Diavik Mines PKMW Hydrodynamic and Water Quality Modelling: Independent Review Panel Final Report

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1.0 Introduction

The Independent Review Panel (the Panel) for the review of the processed kimberlite to mine workings (PKMW) hydrodynamic and water quality model review was convened by the Wek'eezhii Land and Water Board (WLWB) to provide expert opinion on the modeling methodology and results of initial and long term modelling for the proposed PKMW program for pit A418 at the Diavik Diamond mine. The Panel focused on the model results and assessment of the long-term surface water quality of pit A418 and thus evaluated the overall modeling study.

The expected outcome of the PKMW program is a capping of the tailings with fresh water with a resulting slow release of porewater over time and a breach of the berms separating the pit surface water with Lac de Gras. Initial results show that the base case model meets the Aquatic Effects Monitoring Program (AEMP) water quality guidelines in the upper 40 m of the A418 pit. This document provides detailed reviews of the application and input assumptions of each component of the model system, model sensitivity runs and responses to the initial questions from the Panel.

This document is organized based on the individual summaries of the PK Consolidation Model (Section 2, Shahid Azam), the GoldSim pit filling model (Section 3, Scott Tinis) and the long-term CE-QUAL-W2 A418 pit hydrodynamic and water quality model/MIKE3 Lac de Gras berm breach model (Section 4, Scott Wells). Questions presented to the Panel are addressed in Section 5 and concluding remarks and recommendations in Section 6.

Webex meetings between the WLWB, Diavik Mines, the Panel and other stakeholders were held on

- August 20 (Panel introduction),
- September 10 (Diavik Modelling presentation),
- September 24 (Panel initial findings) and
- October 1 (Draft Review discussion).

The principal outcome of the September 24 meeting was a list of Panel comments and requests for further information (Table 1). Responses to these comments have been provided by Diavik Mines and form the basis of the Panel discussion and recommendations presented in this document.

Table 1. Independent Review Panel (IRP) comments and information requests presented to Diavik Mines after September 24 workshop.

Model		Concern	A418 WQ Implication	Action Item
PK Consolidation Model	IRP 1.1	Material Properties - Segregation of coarse material	The fines portion will behave like EFPK	Confirm neglgible segregation by material characterization
	IRP 1.2	Initial Conditions - Discharge conditions not established	Inability of fines to release water	Conduct standpipe tests to confirm
	IRP 1.3	Boundary Conditions - 1-D model applied to 3-D geometry	Overestimated storage capacity of A418	Justify 1-D model captures A418 geometry
	IRP 1.4	Freeze-thaw assumed to be negligible	Potentital impact on consolidation	Justify freez-thaw is negligible
Pit Filling Model	IRP 2.1	Source term conservatism	Underestimate of filled concentrations	Produce a table of upper case pore water concentrations with a description of methodology
	IRP 2.2	High loss of decant/porewater to A154	Underestimate of porewater% at fill	Conduct a total of 5 filling model sensitivity runs using the following combinations: 1) Upper case source terms and base case GW flow 2) high GW flow and base case source terms 3) high GW flow and upper case source terms 4) low GW flow and base case source terms 5) low GW flow and upper case source terms
	IRP 2.3	Large amount of porewater in A154 filled pit	Potentail impact to Lac du Gras through breaches	Produce table of A154 final WQ for the base case
	IRP 2.4	Decant WQ assumed to be equal to Porewater WQ	Some constituents may be higher	Produce table of both source terms with range/uncertainties
W2 Long-term Pit Lake Model and MIKE3 Breach Model	IRP 3.1	Portal water not included	warm water could cause covective mixing	Confirm location of portal, compute sensitivity of neglecting portal
	IRP 3.2	GW not included in W2	None	Revise figures in documentation
	IRP 3.3	Spillway required to balance flow in W2	Mike3 Breach model and W2 model not completely compatible	Include in documentation and try to better synchronize the Breach model and W2 model
	IRP 3.4	Stair-step flow in breaches	Reduces flow into the A418 pond as ice increases	Include in documentation
	IRP 3.5	Is Evap > Precip in region	Affects concentrations in upper 40 m	Review to assess if this is reasonable
	IRP 3.6	Does T difference between MIKE and W2 flow generate convective flow?	Can affect mixing in A418	Revise temperatures in Lac de Gras (Mike3) to be more compatible with A418 (W2)
	IRP 3.7	Turn brine expulsion on in ice scheme	Affects concentrations in upper 40 m	Turn ON in W2 model
	IRP 3.8	Ice thickness in W2 is different	Affects concentrations in upper 40 m	Verify that W2 predictions are reasonable and compatible with Lac de Gras model prescribed ice
	IRP 3.9	Choice of turbulence scheme	Affects vertical mixing in A418	Use TKE model in W2
	IRP 3.10	Surface water runoff has potential to be more important than porewater in determining surface WQ at times	Meeting water quality benchmark in upper 40 m	Carefully assess impications of flow through breach and whether Mike3 model is providing a reasonable prediciton. Where are model vs data comaprisons for Mike3?
	IRP 3.11	Temperature profile bump (possibly near TDS interface)	Not really important for the purposes of this study	An interesting model result, but ultimately not important in assessing the model
	IRP 3.12	Breach flow oscillations	Treatment in W2 impacts ventilation of surface water	Verify that MIKE3 is not unstable and is responding properly to wind and inflow/outfow lake conditons
	IRP 3.13	Met file wind needs correcting	Affects mixing in A418	Add wind speed to ice cover periods and let model turn it ON/OFF
	IRP 3.14	Errors in input files as discovered by W2 model preprocessor	May affect model reading correct input file format of boundary conditons	Revise input files so that there are no preprocessor errors. [I supplied an updated preprocessor that will work for their model input files.]
	IRP 3.15	Effect of porewater initial conditon	If the startification was not as strong to begin with, like a TDS of 500 mg/l, could there be more possibility for chemicals of concern to migrate to the upper 40 m?	Run model sensitivity varying the initial stratification

2.0 PK Consolidation Model

Executive Summary

The main focus of this report is to review the one dimensional large strain consolidation of grit-rich fine processed kimberlite for deposition in A418 mined-out workings. The review identifies the possible impact of material properties, constitutive relationships, initial conditions, and boundary conditions on the numerical modeling. Recommendations related to pre-deposition, ongoing deposition, and post-deposition conditions are provided.

Introduction

Diavik Diamond Mine (2021) Inc. or DDMI plans to deposit grit-rich fine processed kimberlite (FPK) in underground A418 mined-out workings from 01 August 2022 through 31 December, 2025. The initial volume is estimated to be 5.5 x 10^6 m^3 (without consolidation) with a final mass of 3.3 x 10^6 tons (with consolidation). Large-strain consolidation (LSC) modeling was conducted by Golder Associates Ltd. (Golder 2020a) to predict the long-term settling and water release from the deposited grit-rich FPK. The aim of LSC modeling was to identify inputs for hydrodynamic modeling of the pit lake thereby evaluating the impact of FPK storage on post-closure water quality in the pit lake and eventually on Lac de Gras.

The main focus of this review is to evaluate the LSC modeling in terms of input data, inherent assumptions, simulation processes, and predicted results. The objective of LSC modeling was to evaluate the following:

- Rate of release of pore water
- Volume of the released pore water

Generally, LSC modeling is affected by material properties, constitutive relationships, initial conditions, and boundary conditions. The following sections of this review report provide an assessment of the above-mentioned factors on LSC modeling for FPK deposition in A418 mine-out workings. The review is mainly based on the external and internal reports and presentations provided by DDMI and interactions within the Review Panel.

Conceptual Background

LSC modeling is generally used for materials exhibiting about 10% deformation and for facilities of at least 30 m height. Conceptually, LSC comprises of the following two dewatering processes:

Sedimentation

Short-term deformations, due to solid-liquid interactions, result in the initial release of pore water through the slurry microstructure. The settling rate of the 3-D fabric is related to the hydraulic conductivity where the effective stresses are very small. The development of an initial slurry microstructure is primarily governed by the colloids (content and mineralogy) and the ions (valence and concentration). Further details of this phenomena can be found in McRoberts and Nixon (1976) and Pane and Schiffman (1997).

Consolidation

Long-term deformations, due to increase in effective stress, result in the release of pore water through the soil matrix. The settling rate (hydraulic conductivity) and the amount of settlement (volume compressibility) in the soil are related to effective stress. During this process, the significance of the initial slurry microstructure is gradually reduced as physical parameters (gradation and conditions) become dominant. Further details of this phenomena can be found in Abu-Hejleh et al. (1996) and Gibson et al. (1967).

Material Properties

The LSC modeling used historical LSC test results. To select a representative material for numerical modeling, grain size distribution (GSD) from historical LSC tests were compared with the GSD range of grit-rich FPK from the 2019 FPK field investigation program (Golder 2020b). The rationale for this selection process appears to be related to field experience with FPK at the site.

Figure 3 (Golder 2020a) indicates that the grit-rich FPK has a range of particles, as shown in the yellow zone. These investigated FPK shows a fines content (material finer than 0.075 mm) of 6% to 60% including a clay content (material finer than 0.002 mm) of 2% to 18%. In contrast, the extra fine PK (EFPK), shown in the blue zone, has a fines content of 60% to 100% and a clay content of 20% to 50%.

