Appendix X-3

Preliminary Pit Lake Mixing Study

TECHNICAL MEMORANDUM

DATE December 9, 2010

PROJECT No. 10-1328-0028 / 9000

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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^2, which declines gradually over a depth of about 7 m to about 0.84 km^2 (Figures 1 and 2). Between approximately 7 and 8 m, the pit narrows to approximately 0.63 km^2, and it continues to narrow over its remaining 249 m depth to a final bottom surface area of 0.025 km^2. 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

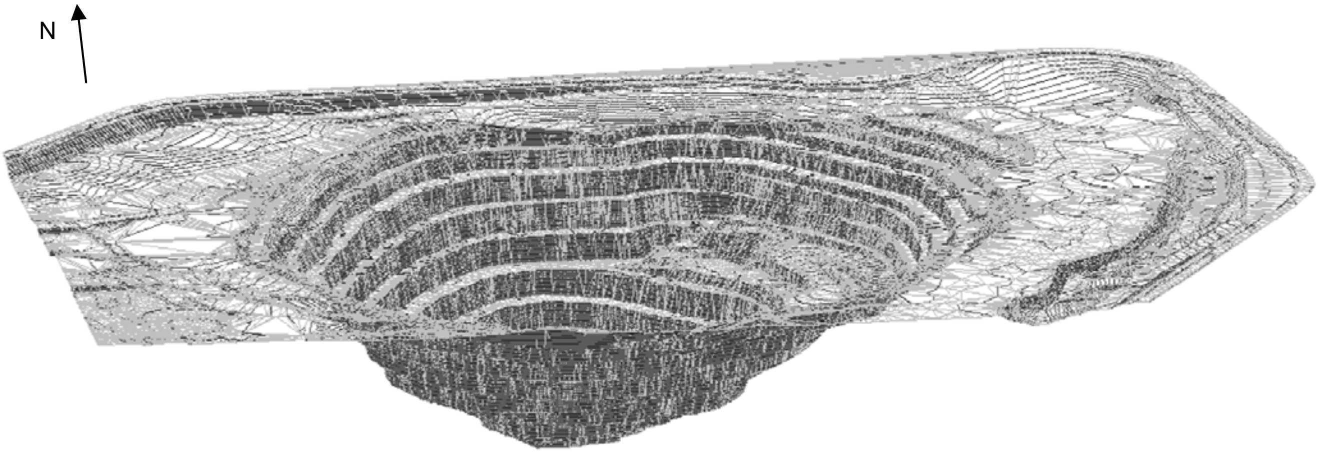
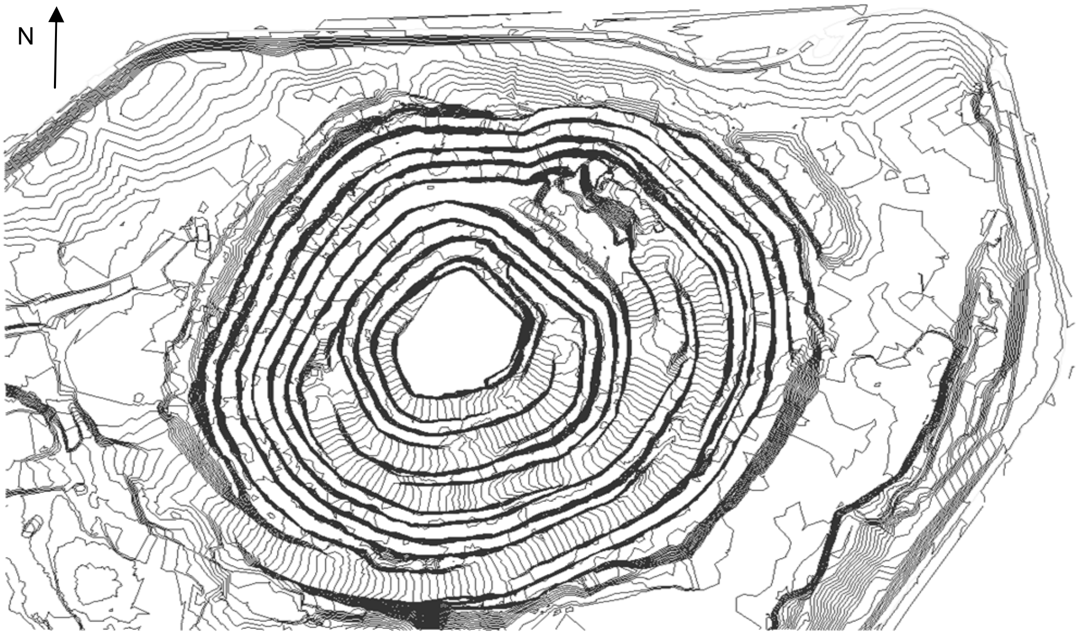


Figure 2: Contour Plot of the A154 Mine Pit (Plan View)

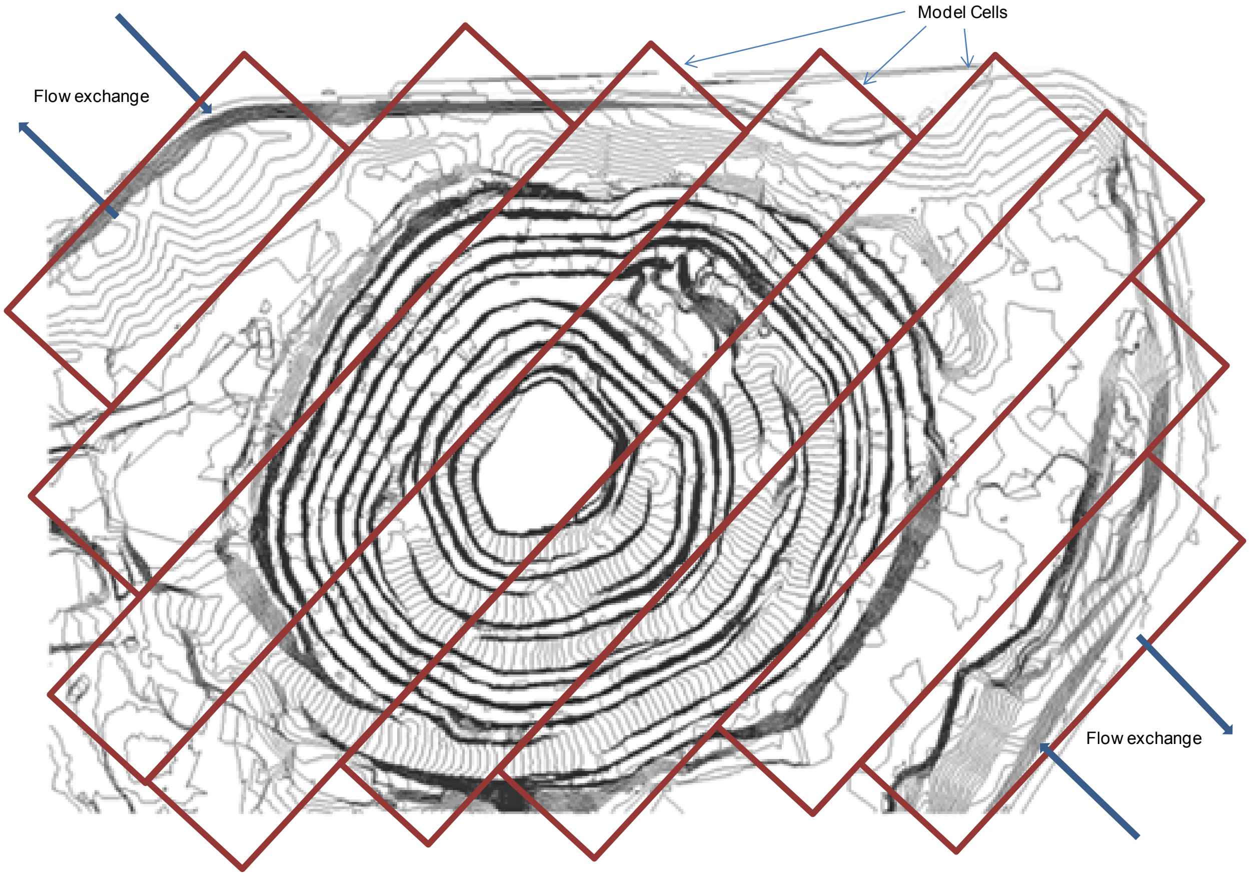


A total of 453 model cells were used to create a model grid that resembled the shape of the A154 mine pit, with the model cells varying in width from 100 to 750 m and in height from 1 to 3 m (Figure 3). The model was oriented such that it extended laterally along the longest axis of the pit, and flow 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^3 (Figure 3).

Figure 3: Configuration of the A154 CE-QUAL-W2 Model

Model Layer	Height (m)	Elevation (masl)		Model Cell (Width [m])								Surface Area (m^2)	Volume (m^3)
		Bottom of Model Cell	Top of Model Cell										
1	1	415	416	1 (550)	2 (750)	3 (750)	4 (750)	5 (750)	6 (750)	7 (750)	8 (400)	977,500	59,268,750
2	1	414	415	9 (500)	10 (650)	11 (700)	12 (700)	13 (700)	14 (700)	15 (650)	16 (400)	895,000	58,291,250
3	1	413	414	17 (500)	18 (650)	19 (700)	20 (700)	21 (700)	22 (700)	23 (650)	24 (350)	885,000	57,396,250
4	1	412	413	25 (500)	26 (650)	27 (700)	28 (700)	29 (700)	30 (700)	31 (650)	32 (350)	885,000	56,511,250
5	1	411	412	33 (450)	34 (650)	35 (650)	36 (650)	37 (650)	38 (650)	39 (650)	40 (350)	842,500	55,626,250
6	1	410	411	41 (450)	42 (650)	43 (650)	44 (650)	45 (650)	46 (650)	47 (650)	48 (350)	842,500	54,783,750
7	1	409	410	49 (450)	50 (650)	51 (650)	52 (650)	53 (650)	54 (650)	55 (650)	56 (350)	842,500	53,941,250
8	1	408	409		57 (600)	58 (600)	59 (600)	60 (600)	61 (600)	62 (600)		630,000	53,098,750
9	1	407	408		63 (600)	64 (600)	65 (600)	66 (600)	67 (600)	68 (600)		630,000	52,468,750
10	1	406	407		69 (600)	70 (600)	71 (600)	72 (600)	73 (600)	74 (600)		630,000	51,838,750
11	1	405	406		75 (570)	76 (570)	77 (570)	78 (570)	79 (570)	80 (570)		598,500	51,208,750
12	1.5	403.5	405		81 (570)	82 (570)	83 (570)	84 (570)	85 (570)	86 (570)		598,500	50,610,250
13	1.5	402	403.5		87 (570)	88 (570)	89 (570)	90 (570)	91 (570)	92 (570)		598,500	49,712,500
14	1.5	400.5	402		93 (550)	94 (550)	95 (550)	96 (550)	97 (550)	98 (550)		577,500	48,814,750
15	1.5	399	400.5		99 (550)	100 (550)	101 (550)	102 (550)	103 (550)	104 (550)		577,500	47,948,500
16	1.5	397.5	399			105 (550)	106 (550)	107 (550)	108 (550)	109 (550)		467,500	47,082,250
17	1.5	396	397.5			110 (550)	111 (550)	112 (550)	113 (550)	114 (550)		467,500	46,381,000
18	1.5	394.5	396			115 (550)	116 (550)	117 (550)	118 (550)	119 (550)		467,500	45,679,750
19	1.5	393	394.5			120 (550)	121 (550)	122 (550)	123 (550)	124 (550)		467,500	44,978,500
20	1.5	391.5	393			125 (550)	126 (550)	127 (550)	128 (550)	129 (550)		467,500	44,277,250
21	1.5	390	391.5			130 (550)	131 (550)	132 (550)	133 (550)	134 (550)		467,500	43,576,000
22	1.5	388.5	390			135 (550)	136 (550)	137 (550)	138 (550)	139 (550)		467,500	42,874,750
23	1.5	387	388.5			140 (550)	141 (550)	142 (550)	143 (550)	144 (550)		467,500	42,173,500
24	1.5	385.5	387			145 (550)	146 (550)	147 (550)	148 (550)	149 (550)		467,500	41,472,250
25	1.5	384	385.5			150 (550)	151 (550)	152 (550)	153 (550)	154 (550)		467,500	40,771,000
26	1.5	382.5	384			155 (550)	156 (550)	157 (550)	158 (550)	159 (550)		467,500	40,069,750
27	1.5	381	382.5			160 (550)	161 (550)	162 (550)	163 (550)	164 (550)		467,500	39,368,500
28	2	379	381			165 (550)	166 (550)	167 (550)	168 (550)	169 (550)		467,500	38,667,250
29	2	377	379			170 (550)	171 (550)	172 (550)	173 (550)	174 (550)		467,500	37,732,250
30	2	375	377			175 (540)	176 (540)	177 (540)	178 (540)	179 (540)		459,000	36,797,250
31	2	373	375			180 (540)	181 (540)	182 (540)	183 (540)	184 (540)		459,000	35,879,250
32	2	371	373			185 (540)	186 (540)	187 (540)	188 (540)	189 (540)		459,000	34,961,250
33	2	369	371			190 (540)	191 (540)	192 (540)	193 (540)	194 (540)		459,000	34,043,250
34	2	367	369			195 (540)	196 (540)	197 (540)	198 (540)	199 (540)		459,000	33,125,250
35	2	365	367			200 (540)	201 (540)	202 (540)	203 (540)	204 (540)		459,000	32,207,250
36	2	363	365			205 (520)	206 (520)	207 (520)	208 (520)	209 (520)		442,000	31,289,250
37	2	361	363			210 (520)	211 (520)	212 (520)	213 (520)	214 (520)		442,000	30,405,250
38	2	359	361			215 (500)	216 (500)	217 (500)	218 (500)	219 (500)		425,000	29,521,250
39	2	357	359			220 (500)	221 (500)	222 (500)	223 (500)	224 (500)		425,000	28,671,250
40	2	355	357			225 (500)	226 (500)	227 (500)	228 (500)	229 (500)		425,000	27,821,250
41	2	353	355			230 (500)	231 (500)	232 (500)	233 (500)	234 (500)		425,000	26,971,250
42	2	351	353			235 (400)	236 (400)	237 (400)	238 (400)	239 (400)		340,000	26,121,250
43	2	349	351			240 (400)	241 (400)	242 (400)	243 (400)			260,000	25,441,250
44	2	347	349			244 (400)	245 (400)	246 (400)	247 (400)			260,000	24,921,250
45	2	345	347			248 (400)	249 (400)	250 (400)	251 (400)			260,000	24,401,250
46	2	343	345			252 (400)	253 (400)	254 (400)	255 (400)			260,000	23,881,250
47	2	341	343			256 (400)	257 (400)	258 (400)	259 (400)			260,000	23,361,250
48	2	339	341			260 (375)	261 (375)	262 (375)	263 (375)			243,750	22,841,250
49	2	337	339			264 (375)	265 (375)	266 (375)	267 (375)			243,750	22,353,750
50	2	335	337			268 (375)	269 (375)	270 (375)	271 (375)			243,750	21,866,250
51	2	333	335			272 (375)	273 (375)	274 (375)	275 (375)			243,750	21,378,750
52	2	331	333			276 (375)	277 (375)	278 (375)	279 (375)			243,750	20,891,250
53	3	328	331			280 (350)	281 (350)	282 (350)	283 (350)			227,500	20,403,750
54	3	325	328			284 (350)	285 (350)	286 (350)	287 (350)			227,500	19,721,250
55	3	322	325			288 (350)	289 (350)	290 (350)	291 (350)			227,500	19,038,750
56	3	319	322			292 (350)	293 (350)	294 (350)	295 (350)			227,500	18,356,250
57	3	316	319			296 (320)	297 (320)	298 (320)	299 (320)			208,000	17,673,750
58	3	313	316			300 (320)	301 (320)	302 (320)	303 (320)			208,000	17,049,750
59	3	310	313			304 (320)	305 (320)	306 (320)	307 (320)			208,000	16,425,750
60	3	307	310			308 (320)	309 (320)	310 (320)	311 (320)			208,000	15,801,750
61	3	304	307			312 (320)	313 (320)	314 (320)	315 (320)			208,000	15,177,750
62	3	301	304			316 (300)	317 (300)	318 (300)	319 (300)			195,000	14,553,750
63	3	298	301			320 (300)	321 (300)	322 (300)	323 (300)			195,000	13,968,750
64	3	295	298			324 (300)	325 (300)	326 (300)	327 (300)			195,000	13,383,750
65	3	292	295			328 (300)	329 (300)	330 (300)	331 (300)			195,000	12,798,750
66	3	289	292			332 (300)	333 (300)	334 (300)	335 (300)			195,000	12,213,750
67	3	286	289			336 (300)	337 (300)	338 (300)	339 (300)			195,000	11,628,750
68	3	283	286			340 (300)	341 (300)	342 (300)	343 (300)			195,000	11,043,750
69	3	280	283			344 (275)	345 (275)	346 (275)	347 (275)			178,750	10,458,750
70	3	277	280			348 (275)	349 (275)	350 (275)	351 (275)			178,750	9,922,500
71	3	274	277			352 (275)	353 (275)	354 (275)	355 (275)			178,750	9,386,250
72	3	271	274			356 (275)	357 (275)	358 (275)	359 (275)			178,750	8,850,000
73	3	268	271			360 (275)	361 (275)	362 (275)	363 (275)			178,750	8,313,750
74	3	265	268			364 (250)	365 (250)	366 (250)	367 (250)			162,500	7,777,500
75	3	262	265			368 (250)	369 (250)	370 (250)	371 (250)			162,500	7,290,000
76	3	259	262			372 (250)	373 (250)	374 (250)	375 (250)			162,500	6,802,500
77	3	256	259				376 (250)	377 (250)	378 (250)			112,500	6,315,000
78	3	253	256				379 (250)	380 (250)	381 (250)			112,500	5,977,500
79	3	250	253				382 (250)	383 (250)	384 (250)			112,500	5,640,000
80	3	247	250				385 (250)	386 (250)	387 (250)			112,500	5,302,500
81	3	244	247				388 (250)	389 (250)	390 (250)			112,500	4,965,000
82	3	241	244				391 (250)	392 (250)	393 (250)			112,500	4,627,500
83	3	238	241				394 (250)	395 (250)	396 (250)			112,500	4,290,000
84	3	235	238				397 (250)	398 (250)	399 (250)			112,500	3,952,500
85	3	232	235				400 (225)	401 (225)	402 (225)			101,250	3,615,000
86	3	229	232				403 (225)	404 (225)	405 (225)			101,250	3,311,250
87	3	226	229				406 (225)	407 (225)	408 (225)			101,250	3,007,500
88	3	223	226				409 (225)	410 (225)	411 (225)			101,250	2,703,750
89	3	220	223				412 (225)	413 (225)				56,250	2,400,000
90	3	217	220				414 (200)	415 (200)				50,000	2,231,250
91	3	214	217				416 (200)	417 (200)				50,000	2,081,250
92	3	211	214				418 (200)	419 (200)				50,000	1,931,250
93	3	208	211				420 (200)	421 (200)				50,000	1,781,250
94	3	205	208				422 (175)	423 (175)				43,750	1,631,250
95	3	202	205				424 (175)	425 (175)				43,750	1,500,000
96	3	199	202				426 (175)	427 (175)				43,750	1,368,750
97	3	196	199				428 (150)	429 (150)				37,500	1,237,500
98	3	193	196				430 (150)	431 (150)				37,500	1,125,000
99	3	190	193				432 (150)	433 (150)				37,500	1,012,500
100	3	187	190				434 (150)	435 (150)				37,500	900,000
101	3	184	187				436 (150)	437 (150)				37,500	787,500
102	3	181	184				438 (125)	439 (125)				31,250	675,000
103	3	178	181				440 (125)	441 (125)				31,250	581,250
104	3	175	178				442 (125)	443 (125)				31,250	487,500
105	3	172	175				444 (125)	445 (125)				31,250	393,750
106	3	169	172				446 (100)	447 (100)				25,000	300,000
107	3	166	169				448 (100)	449 (100)				25,000	225,000
108	3	163	166				450 (100)	451 (100)				25,000	150,000
109	3	160	163				452 (100)	453 (100)				25,000	75,000

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^{o}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^{o}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^3/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^3/s or 379,000 m^3/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^2 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 about 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^3/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[1] 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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[1] In the context of this report, the term saline is being used to describe waters containing TDS levels ≥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	• 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. • All input variables were set to the values outlined in Section 3.1.2.
1b	Base Case Part 2	• 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. • Initial conditions in the pit lake were defined using the output from the Base Case Part 1 model run.
2	GW to 195	• 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. • Climate conditions and influent flow rates matched those used in the Base Case
3	GW to 195 W2	• Identical set-up to Scenario GW to 195, except that wind speeds were doubled
4	GW to 295	• 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. • Climate conditions and influent flow rates matched those used in the Base Case
5	GW to 295 W2	• Identical set-up to Scenario GW to 295, except that wind speeds were doubled
6	GW to 295 W2 RedQ	• Identical set-up to Scenario GW to 295, except that wind speeds were doubled and open-water inflow rates were reduced by 60%
7	GW to 411	• 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. • Climate conditions and influent flow rates matched those used in the Base Case
8	GW to 411 W2	• Identical set-up to Scenario GW to 411, except that wind speeds were doubled

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							
Initial Conditions									
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$^{(e)}$	360$^{(e)}$	360$^{(e)}$	360$^{(e)}$	360$^{(e)}$	360$^{(e)}$	360$^{(e)}$
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
Surface inflow									
Average open-water flow rate (May to September) (m^3/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^3/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
Groundwater inflow									
Flow rate (m^3/s)	0.33 to 0$^{(c)}$	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

(a) 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.

(b) 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.

(c) 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.

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

(e) 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:

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

where: g = acceleration due to gravity (9.8 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 (g-cm/cm^2);

Z_p = thermocline or chemocline depth (m);

Z_m = maximum depth (m);

ρ_m = water density at surface (kg/m^3);

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

A_m = surface area of the lake (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:

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

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

where: ρ_a = density of air (1.209 kg/m^3);
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^2);
Z_0 = surface or zero depth (m);
ρ_z = density at depth Z (kg/m^3);
$\overline{\rho}$ = average lake density (kg/m^3); and
A_z = surface area at depth Z (m^2).

