent subsidence is the backfilling of underground voids.
- R510: Open pits should be backfilled or flooded to the extent practicable to prevent unauthorized access and to protect public safety. In all cases, signs should be posted warning the public of potential dangers associated with the site.

Table 1-C. Guidance for generic options for closure of open-pits and underground mine workings from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

### **Open Pit Workings**

- for multiple pits, sequentially backfill with wasterock and/or tailings as operations proceed
- backfill open pits with appropriate materials (e.g. waste rock, tailings)
- flood the pit (natural or accelerated)
- allow gradual slope failure of pits involving rock masses, or slope pit walls
- block open-pit access routes with boulder fences, berms and/or inulshuks (guidance from local communities and Elders should be sought)
- post warning signs (with visible symbols placed close enough so they are visible from one to another) and fences or berms around the perimeter for actively managed sites (not acceptable for remote sites into the long-term)
- long-term fencing to prevent access may only be appropriate if the mine site is located close to a community where regular access for maintenance is possible and where there is a higher risk of access by the general population
- clover slopes with rip rap thick enough to provide insulation or stabilization to minimize erosion or permafrost degradation
- Stabilize exposed soil along the pit crest or underlying poor quality bedrock that threatens to undermine the soil slope above the final pit water level
- Backbrush area to improve visibility
- Plug drill holes
- Maintain an access/egress ramp down to water level for flooded pits
- Contour to discourage or encourage surface water drainage into pits where appropriate
- Cover exposed pit walls to control reactions where necessary
- Collect waters in pit that do not meet the discharge criteria and treat passively (active treatment is not acceptable for the long term) or passively treat waters in the pit
- Breach diversion ditches and establish new water drainage channel
- Establish aquatic life in flooded pits

### **Underground Workings**

- Seal all drill holes and other surface openings, especially those connecting the underground workings to the surface
- Backfill underground with benign tailings and wasterock
- Secure underground shafts and raise openings using concrete to ensure permanent closure;

wooden barricades are only suitable for temporary closure

- Construct a reinforced concrete wall or a plug of weakly cemented waste if the barricade is for access control only
- Flood and plug workings to control acid generation and associated reactions if appropriate (engineering designs must consider hydrostatic heads and rock mass conditions – reinforced slabs should be avoided)
- Construct pillars to retain long-term structural stability after mining activities cease and to sustain their own weight and, if applicable, the weight of unconsolidated deposits, water bodies and all other surface loads
- Permanent support boundary pillar if practical and necessary
- Avoid the use of fencing for barricades in remote northern mine sites where regular inspection is not feasible
- Use ditches or berms as barricades except in areas of continuous permafrost; where continuous permafrost exists, inukshuks, fencing or some other method may need to be considered
- Remove all hazardous materials from the underground shops, equipment and magazines (fuels, oils, glycol, batteries, explosives, etc.)
- Contour to establish natural drainage patterns and blend in with the surrounding topography or re-contour the surface to prevent natural surface and groundwater flows from becoming contaminated by mine water where appropriate



Table 1-D. General guidance on post-closure monitoring of the open-pit and underground areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

### **Underground Workings**

- Inspect sealed areas
- Check for surface expression (subsidence) of underground failure
- Conduct geotechnical assessment of the overall safety and risk within the subsidence zone.
- Install and check thermistors where appropriate to monitor freeze-back in permafrost areas and to confirm that the ground thermal regime is not degraded
- Periodic backfilling of areas of subsidence may be required
- Inspect groundwater plumes and hydrogeology

### **Open-pit**

- Identify areas that are not stable
- Check ground conditions to confirm permafrost conditions are being re-established as predicted
- Sample surface water and profiles of flooded ponds/pits
- Ensure that there is sufficient water supplied to maintain an appropriate water depth for flooded pits
- Sample quality of groundwater seeping from pit walls to assess potential for contamination of mine water due to melting permafrost and ARD/MLch from pit walls.
- Identify and test water management points (including seepage) that were not anticipated
- Inspect barriers such as berms, fences, signs and inukshuks

