Rook I Project

Environmental Impact Statement

TSD XIV: Groundwater Flow and Solute Transport Modelling Report

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODELLING REPORT

TECHNICAL SUPPORT DOCUMENT

FOR THE ROOK I PROJECT

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Executive Summary

NexGen Energy Ltd. (NexGen) is proposing to develop a new uranium mining and milling operation in northwestern Saskatchewan, called the Rook I Project (Project). The Project would be located approximately 40 kilometres (km) east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon. The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Patterson Lake is at the interface of the Boreal Shield and Boreal Plain ecozones. Access to the Project would be from an existing road off Highway 955, with on-site worker accommodation serviced by fly-in/fly-out access. The Project would include underground and surface facilities to support the extraction and processing of triuranium octoxide (U_3O_8) from the Arrow deposit, a land-based, basement-hosted, high-grade uranium deposit.

Golder Associates Ltd. (Golder) was retained by NexGen to provide estimates of short-term (i.e., Operations) and long-term (i.e., post-closure) solute mass loadings from the waste products associated with the Project (i.e., tailings and waste rock source areas) to downgradient receptors, such that these loadings could be incorporated into an environmental impact statement and risk assessment for the proposed Project. Another objective of this work was to evaluate the potential groundwater management requirements (i.e., groundwater inflow rates) during Construction, Operations, and Decommissioning and Reclamation (i.e., Closure).

To achieve these objectives, a groundwater flow model was developed and calibrated to current (i.e., predevelopment) conditions. Details of the data and conceptual model used to develop the groundwater flow model development and calibration are provided under separate cover (Annex III, Hydrogeology Baseline Report). The groundwater flow model was configured to represent the Operations conditions, and a transient simulation was completed to evaluate the rates of groundwater inflow to the mine through time under various scenarios. It was also adapted to represent post-closure conditions through inclusion of tailings in the underground tailings management facility (UGTMF), backfill in the stopes, and the underground workings that would remain open at Closure, then used to identify groundwater flow pathways from source areas (i.e., UGTMF tailings, stope backfill, and above-grade waste rock) through the geological environment to the downgradient receptors during post-closure.

The results of the groundwater flow and solute transport simulations were reviewed, and the following key findings were identified:

Predictive simulations of Construction and Operations resulted in groundwater inflows that ranged from a total of approximately 1,200 cubic metres per day (m^3/d) to 2,000 m^3/d during the period from 2022 (Year -4) to 2035 (Year 10) of the simulation. The greatest portion of inflow occurring in underground openings was associated with the open workings and not with the UGTMF or stope excavations. At 2035 (Year 10), the total groundwater inflows increased to approximately 3,900 m^3/d, corresponding to the opening of additional stopes. After 2041 (Year 16), the groundwater inflows were relatively stable at approximately 3,500 m^3/d total inflow.

The simulated groundwater inflows were found to be relatively sensitive to the input values applied to the model for hydraulic conductivity of the fault zone and bedrock. Simulated groundwater inflows were found to be up to approximately double the base case values when the fault zone hydraulic conductivity was increased by a factor of 5 and when the hydraulic conductivity of the bedrock was increased by a factor of 2.

It was assumed that all groundwater inflows associated with mine dewatering would contribute to a reduction in baseflows to the Patterson Lake watershed. The peak simulated groundwater inflow rates reflect a reduction in baseflow of approximately 6 percent (%).

At the end of Operations, the simulated drawdown extends approximately 2 km to the north, 4 km to the south, and 3.5 km in both the east and west directions, based on the 5 metres (m) drawdown contour. Vertically, the extent of depressurization is generally limited to the basement rock, as the overlying sandstone aquifer is increasingly more transmissive.

The primary groundwater flow pathway from the waste rock storage areas (WRSAs) was simulated to travel through the overburden (unconsolidated glacial till) via two pathways (i.e., one to the north and one to the south), which both discharge within Patterson Lake. Hydraulic conditions along this pathway are anticipated to be similar for both Operations and Closure. During Operations, a portion of the seepage from the potentially acid generating (PAG) WRSA would be intercepted via the liner.

Upon completion of mining and placement of underground waste, the mine would be flooded and groundwater pressures would re-establish to natural hydrostatic conditions, which are anticipated to be similar to those observed in the predevelopment period. The primary transport pathway from the underground waste would be vertically upwards through the fault zone to the interface with the sandstone, then laterally (i.e., northwest) through the sandstone, with the ultimate groundwater discharge location in Patterson Lake.

The approximate advective groundwater travel time from the upper horizon of the mine to the discharge location at Patterson Lake is estimated to be approximately 4,300 years. For the overburden pathways, the approximate advective groundwater travel time from the waste rock piles to Patterson Lake is estimated at 43 years to the north and 77 years to the south.

Peak mass loadings are driven primarily by waste rock and reflooded mine workings for most solutes (based on a review of mass loadings by source area). For a minority of solutes (e.g., arsenic), the proportions of solute mass from underground backfill and waste rock sources are similar.

The solute loadings were most sensitive to the source terms for backfill and the UGTMF tailings for solutes where the upper bound source was much greater than the base case (e.g., lead, where the upper bound source was much greater than the base case for the UGTMF). Because the surface waste rock loadings represent a large portion of the overall mass loadings, the results were also sensitive to the upper bound waste rock source term.

In general, model results were not sensitive (i.e., resulting in less than 5% difference) in simulations in which adjustments were made to the hydraulic conductivities of the backfill materials or a reduction was made in the area of the bedrock flow pathway.

Abbreviations and Units of Measure

Abbreviation	Definition
3-D	three dimensional
CPB	cemented paste backfill
CPT	cemented paste tailings
Golder	Golder Associates Ltd.
NexGen	NexGen Energy Ltd.
NPAG	non-potentially acid generating
PAG	potentially acid generating
Project	Rook I Project
RSA	regional study area
SR	sensitivity run
UGTMF	underground tailings management facility
WRSA	waste rock storage area

Unit	Definition
%	percent
°	degree
kg/m^3	kilograms per cubic metre
km	kilometre
$L/s/km^2$	litres per second per square kilometre
m	metre
m/day	metres per day
m/s	metres per second
m^2	square metre
m^3/d	cubic metres per day
masl	metres above sea level
mm	millimetre
mm/yr	millimetres per year

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APPENDICES

1 INTRODUCTION

1.1 Background

NexGen Energy Ltd. (NexGen) is proposing to develop a new uranium mining and milling operation in northwestern Saskatchewan, called the Rook I Project (Project). The Project would be located approximately 40 kilometres (km) east of the Saskatchewan-Alberta border, 130 km north of the town of La Loche, and 640 km northwest of the city of Saskatoon (Figure A-1). The Project would reside within Treaty 8 territory and the Métis Homeland. At a regional scale, the Project would be situated within the southern Athabasca Basin adjacent to Patterson Lake, along the upper Clearwater River system. Patterson Lake is at the interface of the Boreal Shield and Boreal Plain ecozones. Access to the Project would be from an existing road off Highway 955, with on-site worker accommodation serviced by fly-in/fly-out access. The Project would include underground and surface facilities to support the extraction and processing of triuranium octoxide (U_3O_8) from the Arrow deposit, a land-based, basement-hosted, high-grade uranium deposit.

1.2 Objectives

The work described in this document was completed as a part of the technical support for NexGen's current Environmental Assessment of the Project. Golder Associates Ltd. (Golder) was retained by NexGen to provide estimates of short-term (i.e., Operations and Closure) and long-term (i.e., post-closure) solute mass loadings from the waste products associated with the Project (i.e., tailings and waste rock source areas) to downgradient receptors. These loadings were incorporated into the Environmental Impact Statement (EIS) and risk assessment for the proposed Project. Note that the EIS risk assessment model used was completed by Ecometrix and is documented in the EIS.

Another objective of this work was to estimate groundwater inflow rates during Construction, Operations, and Decommissioning and Reclamation (i.e., Closure).

1.3 Scope of Work

To meet the work objectives the following tasks were completed:

Estimate groundwater inflows and extent of depressurization: A three dimensional (3-D) numerical groundwater flow model was developed to reflect the conceptual hydrogeological model and calibrated based on target groundwater elevations and baseflow information. The model was first established to represent current (i.e., predevelopment) conditions and subsequently modified to represent various stages of the mine Operations and Closure. This model was reconfigured to represent Operations conditions to estimate groundwater inflows to the underground development and receptors during Operations of the mine and the resulting depressurization in the bedrock.

Delineate groundwater flow pathways: The groundwater flow model was configured to represent long-term post-closure conditions to delineate the groundwater flow pathways from the tailings and waste rock management facilities and groundwater flow rates during post-closure.

Estimate solute mass loadings to receptors: An analytical solute transport model was developed using GoldSim (GTG 2021) based on the delineation of groundwater flow pathways and rates of flow through the backfill mine waste materials, underground tailings management facility (UGTMF) tailings, reflooded mine workings, and waste rock remaining at grade following Closure. The model was used to estimate the solute mass release from the source areas to the surrounding environment and to calculate the rate of transport of this mass to downgradient receptors (i.e., Patterson Lake). The model accounts for seepage from the waste rock storage areas (WRSAs) during the Operations and Closure, and seepage from the underground solute source areas during Closure.

Evaluate model sensitivity: To address the uncertainty associated with key model input parameters and assumptions, a sensitivity analysis was completed where the model was run using alternative configurations, and the results were compared to the base case simulation results.

1.4 Report Organization

Section 2, Groundwater Flow Model Development, of this report provides an overview of the conceptual hydrogeological model and details the development and calibration of the groundwater flow model. Section 3, Impact Assessment, describes the impact assessment approach for Operations and post-closure and Section 4, Results, provides the results of the impact assessment. The sensitivity analysis is described in Section 5.

2 GROUNDWATER FLOW MODEL DEVELOPMENT

2.1 Conceptual Model

The area of the Project has been the subject of previous investigations completed in support of resource exploration, the pre-feasibility study, and the Environmental Assessment. The analysis and interpretation of data collected as a part of these earlier studies have allowed for the development of a conceptual hydrogeological model for the Project. Data used in the development of the conceptual hydrogeological model (e.g., topography and drainage, geology, and hydrogeology) are provided in the baseline hydrogeology report (Golder 2021). Key aspects of the conceptual hydrogeological model that pertain to the development of the numerical groundwater flow model are summarized below:

The topography and drainage in the regional study area (RSA) are illustrated in Figure A-2. The Project is located along the southwestern rim of the Athabasca Basin, a large Paleoproterozoic-aged, flat-lying sedimentary basin that covers much of northern Saskatchewan and part of northern Alberta (RPA 2017). The topography of the Project site is dominated by glacial features including eskers and drumlins locally modified by wind action following retreat of the Laurentide Ice Sheet (Norris et al. 2017). Surface drainage in the RSA occurs as a part of the Clearwater River system, which is defined by the topographic divide of the Broach Lake catchment (i.e., the headwaters of the system) and includes, sequentially downstream in the Clearwater River system, the catchments of Patterson Lake, Forrest Lake, Beet Lake, and Naomi Lake and their associated tributaries.

The primary geological units include crystalline basement rock, paleo-weathered basement rock, Athabasca sandstone bedrock, Devonian sandstone/siltstone/mudstone bedrock, Cretaceous sandstone/siltstone/mudstone bedrock, and glacial drift (i.e., overburden).

These are illustrated as geological cross-sections in Figure A-3a and Figure A-3b. Within the crystalline basement rock and paleo-weathered basement rock there are sub-vertical fracture zones and fault zones. Section 5.1.3 of the baseline hydrogeology report (Annex III) provides additional details.

Results of hydraulic response testing for the geological units are provided in Figure A-4. Based on these results, hydrostratigraphic units were defined that correspond to the geological units. Competent basement rock is considered to have low hydraulic conductivity (i.e., on the order of 10^{-10} metres per second [m/s]). Within the crystalline bedrock, the higher permeability fault zones and shear zones are considered to be the primary hydraulic pathways. The sandstone unit is considered to be the primary bedrock aquifer in the area of the Project, with data from laboratory permeability testing indicating hydraulic conductivity values on the order of 10^{-05} m/s. The glacial drift is also considered to be an aquifer, with interpreted hydraulic conductivity values from hydraulic response testing ranging from 10^{-04} m/s to 10^{-06} m/s. Section 5.2.2 of the baseline hydrogeology report (Annex III) provides additional details.

Within the bedrock, measured hydraulic gradients indicate that under existing conditions the primary groundwater flow direction is upwards and to the north-northwest (i.e., towards Patterson Lake). This is illustrated as a cross-section in Figure A-5 and in plan view in Figure A-6a, Figure A-6b, and Figure A-6c. In the glacial drift deposits, the groundwater flow direction is downwards and to the north-northwest (i.e., towards Patterson Lake). Section 5.2.1 of the baseline hydrogeology report (Annex III) provides additional details.

In areas within the RSA where groundwater elevation monitoring data are not available, it is anticipated that localized discharge of groundwater occurs at surface water features. Groundwater recharge in the RSA occurs within the glacial drift.

Details on the implementation of the hydrogeological conceptual model within the numerical groundwater flow model are described in the following subsections.

2.2 Numerical Model Approach

As noted above, the objectives of groundwater flow modelling were to develop and calibrate a groundwater flow model representing the current (i.e., predevelopment) conditions for the site and use that model to estimate groundwater inflows, estimate the extent and magnitude of groundwater depressurization, and delineate groundwater flow pathways from mine waste source areas to receptors.

To achieve these objectives, a 3-D numerical groundwater model was constructed and calibrated to represent the "best estimate" of groundwater flow conditions based on the conceptual model. The general assumptions and limitations of the numerical model are summarized below:

- Groundwater flow is laminar (i.e., fluid moving along smooth paths), steady, and governed by Darcy's Law.
- Groundwater flow in the model, regardless of the presence of bedrock fractures, is represented by an equivalent porous media approach.
- Hydraulic heads are vertically averaged within a given model layer.
- Material properties applied in the model are based on the units defined in the 3-D geological (Leapfrog) model developed by NexGen. Geological contacts were extrapolated within the areas of the groundwater flow model domain that were not covered by the geological model.

- Recharge estimates reflect deeper recharge and discharge characteristics of the groundwater flow system and do not account for shallow infiltration and discharge to intermittent streams (i.e., interflow).
- A regionalized approach to model calibration was employed such that parameter values were established for the hydrostratigraphic units on a regional scale.
- The most recent available calibration data were used in the calibration process (i.e., typically corresponding to December 2019), which were assumed to be representative of steady-state predevelopment conditions.

A finite element modelling package developed by the DHI-WASY Institute in Germany (FEFLOW; Diersch 2009), was used as the numerical simulation tool for the assessment. FEFLOW is capable of simulating saturated and unsaturated groundwater flow and solute and heat transport in three dimensions. FEFLOW was selected for this work given its capabilities to efficiently discretize local features around each of the main mine features (e.g., mine tunnels, mine workings, and UGTMF) yet maintain a relatively regional overall footprint to estimate changes in more regional groundwater elevations and water balances. FEFLOW v7.2 was used to complete the simulations presented in this report.

2.3 Regional Study Area Flow Model

2.3.1 Model Mesh and Extents

The model extents are illustrated in Figure A-1 and define the RSA boundary. As shown in the figure, the model was constructed based on a rectangular mesh of approximately 26.5 km by 18.5 km that is oriented based on the general regional surface drainage for the area, with the northwest portion of the model domain situated along a topographic high and the southeast portion of the model situated along a topographic low (i.e., with drainage to the Clearwater River). It is thought that the regional deep groundwater flow system does not necessarily reflect the shallow local drainage patterns at surface water features.

The model mesh was configured with an element size of approximately 600 metres (m) along the model periphery, transitioning to approximately 6 m in the central portion of the model in the vicinity of the Project. Vertically, the model was discretized into 38 numerical layers, ranging in thickness from 0.25 m to 20 m. The total number of grid cells was 1,411,038. Section 2.3.3, Material Properties, provides details on the model layering with reference to the hydrostratigraphic units.

2.3.2 Boundaries

Figure A-7 illustrates the groundwater flow model boundaries. Lakes and watercourses (e.g., streams and creeks) within the model domain were represented using fixed head boundaries applied at the elevation of the water feature on model slice 1. Fixed head boundary nodes were also specified along the downstream (i.e., southeast) lateral model boundary on slices (i.e., surfaces that define model layers) 6 to 39 to allow regional outflow of groundwater through the bedrock. In the absence of groundwater elevation data in this area, these nodes were assigned an elevation of 485 metres above sea level (masl), corresponding to the approximate low point in topography along the periphery of the model.