The selected material is a grit-rich FPK containing 33% fines and about 5% clays. This sample is designated as “slimes” in U of A (2020). The sample falls within the yellow zone (Figure 3) and was collected from under the barge using a slurry pump. A deep sample was collected due to a lack of specialized sampling equipment at the site. Although the sample depth was not recorded, it is considered to represent the upper portion of the slimes profile. A relatively coarser sample (14% fines) was also obtained directly from the processing plant prior to discharge. This sample falls within the blue zone (Figure 3).

The selected material (33% fines) represents the median GSD of the grit-rich FPK range (yellow in Figure 3) and, as such, does not cover the entire wide range of possible GSDs. Potential variation in GSD of the deposited slurry can result in vertical segregation (preferential settling of coarse particles with respect to fine particles) in A418. This phenomenon is known to occur in the containment facility where the two materials separate when hydraulically transported such that the coarser particles deposit near the discharge location and the finer particles advance to the central pond (Golder 2020b).

From the afore-mentioned, it is clear that that the grit can deposit earlier leaving the EFPK in suspension that, in turn, will exhibit a low water release. Evidence of this behavior is given in Figure 4 (Golder 2020a) by the volume compressibility curves for materials with more than 90% fines. The hydraulic conductivity curves for these fine grained materials do not show a consistent behavior. In the consolidation range (void ratio of 1 to 4), Figure 5 (Golder 2020a) indicates at least two orders of magnitude difference in hydraulic conductivity for materials with more than 90% fines.

A comparison of Figure 4 and Figure 5 further indicates significant discrepancies in the observed volume compressibility and hydraulic conductivity data. For example, the coarser sample (14% fines) exhibits higher void ratios when compared with the grit-rich FPK (33% fines) although the coarser material is expected to settle more. In contrast, the hydraulic conductivity measured 1 m/day (at a void ratio of 8) for the former material and dropped down to 0.1 m/day (at a void ratio of 4) for the grit-rich FPK. Such inconsistencies may be attributed to several reasons such as the LSC test results pertain to various types of samples, collected over a long time period, and tested at different laboratories.

Constitutive Relationships

LSC tests and column settling tests were conducted on the grit-rich FPK containing 33% fines (slimes) at the University of Alberta (U of A, 2020). The entire data were fitted using power law functions to the test results. The relationships are given as follows:

Modeled Volume Compressibility $e = 2.441\ \sigma'^{-0.136}$

Modeled Hydraulic Conductivity $k = 3.783 \times 10^{-6}\ e^{8.134}$

Where,

e = void ratio

σ' = effective stress

k = hydraulic conductivity

The above-mentioned volume compressibility relationship does not clearly differentiate between the two distinct dewatering processes of sedimentation and consolidation. To understand the initial release of pore water, an extended power law function is usually selected to better capture the settling behavior of slurries under low values of effective stresses (Liu and Znidarcic, 1991). Using fit parameters (A, B, and Z), the test data is fitted to the following modified volume compressibility relationship:

Modified Volume Compressibility $e = A\ (\sigma' + Z)^{B}$

Figure A gives a comparison of the two volume compressibility equations. Using Z = 0.025 to achieve e = 3.5 at σ' = 0.1 kPa (initial void ratio used for LSC modeling), the modified equation indicates that the grit-rich FPK containing 33% fines has to be deposited at *e* = 4.0 as opposed to the modeled equation that requires a much leaner slurry. The sensitivity case (Table 1) in LSC modeling was not described (Golder 2020a).

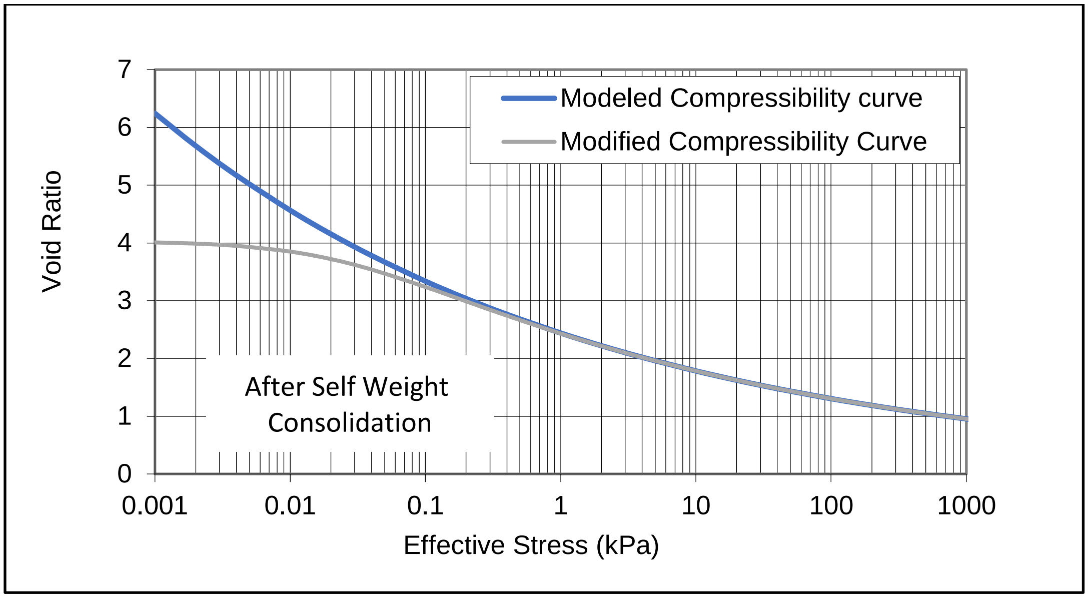


Figure A: Comparison of the volume compressibility relationships

Initial Conditions

The initial slurry microstructure depends on colloid-ion interactions that result in the development of a double layer of ions around charged particles (Mitchell and Soga, 2005). Generally, clay minerals (such as smectite and hydrous mica) can adsorb high amounts of water because their particles possess large surface areas and net negative charges. The amount of adsorbed water is reduced when the pore water contains large amounts of multi-valent ions.

The mineralogy of the "slimes" indicated the presence of 50% clay minerals including 39% smectite. The corresponding numbers in the coarser sample (14% fines) were found to be 52% and 43%, respectively. Likewise, the pore water was found to have a pH of about 8 and an electrical conductivity of 2.7 mS/cm (slimes) and 1.2 mS/cm (coarse). In both cases, the primary ions were found to be Na^+, Cl^- , NO_3^-, and SO_4^{2-}. These data indicate the potential for the development of an initial microstructure. Previous studies have suggested variable degrees of flocculation in FPK (Howe, 1980).

Data on mineralogical composition of FPK (from AGAT, as given in U of A, 2020) have been described to be not consistent with the previous historical reports. Likewise, data on pore fluid composition pertain to the water expelled during consolidation. As such, both of these data sets are not associated with the development of an initial slurry microstructure.

A preliminary assessment of the initial slurry microstructure can be provided by the consistency limits (liquid limit and plastic limit). The plasticity charts indicated “clay like” behavior for FPK (Golder 2020b).

The LSC modeling used initial conditions of a solids content of 45% (e = 3.5) for grit-rich FPK containing 33% fines (slimes). This pertains to the end of the self-weight settling of a slurry with an estimated initial solids content of 29% (e = 6.85). A single data point, based on the column settling test and representing sedimentation, was used and joined with the volume compressibility data from the LSC tests. This means that the initial conditions at low effective stresses were not fully captured in the numerical modeling.

A comparison of column settling tests indicate that the void ratio of the “slimes” decreased from 4.66 to 3.35 whereas that of the “coarse” sample decreased from 7.91 to 4.20. This clearly demonstrates the significance of initial conditions on sedimentation. Generally, the denser slurry will settle less when compared with a leaner slurry, when all other factors remain constant.

The column settling tests provide information on the initial hydraulic conductivity of the slurry at the corresponding void ratio following the method described in Pane and Schiffman (1997). This test does not provide data on effective stress at a given void ratio. The effective stress is assigned a value to develop the volume compressibility relationship.

Effective stress data at low values was not generated using the stand-pipe compressibility test. In this test, pore pressures are monitored at the sample base during self-weight settling (Scott et al., 2008). The data is combined with the results of the column settling tests and LSC tests to develop a volume compressibility relationship covering discharge, deposition, and consolidation.

Boundary Conditions

The LSC modeling simulated 1-D column situated at the centre of A418. This column represented the maximum depth of the deposited FPK in the pit. Figure B gives a comparison of the 1-D column (red) using the 2-D pit geometry, as illustrated in Figure 8 (Golder 2020a): the third dimension is perpendicular to the plane of the paper.