Inspect fish habitat in flooded pits where applicable

Table 2A. General guidance on closure objectives relevant to wasterock and till areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Minimize erosion, thaw settlement, slope failure, collapse or the release of contaminants or sediment
- Build to blend in with current topography, be compatible with wildlife use, and/or meet future land use targets
- Build to minimize the overall project footprint
- Develop and implement preventative and control strategies to effectively minimize the potential for ARD and ML to occur
- Where ARD and ML are occurring as a result of mine activities, mitigate and minimize impacts to the environment
- No reliance on long-term treatment as a management tool (e.g. effluent treatment facilities are not appropriate for final reclamation but may be used as a progressive reclamation tool)
- Minimal maintenance requirements in the long-term

Table 2B. Recommendations for decommissioning of wasterock piles from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

- R 524: At the end of the mine operations phase, detailed inspections and assessments of wasterock piles and tailings management facilities, particularly dams and other containment structures, should be carried out. The objective of these inspections and assessments is to evaluate the actual performance against design projections related to anticipated post-closure conditions. Factors that should be considered include:
  - the extent of deformation;
  - the rate and quality of seepage;
  - the condition of foundations and sidewalls; and
  - design loads, which may be different after mine closure.
- R 525: At the end of the mine operations phase, comprehensive risk assessment should be conducted for mine closure to:
  - evaluate the long-term risk associated with possible failure modes for wasterock piles and tailings management facilities;
  - identify possible impacts on the environment and human health and safety in the event of a failure;
  - determine parameters critical to these failure modes and possible impacts; and
  - develop and implement long-term control strategies to manage the identified risks.
- R 527: At the end of mine operations phase, plans for management of wasterock and tailings to prevent, control and treat metal leaching and acidic drainage should be re-evaluated and revised as necessary, to ensure that they are consistent with the objectives and plans for mine closure and post closure. This evaluation should consider:
  - the results of the re-evaluation of the performance of these facilities;
  - the performance of progressive reclamation to date; and
  - possible alternative technologies for closure.
- R 529: At all mines that exist in permafrost conditions, downstream slopes of tailings containment structures should be revegetated.

Table 2C. Guidance for generic options for closure of wasterock and overburden areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Doze down crest if required or construct toe berm to flatten overall slope
- Remove weak or unstable materials from slopes and foundations
- Off-load materials from crest of the slope
- Leave waste piles composed of durable rock “as is” at the end of mining if there is no concern for deep-seated failure or erosion, and if the end land use targets can be achieved
- Cover to control reactions and/or migration (re-slope to allow for cover placement if necessary)
- Place riprap insulation/stabilization layer
- Freeze waste into permafrost
- Place potentially acid generating rock underwater or underground if available
- Place potentially acid generating within the centre of the waste pile so it is encapsulated by permafrost if conditions permit and underwater or underground disposal are not viable options
- Construct collection system to collect contaminated runoff or leachate
- Construct diversion ditches to divert uncontaminated runoff
- Install horizontal drains or pump leachate from relief wells at the toe of the slope
- Passively treat contaminated waters where necessary, active treatment is not acceptable for the long term
- Use benign waste rock as backfill in underground mine workings, to seal portals, to fill open-pits, or for construction material such as ramps or covers
- Revegetate using indigenous species or use other biotechnical measures (use of living organisms or other biological systems for environmental management) to reduce surface erosion
- Reslope, contour and/or construct ramps to facilitate wildlife access
- Use inukshuks to deter wildlife where appropriate (guidance from local communities and Elders should be sought)
- Include records of construction drawings, as-built drawings, location of landfill sites, and potential ARD material and other contaminated materials which are contained within the rock pile in the reclamation research plan.
- Control acid water at the source, preventing contaminated water flows, and allow contaminated water to be collected and treated (this would be incorporated into water management system)
- Divert or intercept surface and groundwater from ARD source

- Install covers and seals to prevent or reduce infiltration
- Induce or maintain freezing conditions to limit the formation and discharge of leachate
- Place acid generating materials in topographic lows or depressions where they are most likely to be submerged under water under natural conditions
- Mitigate consequences of ARD by the use of passive and active treatment systems, as appropriate for in-situ conditions
- Passive treatment measures include:
  - Chemical (alkali trenches, attenuation along flow path)
  - Biological (sulphate reduction, wetlands, metal uptake in plants)
  - Physical (physical removal – filtration by plants, attenuation)
- Active treatment measures may include:
  - Chemical (Lime neutralization, adsorptive process)
  - Biological (Sulphate reduction)
  - Physical (Solid/liquid separation)