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^3 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 that 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

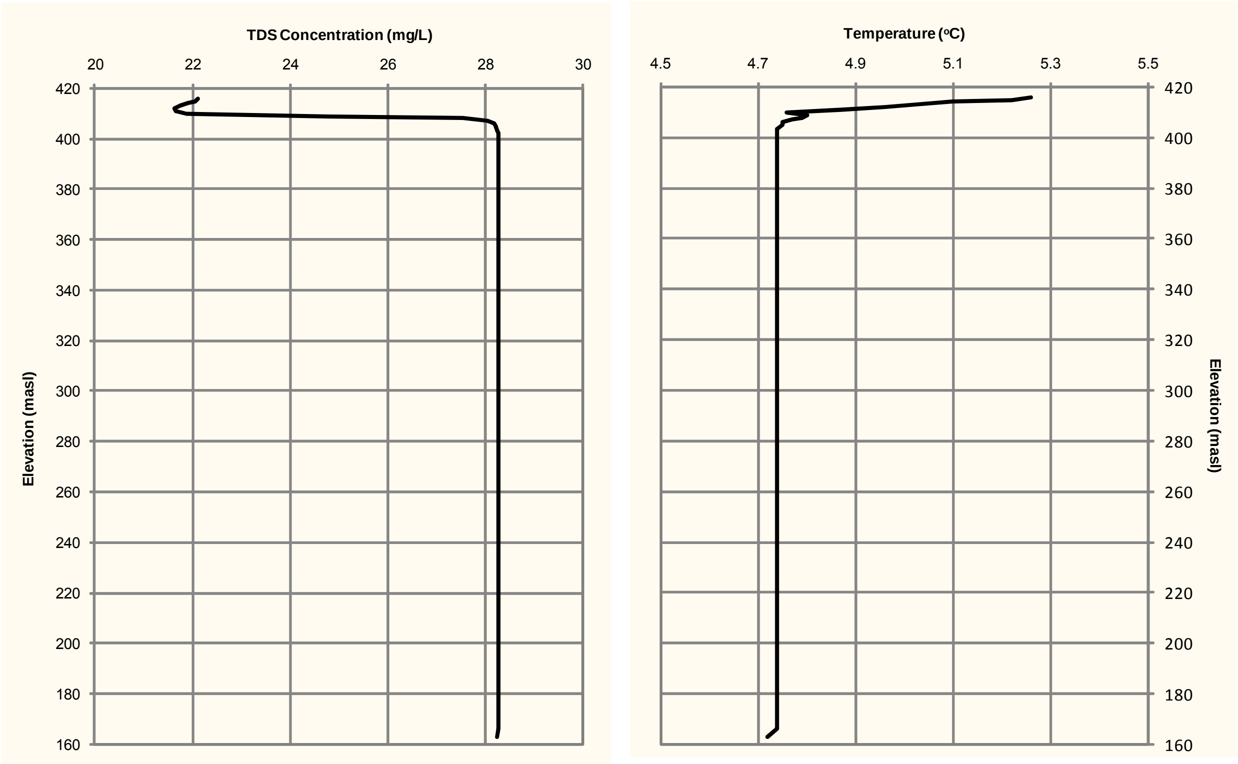
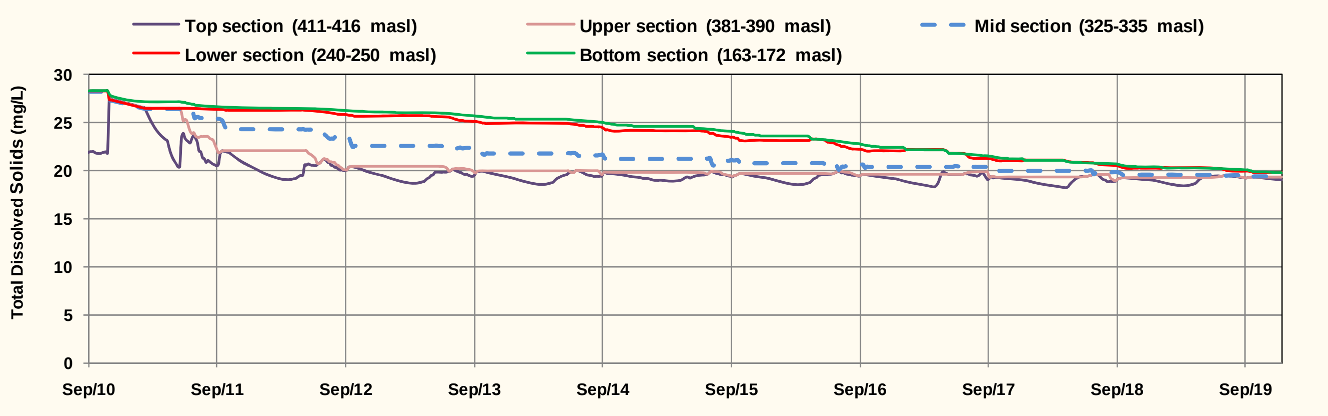
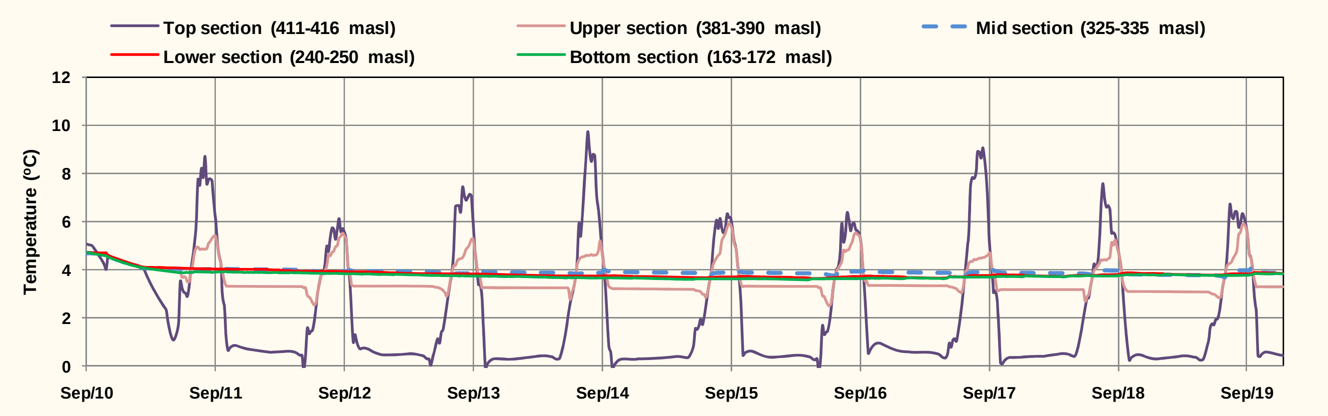


Figure 6: Predicted Levels of Total Dissolved Solids at Various Depths in the A154 Pit Lake from the Completion of Filling to 10 Years Post-Filling under the Base Case Scenario



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.

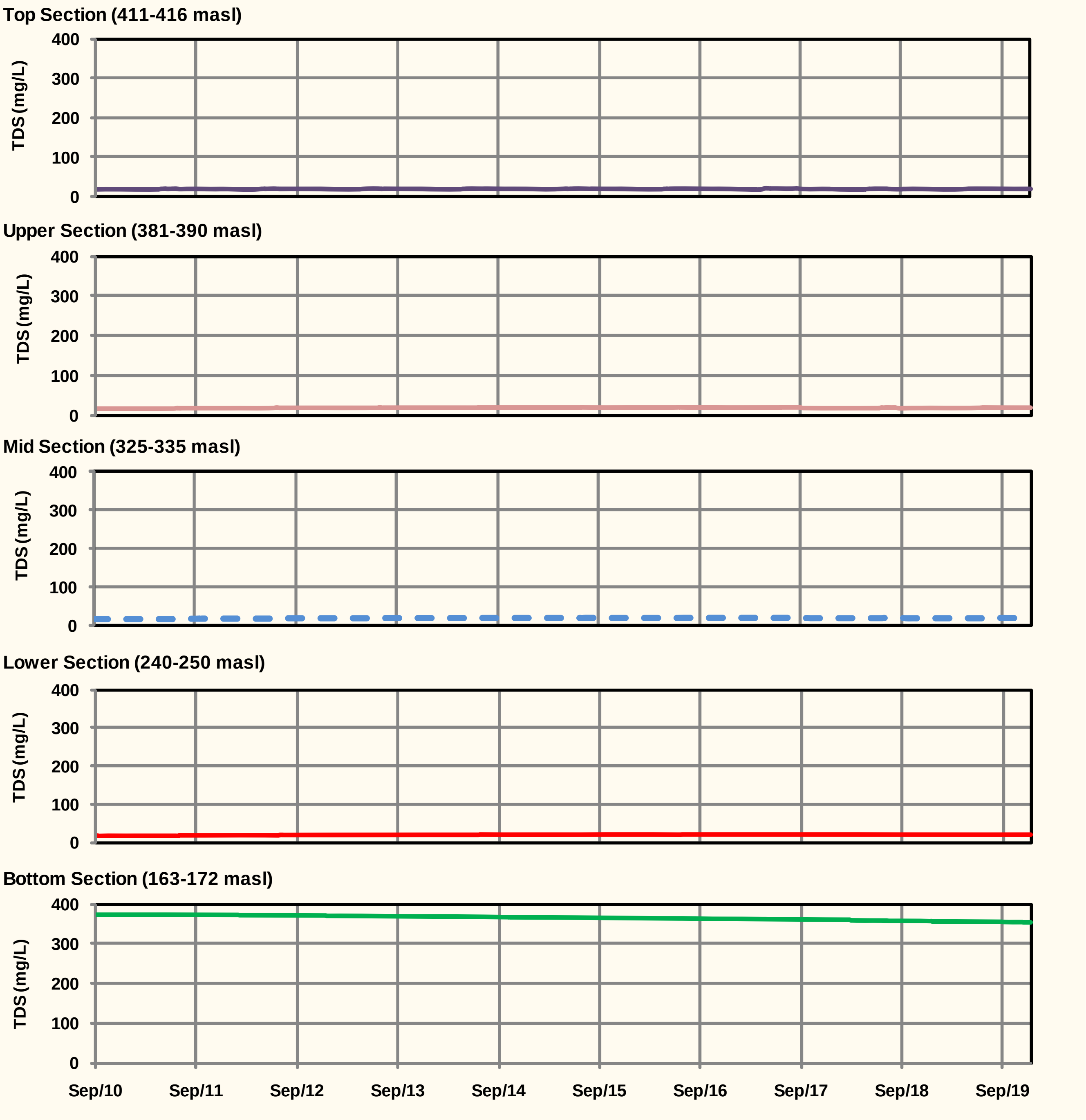
Water temperatures in the top and upper portions of the A154 pit lake were virtually unchanged in the GW to 195 scenario in comparison to those predicted to occur under the Base Case (Figures 7 and 9). They continued to vary in reflection of season changes in air temperature and the presence or absence 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^{o}C and remain around this point though 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^{o}C to just under 2^{o}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

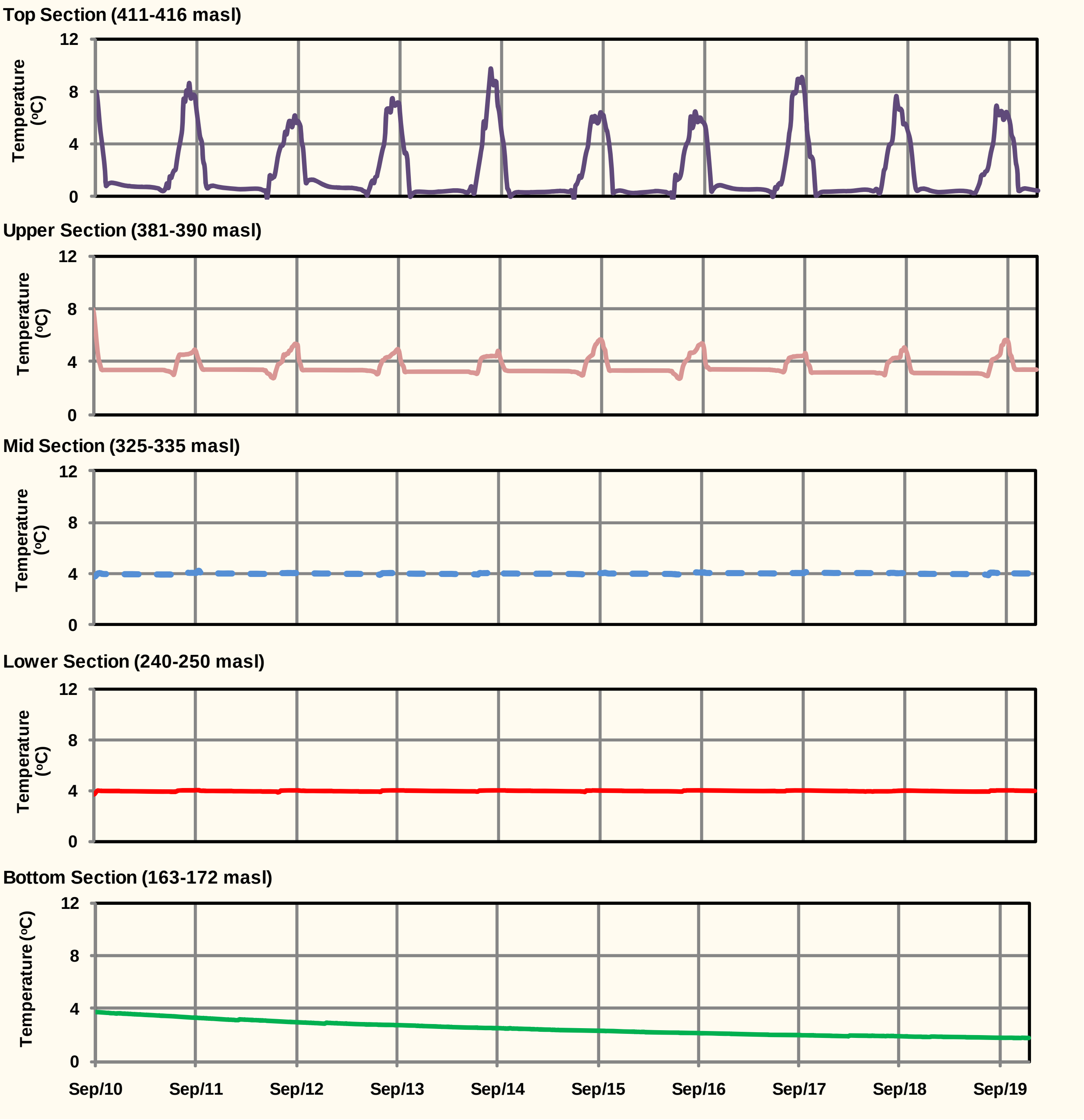
Repeating the GW to 195 simulation with wind speeds increased by a factor of two resulted in a greater level of exchange between the portions of the A154 pit lake situated above and below 195 masl, as suggested by the more rapid decline in TDS levels observed at the bottom of the lake (Figures 8 and 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 to195 Scenario



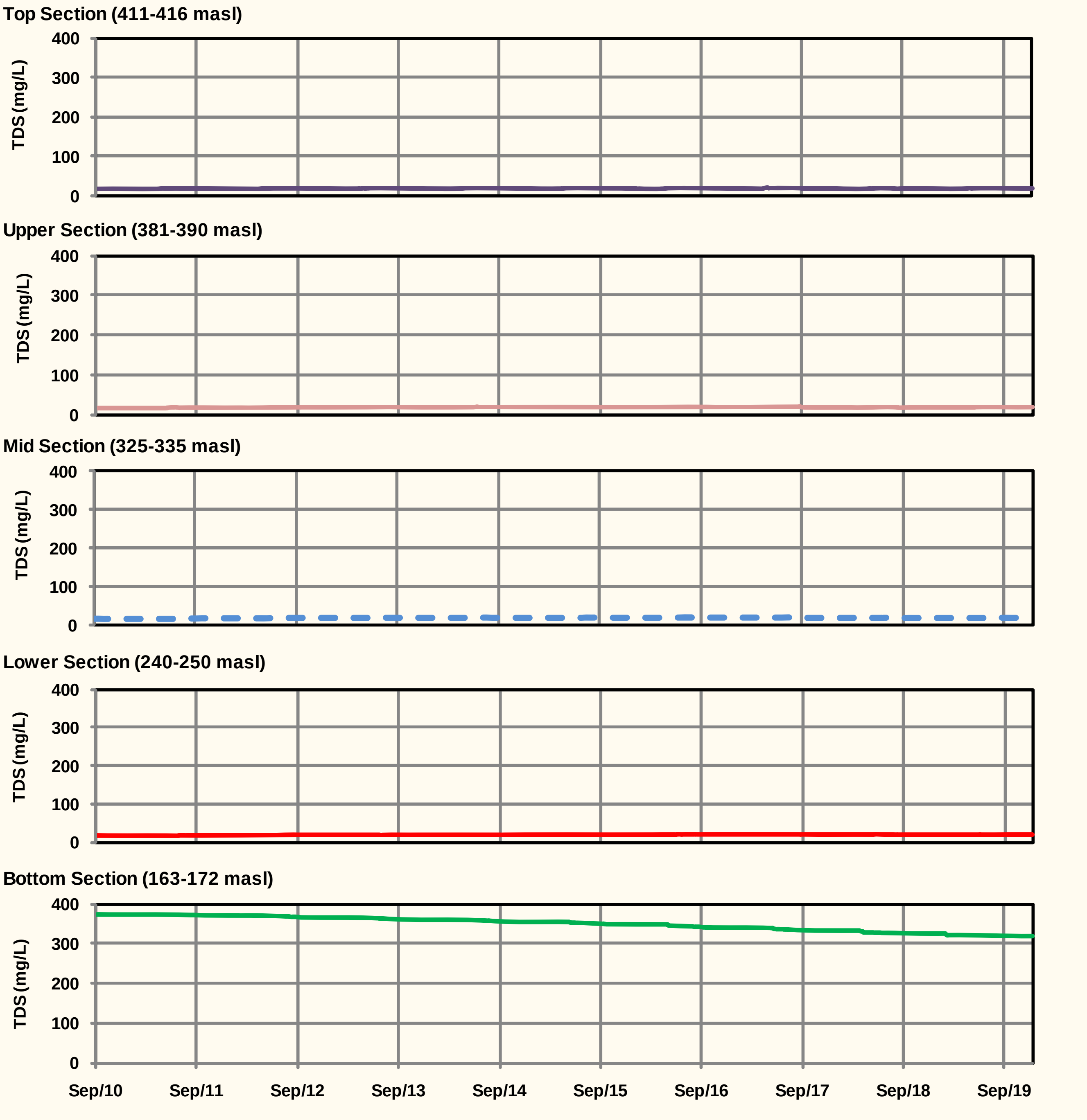
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

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



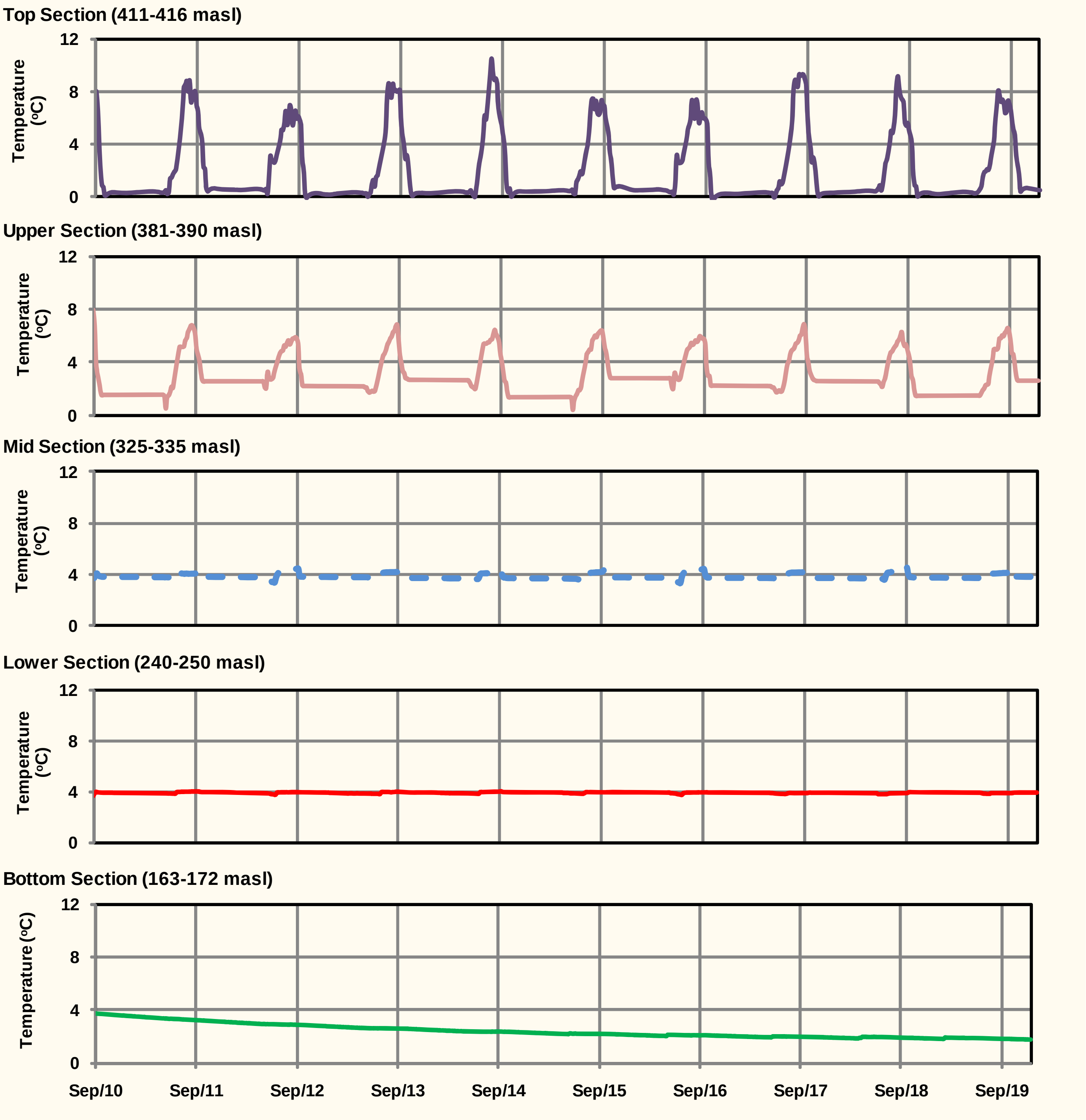
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

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).

