TECHNICAL MEMORANDUM

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TO Samuel Martel, Martin Menard, Nalunaq A/S

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NALUNAQ GOLD PROJECT: MINE INFLOW ASSESSMENT – GROUNDWATER AND SURFACE WATER

1.0 INTRODUCTION

Following 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 ("Nalunaq") are aiming to restart mining operations in 2021.

Golder Associates (UK) Ltd. ("Golder") have been contracted to Nalunaq A/S to provide support for water and tailings management at their Nalunaq Mine. More specifically, Golder has undertaken the following:

- An assessment of the potential groundwater inflow rates to the Nalunaq Mine (specifically the South, Target and Mountain Blocks (Section 2.0); and
- An assessment of the potential inflows to Valley Block (Section 3.0) comprising:
  - A qualitative assessment of the risk of groundwater inrush and the necessary standoff between the flooded South Block and the Valley Block;
  - An assessment of the potential rate of groundwater inflow to the Valley Block through the duration of the exploration drift construction (assuming no engineered connection to South Block); and
  - A qualitative assessment of risks from surface water inflows to the Valley Block 235 Level portal due to flooding of the Kirkespir River and surface water runoff from the overhanging slopes.

Groundwater inflow rates of approximately 50 m^3/hour have been reported by Angel Mining (2009) compared with an average flow of 64 m^3/hour in 2007 and 2008 and a maximum flow of 175 m^3/hour in May 2008 reported by Golder (2009; Figure 1). It is noted that the recorded 2007 and 2008 flows may include both natural groundwater inflows and losses from operational uses such a drilling water. No meteorological data is available for the period to identify the impact of precipitation events.

In this Technical Memorandum are presented the results of a number of analytical calculations to benchmark the reasonableness of these numbers based on typical hydraulic conductivity values for the fractured bedrock in the vicinity of the mine. In addition, we have assessed the potential inflow to the Valley Block development. The results of these calculations are presented in this Technical Memorandum.

It should be noted that these calculations are order of magnitude estimates and are subject to considerable uncertainty. It should be noted that based on our current understanding of the mine environment that groundwater ingress to the current mine workings will vary both seasonally and in response to rainstorm events. We have made an estimate of the potential seasonality of these flows based on the currently available data.

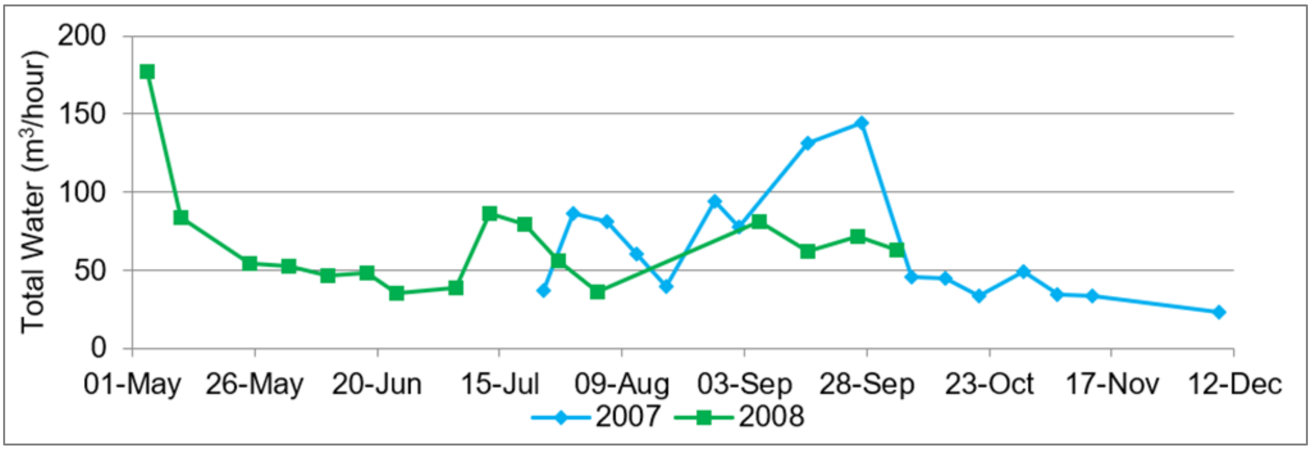


Figure 1: Available mine outflow data (Golder, 2009)

2.0 SOUTH, TARGET AND MOUNTAIN BLOCKS GROUNDWATER INFLOW

2.1 South, Target and Mountain Blocks Water Balance

The potential discharge from the mine can be estimated based on a simple water balance assuming that all the precipitation that falls on the surface catchment overlying the mine either infiltrates to the mine workings and from there is channelled to the mine portal or runs off into the Kirkespirdalen.

The average annual precipitation is estimated as approximately 602 mm (Golder, 2020a). Based on a working assumption that between 25% and 75% of the precipitation either runs off (RO) or is returned to the atmosphere via evapotranspiration (ET) or sublimation, for the purpose of this assessment we have assumed that between approximately 150 mm/year and 300 mm/year infiltrates. Given an estimated surface catchment area of approximately 661,218 m^2 (Figure 2) inflow rates of approximately 99,183 m^3/year (11 m^3/hour), 198,218 m^3/year (23 m^3/hour) and 298,540 m^3/year (34 m^3/hour) are calculated for the 75%, 50% and 25% RO and ET loss assumptions, respectively.

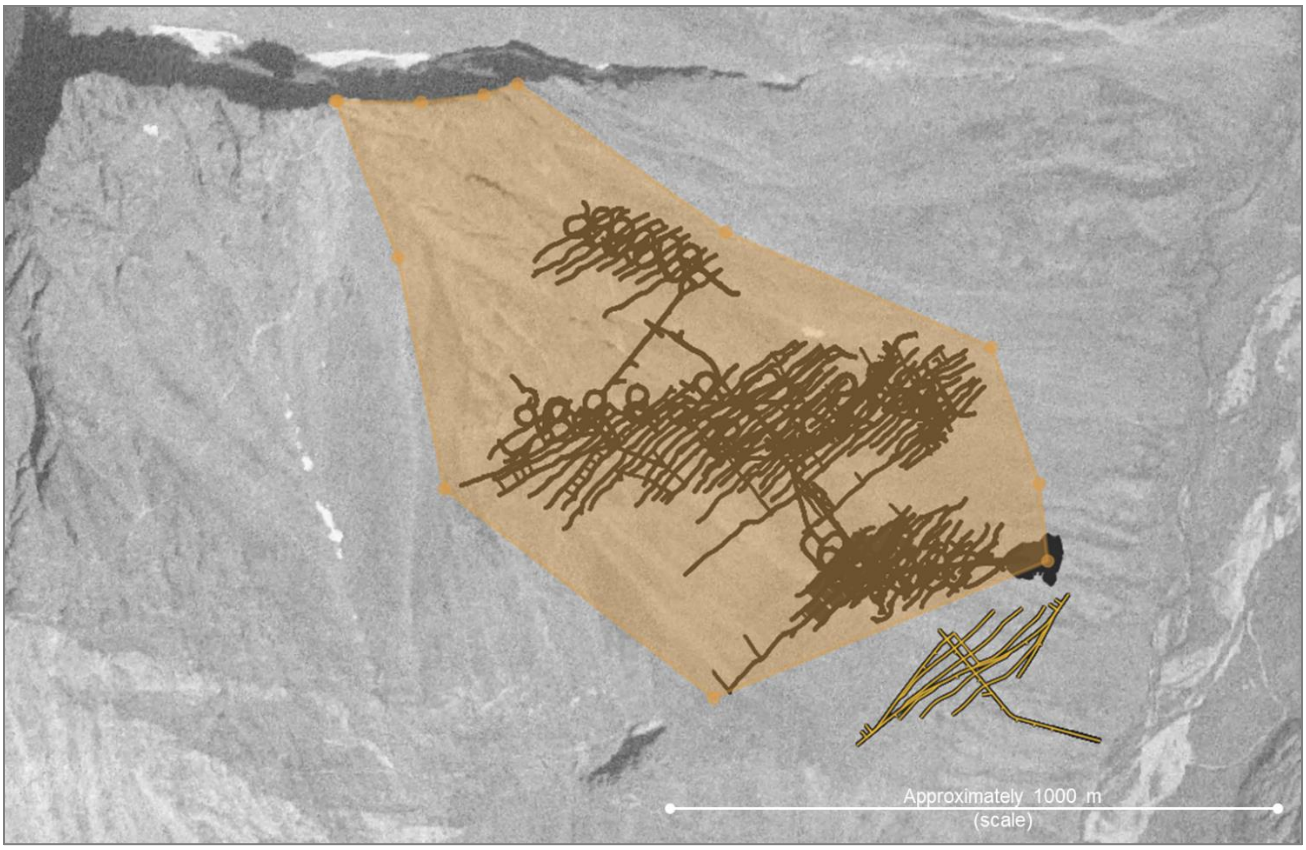


Figure 2: Estimated surface catchment area (661,218 m^2) for infiltration to the South, Target and Mountain Blocks of the Nalunaq Mine

To estimate the potential monthly variation in flows the monthly precipitation data presented in Golder 2020a and reproduced in Table 1 has been used using the same RO and ET/sublimation assumptions. For the purpose of the calculations it has been assumed that during December through March recharge is reduced to just the rainfall component of precipitation on the basis that the majority of precipitation is held in storage in the snowpack until the spring thaw, with some occurring as a result of melting at the base of the snow pack and rainfall infiltrating through the snowpack during rain on snow events. In April and May it is assumed that the snow component is not available due to sublimation and just the rainfall component is used to calculate the recharge plus in each month 50% of the precipitation that fell as snowfall during December to March to account for snow melt during the spring thaw. The results of the calculations are presented in Table 2 and Figure 3. It is noted that the assessment reflects the peak flow reported in May, as shown in Figure 1, by Golder (2009).

Table 1: Average Monthly Precipitation at Narsarsuaq Station (1973 – 2003)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Precipitation (mm)	44.0	37.7	35.6	45.6	35.8	57.4	58.2	64.6	73.8	57.6	47.6	43.9	601.8
Rainfall (mm)	3.2	7.5	2.4	33.5	35.0	57.4	58.2	64.6	73.1	50.4	16.2	6.4	407.8
Snowfall (mm)	40.7	30.3	33.3	12.2	0.8	0.0	0.0	0.0	0.6	7.2	31.4	37.5	194.0

Table 2: Water balance-based inflow assessment for South, Target and Mountain Blocks based on varying runoff, evapotranspiration, sublimation rates

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Infiltration (mm) assuming 25% RO/ET	3.2	7.5	2.4	96.0	97.2	43.1	43.7	48.5	55.4	43.2	35.7	6.4
Inflow (m^3/month)	2116	4959	1587	63493	64237	28465	28862	32036	36598	28565	23605	4232
Inflow (m^3/hour)	3	7	2	87	88	39	40	44	50	39	32	6
Infiltration assuming (mm) 50% RO/ET	3.2	7.5	2.4	87.7	88.8	28.7	29.1	32.3	36.9	28.8	23.8	6.4
Inflow (m^3/month)	2116	4959	1587	57956	58716	18977	19241	21357	24399	19043	15737	4232
Inflow (m^3/hour)	3	7	2	79	80	26	26	29	33	26	22	6
Infiltration (mm) assuming 75% RO/ET	3.2	7.5	2.4	79.3	79.9	14.4	14.6	16.2	18.5	14.4	11.9	6.4
Inflow (m^3/month)	2116	4959	1587	52418	52798	9488	9621	10679	12199	9522	7868	4232
Inflow (m^3/hour)	3	7	2	72	72	13	13	15	17	13	11	6