Table 2-D. General guidance on post-closure monitoring of the wasterock and till areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Periodically inspect areas where stabilization measures may be required
- Periodic inspections by a geotechnical engineer to visually assess stability and performance of waste pile and cover(s)
- Periodically inspect ditches and diversion berms
- Examine ground conditions to confirm predicted permafrost conditions are being established as predicted
- Check thermistor data to determine thermal conditions within waste piles to confirm predicted permafrost aggradation/encapsulation where applicable
- Test water quality and measure volume from controlled discharge points of workings to confirm that drainage is performing as predicted and not adversely affecting the environment
- Identify water discharge areas (including volume and quality) that were not anticipated
- Inspect physical stability of the mine site to confirm that no erosion, slumping or subsidence that may expose potentially ARD/ML material to air and water are occurring
- Inspect any preventative and control measures (e.g. covers) to confirm that they minimize water and/or air exposure
- Confirm that predicted water quality and quantity of chemical reactions is occurring
- Develop monitoring locations and frequency on a site by site basis, incorporating locations where possible contaminated drainage may be generated, and where drainage may be released to the water management system or to the environment (also include downstream/down gradient locations)

Table 3A. General guidance on closure objectives relevant to the processed kimberlite containment area from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Stabilize slopes surrounding the tailings impoundment or containment system for flooded and/or dewatered conditions
- Minimize catastrophic and/or chronic release of the tailings based on associated risk
- Minimize wind migration of tailings dust
- Minimize the threat that the impoundment becomes a source of contamination (e.g. tailings migration outside of contained area, contamination of water outside of contained area)
- Blend with local topography and vegetation where appropriate
- Discourage human and wildlife access from physically and chemically unstable tailings sites

Table 3B. Recommendations for decommissioning of the processed kimberlite containment from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

- R 524: At the end of the mine operations phase, detailed inspections and assessments of wasterock piles and tailings management facilities, particularly dams and other containment structures, should be carried out. The objective of these inspections and assessments is to evaluate the actual performance against design projections related to anticipated post-closure conditions. Factors that should be considered include:
  - the extent of deformation;
  - the rate and quality of seepage;
  - the condition of foundations and sidewalls; and
  - design loads, which may be different after mine closure.
- R 525: At the end of the mine operations phase, comprehensive risk assessment should be conducted for mine closure to:
  - evaluate the long-term risk associated with possible failure modes for wasterock piles and tailings management facilities;
  - identify possible impacts on the environment and human health and safety in the event of a failure;
  - determine parameters critical to these failure modes and possible impacts; and
  - develop and implement long-term control strategies to manage the identified risks.
- R 527: At the end of mine operations phase, plans for management of wasterock and tailings to prevent, control and treat metal leaching and acidic drainage should be re-evaluated and revised as necessary, to ensure that they are consistent with the objectives and plans for mine closure and post closure. This evaluation should consider:
  - the results of the re-evaluation of the performance of these facilities;
  - the performance of progressive reclamation to date; and
  - possible alternative technologies for closure.
- R 529: At all mines that exist in permafrost conditions, downstream slopes of tailings containment structures should be revegetated.

Table 3C. Guidance for generic options for closure of the processed kimberlite containment area from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Stabilize embankments by removing weak or unstable materials from slopes and foundations and/or construct toe berms to flatten overall slope
- Breach water retention dams and drain impoundments, avoid post closure impoundment of water when possible
- Use a natural body of water that has sufficient storage capacity to hold the tailings and also a natural unimpeded flow via the drainage outlet if a permanent water cover is used (this may not be viable if the supernatant water quality does not meet discharge water quality standards)
- Increase freeboard and/or upgrade spillway to prevent overtopping and possible erosion by extreme events
- Relocate and/or deposit tailings into underground mine workings or into flooded pits, depending on water quality considerations
- Flood to control acid generation and related reactions
- Cover to control acid generation and related reaction and surface erosion
- Promote neutralization reactions by use of alkaline materials for acid tailings
- Divert non-contact runoff away from the tailings facility to avoid contamination
- Promote freezing of tailings mass into permafrost if suitable conditions exists.
- Collect waters that do not meet the discharge criteria and treat passively, active treatment is not acceptable for the long term
- Remove structures, decant towers, pipes and drains where they already exist
- Plug decant towers, pipes, and drains with high slump (relatively liquid concrete which will flow to fill all voids) or preferably, expansive concrete, as a last resort
- Assess the soil around pipes for stability under the hydraulic gradients through the embankment, as this may be a potential zone of piping failure
- Avoid using diversion structures and ditching, especially in permafrost soils (diversion structures are not the preferred option into the long-term)
- Where diversion dams and channels are necessary, maintain them indefinitely to meet long term stability and hydraulic design requirements; design diversions and spillways for extreme events suitable for long term stability
- Provide frost protection cap over the phreatic surface for water-retaining dams
- Ditch, berm, fence or use alternative methods to deter access to motorized vehicles if compatible with end-use plans
- Establish indigenous vegetation, soil, riprap or water cover to control erosion