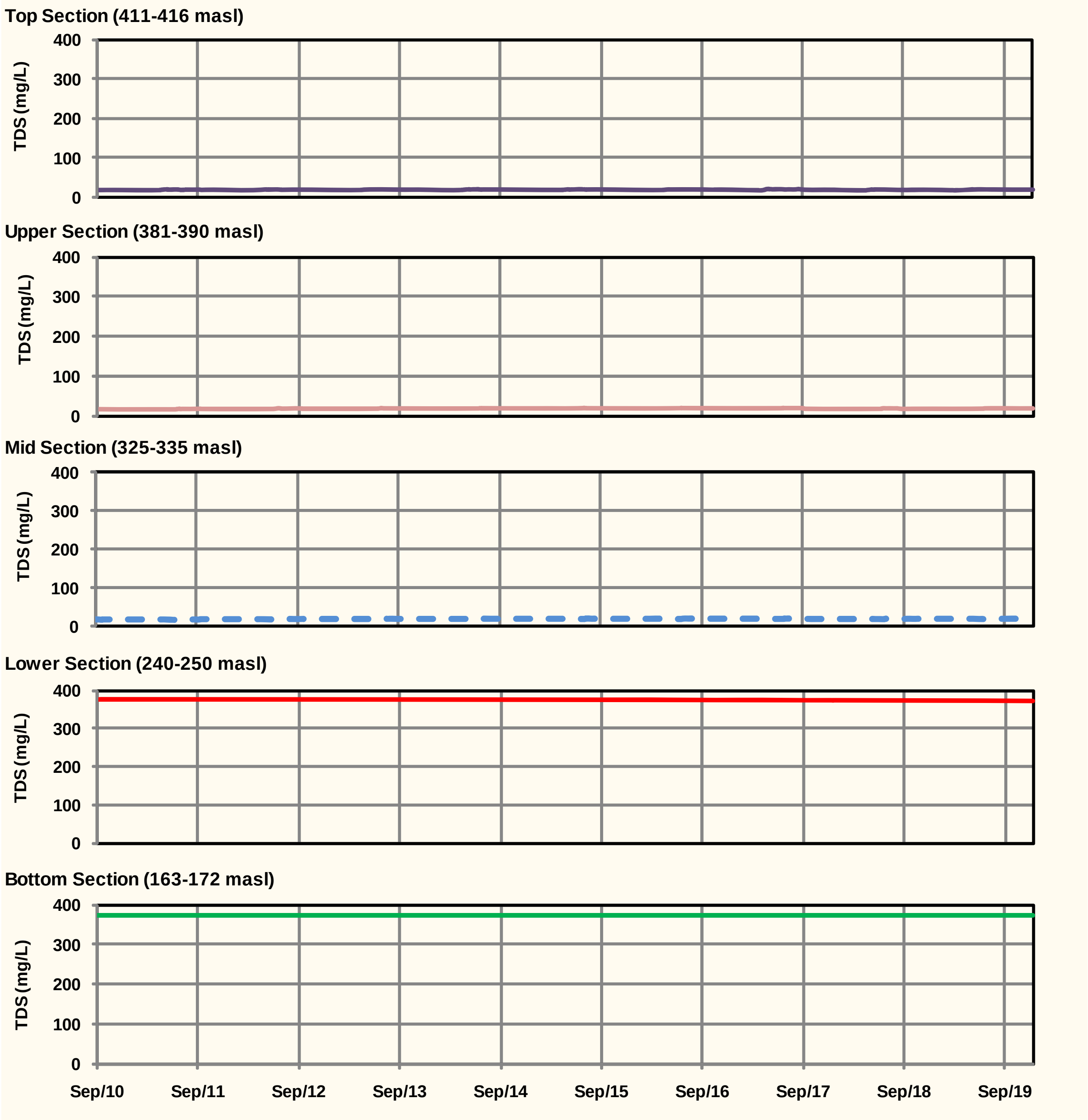
In the upper portion of the A154 pit lake, the increased wind speed resulted in a smaller increase in open-water temperatures (Figure 15), consistent with the changes observed in the GW to 195 W2 scenario (Figure 11). Water temperatures at mid-depth remained around 4°C (Figure 15), consistent with the 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.

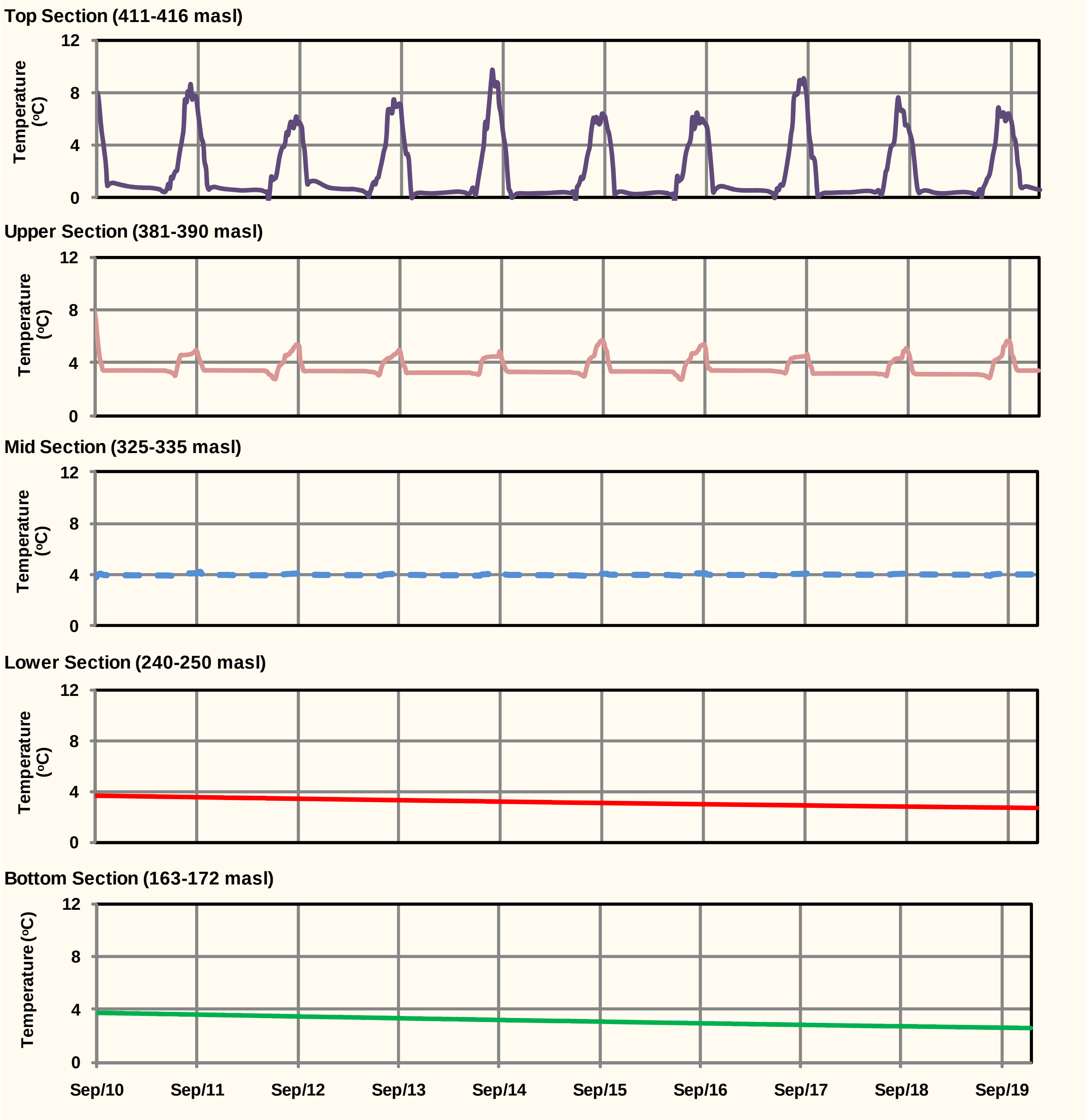
Water temperatures in this portion of the pit lake tended to be cooler than under the higher exchange rate included in the GW to 295 W2 scenario, because of the reduced input of warmer water from Lac de Gras. These trends support the findings of Imberger and Patterson (1990), who suggest that the destabilizing 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



Top Section (411-416 masl)

Upper Section (381-390 masl)

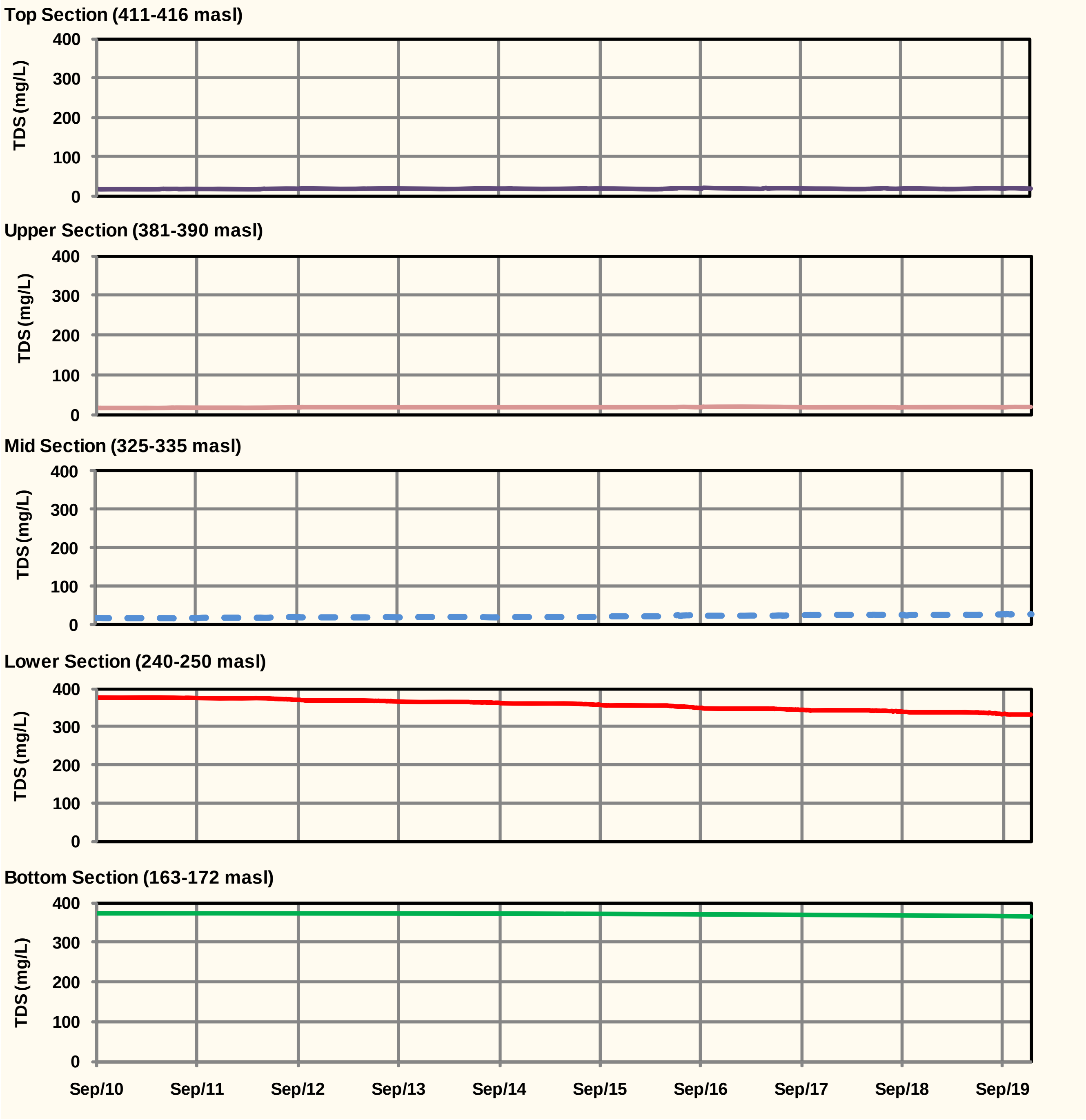
Mid Section (325-335 masl)

Lower Section (240-250 masl)

Bottom Section (163-172 masl)

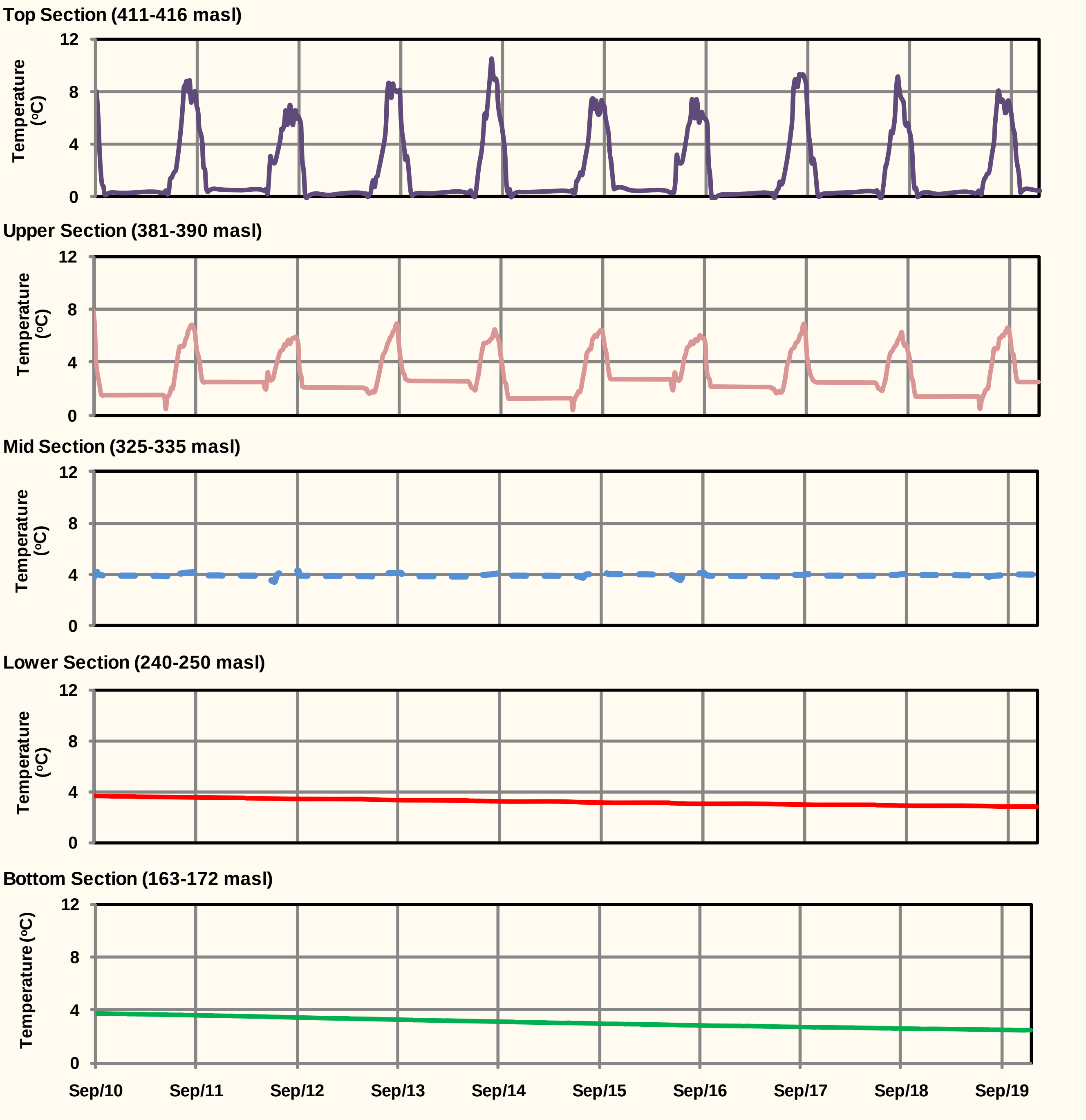
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

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



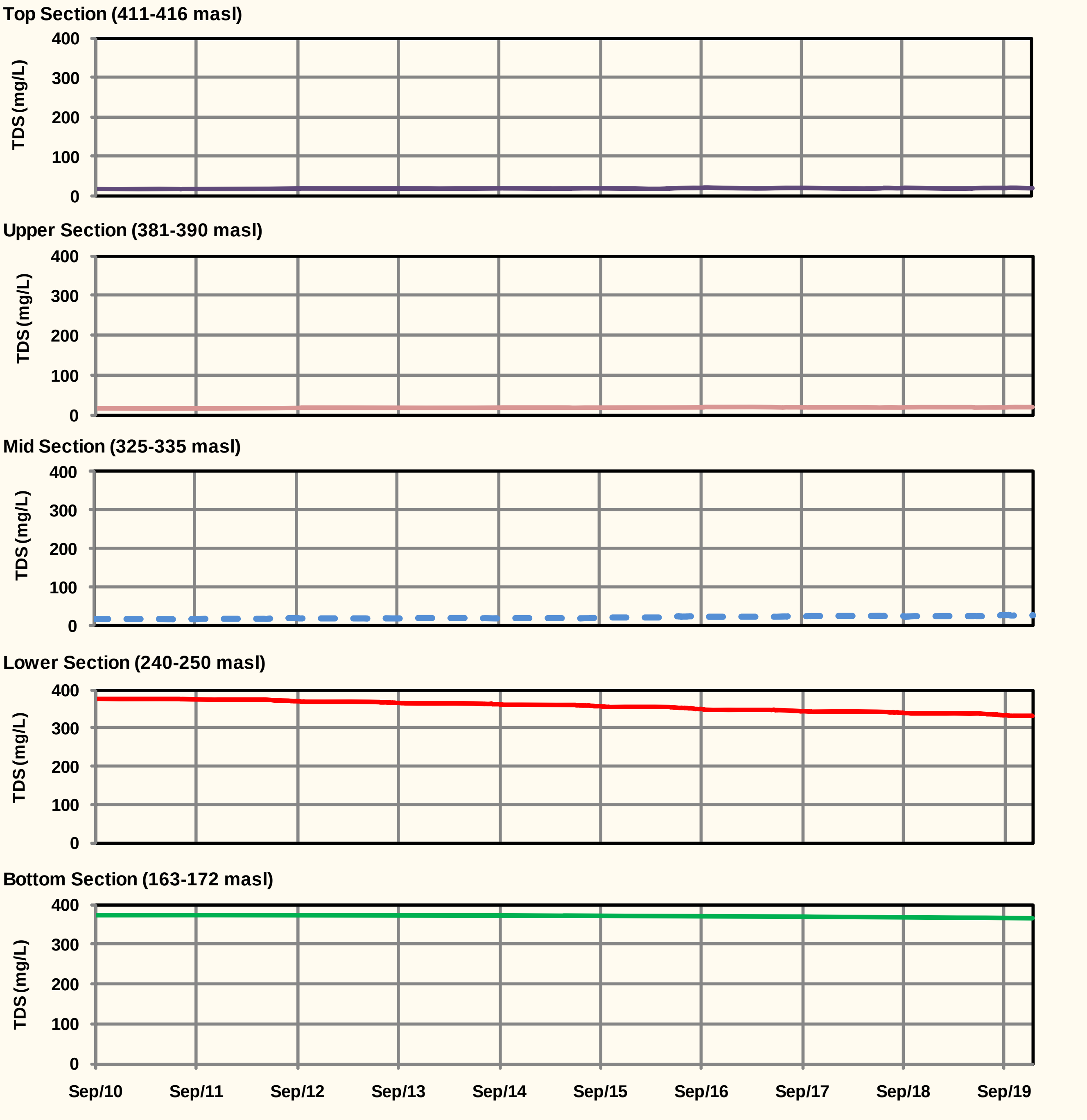
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

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



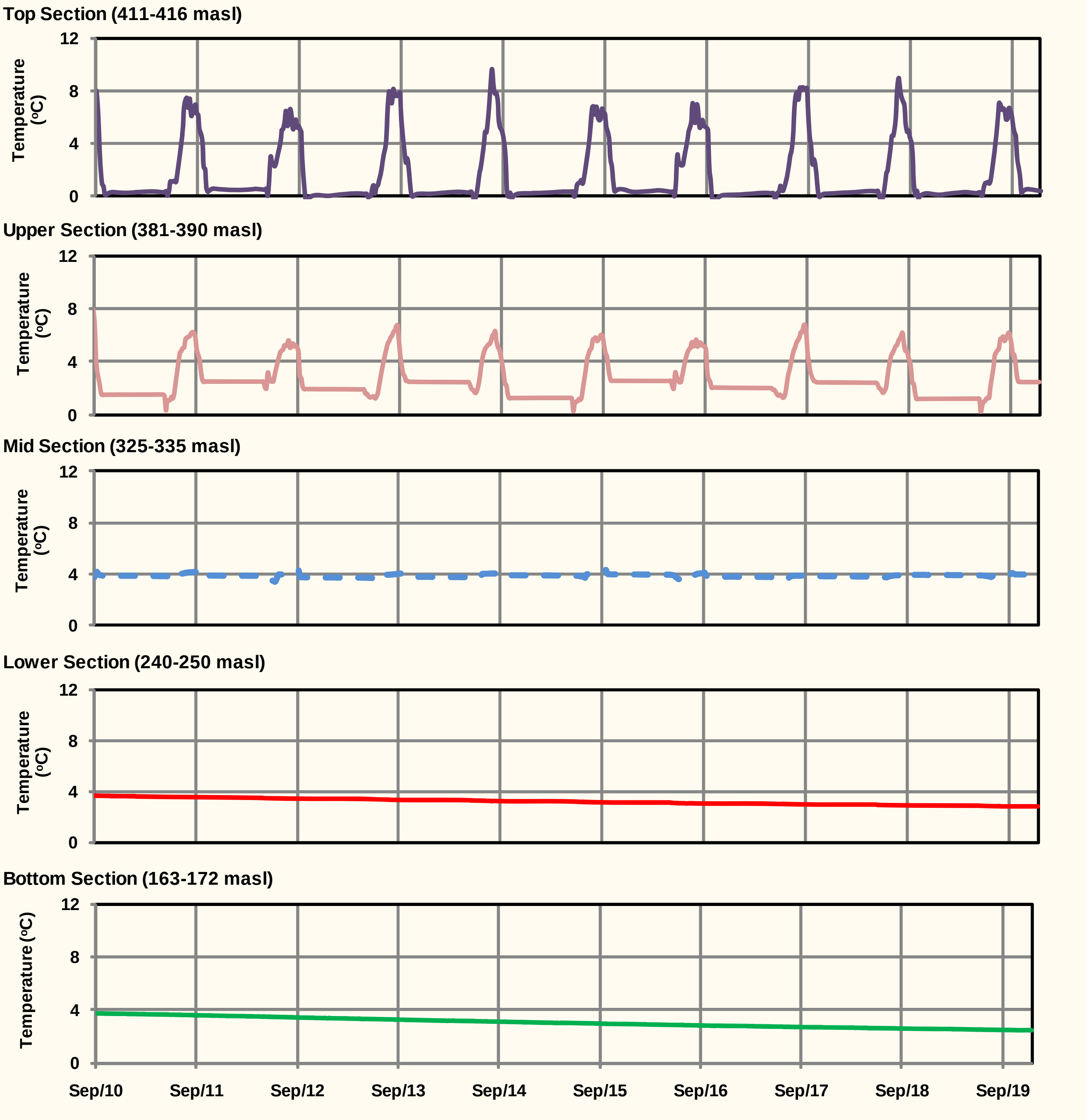
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

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.

