TECHNICAL MEMORANDUM

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NALUNAQ GOLD PROJECT: TAILINGS SEEPAGE ASSESSMENT

1.0 INTRODUCTION

Following the discovery of the Nalunaq gold mine in southern Greenland in the early 1990s and development and operation by Crew Gold Corporation ("Crew Gold"), development was continued by Angus & Ross plc and Angel Mining (Gold) A/S, between 2004 and 2013. Subsequently additional exploration work has been undertaken in the Nalunaq area. It is understood that Nalunaq A/S are aiming to restart mining operations in 2021.

Golder Associates (UK) Ltd. ("Golder") has been contracted to Nalunaq A/S ("the Company") to provide support for the water and tailings management at its Nalunaq mine ("the Project"). As part of its scope, Golder is undertaking an assessment of seepage from the Dry Stack Tailings Storage Facility (DTSF) to inform the engineering design. The assessment is informed by a review of geochemical data available for the Project and the potential impact on water quality from seepage from the DTSF.

In this Technical Memorandum we present the results of an assessment of the impact of the DTSF's seepage on water quality under various design scenarios and leachate quality source terms.

The design scenarios are as follows:

1) Unlined, no cap (Scenario 1);

2) Unlined, capped with a geosynthetic clay liner (GCL) (Scenario 2);

3) Lined with a bituminous geomembrane liner (BGM), no cap (Scenario 3); and

4) Lined with a BGM liner and BGM cap (Scenario 4).

We also present a comparison of seepage rates through bituminous, geosynthetic clay and clay liners.

2.0 FOUNDATION SEEPAGE COMPARISON

At Table 1 are presented the input criteria for, and results of, the calculation of seepage through three potential foundation systems. As may be noted from Table 1 the seepage rates per unit area for both geosynthetic clay liners and bituminous liner systems are less than those through an engineered or compacted clay liner assuming the same head of leachate on the top of the liner system. On this basis it is considered that they provide a suitable alternative to the use of an engineered or compacted clay liner.

Table 1: Input criteria for and results of, seepage rate calculations through bituminous, geosynthetic clay and clay liner systems

	Notation	Units	Value	Reference/Justification
Area of liner in contact with leachate	A	m^2	1.0	Design assumption (unit area)
Head of leachate on liner	h	m	0.1	Design assumption
Geosynthetic Clay Liner (GCL) thickness	z_{gcl}	m	0.005	Design assumption
GCL hydraulic conductivity	K_{gcl}	m/s	1.0×10^{-11}	From Jie *et al*, 2008.
Head gradient across GCL	i_{gcl}	m/m	21.0	Calculated
Flow through GCL	Q_{gcl}	m^3/s	2.1×10^{-10}	Calculated using Darcy's Law
Compacted Clay Liner (CCL) thickness	z_{clay}	m	1.0	Design assumption
CCL hydraulic conductivity	K_{clay}	m/s	1.0×10^{-9}	Design assumption (typical CCL K specification)
Head gradient across CCL	i_{clay}	m/m	1.1	Calculated
Flow through CCL	Q_{clay}	m^3/s	$1.1\ 10^{-9}$	Calculated using Darcy's Law
Bituminous Geomembrane Liner (BGM) thickness	z_{bit}	m	0.005	Design assumption
BGM hydraulic conductivity	K_{bit}	m/s	1.0×10^{-12}	From Lambert and Touze-Foltz, 2000
Head gradient across BGM	i_{bit}	m/m	21.0	Calculated
Flow through BGM	Q_{bit}	m^3/s	2.1×10^{-11}	Calculated using Darcy's Law

3.0 SEEPAGE ASSESSMENT

3.1 Conceptual Model and Receptors

For the purpose of assessing the potential impact of the seepage of leachate from the DTSF we have undertaken some scoping calculations, based on two different leachate source terms, on two receptors:

- **Groundwater**: A notional groundwater monitoring well situated 800 m downgradient of the DTSF, adjacent to the Kirkespir River. The assumed groundwater monitoring well represents the minimum distance to where conceptually the groundwater in the fluvioglacial aquifer is likely to discharge to the river due the lower permeability barrier of the bedrock ridge at that point (Figure 1); and

- **Surface Water**: The Kirkespir River approximately at the location of the historical waterfall monitoring station (Waterfall Station), as used during the Nalunaq historical environmental monitoring program by the Danish Centre for Environment and Energy (DCE).

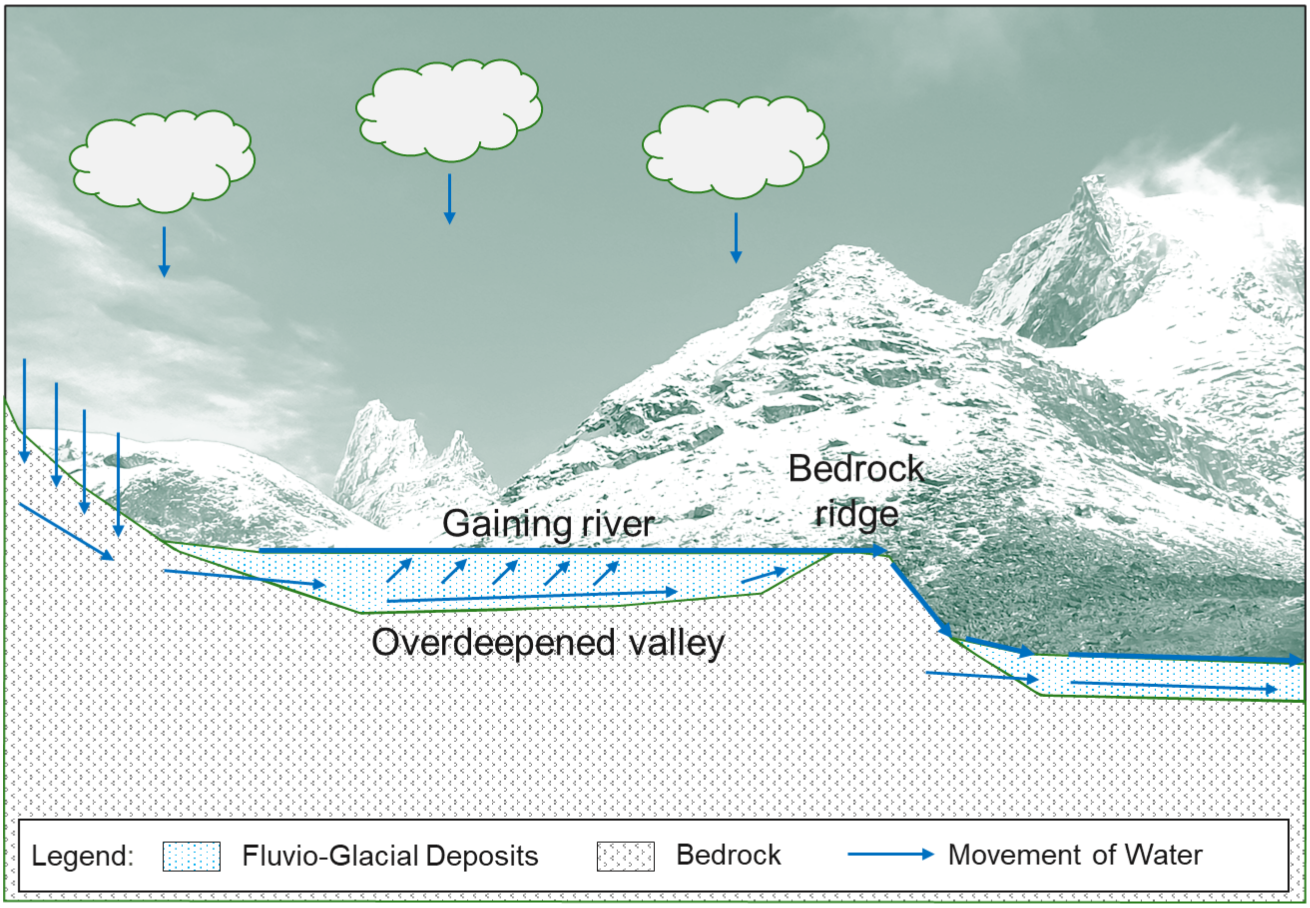

Figure 1: Conceptual Model for Groundwater and Surface Water Movement in the Kirkespirdalen