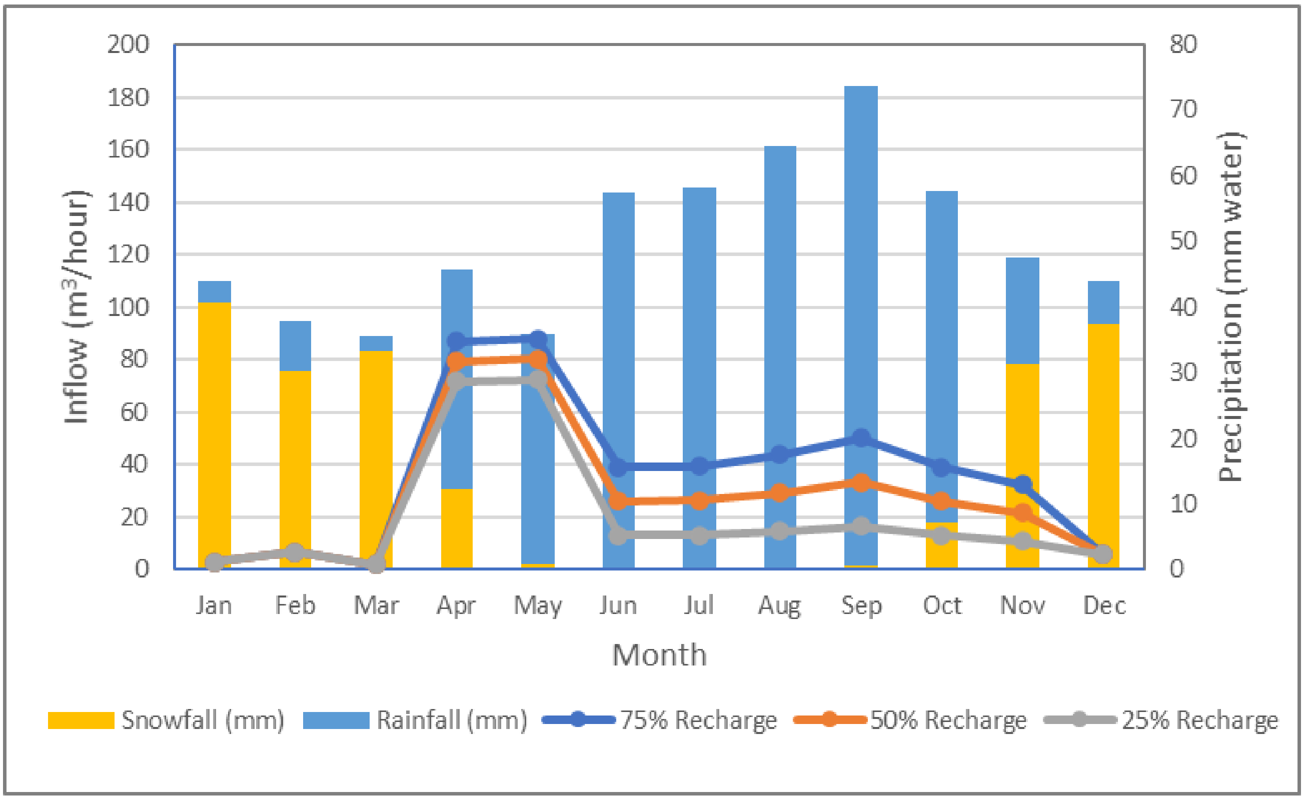


Figure 3: Calculated inflows to South, Target and Mountain Blocks plotted by month

The calculated inflows are of the same order of magnitude as the average inflow rate stated by Angel Mining (2009) (50m^3/hour), however the peak inflows are less than the maxima reported by Golder (2009). The underground mine will have a larger groundwater catchment than surface water catchment, due to the depressurisation effect of the draining workings on the surrounding rock mass which is considered likely to extend the radius of influence of the mine drainage on groundwater, so the number stated by Angel Mining (2009) is not considered unreasonable in this context, although there are no data to support the value. In addition it is possible that the recorded higher flow values include drill water which has been supplied to the mine, thus artificially increasing the outflows.

2.2 South, Target and Mountain Block Inflow Calculation Methods

The potential groundwater inflows to the mine have been calculated using the methods of Goodman (1965) and Hantush (Singh and Atkins, 1985). These methods are designed for calculating inflow to tunnels and single underground voids respectively but may be applied to give order of magnitude estimates to mine workings.

2.2.1 Goodman

The steady state inflow (Q) to a single linear tunnel may be calculated using the method of Goodman (1965) as follows:

$$Q = \frac{2\pi KLH_0}{ln\left(\frac{4H_0}{D}\right)}$$

Where:

K is the hydraulic conductivity (m/s);

L is the tunnel length (m);

H_o is the head of water above the tunnel (m); and

D is the tunnel diameter (m).

The input assumptions are used across a range of hydraulic conductivities (1 x 10^{-7} m/s to 1 x 10^{-10} m/s) and are presented on the calculation sheets presented as APPENDIX A. The calculated inflows ranged from approximately 0.074 m^3/hour to approximately 74 m^3/hour.

For the purpose of comparison only, assuming the average discharge rate of 50 m^3/hour reported by Angel Mining (2009) is valid the hydraulic conductivity value was varied such that the calculation returned a flow rate of 50 m^3/hour. The resulting calculated bulk hydraulic conductivity of the bedrock is approximately 6.73 x 10^{-8} m/s based on the assumptions used such as adit length and head of water remaining constant. This is within the range of 1 x 10^{-7} m/s to 1 x 10^{-10} m/s assumed as likely for the bedrock of the Nalunaq Mine.

2.2.2 Hantush

The steady state inflow (Q) to an underground void tunnel may be calculated using the method of Hantush (Singh and Atkins, 1985) as follows:

$$Q = 2\pi TDG\left(\lambda, \frac{r}{B}\right)$$

Where:

T is the transmissivity (m^2/s);

D is the depth of the workings below the piezometric surface (m);

λ is the Hantush well function;

r is the hydraulic gradient (m/m);

B is the leakage factor; and

G is derived from λ and r/B.

The input assumptions are used across a range of hydraulic conductivities (1 x 10^{-7} m/s to 1 x 10^{-10} m/s) and are presented on the calculation sheets presented as APPENDIX B. The calculated inflows ranged from approximately 1 m^3/hour to approximately 97 m^3/hour.

2.3 South, Target and Mountain Block Groundwater Inflows

As set out above the range of inflows presented in Figure 3 range between approximately 2 m^3/hour to 88 m^3/hour. These inflows, based on a water balance, are of a similar order of magnitude to those calculated using the methods of Goodman and Hantush 0.074 m^3/hour to 97 m^3/hour as set out in Section 2.2. On the basis of the calculations presented above, the average annual flow rates reported by Angel Mining (2009) and the maximum flow rates reported (Golder, 2009) it is recommended that the upper bound value is scaled by a factor of safety of 2 and that for the purpose of water balance modelling the values presented in Figure 4 and Table 3 are used. It is noted that the assessment reflects the peak flow reported in May, as shown in Figure 1, by Golder (2009).

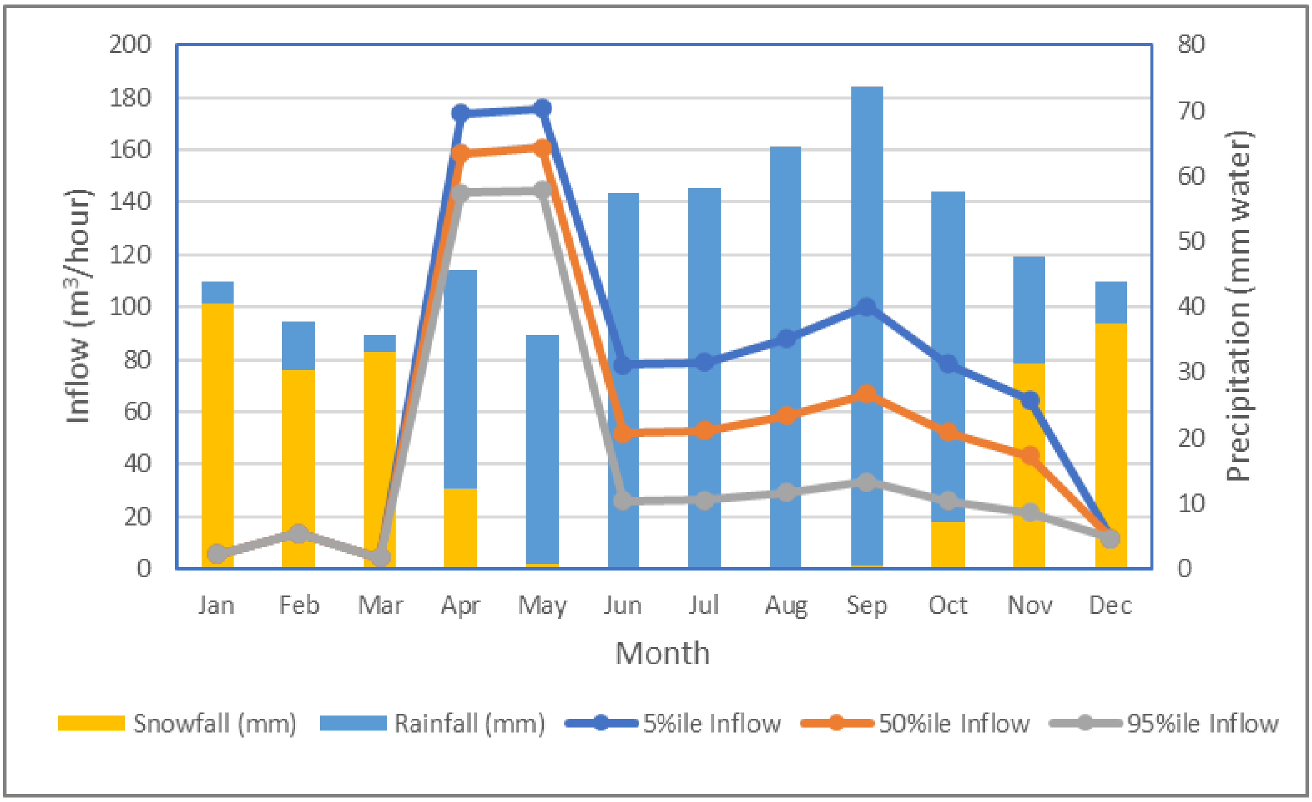


Figure 4: Assessed inflow rates to South, Target and Mountain Blocks for the purpose of water management modelling

Table 3: Assumed inflow rates to South, Target and Mountain Blocks for the purpose of water management modelling

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Assumed 5%ile Inflow (m^3/hour)	6	14	4	174	176	78	79	88	100	78	65	12
Assumed 50%ile Inflow (m^3/hour)	6	14	4	159	161	52	53	59	67	52	43	12
Assumed Minimum (95%ile) Inflow (m^3/hour)	6	14	4	144	145	26	26	29	33	26	22	12

3.0 VALLEY BLOCK INFLOWS

3.1 Introduction

The purpose of the inflow assessment for the Valley Block has the following elements:

- A qualitative assessment of the risk of groundwater inrush and the necessary standoff between the flooded South Block and the Valley Block;
- An assessment of the potential rate of groundwater inflow to the Valley Block through the duration of the exploration drift construction (assuming no engineered connection to South Block); and
- A qualitative assessment of risks from surface water inflows to the Valley Block 235 Level portal due to flooding of the Kirkespir River and surface water runoff from the overhanging slopes.