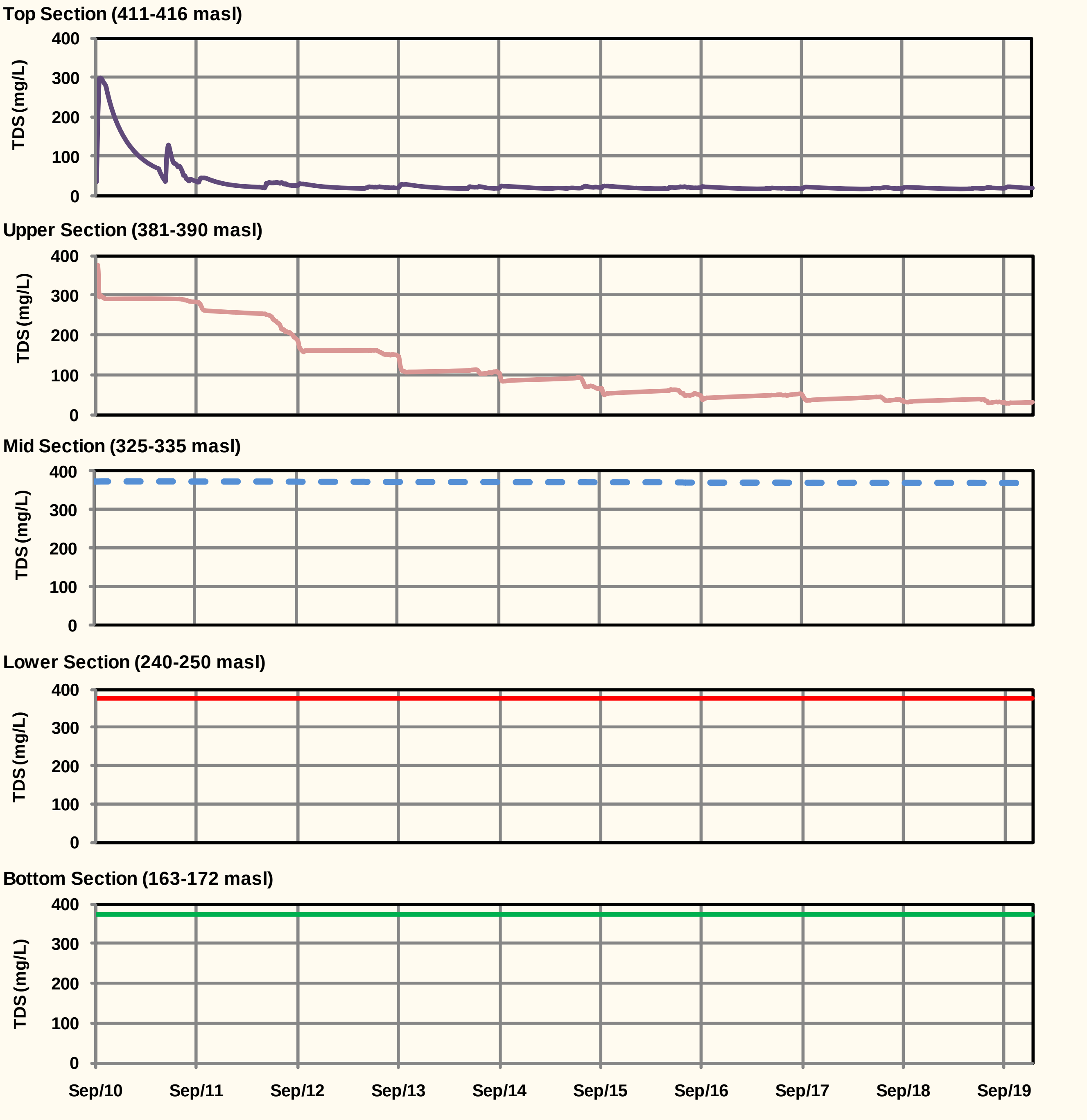
Predicted TDS levels from the GW to 411 simulation indicate that a groundwater – surface water divide at 411 masl cannot be maintained. Although full mixing of the pit lake did not occur at any point in the 10-year simulation, TDS levels in the upper portion of the pit lake (i.e., above 360 to 380 masl) 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.

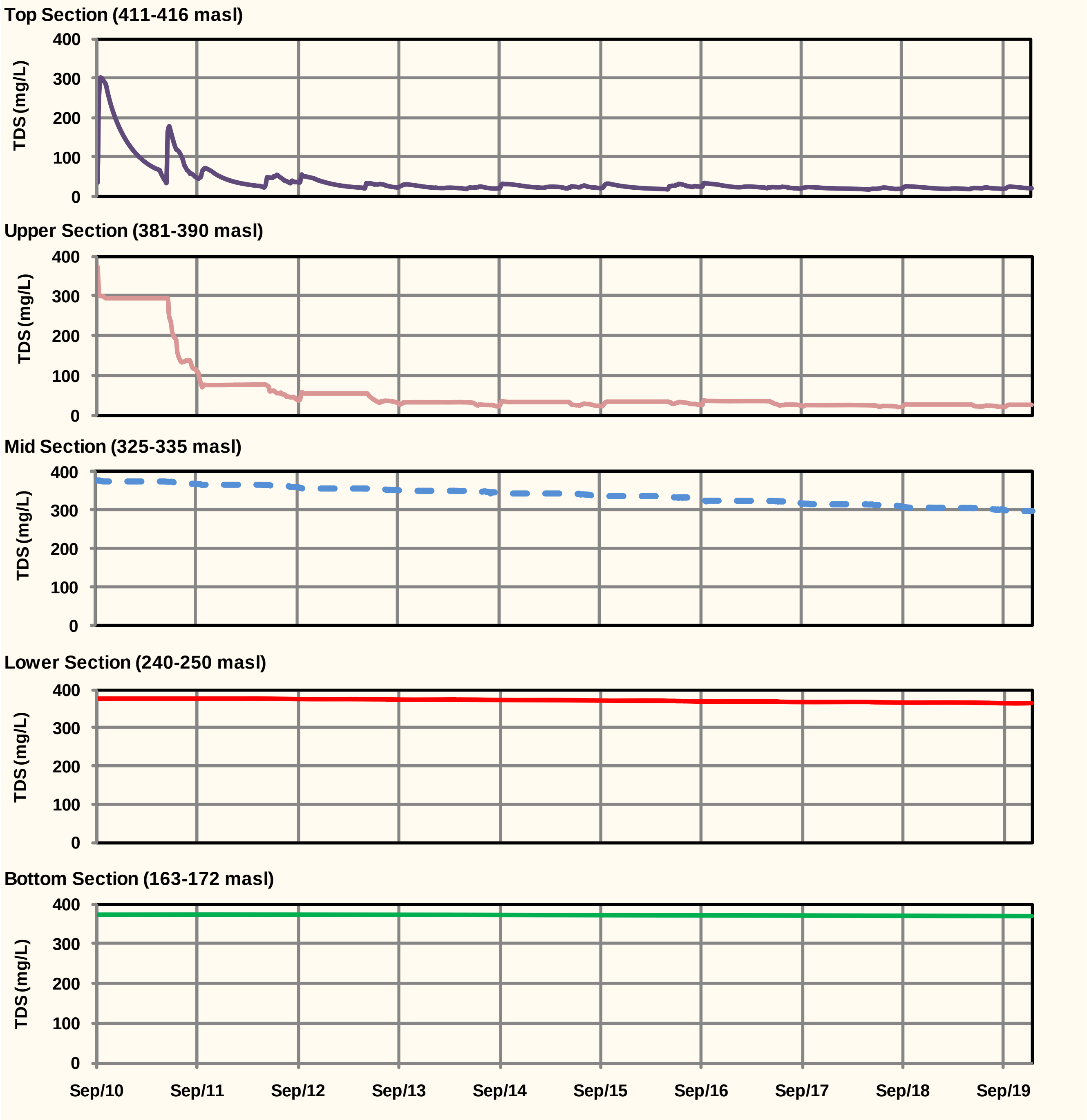
The amount of groundwater initially placed in the A154 pit lake could exert some influence on water temperatures at the bottom of the lake, since model predictions suggest that slightly cooler temperatures may occur with smaller groundwater volumes than with larger initial volumes. However, the predicted 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



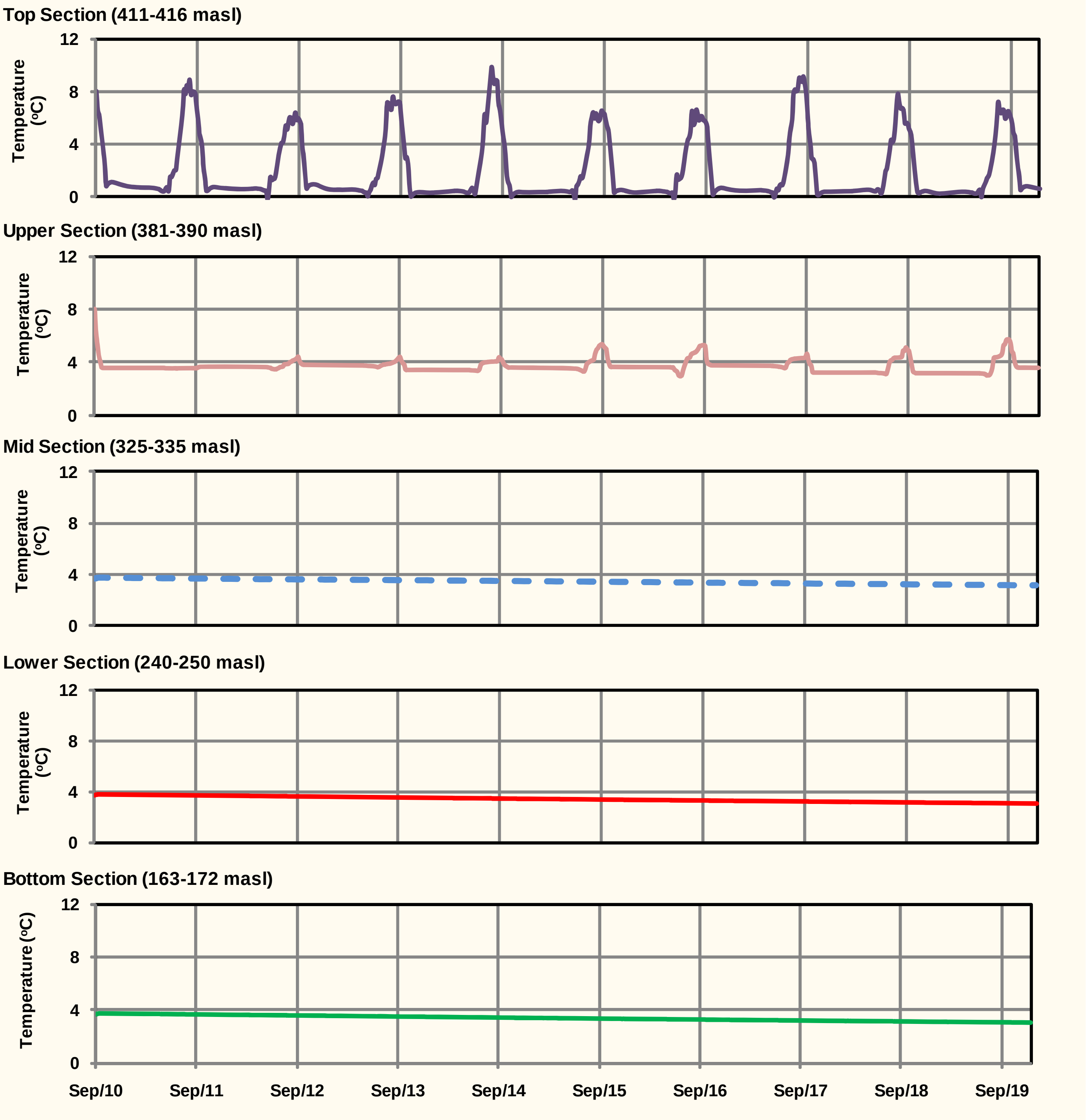
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

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



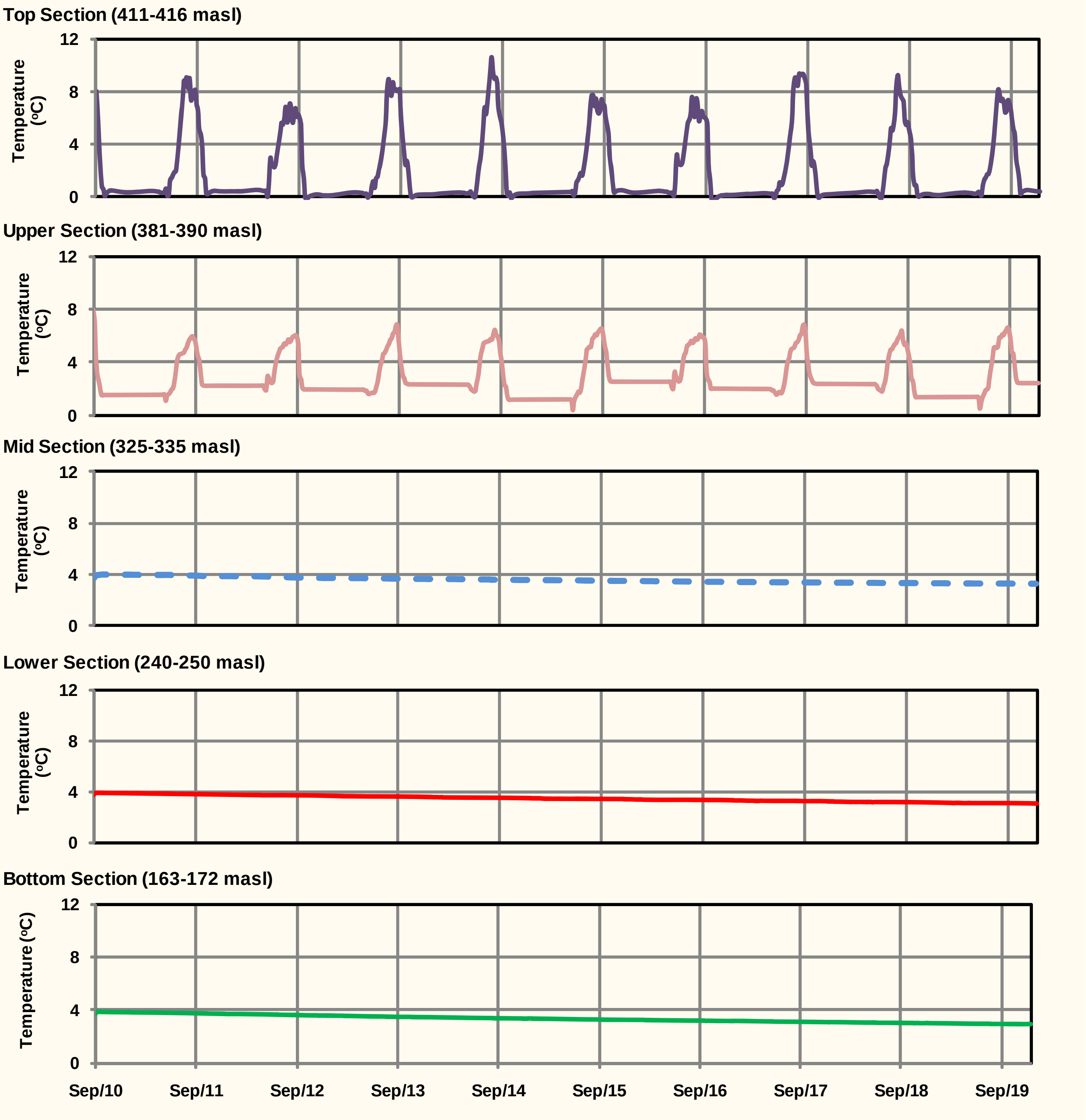
Note: For the purposes of this study, filling was assumed to be completed by September 14, 2010.

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)[a]								
	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

[a] 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)(a)								
	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

(a) 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)(a)								
	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

(a) 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)(a)								
	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

(a) 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
75th Percentile	6.9
95th Percentile	11.0
99th 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,

Dinesh Pokhrel, M.Sc. Water Quality Modeller	J.P. Bechtold, M.A.Sc., P.Biol. Associate, Senior Water Quality Specialist

JPB/kl/aw

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

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7.0 REFERENCES

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

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

(a) Shaded values differ from default values recommended by Cole and Wells (2008).

(b) Selected value has been used in other northern lake modelling studies.

(c) 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.

(d) 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).

Appendix X-4

Initial Screening Assessment of Options for Disposal of Inert Building Materials at Closure – Diavik Mine Site

Golder Associates

TECHNICAL MEMORANDUM

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.

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^3 and total weight of some 58,000 tonnes.

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

Material	Bulk Volume for Disposal (m^3)	Total Weight for Disposal (tonne)
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_2 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

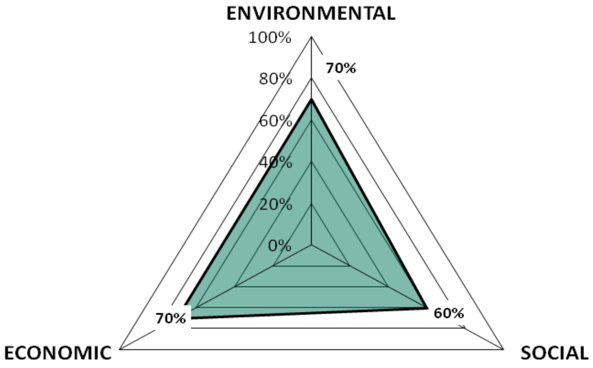
Theme	**Indicator**	**Indicator Description**	**Ranking Description**	**Score**		**Comments**
				On-Site	**Off-Site**	
Environmental						
Use of Natural Resources	Energy Consumption	Direct and/or indirect energy consumption (fuel, electricity, etc.) during disposal operations including transportation.	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. Off-site waste disposal: very high energy consumption required for transporting some 58,000 tonnes to Yellowknife. Trucking alone would required about 150,000 litres of diesel fuel and create over 350 tonnes of equivalent CO_2 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. 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 2, 3, 4 = relative ranking 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. 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 2 = persisting impact 3 = partial recovery 4 = full recovery 5 = Improvement by implementing the option	3	3	On-site waste disposal: disposed within disturbed area. Off-site waste disposal: disposed on existing facility, similar impacts.
			Total Environmental	14 70%	9 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	
Social						
Health and Safety	Public Safety	Potential adverse impacts on public safety arising from the implementation of the option.	1 = significant impact 2 = moderate impact 3 = low impact 4 = no impact 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. 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 2 = moderate impact 3 = low impact 4 = no impact 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. 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 2 = moderate impact/restriction 3 = low impact/restriction 4 = no impact/restriction 5 = potential benefit	3	3	On site waste disposal: facility within currently disturbed areas. Off-site waste disposal: existing facility, similar impacts.
			Total Social	9 60%	7 47%	

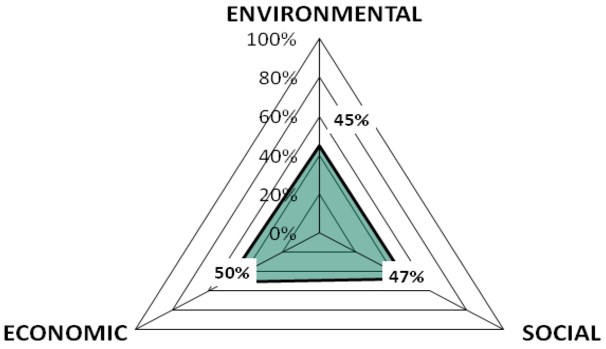
Theme	Indicator	Indicator Description	Ranking Description	Score		Comments
				On Site	**Off Site**	
Economic						
Costs	Tipping fee for waste	Value of construction and capital costs of the option.	A relative score from 1 (high cost) to 5 (low cost) is assigned based on the relative capital cost of the option.	5	1	On-site waste disposal: low cost with the construction of a waste management facility within disturbed mine area. 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. Off-site waste disposal: low cost as limited long term operating cost
			Total Economic	7 70%	5 50%	
			TOTAL	30 67%	21 47%	

On-site



Preferred Option

Off-site



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

ORIGINAL SIGNED

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

GP/JCC/aw/rs

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

\\bur1-s-filesrv2\final\2010\1328\10-1328-0031\1011 10dec_10 tm-ver 0\1011 10dec_10 tm-ver 0 initial screening assessment options disposal inert bldg materials.docx

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 (m2)
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. Base slabs of each structure are assumed to be staying in place. 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. Only building structures have been considered. No structures supporting equipment or equipment has been considered on this estimation. 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. Insulation of all exterior walls and roof has been assumed for all buildings. An exterior concrete wall along the perimeter of buildings 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		
MAC E Wing	268	ATCO Trailer (Single)	1,283	97	117		
North Inlet Water Treatment Plant	140	14	1,125	1,762	1,846		
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		
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		
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	
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		
			TOTAL~	**53,000**	**58,000**	*** Estimated Bulk Volume includes 2.2 bulk factor** **^ 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

Errata – Disposal Alternatives for North Inlet Water Treatment Plant Sludge
August 2011

Section 3.2 Pg 3: The sentence: "*The inert landfill area is also being used for farmed hydrocarbon contaminated soils and is being considered for inert building waste deposit at closure."* Should be replaced with: *The Type III waste rock area immediately west of the inert landfill is also being used for farmed hydrocarbon contaminated soils and is being considered for inert building waste deposit at closure.*

Appendix X-5

Disposal Alternatives for North Inlet Water Treatment Plant Sludge

TECHNICAL MEMORANDUM

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.

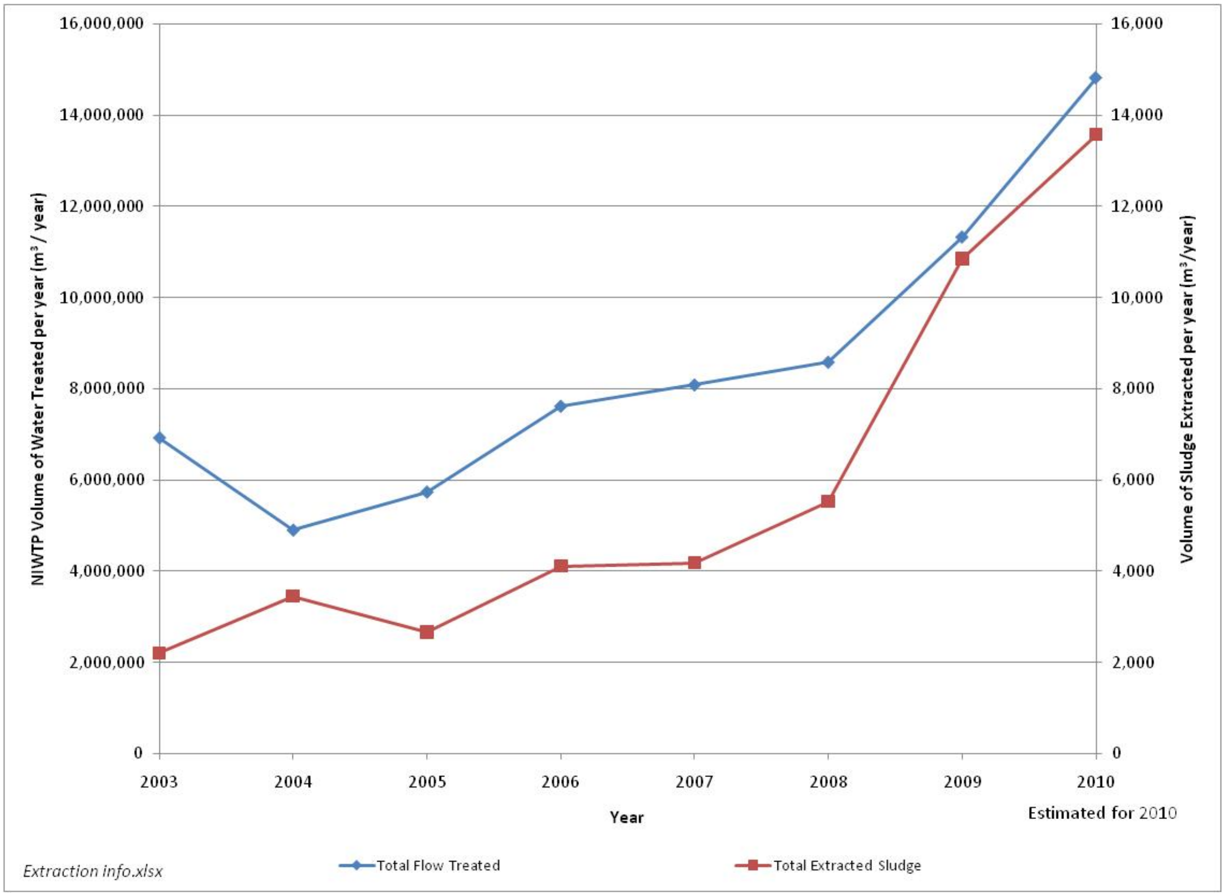


Figure 1: Annual NIWTP quantity of water treated and sludge produced.