3.2 DTSF Flux and Head Calculations

To facilitate the assessment we have undertaken calculations of recharge into the DTSF and seepage from the DTSF based on various cap and liner combinations as outlined in Section 1.0. By way of example the fluxes out of the facility and the build-up of leachate in the DTSF are illustrated graphically in Figure 2 to Figure 5 for each of the four scenarios identified in Section 1.0. It is noted in the lined scenario that the head of leachate builds up in the facility until the site is capped after which it progressively declines.

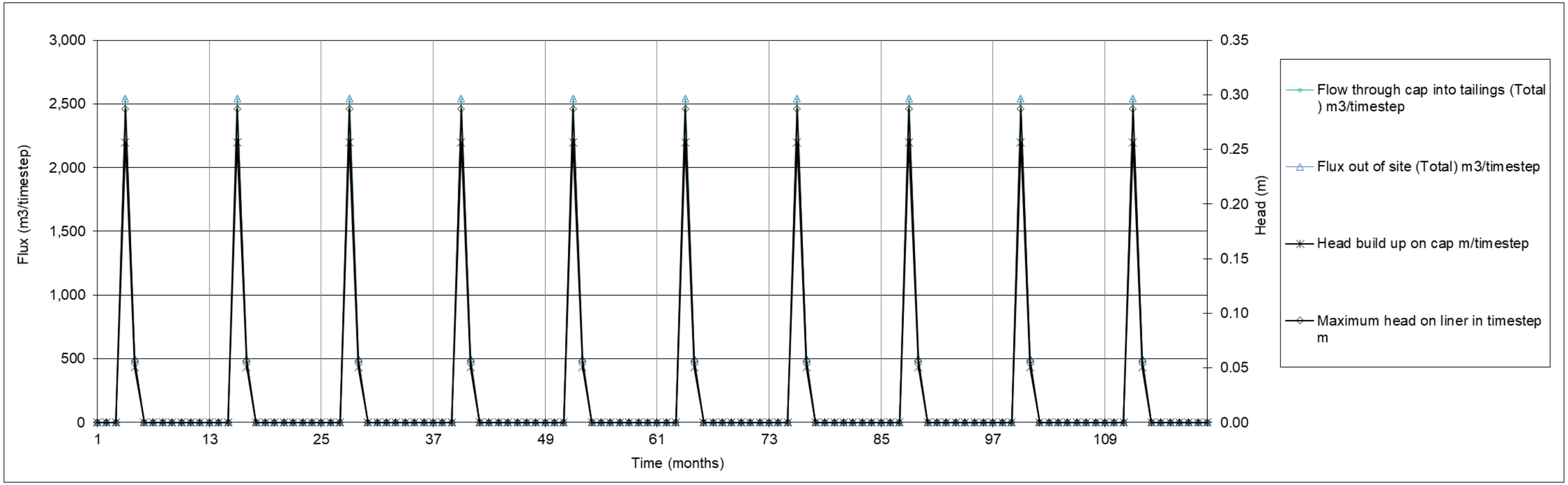

Figure 2: Scenario 1 - Calculated fluxes from and leachate heads in, the unlined DTSF with no cap

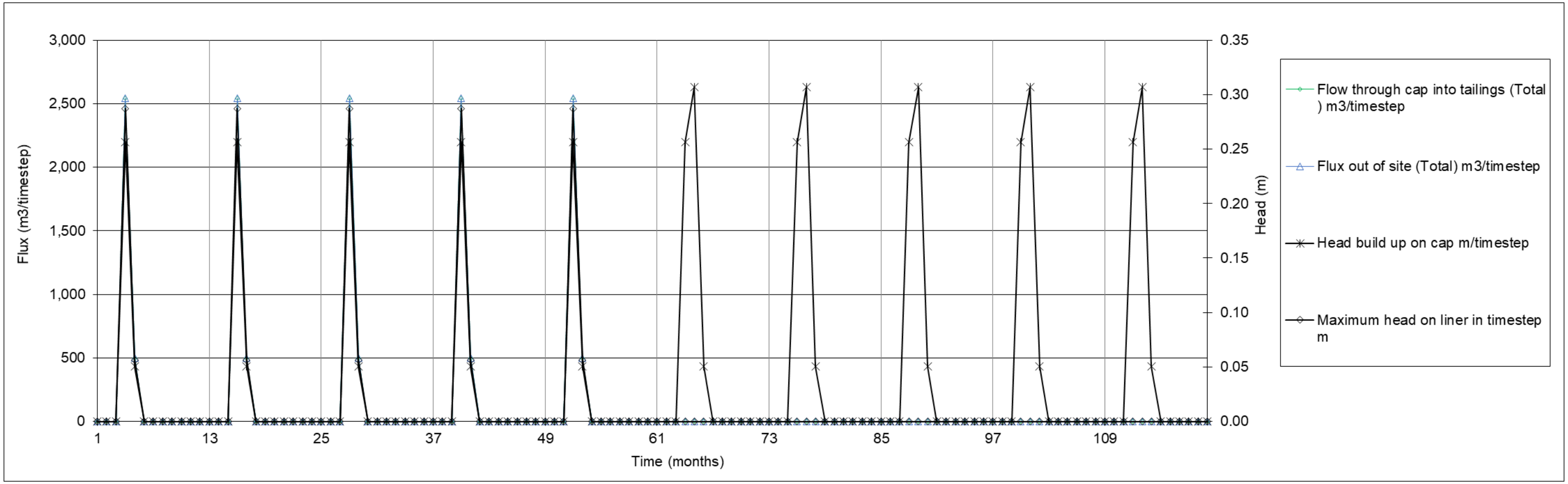

Figure 3: Scenario 2 - Calculated fluxes from and leachate heads in, the unlined DTSF with a GCL cap after 5 years