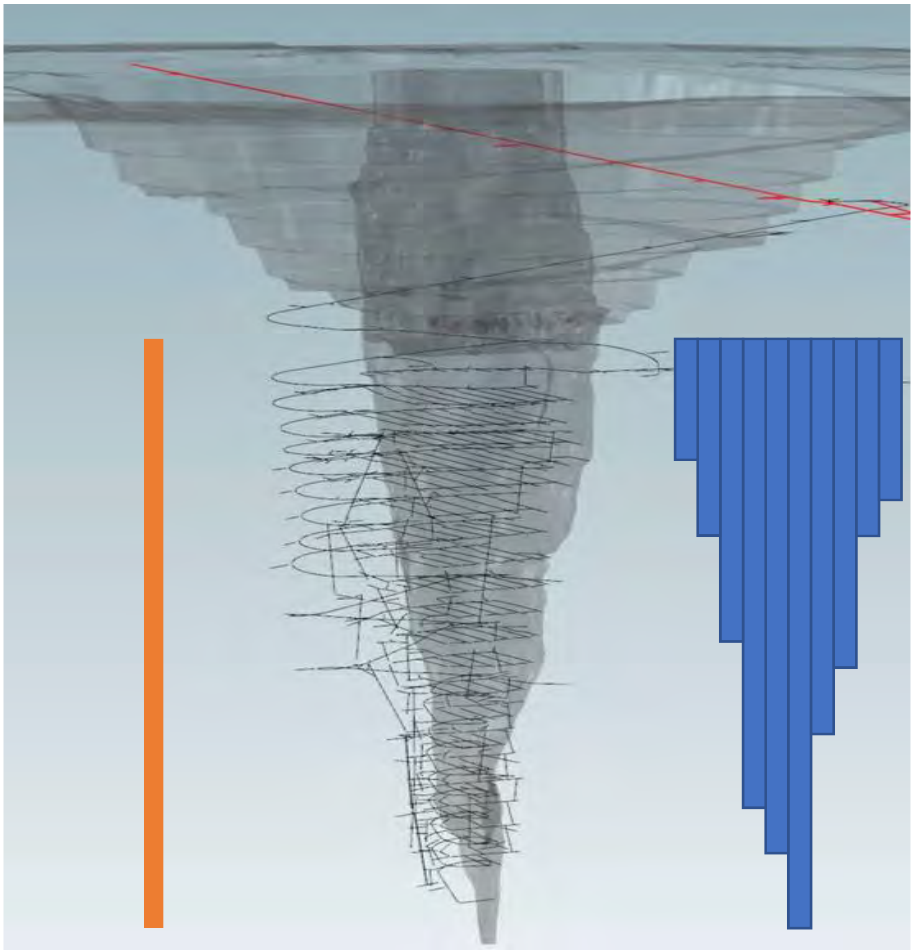


Figure B: Comparison of assumed 1-D column with the 2-D geometry of A418

As shown above, the LSC modeling assumed that the surrounding slurries (with reduced height) settle at the same rate as the tallest one (that is, foundations also settle). This provides an approximate solution of the 3-D settling of the deposited FPK in A418. The discrepancy in model prediction and actual field performance depends on material properties (discussed earlier) and the pit geometry.

The grit-rich FPK is planned to be deposited between 8795 m and 9205 m with the corresponding diameters of about 80 m and 170 m, respectively. For an inverted cone of varying dimensions, actual survey assessment (such as bathymetric data) and/or a more robust 3-D numerical analysis (such as that described in Pinho and Filho (2020)) are required.

3.0 Pit Filling Model

Introduction

The Pit Filling Model provides initial water column concentrations to the long-term W2 A418 pit water quality model. The model predicts the post-filling percentages of slurry decant/porewater, surface runoff, ground water and fresh water from Lac de Gras used for filling. The model review raised several questions that resulted in a set of five sensitivity runs:

1. How does the upper case porewater chemistry affect the final filling model results?
2. Does variability in ground water flow rates affect final pit chemistry?
3. Does the large fraction of porewater that flows to A154 cause A154 chemistry to exceed AEMP guidelines?
4. Is setting decant water chemistry equal to porewater chemistry a conservative assumption?

Discussion

The model is constructed on the GoldSim platform and runs with a daily time step spanning the period from initial tailings placement (January 1, 2026) to the end of pit filling (May 1, 2027) – a total of 16 months. The first five months of the simulation assume only ground water flux in and out of the deep basin of A418 where the tailings placed which affects the flow and concentration of the (assumed) 1.92 million m3 expelled slurry (decant) water. During this initial five-month period there is a net loss of slurry water through ground water paths from A418 to A154 caused by an outflow of around 4000 m3/day partially balanced by an inflow of 400 m3/day. The timeline of the pit filling model is shown in Fig. 3.1.

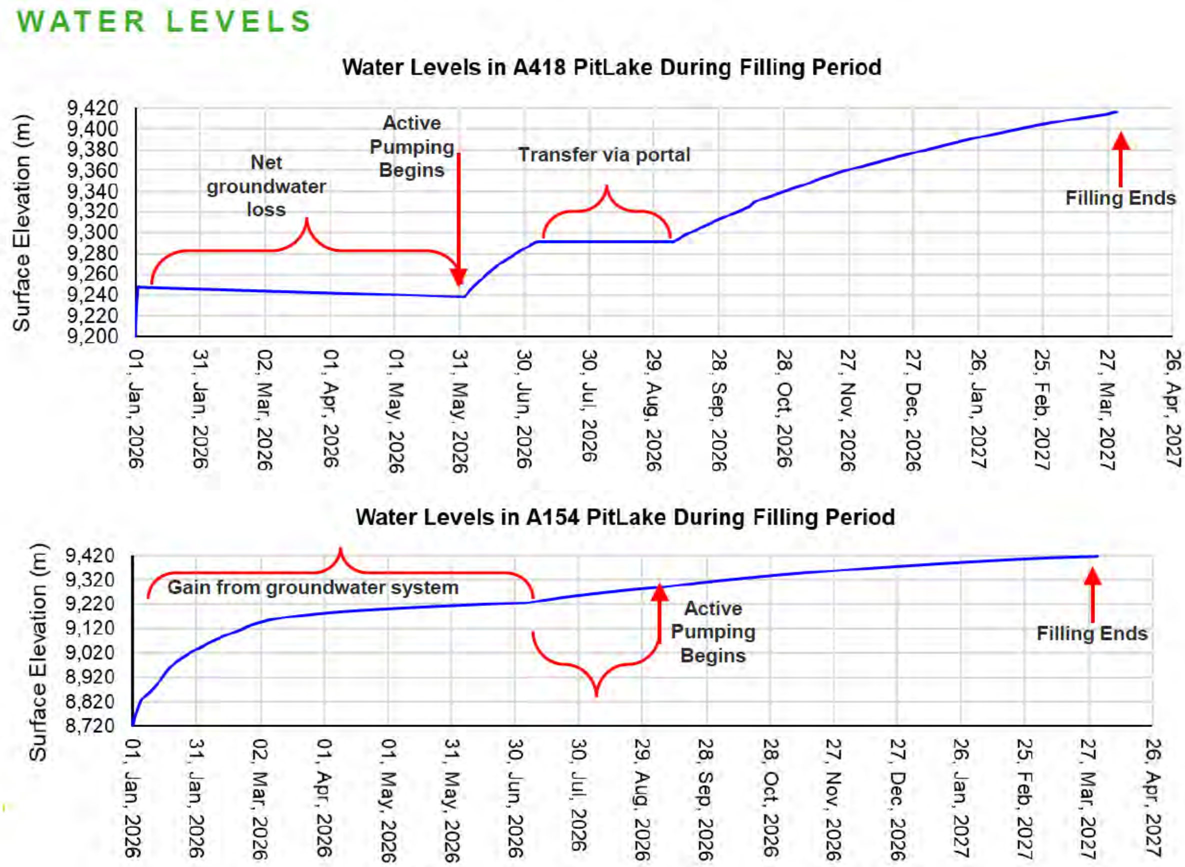


Figure 3.1 (adapted from Slide 23 of Webinar 2 model presentation). Water elevation in Pits A418 and A154.

Beginning in June 2026, the A418 pit is filled until the water level reaches the portal connecting A418 to A154. At this level water freely flows from A418 to A154 until the water levels in each pit equilibrate. Note that prior to this, the only pathway for water to move to A154 was through via ground water. A148 and A154 are both actively filled after equilibrating until May 2027 when both pits are full.