3.2 Conceptual Model

As set out in Golder 2020b the mine is situated in the basement rocks of south Greenland. Dominey *et al*. (2006) report that the site lies in the Psammite Zone which is a supracrustal succession of psammites with pelites and interstratified mafic volcanic rocks with gold mineralisation at Nalunaq hosted by a meta-volcanic unit composed of basaltic pillow lavas and pyroclastics intruded by dolerite sills. The volcanic rocks are reported (Dominey *et al*., 2006) to be metamorphosed to amphibolites and the area is intruded by late- and post-tectonic granitoid plutons. A geological map of the area in the vicinity of the mine is presented at Figure 5. The bedrock in the area is variably weathered at surface but becomes fresh at shallow depth, typically 20 m to 30 m from surface.

The Nalunaq deposit is divided into four main structural blocks. From southeast to northwest these are Valley Block, South Block, Target Block and Mountain Block. South Block and Target Block are separated by the Pegmatite Fault causing approximately 80 m of vertical offset of South Block relative to Target Block, and dextral displacement of approximately 85 m (SRK, 2016).

Two further faults crosscut the orebody, the shallow dipping Your Fault and the more steeply dipping Clay Fault. Both faults typically show less than 5 m of displacement (Golder, 2020c). The immediate zone around the Clay Fault is described (Golder, 2020c) as being highly disturbed whilst the ground leading up to it and beyond does not appear to be any more heavily fractured than surrounding areas.

The bedrock porosity is provided by fractures. Fracture flow is likely to be highly anisotropic and although open fractures will act as conduits to flow, fracture coatings or infills may cause fractures to act as barriers to flow potentially giving rise to perched water in places. With depth the bedrock rock quality designation (RQD) indicates good to excellent quality with values frequently over 90% (Golder, 2020d). The rock is likely to exhibit low hydraulic conductivity due the crystalline nature of the matrix although fractures are likely to facilitate fluid flow. The hydrogeological conceptual model is presented in Golder 2020d and is summarised in Figure 6.

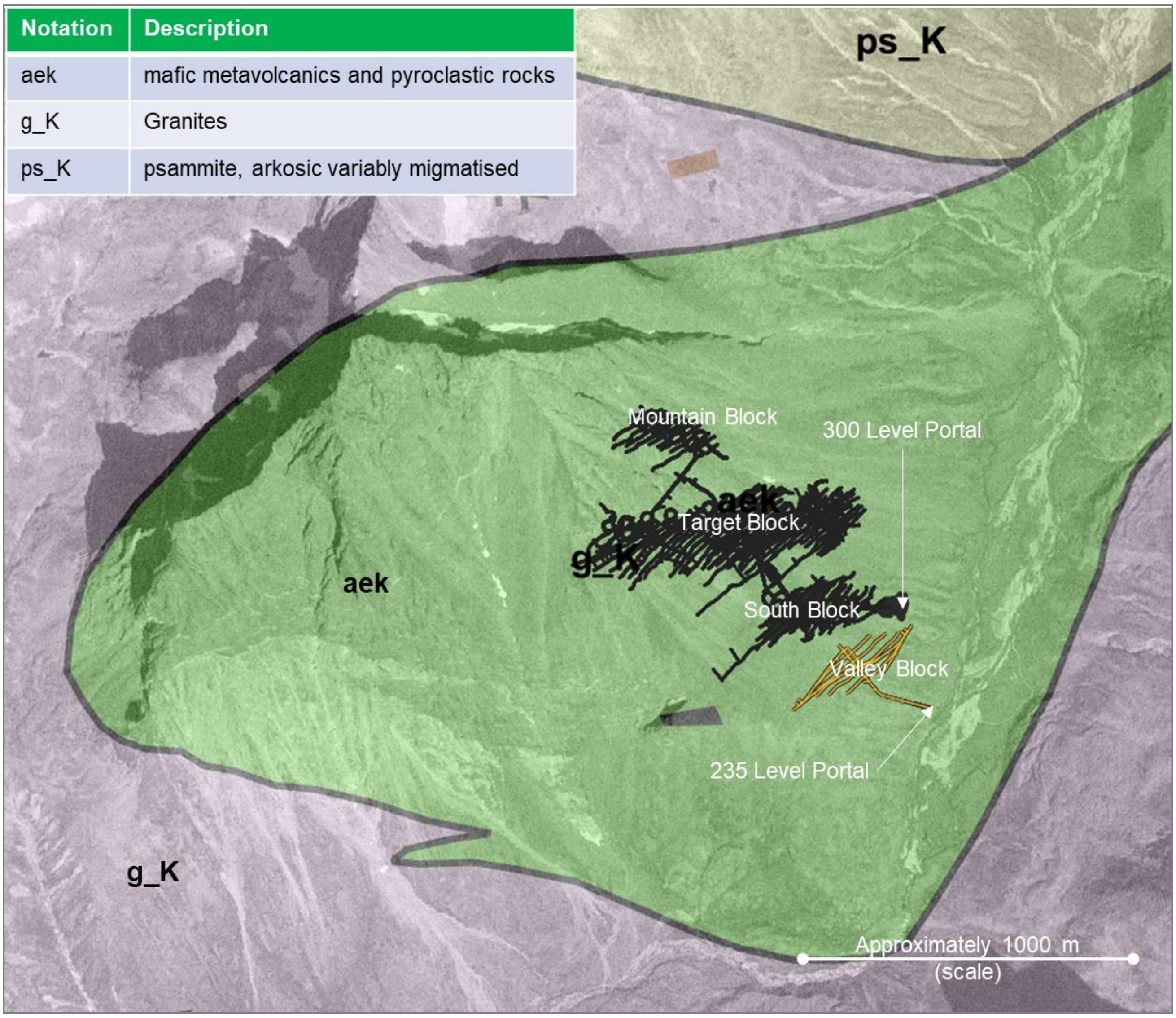


Figure 5: Geological map of the area in the vicinity of the Nalunaq Mine (GEUS, 2019)

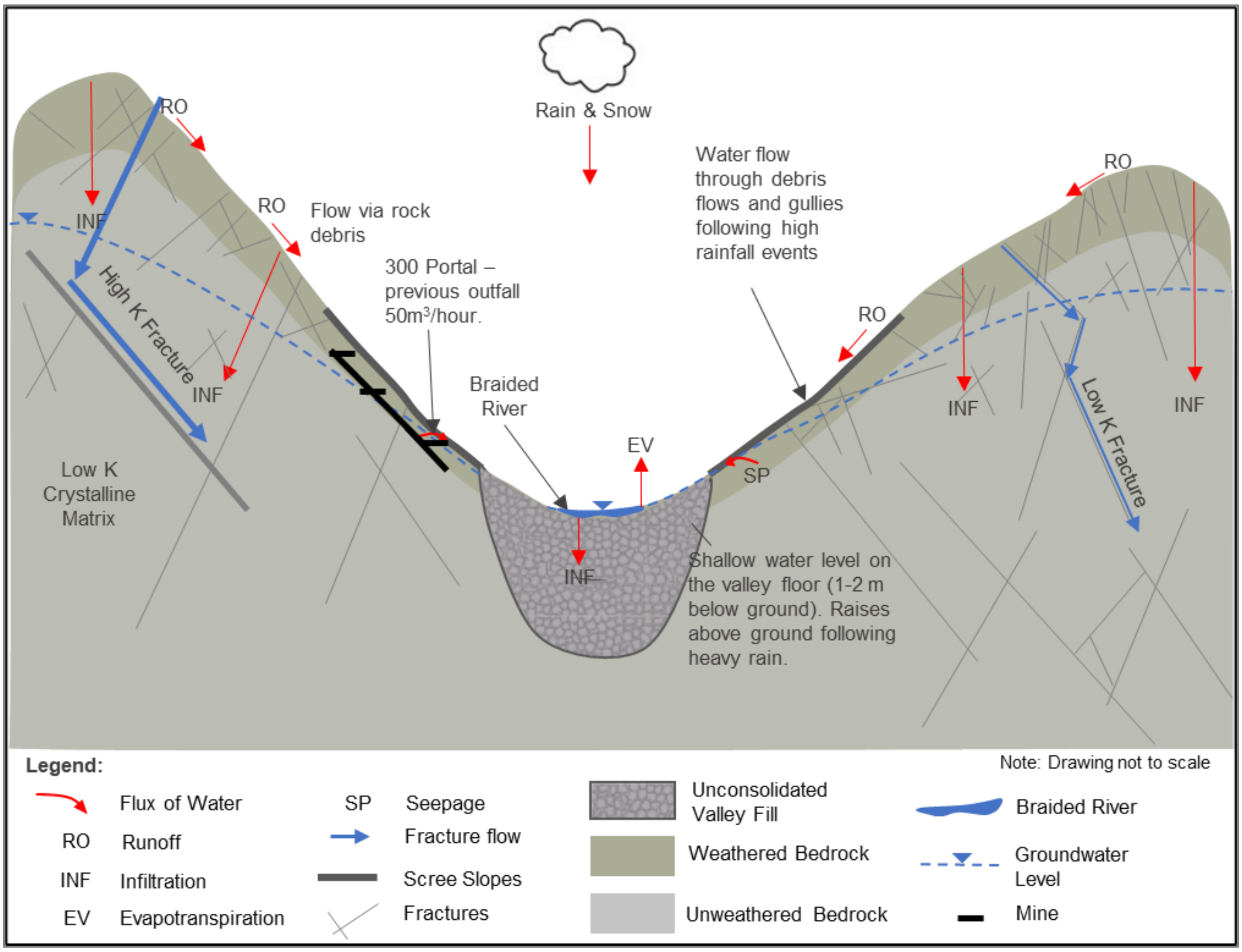


Figure 6: Conceptual model of the bedrock hydrogeology in the vicinity of the Nalunaq Mine showing the interaction with the superficial deposits

The inflow of groundwater to the Valley Block will be derived from a number of sources:

- Infiltration of recharged precipitation through the mountain;
- Inflow from the fluvioglacial deposits infilling Kirkespirdalen; and
- Inflows from the flooded South Block.

The potential for rapid inflows from the flooded South Block to the Valley Block has also been assessed and the results and recommendations of that assessment are presented below.

3.3 Groundwater Inrush Hazard

Due to the proximity of the Valley Block to the flooded South Block an assessment of the potential inrush hazard has been undertaken. For an inrush hazard to be realised the ground between the two areas of working needs to either be weak from a rock mechanics perspective and thus fail resulting in a connection via highly permeable ground or there needs to be a high permeability connection via fractures/faults, or other permeable ground, or other means such as exploration boreholes.

As shown on Figure 5 and Figure 8 the Valley Block is proposed to be developed to within approximately 47 m of the South Block, but that at no point does the South Block directly overlie the Valley Block. As shown on

Figure 8 the Valley Block is bounded by the Justinas Fault. Fracture mapping has been undertaken in South Block with fracture trace lengths of 0.2 m to 10 m being reported, with an average trace length of 2.3 m with a standard deviation of 2.6 m (Golder, 2020c). Based on this data it is considered unlikely that there will be a direct fracture-controlled pathway linking the two working areas. No fault structures are currently known to directly connect the Valley Block and South Block.