The model recharge distribution was determined by applying a uniform infiltration rate equivalent to one-third of the mean annual precipitation (an infiltration rate of 140 millimetres per year [mm/yr] calculated based on a mean annual precipitation of 419 millimetres [mm]) and allowing the model to remove excess infiltration where groundwater elevations in the upper model layer rose above the ground surface. This value was assigned as an initial estimate of the infiltration rate and corresponds to an equivalent basin yield of 4.4 litres per second per square kilometre ($L/s/km^2$). The recharge rate is a function of the infiltration capability of the soil based on surface elevation, glacial drift thickness, glacial drift hydraulic conductivity, and proximity to surface water features. The calculated infiltration rate applied in the model using this approach corresponded to a regional average of 93 mm/yr (i.e., approximately 3 $L/s/km^2$), or approximately 22 percent (%) of the mean annual precipitation.

2.3.3 Material Properties

The generalized hydrostratigraphy for the Project site is described in Section 2.1, Conceptual Model, and illustrated schematically in Figure A-3a and Figure A-3b. To represent this hydrostratigraphy in the groundwater flow model, a total of 38 numerical layers were used and divided as follows:

- Twelve evenly spaced, laterally variable layers were specified between the ground surface, which ranged from 601 masl to 487 masl, and a horizontal slice at elevation 360 masl. This spacing resulted in a thickness of each layer that ranged from approximately 10 m to 20 m and model slice elevations that generally aligned with hydrostratigraphic unit contact elevations in the vicinity of the Project. These layers encompass the upper and lower glacial drift units, Cretaceous bedrock, Devonian bedrock, and the upper portions of the sandstone and paleo-weathered rock units.
- Layers of constant thickness were specified below elevation 360 masl, with a 30 m thickness for layers 13 to 18 (i.e., to elevation 180 masl), then 20 m thickness for layers 19 to 33 (i.e., to elevation -120 masl), and 106 m thickness for layers 34 to 38 (i.e., to elevation -650 masl at the base of the model). These layers encompass the lower portions of the sandstone and paleo-weathered basement rock units and the entirety of the basement rock unit.

Elements within the 3-D model mesh were assigned material properties based on their proximity to the geological units in the 3-D geology model using Leapfrog. In some cases, the interpolation routine resulted in spatial gaps; therefore, manual adjustments were made to improve connectivity of the unit across the mesh. This was particularly relevant for the fault zone and shear zone units, which are relatively thin compared to the mesh spacing. The resulting material distribution applied in the model is illustrated in the cross-sections in Figure A-8, which shows regional northwest-southeast material zones, Figure A-9, which shows regional southwest-northeast material zones, and Figure A-10, which shows local material zones.

The horizontal and vertical hydraulic conductivity values applied to the main hydrostratigraphic units are summarized in the tables embedded in Figure A-8, Figure A-9, and Figure A-10. A summary of the assignment of material properties is as follows:

- In general, the hydraulic conductivity values applied in the model agree with the measured data. For the basement rock, paleo-weathered basement rock, shear zone, and upper glacial drift units, the model value was at or slightly below the geometric mean value from the measured data. For the fault zone, the model value was slightly above the geometric mean value.

For the sandstone unit, the hydraulic conductivity was approximately two orders of magnitude above the geometric mean value. The assignment of these values is detailed further as a part of the discussion on model calibration in Section 2.4, Model Calibration.

- The hydraulic conductivity anisotropy ratios were derived through the model calibration process (detailed in the subsection below). The values assigned to the overburden, Cretaceous and Devonian units reflect the strong vertical (downwards) gradient through the overburden to the underlying rock. These are considered reasonable given the interbedded nature of these units.
- Within the vicinity of the Project (i.e., the local study area), the fault zone and shear zone units were mapped individually in the 3-D geological model and as such have been incorporated in the groundwater flow model as independent material property zones. Therefore, the basement rock in the local area was assigned a lower hydraulic conductivity (i.e., 1.0×10^{-09} m/s, reflective of competent rock) in the local area as compared to the fault zones (i.e., 2.0×10^{-07} m/s) and shear zones (i.e., 8.3×10^{-09} m/s). Based on the geological model, these features extend to the top of the paleo-weathered unit.
- It is understood that the fault zone and shear zone features extend outside of the local area where they are presently mapped. Based on geophysical survey data (i.e., Z-tipper axis electromagnetic and airborne magnetic data) provided by NexGen, these features extend approximately 4 km to the southwest and approximately 700 m to the northeast (i.e., beneath Patterson Lake). To account for the presence of these features, the bedrock in this area was assigned a horizontal hydraulic conductivity of 1.3×10^{-07} m/s with an orientation of 43° from north (i.e., approximating the trend of the fault and shear zones) and 1.0×10^{-08} m/s in the perpendicular (i.e., northwest-southeast) direction.
- Outside of the area where the fault zone and shear zones are assumed to be present, the bedrock was assigned a hydraulic conductivity value of 1.0×10^{-08} m/s, as determined through the model calibration process.
- A zone of high hydraulic conductivity was used to represent Patterson Lake, where necessary, to account for the lake bathymetry.
- Based on the interpreted geological surfaces, Patterson Lake is in direct hydraulic connection with the sandstone unit. For the purposes of the hydrogeological assessment, the delineation of groundwater flow pathways did not consider the presence of lake bottom sediments (a conservative assumption).

In the absence of measured data, the porosity values assigned to the units were based on typical values for similar geological units in the Athabasca basin (COGEMA 1997, 2004). The assigned porosity values range from 0.01 for the basement rock to 0.2 for the till.

2.4 Model Calibration

The groundwater flow model was calibrated using PEST optimization software, which iteratively adjusts model parameters (e.g., hydraulic conductivity and recharge) within user-defined constraints until the model error, as calculated based on target data (e.g., groundwater elevations), is minimized. In this instance, PEST was implemented directly through the FEFLOW user interface. Additional details on PEST can be found in the software user's manual (Watermark Numerical Computing 2021).

Following the completion of the optimization routine, the model results were checked for a reasonable match between the simulated and observed groundwater elevations (i.e., calibration statistics and spatial distribution of residuals), and groundwater flow patterns (i.e., discharge areas and depths to groundwater). If a reasonable match was not achieved, the input parameters and/or constraints on the optimization routine were adjusted and the optimization routine was re-run. Specific calibration targets included the most recent available groundwater elevations measured from 34 monitoring wells and 27 vibrating wire piezometers located in the local study area. Section 5.2 of the baseline hydrogeology report (Annex III) provides a summary of the monitoring locations.

A regionalized approach to parameterization was adopted wherein the calibration process parameter values were associated with regional hydrostratigraphic units and adjusted globally during the calibration process to best match the observed data. Small-scale variations, as may be required to match observed data at the scale of individual wells, were not employed.

Low flow periods from streamflow measurements at monitored watercourses within the model domain were also used to check model calibration.

The results of the model calibration are illustrated in Figure A-11, which shows a statistical summary of the calibration process, and in Figure A-12 through Figure A-15, which show simulated groundwater elevations and flow directions for various hydrostratigraphic horizons. A comparison of the simulated and measured groundwater elevations is provided in Table 1. A review of the results presented in these tables and figures led to the following observations:

The calibrated model achieved a normalized root mean squared error of 8.1% with a root mean square error of 3.7 m and a residual mean error of -0.3 m (Figure A-11), which are considered reasonable. A strong spatial bias was not observed in the simulated groundwater elevations, as shown on the residual error distribution map in Figure A-11.

The groundwater flow patterns simulated by the model appear reasonable given the conceptual understanding of groundwater flow in the area of the Project. As shown in Figure A-6a, Figure A-6b, and Figure A-6c, groundwater flow is generally simulated to occur from south to north (i.e., towards Patterson Lake).

Baseflow (the portion of surface water flows originating as groundwater seepage) estimates for the surface water catchments (Annex IV.2, Hydrometric Monitoring Characterization Report) were approximately 3.5 L/s/km^2. Using the catchment areas for Patterson Lake, this baseflow corresponds to an equivalent recharge rate of approximately 110 mm/yr (i.e., 3.5 L/s/km^2). The model average recharge rate of 93 mm/yr (i.e., 2.9 L/s/km^2) is similar to this estimate and is therefore considered to be reasonable.

Table 1: Comparison of Simulated and Observed Groundwater Elevations

Monitoring Location	Groundwater Elevation (masl)		Difference (m)	Monitoring Location	Groundwater Elevation (masl)		Difference (m)
	Observed Value	Calculated Value			Observed Value	Calculated Value	
2018_MW-002A	520.04	517.78	-2.26	GAR-19-019-VWP1-146	497.74	501.22	3.47
2018_MW-002B	519.93	515.05	-4.88	GAR-19-019-VWP2-248	505.67	502.75	-2.91
2018_MW-003A	512.65	513.60	0.95	GAR-19-019-VWP3-353	504.45	503.85	-0.61
2018_MW-004A	514.06	522.68	8.62	GAR-19-019-VWP4-545	503.86	505.10	1.24
2018_MW-004B	513.82	517.62	3.80	GAR-19-021-VWP1-86	498.95	500.70	1.75
2018_MW-005B	543.78	538.61	-5.17	GAR-19-022-VWP1-131	498.55	500.71	2.17
2018_MW-006A	528.99	534.85	5.86	GAR-19-022-VWP2-287	499.90	503.08	3.18
2018_MW-006B	528.65	532.01	3.36	GAR-19-022-VWP3-482	504.69	504.80	0.11
2018_MW-007A	528.39	526.49	-1.90	GAR-19-022-VWP4-575	508.26	505.32	-2.95
2018_MW-007B	528.40	522.43	-5.97	GAR-19-023-VWP1-116	502.06	507.38	5.32
2018_MW-008A	528.81	521.74	-7.07	GAR-19-024-VWP1-234	508.73	505.65	-3.09
2018_MW-008B	527.67	517.49	-10.2	GAR-19-024-VWP2-301	508.73	505.46	-3.27
2018_MW-009A	523.97	522.83	-1.14	GAR-19-024-VWP3-594	513.01	505.20	-7.82
2018_MW-009B	523.59	522.30	-1.29	GAR-19-024-VWP4-655	508.08	505.33	-2.74
2018_MW-010A	511.93	511.27	-0.66	GAR-18-013_Z1	506.51	505.39	-1.12
2018_MW-010B	498.86	500.56	1.70	GAR-18-013_Z2	506.30	505.38	-0.92
DH-BGC17-01	530.19	525.22	-4.97	GAR-18-013_Z3	505.77	505.26	-0.51
DH-BGC17-02	526.15	523.45	-2.70	GAR-18-013_Z4	505.40	504.99	-0.42
DH-BGC17-03	518.16	529.36	11.2	GAR-18-013_Z5	505.11	504.84	-0.26
DH-BGC17-04	533.48	535.81	2.33	GAR-18-013_Z6	504.51	504.53	0.02
DH-BGC17-05	519.57	519.30	-0.27	GAR-18-013_Z7	504.26	504.13	-0.13
GAR-17-001-VWP1-303	506.37	503.48	-2.89	GAR-18-013_Z8	503.43	503.83	0.40
GAR-17-002-VWP1-654	502.73	505.56	2.83	GAR-18-013_Z9	503.08	503.39	0.32
GAR-17-003-VWP1-276	503.09	503.35	0.27	GAR-18-013_Z10	503.00	502.64	-0.36
GAR-17-004-VWP1-99	498.59	500.19	1.60	GAR-18-013_Z11	502.24	501.82	-0.42
GAR-17-004-VWP2-106	499.16	500.24	1.08	GAR-18-013_Z12	501.70	500.93	-0.77
GAR-19-018-VWP1-159	499.55	500.80	1.25	GAR-18-013_Z13	500.48	503.71	3.23
GAR-19-018-VWP2-235	500.00	502.17	2.17				
GAR-19-018-VWP3-363	504.23	503.73	-0.51	.			
GAR-19-018-VWP4-544	510.41	505.04	-5.37				

Note: GAR-18-013 refers to the Westbay installation.
masl = metres above sea level.

2.5 Baseline Flow Regime

The simulated groundwater conditions under current (i.e., predevelopment) conditions are illustrated in Figure A-12 through Figure A-15. Based on the results of the simulation, the groundwater flow regime in the vicinity of the proposed mine and surrounding area is characterized as follows:

Groundwater flow directions in the glacial drift are predominantly towards the local surface water and drainage features throughout the model domain (Figure A-12). In the area of the surface infrastructure of the mine, the groundwater flow direction in the glacial drift is towards Patterson Lake. Because the mine would be situated on a peninsula within Patterson Lake, a groundwater flow divide in the glacial drift exists to the south of the mine trending parallel to the axis of the peninsula. Groundwater flow to the north of the divide flows to the north and groundwater flow to the south of the divide flows towards the south, ultimately discharging in Patterson Lake in both directions.

The lateral groundwater flow direction in the shallow bedrock (Figure A-13) is predominantly from west to east over most of the model domain, with a component of the flow towards major water features (e.g., Patterson Lake and Forrest Lake) in localized areas. In the northern portion of the groundwater flow model, flow is towards the south. This flow pattern generally follows the topographic setting of the Clearwater River catchment. Local to the mine area, the groundwater flow in the shallow bedrock is similar to the glacial drift. A groundwater flow divide was simulated to the south of the proposed mine, with flow directed to the northern and southern portions of Patterson Lake on the respective sides of the divide.

Groundwater flow directions in the deep bedrock is predominantly from west to east, with the highest hydraulic gradient occurring west of Patterson Lake (Figure A-14). Local to the proposed mine, the lateral groundwater flow direction is to Patterson Lake to the north. The groundwater flow divide noted above in the shallow bedrock was also simulated to occur in the deep bedrock, although less pronounced.

The vertical groundwater flow direction is downwards in the area of the topographic high located to the south of the mine, transitioning to upwards in the area of the underground mine and UGTMF (Figure A-15). The influence of the structures (i.e., fault zones and shear zones) is evident in the simulated groundwater elevations, as indicated by localized reduction in groundwater pressures near these features. The structures are considered more conductive than the adjacent basement rock and represent the primary groundwater flow path between the mine horizon and groundwater discharge locations in Patterson Lake.

3 IMPACT ASSESSMENT

3.1 Assessment Approach

As stated in Section 1, Introduction, a primary objective of the groundwater flow and solute transport modelling is to provide estimates of solute mass loadings resulting from the proposed Project to downstream receptors. To achieve this objective, the approach involved development of a groundwater flow model and calibration of this model to existing (i.e., predevelopment) conditions. The construction and calibration of the groundwater flow model is detailed in Section 2 of this document.

The model was subsequently reconfigured to represent conditions during Operations and over the long term during post-closure. Groundwater flow simulations were completed with the Operations conditions model to estimate the rate of groundwater inflow to the mine, extent of depressurization (i.e., drawdown) in the bedrock, and to delineate the groundwater flow pathways from the surface facilities (i.e., WRSAs) to the discharge location under Operations conditions.

The post-closure groundwater flow model was used to delineate the flow components through the source areas. A particle tracking analysis was completed to delineate the post-closure groundwater flow pathways from the source areas through the geological pathway to the ultimate groundwater discharge location (Section 3.3, Post-closure).

Results of the groundwater flow model were used as input to an analytical solute transport (GoldSim) model, which was used to estimate solute mass flux from the source areas in the underground mine and surface facilities, through the downstream geological pathways to the ultimate receiving environment.

GoldSim is a commercially available, highly graphical, flexible, object-oriented computer program that is designed to provide the user with an understanding of the factors that control the performance of an engineered or natural system, as defined by a user specified mathematical model, and to predict the future behaviour (i.e., performance) of the defined system. A detailed description of the GoldSim software, including example applications and manuals, is documented in the Main Users Guide (GTG 2018a) and the Contaminant Transport Module Users Guide (GTG 2018b). Version 12.1 was used for the predictive calculations completed in this report.

The solute transport simulation completed using the best-estimate parameter set (i.e., the calibrated model with expected source concentrations) is referred to as the Base Case scenario. This is identical to the scenario referred to as the Application Case in the EIS (EIS Section 8.2.5, Assessment Cases). Details on the groundwater flow and solute transport modelling are provided in the following sections.

3.2 Operations

During Operations, groundwater reporting to the underground mine would be pumped to surface and treated and/or managed as needed. As such, the underground mine would be under hydraulic containment and release of mining-affected groundwater from potential underground sources to the surrounding environment would not occur.

3.2.1 Seepage from Surface Facilities

It is understood that the special waste pile and ore storage stockpile would be designed to include double liner systems and as such no seepage is anticipated from these facilities to the receiving environment. For the purposes of this assessment, the WRSAs were conservatively assumed to be in place during Construction and Operations (i.e., 28 years) and remain in place following Closure, and as such, were included in the solute transport model for Construction and Operations.

The placement method evaluated as a part of this assessment included segregation of potentially acid generating (PAG) and non-potentially acid generating (NPAG) waste rock. In addition, the PAG would be placed using engineered controls with design of horizontal layering to limit oxygen ingress into the waste rock (Technical Support Document [TSD] XVII, Waste Rock and Underground Wall Rock Source Term Predictions Report).

