Groundwater Modelling and Site Investigations to Evaluate Groundwater Supply Availability and Withdrawal Impacts for a Proposed Gold Mine in Yukon, Canada

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Abstract The Eagle Gold Project located in central Yukon, Canada is in the process of development. Bedrock groundwater supply wells will be required to meet water supply demands throughout mine construction and operations. A groundwater flow model was developed to evaluate aquifer yield, groundwater supply sustainability, and potential hydrogeologic impacts of groundwater extraction and mining on surface water flows. A bedrock groundwater supply well was later installed and a 10-day pumping test was carried out. The groundwater model was subsequently bench marked against the results of the pumping test showing reasonable agreement with the independent data set.

Keywords groundwater supply, numerical model, pumping test

Introduction

Victoria Gold Corporation is in the process of developing the Eagle Gold Project (the “Project”) at their Dublin Gulch Property located in the center of the Yukon, Canada (Fig. 1). The Project focuses on the Eagle Gold Zone, which contains vein-hosted gold mineralization (Wardrop 2012). The Project will occur over a

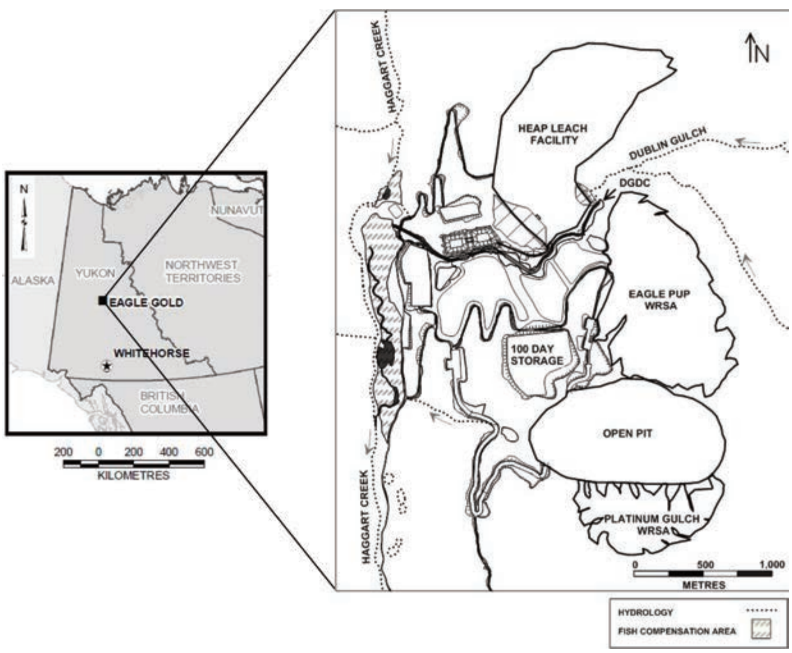

***Fig. 1** Project location and proposed mine layout.*

27-year period in four phases: a 25 month pre-production (construction) phase, a 10 year operations mining phase, and a 10 year closure and reclamation phase, followed by a post-closure and monitoring phase. Mine infrastructure includes an open pit, a lined heap leach facility (HLF), two Waste Rock Storage Areas (WRSAs), a mine water treatment plant (MWTP), and the Dublin Gulch diversion channel (DGDC), which will be constructed to route non-contact water from upstream of the Project area within the Dublin Gulch watershed to Haggart Creek (Fig. 1). Bedrock groundwater supply wells located adjacent to Haggart Creek in the lower Dublin Gulch valley will be required to supplement the makeup water supply demands throughout mine construction and operations.

A three dimensional (3-D) MODFLOW-SURFACT numerical groundwater flow model was developed for the Project area at the Dublin Gulch watershed-scale (*i.e.* a roughly 10 km^2 watershed within a 65 km^2 model domain) to meet the current industry standards and regulatory requirements. This paper describes the development and use of the groundwater model to evaluate the aquifer yield, to assess the ability for groundwater to sustainably meet the Project water supply demands, and to predict the potential hydrogeologic impact of mining and groundwater extraction on surface water flows. In addition, subsequent field investigations and model bench marking are presented.