The United Kingdom Health and Safety Executive (HSE) has developed an Approved Code of Practice (ACoP) with respect to the prevention of inrushes (HSE, 1993) which provides statutory guidance on the *Mines (Precautions Against Inrushes) Regulations 1979* (PAIR) and the *Management and Administration of Safety and Health at Mines Regulations 1993* (MASHAM). As set out in the ACoP, Regulation 6 of PAIR prohibits a mine working which would be within 37 m of any disused mine workings or 45 m of any disused workings (which includes disused shafts and boreholes) or 45 m of any other potentially hazardous areas specified in the Regulations unless the manager follows laid down procedures. “Other potentially hazardous” areas are defined in the ACoP as the ground “surface, water bearing strata, unconsolidated deposits and disused workings not being mine workings”. As stated above the Valley Block is separated from the South Block by approximately 47 m, hence meets the requirements of the ACoP assuming that there are no adverse geotechnical conditions (i.e. weak ground).

An assessment of potential inflows assuming high permeability ground does exist between the Valley Block and South Block has been undertaken. For the purpose of the assessment, it is assumed that the ground has a hydraulic conductivity of 1 x 10^{-5} m/s, which is two orders of magnitude greater than the hydraulic conductivity reported in Golder (2020d). A high hydraulic conductivity is used to provide a conservative assessment of inflows. The potential inflows were calculated using a range of methods (Darcy’s Law, Goodman (1965) and Heuer (1995, 2005) as set out in APPENDIX C). A worst case inflow of 0.38 m^3/s (approximately 1,365 m^3/hour) is calculated using the method of Goodman (1965). The inflows calculated using the other methods were of a similar magnitude.

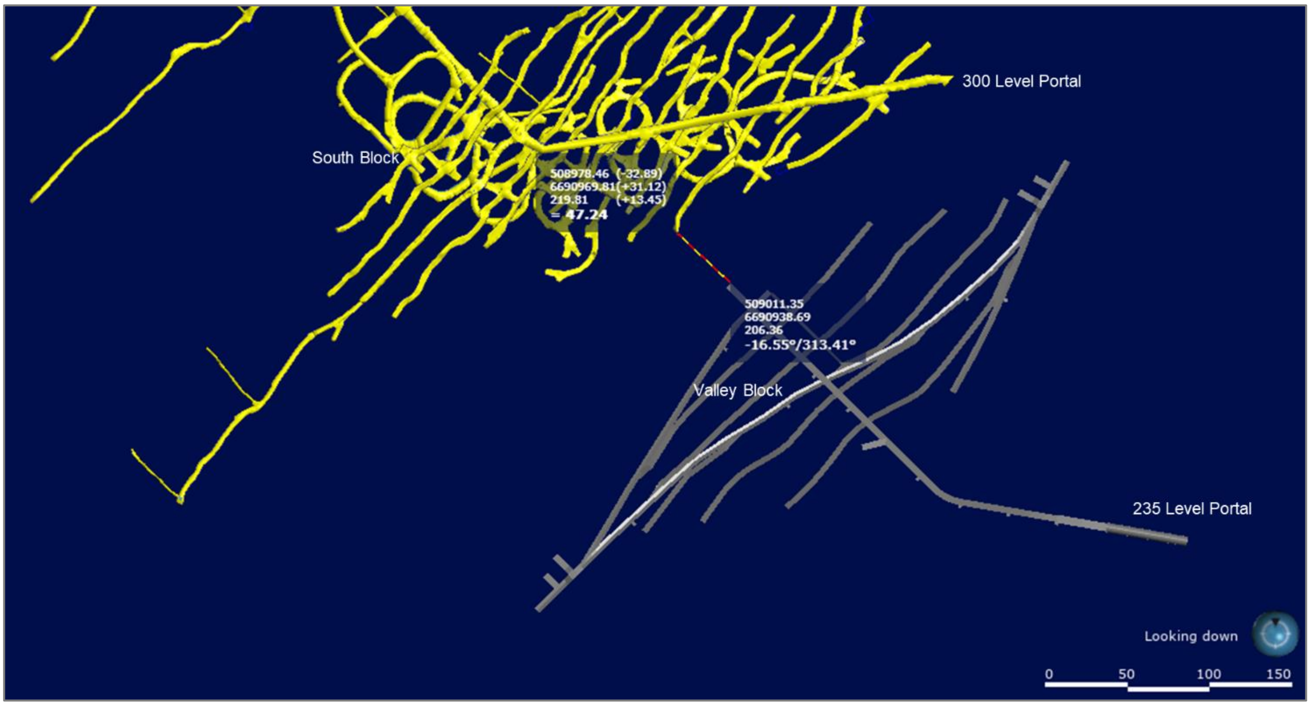


Figure 7: Vertical view of Valley Block and South Block

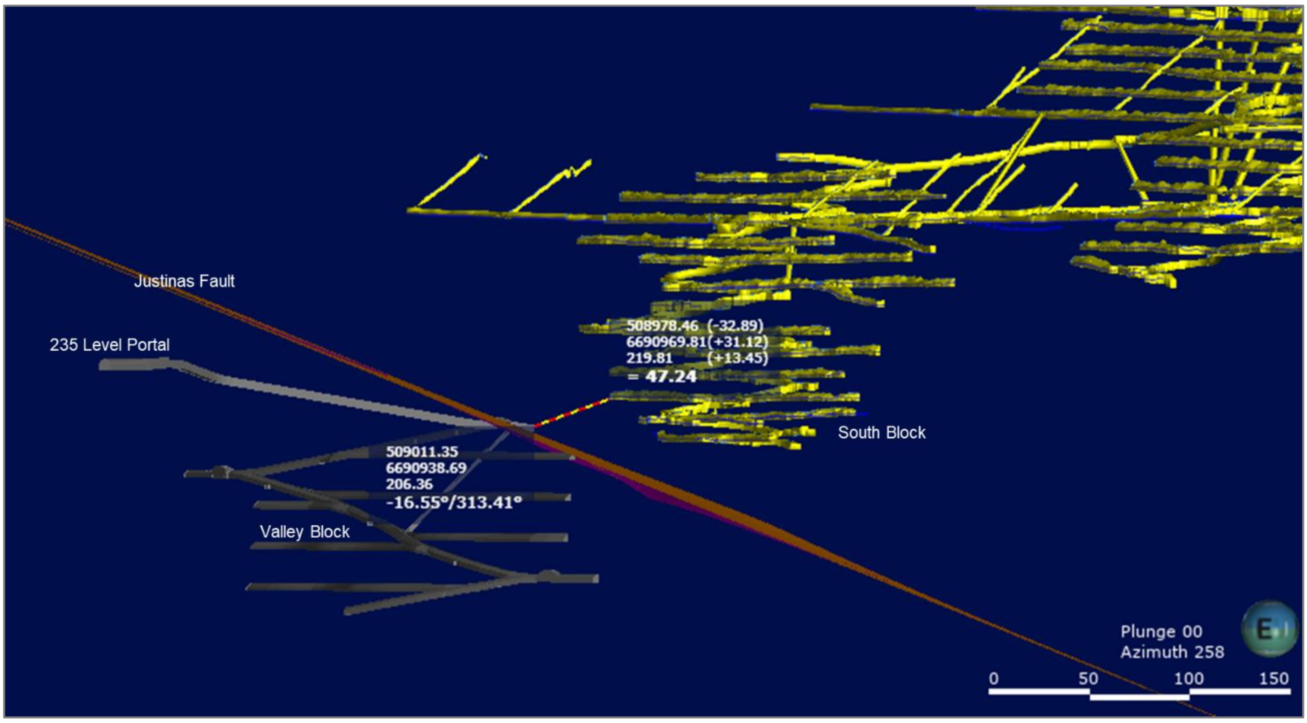


Figure 8: View of Valley Block and South Block (showing the Justinas Fault (250 Level Fault not shown)) in the direction of 258°

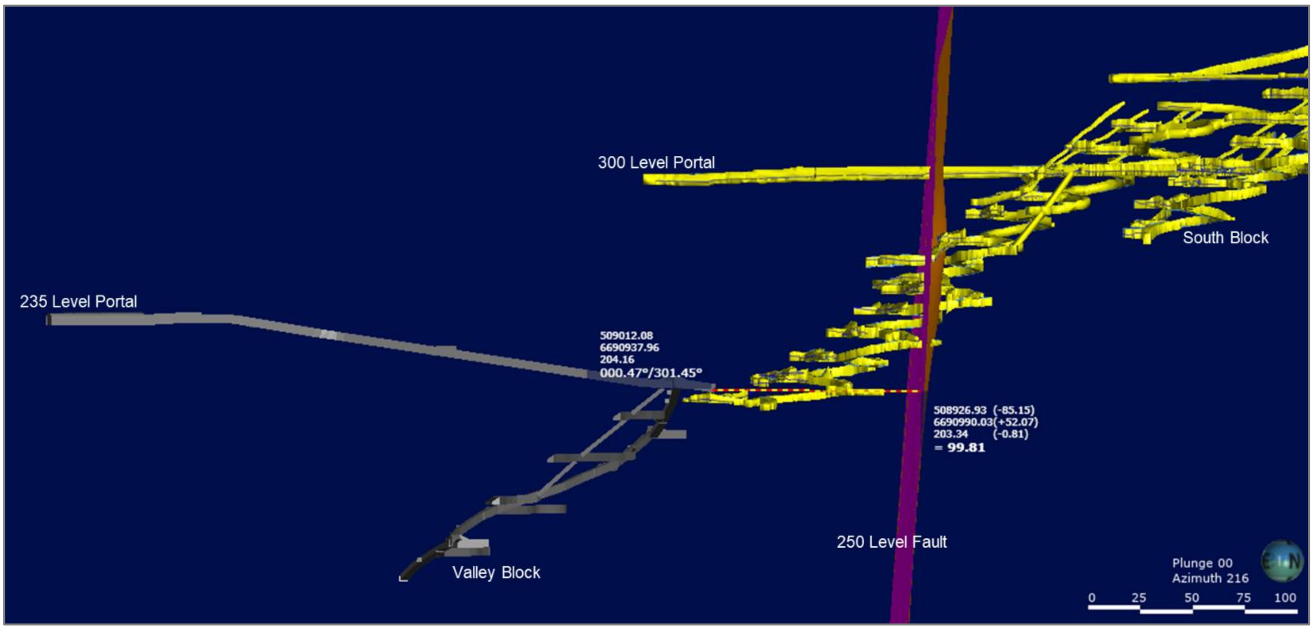


Figure 9: View of Valley Block and South Block (showing the 250 Level Fault (Justinas Fault not shown)) in the direction of 216°

3.4 Groundwater Inflows to the Valley Block

As stated in Section 3.2 there are three potential sources of inflow to the Valley Block:

- Infiltration of recharged precipitation through the mountain;
- Inflow from the fluvioglacial deposits infilling Kirkespirdalen; and
- Inflows from the flooded South Block.

These are assessed separately. Flows from the flooded South Block will be relatively constant as there will be a constant pressure gradient between the two Blocks. Likewise, the inflows from the fluvioglacial deposits are not anticipated to vary greatly with time, although some increase will occur as the development gets deeper. The main variation, as with South, Target and Mountain Block will result from seasonal variations in recharge through the rock mass above the open workings. The calculation of inflows from the three components is set out below.

3.4.1 Recharge Infiltration

As set out in Section 2.1, with regard to South, Target and Mountain Blocks, the direct recharge component of the potential discharge from the mine can be estimated based on a simple water balance assuming that a proportion of the precipitation that falls on the surface catchment overlying the mine infiltrates to the Valley Block and from there is channelled to the mine portal, while the remainder runs off into the Kirkespirdalen.

The average annual precipitation is estimated as approximately 602 mm (Golder, 2020a) and the surface catchment area is estimated as 146,933 m^2 (Figure 10). To estimate the potential monthly variation in flows the monthly precipitation data presented in Golder 2020a and reproduced in Table 1 has been used using the same RO and ET/sublimation assumptions as set out in Section 2.1. The results of the calculations are presented in Figure 11 and Table 4.