3.2.2 Groundwater Inflows and Drawdown under Long-Term Operations

As the mine development progresses, groundwater would continue to seep into the mine, resulting in depressurization of the bedrock. To estimate the rate of groundwater inflow to the mine and the extent of depressurization, the groundwater flow model was configured to represent the progressive mine development as a transient simulation. For this simulation, model boundaries (i.e., seepage nodes) representing the mine workings were “switched on” in annual increments according to the mine development plan.

The mine plan used for this assessment is detailed in RPA (2020). The model boundary configuration for the forecast Operations simulation is shown in Figure A-16.

For the purposes of this assessment, it was assumed that backfilled stopes and UGTMF chambers would continue to be free draining throughout Operations. As such, the seepage boundaries implemented in the model remain active after backfilling has occurred. Further, it was assumed that liners would be installed within the mine shafts throughout the more permeable sandstone unit. As such, these were assumed to be no-flow boundaries in the model.

Two additional simulations were completed using the model to evaluate the potential range in groundwater inflow rates, and to test the sensitivity of key model input values. Because the fault zone is the primary pathway for groundwater flow at the underground mine horizon, the first additional simulation involved a five-fold increase in the hydraulic conductivity of this unit (i.e., from 2×10^{-07} m/s to 1×10^{-06} m/s). Similarly, the second additional simulation involved doubling the hydraulic conductivity of the basement rock adjacent to the mine workings (i.e., from 1×10^{-09} m/s to 2×10^{-09} m/s). The hydraulic conductivity values applied in both additional simulations were within the ranges available from testing (Section 2.1). For both additional simulations, the groundwater flow rates reporting to the model boundaries representing the mine workings were tracked with time as per the Base Case simulation.

3.2.3 Influence of Mine Dewatering on Surface Water Features

Groundwater depressurization associated with mine dewatering would propagate from the underground development outward (i.e., laterally and vertically), potentially affecting the groundwater discharge rates to surface water features. To quantify the potential effect on groundwater discharge rates to surface water features, the simulated flux (i.e., discharge) to model boundaries representing surface water features was compared for the predevelopment and forecast simulations. The simulated change in groundwater flux was calculated independently for each major watershed located within the model domain.

3.3 Post-Closure

Figure A-17 provides a schematic illustration of the GoldSim solute transport model, identifying the source, pathways, and downstream receptor. These were derived through the particle tracking analysis completed using the groundwater flow model as detailed in Section 3.3.2, Groundwater Flow Pathways, and Section 4.4, Pathways Delineation and Travel Times. In summary, mass released from the source area migrates through the subsurface pathways, ultimately discharging to downgradient surface water receptors (i.e., Patterson Lake). A summary of the source areas, pathways, and solute transport model properties is provided below.

3.3.1 Description of Source Areas

As a part of the mine planning process, tailings would be placed in the underground mine workings, including primary and secondary stopes, and a purposely built UGTMF. Tailings material would be converted to cemented paste tailings (CPT) or a cemented paste backfill (CPB) before disposal. The binder content and inclusion of process waste with the CPT and CPB varies depending on where it would be disposed, with higher binder content CPB allocated for primary and secondary stopes and lower binder content CPT allocated for disposal in the UGTMF (Annex III).

A description of the physical and chemical characteristics of each of the source areas is provided below.

Given the relative volumes of waste material and the generally low seepage rates in the geological pathways, it was assumed for the solute transport modelling that the sources were infinite. The one exception to this is the reflooded mine workings, as detailed below.

For the tailings and stope backfill sources, the advective and diffusive components of mass flux were calculated within GoldSim separately. Advective flux was calculated as

$J_A = Q_T C_0$ (Equation 1)

where:

J_A = Advective mass flux (M/T)

Q_T = flow out of the source mass (L^3/T); and

C_0 = source concentration (M/L^3).

Diffusive flux out of the source mass and through the groundwater flow zone normal to the direction of flow was calculated by applying Fick's Second Law:

Diffusive flux (J_D) = $\partial C / \partial t = D^* \frac{\partial^2 C}{\partial x^2}$ (Equation 2)

where:

C = solute concentration (M/L^3);

t = time (T);

D* = effective diffusion coefficient (L^2/T), which accounts for the molecular diffusivity (L^2/T) of the fluid and porosity (-) and tortuosity of the medium; and D* =effective diffusion coefficient (L^2/T); and

x = position (L).

This is illustrated conceptually on Figure A-17. The source concentrations were considered to remain constant over time (i.e., no decay of the source at the tailings/host rock interface).

The concentration profiles adjacent the tailings mass were calculated by dividing the zones into arrays of "mixing" cells within GoldSim for a 5 m wide active flow zone within the host rock. A total of 20 mixing cells were specified over this distance, with variable widths ranging from 0.03 m to 0.8 m. Diffusive mass flux was calculated between each of the cells, and groundwater flow within the host rock, normal to the direction of diffusion, was imposed across each cell based on predictions obtained from the 3-D flow model.

Underground Tailings Storage Facility Tailings

The CPT that would be disposed of in the UGTMF were geochemically and hydraulically characterized, as detailed in TSD XV, Tailings Source Term Derivation Report. A summary of the source term for these materials, based on the geochemical characterization, is provided in Table 2, and hydraulic conductivity values, based on the hydraulic characterization, are provided in Figure A-16. The source concentrations values were applied as an infinite source to represent the UGTMF in the solute transport model.

Stope-Backfill

The CPB that would be disposed of in the stopes were geochemically and hydraulically characterized in TSD XV. These materials were characterized according to their placement destination (i.e., within primary or secondary stopes). A summary of the source term and hydraulic properties for these materials is provided in Table 2. These values were applied to represent the stope backfill sources in the solute transport model.

Flooded Mine Workings

As the mine would be flooded during Closure, the oxidized material remaining in open workings would contact flood water and potentially dissolve into it. This process was accounted for in the solute transport model by the inclusion of an additional source applied as a time-variable mass loading rate over a five-year period (i.e., during reflooding). It was assumed that after the mine workings are reflooded, oxygen availability would be limited and the additional mass loadings from the exposed mine surfaces would be negligible. Source terms for the reflooded mine workings were developed and provided by TSD XVII and are provided in Table 2.

As indicated in Table 2, values for certain solutes (e.g., phosphorus, ammonia, and radium-228) were not included in the source data. To account for potential mass of these solutes in the reflooded mine workings, a mass loading rate was estimated based on the product of the ratio of the chloride mass loading rate in the reflooded mine workings source to chloride concentration in the UGTMF tailings and the CPT concentration for the undefined solute.

Waste Rock

A portion of the precipitation that falls on the WRSAs would infiltrate through the waste rock and report as seepage to groundwater in the underlying overburden. Source terms for the waste rock were developed and provided in TSD XVII. To reflect the distribution of material types included in the WRSAs (i.e., the PAG WRSA and NPAG WRSA), this source was divided into two components: PAG and NPAG sources. The mass loading rates applied to represent the WRSAs in this assessment included Source Term 4 (segregated NPAG) and Source Term 5 (Segregated PAG) in TSD XVII.

To account for changes in the condition of the WRSAs during Operations, Closure, and in post-closure, a time-variable source term was applied in the solute transport model to represent the Operations and post-closure conditions, as summarized in Table 2. The Operations source term was applied as a constant value over the first 30 years of the simulation (i.e., approximating Construction and Operations), and the post-closure source was applied over the remainder of the simulation duration to reflect the cover-in-place WRSAs conditions (e.g., reduced infiltration). As such, the mass loading rates from the WRSAs were assumed to continue indefinitely (i.e., the source was assumed to have infinite mass).

As indicated in Table 2, values for certain solutes (e.g., phosphorus, ammonia, and radium-228) were not included in the source data. To account for potential mass of these solutes in the waste rock sources a mass loading rate was estimated based on the product of the ratio of the chloride mass loading rate in the waste rock source to chloride concentration in the UGTMF tailings and the UGTMF (CPB and CPT) tailings concentration for the undefined solute.

Table 2: Source Terms

Solute	Source Concentration (mg/L)						Mass Loading Rate (kg/yr)													
	Primary Stope		Secondary Stope		UGTMF		Reflooded Mine Workings						Waste Rock (NPAG Component, Base Case)		Waste Rock (PAG Component, Base Case)		Waste Rock (NPAG Component, Upper Case)		Waste Rock (PAG Component, Upper Case)	
	Base Case	Upper Case	Base Case	Upper Case	Base Case	Upper Case	2050	2051	2052	2053	2054	2055	Operations	Post-closure	Operations	Post-closure	Operations	Post-closure	Operations	Post-closure
Aluminum	3.6	26.8	3.3	24.2	1.4	5.3	1600	2100	340	990	1700	99	0.47	0.15	0.039	810	0.48	0.16	0.039	1200
Ammonia[a]	3.3	3.5	3.2	3.4	2.6	2.6	684	252	90	153	288	49	153	87	13	21	234	135	18	30
Arsenic	0.49	0.74	0.64	1.14	1.7	4.11	76	23	10	13	23	5	3.7	2	0.17	0.16	5.5	3.1	0.26	0.24
Boron	0.44	0.5	0.45	0.54	0.55	0.8	760	130	110	120	240	52	19	11	2.8	5.9	28	16	4.1	8.8
Cadmium	0.0029	0.0045	0.0027	0.0045	0.0013	0.0046	8.6	1.4	1.3	1.1	1.9	0.53	0.017	0.0097	0.029	0.078	0.026	0.014	0.044	0.12
Calcium	2139	2490	2251	2566	3085	3138	32000	17000	4100	8500	16000	2000	4200	2300	420	720	6300	3500	630	1100
Chloride	716	754	666	699	287	293	76000	28000	10000	17000	32000	5400	17000	9700	1400	2300	26000	15000	2000	3300
Chromium	0.042	0.14	0.04	0.228	0.025	0.884	6.8	2.3	1.3	1.9	4.7	0.49	0.55	0.31	0.12	0.13	0.83	0.46	0.18	0.2
Cobalt	0.0061	0.0125	0.006	0.0174	0.005	0.0544	94	42	11	22	55	5.1	0.37	0.2	16	32	0.55	0.31	24	49
Copper	0.13	0.19	0.14	0.21	0.23	0.39	95	100	10	41	67	4.9	1.3	0.74	33	52	2	1.1	49	78
Fluoride[a]	5.8	6.5	5.5	6.2	3.7	3.8	967	356	127	216	407	69	216	123	18	29	331	191	25	42
Iron	0.111	1.613	0.108	1.558	0.089	1.144	5200	1100	990	1400	3700	420	230	130	160	470	340	190	240	710
Lead	0.11	0.77	0.10	1.36	0.04	5.82	3.7	2.3	0.72	1.4	2.8	0.26	0.013	0.0031	0.0015	0.56	0.011	0.0027	0.0013	0.63
Lead-210	6.7×10^{-09}	2.7×10^{-08}	6.1×10^{-09}	2.6×10^{-08}	1.6×10^{-09}	1.7×10^{-08}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	1.0×10^{-07}	8.8×10^{-09}	2.8×10^{-09}	7.0×10^{-10}	2.4×10^{-09}	8.8×10^{-09}	2.8×10^{-09}	7.0×10^{-10}	2.4×10^{-09}
Magnesium	1.6	1.8	1.8	2.0	3.1	3.2	8800	6400	1400	3200	5500	660	470	260	420	2100	700	390	630	3100
Manganese	0.025	0.025	0.024	0.053	0.02	0.264	110	110	14	44	60	6.6	5.8	3.2	7.7	45	8.7	4.8	12	68
Mercury	0.0000038	0.000012	0.0000063	0.000016	0.000026	0.000045	0.56	0.26	0.07	0.13	0.24	0.039	0.055	0.031	0.0073	0.0073	0.082	0.046	0.011	0.011
Molybdenum	230	598	218	558	133	263	23000	3300	3300	2700	4600	1400	3.4	1.9	0.36	0.23	5.1	2.8	0.54	0.24
Nickel	0.005	0.035	0.007	0.068	0.02	0.311	64	49	8.5	22	39	3.7	0.76	0.42	6.9	28	1.1	0.64	10	43
Nitrate[a]	0.020	0.020	0.021	0.021	0.023	0.023	6.1	2.2	0.80	1.4	2.6	0.43	1.4	0.8	0.11	0.18	2.1	1.2	0.16	0.26
NO_2 as N[a]	0.025	0.026	0.025	0.025	0.024	0.024	6.3	2.3	0.83	1.4	2.7	0.45	1.4	0.8	0.12	0.19	2.2	1.2	0.17	0.27
Phosphorus[a]	0.027	0.028	0.027	0.028	0.026	0.026	7.0	2.6	0.91	1.6	2.9	0.49	1.6	0.9	0.13	0.21	2.4	1.4	0.18	0.30
Polonium-210	2.0×10^{-11}	2.4×10^{-11}	1.9×10^{-11}	2.3×10^{-11}	1.2×10^{-11}	1.3×10^{-11}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	1.9×10^{-09}	6.6×10^{-11}	2.2×10^{-11}	5.4×10^{-12}	1.9×10^{-11}	6.6×10^{-11}	2.2×10^{-11}	5.4×10^{-12}	1.9×10^{-11}
Radium-226	7.5×10^{-06}	7.8×10^{-06}	7.0×10^{-06}	7.2×10^{-06}	3.1×10^{-06}	3.2×10^{-06}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.4×10^{-03}	1.6×10^{-06}	1.2×10^{-06}	3.0×10^{-07}	1.6×10^{-06}	1.6×10^{-06}	1.2×10^{-06}	3.0×10^{-07}	1.6×10^{-06}
Radium-228[a]	6.6×10^{-10}	1.9×10^{-09}	7.1×10^{-10}	1.8×10^{-09}	1.1×10^{-09}	1.8×10^{-09}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	5.0×10^{-07}	$0.0 \times 10^{+00}$	4.3×10^{-10}	$0.0 \times 10^{+00}$	5.9×10^{-10}	$0.0 \times 10^{+00}$	4.3×10^{-10}	$0.0 \times 10^{+00}$	5.9×10^{-10}
Selenium	1.1	1.6	1.0	1.5	0.5	0.6	27	4.4	4.1	4.1	9.7	1.7	0.36	0.2	0.42	1.8	0.54	0.3	0.63	2.6
Silver	0.0096	0.0195	0.0089	0.0184	0.0031	0.01	3	1.3	0.39	0.71	1.3	0.21	0.29	0.16	0.038	0.039	0.43	0.24	0.057	0.058
Sodium	3048	3267	2893	3205	1728	2745	4000	1300	780	1000	2300	270	230	130	34	22	340	190	51	34
Strontium	0	0	0	0	0	0	420	110	67	89	200	32	22	12	4.6	13	33	19	6.9	20
Sulphate	12091	13837	11764	13336	9315	9577	130000	88000	17000	40000	67000	9000	12000	6400	4700	18000	17000	9700	7000	27000
Thorium-228	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 2: Source Terms

Solute	Source Concentration (mg/L)						Mass Loading Rate (kg/yr)													
	Primary Stope		Secondary Stope		UGTMF		Reflooded Mine Workings						Waste Rock (NPAG Component, Base Case)		Waste Rock (PAG Component, Base Case)		Waste Rock (NPAG Component, Upper Case)		Waste Rock (PAG Component, Upper Case)	
	Base Case	Upper Case	Base Case	Upper Case	Base Case	Upper Case	2050	2051	2052	2053	2054	2055	Operations	Post-closure	Operations	Post-closure	Operations	Post-closure	Operations	Post-closure
Thorium-230	0	0	0	0	0	0	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	2.7×10^{-03}	5.0×10^{-05}	1.6×10^{-05}	3.9×10^{-06}	1.3×10^{-05}	5.0×10^{-05}	1.6×10^{-05}	3.9×10^{-06}	1.3×10^{-05}
Uranium-234	8.9×10^{-07}	6.6×10^{-06}	9.4×10^{-07}	6.7×10^{-06}	1.3×10^{-06}	6.8×10^{-06}	0.18	0.18	0.18	0.18	0.18	0.18	0.00389	0.00124	0.00031	0.00286	0.00389	0.00124	0.00031	0.00286
Uranium-238	0.017	0.123	0.017	0.123	0.024	0.126	3411	3411	3411	3411	3411	3411	72	23	5.7	53	72	23	5.7	53
Vanadium	0.037	0.05	0.057	0.069	0.21	0.214	53	10	7.8	7.8	15	3.4	1.1	0.61	0.1	0.019	1.7	0.92	0.15	0.029
Zinc	0.034	0.053	0.04	0.114	0.089	0.573	130	83	17	39	66	8.9	12	6.5	4.8	16	18	9.8	7.2	24

Source: TSD XVII.