Table 3-D. General guidance on post-closure monitoring of the processed kimberlite containment facility from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- conduct periodic dam safety and stability reviews of structures that remain after closure
- Inspect seepage collection system for water quality flows
- Check for degradation or aggradation of permafrost for tailings containment structures where permafrost was used in the design
- Assess dust dispersion and vegetation uptake with wind dispersion of tailings



Table 4A. General guidance on closure objectives relevant to the North Inlet areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Dismantle and remove/dispose of as much of the system as possible and restore natural or establish new drainage patterns
- Stabilize and protect from erosion and failure for the long term
- Maintain controlled release from water dams, ditches and all points of water discharge to the environment
- Achieve approved water quality limits, and in the case of existing mines, implement long term treatment only if necessary and ensure that minimal maintenance is required.

Table 4B. Recommendations for decommissioning of water management and treatment systems from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

- R531: At the end of the mine operations phase, water management plans should be evaluated and revised as necessary to ensure that they are consistent with the objectives and plans for mine closure and post closure. This evaluation should consider:
  - The results of an evaluation of the performance of the existing water management plan;
  - Expected changes in water flow and water balance on site; and
  - Expected changes in wastewater volume and composition

Based on this evaluation, the following should be identified:

- Water management structures, such as dams and diversion ditches, that will no longer be needed, methods to be used for decommissioning these structures, and the timing of decommissioning;
  - Water management structures that will continue to be needed and any long-term maintenance or replacement requirements associated with these structures;
  - Water management structures that will need to be modified, methods to be used to modify these structures, the timing of modification, and any long-term maintenance requirements associated with these structures; and
  - Long-term monitoring requirements to ensure that the water management system continues to function as designed.
- R532: At sites where it is determined that long-term treatment of wastewater will be necessary during post closure, a long-term wastewater treatment plan should be developed and implemented. This plan should include the following elements:
    - Identification of roles and responsibilities of persons to be involved in operation and maintenance of the treatment system;
    - Identification of the types of treatment system to be used;
    - Identification of any by-products from the treatment system, such as treatment sludge and management plans for the disposal of those by-products;
    - Identification of routine maintenance activities to be conducted on the treatment system and the frequency;
    - Identification of monitoring to assess ongoing performance of the treatment system and the frequency;
    - Identification of reporting requirements for internal management and regulatory agencies; and
    - Description of contingency plans to address any problems associated with the treatment system.

Table 4C. Guidance for generic options for closure of water management facilities from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Water management facilities including ditching and settling ponds that are not required for long-term use should be treated and discharged, sediment should be removed and disposed of properly, and the embankments, dams and culverts should be breached if not required
- Use passive treatment systems as the preferred method for dealing with contaminated waters if it can be demonstrated to be effective
- Locate permanent spillways in competent rock
- Drain, dismantle and remove tanks and pipelines from the site or fill and cover them with appropriate materials if they are approved to remain
- Cover embankments, ditches, culverts, and other drainage channel slopes with erosion resistant material (e.g. soil, riprap, vegetation)

Table 4-D. General guidance on post-closure monitoring of the North Inlet from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Periodically inspections are required in the post-closure period to assess the performance of the existing water management structures
- Check the performance of erosion protection on embankment structures such as rip rap or vegetation and the physical stability of water management systems including permafrost integrity where applicable
- Check water quality and flows to ensure system is working as predicted
- Conduct ongoing inspection and maintenance of passive or active water treatment facilities associated with non-compliant mine water or runoff discharges
- Sample surface and groundwater if site specific conditions dictate
- Check the smell and taste of water and fish (guidance from local communities and Elders should be sought)

Table 5A. General guidance on closure objectives relevant to mine infrastructure areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Ensure buildings and equipment do not become a source of contamination or a safety hazard to wildlife and humans
- Return area to its original state or to a condition compatible with the end-use targets
- Remediate any sources of contamination that may have been created during the development and operation of the mine site in order to protect humans, wildlife and environmental health
- Prevent significant releases of substances that could damage the receiving environment
- Remediate contaminated soil such that the area is compatible with future uses of the surrounding local area
- Re-establish the pre-mining ground cover, which may involve encouraging self-sustaining indigenous vegetation growth
- Provide wildlife habitat where appropriate and feasible
- Assist with providing physical stability of mine components



Table 5B. Recommendations for decommissioning of mine infrastructure from *Environment Canada Code of Practice for Metal Mines* (Environment Canada 2009).