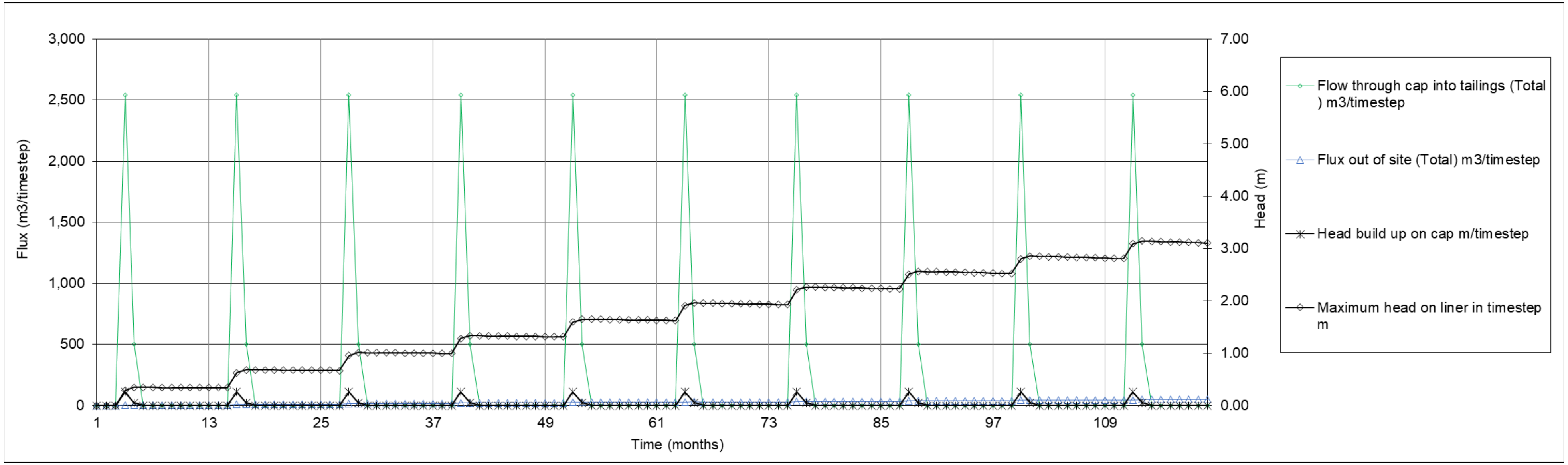

Figure 4: Scenario 3 - Calculated fluxes from and leachate heads in, the BGM lined DTSF with no cap

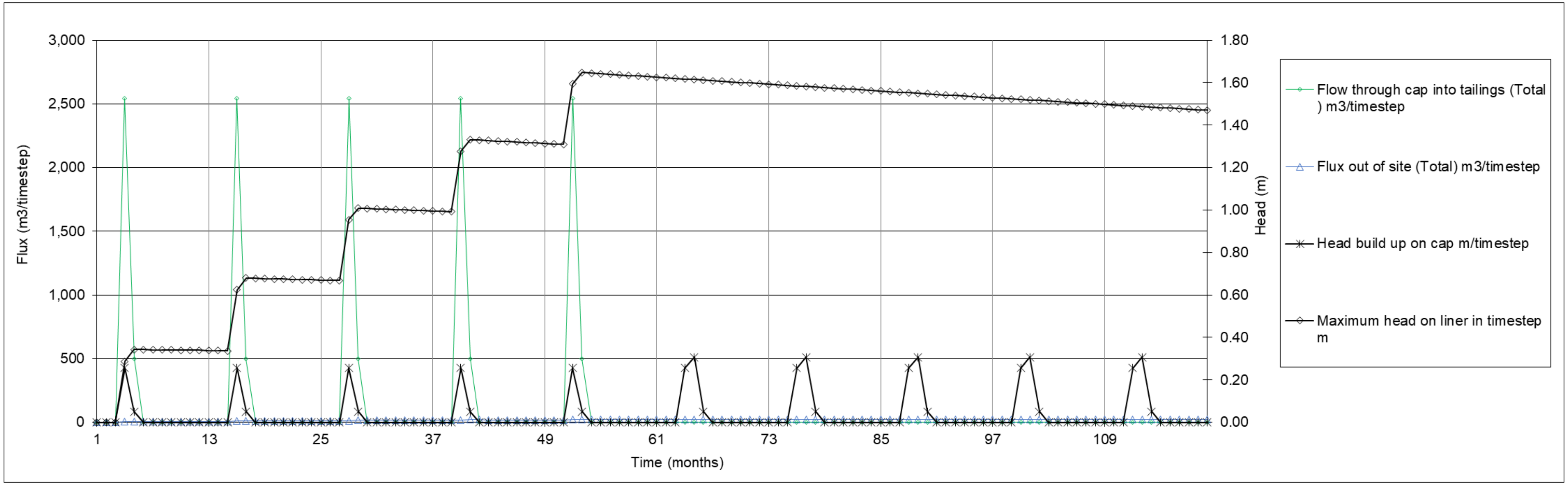

Figure 5: Scenario 4 - Calculated fluxes from and leachate heads in, the BGM lined DTSF capped with a BGM after 5 years

3.3 Tailings Leachate Source Terms

For a number of selected potential contaminants of concern (PCOC) downgradient concentrations in groundwater have been calculated at the groundwater monitoring point 800 m downgradient of the DTSF in the vicinity of the Waterfall Station; and in surface water in the Kirkespir River. The input assumptions and further details on the methodology used are presented at Appendix A. These scenarios cover both operational and closure scenarios through the consideration of both capped and uncapped situations.

An initial assessment, reported in Golder (2020), of the potential impact was undertaken based on a source term derived from the tailings filtrate concentrate values reported in Kvaerner (2002) and calculated pore water concentrations based on calculated leachate values using the mass concentrations in the rock and partition coefficients. The latter is considered likely to be very conservative as the PCOC are not absorbed onto the tailings matrix but are a constituent part of the rock material.

Subsequently the results of leaching tests on processed tailings using both a gravity and a flotation circuit have become partially available (SGS (2020); attached at Appendix B). This data has been used as the updated source term for the seepage assessment. A comparison of the source terms used in Golder (2020) and in this updated assessment is presented in Table 2 below. It is noted that the concentrations from the SGS static test results are lower for arsenic, cobalt and nickel than for the assessment in Golder 2020, while being higher for iron and zinc. Zinc and cadmium concentrations were taken as 50% of the method detection limit[1] as for a number of samples these were greater than the recorded concentrations in other samples. This is considered likely to be a conservative assumption.

Table 2: Source term comparison (concentrations in mg/l)

	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Golder, 2020	0.315	0.985	0.0044	0.135	0.009	-	-	-
Gravity tailings (from SGS, 2020)	0.154	0.00115	0.0037	0.909	0.01^	0.0064	0.000015	0.00908
Flotation tailings (from SGS, 2020)	0.0646	0.0014	0.0035	1.13	0.01^	0.0053	0.000015	0.00726

NOTE: ^ Concentrations assumed to be 50% of the method detection limit.

3.4 Calculated Concentrations at Receptors

Groundwater Concentrations

In order to undertake the seepage assessment, the leachate source terms are diluted in the groundwater flow under the DTSF and then the downgradient concentrations are calculated based on the Domenico equation (ASTM, 1995) for contaminant transport that accounts for retardation, advection, dispersion and diffusion. Two conceptual scenarios were used as follows:

- DTSF built direct on the prepared current surface (Scenario A); and
- DTSF built on a platform raised 1.8 m above the current surface (Scenario B).

[1] Where the laboratory limit of detection (LOD) for a particular sample was greater than the concentrations detected in other samples the concentration used for the assessment were taken as half of the LOD, where this was higher than the detected concentrations in other samples, consistent with practice set out by the United States Geological Survey (1999) and the American Petroleum Institute (2002).

The results of the calculations for the gravity tailings source term for a monitoring point in groundwater 800 m downgradient are summarised in Table 3 and

Table 4 for Scenario A and B, respectively. The results of the calculations, for the flotation tailings source term, for a monitoring point in groundwater 800 m downgradient are summarised in Table 5 and Table 6 for Scenario A and B, respectively.

None of the calculated receptor concentrations, presented in Table 3 to Table 6, exceed the relevant water quality criteria which are taken from the Government of Greenland Mineral Resources Authority (GMRA) guidance of preparing environmental impact assessments (EIA) for mining operations (GMRA, 2015), with the exception of cobalt which is taken from groundwater threshold value guidelines used in Finland (European Commission (EC), 2009).