Notes: Waste rock loadings applied in the solute transport model include the sum of PAG and NPAG components. The Operations source applies in the first 30 years of the simulation, and the Closure source applies for the remainder of the simulation. Reflooded mine workings reflect by-year loadings following reflooding.

a) The mass loading for this solute was not provided in data (including waste rock and reflooded mine workings). Source concentrations were approximated based on the ratio of chloride in UTGMF tailings to chloride in the waste rock or reflooded mine workings components, except for Radium-228, which was based on the ratio of Radium-226.

PAG = potentially acid generating; NPAG = non-potentially acid generating; UGTMF = Underground Tailings Management Facility.

3.3.2 Groundwater Flow Pathways

As mining progresses, the stopes and UGTMF chambers would be backfilled with CPB and CPT, as outlined above. Upon completion of mining and placement of underground waste, the mine would be flooded, and groundwater pressures would re-establish to natural hydrostatic conditions, which are anticipated to be similar to those observed in the predevelopment period. Upon saturation of the mine backfill and open workings, groundwater would migrate from these source areas, through the geological pathways, discharging to the receiving environment. Similarly, seepage from the waste rock remaining at grade would continue at a reduced rate, as compared to Operations, following cover system placement.

The groundwater flow model was used to estimate the rates of flow through the underground waste materials and within the flow pathways. This was achieved using the current conditions (i.e., calibrated) model as a starting point and adding hydraulic conductivity zones to represent the CPT in the UGTMF, CPB in the mined stopes, and open workings, as illustrated in Figure A-16. A steady state simulation was completed using this model and results of the simulation were analyzed to estimate rates of flow through the waste zones. This model is distinct from that used to estimate groundwater inflows to the underground workings and as such does not include any boundaries to represent dewatering.

Delineation of the groundwater flow pathways and travel times was completed by releasing particles at the mine waste storage areas (e.g., UGTMF, backfilled stopes, and WRSAs) and forward-tracking their position through the simulated groundwater flow field to the ultimate groundwater discharge location. Groundwater travel time through the pathways is estimated in the model as a function of the simulated hydraulic gradients, applied hydraulic conductivity values, and effective porosity values.

The governing equation for 1-D transport of a solute can be written as

$$R\frac{\partial c}{\partial t} = D_x\frac{\partial^2 c}{\partial x^2} - u\frac{\partial c}{\partial x} - \lambda Rc \qquad \text{(Equation 3)}$$

$$u = \frac{V_D}{n_e} \qquad \text{(Equation 4)}$$

$$R = 1 + \frac{K_D \rho}{n_e} \qquad \text{(Equation 5)}$$

where:

R = retardation factor;

c = solute concentration (M/L^3);

t = time (T);

D_x = dispersion coefficient in the direction of flow (L^2/T);

x = position in the direction of flow (L);

λ = first-order decay rate (T^{-1}).

u = pore water velocity (L/T);

V_D = Darcy velocity (L/T);

K_D = distribution coefficient (L^3/M).

ρ_D = bulk dry density (M/L^3); and

n_e = effective porosity (-).

To simulate transport of solutes involved in sequential first-order decay reactions, Equation 3 is applied to the first species in the decay chain and coupled with the following, which represents transport of the remaining species:

$$R_i \frac{\partial c_i}{\partial t} = D_x \frac{\partial^2 c_i}{\partial x^2} - u \frac{\partial c_i}{\partial x} - \lambda_i R_i c_i + \lambda_{i+1} R_{i+1} c_{i+1} \quad \text{(Equation 6)}$$

for i = 1…n

3.4 Solute Transport Properties

Table 3 includes details on the properties applied to the solute transport model. The data used to support these values are summarized as follows:

- Adsorption to the materials within the seepage pathways was considered. Solute partitioning coefficients were applied to the bedrock pathways (i.e., within the fault zone and sandstone) as specified in Table 3. The values selected for this assessment were derived from site analogue values, where available, or literature values as indicated in the table.
- Effective porosity and density values were assigned based on site analogue data (Golder 2006). Porosities were 1.5% for the fault zone, 9.8% for the sandstone, and 30% for the overburden, and density was 2,610 kilograms per cubic metre (kg/m^3) for the fault zone, 2,390 kg/m^3 for the sandstone, and 1,800 kg/m^3 for the overburden.
- The surface areas of the UGTMF CPT and primary and secondary stope CPB were determined based on 3-D mine plan files for the underground workings provided by NexGen (provided November 19, 2020).
- Groundwater flow pathway dimensions were delineated through a particle tracking analysis, as detailed in Section 3.3.
- The specific discharge through the host rock adjacent the tailings and backfill applied to the solute transport calculation was conservatively selected as the greatest value (i.e., 1×10^{-05} m/day) predicted by the flow model.
- Dispersivity was assumed to be 10% of the pathway length (Thompson 2006).
- In the absence of data, the diffusivity source for boron and nickel were assumed to be the same as bicarbonate (HCO_3; Li and Gregory 1974) and ammonium (Li and Gregory 1974), respectively.

Table 3: Solute Transport Properties

Solute	Adsorption-Partition Coefficient				Diffusivity	
	Fault		Sandstone			
	(m^3/kg)	Source	(m^3/kg)	Source	1×10^{-05} cm^2/s	Source
Aluminum	0	2	0	2	0.346	7
Ammonia	0	1	0	1	1.96	8
Arsenic	0.0011	3	0.0015	5	0.31	3
Boron	0.00019	1	0.00019	1	1.18	Assumed same as bicarbonate (HCO_3) in 8
Cadmium	0.017	4	0	6	0.72	7
Calcium	0	2	0	2	0.673	7
Chlorine	0	2	0	2	2.03	7
Chromium	0.001	1	0.001	1	0.6	7
Cobalt	0.019	1	0	2	0.34	7
Copper	0.04	4	0.017	6	0.71	7
Fluoride	0	1	0	1	2.03	Assumed same as Chloride
Iron	0.0015	1	0.0015	1	0.719	7
Lead	0.053	3	0.023	5	0.95	7
Magnesium	0	2	0	2	0.594	8
Manganese	0	2	0	2	0.575	7
Mercury	0.03	1	0.03	1	0.03	7
Molybdenum	0.000455	4	0.0015	5	0.31	8
Nickel	0.0055	4	0.0063	5	0.66	Assumed the same as ammonium (NH_4) in 7
Nitrate	0	2	0	2	1.9	7
Nitrogen dioxide	0	2	0	2	1.91	8
Phosphorus	0	2	0	2	0.824	8
Polonium	0.029	3	0.013	5	0.45	7
Radium	0.081	4	0.043	5	0.89	7
Selenium	0.0011	4	0.0015	5	0.31	7
Silver	0.0004	1	0.0004	1	1.648	7
Sodium	0	2	0	2	1.13	Assumed same as Molybdenum
Strontium	0	2	0	2	0.794	8
Sulphate	0	4	0	5	0.54	7
Thorium	0.1	4	0.28	6	0.15	8
Uranium	0.0071	3	0.003	5	0.43	8
Vanadium	0	2	0	2	1	Assumed value
Zinc	0.04	3	0.017	5	0.34	8

Parameter	Value
UGTMF Surface Area	1,565,500 m^2
Primary Backfill Surface Area	531,700 m^2
Secondary Backfill Surface Area	1,013,100 m^2
Specific Discharge in Host Rock (q)	1×10^{-05} m/day
Fault zone effective porosity (n_e)	1.5%
Sandstone effective porosity (n_e)	9.8%
Overburden effective porosity (n_e)	30%
Fault zone density	2,610 kg/m^3
Sandstone density	2,390 kg/m^3
Overburden density	1,800 kg/m^3
Overburden pathway 1 gradient	0.046 m/m
Overburden pathway 2 gradient	0.035 m/m
Overburden pathway 1 cross-sectional area	17,000 m^2
Overburden pathway 2 cross-sectional area	10,000 m^2
Overburden pathway 1 length	900 m
Overburden pathway 2 length	1,200 m
Fault pathway cross-sectional area	34,000 m^2
Fault pathway length	260 m

Sources:

1. Stenge and Peterson 1989, Table 4.1. The value was selected based on less than 10% clay and a pH of 5-9.
2. Assumed zero.
3. Value used from Golder 2006 for Regolith / Fault and diffusivity.
4. Value used from Golder 2013 for Regolith.
5. Value used from Golder 2006 for Sandstone.
6. Value used from Golder 2013 for Sandstone.
7. CRC 2004, Section 5.
8. Li and Gregory 1974, Table 1.

Note: Solute partitioning coefficients were not applied to the overburden pathway.

4 RESULTS

The main objectives of the predictive modelling were to estimate the groundwater inflows to the underground development and extent of depressurization during Operations, and the solute mass loading rates from groundwater pathways to downgradient environmental receptors.

4.1 Groundwater Inflows

Figure A-18 provides the simulated groundwater inflow rates to the underground development during Operations. For the base case simulation, during the period from 2022 (Year -4) to 2035 (Year 10), the groundwater inflows ranged from a total of approximately 1,200 cubic metres per day (m^3/d) to 2,000 m^3/d, with the greatest portion of inflow occurring at the “other workings” (i.e., any underground opening not associated with the UGTMF or stope excavations). At 2035 (Year 10), the total groundwater inflows increased to approximately 3,900 m^3/d, corresponding to the opening of additional stopes in the upper levels of the mine (at 360 masl). After 2041 (Year 16), the groundwater inflows are relatively stable at approximately 3,500 m^3/d total inflow, with approximately 60% of inflows derived from stopes and 20% derived from each of the UGTMF and additional workings areas.

When the hydraulic conductivity of the fault zone was increased by a factor of 5, the simulated groundwater inflows to the underground mine increased by a factor of approximately 2 for the first 11 years of the simulation, then gradually declined to a factor of 1.2 above the base case for the remainder of the simulation. This indicates that the simulated groundwater inflow rates are relatively sensitive to the input value assigned to the hydraulic conductivity of the fault zone.

For the simulation where hydraulic conductivity of the basement rock was increased by a factor of 2, the groundwater inflows to the underground mine increased by a factor of approximately 1.6 in the first 11 years of the simulation, then gradually declined to a factor of 1.1 above the base case for the remainder of the simulation. For Years 2 and 3, the simulated groundwater inflow rates were greater than the base case by a factor of 1.8. This indicates that the simulated groundwater inflow rates are approximately proportional to the hydraulic conductivity value for the basement rock for the early period of mine development.

4.2 Drawdown

The extent of the simulated groundwater drawdown in bedrock (i.e., at approximately the upper horizon of the mine) at the end of Operations is illustrated in Figure A-19, represented as metres of water depressurization of the bedrock. The simulated drawdown extends approximately 2 km to the north, 4 km to the south, and 3.5 km in both the east and west directions, based on the 5 m depressurization contour. Vertically, the extent of depressurization is generally limited to the basement rock, as the overlying sandstone aquifer is more transmissive by over four orders of magnitude.

4.3 Baseflow

The results of the groundwater flow model were reviewed to evaluate the changes in groundwater discharge to surface water features within the model domain. Based on this review, it was determined that a conservative approach would be taken to apply a reduction in groundwater discharge to the Patterson Lake watershed that is equivalent to the calculated groundwater inflow to the underground mine workings. Under predevelopment conditions, the estimated groundwater discharge to the watershed is approximately 68,300 m^3/d.

As noted above, peak groundwater inflows to the mine are approximately 3,900 m^3/d, representing a total baseflow reduction of approximately 6%.

4.4 Pathways Delineation and Travel Times

The groundwater flow pathways for the long-term post-closure condition are illustrated in Figure A-20a for underground sources and Figure A-20b for at-grade sources. Based on the particle tracking analysis, groundwater originating at the UGTMF, and stope backfill source areas migrated vertically upward primarily through the fault and shear zones, then laterally through the sandstone, before discharging within Patterson Lake. The total vertical length of the flow pathway for the underground sources is approximately 260 m, as measured from the top of the mine (i.e., 180 masl) to the top of the paleo weathered rock unit (i.e., 440 masl). The cross-sectional area through the fault zones was estimated to be 34,400 m^2 based on the number of fault zones intersected by the mine workings (i.e., 10), the average length of faults intersected by the source areas (i.e., 344 m), and an assumed width of 10 m per fault zone. The total horizontal length through the sandstone is approximately 1,000 m, with a flow pathway width of 350 m and height of 20 m estimated based on the particle pathway dimensions.

Based on the hydraulic gradients, hydraulic conductivities, pathway dimensions, and effective porosity values applied to the pathways (i.e., 0.015 for the fault zone and 0.098 for the sandstone), the approximate advective groundwater travel time from the upper horizon of the mine to the discharge location at Patterson Lake is estimated to be approximately 1,000 years.

Groundwater originating beneath the WRSAs travels through the overburden bidirectionally to the north and south, ultimately discharging in Patterson Lake for both pathways. The flow component to the south originates primarily from the NPAG WRSA and the component directed to the north originates from both the NPAG and PAG WRSAs. The approximate advective groundwater travel time from the WRSAs to Patterson Lake was estimated at 43 years to the north and 77 years to the south.

4.5 Mass Loadings to Receptors

The simulated peak solute mass loading rates are provided in Table 4, along with sensitivity scenarios described in Section 4, Results, and plotted for selected solutes in Figure A-21. Peak mass loadings are driven primarily by waste rock and reflooded mine workings, based on a review of mass loadings by source area. This is evident in the Figure A-21 plots for copper, uranium, and radium, for example, where solute mass arrives at the receptor early (i.e., approximately 100 years), and the loading rate is maintained throughout the simulation duration due to the infinite source assumption. For some solutes, the arrival of mass loading from the reflooded mine workings is visible in the loading curves (e.g., for uranium this occurs at around 10,000 years). For a minority of solutes, the relative portions of mass from underground backfill and waste rock sources are more balanced (i.e., for sulphate, calcium, and strontium). Solutes where the peak mass loading rates are driven by underground sources include molybdenum, sodium, and (to a lesser extent) vanadium.

Table 4: Results Summary

		Solute																	
		Ag	Al	As	B	Ca	Cd	Cl	Co	Cr	Cu	F	Fe	Hg	Mg	Mn	Mo	Na	NH3
Base Case Peak Mass Loading Rate (g/yr)		210.6	812669	2918	20756	5376000	89.78	13030000	32209	472	52879	163880	604519	38.93	2362000	48220	175901	2463000	115559
Percent Change Relative to Base Case	SR1 - Bedrock K	0.9%	0.0%	3.0%	2.8%	1.1%	0.1%	-1.5%	0.0%	0.2%	0.0%	-1.5%	0.2%	0.0%	0.0%	0.0%	2.8%	2.6%	-1.5%
	SR2 - Fault Zone K	2.2%	0.1%	6.2%	8.4%	7.1%	0.6%	-1.4%	0.0%	1.7%	0.1%	-1.8%	0.4%	0.0%	0.0%	0.0%	25.3%	23.9%	-1.9%
	SR3 - UGTMF Tailings K	0.1%	0.0%	11.2%	0.3%	10.1%	0.3%	0.4%	0.0%	1.0%	0.1%	0.4%	0.0%	0.0%	0.0%	0.0%	14.6%	13.5%	0.4%
	SR4 - Backfill K	0.8%	0.1%	7.1%	0.5%	12.9%	1.0%	1.5%	0.0%	2.9%	0.1%	1.0%	0.0%	0.0%	0.0%	0.0%	42.6%	40.3%	0.8%
	SR5 - Fracture Zone Area	3.1%	0.0%	0.0%	11.3%	-2.9%	0.0%	-2.8%	0.0%	0.3%	0.0%	-2.9%	0.6%	0.0%	0.0%	0.0%	0.0%	0.0%	-3.0%
	SR6 - Upperbound UGTMF Source	0.3%	0.1%	17.1%	0.1%	0.2%	0.8%	0.0%	0.0%	37.9%	0.1%	0.0%	0.0%	0.0%	0.0%	0.1%	15.3%	8.7%	0.0%
	SR7 - Upperbound Backfill Source	1.6%	1.7%	10.4%	0.1%	3.7%	1.3%	0.2%	0.0%	24.2%	0.1%	0.3%	0.1%	0.0%	0.0%	0.0%	130%	8.0%	0.1%
	SR8 - Upperbound Waste Rock Source	47.0%	48.0%	40.4%	38.1%	27.2%	51.6%	46.4%	53.1%	46.6%	49.8%	46.9%	49.6%	48.9%	47.8%	51.0%	0.5%	2.9%	47.1%
	SR9 - All Upperbound Sources	52.3%	51.0%	107.1%	39.1%	57.4%	56.3%	48.7%	53.2%	160%	50.3%	48.7%	49.8%	48.9%	47.9%	51.3%	284%	85.2%	48.4%