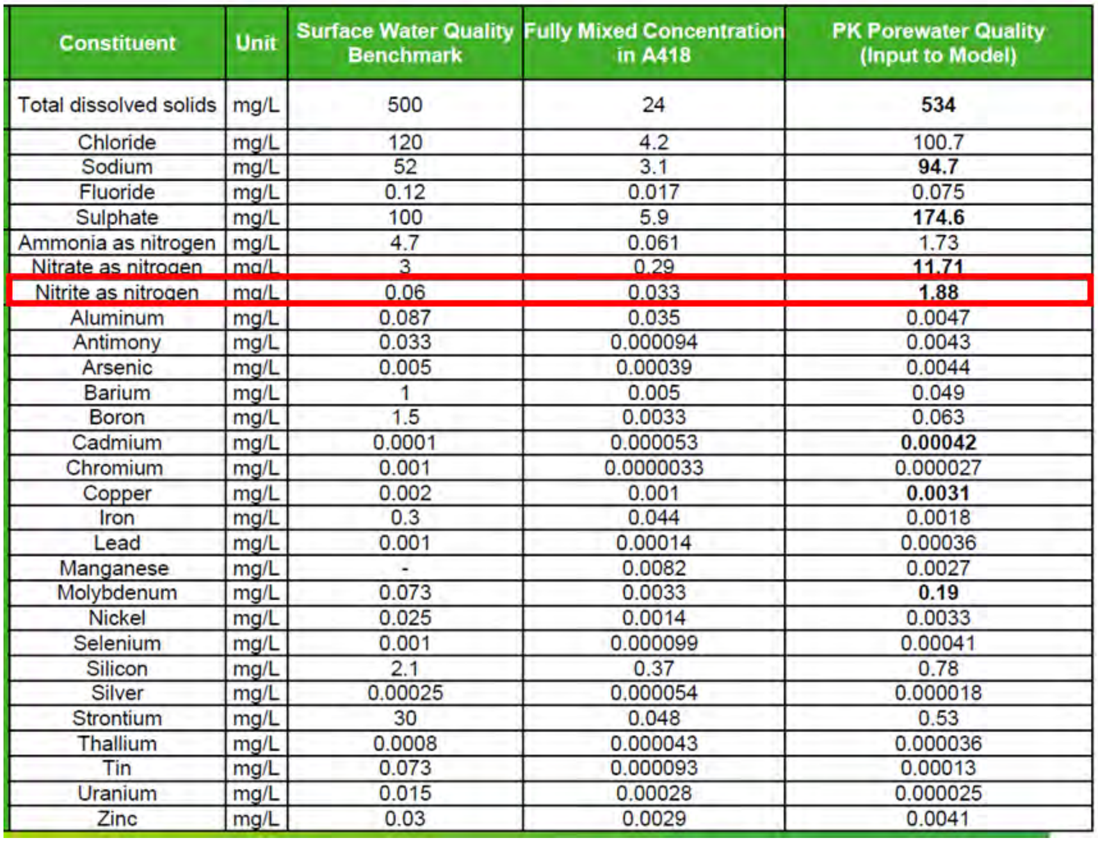
In the base case model only 1.2% of the approximately 30 million m3 of total water in A418 is made up of decant (slurry) water and a comparatively small amount of porewater released during the 16-month fill period (Table 3.1). If there were no water lost from A418 to A154, the porewater would comprise nearly 6% of the volume at the end of filling. The base case loss of porewater to A154 is approximately 80%.

Table 3.1. Final fill composition of A418 by water type (base case)

Distinct Water Type	Volume (%) at End of Filling
PK Porewater	**1.19%**
Local Runoff	**0.06%**
Freshwater	**98.46%**
Groundwater	**0.29%**
Pitwall Runoff	**0.00%**

The final fill concentrations for the A418 pit are shown in Table 3.2. Geochemical source terms applied to the final water makeup in the pit are based on median values from observations including anerobic testing of porewater from a single duplicated sample taken over a 3 month period in 2019 (U of A 2019).

Table 3.2. Final fill base case concentrations for Pit A418. Nitrite (highlighted) is the only parameter within 50% of its AEMP guideline.



Constituent	Unit	Surface Water Quality Benchmark	Fully Mixed Concentration in A418	PK Porewater Quality (Input to Model)
Total dissolved solids	mg/L	500	24	**534**
Chloride	mg/L	120	4.2	100.7
Sodium	mg/L	52	3.1	**94.7**
Fluoride	mg/L	0.12	0.017	0.075
Sulphate	mg/L	100	5.9	**174.6**
Ammonia as nitrogen	mg/L	4.7	0.061	1.73
Nitrate as nitrogen	mg/L	3	0.29	**11.71**
Nitrite as nitrogen	mg/L	0.06	0.033	**1.88**
Aluminum	mg/L	0.087	0.035	0.0047
Antimony	mg/L	0.033	0.000094	0.0043
Arsenic	mg/L	0.005	0.00039	0.0044
Barium	mg/L	1	0.005	0.049
Boron	mg/L	1.5	0.0033	0.063
Cadmium	mg/L	0.0001	0.000053	**0.00042**
Chromium	mg/L	0.001	0.0000033	0.000027
Copper	mg/L	0.002	0.001	**0.0031**
Iron	mg/L	0.3	0.044	0.0018
Lead	mg/L	0.001	0.00014	0.00036
Manganese	mg/L	-	0.0082	0.0027
Molybdenum	mg/L	0.073	0.0033	**0.19**
Nickel	mg/L	0.025	0.0014	0.0033
Selenium	mg/L	0.001	0.000099	0.00041
Silicon	mg/L	2.1	0.37	0.78
Silver	mg/L	0.00025	0.000054	0.000018
Strontium	mg/L	30	0.048	0.53
Thallium	mg/L	0.0008	0.000043	0.000036
Tin	mg/L	0.073	0.000093	0.00013
Uranium	mg/L	0.015	0.00028	0.000025
Zinc	mg/L	0.03	0.0029	0.0041

The largest factors governing the base case filling model results were determined to be the ground water fluxes in and out of the A418 pit and the porewater source terms. Five sensitivities were requested to explore how dependent the fill model results are on uncertainty in these governing factors. The sensitivities are:

1. Generate upper case porewater source terms and run with base case flow conditions
2. Use high ground water flow and base case source terms
3. Use high ground water flow and upper case source terms
4. Use low ground water flow and base case source terms
5. Use low ground water flow and upper case source terms

Upper case source concentrations for the porewater were provided by Diavik (Table 3.3).

Table 3.3. Porewater concentration statistics

Group	Constituent	Unit	Porewater				Groundwater			
			25th	Median	75th	Geomean	25th	Median	75th	Geomean
Conventional Constituents	TDS	mg/L	506	528	562	535	72	132	232	126
Major Ions	Chloride	mg/L	98	101	102	101	8.0	26	52	24
	Sodium	mg/L	91	95	98	95	13	24	39	24
	Fluoride	mg/L	0.052	0.077	0.12	0.075	0.08	0.1	0.12	0.092
	Sulphate	mg/L	161	171	185	175	6.6	8.8	15	9.0
Nutrients	Ammonia as N	mg/L	1.7	1.8	1.8	1.7	0.051	0.073	0.57	0.19
	Nitrate as N	mg/L	10	11	13	12	0.0033	0.015	2.1	0.059
	Nitrite as N	mg/L	0.97	2.0	4.3	1.9	0.0012	0.004	0.14	0.01
Trace Elements	Aluminum	mg/L	0.0045	0.0055	0.0069	0.0047	0.0010	0.0019	0.0044	0.0021
	Antimony	mg/L	0.0041	0.0043	0.0045	0.0043	0.000013	0.00004	0.00038	0.000063
	Arsenic	mg/L	0.0041	0.0043	0.0045	0.0044	0.0032	0.005	0.0068	0.0039
	Barium	mg/L	0.047	0.048	0.049	0.049	0.019	0.03	0.085	0.035
	Boron	mg/L	0.054	0.058	0.077	0.063	0.017	0.027	0.036	0.024
	Cadmium	mg/L	0.0004	0.00041	0.00044	0.00042	0.000005	0.000019	0.000045	0.000015
	Chromium	mg/L	0.000025	0.00004	0.000054	0.000027	0.000027	0.00005	0.0001	0.000057
	Copper	mg/L	0.0022	0.0037	0.0047	0.0031	0.00009	0.00024	0.00048	0.0002
	Iron	mg/L	0.001	0.0016	0.0029	0.0018	0.0032	0.009	0.082	0.013
	Lead	mg/L	0.00032	0.00043	0.00047	0.00036	0.0000078	0.000021	0.000043	0.000017
	Manganese	mg/L	0.0024	0.0026	0.0027	0.0027	0.04	0.053	0.089	0.042
	Molybdenum	mg/L	0.18	0.19	0.2	0.19	0.0082	0.021	0.036	0.017
	Nickel	mg/L	0.003	0.0032	0.0034	0.0033	0.00012	0.0005	0.0018	0.00047
	Selenium	mg/L	0.00031	0.00065	0.0011	0.00041	0.00010	0.00023	0.0005	0.00019
	Silicon	mg/L	0.65	1.1	1.3	0.78	5.0	5.6	6.7	5.6
	Silver	mg/L	0.000011	0.000027	0.000046	0.000018	0.0000032	0.000021	0.000072	0.000014
	Strontium	mg/L	0.51	0.52	0.53	0.53	0.066	0.21	0.4	0.21
	Thallium	mg/L	0.000029	0.000036	0.000041	0.000036	.00000092	0.0000018	0.000013	.0000031
	Tin	mg/L	0.000063	0.00023	0.00033	0.00013	0.0000095	0.000065	0.00014	0.000034
	Uranium	mg/L	0.000027	0.000028	0.000031	0.000025	0.000044	0.00038	0.0096	0.00073
	Zinc	mg/L	0.0019	0.0025	0.0086	0.0041	0.00038	0.00077	0.0018	0.0008

The final fill composition by water type in A418 for all five sensitivities is listed in Table 3.4. The resulting fill concentrations in A418 and A154 for all five sensitivities is shown in Table 3.5. The final fill composition is largely insensitive to changes in ground water flux due to the fact that slower ground water flux results in less early (first 5 months) migration of porewater to A154, but when transfer begins through the portal the porewater concentration is higher. The opposite effect happens when ground water flux is higher than the base case. In both cases, the total porewater transferred to A154 is about the same. The remaining variable driving the final concentration then is the porewater source term.

