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Memorandum

To:	Michel Groleau, Agnico Eagle Mines Ltd.
From:	Gillian Allen, Geoenvironmental Engineer
Our ref:	948-011-M-011 Rev0
Date:	June 20, 2019
Re:	**Whale Tail Project - Thermal Modelling of Whale Tail WRSF Under RCP8.5**

Okane Consultants Inc. (Okane) was retained by Agnico Eagle Mines Limited – Meadowbank Division (AEM), to complete an updated thermal assessment of the Whale Tail waste rock storage facility (WRSF) at the Amaruq property under the Representative Concentration Pathway 8.5 (RCP8.5) climate change scenario. Previous modelling was carried out under RCP6.0[1]. This memorandum summarizes the differences in water balance and thermal regime of the Whale Tail WRSF between RCP6.0 and RCP8.5.

The thermal assessment determined that overall thaw depth increases by up to 2 m, but thaw driven by annual climate cycling only marginally increases up to 30 cm. The mechanisms driving freezing and thawing near surface and at depth remained the same between the two climate scenarios. Annual thaw of the active zone began approximately two weeks earlier under RCP8.5, while freeze-back was delayed approximately three to four weeks, lengthening the annual unfrozen period.

The overall annual runoff volumes remain similar, but timing of runoff was shifted to earlier in the year, with the majority of runoff occurring in April and May under the RCP8.5 scenario. Greater net radiation under RCP8.5 increases actual evaporation at the surface, while reducing net infiltration into the waste rock.

[1] Okane Consultants Inc. 2019. Whale Tail Project – Thermal Modelling of the Whale Tail and IVR WRSFs. 948-011-R-009. May 2019.

The overall likelihood of risk to water quality remains very similar to previous modelling. The likelihood of production of ML/ARD is similar or slightly higher than RCP6.0, but likelihood of mobilization is similar or slightly lower than RCP6.0, due to decreased infiltration.

Climate Change

As part of the Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5), the IPCC adopted new representative concentration pathways (RCPs) to replace the previous emission scenarios of the Special Report on Emission Scenarios (SRES)[2]. The four scenarios (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) are named after the radiative target forcing level for 2100, which are based on the forcing of greenhouse gases and other agents and are relative to pre-industrial levels[3]. RCP6.0 represents a medium-high RCP with stabilization of radiative forcing shortly after 2100 through the use of technology and policy. RCP8.5 represents a high RCP with increasing emissions that do not stabilize until after 2100[3]. This RCP is typically used as a worst-case scenario where no climate policy is undertaken. The RCP8.5 results can be used as an extreme to estimate performance if the change in forcing is lower.

Temperature and precipitation at Amaruq are expected to increase under both climate change scenarios, with temperatures expected to increase at a higher rate under RCP8.5 (approximately 0.12°C/year) than RCP6.0 (approximately 0.06°C/year). Precipitation increases approximately 0.6 mm/year (90 mm total increase over 150 years) for RCP6.0 and 0.7 mm/year (100 mm total increase over 150 years) for RCP8.5. Figure 1 and Figure 2 show the annual temperature and precipitation, respectively, estimated for the RCP6.0 and RCP8.5 150-year climate database developed for. Results from the period indicated by the black dashed lines (2093-2118) are shown below.

[2] IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.). Cambridge University Press. Cambridge, United Kingdom and New York, NY, USA.

[3] Van Vuuren, D.P., Edmonds, J., Kainuma, M., Raihi, K., Thomson, A., Hibbard, K. Hurtt, G.C., Kram, T. Krey, V., Lamarque, J.F., et al. 2011. The representative concentration pathways: an overview. Climatic Change. Vol. 109.