Conceptual Hydrogeologic Model

The Project lies within the upper regions of the Haggart Creek drainage basin, within the Dublin Gulch and Eagle Creek sub-basins (Fig. 2). Haggart Creek flows to the south, ultimately flowing into the South McQuesten River. The average annual precipitation for the Project is estimated to be 557 mm, with approximately 50 % of the annual precipitation falling as snow. The hydrology of the region is generally characterized by large snowmelt runoffs during the freshet, which quickly taper off to low summer stream flows interspersed with periodic increases in flow associated with intense rainfall events.

Placer mining has been conducted in both Haggart Creek and the Dublin Gulch basins

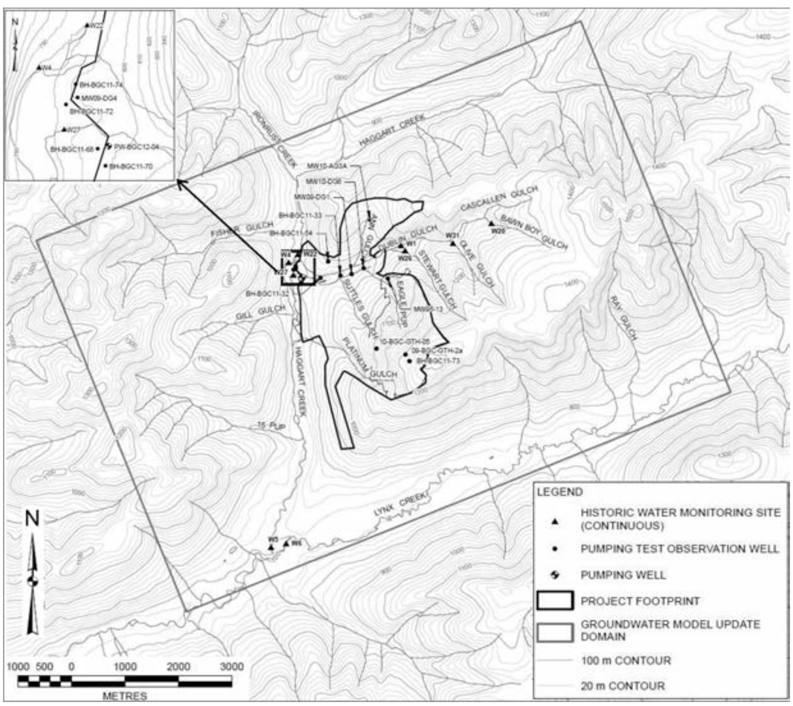

Fig. 2 *Groundwater flow model domain.*

over the past century. Surficial materials are generally composed of a veneer of colluvium in the uplands; while alluvium and reworked placer tailings dominate in the valley bottoms and generally vary from 10 to 30 m thick between Eagle Pup and Haggart Creek. The Project area is underlain by Upper Proterozoic to Mississippian sedimentary rocks of the Selwyn Basin (Smit *et al.* 1995). The bedrock of the Project area can be broadly divided into the Hyland Group metasediments and intrusive rocks of the Dublin Gulch Stock. Results from hydrogeologic tests (*i.e.* over 80 slug tests and packer tests in over 50 boreholes and four pumping tests) conducted in the bedrock suggest that the hydraulic conductivity of the intrusive and metasediment units is generally similar, and a general trend of decreasing permeability with depth is discernible from the data.

The observed water table is a subdued replica of topography, with depths to groundwater typically being greater in the uplands relative to the valley bottom. Groundwater enters the flow system from infiltration of precipitation and snowmelt, as well as by surface water infiltration in creeks and gullies. Groundwater discharge occurs to creeks, gullies, and at breaks in slope. Groundwater elevations are observed to decline through the winter and spring, and are highest during the summer and fall quarter. The seasonal variation in groundwater levels is consistent with the seasonal precipitation and temperature trends.