Table 3.4. Final A418 pit water concentrations (base case and five sensitivities).

Group	Constituent	Unit	Surface Water Quality Benchmark	Original	Sensitivity 1 Base GW High Source Term	Sensitivity 2 High GW (+50%) Base Source Term	Sensitivity 3 High GW (+50%) High Source Term	Sensitivity 4 Low GW (-50%) Base Source Term	Sensitivity 5 Low GW (-50%) High Source Term
Conventional Constituents	Total dissolved solids	mg/L	500	24	25	23	24	25	25
Major Ions	Chloride	mg/L	120	4.2	4.2	4.1	4.1	4.4	4.4
	Sodium	mg/L	52	3.1	3.2	3.0	3.0	3.3	3.3
	Fluoride	mg/L	0.12	0.017	0.017	0.016	0.017	0.017	0.017
	Sulphate	mg/L	100	5.9	6.0	5.6	5.7	6.1	6.2
Nutrients	Ammonia as nitrogen	mg/L	4.7	0.061	0.062	0.058	0.059	0.063	0.064
	Nitrate as nitrogen	mg/L	3.0	0.29	0.31	0.27	0.29	0.3	0.32
	Nitrite as nitrogen	mg/L	0.06	0.033	**0.062**	0.03	0.055	0.036	**0.068**
Trace Elements	Aluminum	mg/L	0.087	0.035	0.035	0.035	0.035	0.035	0.035
	Antimony	mg/L	0.033	0.000094	0.000098	0.000088	0.00009	0.0001	0.0001
	Arsenic	mg/L	0.005	0.00039	0.00039	0.00038	0.00038	0.00039	0.00039
	Barium	mg/L	1.0	0.005	0.005	0.0049	0.0049	0.0051	0.0051
	Boron	mg/L	1.5	0.0033	0.0035	0.0032	0.0034	0.0034	0.0036
	Cadmium	mg/L	0.0001	0.000053	0.000053	0.000052	0.000052	0.000053	0.000053
	Chromium	mg/L	0.001	0.0000033	0.0000036	0.0000033	0.0000036	0.0000034	0.0000037
	Copper	mg/L	0.002	0.001	0.001	0.001	0.001	0.001	0.001
	Iron	mg/L	0.3	0.044	0.044	0.044	0.044	0.043	0.043
	Lead	mg/L	0.001	0.00014	0.00014	0.00014	0.00014	0.00014	0.00014
	Manganese	mg/L	-	0.0082	0.0082	0.0082	0.0082	0.0082	0.0082
	Molybdenum	mg/L	0.073	0.0033	0.0034	0.003	0.0031	0.0036	0.0037
	Nickel	mg/L	0.025	0.0014	0.0014	0.0014	0.0014	0.0014	0.0014
	Selenium	mg/L	0.001	0.000099	0.00011	0.000099	0.00011	0.000099	0.00011
	Silicon	mg/L	2.1	0.37	0.38	0.37	0.38	0.37	0.38
	Silver	mg/L	0.00025	0.000054	0.000055	0.000054	0.000055	0.000054	0.000055
	Strontium	mg/L	30	0.048	0.048	0.047	0.047	0.049	0.049
	Thallium	mg/L	0.0008	0.000043	0.000043	0.000043	0.000043	0.000043	0.000043
	Tin	mg/L	0.073	0.000093	0.000095	0.000093	0.000095	0.000093	0.000096
	Uranium	mg/L	0.015	0.00028	0.00028	0.00028	0.00028	0.00028	0.00028
	Zinc	mg/L	0.03	0.0029	0.0029	0.0029	0.0029	0.0029	0.0029

Table 3.5. Final A154 pit water concentrations (base case and five sensitivities).

Group	Constituent	Unit	Surface Water Quality Benchmark	Original	Sensitivity 1 Base GW High Source Term	Sensitivity 2 High GW (+50%) Base Source Term	Sensitivity 3 High GW (+50%) High Source Term	Sensitivity 4 Low GW (-50%) Base Source Term	Sensitivity 5 Low GW (-50%) High Source Term
Conventional Constituents	Total dissolved solids	mg/L	500	42	43	43	44	42	43
Major Ions	Chloride	mg/L	120	7.6	7.6	7.6	7.7	7.5	7.5
	Sodium	mg/L	52	6.6	6.7	6.7	6.7	6.5	6.6
	Fluoride	mg/L	0.12	0.026	0.027	0.026	0.027	0.026	0.027
	Sulphate	mg/L	100	8.7	9.0	8.9	9.2	8.6	8.9
Nutrients	Ammonia as nitrogen	mg/L	4.7	0.096	0.098	0.098	0.099	0.095	0.097
	Nitrate as nitrogen	mg/L	3.0	0.42	0.45	0.43	0.47	0.41	0.45
	Nitrite as nitrogen	mg/L	0.06	0.055	**0.11**	0.056	**0.12**	0.053	**0.11**
Trace Elements	Aluminum	mg/L	0.087	0.031	0.031	0.031	0.031	0.031	0.031
	Antimony	mg/L	0.033	0.00015	0.00015	0.00015	0.00016	0.00014	0.00015
	Arsenic	mg/L	0.005	0.00082	0.00082	0.00082	0.00082	0.00082	0.00082
	Barium	mg/L	1.0	0.0088	0.0088	0.0088	0.0088	0.0088	0.0088
	Boron	mg/L	1.5	0.0064	0.0067	0.0065	0.0068	0.0064	0.0067
	Cadmium	mg/L	0.0001	0.000054	0.000054	0.000054	0.000055	0.000053	0.000054
	Chromium	mg/L	0.001	0.0000095	0.00001	0.0000095	0.00001	0.0000095	0.00001
	Copper	mg/L	0.002	0.00097	0.001	0.00097	0.001	0.00097	0.001
	Iron	mg/L	0.3	0.04	0.04	0.04	0.04	0.04	0.04
	Lead	mg/L	0.001	0.00013	0.00013	0.00013	0.00013	0.00013	0.00013
	Manganese	mg/L	-	0.012	0.012	0.012	0.012	0.012	0.012
	Molybdenum	mg/L	0.073	0.0073	0.0075	0.0075	0.0077	0.0072	0.0074
	Nickel	mg/L	0.025	0.0013	0.0013	0.0013	0.0013	0.0013	0.0013
	Selenium	mg/L	0.001	0.00012	0.00013	0.00012	0.00013	0.00012	0.00013
	Silicon	mg/L	2.1	0.95	0.97	0.95	0.97	0.96	0.97
	Silver	mg/L	0.00025	0.00005	0.000051	0.00005	0.000051	0.00005	0.000051
	Strontium	mg/L	30	0.073	0.073	0.073	0.073	0.072	0.073
	Thallium	mg/L	0.0008	0.000039	0.000039	0.000039	0.000039	0.000039	0.000039
	Tin	mg/L	0.073	0.000087	0.000092	0.000087	0.000092	0.000087	0.000092
	Uranium	mg/L	0.015	0.00037	0.00037	0.00037	0.00037	0.00037	0.00037
	Zinc	mg/L	0.03	0.0027	0.0028	0.0027	0.0028	0.0027	0.0028

Summary

The fill model results are robust and largely invariant to ground water flow uncertainties. However, the results are highly dependent on assumed porewater chemistry. The geochemical testing that generated the porewater source terms was based on a single (duplicate) sample that was measured several different times in 2019. The porewater was anerobic which is the expected state of the porewater at the bottom of A418; however, the low variability in the sample concentrations might underestimate actual variability if the measurements had come from multiple random samples. The fill model result forms the initial conditions to the long-term model, and therefore has important implications to the long-term surface water quality predictions in A418. Because of this**, it is recommended that there be subsequent anaerobic test monitoring of randomly selected porewater samples** between now and PK deposition to ensure that the model inputs have not varied substantially prior to pit filling.

4.0 Long-term A418 Pit Hydrodynamic and WQ Model

Introduction

The CE-QUAL-W2 model of the A418 pit and the Mike3 model for the Lac de Gras breach model were reviewed. Materials provided for the review consisted of the following:

- CE-QUAL-W2 model files for running 200-year simulations
- Documents provided by Diavik on the overall mining process and closure plan (Diavik, 2020)
- Documents provided by Golder on the modeling effort (Golder, 2019; Golder, 2020)

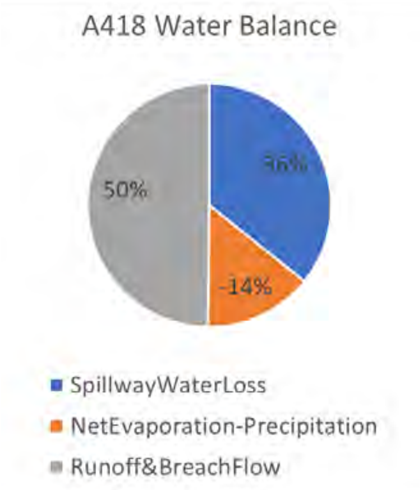
Review of Model

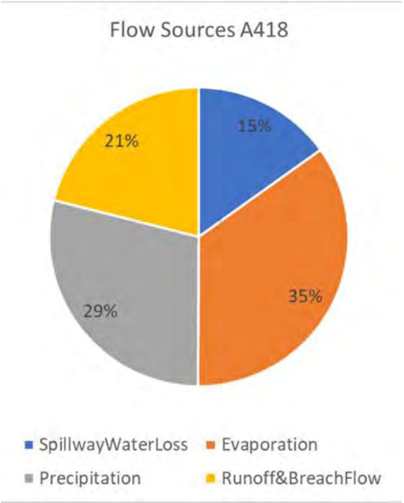
The review of the CE-QUAL-W2 model and the Mike3 Breach model are summarized in Table 4.1. These points are based on the numbering started during the series of Independent Review Panel (IRP) sessions help in September and October 2020. The numbering has not changed from those original presentations even though a more optimized organization could have grouped the points in a more logical fashion.