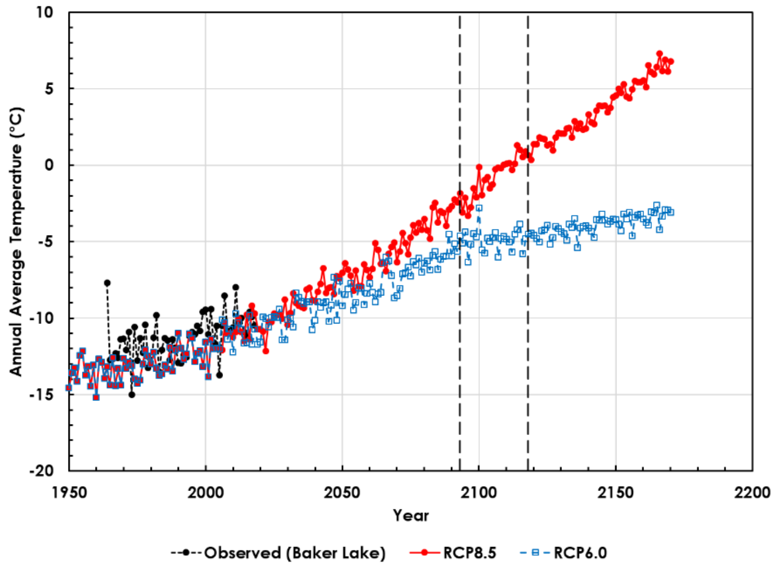

Figure 1: **Annual average temperature estimated for the RCP6.0 and RCP8.5 climate change scenarios. Observed temperature at Baker Lake is also shown.**

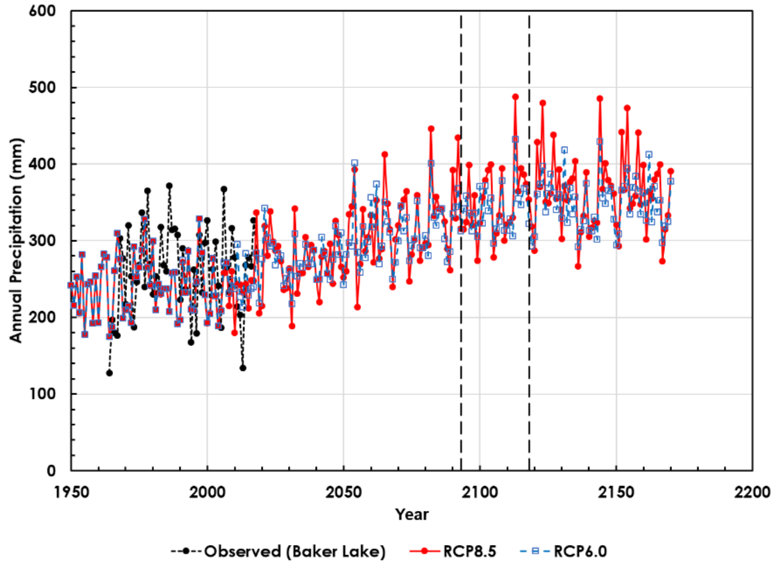

Figure 2: **Annual precipitation estimated for the RCP6.0 and RCP8.5 climate change scenarios. Observed precipitation at Baker Lake is also shown.**

Model Inputs

Daily inputs of maximum and minimum air temperature; maximum and minimum relative humidity (RH); average wind speed; daily net radiation; and precipitation (amount and duration) are required for modelling. The climate change database was developed following the recommendations outlined on the Canadian Climate Data and Scenarios (CCDS) website, which is wholly supported by Environment and Climate Change Canada (ECCC)[4]. The second-generation Canadian Earth System Model (CanESM2), developed by the Canadian Centre for Climate Modelling and Analysis (CCCma), was used as the predictor global circulation model (GCM) to downscale and make climate change databases representative of Amaruq. Statistically downscaled daily temperature and precipitation under RCP8.5 from the Pacific Climate Impact Consortium[5] were used to develop the RCP8.5 climate change database. The other climate variables (i.e. relative humidity and net radiation) were downscaled using the Statistical Downscaling Model (SDSM)[6,7,8], with the exception of wind speed due to the lack of climate change predictors. Current CCCma CanESM2 model runs are limited temporally to 2100. Predictions beyond 2100 for the modelling program are based upon general trends and can therefore be considered to include much greater uncertainty. Results shown in this memo are based around 2100 to reflect this uncertainty in predictions beyond 2100. Refer to Appendix A of Okane (2019)[1] for a detailed description of the climate database basis and development.

All other modelling inputs and parameters remain consistent with previous modelling. A complete description can be found in Okane (2019)[1].

Numerical modelling under RCP8.5 was completed for the NW-SE Whale Tail cross section labelled ‘A’ in Figure 3 and shown in Figure 4, as it is expected to have the most diverse range in behaviour due to the potential for advective cooling in the predominant wind direction.

[4] Canadian Climate Data and Scenarios (CCDS). 2018. Online. http://climate-scenarios.canada.ca/

[5] Pacific Climate Impacts Consortium (PCIC). 2018. Online. https://pacificclimate.org/

[6] Wilby, R.L., Dawson, C.W. Murphy, C. O’Conner, P., and Hawkins, E. 2014. The Statistical DownScaling Model – Decision Centric (SDSM-DC): Conceptual basis and applications. Climate Research, 61, 251-268.