Groundwater extraction wells will be required within the lower Dublin Gulch valley to supplement the Project makeup water supply demands. Under average conditions, groundwater supply requirements will be approximately 200 m^3/d during construction and operations, but will peak annually during late spring (typically April, when observed stream flows are low) at rates from 1,600 m^3/d to 2,500 m^3/d. Also, the hydrogeologic regime of the mine site will change during construction and operations due to the open pit advance and mine dewatering, overburden dewatering and removal, surface water diversions, and changes in land use (*e.g.* placement of a lined HLF and underdrains beneath the WRSAs which may reduce groundwater recharge).

Numerical Groundwater Model Development and Results

The domain of the 3D groundwater flow model developed for the Project encompasses the area shown in Fig. 2. The model domain is bounded by a combination of Haggart Creek and a topographic divide in Fisher Gulch along the north edge, by Lynx Creek in the south, by topographic divides to the west, and by a combination of drainage channels and a topographic divide in the east. Eight model layers were used to discretize the domain in the vertical dimension. The upper layer of the model was divided into six overburden units which included alluvium deposits, colluvium deposits, bedrock with colluvium veneer, glaciofluvial terrace deposits, placer tailings, and glacial till. Layers 2 to 8 were divided into intrusive and metasediments bedrock hydrostratigraphic units based on local geologic mapping. In addition, Layer 2 was assigned as an overburden deposit within the Dublin Gulch valley where surficial material is the deepest.

The groundwater flow model was calibrated to available site data, including average and seasonal hydraulic heads, estimated mean monthly stream flows, and pumping test data. Streams in the model domain were simulated using the Streamflow-Routing (SFR) package (Niswonger and Prudic 2005) and monthly stress periods were used to represent seasonality during calibration, and to evaluate the seasonal effects of the Project during predictive simulations. Assigned boundary conditions were modified on a monthly basis for the transient predictive simulations to represent fluctuating groundwater extraction well water supply demands, the open pit advance and mine dewatering, overburden dewatering and removal, surface water diversions, and changes in land use (*e.g.* modified recharge rates beneath HLF and WRSA footprints).

The results of the predictive simulations indicate that one to two groundwater supply wells installed in the bedrock of the lower Dublin Gulch Valley will be able to sustain the groundwater supply demands. Model results also predict that mine development will cause a reduction in hydraulic heads (*i.e.* drawdown) within the Project area sub-basins of the Haggart Creek watershed. The predicted drawdown will alter groundwater gradients and therefore groundwater flow.

Stream station W5 is located south of the Project footprint on Haggart Creek (Project compliance point, Fig. 2). Estimated pre-development mean monthly flows at stream station W5 range from lows of 11,800 m^3/d in March just before freshet, to highs of 275,000 m^3/d in May. The changes to the monthly model water budget through closure including: 1) reductions in groundwater discharge to streams, and 2) increased leakage from streams, were combined to present the net change to baseflow. Net baseflow reduction was compared to model calibrated mean monthly pre-development stream flows as rates (Fig. 3A) and as percentages (Fig. 3B). The net baseflow reduction at W5 is up to 1,400 m^3/d during operations, but typically varies from 600 m^3/d to 1,100 m^3/d during construction and operations and from approximately 400 m^3/d to 1,100 m^3/d during the closure periods. During operations, the predicted reductions to stream flow at W5 are generally less than 1 % from May through October to 3 % to 6 % from December to April (Fig. 3B). During closure, the net baseflow reduction is estimated to decrease stream flow at W5 by less than 1 % to 2 % from May through November, and by 2 % to 5 % from December to April. Predicted reductions to stream flow peak during construction, but per-