Table 3: Scenario A: Calculated concentrations in groundwater 800 m downgradient of the DTSF using the gravity tailings source term (DTSF on current surface)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Gravity tailings concentration	mg/l	*0.154*	*0.00115*	*0.0037*	*0.909*	*0.01*	*0.0064*	*0.000015*	*0.00908*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	0.002	0.00001	0.00005	0.011	0.0001	0.00008	1.89×10^{-7}	0.00011
No liner, cap	mg/l	0.002	0.00001	0.00005	0.011	0.0001	0.00008	1.89×10^{-7}	0.00011
Bituminous liner, no cap	mg/l	3.20×10^{-6}	2.39×10^{-8}	7.68×10^{-8}	1.89×10^{-5}	2.08×10^{-7}	1.33×10^{-7}	3.11×10^{-10}	1.88×10^{-7}
Bituminous liner, cap	mg/l	3.78×10^{-7}	2.82×10^{-9}	9.08×10^{-9}	2.23×10^{-6}	2.45×10^{-8}	1.57×10^{-8}	3.68×10^{-11}	2.23×10^{-8}

Table 4: Scenario B: Calculated concentrations in groundwater 800 m downgradient of the DTSF using the gravity tailings source term (DTSF on platform, 1.8 m above current surface)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Gravity tailings concentration	mg/l	*0.154*	*0.00115*	*0.0037*	*0.909*	*0.01*	*0.0064*	*0.000015*	*0.00908*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	0.002	0.00001	0.00005	0.011	0.0001	0.00008	1.90×10^{-7}	0.00011
No liner, cap	mg/l	0.002	0.00001	0.00005	0.011	0.0001	0.00008	1.89×10^{-7}	0.00011
Bituminous liner, no cap	mg/l	3.20×10^{-6}	2.39×10^{-8}	7.68×10^{-8}	1.89×10^{-5}	2.08×10^{-7}	1.33×10^{-7}	3.11×10^{-10}	1.88×10^{-7}
Bituminous liner, cap	mg/l	3.78×10^{-7}	2.82×10^{-9}	9.08×10^{-9}	2.23×10^{-6}	2.45×10^{-8}	1.57×10^{-8}	3.68×10^{-11}	2.23×10^{-8}

Table 5: Scenario A: Calculated concentrations in groundwater 800 m downgradient of the DTSF using the flotation tailings source term (DTSF on current surface)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Flotation tailings concentration	mg/l	*0.0646*	*0.0014*	*0.0035*	*1.13*	*0.01*	*0.0053*	*0.000015*	*0.00726*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	0.001	0.00002	0.00004	0.014	0.0001	0.00007	1.89×10^{-7}	0.00009
No liner, cap	mg/l	0.001	0.00002	0.00004	0.014	0.0001	0.00007	1.89×10^{-7}	0.00009
Bituminous liner, no cap	mg/l	1.34×10^{-6}	2.91×10^{-8}	7.62×10^{-8}	2.35×10^{-5}	2.08×10^{-7}	1.11×10^{-7}	3.11×10^{-10}	1.61×10^{-7}
Bituminous liner, cap	mg/l	1.58×10^{-7}	3.43×10^{-9}	8.58×10^{-9}	2.77×10^{-6}	2.45×10^{-8}	1.30×10^{-8}	3.68×10^{-11}	1.78×10^{-8}

Table 6: Scenario B: Calculated concentrations in groundwater 800 m downgradient of the DTSF using the flotation tailings source term (DTSF on platform, 1.8 m above current surface)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Flotation tailings concentration	mg/l	*0.0646*	*0.0014*	*0.0035*	*1.13*	*0.01*	*0.0053*	*0.000015*	*0.00726*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	0.001	0.00002	0.00004	0.014	0.0001	0.00007	1.90×10^{-7}	0.00009
No liner, cap	mg/l	0.001	0.00002	0.00004	0.014	0.0001	0.00007	1.89×10^{-7}	0.00009
Bituminous liner, no cap	mg/l	1.34×10^{-6}	2.91×10^{-8}	7.26×10^{-8}	2.35×10^{-5}	2.08×10^{-7}	1.10×10^{-7}	3.11×10^{-10}	1.51×10^{-7}
Bituminous liner, cap	mg/l	1.58×10^{-7}	3.43×10^{-9}	8.58×10^{-9}	2.77×10^{-6}	2.45×10^{-8}	1.30×10^{-8}	3.68×10^{-11}	1.78×10^{-8}

Surface Water Concentrations

On the basis that the groundwater plume discharges into the Kirkespir River the concentrations of the PCOCs will be further diluted. A dilution factor may be calculated from the ratio of groundwater discharge to the river compared with the flow in the river.

Based on the limited flow monitoring data available it is estimated that the low flow in the river is approximately 3 m^3/s immediately upstream of the Waterfall Station. This is derived from flow monitoring undertaken during May to August 1998, from which it was calculated that the average flow at monitoring station 1 (Figure 6) immediately upstream of the Waterfall Station was 3.29 m^3/s (SRK, 2002). This value is conservatively reduced to 3 m^3/s to account for uncertainty in the dataset due to the limited monitoring period.

The groundwater discharge (Q_{gw}) into the river, sourced from the DTSF, is calculated using Darcy's Law as follows:

$$Q_{gw} = K\ i\ A$$

Where:

K is the hydraulic conductivity of the aquifer (m/s);

i is the hydraulic gradient (m/m); and

A is the area (m^2) of the aquifer that contributes flow to the river.

The area (A) is calculated from the mixed depth of the plume, calculated to be 10 m, and the width of the source zone (assumed to be 150 m) plus an allowance for the lateral spread of the plume, calculated to be approximately 26.67 m in each direction. This result is in a maximum plume width of approximately 203 m. The resulting area is thus 2030 m^2. Based on a hydraulic conductivity (K) of 2.45 x 10^{-4} m/s (Golder, 2021) and a hydraulic gradient of 0.01 the discharge is calculated as approximately 0.005 m^3/s.

Using the calculated groundwater discharge of 0.005 m^3/s and a low flow of 3 m^3/s in the river a dilution factor of approximately 602 is calculated. Using this dilution factor the diluted concentrations in the Kirkespir River have been calculated and the results are presented based on the gravity tailings source term in Table 7 and Table 8 for Scenario A and B, respectively; and for the flotation tailings source term in Table 9 and Table 10 for Scenario A and B, respectively.