[7] Wilby, R.L. and Dawson, C.W. 2013. The Statistical DownScaling Model (SDSM): Insights from one decade of application. International Journal of Climatology, 33, 1707-1719.

[8] Wiby, R.L., Dawson, C.W. and Barrow, E.M. 2002. SDSM – a decision support tool for the assessment of regional climate change impacts. Environmental and Modelling Software, 17, 145-157.

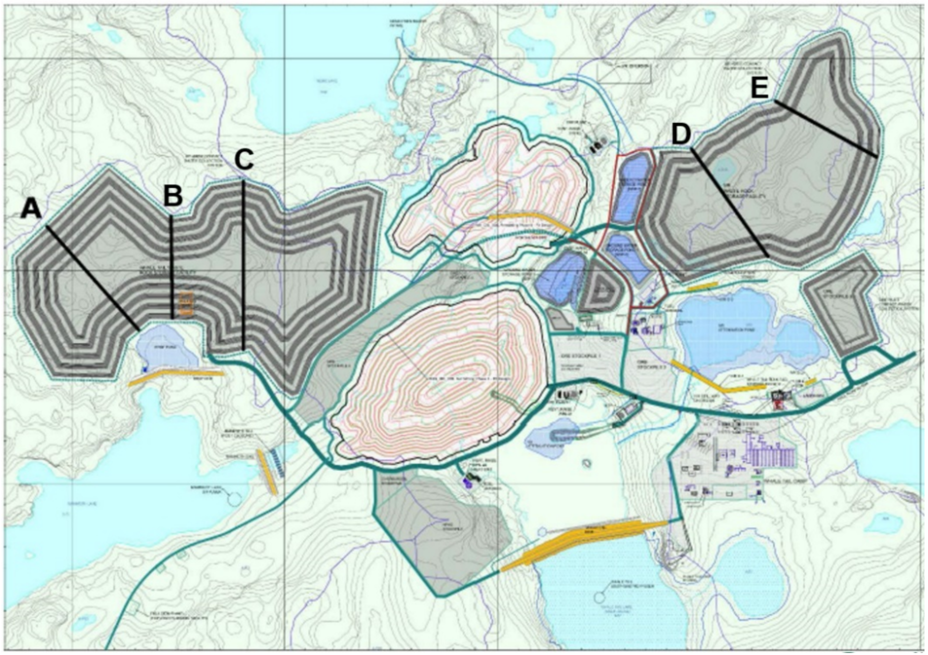

Figure 3: Location of cross-sections of Whale Tail and IVR WRSFs.

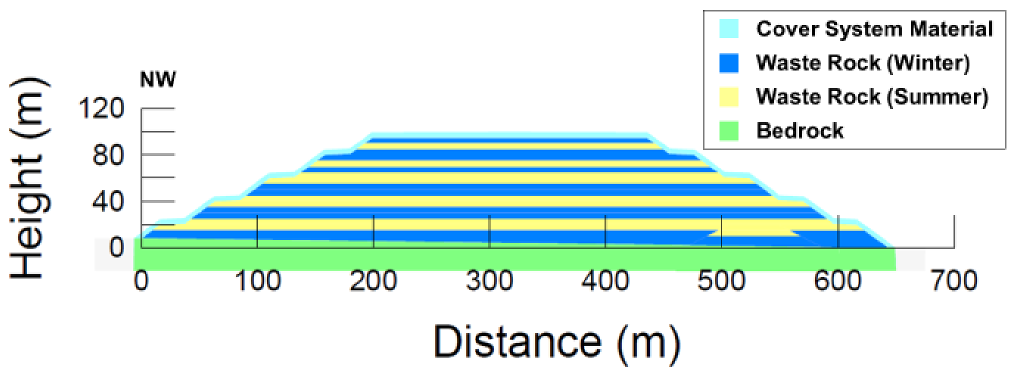

Figure 4: Northwest-Southeast cross-section through Whale Tail WRSF at closure (A).

Results

Freeze-back Curves

Typical freeze-back curves were developed for depths beyond the influence of annual climatic variability. Figure 5 compares the freeze-back curve for the NW and SE aspects of Section A under RCP6.0 and RCP8.5, while Figure 6 compares the freeze-back curves along the plateau.