		Solute																	
		Ni	NO2	NO3	P	Pb	Pb210	Po210	Ra226	Ra228	Se	SO4	Sr	Th228	Th230	U234	U238	V	Zn
Base Case Peak Mass Loading Rate (g/yr)		28441	1066	1023	1171	638.8	0.00003081	5.243E-07	0.002796	2.377E-09	2779	34200000	28880	1.184E-09	0.03176	4.191	77582	3082	22544
Percent Change Relative to Base Case	SR1 - Bedrock K	0.0%	-1.5%	-1.5%	-1.5%	0.2%	0.0%	0.0%	0.0%	0.0%	0.6%	1.1%	3.8%	0.0%	0.0%	0.5%	0.5%	4.0%	0.0%
	SR2 - Fault Zone K	0.0%	-2.1%	-2.1%	-2.0%	3.1%	0.1%	0.1%	0.0%	0.0%	7.2%	7.3%	6.5%	0.0%	0.0%	1.1%	1.1%	6.8%	0.0%
	SR3 - UGTMF Tailings K	0.0%	0.4%	0.4%	0.3%	1.2%	0.0%	0.0%	0.0%	0.0%	3.5%	5.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.6%	0.1%
	SR4 - Backfill K	0.0%	0.6%	0.5%	0.6%	5.4%	0.0%	0.0%	0.0%	0.0%	12.5%	11.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.5%	0.1%
	SR5 - Fracture Zone Area	0.0%	-3.0%	-3.0%	-3.1%	0.0%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	8.7%	0.0%	0.0%	1.9%	1.9%	8.8%	0.0%
	SR6 - Upperbound UGTMF Source	0.2%	0.0%	0.0%	0.0%	185.4%	0.0%	0.1%	0.0%	0.0%	0.8%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
	SR7 - Upperbound Backfill Source	0.1%	0.0%	0.0%	0.0%	119.6%	0.2%	0.2%	0.1%	0.0%	12.0%	3.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%
	SR8 - Upperbound Waste Rock Source	53.5%	47.2%	47.3%	47.1%	10.9%	0.0%	0.0%	0.0%	0.0%	32.4%	36.0%	35.0%	0.0%	0.0%	0.0%	0.0%	0.0%	50.1%
	SR9 - All Upperbound Sources	54.1%	48.3%	48.3%	48.2%	556%	0.4%	0.5%	0.3%	0.0%	67.8%	58.0%	35.0%	0.0%	0.0%	0.1%	0.1%	1.3%	51.4%

SR = sensitivity run; UGTMF = underground tailings management facility
Shading indicates range in values:

minimum (-3.1%) — 0% — maximum (556%)

5 SENSITIVITY ANALYSIS

To address the uncertainty associated with model input parameters and assumptions, a sensitivity analysis was completed. This involved completing additional simulations with varied inputs and comparing their output (i.e., in terms of peak mass loading rates to receptors) with the base case results. The additional simulations consisted of the following:

- **Sensitivity Run 1 (SR1):** increase hydraulic conductivity of bedrock by a factor of 5;
- **Sensitivity Run 2 (SR2):** increase hydraulic conductivity of fault zone by a factor of 5;
- **Sensitivity Run 3 (SR3):** increase hydraulic conductivity of the UGTMF tailings to the maximum value from testing (i.e., factor of 4);
- **Sensitivity Run 4 (SR4):** increase hydraulic conductivity of the backfill to the maximum value from testing (i.e., factor of 5);
- **Sensitivity Run 5 (SR5):** reduce fault zone contact area (i.e., the cross-sectional area of the flow path) by a factor of 2;
- **Sensitivity Run 6 (SR6):** upper bound UGTMF source;
- **Sensitivity Run 7 (SR7):** upper bound primary + secondary backfill source;
- **Sensitivity Run 8 (SR8):** upper bound waste rock source; and
- **Sensitivity Run 9 (SR9):** all upper bound sources combined.

Results of the sensitivity analysis in terms of the peak mass loading rates are provided in Table 4 and in terms of the relative change in peak mass loading as compared to the base case in Figure A-22; the time-history plots for select solutes are provided in Figure A-21. A review of the results led to the following observations:

- Because the surface waste rock loadings represent a large portion of the overall mass loadings, the results were generally most sensitive to the upper bound waste rock source term.
- The overall highest peak mass loading rates occurred when all upper bound sources were combined (SR9).
- The solute loadings were also sensitive to the source terms for backfill and the UGTMF tailings for solutes where the upper bound source was much greater than the base case (e.g., lead, where the upper bound source was much greater than the base case for the UGTMF).
- In general, model results were not sensitive (i.e., less than 5% difference) for simulations in which adjustments were made to the hydraulic conductivities of the materials (SR1 to SR4) and the cross-sectional area of the fracture zone (SR5).

6 KEY FINDINGS

The potential residual effects of the Project on hydrogeology, or groundwater quantity and quality, which represents an intermediate component for the EA, were characterized through an evaluation of baseline data and a hydrogeological modelling approach. The Project has the potential to cause adverse effects on hydrogeology through the inflow of groundwater during Operations of the underground mine. Seepage from the WRSAs have the potential to affect groundwater quality in the shallow overburden aquifer. Following Closure of the mine, groundwater elevations would re-establish to current conditions (i.e., static) and groundwater would be in contact with the backfilled materials. Therefore, the Project has the potential to cause adverse effects on groundwater quality in the bedrock aquifer, and along the groundwater flow pathway to its ultimate discharge location. A summary of the key findings from this assessment is provided as follows:

- During Operations, seepage to the mine would result in a depressurization of the surrounding bedrock, which would be observed as a reduction in groundwater elevation at monitoring locations (i.e., groundwater drawdown). The extent of the simulated groundwater drawdown in bedrock resulting from the mine dewatering at the end of Operations is extended approximately 2 km to the north, 4 km to the south, and 3.5 km in both the east and west directions, based on the 5 m drawdown contour. Vertically, the extent of depressurization is generally limited to the basement rock, as the overlying sandstone aquifer is considerably more transmissive. The maximum simulated drawdown within the sandstone was estimated to be less than 5 m in the immediate area of the mine workings.
- For the Base Case simulation, during the period from 2022 to 2035, the groundwater inflows to the underground development were predicted to range from a total of approximately 1,200 m^3/d to 2,000 m^3/d, with the greatest portion of inflow occurring at the underground openings not associated with the UGTMF or stope excavations. At 2035, the total groundwater inflows increased to approximately 3,900 m^3/d, corresponding to the opening of additional stopes. After 2041, the groundwater inflows are relatively stable at approximately 3,500 m^3/d total inflow, with approximately 60% of inflows derived from stopes and 20% derived from each of the UGTMF and additional workings areas.
- During Operations, the groundwater seepage collected from the underground mine would be treated and discharged to Patterson Lake. Assuming that all groundwater seepage collected at the underground mine originates as surface infiltration from the Patterson Lake catchment, the resulting long-term net change to the overall water balance of the surface water system is negligible.
- Based on the particle tracking analysis, groundwater originating at the UGTMF and stope backfill source areas is predicted to migrate vertically upward primarily through the fault and shear zones, then laterally through the sandstone, before discharging within Patterson Lake (the “receptor”). The total vertical length of the flow pathway for the underground sources is approximately 260 m, as measured from the top of the mine (i.e., 180 masl) to the top of the paleoweathered rock unit (i.e., 440 masl). The approximate advective groundwater travel time from the upper horizon of the mine to the discharge location at Patterson Lake is estimated to be approximately 1,000 years.
- Seepage from beneath the WRSAs was predicted to infiltrate vertically downward to the water table then laterally towards Patterson Lake in both the northerly and southerly directions. For the overburden pathways, the approximate advective groundwater travel time from the piles to Patterson Lake was 43 years to the north and 77 years to the south.

- Based on a review of the solute transport model output, including a comparison of mass loading rates from individual source areas, it was determined that peak mass loadings are driven primarily by waste rock and reflooded mine workings for most solutes. For a minority of solutes, the relative portions of mass from underground backfill and waste rock sources is more balanced (i.e., for sulphate, calcium, and strontium). Solutes where the peak mass loading rates are driven by underground sources include molybdenum, sodium, and, to a lesser extent, vanadium.
- The model sensitivity analysis indicated that because the surface waste rock loadings represent a large portion of the overall mass loadings, the results were generally most sensitive to the upper bound waste rock source term. The loadings to Patterson Lake were also sensitive to the source terms for backfill and the UGTMF tailings for solutes where the upper bound source was much greater than the Base Case (e.g., lead, where the upper bound source was much greater than the Base Case for the UGTMF).
- In general, model results were not sensitive (i.e., less than 5% difference) for simulations in which adjustments were made to the hydraulic conductivities of the groundwater flow pathways and backfill materials and the cross-sectional area of the fracture zone area.

Results from the hydrogeological modelling and assessment were provided to the hydrology (EIS Section 9, Hydrology) and surface water quality (EIS Section 10, Surface Water Quality and Sediment Quality) disciplines for the assessment of how changes to groundwater may affect the receiving environment.

7 MODEL LIMITATIONS

Hydrogeological investigations and groundwater modelling are dynamic and inexact sciences. They are dynamic in the sense that the state of any hydrological system is changing with time and in the sense that the science is continually developing new techniques to evaluate these systems. They are inexact in the sense that groundwater systems are complicated beyond human capability to evaluate them comprehensively in detail, and we invariably do not have sufficient data to do so. A groundwater model uses the laws of science and mathematics to draw together the available data into a mathematical or computer-based representation of the essential features of an existing hydrogeological system. While the model itself obviously lacks the detailed reality of the existing hydrogeological system, the behaviour of a valid groundwater model reasonably approximates that of the real system. The validity and accuracy of the model depends on the amount of data available relative to the degree of complexity of the geologic formations, the site geochemistry, the fate and transport of the dissolved compounds, and on the quality and degree of accuracy of the data entered. Model predictions are expected to differ from measured data collected in the future due to the inherent uncertainty of hydrogeological systems. Therefore, every groundwater model is a simplification of a reality and the model described in this report is not an exception.

This model provides a predictive scientific tool to evaluate the effects on a real groundwater system of specified hydrological stresses and/or to compare various scenarios in a decision-making process; however, despite the professional care taken during the construction of the model and in conducting the simulations, its accuracy is bound to the normal uncertainty associated to groundwater modelling and no warranty, expressed or implied, is made.

CLOSING

Golder is pleased to submit this report to NexGen in support of the environmental assessment for the Rook I Project. For details on the limitations and use of information presented in this report, please refer to the Study Limitations section following this page. If you have any questions or require additional details related to this study, please contact the undersigned.

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STUDY LIMITATIONS

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Golder has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practicing under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty expressed or implied is made. The findings and conclusions documented in this report have been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of or variation in the site conditions, purpose or development plans, or if the project is not initiated within a reasonable time frame after the date of this report, may alter the validity of the report.

The scope and the period of Golder's services are as described in Golder's proposal, and are subject to restrictions and limitations. Golder did not perform a complete assessment of all possible conditions or circumstances that may exist at the site referenced in the report. If a service is not expressly indicated, do not assume it has been provided. If a matter is not addressed, do not assume that any determination has been made by Golder in regard to it. Any assessments, designs and advice made in this report are based on the conditions indicated from published sources and the investigation described. No warranty is included, either express or implied, that the actual conditions will conform exactly to the assessments contained in this report. Where data supplied by the Client or other external sources (including without limitation, other consultants, laboratories, public databases), including previous site investigation data, have been used, it has been assumed that the information is correct unless otherwise stated. No responsibility is accepted by Golder for incomplete or inaccurate data supplied by others.

The passage of time affects the information and assessment provided in this report. Golder's opinions are based upon information that existed at the time of the production of the report. The Services provided allowed Golder to form no more than an opinion of the actual conditions of the site at the time the site was visited and cannot be used to assess the effect of any subsequent changes in the quality of the site, or its surroundings, or any laws or regulations.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be to the foregoing and to the entirety of the report. Golder cannot be responsible for use of portions of the report without reference to the entire report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client and were prepared for the specific purpose set out herein. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, is the responsibility of such third parties. Golder accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

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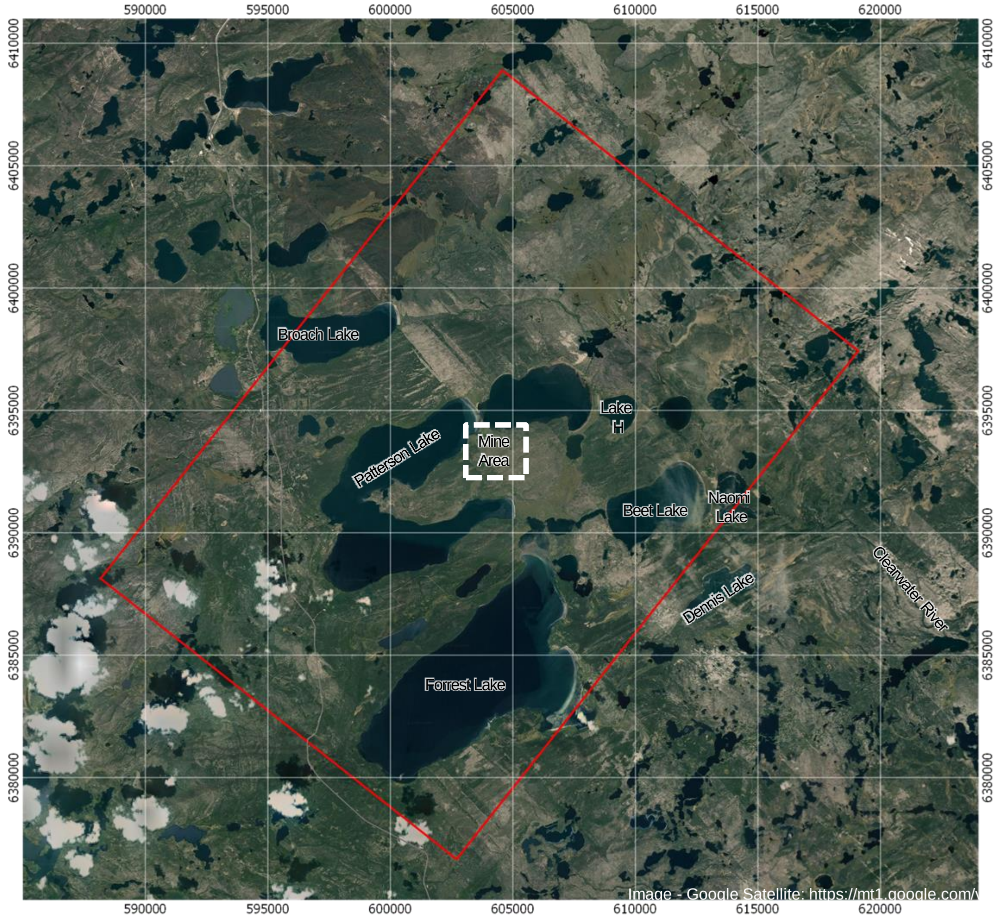
Appendix A

Solute Transport Modelling Figures



LEGEND

- Surface Facilities
- Underground Development
- Waste Rock Stockpiles
- Extent of Groundwater Flow Model