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^3 per year. The total sludge extracted in 2009 and 2010 averaged some 12,250 m^3. For the purpose of this memorandum, it is assumed that the NIWTP will treat an average of 14 million m^3 of water per year, and produce an average of 13,000 m^3 of sludge per year.

Between start up in 2003 and June 2010, the NIWTP has treated a total of 68 M m^3 of water and produced about 46,500 m^3 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^3 of water, and assuming conditions do not change, it is estimated that this will create over 182,000 m^3 of sludge to be disposed of. The current frequency of sludge production is between 30 and 37 m^3 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^3.

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.

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

ORIGINAL SIGNED

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

Attachment: Study Limitations

JCC/PMC/rs/aw

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STUDY LIMITATIONS

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Appendix X-6

Diavik Waste-Rock Research Program
2009 Progress Report

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

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_2 concentrations have been observed below the till layer, indicating that the till layer provides a barrier to gas transport. O_2 depletion rates through the summer of 2008 are used to calculate a rate of sulfide oxidation. The calculated rate ranges from 1.7×10^{-11} to 4.1×10^{-11} kg O_2 m^{-3} s^{-1}. In comparison, humidity cell experiments on Type III rock from the Diavik site give average oxidation rates of approximately 2×10^{-12} kg O_2 m^{-3} s^{-1}.

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 ^{o}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 x 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 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_2/CO_2 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_2/CO_2 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_2 sensor, which is less sensitive to temperature fluctuations than previous instruments, and the automated two-point calibration of both the CO_2 and O_2. 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_2/CO_2 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.

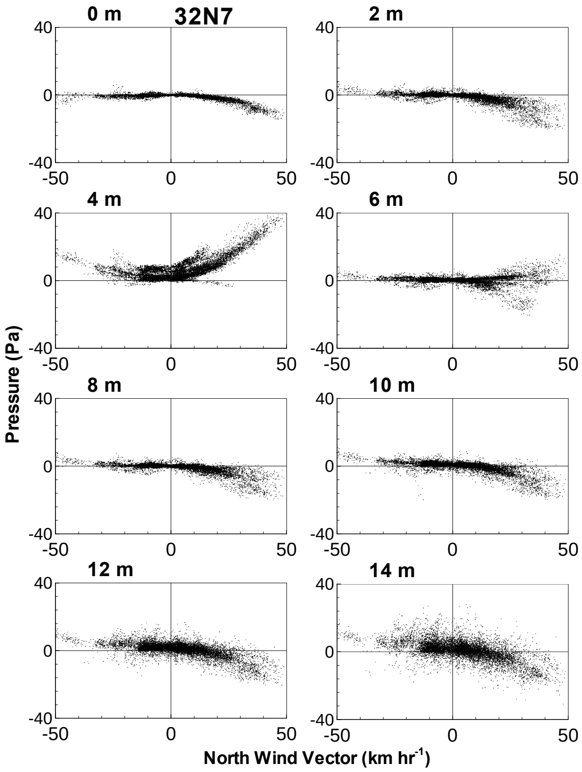

Figure 2-3. Measured differential pressures plotted against the north wind vector for the Diavik Type III test pile. Pressures are shown as the differential pressure between the sampling point and the reference point 32N2-0.

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.

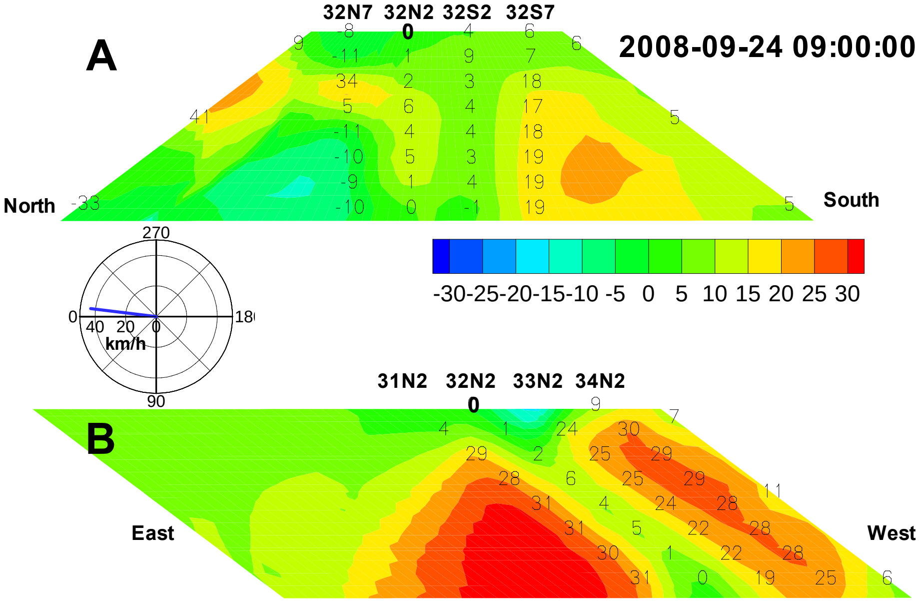

Figure 2-4. 2-D spatial profiles of differential pressure within and around the Type III test pile along with the prevailing wind conditions on September 24, 2008 at 9:00 am. Numbers on the contour plots represent measured data points spaced 2 m vertically. All differential pressures are referenced to 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_2 are below atmospheric levels and the concentrations of CO_2 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_2 concentrations decrease and CO_2 concentrations increase. Furthermore, at 7-8 m depth, the O_2 concentrations decrease with time and CO_2 concentrations increase with time. The observed changes in gas concentrations suggest that in certain locations within the pile, the rate of O_2 consumption through sulfide oxidation and the rate of CO_2 production through carbonate dissolution exceed the rate of gas transport.

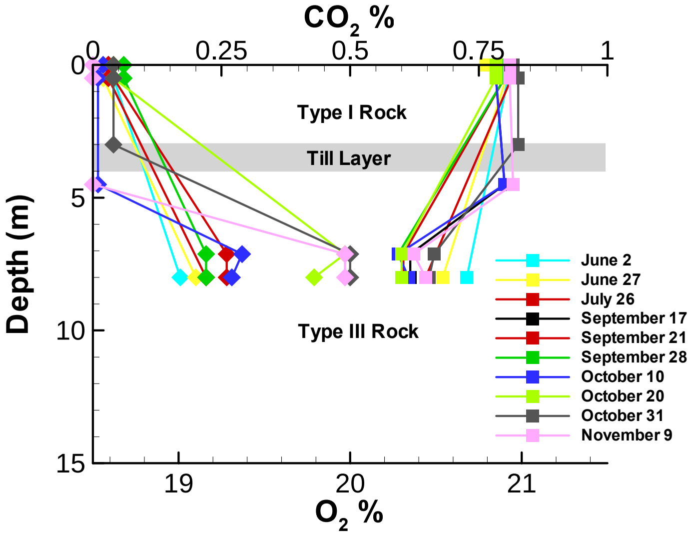

Figure 2-5. O_2 (squares) and CO_2 (diamonds) concentrations along sampling bundle C3W2 for June to Novemeber, 2008.

The temporal trends in O_2 concentrations are shown in greater detail for the three sampling locations within the Covered pile Type III core that showed depletions in O_2 concentrations and increases in CO_2 concentrations (Figure 2-6). For each of these locations, there is a period of decreasing O_2 concentrations starting in early June (≈day 0) and going to late august (≈day 110). Assuming a linear decrease in O_2 concentrations during this period, the rate of O_2 depletion ranges from 9.1×10^{-11} to 3.8×10^{-10} kg O_2 m^{-3} s^{-1} (Table 2-1). Assuming that diffusion is the dominant O_2 transport mechanism, the maximum O_2 transport rates can be estimated based on the lowest observed concentrations. Diffusion rates range from 2.2×10^{-12} to 7.7×10^{-12} kg O_2 m^{-2} s^{-1}. Therefore, for the period with the lowest observed O_2 concentrations, the total oxidation rate, equal to the sum of O_2 depletion rates and the influx of O_2 through diffusion, range from 9.9 x 10^{-11} to 3.9 x 10^{-10} kg O_2 m^{-3} 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 x 10^{-11} kg O_2 m^{-3} s^{-1}. Further analysis is required to investigate the relationship between the lab measured rates and those determined from the gas concentration measurements.

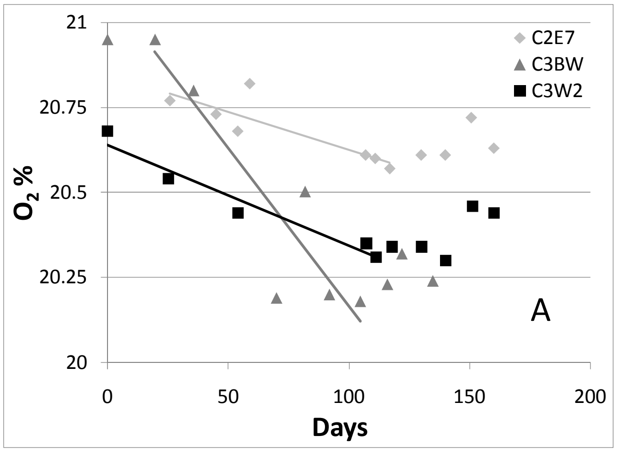

Figure 2-6. O_2 concentrations with time for selected sampling locations C2E7-4.5, C3BW-24, and C3W2-8. Lines are linear regressions of data points during the period of decreasing O_2 concentrations. Day '0' is June 2, 2008.

Table 2-1. Oxidation rate calculation results from Covered pile O_2 data.

	C2E7	C3BW	C3W2
O_2 depletion rate (kg O_2 m^{-3} s^{-1})	9.1 x 10^{-11}	3.8 x 10^{-10}	1.2 x 10^{-10}
Maximum O_2 diffusion rate (kg O_2 m^{-2} s^{-1})	7.7 x 10^{-12}	2.2 x 10^{-12}	4.6 x 10^{-12}
Total oxidation rate (kg O_2 m^{-3} s^{-1})	9.9 x 10^{-11}	3.9 x 10^{-10}	1.3 x 10^{-10}

In 2009 and 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.

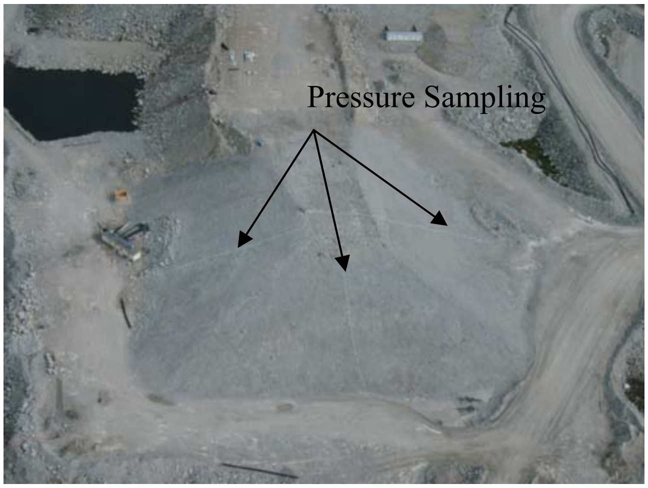

Figure 2-7. Arial view of Covered test pile showing surface pressure sampling conduit; part of the automated pressure and gas sampling system installed in 2009.

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 ^{o}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 ^{o}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.

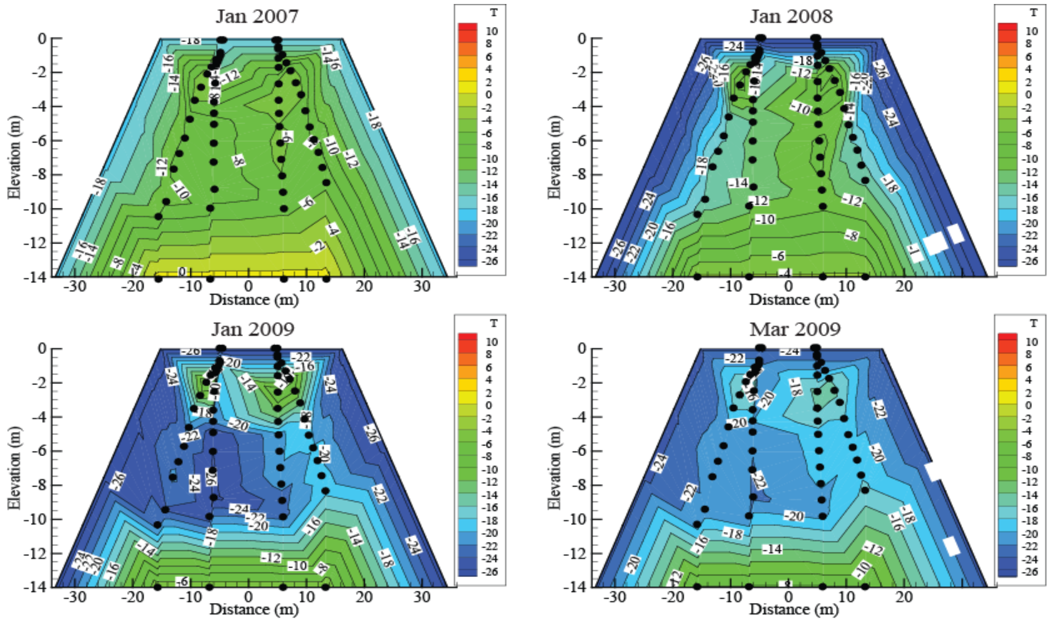

Figure 2-8. Contour temperature in Jan at face 4 type III pile since 2007.

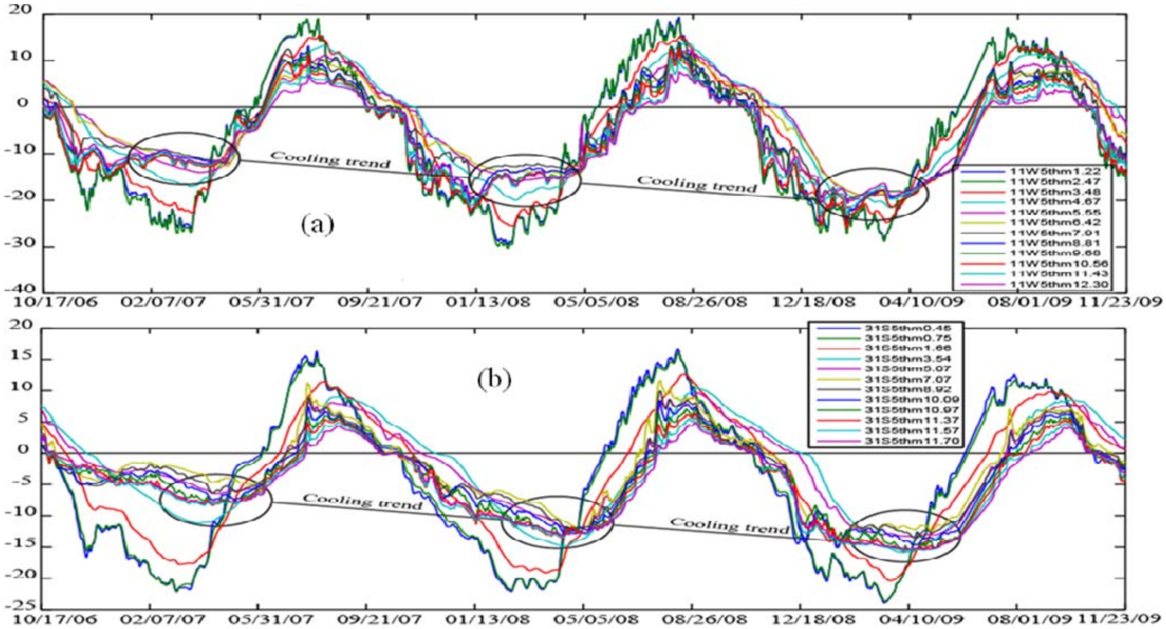

Figure 2-9. Thermistor string at face 1 Type I (a) and Type III (b) pile shows cooling trend.

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.

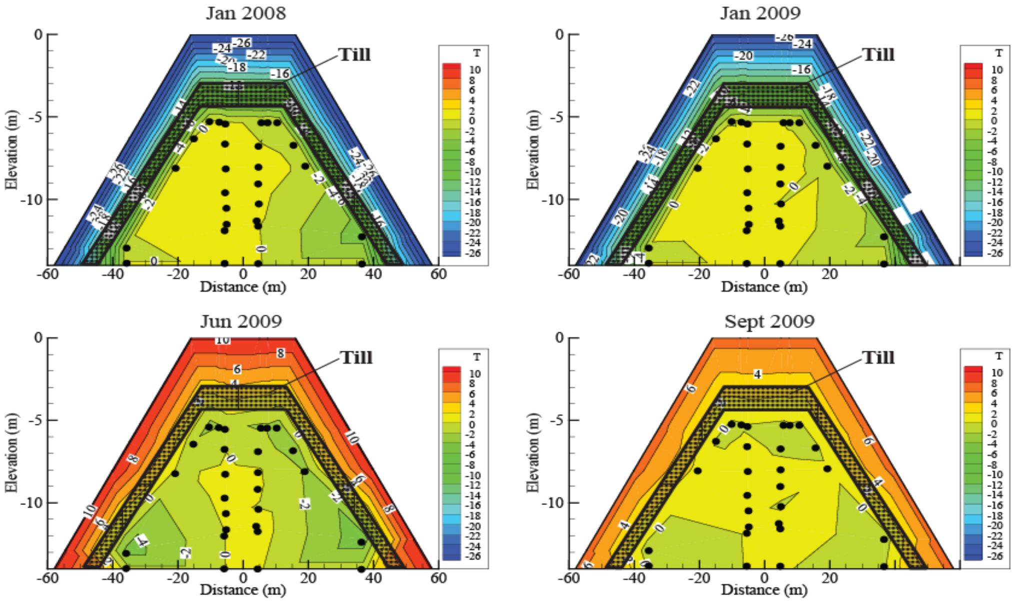

Figure 2-10. Contour temperature at face 4 covered pile since 2007.

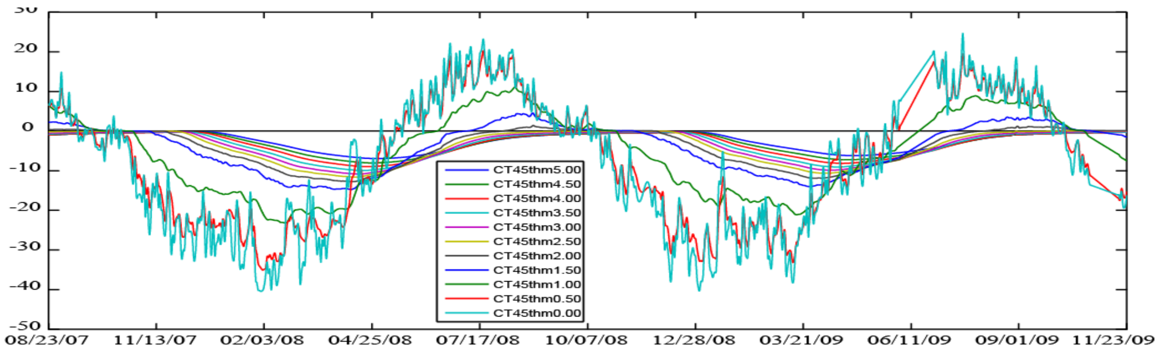

Figure 2-11. Thermistor string drilled from the top of covered pile shows an active layer of 3m at this string since 2008.

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).

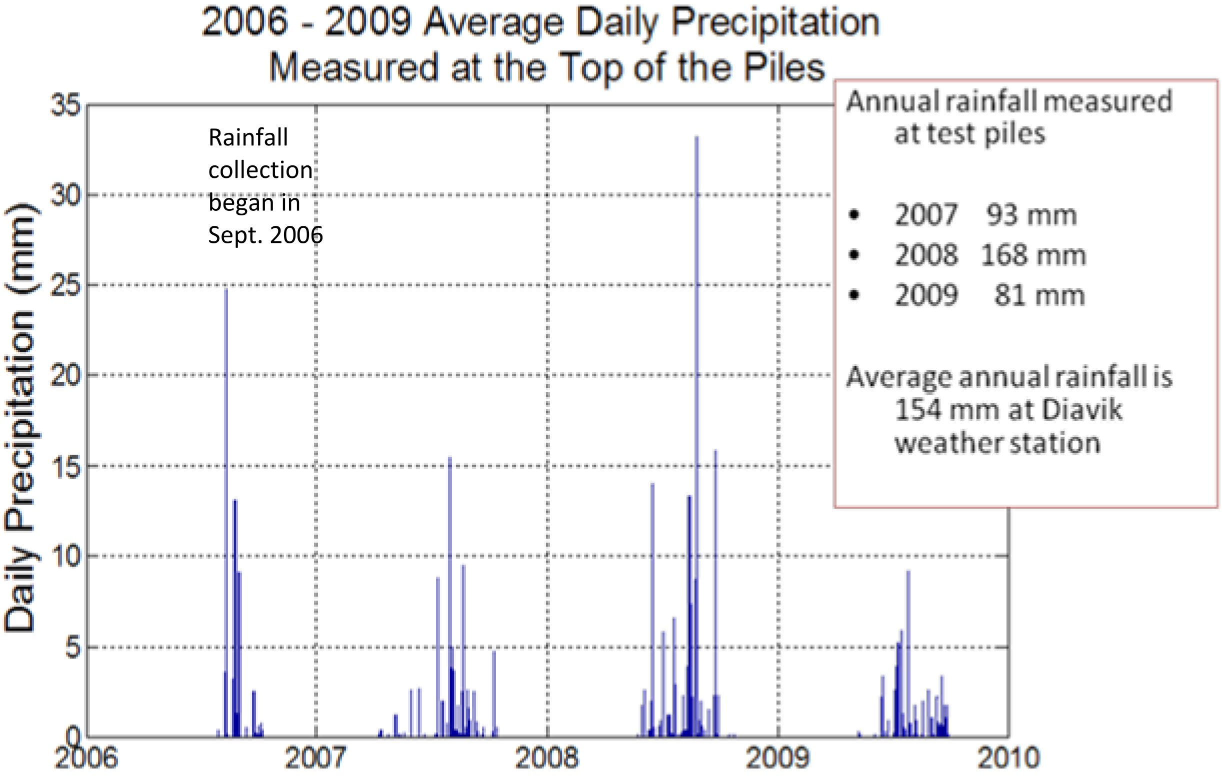

Figure 2-12. Average daily precipitation at top of test piles.

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).