Figure 10: Estimated surface catchment area (146,933 m²) for infiltration to the Valley Block of the Nalunaq Mine

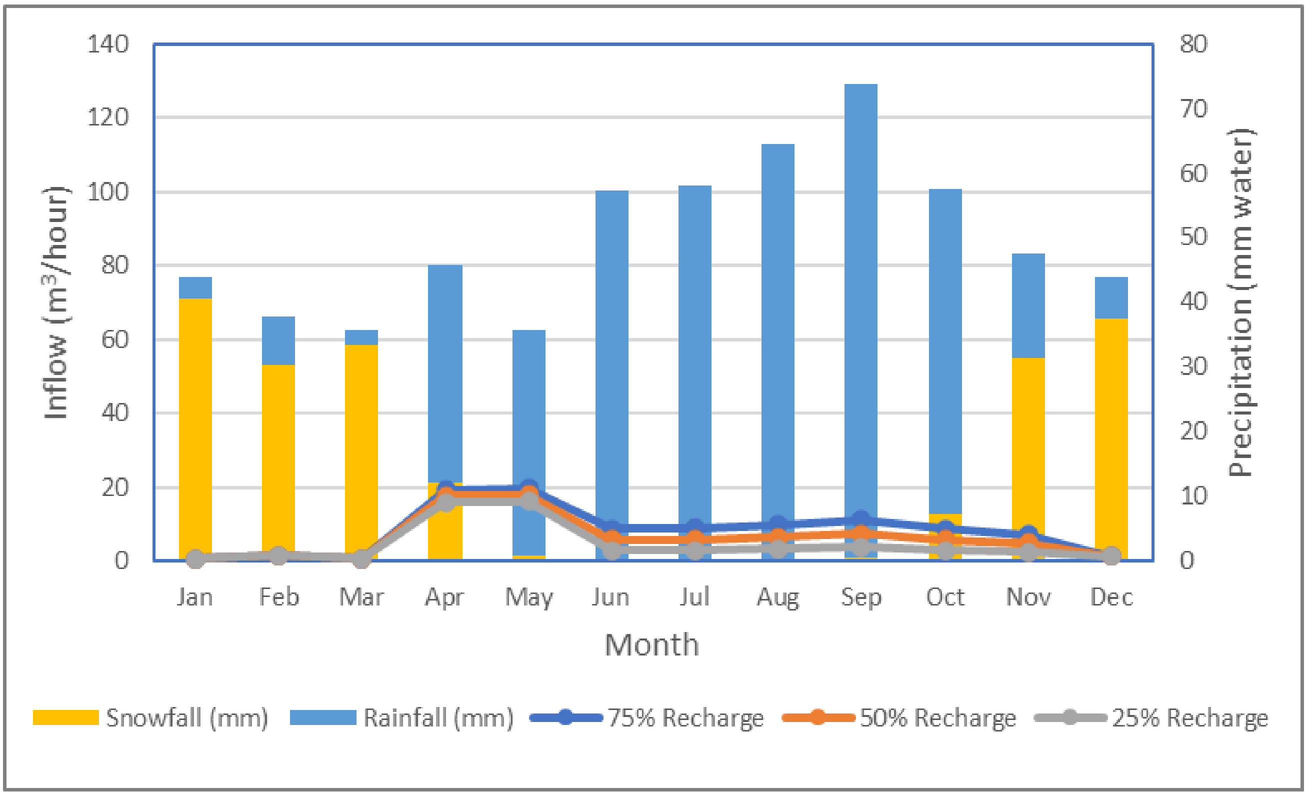


Figure 11: Calculated recharge groundwater inflows to Valley Block plotted by month

Table 4: Water balance-based groundwater inflow assessment for Valley Block based on varying runoff, evapotranspiration, sublimation rates

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Infiltration assuming 25% RO/ET	3.2	7.5	2.4	96.0	97.8	43.1	43.7	48.5	55.4	43.2	35.7	6.4
Inflow (m^3/month)	470	1102	353	14109	14363	6325	6414	7119	8133	6348	5246	940
Inflow (m^3/hour)	1	2	0.5	19	20	9	9	10	11	9	7	1
Infiltration assuming 50% RO/ET	3.2	7.5	2.4	87.7	88.8	28.7	29.1	32.3	36.9	28.8	23.8	6.4
Inflow (m^3/month)	470	1102	353	12879	13048	4217	4276	4746	5422	4232	3497	940
Inflow (m^3/hour)	1	2	0.5	18	18	6	6	7	7	6	5	1
Infiltration assuming 75% RO/ET	3.2	7.5	2.4	79.3	79.9	14.4	14.6	16.2	18.5	14.4	11.9	6.4
Inflow (m^3/month)	470	1102	353	11648	11733	2108	2138	2373	2711	2116	1749	940
Inflow (m^3/hour)	1	2	0.5	16	16	3	3	3	4	3	2	1

3.4.2 Inflow from the Fluvioglacial Deposits

The inflows to the Valley Block from the fluvioglacial deposits are controlled by the hydraulic conductivity of the intact bedrock (assumed to be 1 x 10^{-7} m/s) and the head difference (120 m) between groundwater levels in the fluvioglacial deposits (approximately 234 masl) and the base of the Valley Block (approximately 114 masl). The inflows are evaluated using the methods of Heuer (1995, 2005) and Goodman (1965). The calculated rate of inflows ranged from 0.012 m^3/s (approximately 43 m^3/hour) to 0.026 m^3/s (approximately 93 m^3/hour). The results of the calculation are presented in APPENDIX C.

3.4.3 Inflows from South Block

The inflows from the South Block have been evaluated using the methods of Heuer (1995, 2005) and Goodman (1965) assuming a hydraulic conductivity of 1 x 10^{-7} m/s. The calculated rate of inflows ranged from 0.002 m^3/s (approximately 6 m^3/hour) to 0.004 m^3/s (approximately 14 m^3/hour). The results of the calculation are presented in APPENDIX C.

3.4.4 Total Groundwater Inflows

The total inflows are derived by combining the three identified components to derive the flow rates for the purpose of water balance modelling and are presented in Table 5 and Figure 12.

Table 5: Assumed groundwater inflow rates to Valley Block for the purpose of water management modelling

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Assumed 5%ile Inflow (m^3/hour)	108	109	107	127	116	116	116	117	118	116	114	108
Assumed 50%ile Inflow (m^3/hour)	108	109	107	125	113	113	113	114	114	113	112	108
Assumed Minimum (95%ile) Inflow (m^3/hour)	108	109	107	123	110	110	110	110	111	110	109	108

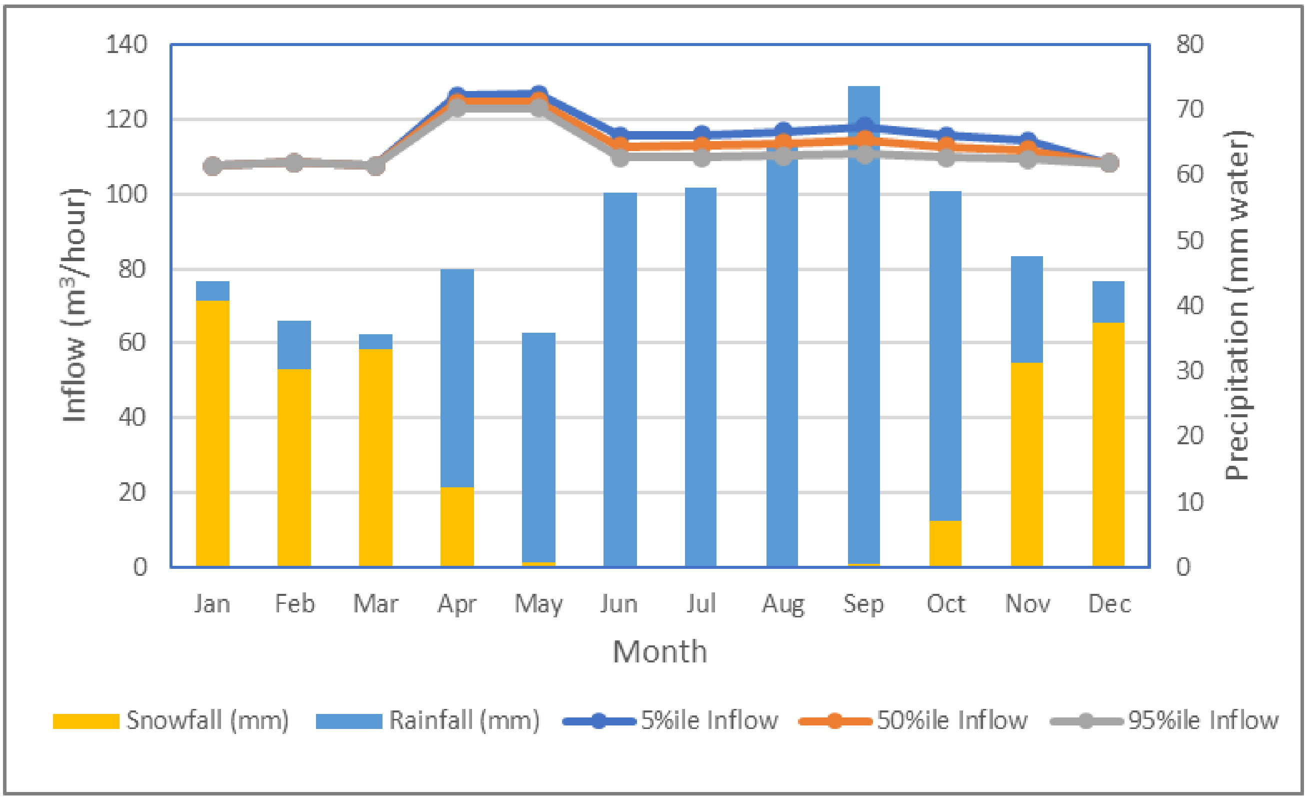
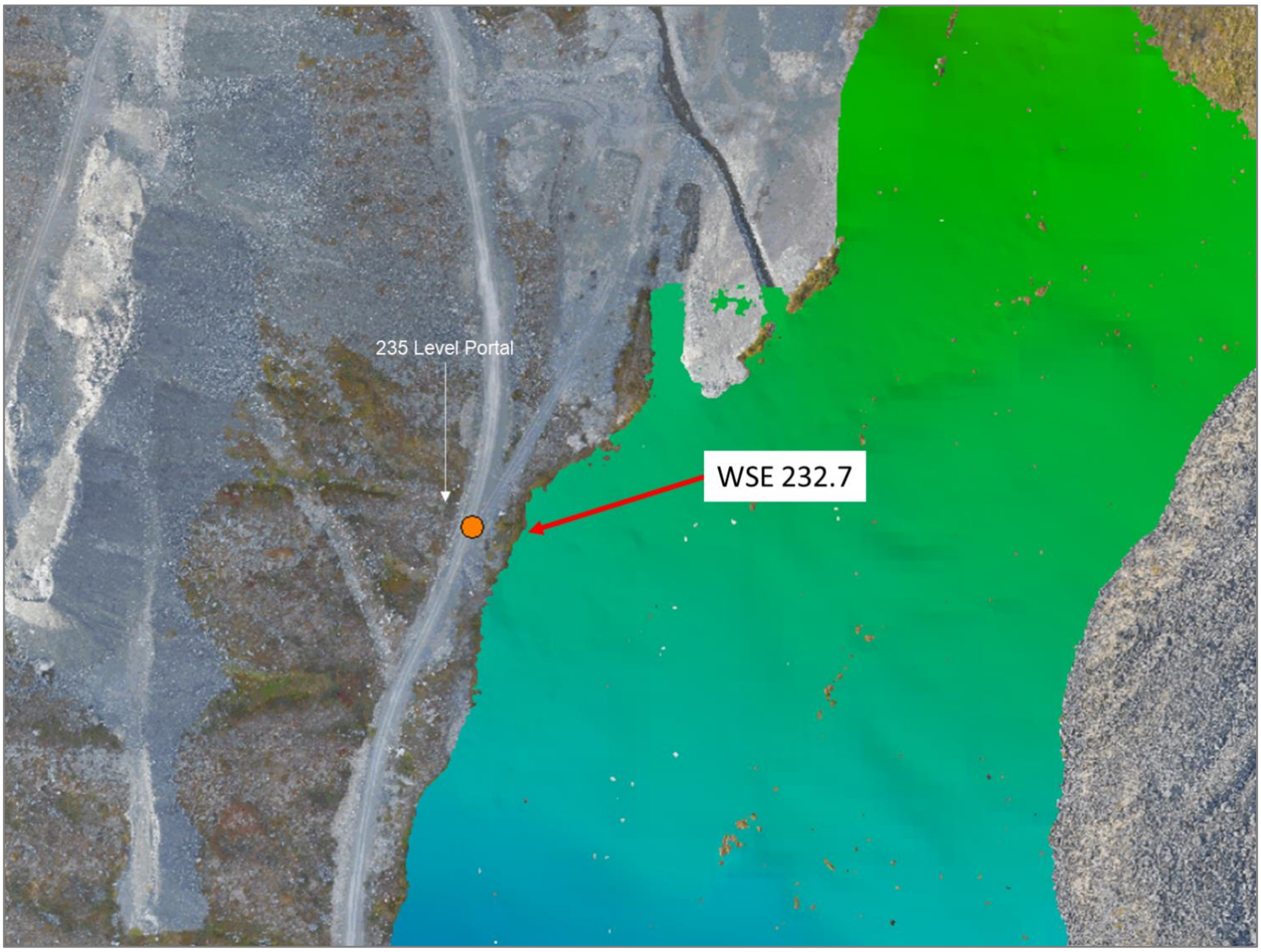