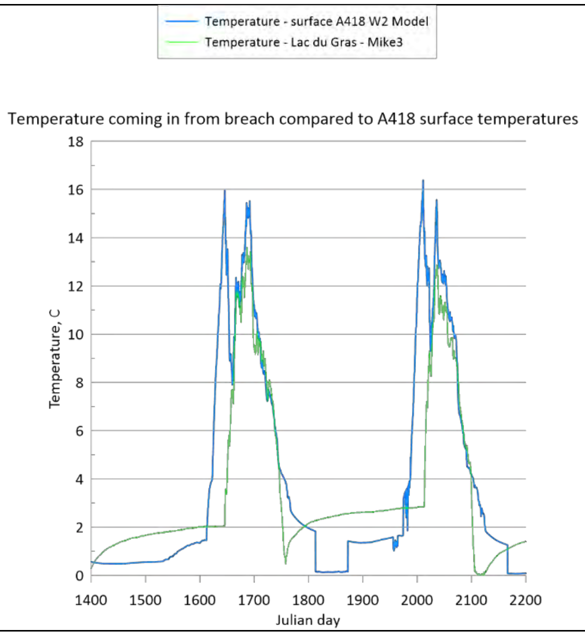
The purpose of the review was to evaluate the A418 CE-QUAL-W2 model and the Mike3 breach model that provided boundary conditions to the A418 pit model. The suggestions in Table 4.1 are meant to improve the quality of the model tools used in the simulation

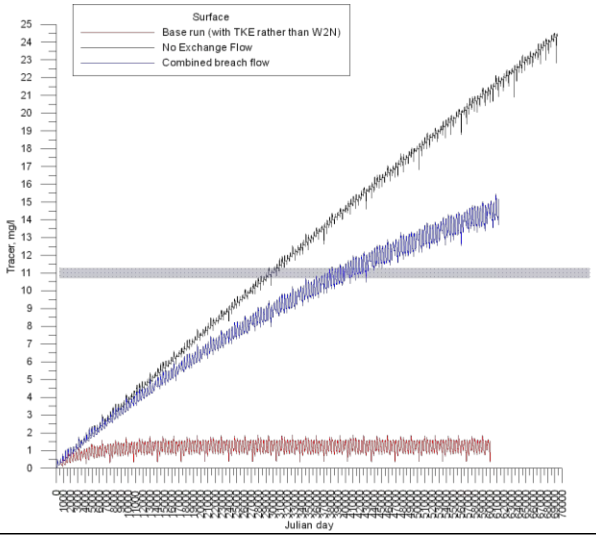
Table 4.1. List of Concerns for modeling the A418 pit using CE-QUAL-W2 and the Mike3 breach model.

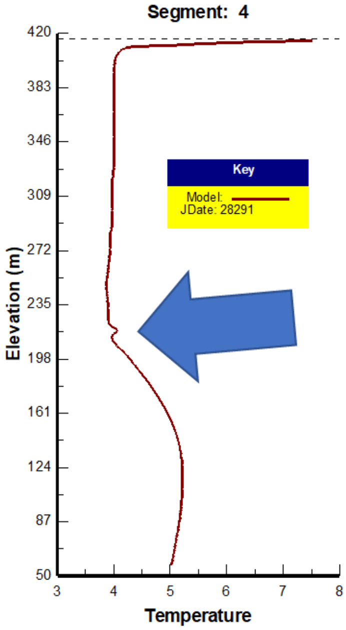
Point #	Concern	A418 Water Quality Implication	Action Item
IRP 3.1	Portal between A418 and A154 not modeled in CE-QUAL-W2 Background: From Golder (2020), the portal (apparently rectangular with dimensions of 5 m X 5m) between A418 to A154. The portal is located at 9290 m in A418 (and 9270 m in A 154). As stated in the documentation, “water transfers from A418 to A154 through portal”.	Because this portal is connecting 2 pits and is in contact with the ground, there is the possibility that convective currents could be induced that may enhance mixing in A418 (and/or in A154).	Perform an evaluation of movement of water stored in the portal into A154 or A418 and evaluate whether this could affect A418 water quality.
IRP 3.2	Groundwater not included in CE-QUAL-W2 model even though documentation showed groundwater was included.	Groundwater is not included in the CE-QUAL-W2 model after the pit is filled. It is not unreasonable to neglect groundwater since this would be a conservative assumption (the groundwater concentrations would generally be of better quality than the mine tailings).	Revise figure in CE-QUAL-W2 documentation.
IRP 3.3	A spillway required to balance flow in the A418 CE-QUAL-W2 model. This point is one of several points mentioned below that focus on the linkage of the CE-QUAL-W2 model and the Mike3 Breach model. Background: The inflows into A418 through the 2 breaches was computed using a Mike3 model. The inflow and outflow predicted from the Mike3 breach model did not agree with the water balance in the CE-QUAL-W2 model. The CE-QUAL-W2 model had more water coming into it (or less water loss) than the Mike3 Breach model. As a result, to keep the water level at 416 m and not	Mike3 Breach model and W2 model are not completely compatible regarding the water balance between the 2 models. This can affect the amount of mixing of clean water from Lac de Gras affecting surface concentrations in A418.	Review water balance in A418 CE-QUAL-W2 and Mike3 model and evaluate ways to better synchronize the 2 models and whether the current situation is conservative or not.

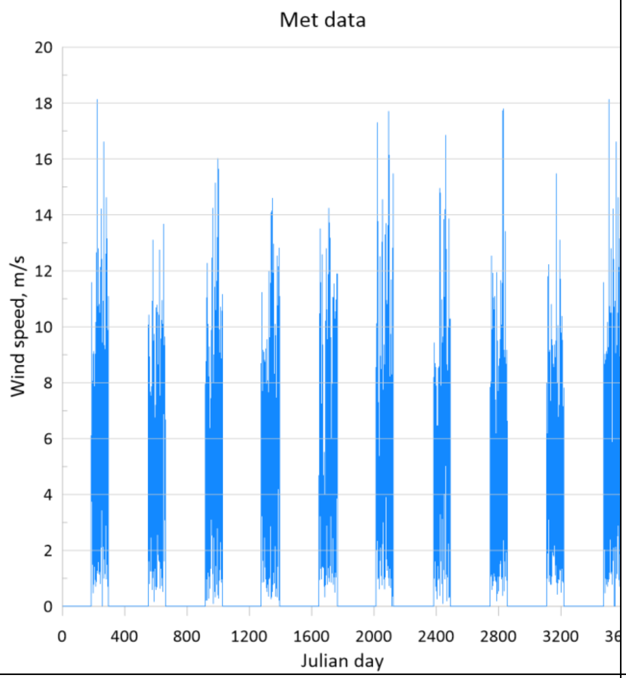
Point #	Concern	A418 Water Quality Implication	Action Item
	higher, a spillway was added that lost water. This water was not transferred anywhere, it was just lost from the system. The spillway water loss is a significant part of the water balance, as shown in the pie chart below:  		
IRP 3.4	Flow in the winter through the breaches from Lac de Gras Mike3 model may not be realistic as a result of the ice model used in the Mike3 model. Background: This point also points to whether there is a the lack of consistency between the CE-QUAL-W2 model and the Mike3 model. The breach Mike 3 model predicted winter flow into and out of A418 through from the breaches based on the prescribed ice cover.	The flow through the breaches can affect the mixing of Lac de Gras water with A418. With ice cover, there is the possibility that the ice could close the breaches or restrict the exchange flow during ice cover.	Evaluate whether the assumptions of the A418 model are conservative. I would assume as a conservative assumption that every winter at the peak of ice formation that the breaches may be closed for a period of time as a result of ice blockage of the breaches.
IRP 3.5	Evaporation water loss predicted by the CE-QUAL-W2 is greater than precipitation. This may be fine if this is consistent with observations in the region. Background: The CE-QUAL-W2 water balance over 200 years includes the following sources and sinks, with evaporation accounting for 35% of the	Evaporation can concentrate pollutants in the upper layers. If the model does not have enough precipitation or too much evaporation, this is a	Check on the A418 water balance. If the water balance is reasonable, then nothing needs to be changed. Also, there was

Point #	Concern	A418 Water Quality Implication	Action Item
	overall water transfer and precipitation accounting for 29%: 	conservative assumption.	no discussion of the impacts of climate change on this water balance. Would there be less precipitation or more in the future rather than running scenarios repeating meteorological conditions for the 200 year time period? Factoring in climate change on the overall water balance would be useful since the model is extending so far into the future.
IRP 3.6	There were large temperature differences between the Mike3 breach model input temperatures and those predicted within the CE-QUAL-W2 model. Background: During some periods of the year, input temperatures from the breaches were over 10°C colder than those predicted in A418. This is illustrated in the figure below:	With significantly cooler inflow water coming into A418, these inflows could plunge to their own density level creating vertical mixing as they plunge.	Evaluate the consistency of the Mike 3 model and the CE-QUAL-W2 model since they do not seem synchronized. One could take the CE-QUAL-W2 predicted temperatures and use them for the inflow temperature thus ensuring some consistency between A418 and Lac de Gras.