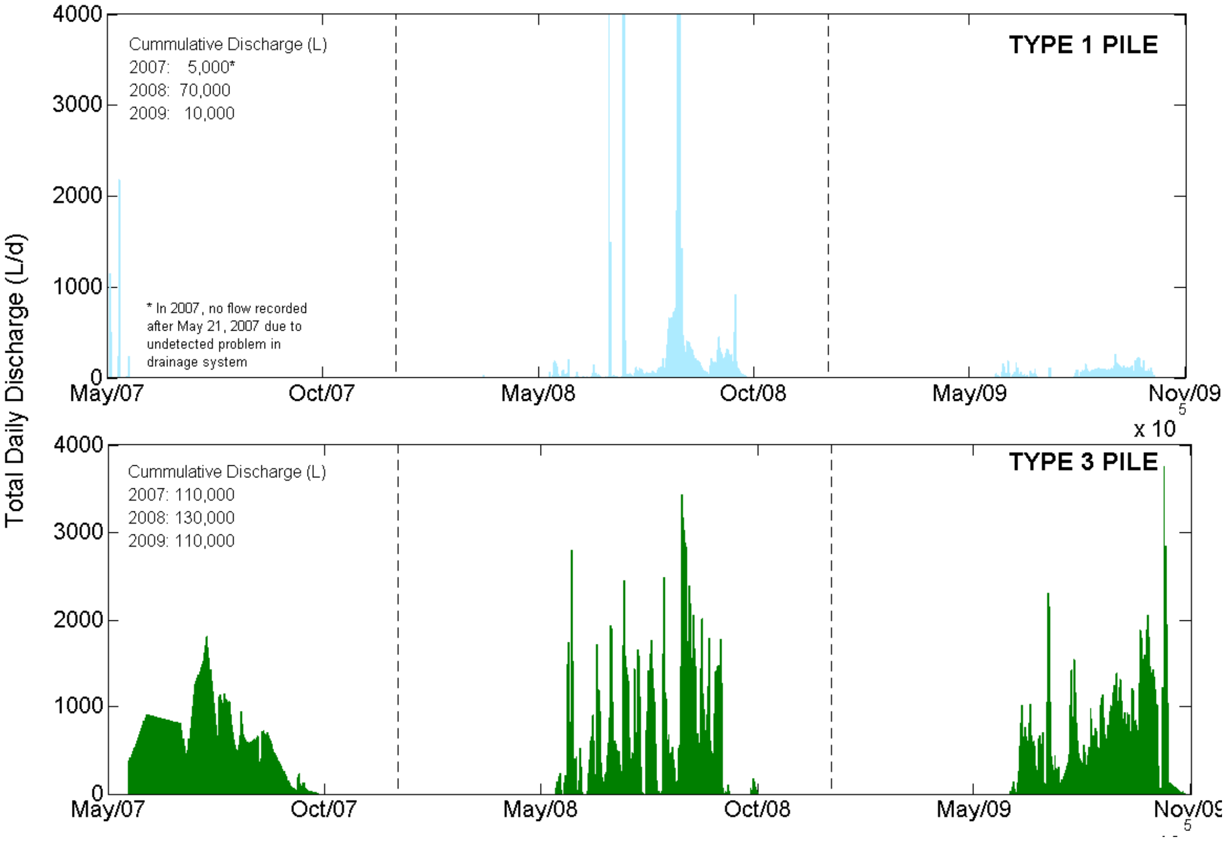

Figure 2-13. Total daily outflow volume at Type I and Type III basal drains.

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.

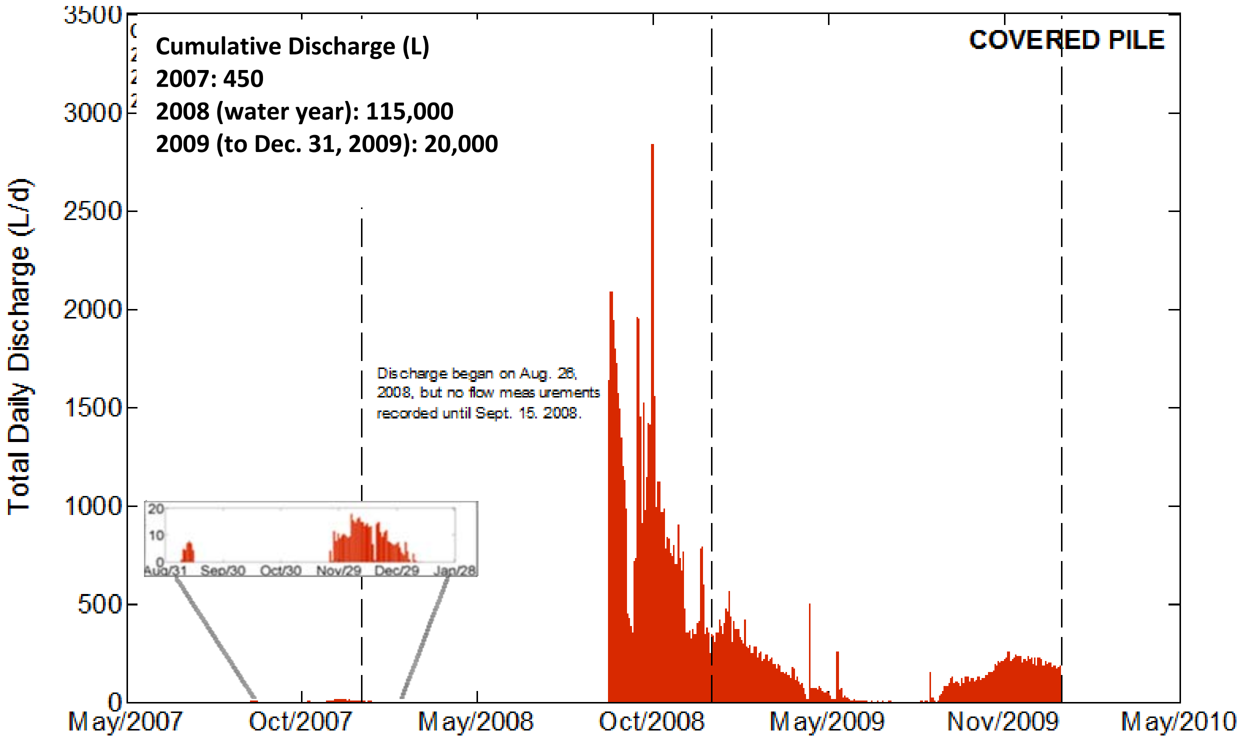

Figure 2-14. Total daily outflow volume at Covered pile basal drain.

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 x 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.

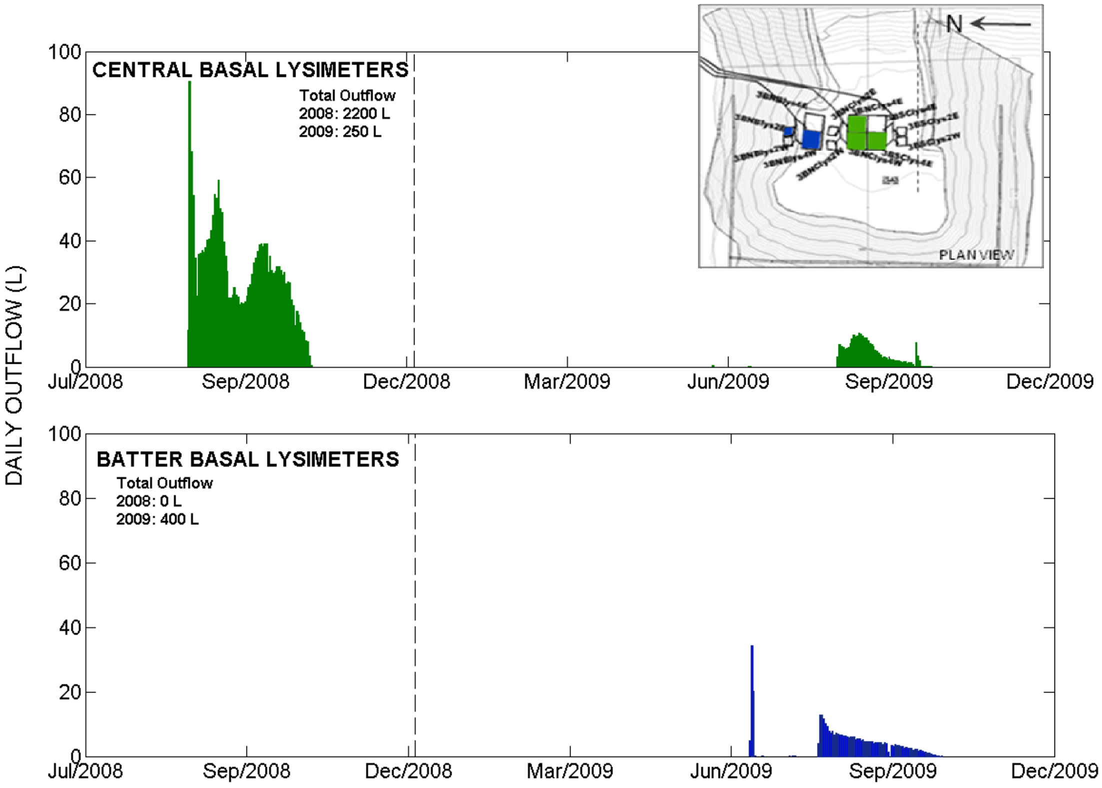

Figure 2-15. Total daily outflow volume at Type III basal lysimeters.

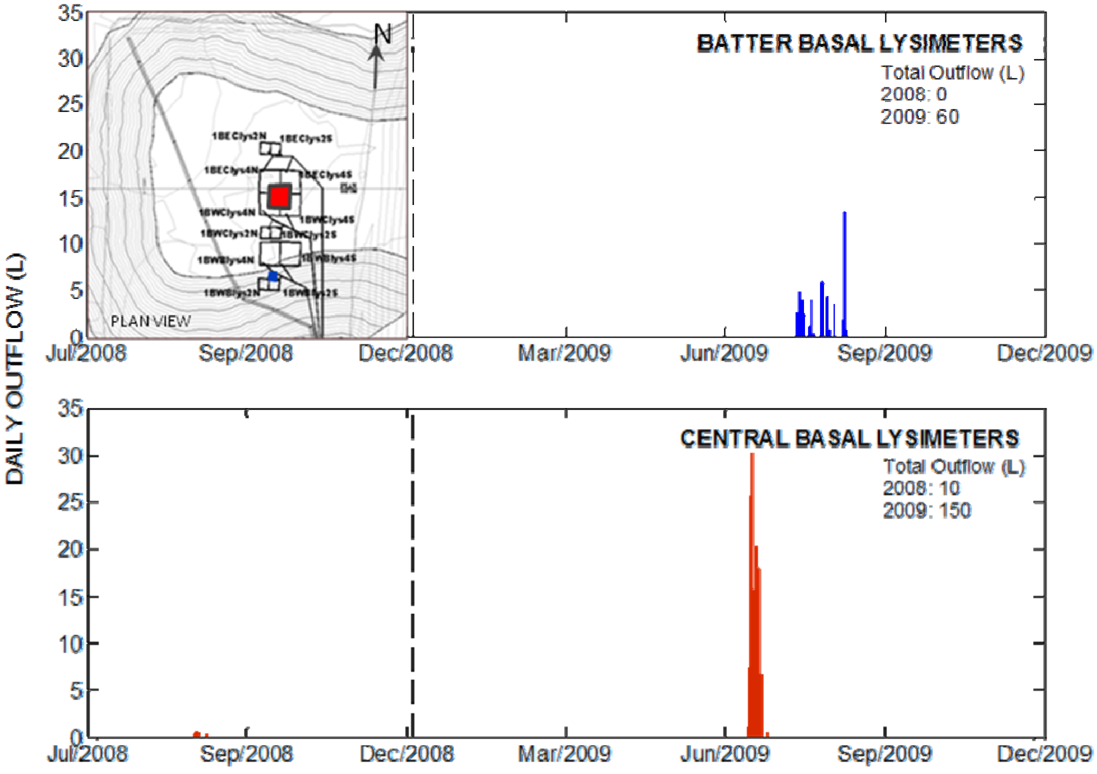

Figure 2-16. Total daily outflow volume at Type I basal lysimeters.

Figure 2-17. Construction of 32 m^3 field permeameter experiment.

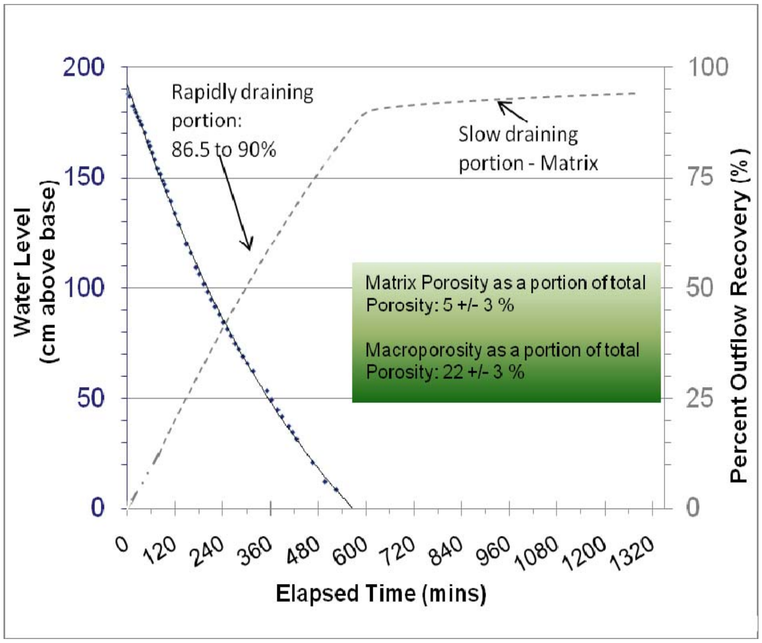

Figure 2-18. Results of 32 m^3 field permeameter experiment.

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.

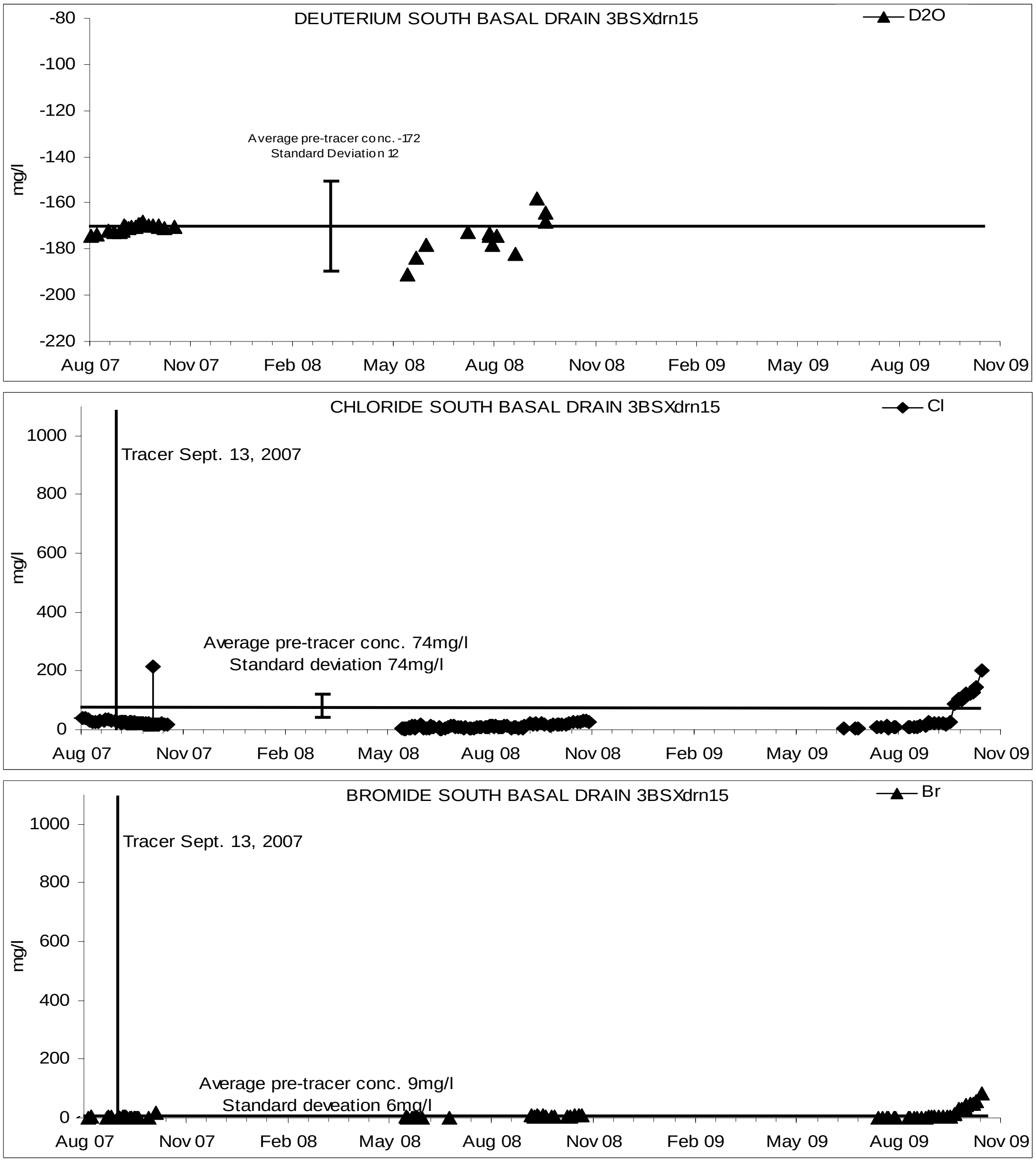

Figure 2-19. Tracer breakthrough at Type III basal drain.

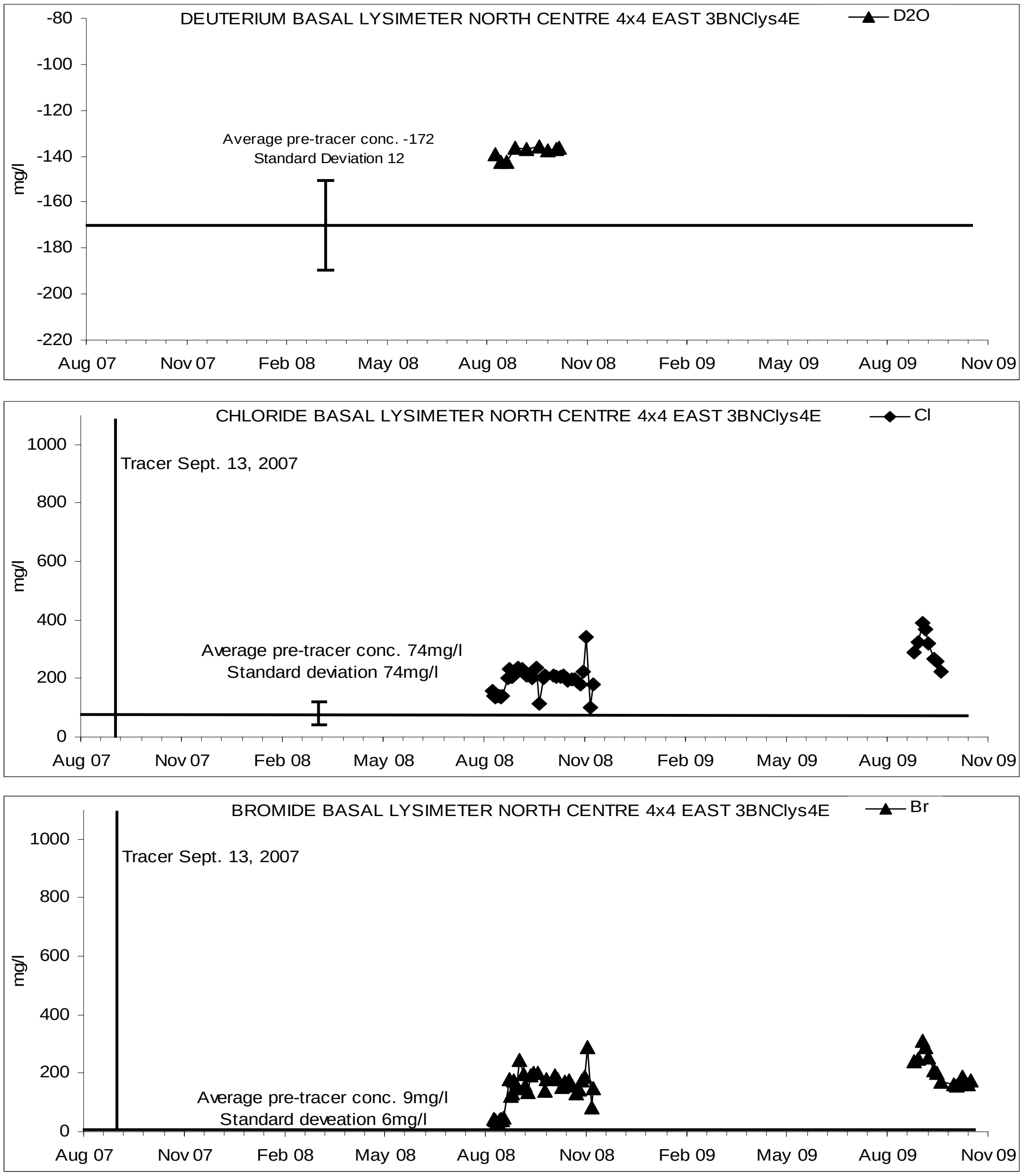

Figure 2-20. Tracer Breakthrough at Type III north centre 4 m by 4 m lysimeter.

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.

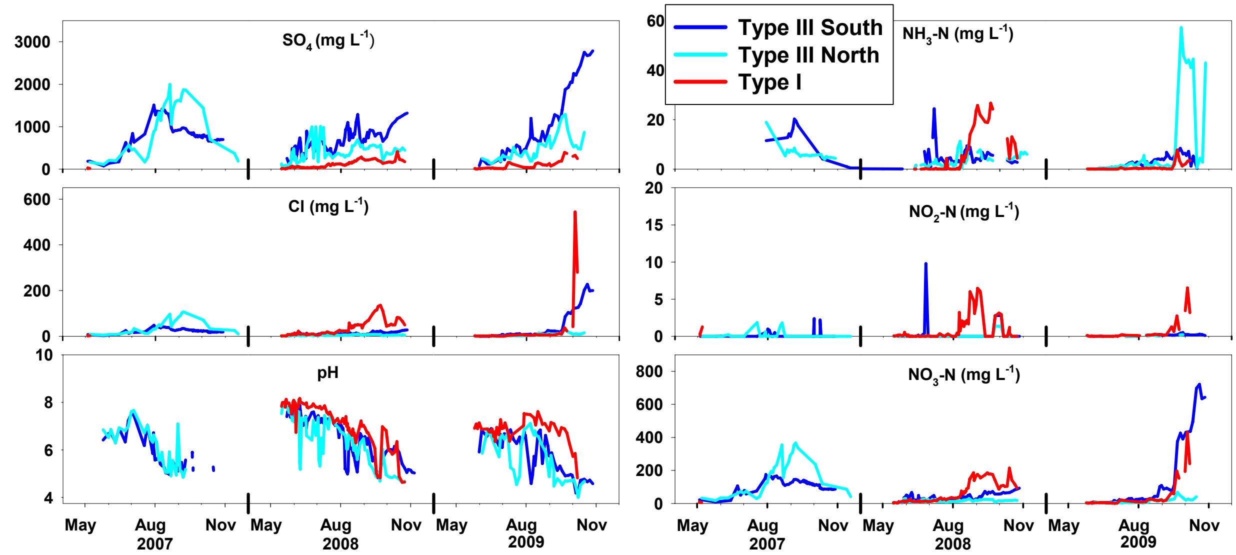

Figure 2-21. Type I and Type III basal drains general geochemistry and blasting residuals.

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 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 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 mg L^{-1}, cobalt reaching 0.5 mg L^{-1}, zinc up to 1 mg L^{-}1, and cadmium exceeding 5 µg 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^{-1}, cobalt less than 0.3 mg L^{-1}, cadmium less than 0.01 µg L^{-1}, and zinc below 1.5 mg L^{-1} (Figure 2-22).