- R514: On-site facilities and equipment that are no longer needed should be removed and disposed of in a safe manner, unless facilities or equipment are to be preserved for post-closure land use. Efforts should be made to sell equipment for reuse elsewhere or to send equipment for recycling, rather than disposing of it in landfill facilities.
- R515: The walls of on-site buildings should be razed to the ground, except in cases where they are to be preserved for post-closure land use. Foundations should be removed or covered with a sufficient thick layer of soil to support revegetation.
- R516: If buildings are to be preserved, either as a heritage resource or for some other post-closure land use, structures and foundations should be inspected to ensure that no contamination is present. If the structures or foundations are contaminated, they should be remediated as necessary to ensure public health and safety for post-closure land use.
- R517: Support infrastructure, such as fuel storage tanks, pipelines, conveyors and underground services should be removed, except in cases where it is to be preserved for post-closure land use.
- R518: The main access road to the site (or runway in the case of remote sites) and other on-site roads, as appropriate, should be preserved in a sufficient condition to allow post-closure access for monitoring, inspection and maintenance activities.
- R519: Roads, runways or railways that will not be preserved for post-closure should be reclaimed:
  - Bridges, culverts and pipes should be removed, natural stream flow should be restored, and stream banks should be stabilized by revegetating or by using rip-rap.
  - Surfaces, shoulders, escarpments, steep slopes, regular and irregular benches, etc. should be rehabilitated to prevent erosion; and
  - Surfaces and shoulders should be scarified, blended into natural contours, and revegetated.
- R520: electrical infrastructure, including pylons, electric cables and transformers should be dismantled and removed, except in cases where this infrastructure is to be preserved for post-closure land use or will be needed for post-closure monitoring, inspection and maintenance. This includes infrastructure on site, as well as any off-site infrastructure owned by the mining company.
- R522: Waste from the decommissioning of ore processing facilities and site infrastructure, such as waste from the demolition of buildings and the removal of equipment, should be removed from the site and stored in an appropriate waste disposal site or disposed of on site in an appropriate manner in accordance with relevant regulatory requirements. If material is disposed of on site, the location and contents of the disposal site should be documented.
- R523: Sampling and analysis of soils and other materials should be conducted to ensure that none of the material is contaminated, e.g. with asbestos and mercury from buildings. If

contaminated materials are identified, they should be handled and disposed of in an appropriate manner in accordance with all applicable regulatory requirements.

Table 5C. Guidance for generic options for closure of mine infrastructure areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Dismantling all buildings that are not necessary to achieve the future land use target
- Raze/level all walls to the ground and remove foundations
- Cover remaining foundations with materials conducive to vegetation growth
- Remove buildings and equipment during the winter to minimize damage to the land where appropriate
- remove and dispose concrete in an approved landfill if it contains contaminants such as hydrocarbons or PCB's that may pose a hazard over time
- where approved, break or perforate concrete floor slabs and walls to create a free draining condition in order that vegetation can be established
- backfill all excavations below final grade to achieve the final desired surface contours to restore the natural drainage or a new acceptable drainage
- cover excavated sites which have exposed permafrost with a rock cap to prevent thermokarst erosion
- Bury materials in the unsaturated zone or below the active layer
- Decontaminate equipment (free of any batteries, fuels, oils or other deleterious substances) and reuse or sell (local communities may have interest in some of the materials)
- If sale or salvage of equipment is not possible, dispose of decontaminated equipment in an approved landfill or as recommended by the regulatory authorities
- Cut, shred or crush and break demolition debris to minimize the void volume during disposal
- Maintain photographic records of major items placed into landfills, as well as a plan showing the location of various classes of demolition debris (e.g. concrete, structural steel, piping, metal sheeting and cladding)
- Leave non-salvageable materials and equipment from underground operations in the underground mine upon approval from the regulatory authorities
- Remove all hazardous materials and chemicals prior to demolition to national approved hazardous material treatment facilities, recycle, reuse, or dispose of in a appropriate manner upon approval from the regulatory authorities (check for PCBs in fluorescent light fixtures, lead-based paints, mercury switches or radioactive instrument controls)
- Backhaul materials for recycling or disposal to a southern location
- Excavate and remove contaminated soil and place into a designated and properly managed containment area on-site
- Treat contaminated soil in-situ (bioremediation, soil leaching, washing, etc.)
- Immobilize contaminated soil (cement solidification, lime/silicate stabilization, etc.)