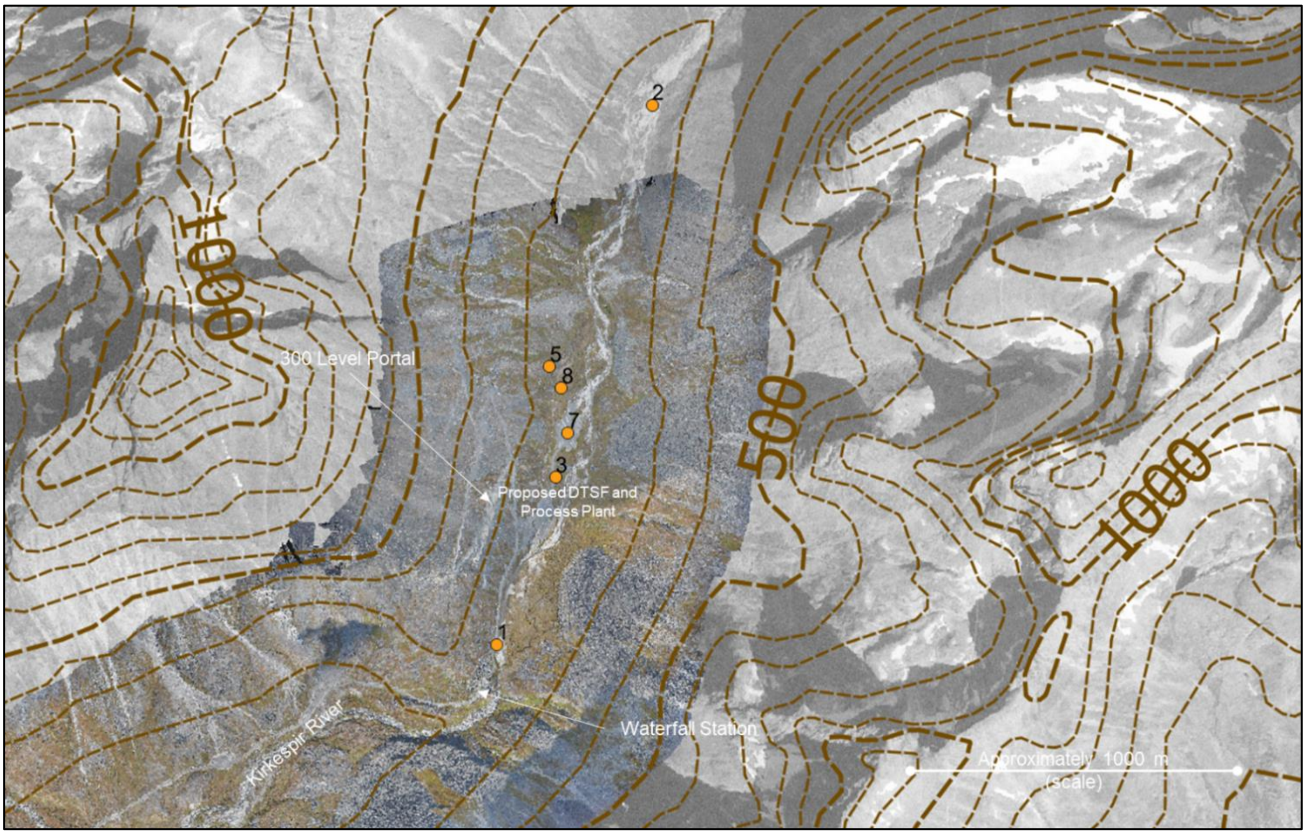

Figure 6: Approximate location of surface water flow monitoring stations (orange dots) reported in SRK, 2002

Table 7: Scenario A: Calculated concentrations in the Kirkespir River at the Waterfall Monitoring Station downgradient of the DTSF using the gravity tailings source term (DTSF on current surface, low flow scenario)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Gravity tailings concentration	mg/l	*0.154*	*0.00115*	*0.0037*	*0.909*	*0.01*	*0.0064*	*0.000015*	*0.00908*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	3.23×10^{-6}	2.41×10^{-8}	7.76×10^{-8}	1.91×10^{-5}	2.10×10^{-7}	1.34×10^{-7}	3.14×10^{-10}	1.90×10^{-7}
No liner, cap	mg/l	3.23×10^{-6}	2.41×10^{-8}	7.76×10^{-8}	1.91×10^{-5}	2.09×10^{-7}	1.34×10^{-7}	3.13×10^{-10}	1.89×10^{-7}
Bituminous liner, no cap	mg/l	5.31×10^{-9}	3.96×10^{-11}	1.28×10^{-10}	3.13×10^{-8}	3.44×10^{-10}	2.20×10^{-10}	5.15×10^{-13}	3.11×10^{-10}
Bituminous liner, cap	mg/l	6.27×10^{-10}	4.69×10^{-12}	1.51×10^{-11}	3.70×10^{-9}	4.07×10^{-11}	2.60×10^{-11}	6.09×10^{-14}	3.68×10^{-11}

Table 8: Scenario B: Calculated concentrations in the Kirkespir River at the Waterfall Monitoring Station downgradient of the DTSF using the gravity tailings source term (DTSF on platform, 1.8 m above current surface, low flow scenario)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Gravity tailings concentration	mg/l	*0.154*	*0.00115*	*0.0037*	*0.909*	*0.01*	*0.0064*	*0.000015*	*0.00908*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	3.23×10^{-6}	2.41×10^{-8}	7.77×10^{-8}	1.91×10^{-5}	2.10×10^{-7}	1.34×10^{-7}	3.14×10^{-10}	1.90×10^{-7}
No liner, cap	mg/l	3.23×10^{-6}	2.41×10^{-8}	7.76×10^{-8}	1.91×10^{-5}	2.09×10^{-7}	1.34×10^{-7}	3.13×10^{-10}	1.89×10^{-7}
Bituminous liner, no cap	mg/l	5.31×10^{-9}	3.96×10^{-11}	1.28×10^{-10}	3.13×10^{-8}	3.44×10^{-10}	2.20×10^{-10}	5.13×10^{-13}	3.11×10^{-10}
Bituminous liner, cap	mg/l	6.27×10^{-10}	4.69×10^{-12}	1.51×10^{-11}	3.70×10^{-9}	4.07×10^{-11}	2.60×10^{-11}	6.09×10^{-14}	3.68×10^{-11}

Table 9: Scenario A: Calculated concentrations in the Kirkespir River at the Waterfall Monitoring Station downgradient of the DTSF using the flotation tailings source term (DTSF on current surface, low flow scenario)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Flotation tailings concentration	mg/l	*0.0646*	*0.0014*	*0.0035*	*1.13*	*0.01*	*0.0053*	*0.000015*	*0.00726*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	1.36×10^{-6}	2.94×10^{-8}	7.34×10^{-8}	2.37×10^{-5}	2.09×10^{-7}	1.11×10^{-7}	3.13×10^{-10}	1.51×10^{-7}
No liner, cap	mg/l	1.36×10^{-6}	2.94×10^{-8}	7.34×10^{-8}	2.37×10^{-5}	2.09×10^{-7}	1.11×10^{-7}	3.13×10^{-10}	1.51×10^{-7}
Bituminous liner, no cap	mg/l	2.23×10^{-9}	4.83×10^{-11}	1.21×10^{-10}	3.90×10^{-8}	3.45×10^{-10}	1.82×10^{-10}	5.15×10^{-13}	2.49×10^{-10}
Bituminous liner, cap	mg/l	2.63×10^{-10}	5.70×10^{-12}	1.43×10^{-11}	4.60×10^{-9}	4.07×10^{-11}	2.16×10^{-11}	6.09×10^{-14}	2.94×10^{-11}

Table 10: Scenario B: Calculated concentrations in the Kirkespir River at the Waterfall Monitoring Station downgradient of the DTSF using the flotation tailings source term (DTSF on platform, 1.8 m above current surface, low flow scenario)

PARAMETER	UNITS	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Flotation tailings concentration	mg/l	*0.0646*	*0.0014*	*0.0035*	*1.13*	*0.01*	*0.0053*	*0.000015*	*0.00726*
Water target concentration	mg/l	*0.004*	*0.002*	*0.005*	*0.3*	*0.01*	*0.002*	*0.0001*	*0.003*
No liner, no cap	mg/l	1.36×10^{-6}	2.94×10^{-8}	7.35×10^{-8}	2.37×10^{-5}	2.10×10^{-7}	1.11×10^{-7}	3.13×10^{-10}	1.51×10^{-7}
No liner, cap	mg/l	1.36×10^{-6}	2.94×10^{-8}	7.34×10^{-8}	2.37×10^{-5}	2.09×10^{-7}	1.11×10^{-7}	3.13×10^{-10}	1.51×10^{-7}
Bituminous liner, no cap	mg/l	2.23×10^{-9}	4.83×10^{-11}	1.21×10^{-10}	3.90×10^{-8}	3.45×10^{-10}	1.82×10^{-10}	5.15×10^{-13}	2.49×10^{-10}
Bituminous liner, cap	mg/l	2.63×10^{-10}	5.70×10^{-12}	1.43×10^{-11}	4.60×10^{-9}	4.07×10^{-11}	2.16×10^{-11}	6.09×10^{-14}	2.94×10^{-11}

4.0 CONCLUSION AND RECOMMENDATIONS

It is emphasised that, due to the Project's history, the above analyses have been conducted in the context of the background data and observations recorded prior to the development of the Nalunaq Project in the early 2000s, during the exploitation which spanned 2004-2013, and post closure until 2019. Specifically, the yearly reports of the DCE have been used to inform the approach to assess the potential impact of the DTSF in this seepage assessment. The source terms for the DTSF leachate have been derived from the most recently available geochemical test data (SGS, 2020). It is to note that while all of the results are not yet available, it is considered unlikely that the remaining test results will be significantly different to those presented and used for modelling purposes in this report.

