A Changing Climate: Environmental Assessment for a Proposed Mine in Yukon, Canada.

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1.0 Introduction: This paper pertains to the construction, operation, reclamation and closure of the Coffee Gold Mine (Coffee Project or Project), a proposed gold development project in west-central Yukon, approximately 130 km south of Dawson, Yukon, Canada. Major infrastructure related to mining and processing at the Project area includes: an upgraded road; a primary waste rock storage facility; several open pits; water diversion structures and storage ponds; haul roads; primary and secondary crushing facilities; heap leach facilities; a gold refinery; an accommodation complex; and an all-weather airstrip.

Local climate conditions for the site are typical for the region: average annual air temperature (T) is -2.6 °C and mean annual precipitation (P) is estimated to be 485 mm (65% rain, 35% snow) at elevation 1,300 m above sea level. Inspection of the instrumental records from nearest weather stations (e.g., Dawson, Mayo, Pelly Ranch) confirms T and P have been increasing on an annual basis since the 1960s. Further, climate change scenario data for the Project area indicate continued change for these key water balance variables (i.e., +5°C and +20% increases by 2100).

2.0 Objectives of the Poster: The sections below summarize steps taken to create a long-term (84-year), daily- climate record that accounts for a changing climate and then introduces a site-specific water balance model (WBM) that has been constructed and calibrated using GoldSim modelling software. To evaluate potential issues and risks associated with the Project and to fulfill requirements for an EA submission, the long-term climate record was used to drive the WBM with outputs being used to quantify residual streamflow changes attributable to the Project.

3.0 Baseline Monitoring: A baseline hydrology program was initiated at the Project site in the autumn of 2010, starting with installation of 3 automated hydrometric stations. Eight additional stations were established in 2014 to further characterize the streamflow regime of headwater basins containing Project infrastructure. A high-elevation climate station was installed in summer 2012 and measures: air temperature and relative humidity (2 m); wind speed and direction (10 m); incoming solar radiation (2 m); barometric pressure; and precipitation (tipping bucket rain gauge with solid phase adapter and Alter shield). Snow course measurements are also carried out at several site stations (i.e., various elevations, aspects and cover types) following Yukon protocols.

4.0 Generation of a Long-term, Daily- Climate Record for the Project: The procedures below were followed to generate a long-term climate record for the mine site:

- Daily climate data from the mine site and a nearby regional station were assembled to create monthly predictive relationships (i.e., x-axis, regional station; y-axis, mine site climate station) based on 4-years of overlapping data.
- Next, the regional station (predictor) and the monthly predictive relationships derived for T and P were utilized to compute a long-term synthetic climate record representative of the mine site.
    - The McQuesten, YT, climate station was selected as the most desirable regional predictor station owing to proximity to the mine, overall duration (28 years) and active monitoring status through 2015.
- To span the full Project life (i.e., Construction (Today to 2021); Operations (2020 to 2029); Closure (2030 to 2040); and Post-closure (2041 to 2100), the 28-year climate record was looped three times to create an 84-year, daily climate record.
- To represent a plausible future condition, climate change scenario data were downloaded from the Scenario Network for Alaska and Arctic Planning (SNAP, 2016), a research collaborative that produces downscaled, historical and projected climate data for sub-Arctic and Arctic regions of Alaska and Canada.
- Monthly T an P predictions (2001 to 2100, CMIP3/AR4 – A2 Scenario, 2 km grid) for grid points covering the mine site extent were downloaded, averaged and then used to scale the 84-year, looped daily climate record.
- For water balance modelling, the resultant climate-scaled daily dataset was utilized to represent years 2018 to 2101 inclusive (shown in Figure 1 below).