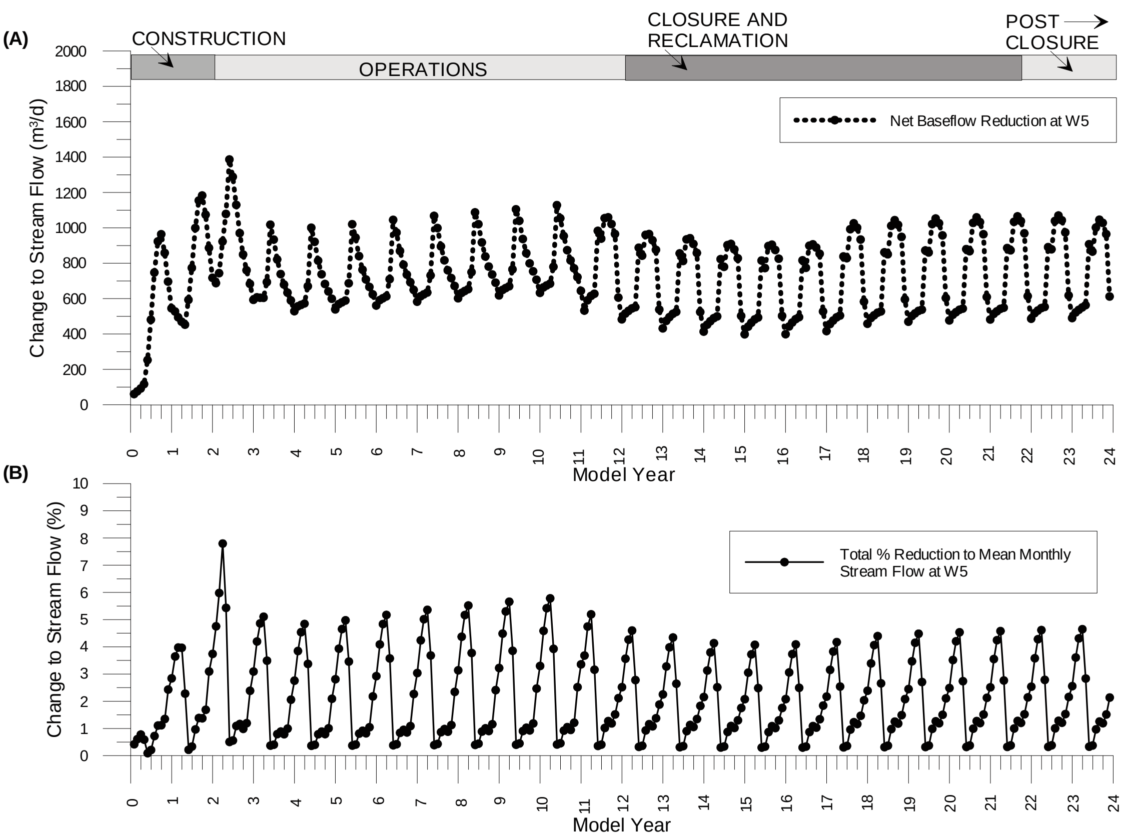

***Fig. 3** Model predicted reductions to stream flow as (A) m³/d and (B) % of mean monthly stream flow.*

sist through closure due to the overall changes to land use simulated (*i.e.* reduced groundwater recharge beneath HLF and WRSA footprints).

Field Investigations and Model Benchmarking

Following the groundwater modelling study, a 407 mm (16 in) diameter bedrock groundwater supply well (PW-BGC12-04) was installed in the Lower Dublin Gulch valley adjacent to Haggart Creek to confirm well constructability and to evaluate safe well yield. The well was constructed by simultaneously drilling and casing through alluvial overburden and metasedimentary bedrock using the dual rotary drilling method. The well was completed with 31 m telescoping screen installed from 52 to 83 meters below ground, and draws water from highly fractured zones within the metasediments bedrock. This bedrock aquifer is interpreted to be a leaky confined aquifer system recharged from the overlying alluvial sediments and adjacent uplands. This zone corresponds to Layers 3 and 4 in the groundwater model.

A step-rate pumping test followed by a 10-day constant rate pumping test was carried out at a rate of 2500 m^3/d to evaluate the safe well yield. Aquifer drawdown during the pumping test was monitored using electronic dataloggers at 17 locations around the site including nine monitoring wells, five vibrating wire piezometers and three stream gauging stations (Fig. 2).

The monitoring wells and vibrating wire piezometers used for aquifer test monitoring are screened in both alluvial overburden and metasediments bedrock. The three stream gauging stations were located on Haggart Creek upstream and downstream of the pumping well. Pumping test observed drawdowns at the pumping well and observation wells with measurable drawdown are included as Fig. 4.