It can be inferred from the results of the calculations that the downgradient concentrations of the PCOCs in groundwater without any low permeability engineered liner constructed at the base of the facility are well within the limits of the guidelines in Greenland.

When integrating the results of the groundwater concentrations 800 m downgradient into the surface water system of the Kirkespirdalen, the worst-case scenario (i.e. low flow in the Kirkespir River) shows that the concentrations of PCOCs at the historical Waterfall monitoring point are significantly lower than the Greenlandic guidelines and would be compliant with the past historical environmental monitoring program.

The results of the seepage assessment based on the currently available (i.e. SGS, 2020) geochemical test work confirms results of the preliminary assessment presented in Golder (2020) and support the conclusion that the calculated contaminant concentrations at the Waterfall Station monitoring point will not increase over the water quality target concentrations used even at a low flow condition.

We trust the above are of use to guide your ongoing discussions with the Greenland authorities and to guide the design process for the DTSF.

5.0 REFERENCES

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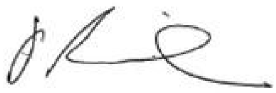
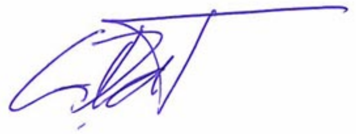


Jo Birch
Project Manager



Gareth Digges La Touche
Project Director

GDLT/JB/jlb

APPENDIX A

Input Assumptions

Recharge Input Assumptions

Recharge to the DTSF was calculated on a monthly basis using the methods set out in the Food and Agricultural Organisation (FAO) guidance document 56[1] and summarised in Rushton (2003[2]). The main assumptions are summarised in **Table 1**.

Table 1: Recharge assumptions

Notation	Parameter	Value	Units	Comment
Ro	% of precipitation that runs off	Monthly	%	Assumes December - March snowfall is redistributed as melt recharge in April – May and there is no melt and no runoff in December – March. Assumed that 1/3 of the precipitation runs-off during the summer months.
BPF	% of effective precipitation which forms by-pass flow	0	%	Assumption
Zr	Rooting depth	0.1	m	Based on soil depth and Iverson *et al*, 2015[3]
p	Fraction of total available water (TAW) that can be depleted before the moisture content falls below the threshold value	0.5		Rushton, 2003 Table 3.2 p76 Grass
Q_{FC}	Moisture content at field capacity	0.12	$m^3\ m^{-3}$	Median of range for sand soils in Rushton, 2003 Table 3.3 p76
Q_{WP}	Moisture content at wilting point	0.045	$m^3\ m^{-3}$	Median of range for sand soils in Rushton, 2003 Table 3.3 p76
ET	Evapotranspiration	Monthly	mm	Calculated using the method of Thornthwaite (1948)[4]

Leachate Head Development

The build up of leachate in the base of the DTSF was calculated based on a water balance taking into account the calculated recharge to the facility, the flow of water through any capping layer (if present) and the flow of water through the base (calculated using Darcy's Law).

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[1] FAO, 1998. *Crop evapotranspiration - Guidelines for computing crop water requirements* - FAO Irrigation and drainage paper 56.

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[3] Iversen, C.M., Sloan, V.L., Sullivan, P.F., Euskirchen, E.S., McGuire, A.D., Norby, R.J., Walker, A.P., Warren, J.M. and Wullschleger, S.D., 2015. *The unseen iceberg: plant roots in arctic tundra*. New Phytologist, 205, pp.34-58.

[4] Thornthwaite, C.W., 1948. *An approach toward a rational classification of climate*. Geographical review, 38(1), pp.55-94.

Seepage and Risk Assessment Assumptions

The assumptions and parameters used in the seepage risk assessment are presented in Table 2, Table 3 and Table 4. The model comprises a number of elements as shown on Figure 1.

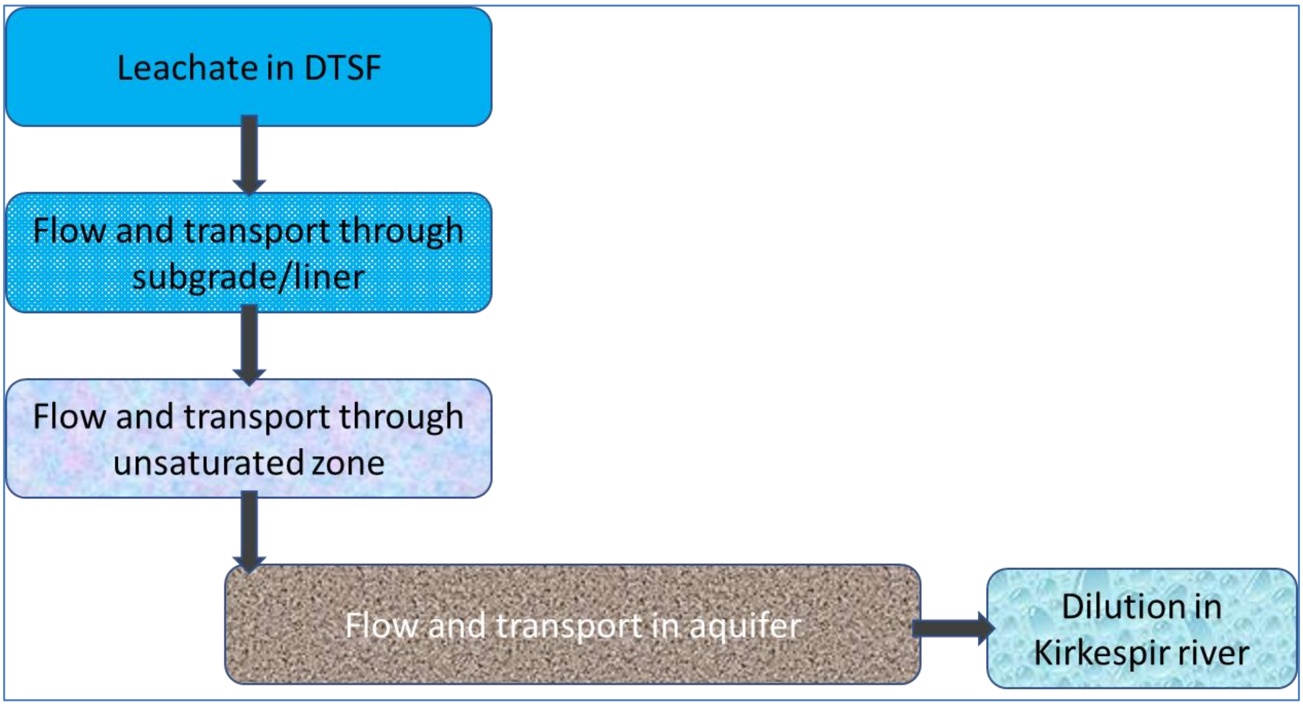

Figure 1: Seepage risk assessment model components

The flow and transport of the PCOC between each element is simulated using the Domenico equation as follows:

$$C_x = C_0 \, exp\left\{\frac{x}{2\alpha_x}\left[1 - \left(1 + \frac{4\,\lambda\,\alpha_x}{u}\right)^{1/2}\right]\right\} . \left(erf\left[\frac{S_w}{4\sqrt{\alpha_x\,x}}\right]\right) . \left(erf\left[\frac{S_d}{4\sqrt{\alpha_x\,x}}\right]\right)$$ equation 1

$$u = \frac{Ki}{nR_c}$$ equation 2

Where: C_o is the concentration at the source;

C_x is the concentration at distance x;

α is a dispersion coefficient;

λ is a decay constant (half-life);

u is the rate of contaminant movement;

S_w, S_d are the width and thickness of the plume;

K is the hydraulic conductivity;

i is the hydraulic gradient;

n is the porosity; and

R_c is the retardation coefficient.