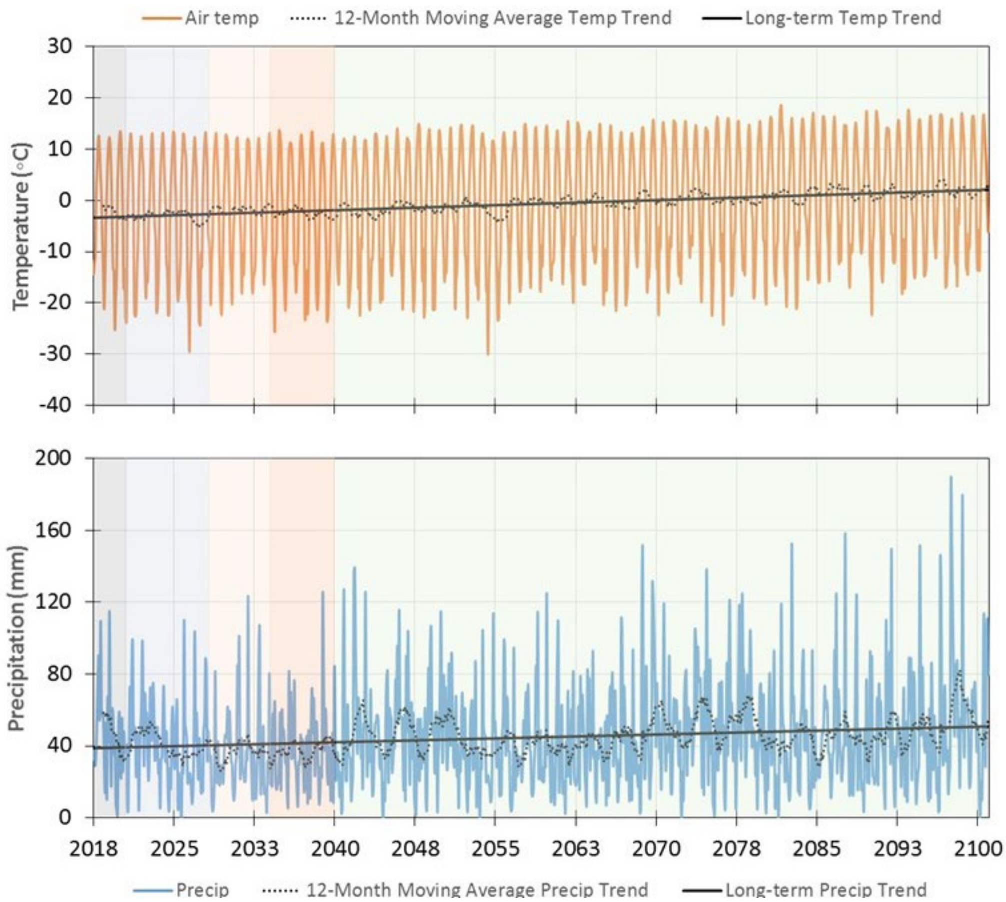

Figure 1: Climate inputs to the Project WBM for the period 2018 to 2101.

5.0 Construction of a Site-Wide Water Balance Model for Natural and Base Case Conditions:

The WBM for the Coffee Gold Mine was developed in GoldSim and considers ten receiving environment nodes, each situated downstream of mine drainages containing waste rock and/or open pits. The WBM was first constructed and calibrated to predict streamflow conditions in local watercourses for a Natural Flow condition (i.e., a baseline scenario that considers no Project). A detailed description of this model is presented in Table 1, which serves as a summary of how geospatial data and baseline/synthetic climate and hydrometric information were used to construct and calibrate the watershed model. Representative model output from the Natural Flow sub-model is shown in Figure 2 (i.e., the figure shows measured/baseline flows (red lines) versus modelled flows (blue)) and provides an overall indication of the reasonableness of the WBM calibration.

Table 1: Water Balance Model – Natural Flow Sub-model

Natural Flow (Baseline) Sub-model	
GIS Data	• Watershed boundaries and hypsometric outputs (*i.e.*, curves and representative bands of elevation data) for local catchments were generated from 1:50,000 mapping data. • To encode elevation dependent climate parameterizations into the WBM, drainages were separated into three elevation bands (400-800 m, 800-1200 m and >1200 m).
Climate	• The natural flow sub-model of the WBM was driven by a 28-year P, T and evaporation record that was looped three times. • P and T inputs were scaled by elevation using gradients ascertained from site- and regional climate data. • Monthly climate change scenario data (from the Scenario Network for Arctic Planning) for the A2 emission scenario (2-km resolution) were used to scale P and T inputs over the long term (Closure and Post-closure phases).
Hydrology	• Baseline hydrology data from autumn 2010 to December 2015 were combined with regional streamflow data to generate long-term synthetic streamflow records. • The sub-model was calibrated at daily time-step using long-term, daily- synthetic streamflow data as the target.
Outputs	• For this sub-model and Base Case, 84-year predicted streamflow records are generated for seven local tributaries and three large river nodes at a monthly time step. • The outputs per WBM node consist of 28 unique iterations (*i.e.*, 28-year climate record is time stepped) each extending the 84-year time-period.