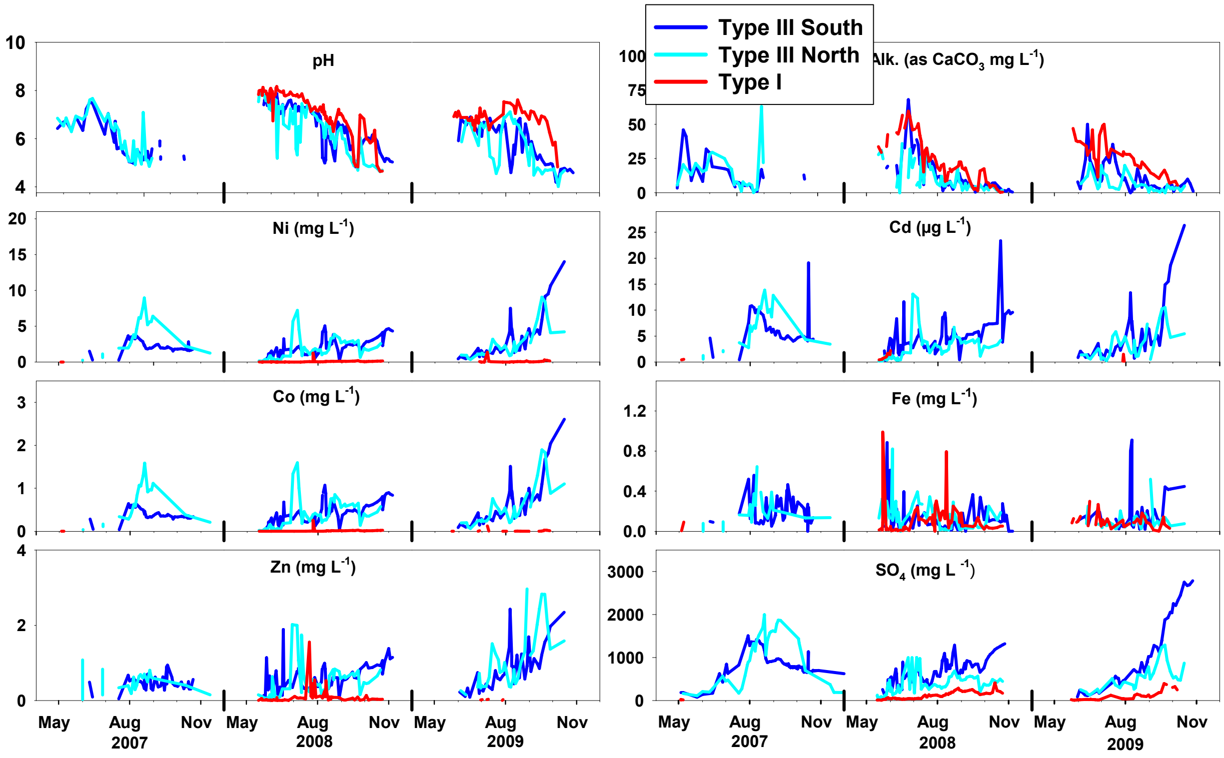

Figure 2-22. Type I and Type III basal drains geochemistry including major ion and metals.

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^{-1}, and increased concentrations of dissolved metals persist, including nickel above 5 mg L^{-1}, zinc exceeding 2 mg L^{-1}, cobalt in excess of 1 mg L^{-1}, and cadmium above 20 µg L^{-1} (Figure 2-23).

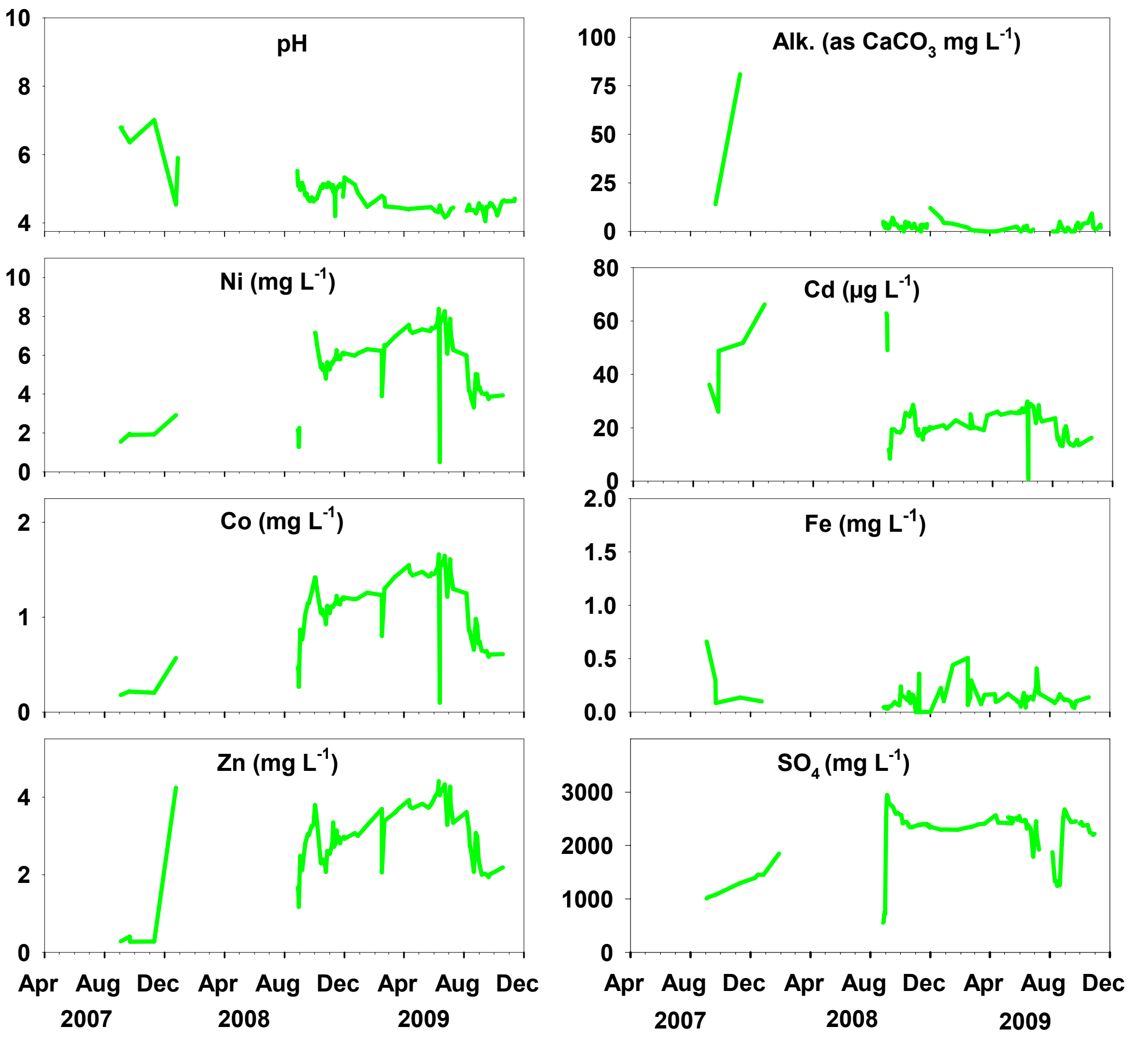

Figure 2-23. Covered pile basal drain geochemistry.

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).

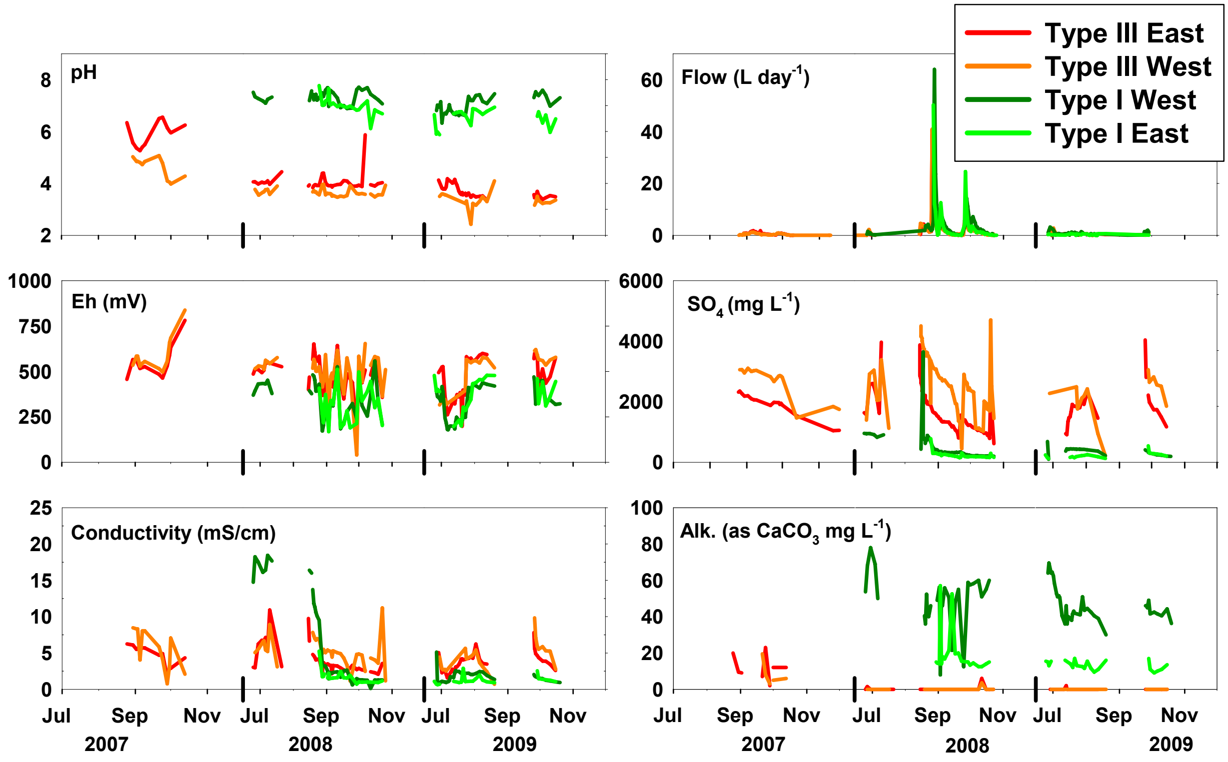

Figure 2-24. Upper collection lysimeter geochemical parameters and flow data.

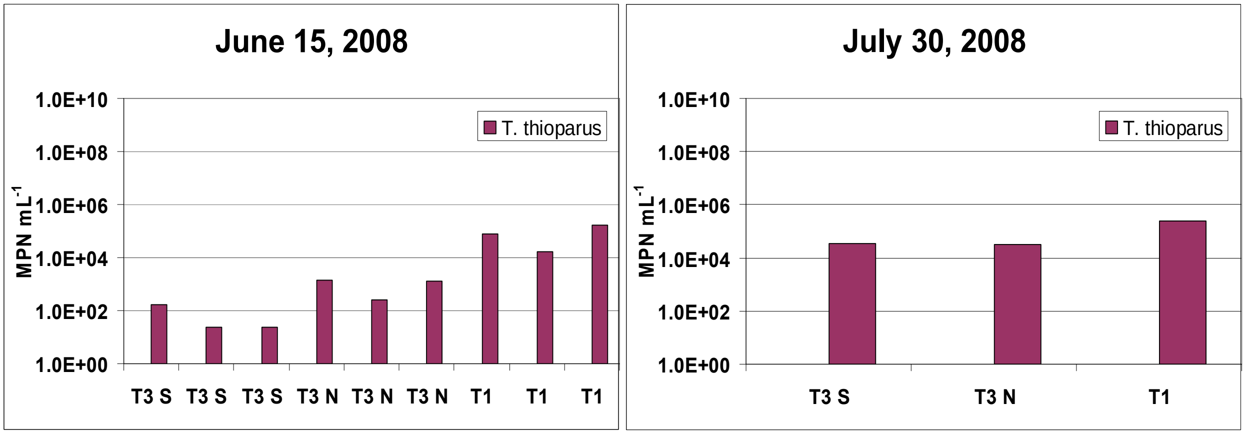

Figure 2-25. Type I and Type III pile microbial enumerations for 2008 – effluent water samples.

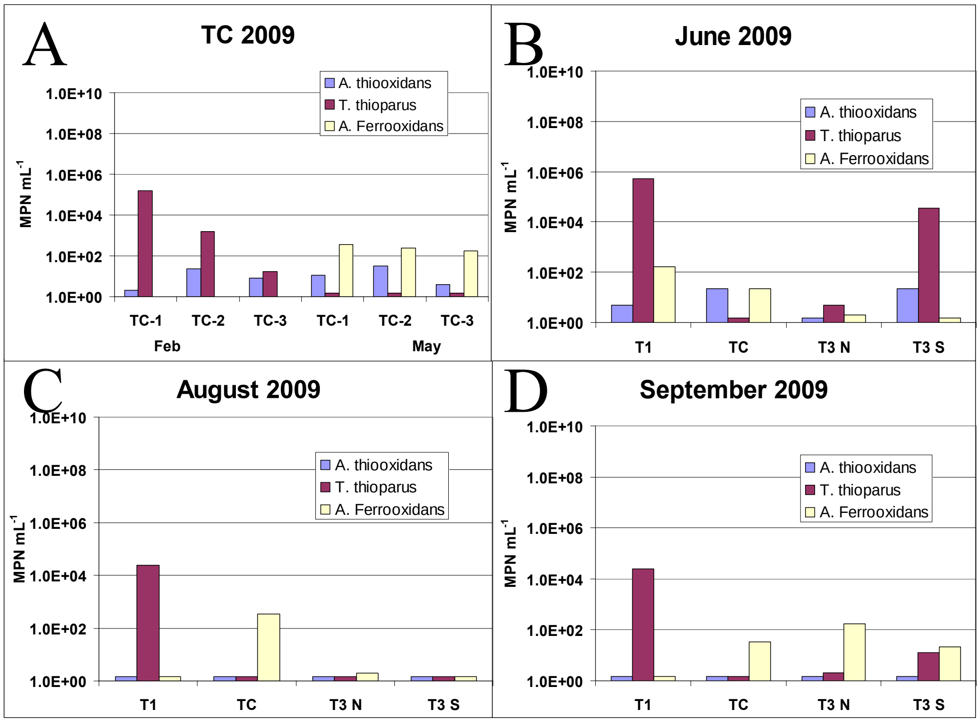

Figure 2-26. A: Covered pile microbial enumerations in 2009. B-D: Type I, Type III and Covered pile microbial enumerations in June (B), August (C) and September (D) 2009 – effluent water samples.

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.

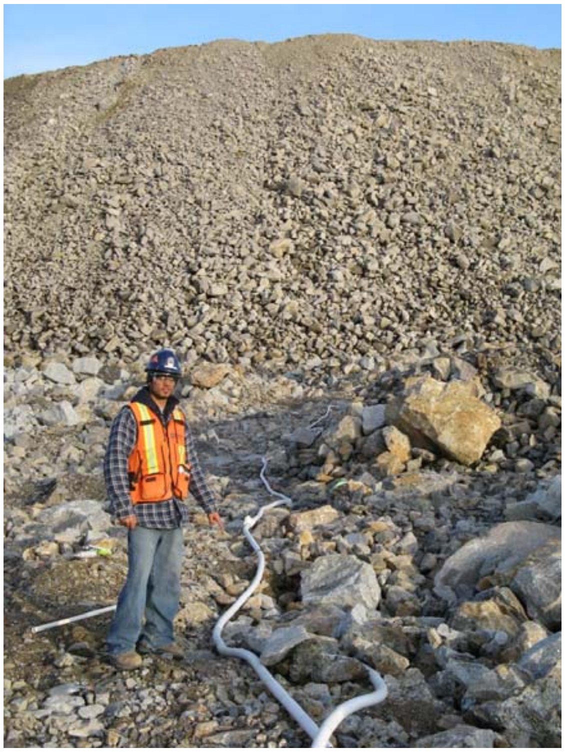

Figure 2-27. Horizontal instrument installation in full-scale Type III dump.

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.

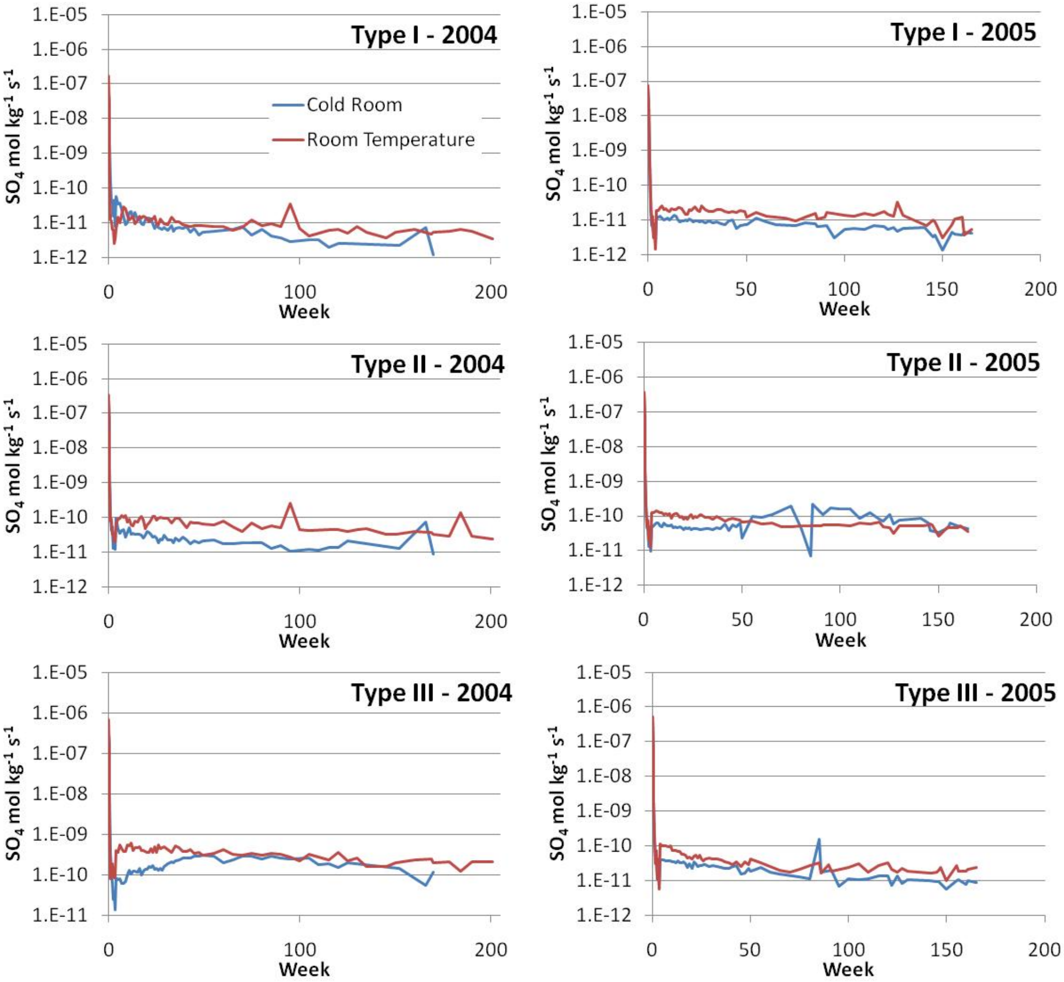

Figure 3-2. Average sulfate release rates from Type I, II and III rock collected in 2004 and 2005 for both cold room and room temperature experiments.

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 (kg rock)$^{-1}$	g S (m^2 rock)$^{-1}$	g S (Kg S)$^{-1}$	g S (m^2 S)$^{-1}$
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 - 3BNClys4E	0.0018	9.9E-06	2.83	0.02
	3BNClys4W	0.0017	9.3E-06	2.64	0.01
	3BSClys4E	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.

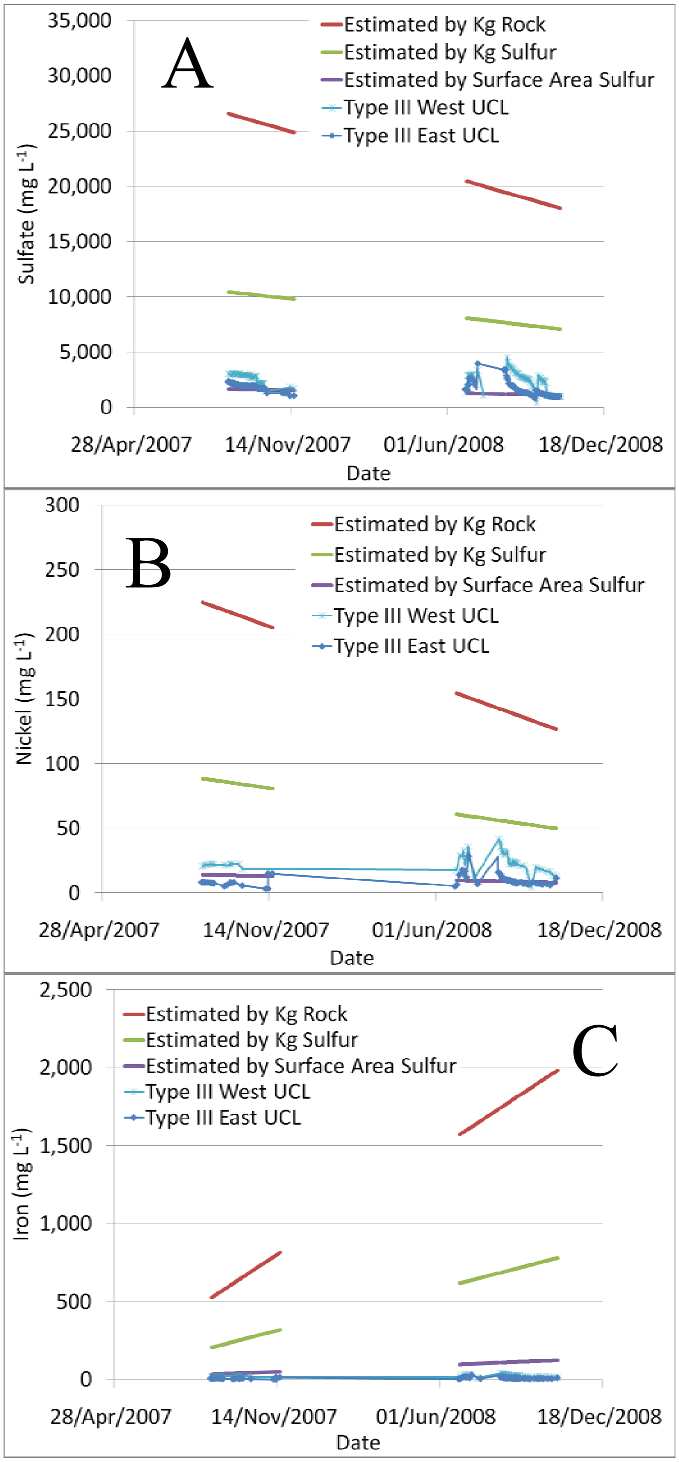

Figure 3-3. Concentration estimates for A: sulfate, B: nickel and C: iron for Type III upper collection lysimeters based on release rates derived from room temperature humidity cell experiments.