Table 2: Input assumptions for the unlined DTSF

PARAMETER	UNITS	Parameter	Reference/Justification
Compacted sub-grade thickness	m	0.500	Assumed thickness of compacted sub-grade. Note this is not the whole platform thickness.
Longitudinal dispersivity	m	0.05	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Transverse dispersivity	m	0.02	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Vertical dispersivity	m	0.0025	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Liner hydraulic conductivity	m/s	2.45E-05	Assumed reduction from compaction based on PSD calculated value for insitu material (Golder, 2020)
Fraction of organic carbon in the liner	fraction	0.0001	Professional judgement
Area of liner in contact with leachate	m^2	28553	Basal area of DTSF
Dry bulk density of liner	g/cm^3	1.80	Assumption for sand and gravel
Compacted subgrade porosity	fraction	20%	Assumed porosity reduction from compaction based on PSD calculated porosity for in situ material (Golder, 2020)
Saturated zone parameters			
Target distance from edge of site	m	800	Assumption
Hydraulic conductivity	m/d	21.202	Midpoint of range from PSD analysis (Golder, 2020)
Hydraulic gradient	m/m	0.01	Based on measured groundwater levels (Golder, 2020)
Aquifer thickness	m	10	Conservative assumption based on site data
Mixing zone depth	m	1.00E+01	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Effective porosity	fraction	0.27	From PSD analysis (Golder, 2020)
Fraction of organic carbon (foc)	fraction	0.0001	Professional judgement
Dry bulk density	g/cm^3	1.8	Assumption for sand and gravel
Longitudinal dispersivity	m	80	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Transverse dispersivity	m	26.67	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)

PARAMETER	UNITS	Parameter	Reference/Justification
Vertical dispersivity	m	4	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
DTSF length parallel to flow	m	250	Design assumption
DTSF width perpendicular to flow	m	150	Design assumption
Unsaturated zone parameters			
Saturated hydraulic conductivity	m/d	21.202	Midpoint of range from PSD analysis (Golder, 2020)
Unsaturated hydraulic conductivity	m/d	0.38	Calculated (Spitz & Moreno, 1996. A practical guide to groundwater and solute transport modelling. Wiley Interscience)
Water filled porosity	fraction	0.20	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Air filled porosity	fraction	0.06	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Residual moisture content	fraction	0.01	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Dry bulk density	g/cm^3	1.8	Assumption for sand and gravel
Fraction of organic carbon	%	0.0001	Professional judgement
Supplementary information			
Minimum depth to water table	m	0.5	From site observations
Maximum depth to water table	m	3.5	From site observations
Height of capillary fringe	m	0.1	Professional judgement
Water filled porosity	fraction	0.21	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Air filled porosity	fraction	0.06	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)

Table 3: Input assumptions for the lined DTSF

PARAMETER	UNITS	Parameter	Reference/Justification
Liner thickness	m	0.005	Design assumption for a bituminous geomembrane liner
Longitudinal dispersivity	m	0.0005	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Transverse dispersivity	m	0.0002	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Vertical dispersivity	m	0.000025	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Liner hydraulic conductivity	m/s	1.00E-12	Design assumption for a bituminous geomembrane liner
Fraction of organic carbon in the liner	fraction	0.0001	Professional judgement
Area of liner in contact with leachate	m^2	28553	Basal area of DTSF
Dry bulk density of liner	g/cm^3	2.00	Design assumption for a bituminous geomembrane liner
Compacted subgrade porosity	fraction	2%	Design assumption for a bituminous geomembrane liner
Saturated zone parameters			
Target distance from edge of site	m	800	Assumption
Hydraulic conductivity	m/d	21.202	Midpoint of range from PSD analysis (Golder, 2020)
Hydraulic gradient	m/m	0.01	Based on measured groundwater levels (Golder, 2020)
Aquifer thickness	m	10	Conservative assumption based on site data
Mixing zone depth	m	1.00E+01	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Effective porosity	fraction	0.27	From PSD analysis (Golder, 2020)
Fraction of organic carbon (foc)	fraction	0.0001	Professional judgement
Dry bulk density	g/cm^3	1.8	Assumption for sand and gravel
Longitudinal dispersivity	m	80	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Transverse dispersivity	m	26.67	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)
Vertical dispersivity	m	4	Calculated (US EPA, 1996. Soil screening guidance: technical background document. EPA/540/R95/128)

PARAMETER	UNITS	Parameter	Reference/Justification
DTSF length parallel to flow	m	250	Design assumption
DTSF width perpendicular to flow	m	150	Design assumption
Unsaturated zone parameters			
Saturated hydraulic conductivity	m/d	21.202	Midpoint of range from PSD analysis (Golder, 2020)
Unsaturated hydraulic conductivity	m/d	0.38	Calculated (Spitz & Moreno, 1996. A practical guide to groundwater and solute transport modelling. Wiley Interscience)
Water filled porosity	fraction	0.20	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Air filled porosity	fraction	0.06	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Residual moisture content	fraction	0.01	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Dry bulk density	g/cm^3	1.8	Assumption for sand and gravel
Fraction of organic carbon	%	0.0001	Professional judgement
Supplementary information			
Minimum depth to water table	m	0.5	From site observations
Maximum depth to water table	m	3.5	From site observations
Height of capillary fringe	m	0.1	Professional judgement
Water filled porosity	fraction	0.21	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)
Air filled porosity	fraction	0.06	Professional judgement based on midpoint of total porosity range from PSD analysis (Golder, 2020)

Table 4: Physical and chemical properties of the PCOC

Parameter	Units	Arsenic	Cobalt	Nickel	Iron	Zinc	Copper	Cadmium	Chromium
Soil-water partition coefficient (Kd) in the liner	l/kg	29[^]	2000[^]	530[^]	4900[^]	62[^]	350[&]	750[&]	250[^]
Soil-water partition coefficient (Kd) in the USZ	l/kg	33[^]	2000[^]	530[^]	4900[^]	1.90E+01[^]	350[&]	750[&]	250[^]
Soil-water partition coefficient (Kd) in the aquifer	l/kg	33[^]	2000[^]	530[^]	4900[^]	1.90E+01[^]	350[&]	750[&]	250[^]
Half life for biodegradation	days	1.00E+99[$]	1.00E+99[$]	1.00E+99[$]	1.00E+99[$]	1.00E+99[$]	1.00E+99[$]	1.00E+99[$]	1.00E+99[$]
Water target concentration	mg/l	0.004[£]	0.002[€]	0.005[£]	0.3[£]	0.01[£]	0.002[£]	0.0001[£]	0.003[£]

^ SKB, 2009. Solid/liquid partition coefficients (Kd) for selected soils and sediments at Forsmark and Laxemar-Simpevarp. Report reference R09-27.