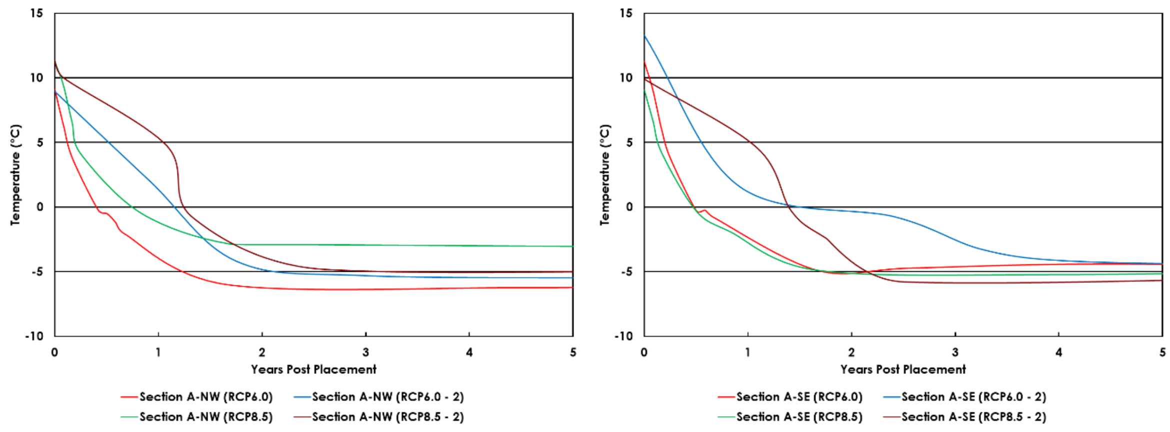

Figure 5: **Typical freeze back curves in waste rock under two benches for north (left) and south (right) slopes at a depth of 7 m below the cover system surface under RCP6.0 and RCP8.5.**

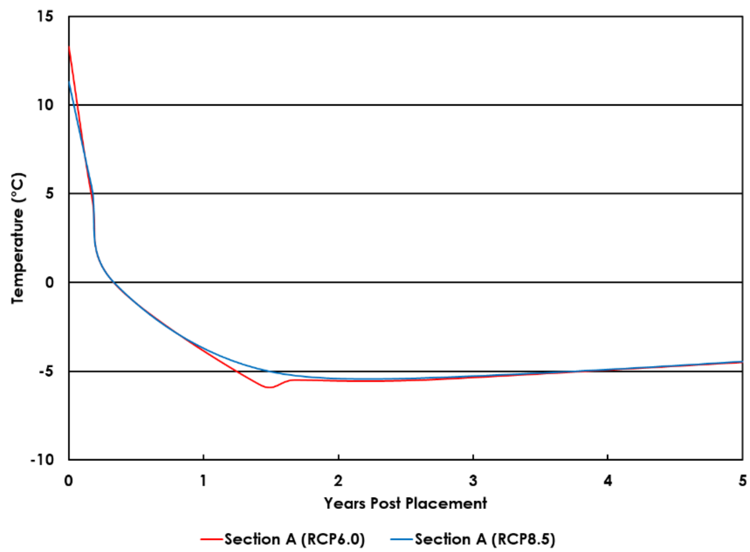

Figure 6: **Typical freeze-back curves in waste rock along the plateau at a depth of 39 m below the cover system surface.**

Freeze-back curves under RCP8.5 are similar to previous modelling completed under RCP6.0, as the climate does not vary greatly between the two scenarios during the life of mine and early closure periods. Figure 7 shows the average annual temperature for RCP6.0 and RCP8.5 for this period.

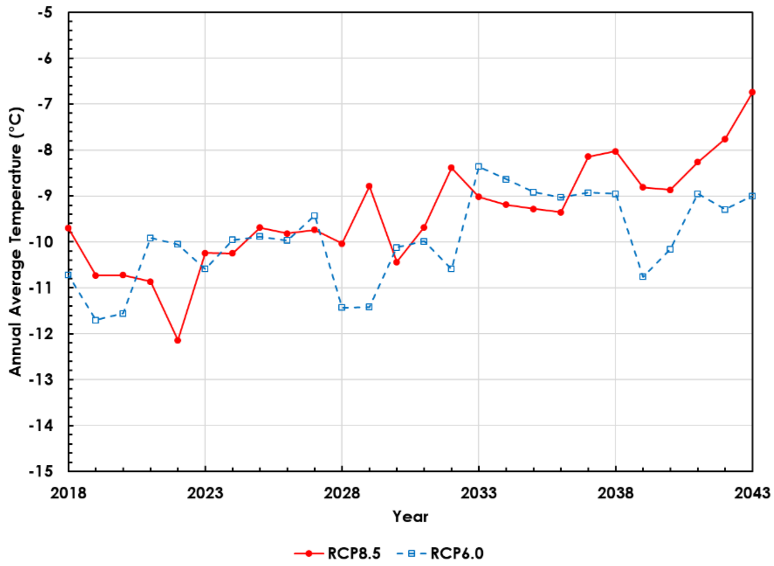

Figure 7: **Annual average temperature for the RCP6.0 and RCP8.5 climate change scenarios during the first 25 years.**