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 60th 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 61th 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

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 extent 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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Appendix X-7

Reclamation Materials Inventory and Mapping
1996 Environmental Baseline Program

TECHNICAL MEMORANDUM
DIAVIK DIMOND MINES INC. PROJECT

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

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

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

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

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

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

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

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

SITE	LANDSCAPE	HOR	DEPTH (cm)	COLOUR	TEXT	RECL RATING	STRUCT	CONS	RECL RATING	ROCKS (%)	RECL RATING
29	Topography: Gently Sloping Slope: 3% Slope Position: Middle Surface Stoniness: Slightly Stony Drainage: Well Parent Material: Glaciolacustrine UTM Coordinates: E534894 N7152262	Of irreg.	0 - 5							0	
		Om wavy	5 - 10							0	
		Cy1 wavy	10 - 43	10YR6/6	S	poor	SGR	ML	fair	5	good
		Cy2 wavy	43 - 78	10YR3/3	S	poor	SGR	ML	fair	5	good
		Cz	78 - 99+	10YR3/3	S	poor	SGR	frozen	n/a	5	good
30	Topography: Level Slope: 0% Slope Position: n/a Surface Stoniness: Moderately Stony Drainage: Well Parent Material: Glaciolacustrine UTM Coordinates: E534905 N7151602	Of wavy	0 - 2							0	
		Cy wavy	2 - 40	7.5YR4/4	S	poor	SGR	ML	fair	0	good
		Cgy wavy	40 - 85	10YR6/3	S	poor	SGR	ML	fair	0	good
		Cz	85 - 99+	10YR6/3	S	poor	SGR	frozen	n/a	0	good
31	Topography: Level Slope: 1% Slope Position: n/a Surface Stoniness: Nonstony Drainage: Imperfect Parent Material: Glaciolacustrine UTM Coordinates: E535247 N7152015	Of wavy	0 - 5							0	
		Om wavy	5 - 10							0	
		Cgy wavy	10 - 93	10YR6/3	S	poor	SGR	ML	fair	5	good
		Cz	93 - 99+	10YR6/3	fS	good	SGR	frozen	n/a	10	good
32	Topography: Gently Sloping Slope: 3% Slope Position: Middle Surface Stoniness: Very Stony Drainage: Imperfect Parent Material: Colluvial/Morainal UTM Coordinates: E535254 N7153635	Of wavy	0 - 5							0	
		Bmy wavy	5 - 24	10YR5/4	grSL	good	GR	MFR	good	20	fair
		Cy wavy	24 - 68	10YR5/3	grSL	good	MA	MFR	good	20	fair
		Cz	68 - 99+	10YR5/3	grSL	good	MA	frozen	n/a	20	fair

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

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

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

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

TABLE 1 LEGEND:

Texture

SL	sandy loam
fSL	fine sandy loam
grSL	gravelly sandy loam
SiL	silt loam
grSiL	gravelly silt loam
LS	loamy sand
grLS	gravelly loamy sand
L	loam
S	sand
grS	gravelly sand
fS	fine sand

Structure

GR	granular
SGR	single grained
MA	massive

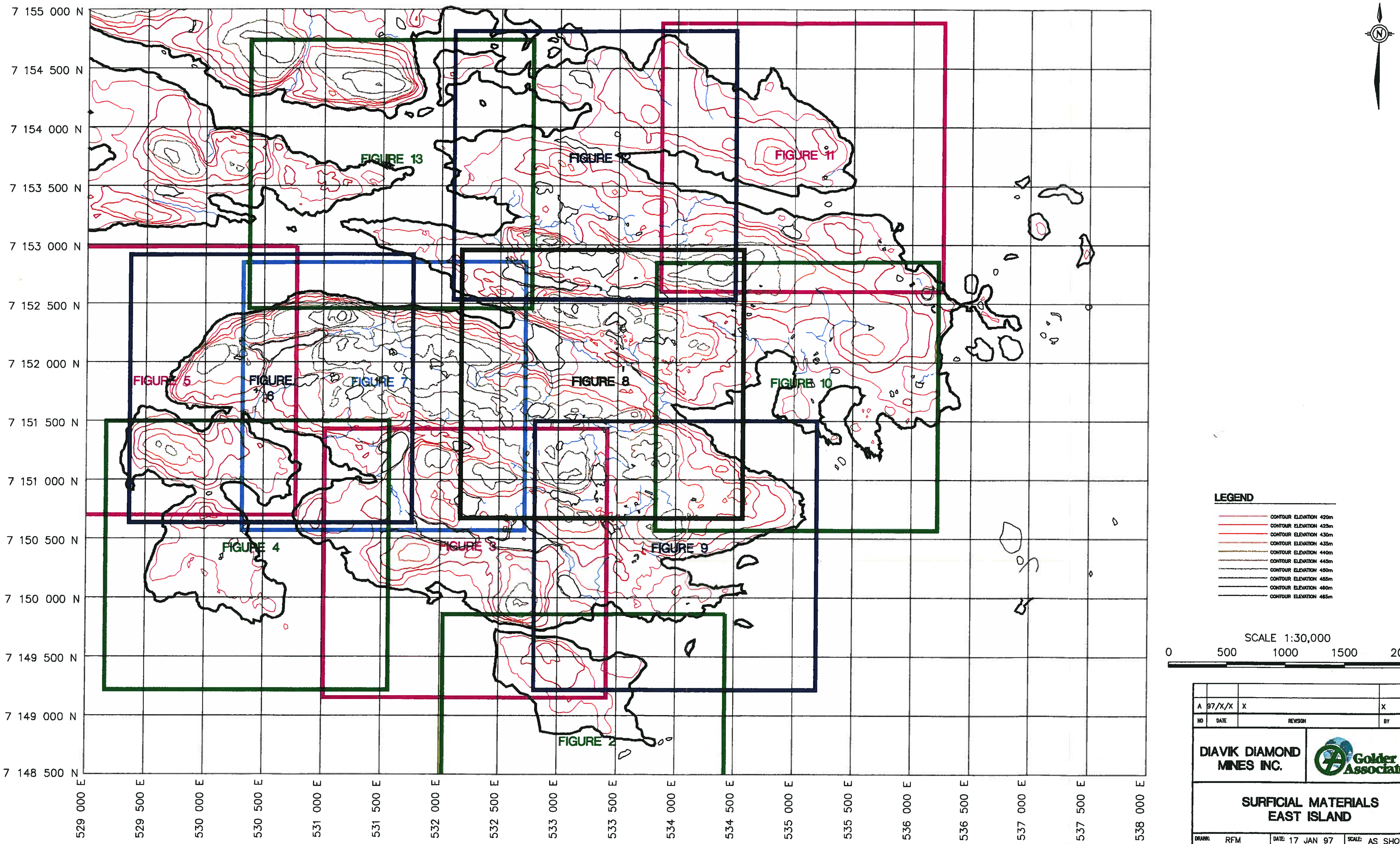
Consistence

MVFR	moist very friable
MFR	moist friable
ML	moist loose
DS	dry soft
DL	dry loose
WNS	wet nonsticky
WSS	wet slightly sticky

Reclamation Ratings

Texture	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
Consistence	Good	Very Friable, Friable
	Fair	Loose, Firm
	Poor	Very Firm
	Unsuitable	Extremely Firm
Stone Content	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 465m
CONTOUR ELEVATION 480m
CONTOUR ELEVATION 485m

SCALE 1:30,000
0 500 1000 1500 2000

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

DIAVIK DIAMOND
MINES INC.

Golder Associates

SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
CHECKED TB	ACAD FILE:	DRAWING No. 1 / REV A
REVIEWED TB	J:\1996\2309\5551\FIGLOCS.dwg	

LEGEND

R	Bedrock
Rf	Felsenmeer
Tg	Glacial Till
Gl	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

0 100 200 300 400 500 metres

SCALE 1:10000

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

DIAVIK DIAMOND
MINES INC.

Golder Associates

SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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REVIEWED: TB		REV A

LEGEND

P1 ↗ 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 4
REFER TO FIGURE 1.

REFERENCE

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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REVIEWED TB	J:\1996\2309\5551\SURF1.dwg	

LEGEND

P6 ↗ 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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
CHECKED TB	ACAD FILE: J:\1996\2309\5551\SURF1.dwg	DRAWING No. 5 — REV A
REVIEWED TB		

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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REVIEWED TB		REV A

N

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

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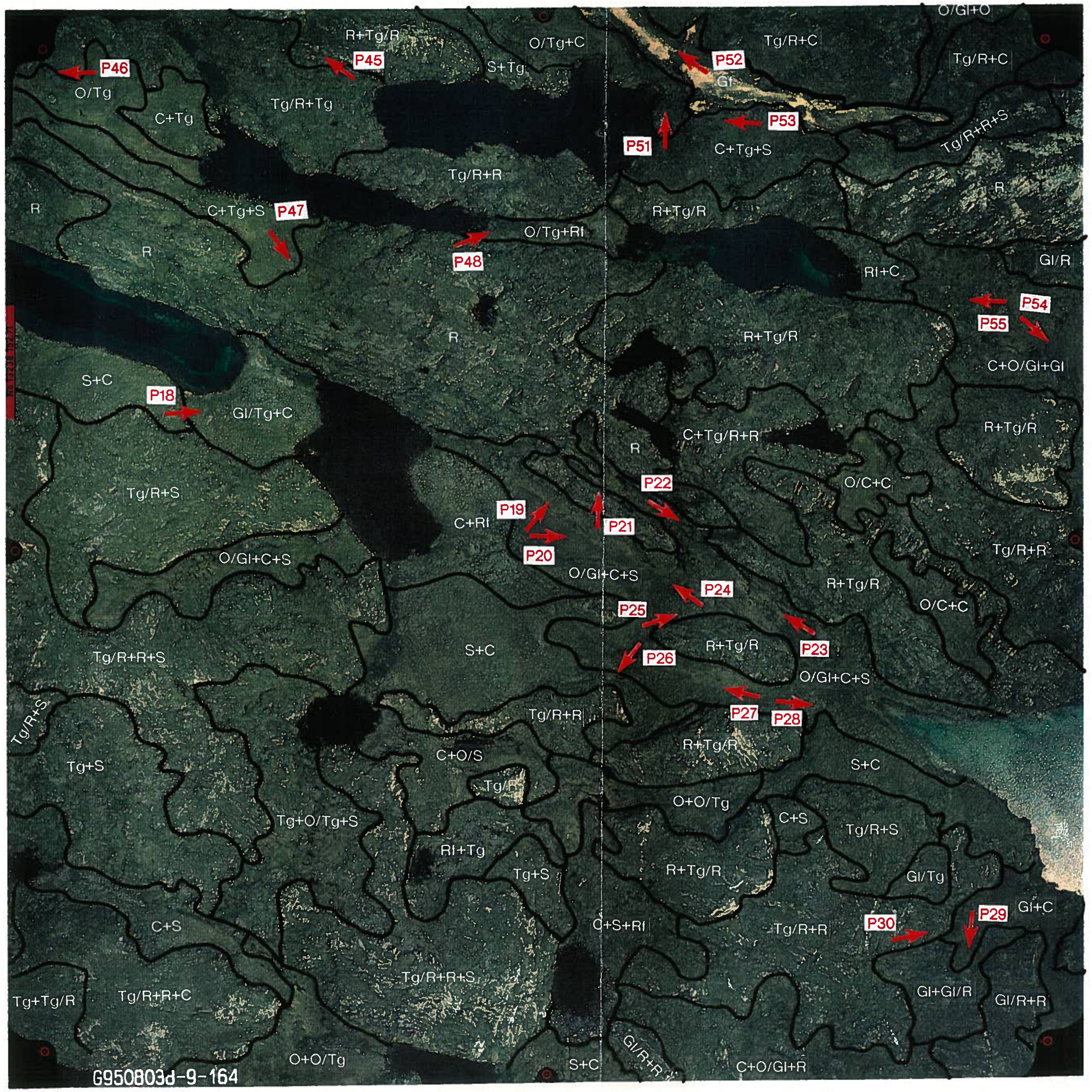
REVIEWED TB	J:\1996\2309\5551\SURF1.dwg	7	A



N

LEGEND

P20 ↗ 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 8
REFER TO FIGURE 1.

REFERENCE

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN	
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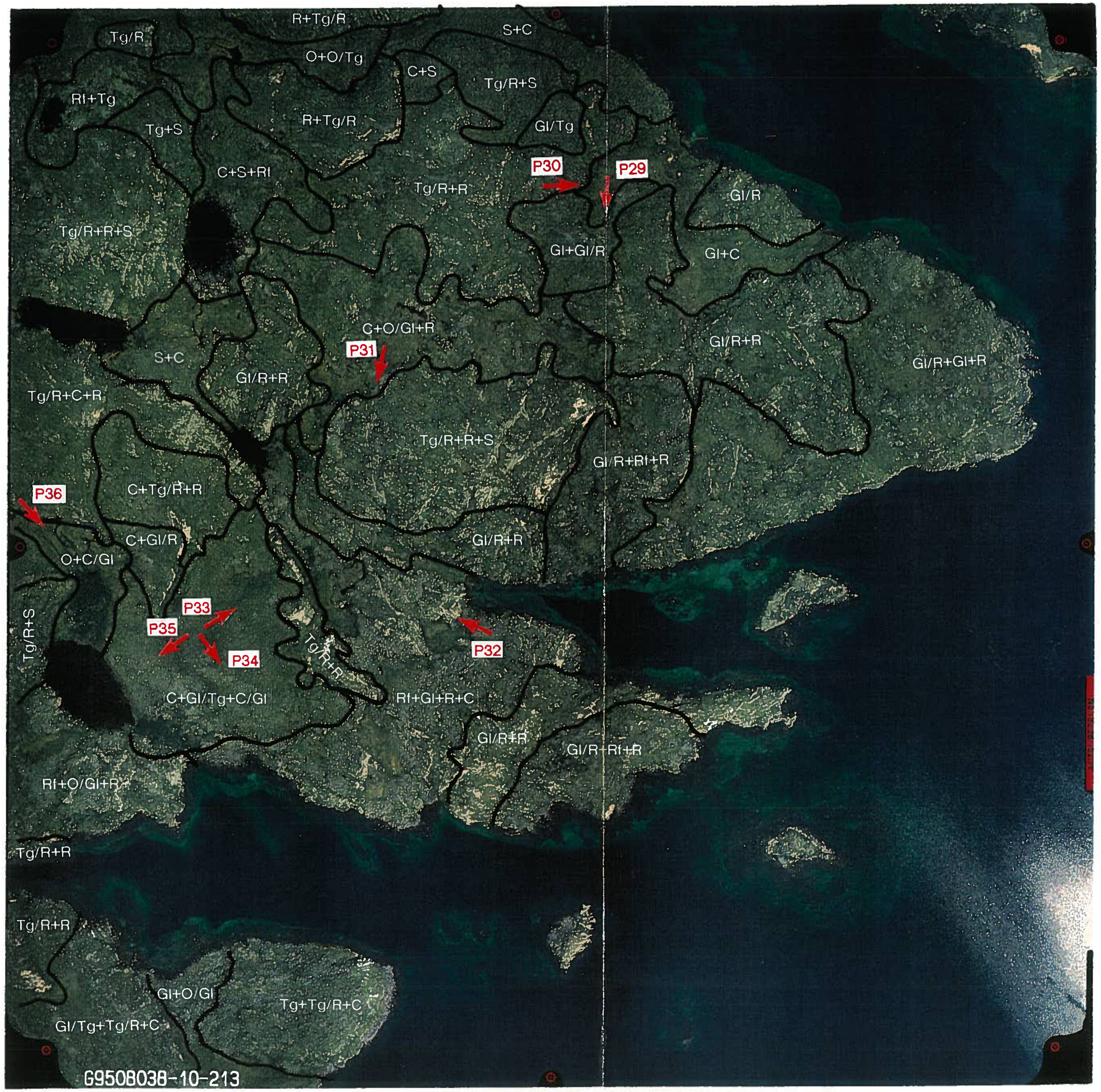
REVIEWED TB	J:\1996\2309\5551\SURF1.dwg	8	A



LEGEND

P32 ↗ 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 9
REFER TO FIGURE 1.

REFERENCE

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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REVIEWED: TB		

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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REVIEWED TB		

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

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REVIEWED TB	J:\1996\2309\5551\SURF1.dwg	

LEGEND

P74 ↗ 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 12
REFER TO FIGURE 1.

REFERENCE

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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REVIEWED TB		

LEGEND

P70 ↗ 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 13
REFER TO FIGURE 1.

REFERENCE

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

0 100 200 300 400 500 metres

SCALE 1:10000

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

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SURFICIAL MATERIALS
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
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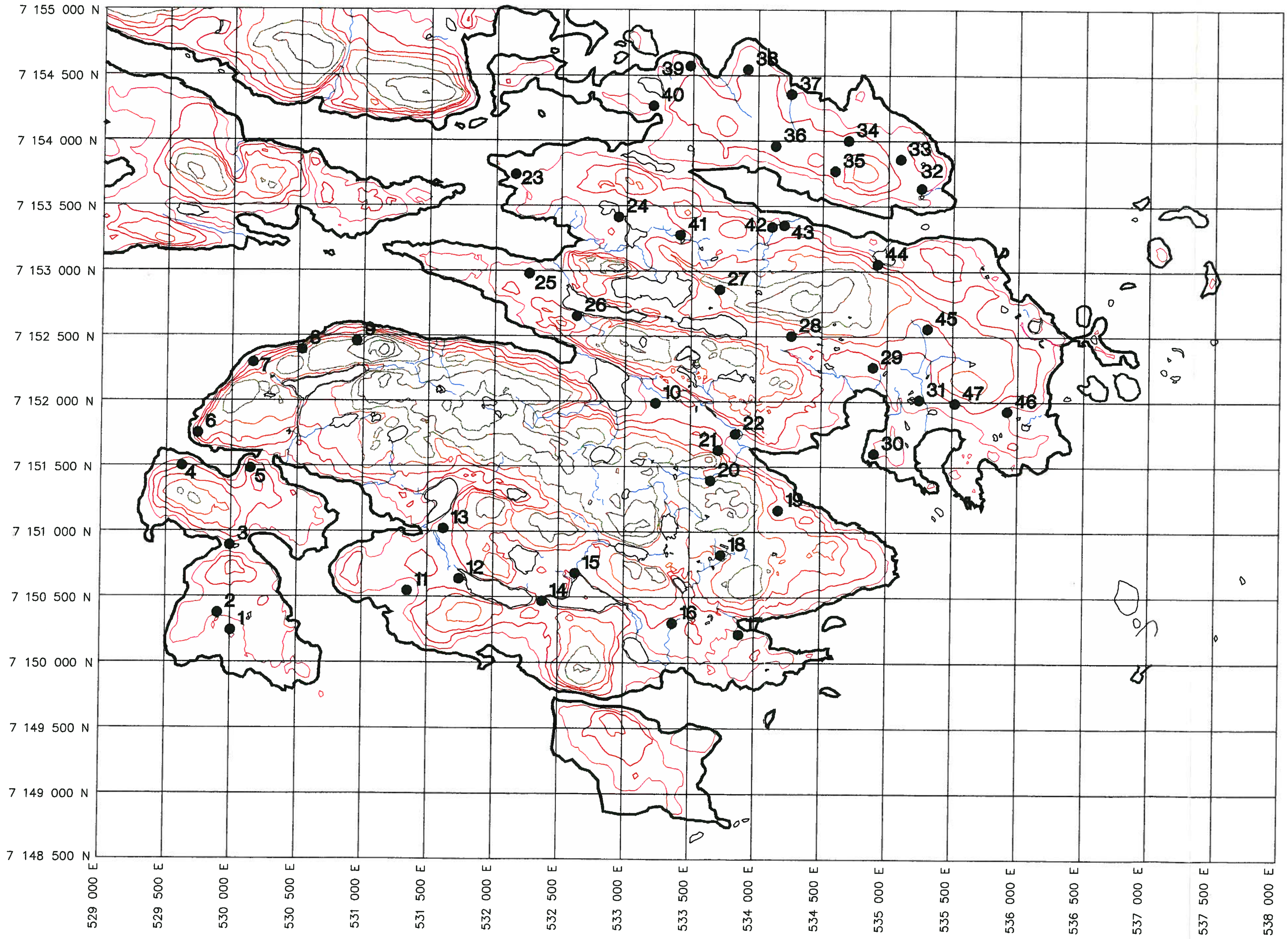
REVIEWED TB		



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

SCALE 1:30,000

0 500 1000 1500 2000

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

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SOIL INSPECTION SITES
EAST ISLAND

DRAWN: RFM	DATE: 17 JAN 97	SCALE: AS SHOWN
CHECKED RFM	ACAD FILE:	DRAWING No. 14 / REV A
REVIEWED TB	J:\1996\2309\5551\SOILPNTS.dwg	

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.

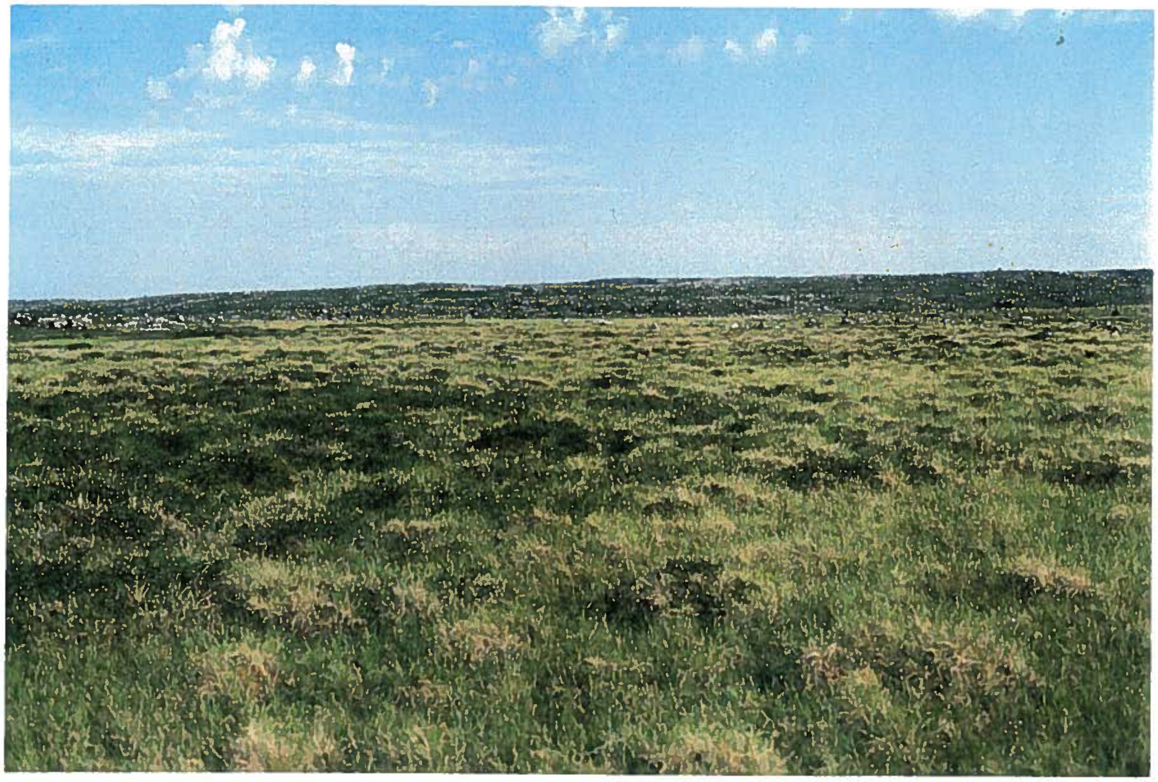

Plate 42 Looking north-west from Soil Inspection Site #12. Organic and organic over glacial till deposits. This area is an important source of reclamation materials.

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 absense 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.