Point #	Concern	A418 Water Quality Implication	Action Item
			
IRP 3.7	The CE-QUAL-W2 A418 model did not have brine exclusion turned on during the ice simulation.	Without brine exclusion, there would be no concentrating of pollutants in the surface layer during ice formation. Not having brine exclusion in the ice model would not be a conservative assumption.	This is easily remedied by setting ICEC=ONWB in the CE-QUAL-W2 input control file, w2_con.npt.
IRP 3.8	Ice thickness in the A418 CE-QUAL-W2 model is not in agreement with the ice thickness of the Mike 3 Breach model. Background: The CE-QUAL-W2 model predicts ice thickness dynamically. The A418 model then predicts ice thickness ranging from 1.6 to 2 m thickness with an average of more than 1.8 m. The long-term average used in the Lac de Gras model was 1.6 m ice thickness and was prescribed rather than predicted.	Because of differing ice thicknesses, the flows and temperatures of the Mike 3 Breach model will be incompatible with the ice predictions in CE-QUAL-W2. This could affect inflow and outflow dynamics in the breaches between A418 and Lac de Gras.	Verify that the CE-QUAL-W2 A418 model predictions of ice do not affect the prescribed ice conditions imposed on the Mike3 Breach model.
IRP 3.9	The CE-QUAL-W2 model used the W2N turbulence closure scheme.	The model predicted vertical mixing in	Recommend using the k-ε

Point #	Concern	A418 Water Quality Implication	Action Item
	Background: The choice of turbulence scheme affects the vertical mixing in the model and hence is a key parameter to understand how quickly vertical mixing will take place.	A418 is affected by the choice of turbulence closure scheme.	(AZC=TKE in w2_con.npt) turbulence closure scheme in CE-QUAL-W2.
IRP 3.10	Breach flows predicted by the Mike3 model are critical to examining whether the mine surface runoff causes concentrations to exceed limits. Background: The flows through the two breaches were computed using the Mike3 model which has a grid that has not been calibrated to field data. If those flows are lower than expected, they could cause concentrations from surface runoff to build up in A418 upper 40 m and violate water quality benchmarks. Showing the sensitivity of the breach flow to surface concentrations in A418, the following graph shows the case with the existing breach flows, the case where the breach flows are combined into one flow rather than two, and one where the breaches are closed or blocked completely. If the tracer concentration is above 11 mg/l, there is a violation of the surface water quality benchmark.  	The flows into and out of the breaches significantly affect the mixing of surface runoff in A418.	Carefully assess implications of flow through breach and whether Mike3 model is providing a reasonable prediction. The Mesh 2 grid (Golder, 2019) used for the Mike3 Breach model is not calibrated.
IRP 3.11	Temperature profile bump (possibly near TDS interface)	This has little is any implications for mixing in A418 but is a model curiosity.	No action required.

Point #	Concern	A418 Water Quality Implication	Action Item
	Background: The CE-QUAL-W2 model predicts a slight bump in the temperature profile such as shown below.  		
IRP 3.12	Breach flow oscillations are unusual in that the flow between Breach 1 and Breach 2 are 99.3% of the time in opposite directions Background: The Mike3 Breach model has not been calibrated to field data since it used a different Mesh than the calibration model (Golder, 2019).	The ventilation or mixing of clean water from Lac de Gras to A418 is directly impacted by the breach flow oscillations.	Even though results from the Mike 3 model show that when the wind changes, there is a change in flow through the breaches, this does not account for the 68.8% of all wind values being zero velocity. If 99.3% of the breach flow is in opposite directions, and 68.8% of the wind data are zero, what is causing this breach flow alternation? This

Point #	Concern	A418 Water Quality Implication	Action Item
			is another possible incompatibility of the Mike3 model and CE-QUAL-W2 that could affect the dilution in A418.
IRP 3.13	Meteorological wind data for the CE-QUAL-W2 model has zero values during prescribed ice cover in the Mike3 model even when the CE-QUAL-W2 A418 model is not predicting ice cover. The wind speed is shown below showing periods with zero wind speed. 	Wind speed affects vertical mixing in A418.	Add real wind speed to the meteorological input file and let the CE-QUAL-W2 model turn off wind internally once ice forms. In this way, the model results are not biased.
IRP 3.14	Errors in input files as discovered by W2 model preprocessor Background: The original model preprocessor was not able to read the 200 year input files correctly and hence did not run. After fixing the model preprocessor, the following errors were discovered: `QTR file: File not designated as a CSV file (no "$" as first character) but commas found between input values for Input\qtr_Runoff.csv`	May affect model reading correct input file format of boundary conditions and not being synchronized in time by the Julian day error.	Use updated preprocessor and correct model file errors.

Point #	Concern	A418 Water Quality Implication	Action Item

	`Duplicate file name in control file for file Input\ttr_Breach.npt`
	`Duplicate file name in control file for file Input\ctr_Breach.npt`
	`Duplicate file name in control file for file Input\ttr_Breach.npt`
	`Duplicate file name in control file for file Input\ctr_Breach.npt`
	
	Also, many of the input files had an error in Julian days mistakenly assuming that Julian day 0 was January 1.		

IRP 3.15	Effect of porewater initial condition	If the stratification was not as strong to begin with either the porewater TDS much less than 500 mg/l or the surface water much higher than the initial condition of 24 mg/l, could there be more possibility for chemicals of concern to migrate to the upper 40 m?	Run model sensitivity varying the initial stratification
IRP 3.16	Compatibility of Mike3 Breach model and CE-QUAL-W2 Background: If the Mike3 Breach model is used to predict breach flow, then the coefficients used in the 2 models should probably be similar. In Table 6 (Golder, 2019), the horizontal eddy viscosity is 0.1 (The units are unclear but assume they are in units of m^2/s) for the Mike3 model. For the CE-QUAL-W2 model they are 1 m^2/s.	The specification of the horizontal eddy viscosity can affect horizontal mixing of material within A418.	The 2 models should be consistent in choice of model coefficients and the CE-QUAL-W2 model could use AX=DX=0.1 m^2/s rather than 1 m^2/s.

Conclusions

The review of the CE-QUAL-W2 and Mike 3 Breach models show the following:

- There were several errors that can be easily fixed for the A418 model – Julian day discrepancy, file name issues, csv file format issue, and setting the proper wind speed for the meteorological input file.
- The main issue is related to the breach flow and the dilution of the surface runoff in A418 in terms of a likelihood of violating the Water Quality Benchmarks. The incompatibility of the Mike3 and the CE-QUAL-W2 models is an issue that needs to be resolved. Using a CE-QUAL-W2 model for the entire system would have probably been better than meshing 2 models together, both of which were uncalibrated. Even the Mike3 Mesh 1 model that was calibrated (Golder, 2019) did not have very good water level or temperature calibration compared to other lake and reservoir temperature model calibrations.
- There were recommended further sensitivity runs, but the deep porewater seems to move very, very slowly vertically and during the period of simulation it is unlikely if the initial conditions are correct, that the porewater after 200 years would lower water quality in the surface to below the water quality benchmarks.
- Since the model was run for 200 years with repeated sets of meteorological conditions, climate change scenarios should also be simulated to evaluate potential changes in meteorological conditions over the long time period.
- In general, given the initial conditions of the porewater in the deep pit, the model results do indicate that the porewater contaminants will not violate the water quality benchmarks in the upper 40 m surface layers.

5.0 External Questions to the Panel

A number of participants in the Panel review workshops submitted questions to the Panel for consideration. Some questions fall outside of the immediate scope of the Panel review, but we have attempted to give the best and most complete answer to each based on our experience.

The external questions collated by the WLWB were asked and responded to at various stages of the review process; the are listed below with the Panel's response following in italics:

Questions posed at/after the draft Panel presentation September 24th

1. In your opinion, does this model help us to answer whether the silt will settle?
   The model is helpful in answering the question of FPK settling. Material characterization and sensitivity analysis would improve the confidence level in achieving the desired settling in A418.

2. Does this modeling follow best practice?
   Generally, the use of a numerical model represents best practice for slurry consolidation and water flow and quality predictions. The models used for all aspects of this study are industry standard and well documented. The Panel is assessing how these models are applied and

interpreted. For the flow and water quality models, there have been no model comparison to field data shown for the Lac de Gras model. This would be helpful in assessing the reasonableness of the Breach model predictions.