Active Thermal Layer Depth

The thermal modelling of Section A under RCP8.5 indicates a deeper active layer will form compared to RCP6.0. The following figures (Figure 8 to Figure 10) illustrate average long-term near surface thermal conditions under RCP8.5 for Section A at several locations along the slope and plateau area (Figure 10) between 2093 and 2118. The zero-degree isotherm for RCP6.0 is shown as a black dotted line for reference.

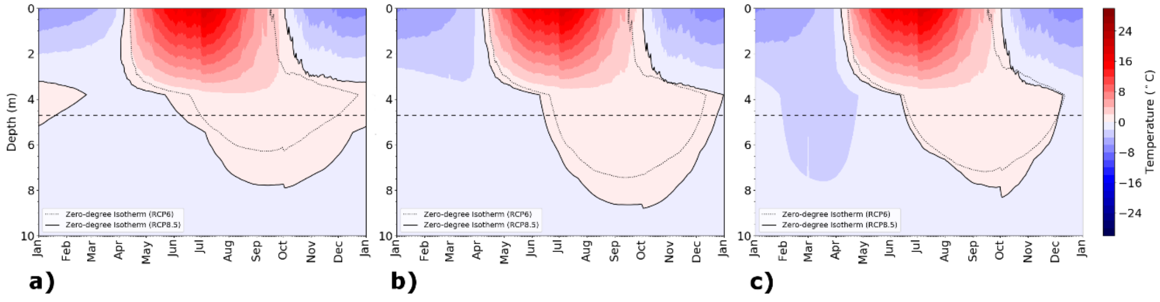

Figure 8: **Annual long term near surface temperature along the NW slope of Section A and the a) crest, b) mid slope, and c) toe location with the proposed cover system interface shown by the black dashed line.**

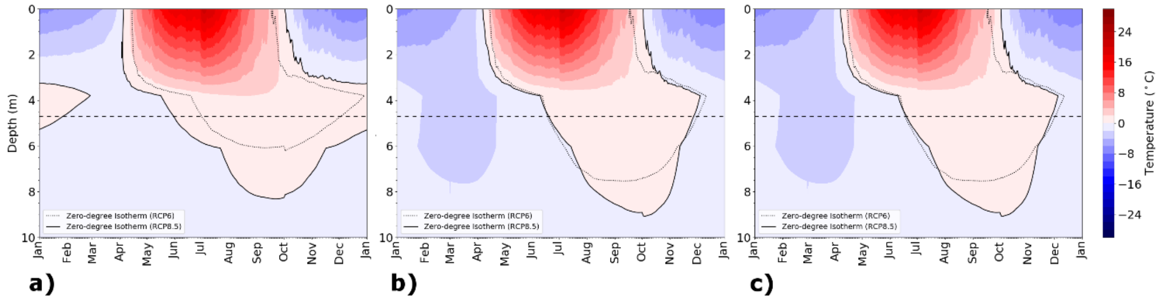

Figure 9: **Annual long term near surface temperature along the SE slope of Section A and the a) crest, b) mid slope, and c) toe location with the proposed cover system interface shown by the black dashed line.**

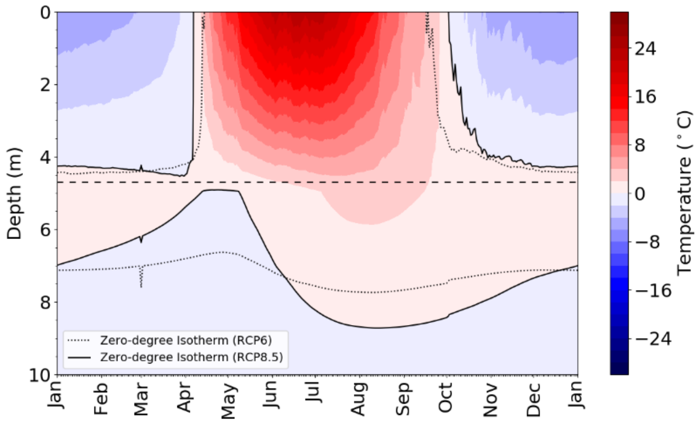

Figure 10: **Annual long term near surface temperature along the plateau of Section A with the proposed cover system interface shown by the horizontal black dashed line.**