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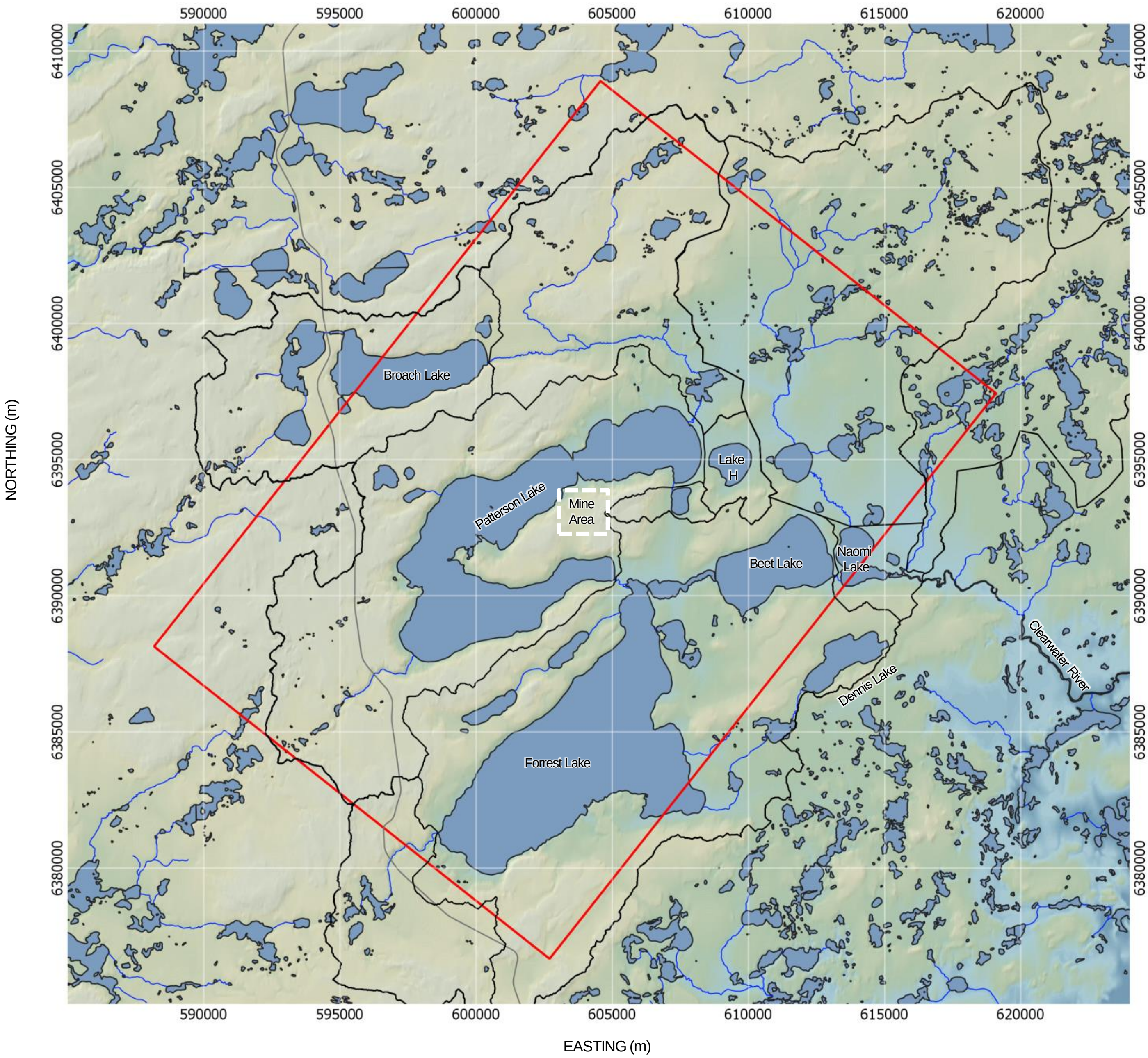
DESIGN	NB
REVIEW	MT
APPROVED	MT

TITLE
SITE LAYOUT AND MODEL DOMAIN

PROJECT No.	PHASE	Rev.	Figure
20144150	3104	1	A-1



LEGEND

- Extent of Groundwater Flow
- Model Surface Drainage
- Catchments Watercourse
- Waterbody

Ground Surface Elevation (masl)

540 490

Note:

1) Surface water features shown for Clearwater River catchment only

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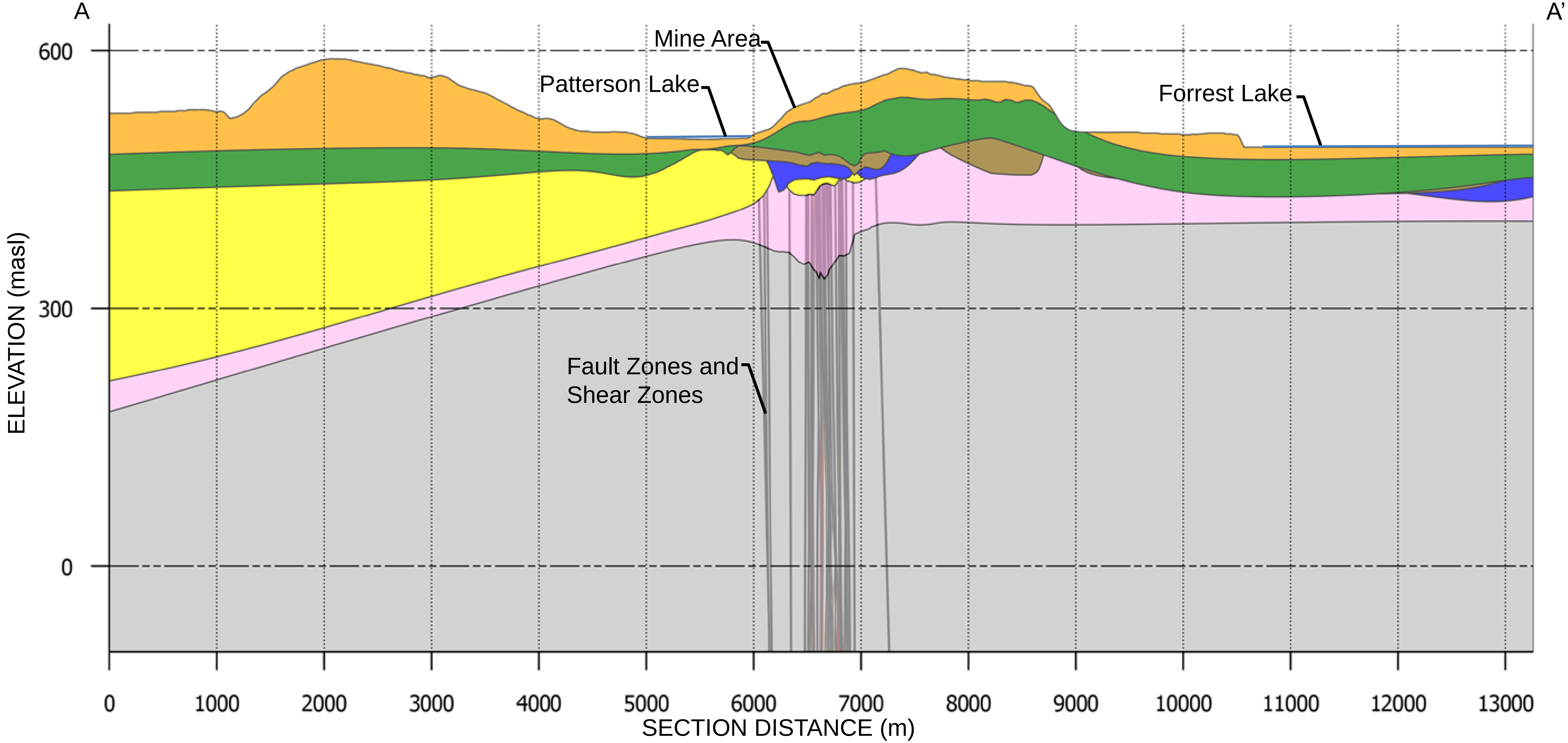
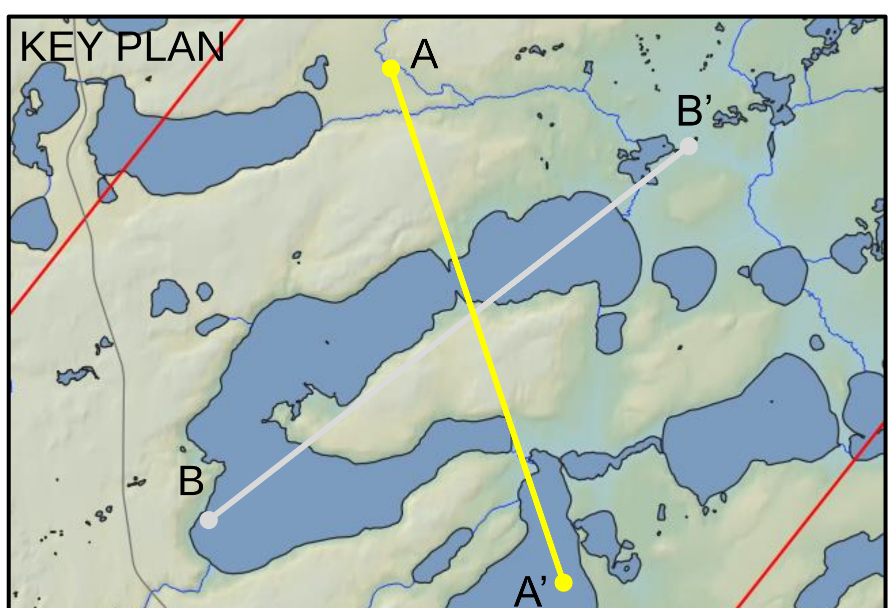
TITLE

TOPOGRAPHY AND DRAINAGE

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-2





LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK

Notes:
Vertical exaggeration: 8x

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PROJECT
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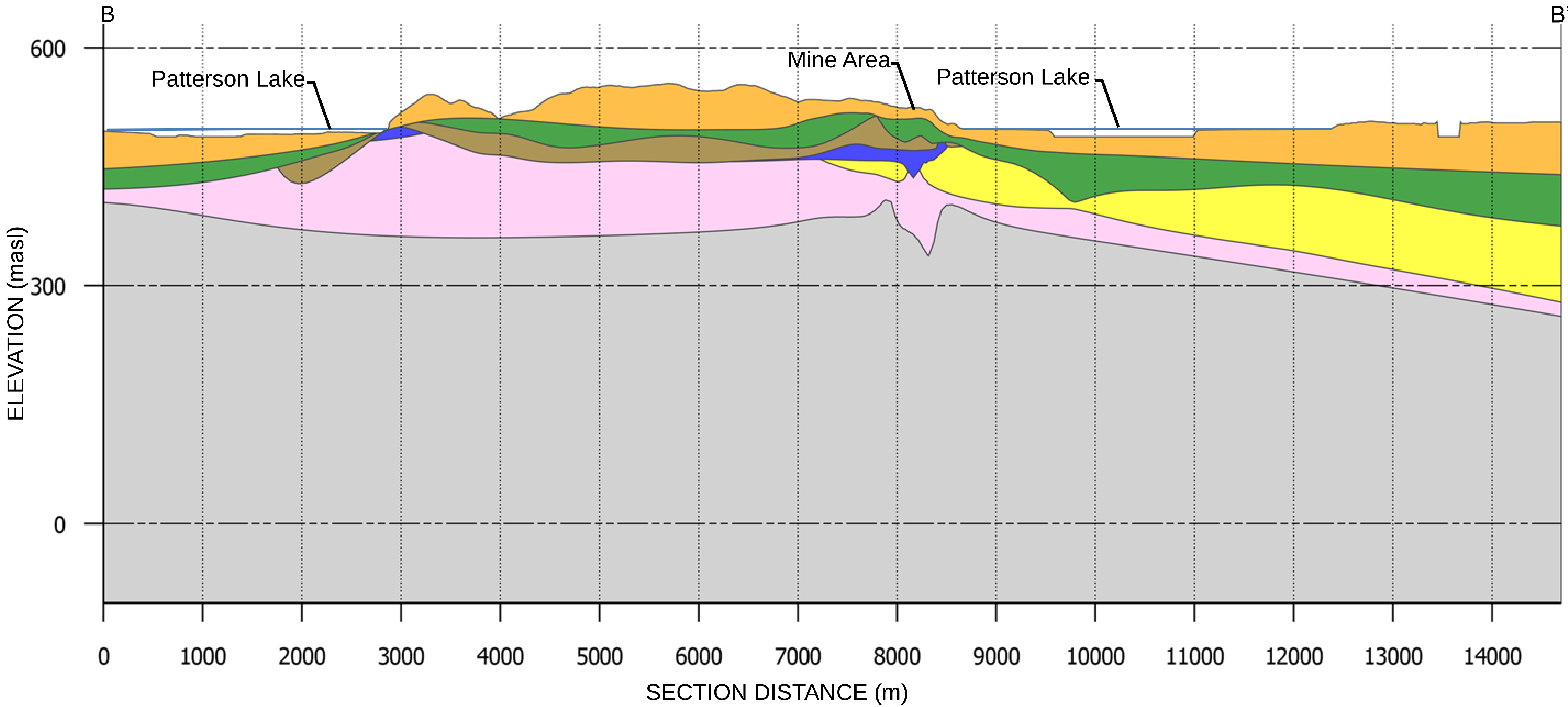
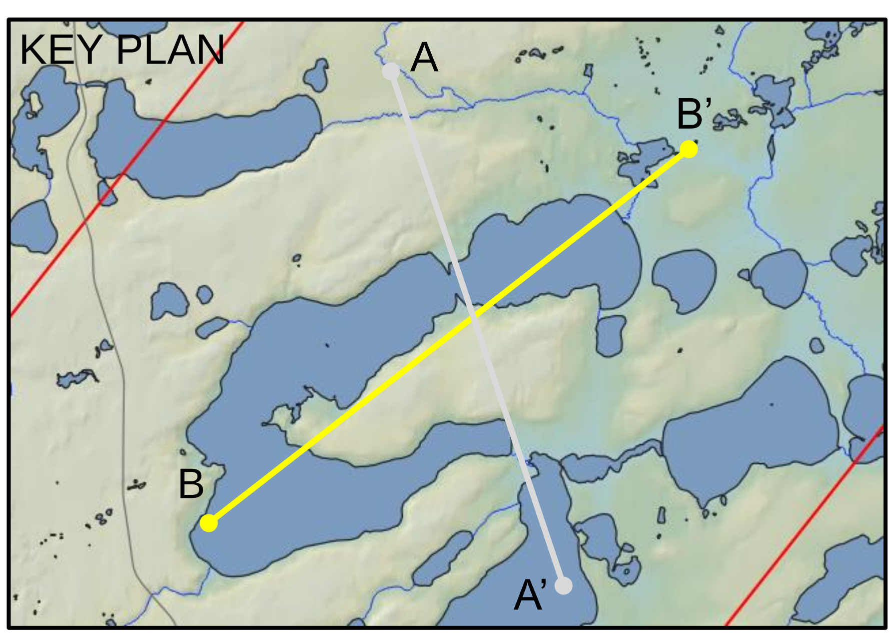
TITLE
CONCEPTUAL HYDROGEOLOGICAL MODEL
REGIONAL CROSS-SECTION A-A'
(NORTHWEST-SOUTHEAST)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-3a





LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK

Notes:
Vertical exaggeration: 8x

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PROJECT
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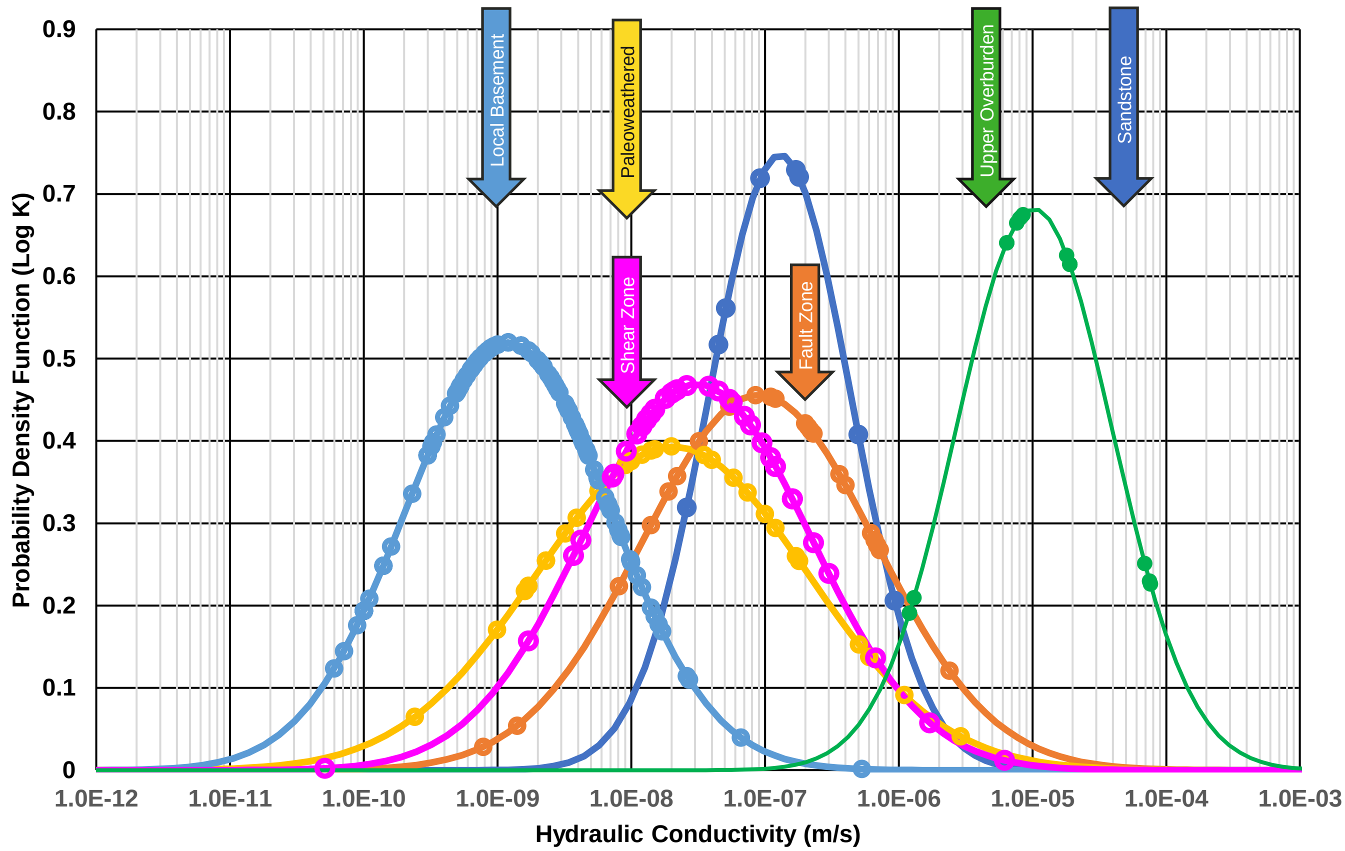
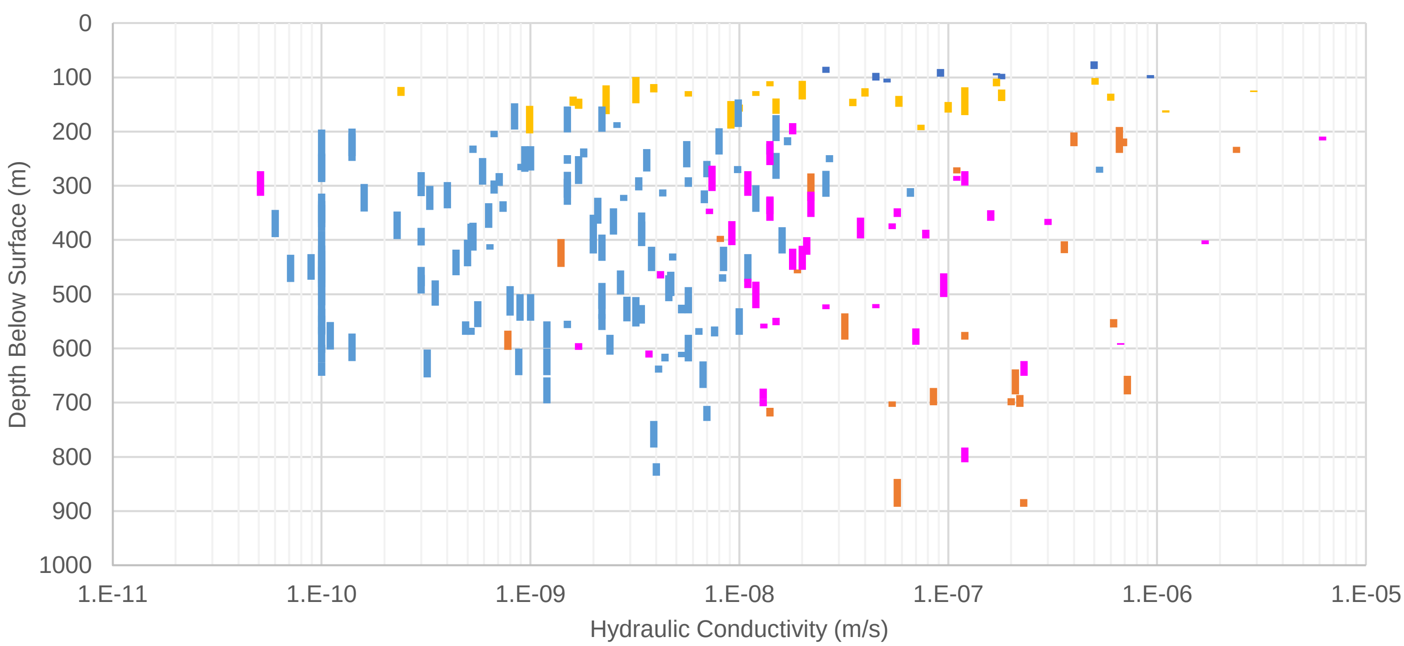
TITLE
CONCEPTUAL HYDROGEOLOGICAL MODEL
REGIONAL CROSS-SECTION B-B'
(SOUTHWEST-NORTHEAST)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-3b





Note:

1) Not shown are the lower till, Cretaceous and Devonian units, for which specific testing data was unavailable.

Legend:

AthabascaSS
Fault Zone
Paleoweathered
SPG
Shear Zone
Overburden

Arrow Indicates Value Applied in the Groundwater Flow Model

Fault Zone

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PROJECT

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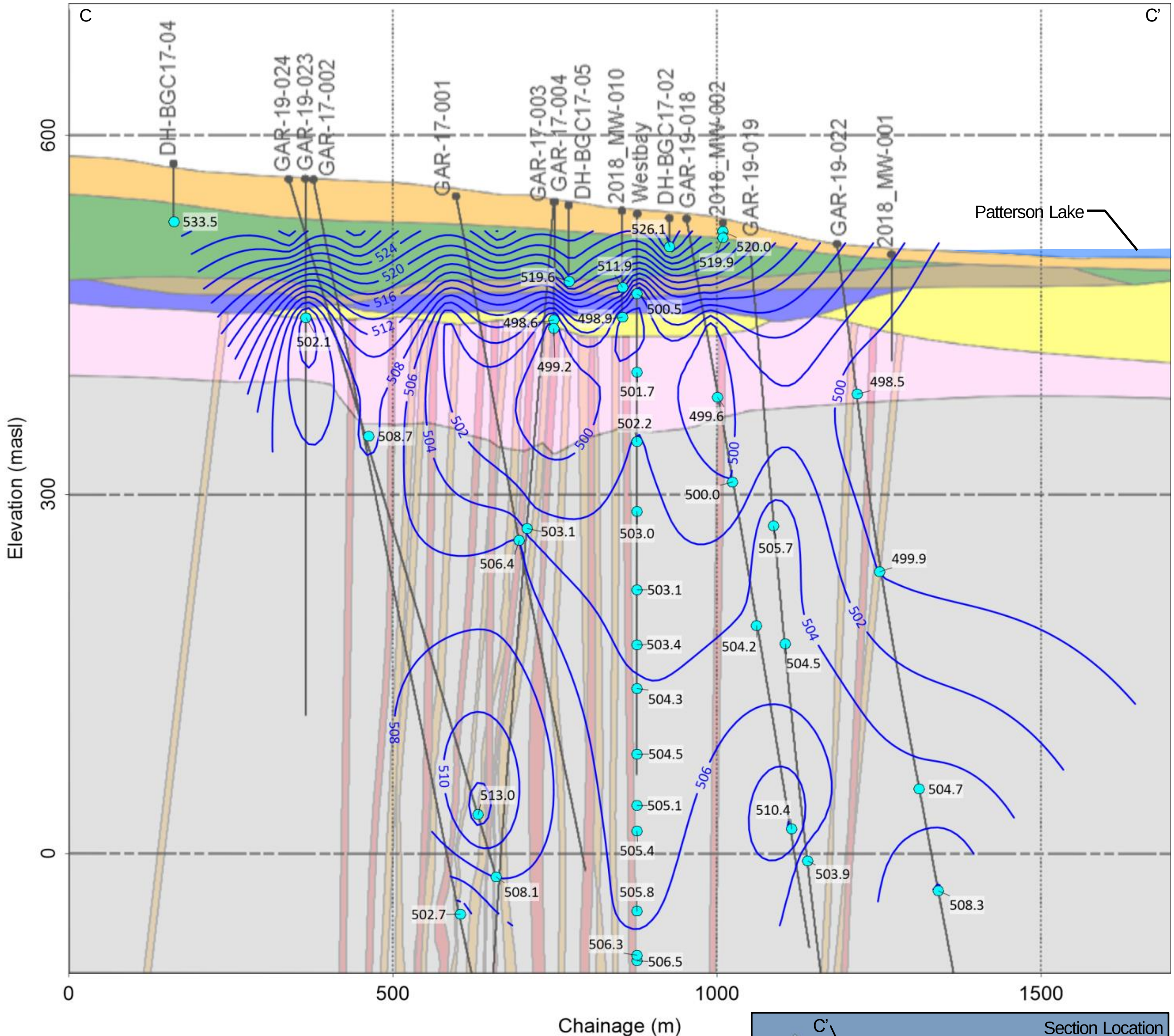
TITLE

HYDRAULIC CONDUCTIVITY BY UNIT AND DEPTH

PROJECT No.	PHASE	Rev.	FIGURE
20144150	**3104**	**1**	**A-4**

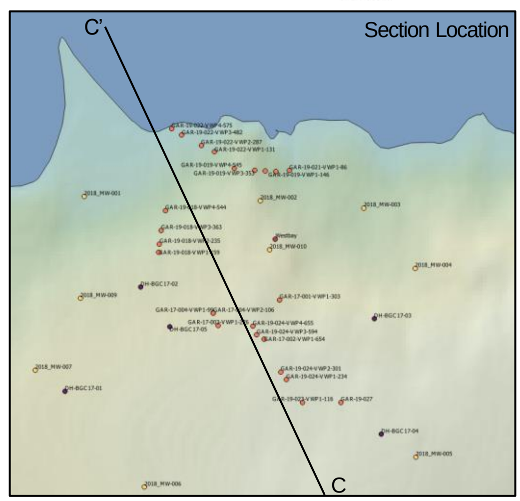


LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INTERPRETED GROUNDWATER ELEVATION CONTOUR (mASL)

Note:

1) Groundwater contours based on the most recent available measurement as of July 2019.



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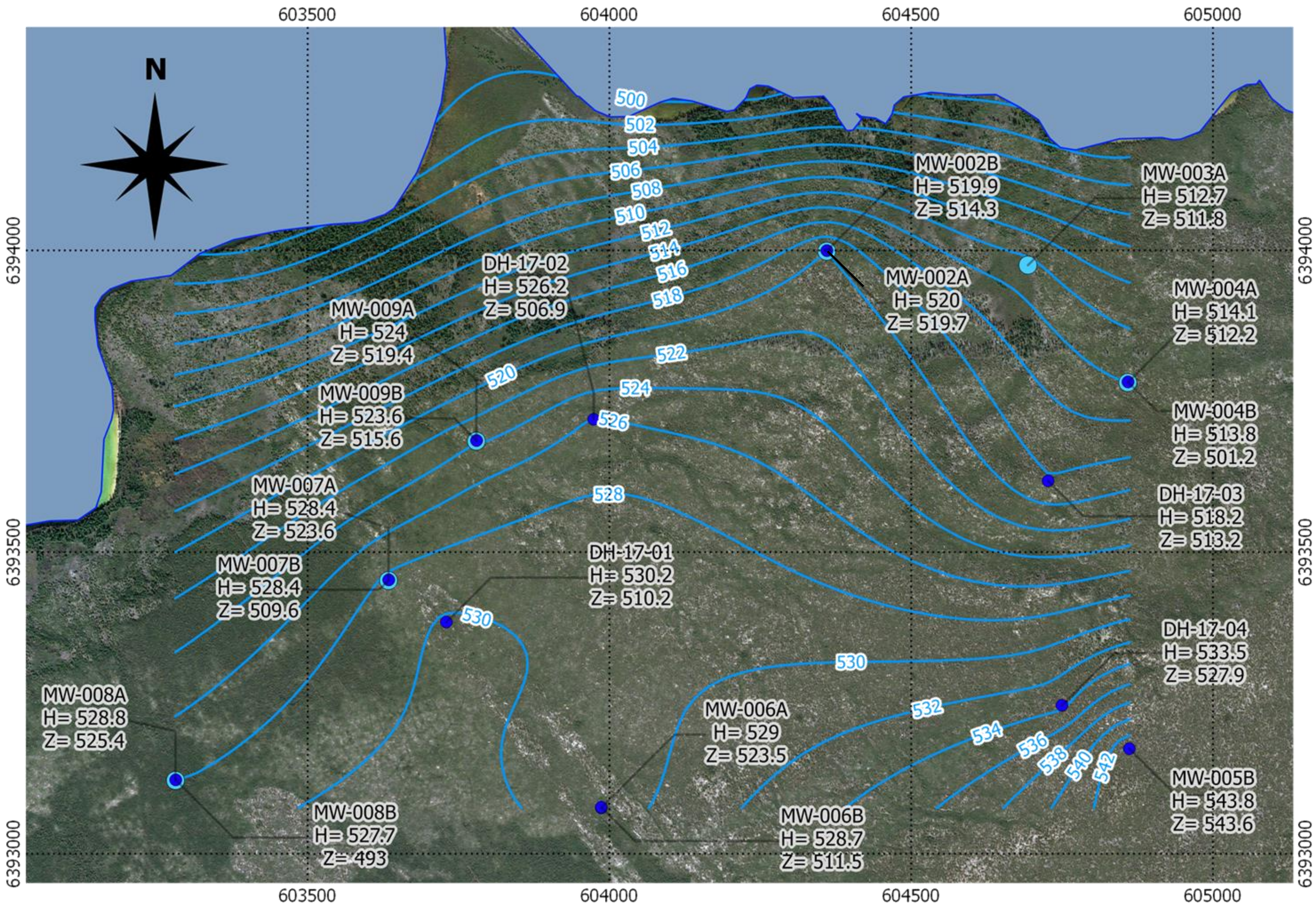
PROJECT

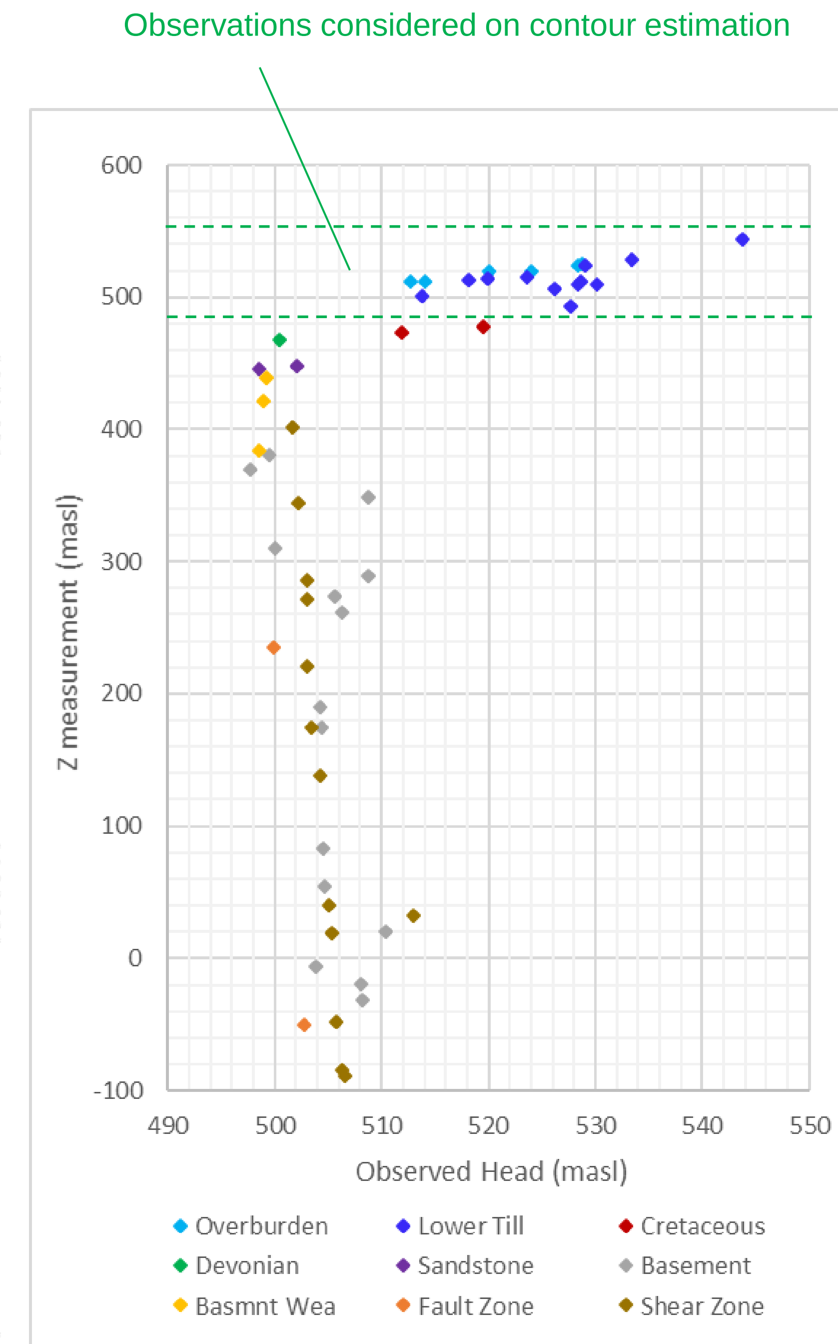
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

CONCEPTUAL HYDROGEOLOGICAL MODEL LOCAL CROSS-SECTION C-C' (NORTHWEST-SOUTHEAST)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-5





LEYEND

WATER BODY

GROUNDWATER CONTOUR

OBSERVATION POINT

- Name
  H= GW Elv
  Z= Meas Elv

OBSERVATION POINT BY UNIT

- Overburden
- Lower till

NOTAS

1. Groundwater observation point labels shows name of the borehole, groundwater elevation (GW Elv) and measurement point elevation (Meas Elv) which considers the screen mid-point for screened boreholes, or the exact elevation for vibrating wires.
2. Groundwater contour level shown on top of the line.