Drawdown was measured a maximum distance of 700 m away from the pumping well in bedrock monitoring well BH-BGC11-33 (Fig. 2). Discernible drawdown was not measured in Haggart Creek; however since winter freeze-up was taking place during the pumping test there was significant ice build-up at the stream gauging stations. Aquifer transmissivity interpreted from this long term pumping test was on the order of 50 – 900 m^2/d, consistent with previous pumping test results from the site.

As the data collected during drilling and testing PW-BGC12-04 was not used to build or calibrate the numerical model, it could be used

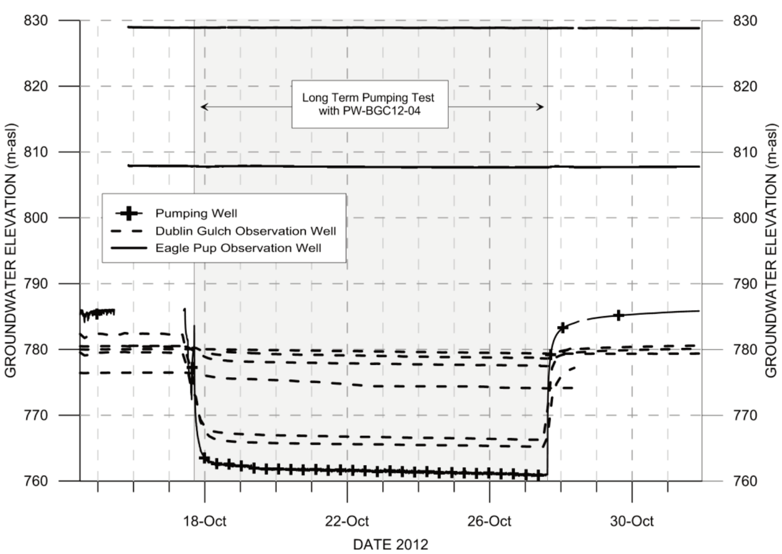

***Fig. 4** Observed drawdowns for PW-BGC12-04 Long Term Pumping Test*

Well ID	Distance from Pumping Well (m)	Observed Drawdown (m)	Simulated Drawdown (m)
PW-BGC12-04	-	25.2	46.3
BH-BGC11-68-S	40	2.4	12.2
BH-BGC11-68-M	40	11.2	13.2
BH-BGC11-68-D	40	12.7	1.3
BH-BGC11-72	218	3.0	0.2
BH-BGC11-74	256	1.9	0.1
BH-BGC11-32	348	0.2	0.1
BH-BGC11-33	720	0.1	0.0
MW09-DG4	210	0.7	0.6
BH-BGC11-54	580	0.0	0.0
MW10-AG3, MW96-13A	1672, 1606	0.0	0.0
MW96-13B, 09-GTH-BGC-02a-D	1606, 2411	0.0	0.0

Table 1 *Simulated versus observed total draw*

as an independent data set to evaluate the groundwater model as a predictive decision making tool (Konikow and Bredehoft 1992). Of particular interest for this aspect of the project are model simulated impacts to Haggart Creek on the operational time scale.

Observed and simulated results are in general agreement (Table 1), and show similar areal extents for the cone of depression and reasonable agreement in drawdown values. These results show that the groundwater flow model can reasonably reproduce the water levels and drawdown observed during the 10-day constant rate pumping test. This increases confidence in the long term (25 year) prediction results from the groundwater model, especially in the lower valley area.

Conclusions

A MODFLOW-SURFACT groundwater flow model was developed to evaluate impacts of mine development on the groundwater flow regime at the Eagle Gold site including the effects of groundwater extraction on nearby Haggart Creek. Monthly stress periods were used to evaluate the net baseflow reduction to Haggart Creek. Predicted results indicate peak stream flow reductions at station W5 of 6 % during the low flow months during operations and an average reduction of 2 % during closure and post-closure.

Following model development, a bedrock groundwater supply well was installed and tested to evaluate well constructability and aquifer yield. The well construction and pumping test data was subsequently used to benchmark the groundwater model and showed reasonable agreement with the independent dataset.

Acknowledgements

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