* RBCA Tool Kit for Chemical Releases Version 1.0

Assuming cobalt sulphide (https://en.wikipedia.org/wiki/Cobalt_sulfide).

+ Professional judgement.

$ Species is assumed not to biodegrade and therefore the half-life is set to a time beyond the maximum timescale of interest.

£ Government of Greenland Mineral Resources Authority, 2015. Guidelines for preparing an Environmental Impact Assessment (EIA) report for mineral exploitation in Greenland.

€ Finnish Groundwater Threshold Value: https://ec.europa.eu/environment/water/water-framework/groundwater/pdf/com_swd_annex_iii.pdf.

& US Department of Energy, Risk Assessment Information System. https://rais.ornl.gov/index.html.

APPENDIX B

SGS Geochemical Analyses

Synthetic Precipitation Leaching Procedure - EPA Method 1312

Parame	Unit	CCME FAL	*CCME Marine*	MDMER	ENV #1-300-18	GRG-2 Knelson Tl	GDG-3 Knelson Tl	GDG-4 Knelson Tl	GDG-5 Knelson Tl	F2 Ro Tl	F3 Ro Tl	F4 Ro Tl	F5 Ro Tl
LIMS				Effective	14682-NOV20	14748-NOV20	14682-NOV20	14682-NOV20	14682-NOV20	14748-NOV20	14682-NOV20	14682-NOV20	14682-NOV20
Sample	g	-	-	01-Jun-2021	25	100	25	25	25	100	25	25	25
Ext Fluic	#1 or #2	-	-	-	1	1	1	1	1	1	1	1	1
Ext Volu	mL	-	-	-	500	2000	500	500	500	2000	500	500	500
Final pH	no unit	6.0-9.5	*7.0-8.7*	6.0-9.5	***9.27***	***9.17***	***9.31***	***9.01***	***9.25***	***9.47***	***9.32***	***9.28***	***9.43***
Hg	mg/L	0.000026	-	-	< 0.00001	0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001	< 0.00001
Al	mg/L	0.1@pH>6.5	-	-	**0.609**	**0.27**	**0.904**	**0.352**	**0.612**	**0.39**	**0.748**	**0.711**	**0.746**
As	mg/L	0.005	*0.013*	0.10	**0.0646**	**0.154**	**0.154**	**0.0549**	**0.0785**	**0.054**	**0.0512**	**0.0291**	**0.0413**
Ag	mg/L	0.00025	*0.0075*	-	< 0.00005	< 0.0005	< 0.00005	< 0.00005	< 0.00005	< 0.0005	< 0.00005	< 0.00005	< 0.00005
Ba	mg/L	-	-	-	0.00625	0.0148	0.00511	0.00494	0.00568	0.0173	0.00386	0.00508	0.00647
Be	mg/L	-	-	-	0.000035	< 0.00007	< 0.000007	< 0.000007	0.000016	< 0.00007	< 0.000007	0.000013	0.000022
B	mg/L	1.5	-	-	0.012	< 0.02	0.008	0.008	0.010	< 0.02	0.007	0.012	0.014
Bi	mg/L	-	-	-	0.000505	< 0.00007	0.000104	0.000586	0.000331	< 0.00007	0.000056	0.000885	0.000356
Ca	mg/L	-	-	-	9.05	10.0	7.87	13.3	9.58	7.94	7.11	8.69	7.67
Cd	mg/L	0.00009	*0.00012*	-	0.000008	< 0.00003	0.000007	0.000007	0.000008	< 0.00003	0.000011	0.000008	0.000015
Co	mg/L	-	-	-	0.00140	0.00012	0.00115	0.000334	0.00102	0.00014	0.000657	0.000611	0.000946
Cr	mg/L	-	-	-	0.00467	0.0011	0.00553	0.00337	0.00908	0.0015	0.00404	0.00726	0.0122
Cu	mg/L	0.002	-	0.10	**0.0053**	< 0.002	**0.0064**	0.0014	**0.0024**	< 0.002	**0.0031**	**0.0020**	**0.0021**
Fe	mg/L	0.3	-	-	**1.10**	< 0.07	**0.819**	**0.357**	**0.909**	0.12	**0.593**	**0.937**	**1.13**
K	mg/L	-	-	-	0.151	0.12	0.119	0.091	0.229	0.06	0.116	0.096	0.216
Li	mg/L	-	-	-	0.0031	0.003	0.0038	0.0030	0.0047	0.002	0.0025	0.0027	0.0036
Mg	mg/L	-	-	-	0.778	0.69	0.929	0.788	0.671	0.50	0.664	0.587	0.626
Mn	mg/L	0.43	-	-	0.0132	0.0033	0.0108	0.00404	0.0118	0.0033	0.00761	0.00979	0.0133
Mo	mg/L	0.073	-	-	0.00133	0.0016	0.00090	0.00191	0.00178	0.0011	0.00055	0.00107	0.00142
Na	mg/L	-	-	-	6.24	5.06	6.24	4.95	4.96	5.88	5.10	5.51	5.68
Ni	mg/L	0.03	-	0.25	0.0035	< 0.001	0.0029	0.0023	0.0037	< 0.001	0.0019	0.0029	0.0027
P	mg/L	-	-	-	0.006	< 0.003	0.004	< 0.003	< 0.003	< 0.003	0.006	< 0.003	0.007
Pb	mg/L	0.001	-	0.08	**0.00110**	< 0.0001	0.00035	0.00004	0.00015	< 0.0001	0.00061	0.00012	0.00036
Sb	mg/L	-	-	-	< 0.0009	< 0.009	0.0108	0.0035	0.0011	< 0.009	0.0026	0.0015	0.0009
Se	mg/L	0.001	-	-	0.00023	0.0004	0.00033	0.00072	0.00029	< 0.0004	0.00009	0.00023	0.00011
Si	mg/L	-	-	-	3.10	2.49	3.90	2.40	3.12	2.57	3.00	3.23	3.63
Sn	mg/L	-	-	-	0.00017	< 0.0006	0.00010	< 0.00006	0.00012	< 0.0006	0.00008	0.00013	0.00014
Sr	mg/L	-	-	-	0.00917	0.0107	0.0106	0.0117	0.0120	0.0083	0.00918	0.00833	0.00925
Ti	mg/L	-	-	-	0.0396	0.0036	0.0415	0.0103	0.0314	0.0062	0.0270	0.0259	0.0406
Th	mg/L	-	-	-	0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0002
Tl	mg/L	0.0008	-	-	0.000005	< 0.00005	0.000005	< 0.000005	0.000007	< 0.00005	< 0.000005	< 0.000005	0.000014
U	mg/L	0.015	-	-	0.000142	0.00010	0.000049	0.000029	0.000281	0.00003	0.000052	0.000025	0.000322
V	mg/L	-	-	-	0.00352	0.0026	0.00551	0.00187	0.00364	0.0023	0.00382	0.00324	0.00405
W	mg/L	-	-	-	0.00078	0.0018	0.00100	0.00024	0.00065	0.0020	0.00060	0.00021	0.00095
Y	mg/L	-	-	-	0.000177	< 0.00002	0.000144	0.000033	0.000117	0.00002	0.000113	0.000118	0.000158
Zn	mg/L	0.007	-	0.40	0.003	< 0.02	< 0.002	< 0.002	0.003	< 0.02	0.002	< 0.002	0.004

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