The same catchment boundaries, climate and hydrology inputs described for the Natural Flow sub-model (Table 1) were used to populate undisturbed portions of local watersheds in the Base Case (With Project) sub-model. However, to represent the disturbed condition, year-by-year mine footprints for proposed open pits, a waste rock storage facility, the heap leach facility, soil and ore stockpiles and related Project infrastructure were encoded into the Base Case sub-model. Sediment control ponds and conveyance structures (e.g., drains, interception ditches) envisioned for the Project were also represented in the Base Case model.

A notable feature of the WBM was that it was configured in GoldSim using separate 'reservoirs' to track different types of flow, building upon applicable research and modelling of Christophersen and Seip, 1982 and Seip et al., 1985. Briefly, the architecture of the watershed model is predicated on the concept that natural streamflow, or any runoff generated from mine footprint areas, is comprised of three types of flow as described by Maidment (1993): 1) quickflow, generated by storm or snowmelt events and often resulting in peak flow events; 2) interflow, derived from near-surface, lateral movement of infiltrated meteoric water through the catchment; and 3) baseflow, the portion of surface discharge derived from groundwater discharge.

The WBM was accurately calibrated to replicate baseline flow conditions for undisturbed areas (e.g., Figure 2), or to conditions consistent with professional practices (e.g., targeting a desired waste rock seepage runoff coefficient or pitwall runoff efficiency) in the case of the Base Case module, over a wide range of flow conditions and at high-resolution time-step. Accordingly, surface runoff, snowfall/melt processes and aufeis production from winter baseflow are all represented in the Natural Flow and Base Case modules of the WBM.

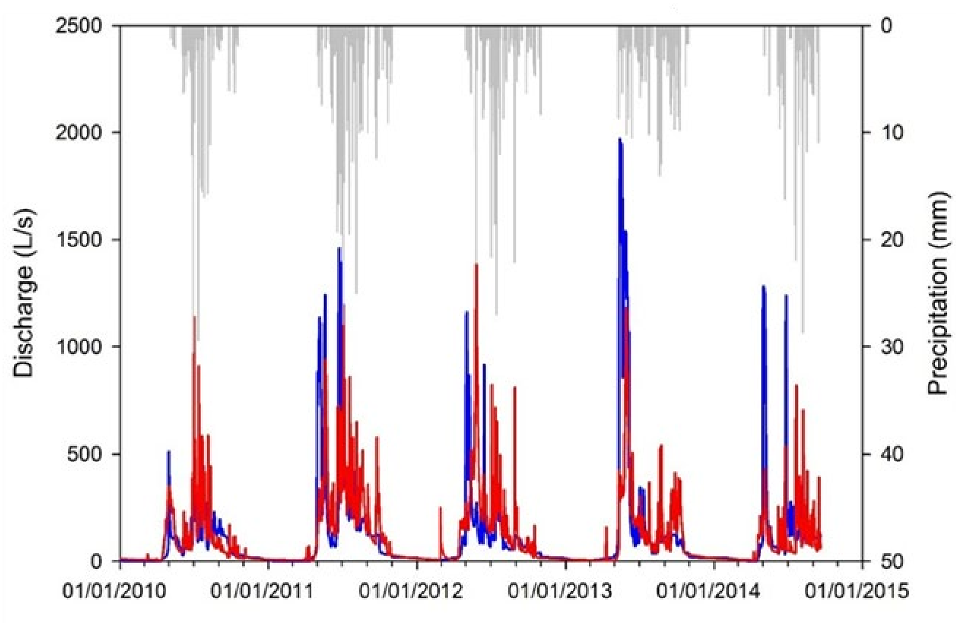

Figure 2: Measured (red) and modelled (blue) natural flow series for a sample WBM node. Growing season rainfall is shown in the figure using grey bars.