- Include all relevant variables?

  Yes, in the Panel's view all relevant physical and chemical variables are included in the models. The Panel is unaware of any potential contaminant of concern that is not included in the source terms.

- Accurately represent all relevant physical and chemical processes?

  The outcome of the IRP review will focus on this question. Physical processes in the model are primarily governed by experience of field personnel and the parameterizations adopted by the modellers; all chemical constituents are treated as conservative tracers so chemical processes per se are not included in the modeling (they may form part of the boundary and initial conditions as the result of laboratory testing).

- How confident are you in the model predictions?

The model predictions must be taken into context with the ongoing test data and the sensitivity runs to establish a level of confidence in the overall model predictions. That will be the primary outcome of the IRP review.

3. Do you think it answers the question of whether this will be safe?
   - What is the range of uncertainty?
     The Panel has requested ongoing test data and a range of sensitivity runs to address this.
   - What is the risk that model predictions are a little bit off? a lot? Totally wrong?
     The material characterization and the sensitivity outcomes should bracket the majority of potential outcomes and also reveal trends that may indicate further sensitivities are required.

   - Is the model good enough to give us a sense of the risk of an upset condition?
     Upset conditions are difficult to predict as they, by definition, fall outside of the normal parameters of the models. The Panel has considered several potential upset conditions and others have been addressed in completed sensitivity runs, including:
     - *Turnover driven by excessive wind stress*
     - *Convective turnover (or partial turnover) by fluid from the A418/A154 port*
     - *Side-wall cave ins (not covered by this present modeling and not part of the panel's scope)*
     - *Blockage of inflow from Lac de Gras*
4. Is the model taking into account the cultural uses?
   Cultural uses are usually considered at the environmental assessment level as a valued component and are subject to consultation as part of licensing. Traditional use of the area considered by the Panel (the footprint of A418) is not known to the Panel, but could include recreational use, fishing, drinking water, wildlife, and other uses of cultural significance.

   The outcomes of the models will allow the assessment of water quality in the A418 footprint in support of a return to traditional use; predicted water quality needs to be screened against the *appropriate water quality guidelines that protect each use. The plan to reopen the current closed section of Lac de Gras to restore fish habitat points to the desire to return the area back towards its pre-mining state.*

Additional questions posed on/after the October 1 Panel presentation

5. Would there be any long-term effects to Harvesting from a visual perspective?
   The change in visual aspects of the site, including berms surrounding the former lake shore area, could be barriers to the ongoing harvesting if users are uncertain about the safety of the area or the water resources. Reclamation of the area could include visual remediation to bring the area further back to pre-mine conditions and education for users of the area once the mine is closed.

6. Are there any critical recommendations the IRP feel are necessary to address, prior to the deposition of PK in the mine workings?
   Yes, a set of recommendations is presented in the summary section of this document

7. What does the IRP view as the major sources of uncertainty regarding model conclusions regarding AEMP benchmark exceedances?
   The main sources of uncertainty are:
   - Porewater release rate and amount of the consolidating PK
   - Geochemical characteristics of the porewater affecting the initial conditions of the model
   - Ventilation of the surface waters of A418 by the flows through the berm breaches

8. Does the IRP feel that a Monte Carlo analysis with reasonable run times is possible? If yes, what key stochastic variables should be considered and how should the model distributions and parameters be estimated?
   A multi-variate stochastic model for water quality predictions would require between 100-1000 realizations to properly characterize the range of probable model outcomes. Potential stochastic variables would include porewater release rate, geochemical source concentrations, breach flow, (please add any you feel are important). While a stochastic run would be desirable, the run time cost is prohibitive (months to years). Bracketing the key variables and running a series of sensitivities, while not perfect, gives a very good idea of the potential uncertainty in the model's base case results.
   Also, in most Monte Carlo simulations of water quality models, the uncertainty is usually in the water quality kinetics, rather than in the hydrodynamic simulation. Since all state variables are conservative, there is little to vary stochastically in the model. Hence, we recommend keeping constituents conservative and using conservative assumptions in the hydrodynamic model rather than a stochastic model approach.

9. Can the IRP comment on the combination of input variables that are most likely to occur; i.e. the "plausible scenario" case? It would be useful to run the linked models to determine if there would be an upset of meromixis and if yes, what surface water concentrations would be.
   The plausible scenario is captured by the base case model presented by Diavik. This represents the expected outcome based on the variability of input parameters and known (measured) statistics of geochemical loading. A worst case could be envisioned by a complete overturning

of the pit lake followed by a mixing of all expelled porewater (a function of time) throughout the water column. Additional conservatism could be added to the scenario by considering upper case (statistically elevated) porewater concentrations. This scenario has not been requested by the Panel as it believes the suite of sensitivities both previously run and requested by the Panel are sufficient to cover the range of potential upset conditions.

6.0 Summary

It is the Panel's opinion that:

1. The modeling effort put forward to examine the long-term water quality in pit A418 under the Processed Kimberlite to Mine Workings scenario is appropriate and that the modeling software used are of sufficient quality.
2. The base case results of the updated model (which includes previously expressed recommendations from the Panel) may be interpreted to show that water quality in the upper 40 m of pit A418 are not expected to exceed the AEMP water quality guidelines.
3. Sufficient sensitivity runs have been completed to support the conclusion that water quality in the upper 40 m of A418 is unlikely to be exceeded under anticipated variability in forcing possible upset conditions.
4. Certain model parameters require ongoing testing and monitoring to sufficiently understand their uncertainty which may not be currently taken into account in either the base case model or its sensitivities; these will be the subject of the Panel's recommendations below.

Conclusions and Recommendations

While the base case model and sensitivities comprise a comprehensive set of surface water quality predictions in Pit A418, they are based on current knowledge of physical and chemical parameters that form the keys assumptions in the model which have the potential to change prior to actual placement of tailings in Pit A418. The Panel understands that a deposition monitoring program is proposed to characterize the material during deposition of FPK in A418 (2023-2025). It is also understood that such monitoring has to be based on the actual grit-rich FPK being deposited because its composition and behavior might be different from current FPK owing to geological and mineralogical variation in the kimberlite pipes. Therefore, the Panel recommends that in addition to monitoring of grit-rich FPK slurry during deposition, a comprehensive laboratory investigation program be enacted to provide a benchmark for material properties and consolidation behavior in advance of deposition. Geotechnical investigations for large strain consolidation and geochemical characterization of the porewater should be started as soon as the relevant FPK material is available – ideally 6-12 months in advance of the start of deposition.

To address the uncertainties identified in this review, the following are Panel recommendations (along with a rationale) related to PK placement and subsequent flooding of A418:

- A consistent tailings gradation (minimal segregation) and a standardized test procedure (minimal systemic error) are recommended during the entire tailings deposition schedule. This will provide a quality control measure for the as-deposited material when compared with the actual FPK.

- Model sensitivity for initial conditions (void ratio of 6.85 to 3.5), should be further explored using the two different constitutive relationships for volume compressibility. This will provide a design criteria for selecting an appropriate solids content at the onset of deposition that, in turn, will help in estimating the rate/quantity of the released pore water in the pit.
- It is recommended that consistency limits (liquid limit and plastic limit) should be obtained and used in conjunction with GSD to classify FPK prior to and during tailings deposition. Again, this will provide a quality control measure for the as-deposited material when compared with the actual FPK.
- An assessment of the initial slurry microstructure should be conducted based on mineral and pore water composition of the discharged FPK at various stages of deposition. This will help in evaluating slurry dewatering (rate/quantity) and in selecting the initial solids content as mentioned above.
- It is recommended to conduct stand-pipe compressibility tests to determine the volume compressibility relationship at low effective stresses prior to deposition. Again, this will provide a design criteria for selecting an appropriate solids content at the onset of deposition that, in turn, will help in estimating the rate/quantity of the released pore water in the pit.
- It is recommended to conduct ongoing bathymetric assessment during deposition and/or a more robust 3-D numerical modeling at the onset of deposition. This will confirm the final configuration of the deposited FPK in the pit that, in turn, will be used for model iteration 4 before flooding A418 with water.
- Although freezing of the FPK deposit in A418 (situated in the thawed talik zone) may not be expected, it is recommended to monitor temperature at depth during deposition. Again, this will confirm the final configuration of the deposited FPK in the pit that, in turn, will be used for model iteration 4 before flooding A418 with water.
- It is recommended to ensure that the breach debris is not deposited in the pit so as to avoid an upset condition for FPK consolidation after deposition.
- It is recommended that Diavik initiate a randomized anaerobic porewater sampling program to build a better statistical foundation for the porewater geochemistry. This will constrain future mixing model results and inform subsequent long-term modelling initial conditions in A418.
- Reassess the compatibility of the Mike3 breach model and the CE-QUAL-W2 A418 model looking for ways to confirm that assumptions made in computing breach flow are conservative. While these may not affect the porewater mixing directly, they do affect the surface runoff dilution.
- Correct minor errors and follow suggestions for turbulence closure and wind speed in the CE-QUAL-W2 A418 model.
- Consider running climate change scenarios rather than repeating current meteorological data for the 200-year simulation period.

7.0 References

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