Figure 12: Assessed groundwater inflow rates to Valley Block for the purpose of water management modelling

3.5 Surface Water Ingress to Valley Block

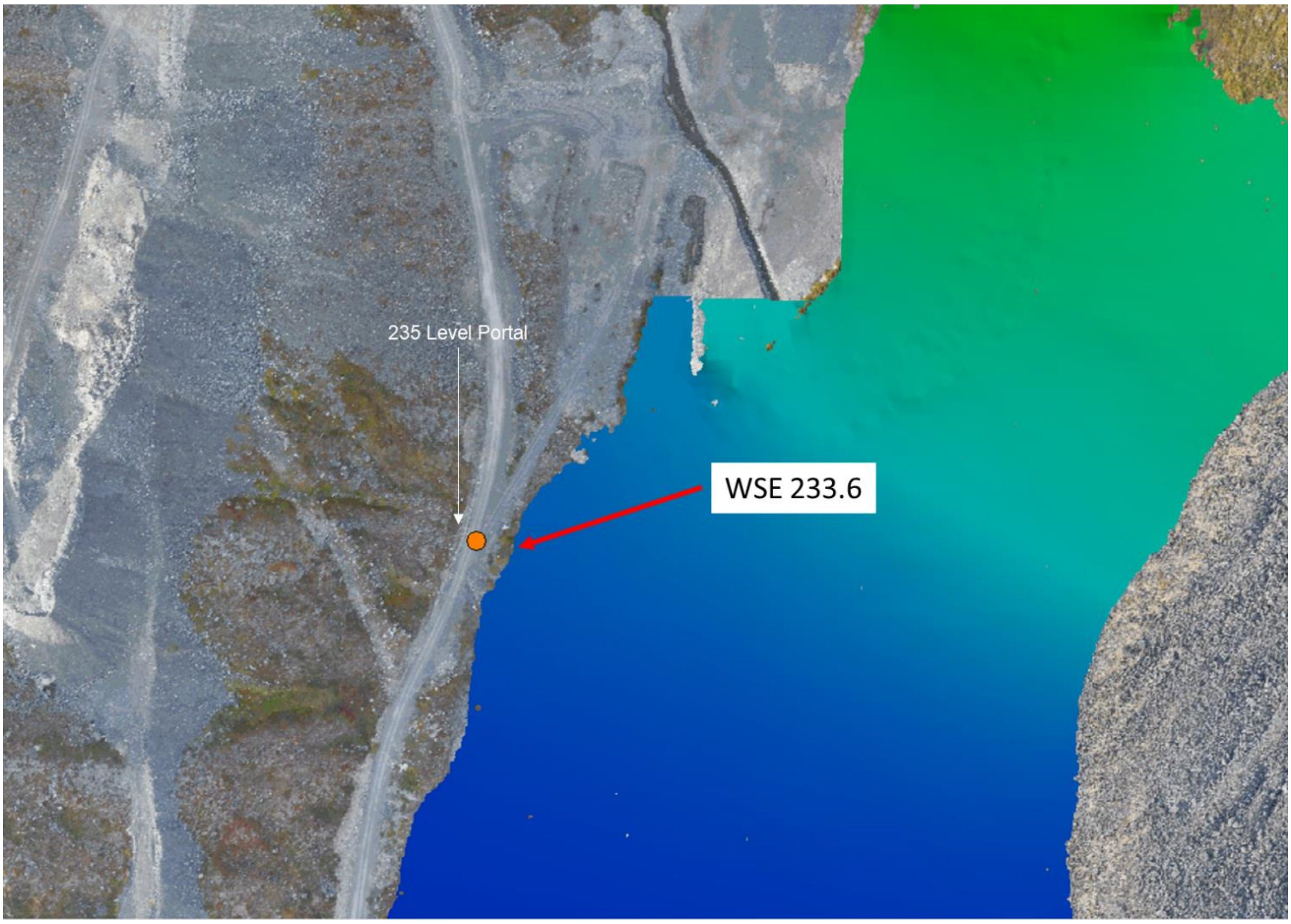
The proposed 235 Level portal is situated approximately 2 m above the level (232.7 masl) of the modelled 1:1000 year return period flood (Golder, 2020a) (Figure 13) (i.e. the flood event with a 0.1% probability of occurrence in any one year) and 1.4 m above the modelled level of the probable maximum flood (PMF 233.6 masl) (Golder, 2020a) (Figure 13). For the purpose of design, it is recommended that the initial entry is inclined upwards for the first 45 m to 75 m horizontal length of the adit at a gradient of 0.088 (5º) to allow free drainage of water from the drive and to provide a margin of safety with regard to flood levels.

Surface water diversion measures should be put in place to ensure that water from the road to the 300 Level portal is not inadvertently channelled into the 235 Level portal.



Note: WSE = water surface elevation.

Figure 13: Location of the 235 Level Portal relative to the 1:1000 year return period flood extent



Note: WSE = water surface elevation.

Figure 14: Location of the 235 Level Portal relative to the Probable Maximum Flood extent

4.0 CONCLUSIONS AND RECOMMENDATIONS

Groundwater inflows to the Nalunaq Mine have been calculated for the purpose of informing water management requirements. These have been calculated by month as follows for South, Target and Mountain Blocks; and for Valley Block, respectively (as originally presented in Table 3 and Table 5 above):

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
South, Target and Mountain Blocks												
Assumed 5%ile Inflow (m^3/hour)	6	14	4	174	176	78	79	88	100	78	65	12
Assumed 50%ile Inflow (m^3/hour)	6	14	4	159	161	52	53	59	67	52	43	12
Assumed Minimum (95%ile) Inflow (m^3/hour)	6	14	4	144	145	26	26	29	33	26	22	12
Valley Block												
Assumed 5%ile Inflow (m^3/hour)	108	109	107	112	112	116	116	117	118	116	114	108
Assumed 50%ile Inflow (m^3/hour)	108	109	107	110	111	113	113	114	114	113	112	108
Assumed Minimum (95%ile) Inflow (m^3/hour)	108	109	107	109	109	110	110	110	111	110	109	108

It is recommended that on the restart of operations a number of monitoring points are established in the mine and that v-notch weirs (see APPENDIX D for typical arrangements) are used to monitor the inflows to allow a refinement of this estimate and to establish the magnitude of seasonal variation and the response of the mine to rainstorm events.

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APPENDIX A

Groundwater Inflow Calculation Worksheet (Goodman) For Areas Above The 300 Level

Calculation of Groundwater Inflow to Underground Mine Workings

Inflows to 300 level

Parameter	Notation	Units	Most Likely	Justification
Hydraulic conductivity	K	m/s	6.73E-08	Value optimised to calculate the desired discharge rate of 50 m3/hour
Adit length	L_1	m	600	Approximate width of workings
Head of water	H_{o1}	m	300	Assuming inflows at 300 level and a water level at 600 masl
Adit diameter	D_1	m	5	Approximation of drive diameter
Inflow	Q_1	m^3/s	0.0139	Goodman et al (1965)
Total Inflow (m^3/day)	Q_T	$m^3/hour$	50.00	from Total inflow
Total Inflow (m^3/day)	Q_T	m^3/day	1200	from Total inflow
Total Inflow (Ml/day)	Q_T	Ml/day	1.20	from Total inflow

Inflows to 300 level

Parameter	Notation	Units	Minimum	Maximum	Justification
Hydraulic conductivity	K	m/s	1.00E-10	1.00E-07	Typical range for fractured bedrock
Adit length	L_1	m	600	600	Approximate width of workings
Head of water	H_{o1}	m	300	300	Assuming inflows at 300 level and a water level at 600 masl
Adit diameter	D_1	m	5	5	Approximation of drive diameter
Inflow	Q_1	m^3/s	0.000021	0.021	Goodman et al (1965)
Total Inflow (m^3/day)	Q_T	$m^3/hour$	0.074	74	from Total inflow
Total Inflow (m^3/day)	Q_T	m^3/day	2	1783	from Total inflow
Total Inflow (Ml/day)	Q_T	Ml/day	0.00	1.78	from Total inflow

Inflow, Q, calculated from Goodman et al (1965):

$$Q = \frac{2\pi K L H_0}{\ln\left(\frac{4H_0}{D}\right)}$$

Method from: Goodman, R.E., Moye, D.G., van Schalkwyk, A. and Javandel, I., 1965. Ground water inflows during tunnel driving. Engineering Geology, 2(1), pp. 39-56.