6.0 Data Analysis and Streamflow Assessment Results:

For each identified WBM node, resultant flow series from the Natural Flow and Base Case sub-models were compared to one another with Project-related flow changes being indexed against natural/baseline conditions. Daily WBM model outputs were averaged to monthly flow values and predicted streamflow changes were then represented by a percent change metric as follows:

Percent change (%) = ((Mine Altered Flow – Natural Flow)/Natural Flow) x 100 [Eqn 1]

A suite of streamflow change characteristics (i.e., direction, magnitude, frequency and reversibility of streamflow change) were selected to guide a detailed streamflow change assessment. These change characteristics were selected to best quantify and describe potential streamflow changes against key components of a natural flow regime as described by Poff et al. (1997).

Natural Flow and Base Case WBM outputs were screened using tabular and graphical formats (e.g., flow vs. percent change plots, comparative flow duration curve plots, time series plots). Figure 3 (upper panel) shows sample Natural Flow and Base Case time series results for three different flow conditions. These flow predictions are for a location currently predicted to experience minimal change to streamflow indicators owing to the Project. While predicted flow changes at this location are minor, it is important to note that the surface water quantity (streamflow) valued component is closely linked to other water-related studies (e.g., groundwater quantity and quality, surface water quality, fish and aquatic habitat) and necessary that streamflow changes be assessed through the lenses of these related disciplines.

Decadal patterns and trends in streamflow were also assessed in this study by analyzing Natural Flow sub-model outputs (see Figure 3, lower panel) from the WBM. Consistent with recent findings for the Yukon (Streiker, 2016), these model results confirm the following streamflow changes for a warmer and wetter future climate regime: progressively earlier onset of freshet; later occurrence of autumn freeze up and longer ice-free season; changes to the relative proportions of P realized as rainfall vs. snowfall, especially in the spring and autumn seasons; increases in winter baseflow conditions and likelihood of mid-winter melt event; and, progressive increase in annual discharge over time.

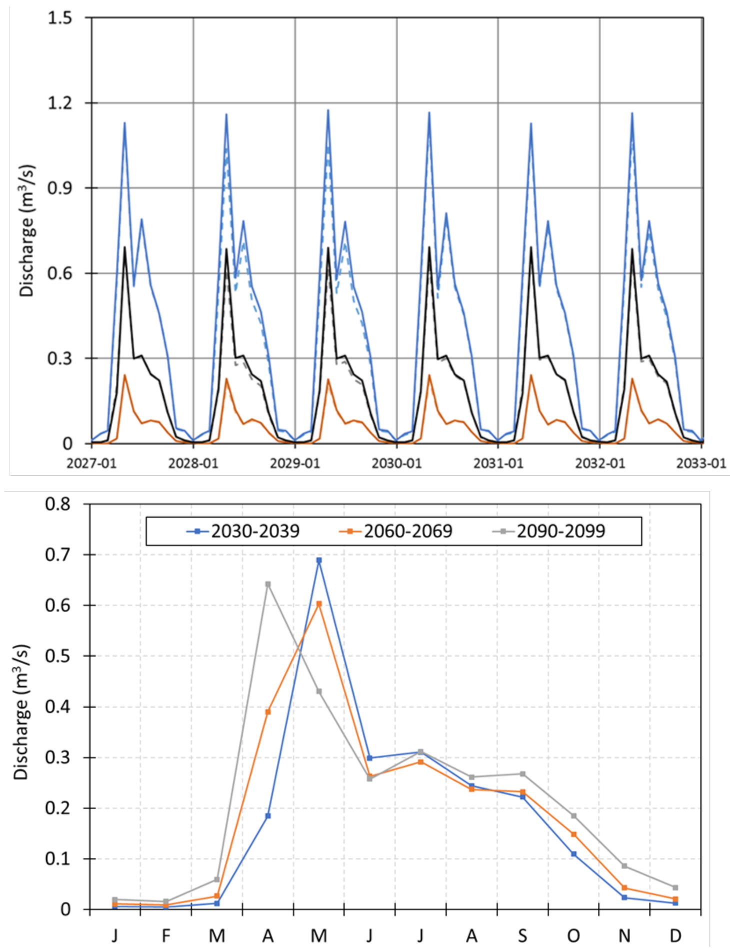

Figure 3: Example flow outputs for a WBM node. The upper panel compares Natural Flow and Base Case outputs for a 6-year period. The lower panel, which is based on output from the Natural Flow sub-model, shows predicted decadal shifts in monthly streamflow owing to future T and P changes.

7.0 References

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