- Excavate and relocate contaminated soil to approved facilities off-site.
- Some low level contaminated soil may be used progressively to cover landfills if the entire landfill is designed to be ultimately encapsulated in permafrost
- Dispose of wastes in quarries, borrow pits, underground mine workings, tailings impoundments, and waste rock piles
- Burn domestic waste in an incinerator during operations and at closure as part of camp maintenance
- Burn waste oils, solvents and other hydrocarbons on-site with an incinerator if approved (chlorinated substances should not be burned)
- Cover landfills and other waste disposal areas with erosion resistant material (e.g. soil, riprap, vegetation)
- Divert runoff with ditches or covers
- Ditch, berm, fence or use alternative methods to limit access to waste storage areas
- Contour/blend to match the natural topography or a new desired topography and re-vegetate with indigenous species to meet end use land targets
- Consider surface application of sewage for re-vegetation
- Begin revegetation efforts as soon as possible for mine site areas/components (progressively reclaim)
- Contour, scarify, and seed are using native seed mixes to establish vegetative cover
- Apply gravel barriers or other underlying cover systems where desired to control or limit the upward movement of acidic pore water or heavy metals that may inhibit plant growth or for moisture retention near the surface
- Apply stripped/stockpiled soil or growth medium to a depth sufficient to maintain root growth and nutrient enrichments
- Incorporate organic materials, mulches, fertilizers, or other amendments based upon local soil assessment
- Establish appropriate temporary or permanent wind breaks where necessary to establish vegetation
- Transplant vegetation that would otherwise be lost to mine disturbance where feasible
- Select indigenous vegetation for reclaimed sites that have a low potential for metal accumulation
- Re-vegetate with indigenous vegetation not used by wildlife or people if uptake of metals is a concern
- Place a gravel or coarse cover to discourage vegetation growth where desired

Table 5-D. General guidance on post-closure monitoring of the Infrastructure Areas from *Mine Site Reclamation Guidelines for the Northwest Territories* (INAC 2007).

- Maintain all buildings and equipment left onsite
- Inspect disposal areas periodically to establish if buried materials are being pushed to surface as a result of frost heaving
- Maintain access infrastructure to support on-going reclamation and closure monitoring
- Monitor wildlife/fish use of area to ensure mitigation measures are successful
- Monitor other land users access and activity in the area
- Check stream crossing remediation and any degradation associated with decommissioned roads such as erosion and ponding of water.
- Carry out periodic inspections to investigate the quality of air, groundwater, discharge water, and water body sediment where contaminated soils have occurred
- Carry out periodic inspections to investigate thermal degradation, and physical stability where contaminants have occurred
- An assessment of residual contamination should be carried out to confirm the success of the remediation
- Inspect re-vegetation areas periodically following initial planting until vegetation is successfully established and self sustaining in accordance with the agreed criteria
- Conduct soil analysis for nutrients and pH until the vegetation is successfully established and self-sustaining
- Inspect vegetated areas that may be obscuring possible cracks and other problems on dams and embankments
- Inspect for root systems that are penetrating protective covers or decaying/rotting providing tunnels for water to pass through protective covers
- Identify excessive vegetation stress or poorly established areas and implement contingency measures if required.
- Sample water treatment sludge periodically to determine the chemical characteristics, sludge stability, and leachability under the proposed long-term storage conditions
- Test water quality and quantity to measure the success of the mitigation measures for waste disposal areas
- Identify and unpredicted sources of potential contamination
- Check the ground thermal regime (by means of thermistors) and cover performance to check if permafrost has aggraded into the landfill and if the seasonal active zone remains within the cover
- Check for cracking or slumping of the cover and for underlying waste material pushing its way



up through the cover