APPENDIX B

Groundwater Inflow Calculation Worksheet (Hantush) For Areas Above The 300 Level

Notation	Parameter	Units	Value		Comments
L	Thickness of mined hydrogeological unit	m	100.000	100.000	
L'	Thickness of saturated zone in the overlying formation(	m	300	300	
K	Hydraulic conductivity of the mined hydrogeological un	m/s	1.00E-08	1.00E-08	
K'	Hydraulic Conductivity of the overling formation(s)	m/s	1.00E-07	1.00E-07	
S	Storativity of the mined hydrogeological unit	-	1.00E-03	1.00E-03	
D	Depth from base of workings to piezometric surface	m	300	300	
r	Radius of the excavation	m	600	300	
B		m	5.48E+01	5.48E+01	
r/B			1.10E+01	5.48E+00	
B	Check calculation only. Should = B above		5.48E+01	5.48E+01	
T	Transmisivity of the mined hydrogeological unit	m^2/s	1.00E-06	1.00E-06	
λ			4.E-01	2.E+00	
t	Elapsed time	years	5	5	
t	Elapsed time	s	1.58E+08	1.58E+08	
G	Hantush well function		1.81	1.44	From Table 4 using values of λ and r/B above
Q	Inflow (i.e. Pumping Rate)	m^3/s	3.41E-03	2.71E-03	
Q	Inflow (i.e. Pumping Rate)	$m^3/hour$	12	10	

Note: Parameter is entered as a single value (green); Value is calculated (blue)

Notation	Parameter	Units	Value		Comments
L	Thickness of mined hydrogeological unit	m	100.000	100.000	
L'	Thickness of saturated zone in the overlying formation(	m	300	300	
K	Hydraulic conductivity of the mined hydrogeological ur	m/s	1.00E-07	1.00E-07	
K'	Hydraulic Conductivity of the overling formation(s)	m/s	1.00E-07	1.00E-07	
S	Storativity of the mined hydrogeological unit	-	1.00E-03	1.00E-03	
D	Depth from base of workings to piezometric surface	m	300	300	
r	Radius of the excavation	m	600	300	
B		m	1.73E+02	1.73E+02	
r/B			3.46E+00	1.73E+00	
B	Check calculation only. Should = B above		1.73E+02	1.73E+02	
T	Transmisivity of the mined hydrogeological unit	m^2/s	1.00E-05	1.00E-05	
λ			4.E+00	2.E+01	
t	Elapsed time	years	5	5	
t	Elapsed time	s	1.58E+08	1.58E+08	
G	Hantush well function		1.44	1.43	From Table 4 using values of λ and r/B above
Q	Inflow (i.e. Pumping Rate)	m^3/s	2.70E-02	2.70E-02	
Q	Inflow (i.e. Pumping Rate)	$m^3/hour$	97	97	

Note: Parameter is entered as a single value (green); Value is calculated (blue)

Notation	Parameter	Units	Value		Comments
L	Thickness of mined hydrogeological unit	m	100.000	100.000	
L'	Thickness of saturated zone in the overlying formation(	m	300	300	
K	Hydraulic conductivity of the mined hydrogeological un	m/s	1.00E-09	1.00E-09	
K'	Hydraulic Conductivity of the overling formation(s)	m/s	1.00E-08	1.00E-08	
S	Storativity of the mined hydrogeological unit	-	1.00E-03	1.00E-03	
D	Depth from base of workings to piezometric surface	m	300	300	
r	Radius of the excavation	m	600	300	
B		m	5.48E+01	5.48E+01	
r/B			1.10E+01	5.48E+00	
B	Check calculation only. Should = B above		5.48E+01	5.48E+01	
T	Transmisivity of the mined hydrogeological unit	m^2/s	1.00E-07	1.00E-07	
λ			4.E-02	2.E-01	
t	Elapsed time	years	5	5	
t	Elapsed time	s	1.58E+08	1.58E+08	
G	Hantush well function		2.43	1.96	From Table 4 using values of λ and r/B above
Q	Inflow (i.e. Pumping Rate)	m^3/s	4.58E-04	3.69E-04	
Q	Inflow (i.e. Pumping Rate)	$m^3/hour$	2	1	

Note: Parameter is entered as a single value (green); Value is calculated (blue)

Notation	Parameter	Units	Value		Comments
L	Thickness of mined hydrogeological unit	m	100.000	100.000	
L'	Thickness of saturated zone in the overlying formation(	m	300	300	
K	Hydraulic conductivity of the mined hydrogeological ur	m/s	6.73E-08	6.73E-08	
K'	Hydraulic Conductivity of the overling formation(s)	m/s	6.73E-07	6.73E-07	
S	Storativity of the mined hydrogeological unit	-	1.00E-03	1.00E-03	
D	Depth from base of workings to piezometric surface	m	300	300	
r	Radius of the excavation	m	600	300	
B		m	5.48E+01	5.48E+01	
r/B			1.10E+01	5.48E+00	
B	Check calculation only. Should = B above		5.48E+01	5.48E+01	
T	Transmisivity of the mined hydrogeological unit	m^2/s	6.73E-06	6.73E-06	
λ			3.E+00	1.E+01	
t	Elapsed time	years	5	5	
t	Elapsed time	s	1.58E+08	1.58E+08	
G	Hantush well function		1.44	1.43	From Table 4 using values of λ and r/B above
Q	Inflow (i.e. Pumping Rate)	m^3/s	1.82E-02	1.81E-02	
Q	Inflow (i.e. Pumping Rate)	$m^3/hour$	66	65	

Note: Parameter is entered as a single value (green); Value is calculated (blue)

Notation	Parameter	Units	Value		Comments
L	Thickness of mined hydrogeological unit	m	100.000	100.000	
L'	Thickness of saturated zone in the overlying formation(	m	300	300	
K	Hydraulic conductivity of the mined hydrogeological un	m/s	5.13E-08	5.13E-08	
K'	Hydraulic Conductivity of the overling formation(s)	m/s	5.13E-08	5.13E-08	
S	Storativity of the mined hydrogeological unit	-	1.00E-03	1.00E-03	
D	Depth from base of workings to piezometric surface	m	300	300	
r	Radius of the excavation	m	600	300	
B		m	1.73E+02	1.73E+02	
r/B			3.46E+00	1.73E+00	
B	Check calculation only. Should = B above		1.73E+02	1.73E+02	
T	Transmisivity of the mined hydrogeological unit	m^2/s	5.13E-06	5.13E-06	
λ			2.E+00	9.E+00	
t	Elapsed time	years	5	5	
t	Elapsed time	s	1.58E+08	1.58E+08	
G	Hantush well function		1.44	1.43	From Table 4 using values of λ and r/B above
Q	Inflow (i.e. Pumping Rate)	m^3/s	1.39E-02	1.38E-02	
Q	Inflow (i.e. Pumping Rate)	$m^3/hour$	50	50	

Note: Parameter is entered as a single value (green); Value is calculated (blue)

Hantush Equation

$$Q = 2\pi TDG\left(\lambda, \frac{r}{B}\right) \quad [4a]$$

$$\lambda = \frac{Tt}{r^2 S} \quad [4b]$$

$$\frac{r}{B} = r\sqrt{\frac{K'}{KLL'}} \quad [4c]$$

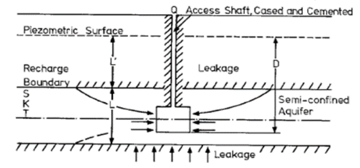

Fig. 7. Dewatering of a large underground chamber—non-steady.

The notations in the formulae given in Figs. 3–7 are defined as follows:

B	Leakage factor (m) = $\sqrt{KLL'/K'}$
D	Draw down (m) (Fig. 1)
$G(\lambda, r/B)$	Hantush well function (Table 4)
i	Hydraulic gradient (dimensionless)
K	Aquifer permeability or hydraulic conductivity (m/d)
K'	Hydraulic conductivity of aquitard (m/d)
$K_0(r/B)$	Hantush–Jacob well function for steady state leaking aquifer (Table 3)

TABLE 4

Values of the function $G(\lambda, r/B)$ [8]

$\lambda, r/B$	0	1×10^{-2}	2×10^{-2}	4×10^{-2}	6×10^{-2}	8×10^{-2}	1×10^{-1}	2×10^{-1}	4×10^{-1}	6×10^{-1}	8×10^{-1}	1
1×10^{-1}	2.24	2.24	2.25	2.25	2.25	2.25	2.25	2.26	2.28	2.31	2.36	2.43
2	1.71	1.71	1.71	1.72	1.72	1.72	1.72	1.73	1.76	1.81	1.87	1.96
5	1.23	1.23	1.23	1.23	1.23	1.24	1.24	1.25	1.30	1.38	1.48	1.81
1×10^{0}	0.983	0.983	0.984	0.985	0.986	0.987	0.900	1.01	1.07	1.18	1.32	1.49
2	0.800	0.800	0.801	0.802	0.804	0.806	0.809	0.834	0.929	1.07	1.25	1.44
5	0.632	0.628	0.629	0.630	0.633	0.637	0.642	0.682	0.824	1.01	1.22	1.43
1×10^{1}	0.534	0.534	0.535	0.537	0.541	0.547	0.554	0.661	0.793	1.01	1.22	1.43
2	0.461	0.461	0.462	0.466	0.472	0.481	0.401	0.569	0.785			
5	0.389	0.389	0.390	0.397	0.407	0.431	0.436	0.546	0.784			
1×10^{2}	0.346	0.346	0.349	0.359	0.374	0.394	0.417	0.545	0.784			
2	0.311	0.312	0.316	0.331	0.353	0.380	0.408	0.545				
5	0.274	0.276	0.284	0.309	0.341	0.374	0.406					
1×10^{3}	0.251	0.255	0.266	0.301	0.339	0.374	0.406					
2	0.232	0.238	0.255	0.299	0.330							
5	0.210	0.222	0.249	0.290								
1×10^{4}	0.196	0.216	0.248									
2	0.185	0.213	0.248									
5	0.170	0.212										
1×10^{5}	0.161	0.212										
2	0.152											
5	0.143											

Method from Singh, R.N. and Atkins, A.S., 1985. Application of idealised analytical techniques for prediction of mine water inflow. Mining Science and Technology, 2, pp.131-138.

APPENDIX C

235 Level Portal Inflow Calculations

Calculation of Groundwater Inflow to Underground Mine Workings

Parameter	Notation	Value	Units	Justification
Hydraulic conductivity	K	1.00E-05	m/s	Assume K is 2 order of magnitude greater than maximum K reported in Golder, 2020
Area	A	3750	m^2	Nominal 150m width x 25m height
Area separation	x	47	m	Minimum distance between South and Valley Block
Head difference	dh	80	m	Elevation between top of water at 270m in South Block and the 190m level in Valley Block
Flow	Q	0.06	m^3/s	Calculated using Darcy's Law

Calculation of Groundwater Inflow to Underground Mine Workings

Parameter	Notation	Units	Minimum	Maximum	Worst Case	Justification
Hydraulic conductivity	K	m/s	1.00E-07	1.00E-10	1.00E-05	From Golder, 2020
Adit length	L_1	m	300	300	300	Nominal overlap length
Head of water	H_{o1}	m	80	80	80	Elevation between top of water at 270m in South Block and the 190m level in Valley Block
Adit diameter	D_1	m	6	6	6	Approximate width
Inflow	Q_1	m^3/s	0.004	0.000004	0.38	Goodman et al (1965)
Total Inflow (m^3/day)	Q_T	$m^3/hour$	14	0.014	1365	from Inflow
Total Inflow (m^3/day)	Q_T	m^3/day	328	0.328	32764	from Inflow

Inflow, Q, calculated from Goodman et al (1965):

$$Q = \frac{2\pi K L H_0}{\ln\left(\frac{4H_0}{D}\right)}$$

Method from: Goodman, R.E., Moye, D.G., van Schalkwyk, A. and Javandel, I., 1965. Ground water inflows during tunnel driving. Engineering Geology, 2(1), pp. 39-56.