Overall depth of thaw increases by up to 2 m under RCP8.5, but the majority of thaw greater than 2°C increase only marginally, approximately 30 cm. The mechanisms controlling freezing and thawing at surface and at depth are consistent under both climate scenarios. The primary mechanism responsible for thaw, annual climate cycling, remained constrained to the cover system on the NW and SE slopes; however, thaw through this mechanism reached below the cover system and into the waste rock on the plateau.

Annual thaw of the active zone began approximately two weeks earlier under RCP8.5, while freezing was delayed three to four weeks in the fall, lengthening the annual unfrozen period.

Landform Water Balance

A landform water balance was completed to aid in the site-wide load balance modelling for Amaruq under RCP8.5, including estimates of runoff, interflow and basal seepage rates.

RCP8.5 is expected to receive higher net radiation than RCP6.0, resulting in greater evaporation. The increased evaporation will also reduce the amount of water available to runoff and/or infiltrate. A comparison of the surface water balance for the plateau of the WRSF under RCP6.0 and RCP8.5 is provided in Table 1.

Table 1: Summary of average surface water balance for the plateau under RCP6.0 and RCP8.5

Water Balance Parameters	Plateau (RCP6.0)	Plateau (RCP8.5)
Total Precipitation (mm)	296 mm	329 mm
Rainfall (% of Total Precipitation)	55-60%	60-65%
Snow (% of Total Precipitation)	40-45%	35-40%
Actual Evaporation (% of Total Precipitation)	25-30%	50-55%
Runoff (% of Total Precipitation)	<5%	<5%
Net Percolation (% of Total Precipitation)	30-35%	10-15%
Sublimation (% of Total Precipitation)	35-40%	30-35%

Table 2 compares the runoff distribution from RCP8.5 to RCP6.0.

Table 2: Runoff distribution by month for Whale Tail WRSF under RCP6.0 and RCP8.5

Month	Percent of Total Annual Runoff by Month under RCP6.0 (%)	Percent of Total Annual Runoff by Month under RCP8.5 (%)
January	0%	0%
February	0%	0%
March	0%	<5%
April	0%	55-60%
May	0%	20-25%
June	85-90%	5-10%
July	5-10%	<5%
August	5-10%	<5%
September	<5%	<5%
October	0%	0%
November	0%	0%
December	0%	0%

Basal seepage for the landform remains negligible under RCP8.5, as the base layer of the WRSF is consistently frozen from the time of placement and net percolation, flowing vertically through the WRSF, freezes back at depth.

As with the WRSF under RCP6.0, there is some interflow within the cover system on the slopes of the WRSF due to vertical infiltration along the toe of each bench of the WRSF. However, the only precipitation expected to exit the landform as interflow occurs along the lowest bench of the WRSF.

Discussion

The likelihood of risk to water quality under the RCP8.5 thermal assessment remained very similar to the thermal assessment under RCP6.0. The likelihood of generation of ML/ARD products is moderate in the surficial waste rock material, which is similar or slightly higher than under RCP6.0. Previous definitions of likelihood produced by AEM define ‘moderate’ likelihood as “a similar outcome has arisen at some time previously in local operations”[9]. However, the likelihood of mobilization of any ML/ARD products is very low, which is similar or slightly lower than RCP6.0. A very low likelihood indicates “No experience of this happening in the broader worldwide industry but is theoretically possible”[9].

Given these classifications of likelihood, should the consequence of unacceptable receiver water quality as a result of load from the WRSF be catastrophic, the risk could be classified at ‘High’ for the lower slopes of the WRSF and ‘Moderate’ for the remainder of the WRSF.

[9] Okane Consultants Inc. 2019. Whale Tail – Waste Rock Storage Facility Failure Modes and Effects Analysis Workshop. February 2019.

These risks should be verified by AEM to ensure that the likelihoods provided herein are consistent with AEM's risk profile.

We trust information provided in this memorandum is satisfactory for your requirements. Please do not hesitate to contact me at 306-713-1568 or gallen@okc-sk.com should you have any questions or comments.