Calculation of Groundwater Inflow to Underground Mine Workings

Parameter	Notation	Units	Minimum	Maximum	Justification
Hydraulic conductivity	*K*	*m/s*	1.00E-07	1.00E-10	From Golder, 2020
Adit length	L_1	*m*	1500	1500	Nominal development length
Head of water	H_{o1}	*m*	120	120	Elevation between Groundwater in the fluvioglacial deposits of Kirkespirdalen and the base of the Valley Block
Adit diameter	D_1	*m*	6	6	Approximate width
Inflow	Q_1	m^3/s	0.026	0.000026	Goodman et al (1965)
Total Inflow (m^3/day)	Q_T	$m^3/hour$	93	0.093	from Inflow
Total Inflow (m^3/day)	Q_T	m^3/day	2230	2.230	from Inflow

Inflow, Q, calculated from Goodman et al (1965):

$$Q = \frac{2\pi K L H_0}{\ln\left(\frac{4H_0}{D}\right)}$$

Method from: Goodman, R.E., Moye, D.G., van Schalkwyk, A. and Javandel, I., 1965. Ground water inflows during tunnel driving. Engineering Geology, 2(1), pp. 39-56.

Calculation of Groundwater Inflow to Underground Mine Workings

Parameter	Notation	Units	Values								Justification
Adit/tunnel length	L	m	300								*Nominal Length*
Head of water	H_o	m	80								*Elevation between top of water at 270m in South Block and the 190m level in Valley Block*
Hydraulic conductivity	K	m/s	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	*Assume 2 orders of magnitude greater than intact rock reported in Golder, 2020*
		cm/s	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	
Inflow factor	F_h	-	4	4	4	4	4	4	4	4	*From Figure 4, Heuer (2005)*
Length of adit/tunnel in interval	L_i	m	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	*Assumption*
Percent adit/tunnel in interval	L_{ip}	%	13%	13%	13%	13%	13%	13%	13%	13%	*Calculated*
	q_s/H	l/min/100 m/m	40	40	40	40	40	40	40	40	*From Figure 4 based on F_h*
Inflow per unit length of adit/tunnel	q_s	l/min/m	32	32	32	32	32	32	32	32	*Calculated*
Flow for each length of tunnel	ΔQ_s	l/min	1200	1200	1200	1200	1200	1200	1200	1200	*Calculated*
Total inflow	$\Sigma\Delta Q_s$	l/min	**9600**								
		m^3/s	**0.16**								
Initial inflow											
Length of initial heading	L_{ih}	m	25	*Assumption*							
Initial heading inflow (worst case)	Q_h	l/min	**3200**	*Calculated*							
		m^3/s	**0.053**	*Calculated*							
Assessment of grouting											
Trigger for grouting	G_t	l/min/100 m/m	240	*From Heuer, 2005*							
Inflow through ungrouted section	$\Sigma\Delta Q_{ug}$	l/min	[redacted]	*Calculated*							
Grouted inflow	q_{sg}/H	l/min/100 m/m	[redacted]	*Assume grouted to average of K of 1st two division above trigger*							
	q_{sg}	l/min/m	[redacted]	*Calculated*							
Pre-grout inflow to grouted section	ΔQ_{pg}	l/min	[redacted]	*Calculated*							
Inflow through grouted section	$\Sigma\Delta Q_g$	l/min	[redacted]	*Calculated*							
Inflow to tunnel after grouting	$\Sigma\Delta Q_{hg}$	l/min	[redacted]	*Calculated*							
Method from:	Heuer, R.E., 1995. Estimating rock tunnel water inflow. in Proceedings of the rapid excavation and tunneling conference (12th Rapid excavation and tunneling conference), Society for Mining, Metallurgy, https://www.tib.eu/en/search/id/BLCP%3ACN012010035/Estimating-Rock-Tunnel-Water-Inflow/ Heuer, 2005. Estimating rock tunnel water inflow - II. Society for Mining, Metallurgy & Exploration 36886, pp.394-407. https://www.onemine.org/document/abstract.cfm?docid=36886&title=Estimating-Rock-Tunnel-Water-InflowII										

Calculation of Groundwater Inflow to Underground Mine Workings

Parameter	Notation	Units	Values								Justification
Adit/tunnel length	L	m	300								*Nominal Length*
Head of water	H_o	m	80								*Elevation between top of water at 270m in South Block and the 190m level in Valley Block*
Hydraulic conductivity	K	m/s	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	*Golder, 2020*
		cm/s	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	
Inflow factor	F_h	-	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	*From Figure 4, Heuer (2005)*
Length of adit/tunnel in interval	L_i	m	37.5	37.5	37.5	37.5	37.5	37.5	37.5	37.5	*Assumption*
Percent adit/tunnel in interval	L_{ip}	%	13%	13%	13%	13%	13%	13%	13%	13%	*Calculated*
	q_s/H	l/min/100 m/m	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	*From Figure 4 based on F_h*
Inflow per unit length of adit/tunnel	q_s	l/min/m	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	*Calculated*
Flow for each length of tunnel	ΔQ_s	l/min	12	12	12	12	12	12	12	12	*Calculated*
Total inflow	$\Sigma\Delta Q_s$	l/min	**96**								
		m^3/s	**0.002**								
Initial inflow											
Length of initial heading	L_{ih}	m	37.5	*Assumption*							
Initial heading inflow (worst case)	Q_h	l/min	**14.4**	*Calculated*							
		m^3/s	**0.0002**	*Calculated*							
Assessment of grouting											
Trigger for grouting	G_t	l/min/100 m/m	240	*From Heuer, 2005*							
Inflow through ungrouted section	$\Sigma\Delta Q_{ug}$	l/min	[redacted]	*Calculated*							
Grouted inflow	q_{sg}/H	l/min/100 m/m	[redacted]	*Assume grouted to average of K of 1st two division above trigger*							
	q_{sg}	l/min/m	[redacted]	*Calculated*							
Pre-grout inflow to grouted section	ΔQ_{pg}	l/min	[redacted]	*Calculated*							
Inflow through grouted section	$\Sigma\Delta Q_g$	l/min	[redacted]	*Calculated*							
Inflow to tunnel after grouting	$\Sigma\Delta Q_{hg}$	l/min	[redacted]	*Calculated*							
Method from:	Heuer, R.E., 1995. Estimating rock tunnel water inflow. in Proceedings of the rapid excavation and tunneling conference (12th Rapid excavation and tunneling conference), Society for Mining, Metallurgy, https://www.tib.eu/en/search/id/BLCP%3ACN012010035/Estimating-Rock-Tunnel-Water-Inflow/ Heuer, 2005. Estimating rock tunnel water inflow - II. Society for Mining, Metallurgy & Exploration 36886, pp.394-407. https://www.onemine.org/document/abstract.cfm?docid=36886&title=Estimating-Rock-Tunnel-Water-InflowII										

Calculation of Groundwater Inflow to Underground Mine Workings

Parameter	Notation	Units	Values								Justification
Adit/tunnel length	L	m	1500								*Nominal development length*
Head of water	H_o	m	120								*Elevation between Groundwater in the fluvioglacial deposits of Kirkespirdalen and the base of the Valley Block*
Hydraulic conductivity	K	m/s	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	1.00E-07	*Golder, 2020*
		cm/s	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	
Inflow factor	F_h	-	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	*From Figure 4, Heuer (2005)*
Length of adit/tunnel in interval	L_i	m	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5	*Assumption*
Percent adit/tunnel in interval	L_{ip}	%	13%	13%	13%	13%	13%	13%	13%	13%	*Calculated*
	q_s/H	l/min/100 m/m	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	*From Figure 4 based on F_h*
Inflow per unit length of adit/tunnel	q_s	l/min/m	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	*Calculated*
Flow for each length of tunnel	ΔQ_s	l/min	90	90	90	90	90	90	90	90	*Calculated*
Total inflow	$\Sigma\Delta Q_s$	l/min	**720**								
		m^3/s	**0.012**								

Method from:

Heuer, R.E., 1995. Estimating rock tunnel water inflow. in Proceedings of the rapid excavation and tunneling conference (12th Rapid excavation and tunneling conference), Society for Mining, Metallurgy,
https://www.tib.eu/en/search/id/BLCP%3ACN012010035/Estimating-Rock-Tunnel-Water-Inflow/
Heuer, 2005. Estimating rock tunnel water inflow - II. Society for Mining, Metallurgy & Exploration 36886, pp.394-407.
https://www.onemine.org/document/abstract.cfm?docid=36886&title=Estimating-Rock-Tunnel-Water-InflowII

APPENDIX D

Typical Weir Arrangements

Typical Weir Arrangements

The following illustrations are provided to illustrate typical weir arrangements. These would need to be appropriately scaled for use at Nalunaq. The dimensions and operation of thin plate weirs are set out in British Standard 3680 Part 4A.

Figure 1: Concrete weir tank with steel 90° plate weir.

Figure 2: V-notch weir for measuring flows from a piped flow.

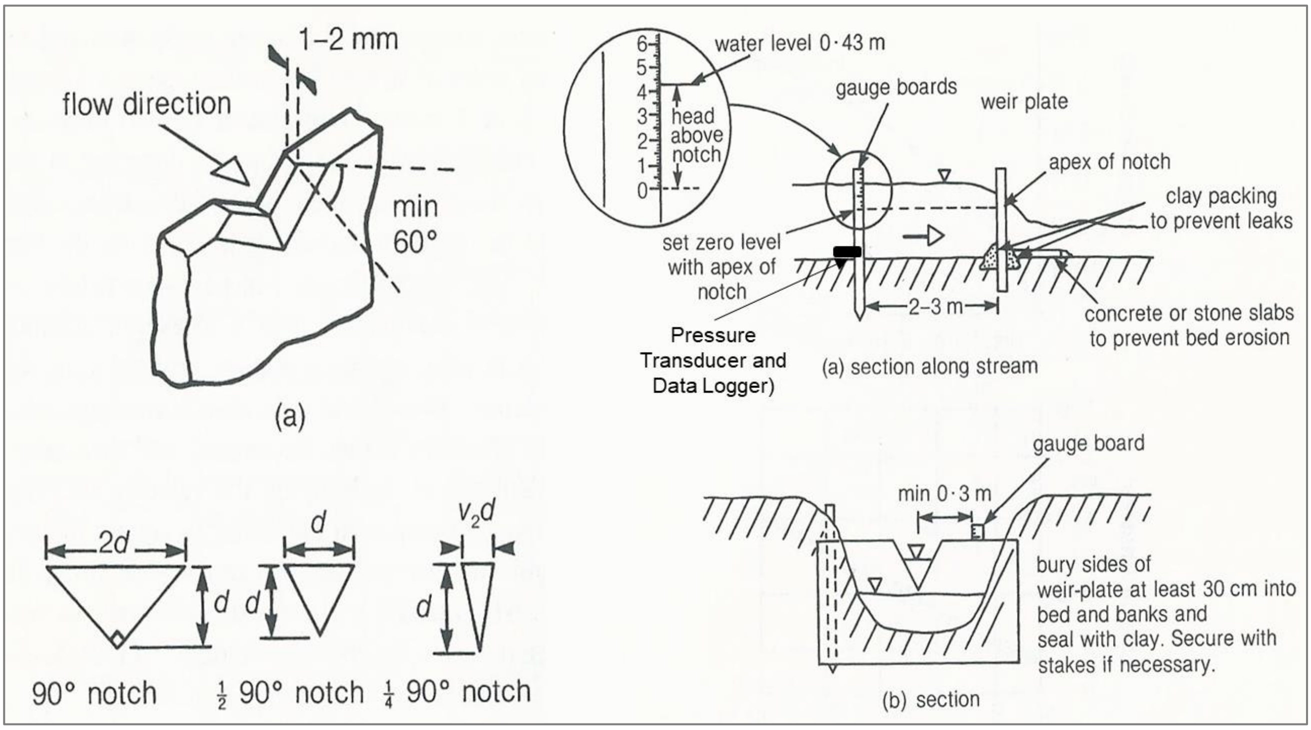

Figure 3: Notch dimensions and installation arrangements (from Brassington, 2007)