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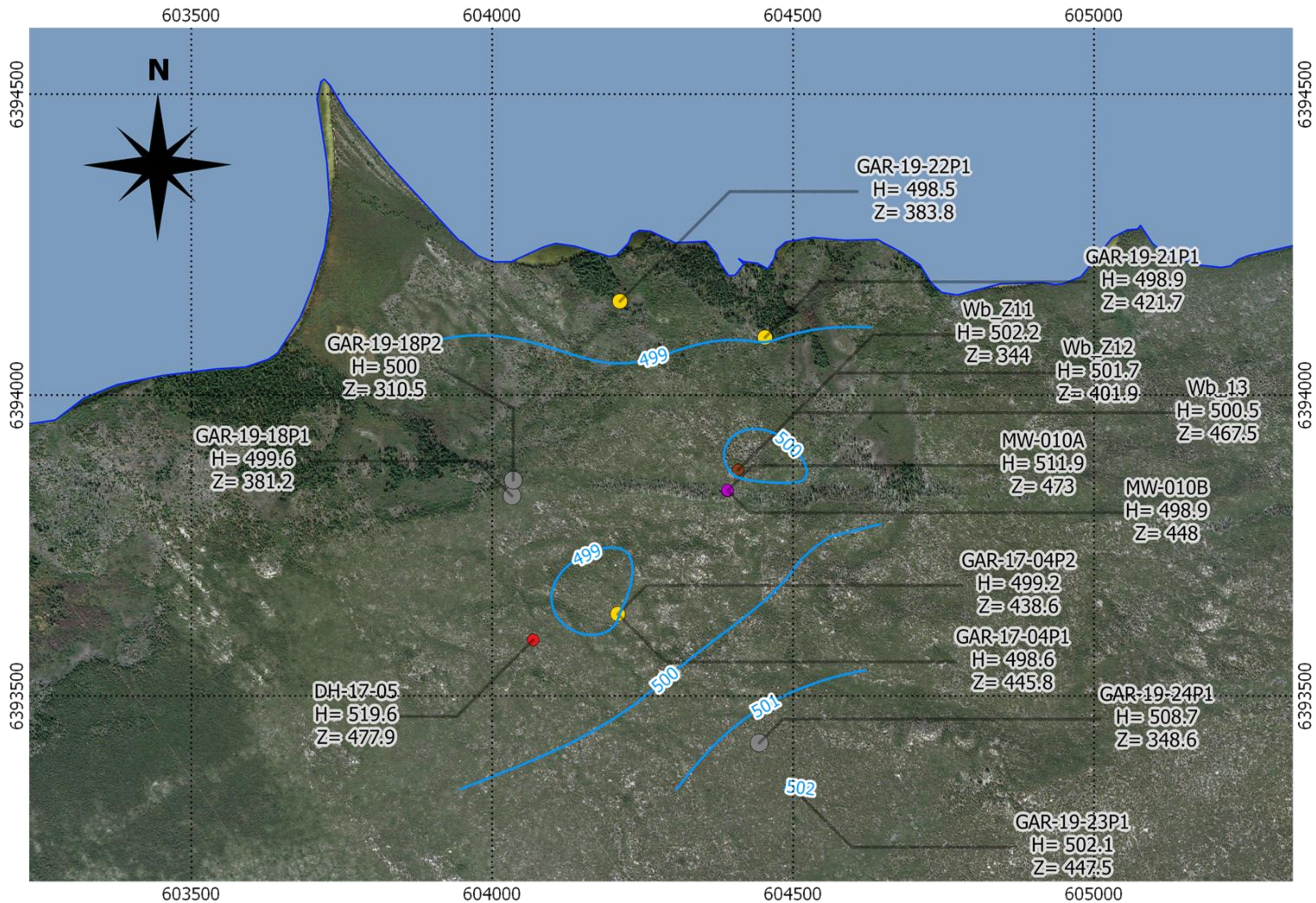
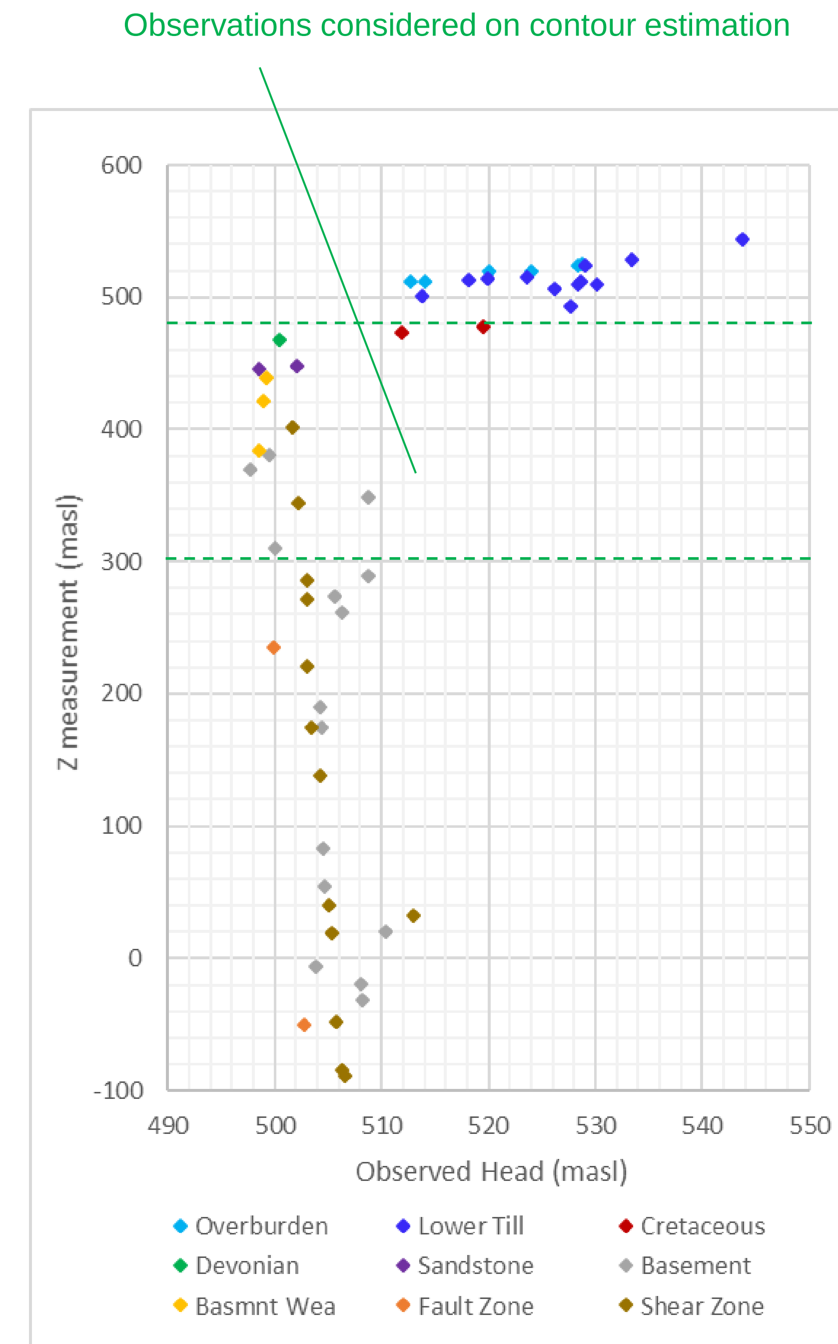
TITLE
CONCEPTUAL HYDROGEOLOGICAL MODEL
GROUNDWATER CONTOUR MAPS (GLACIAL DRIFT)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-6a





LEYEND

WATER BODY

GROUNDWATER CONTOUR

OBSERVATION POINT

Name
H= GW Elv
Z= Meas Elv

OBSERVATION POINT BY UNIT

- Basement
- Basement (w)
- Sandstone
- Cretaceous
- Devonian
- Shear Zone

NOTAS

1. Groundwater observation point labels shows name of the borehole, groundwater elevation (GW Elv) and measurement point elevation (Meas Elv) which considers the screen mid-point for screened boreholes, or the exact elevation for vibrating wires.
2. Groundwater contour level shown on top of the line.
3. Cretaceous and GAR-19-24P1 observations ignored for contour definition. Cretaceous water levels observed shows a behavior similar to shallow boreholes, while GAR-19-24P1 measuring location is deeper than surrounding observations.

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PROJECT

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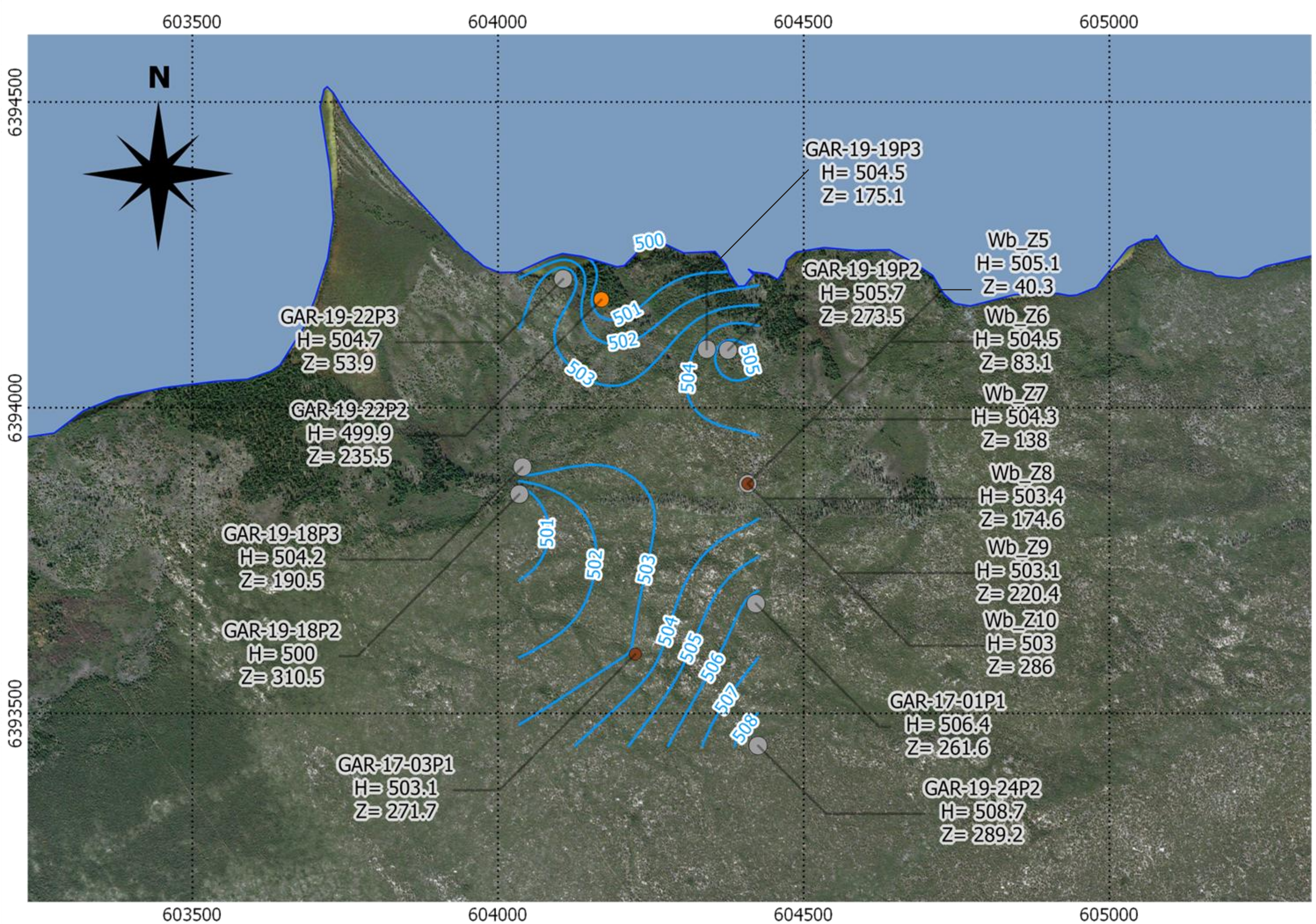
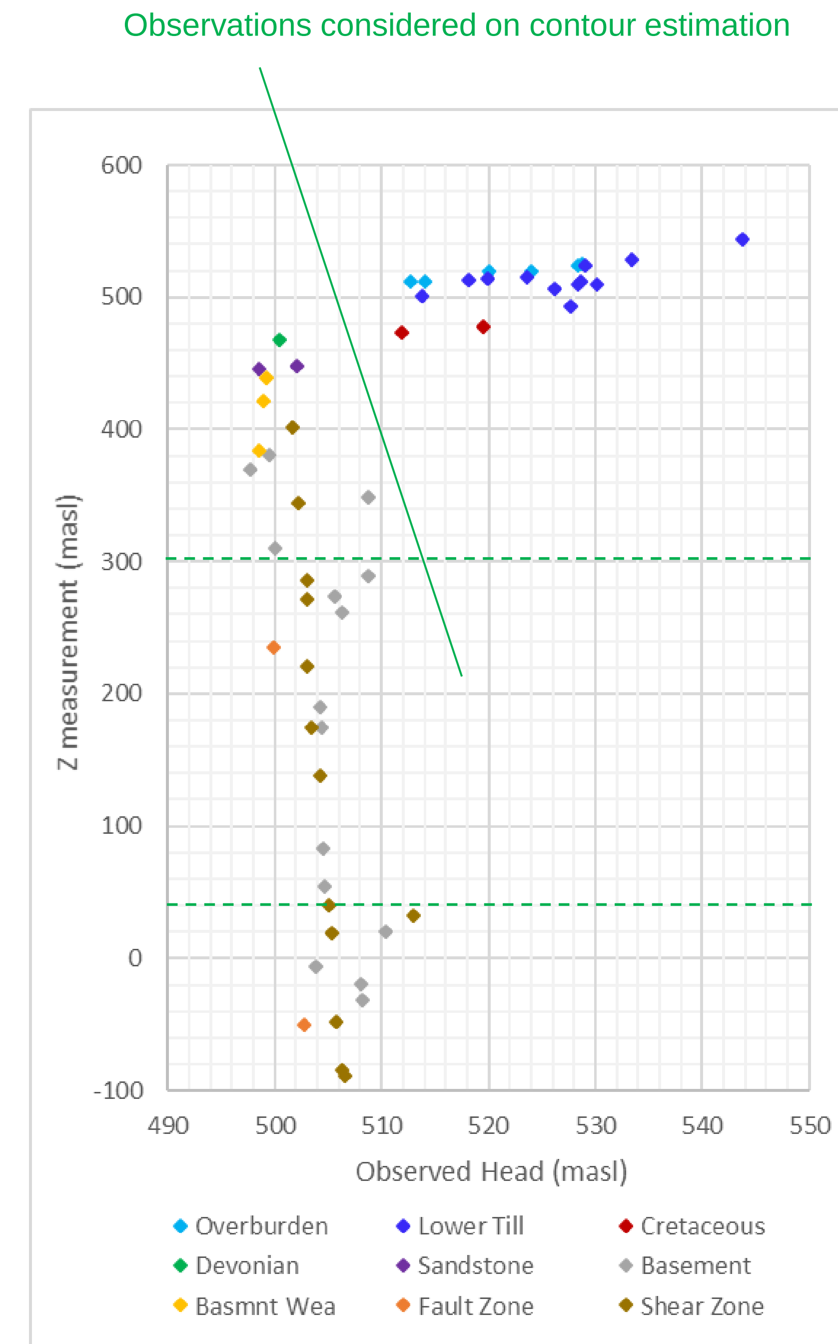
TITLE

CONCEPTUAL HYDROGEOLOGICAL MODEL
GROUNDWATER CONTOUR MAPS (MID-MINE LEVEL)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-6b





LEYEND

WATER BODY
GROUNDWATER CONTOUR

OBSERVATION POINT
Name
H= GW Elv
Z= Meas Elv

OBSERVATION POINT BY UNIT
Basement
Fault Zone
Shear Zone

NOTAS

1. Groundwater observation point labels shows name of the borehole, groundwater elevation (GW Elv) and measurement point elevation (Meas Elv) which considers the screen mid-point for screened boreholes, or the exact elevation for vibrating wires.
2. Groundwater contour level shown on top of the line.

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PROJECT
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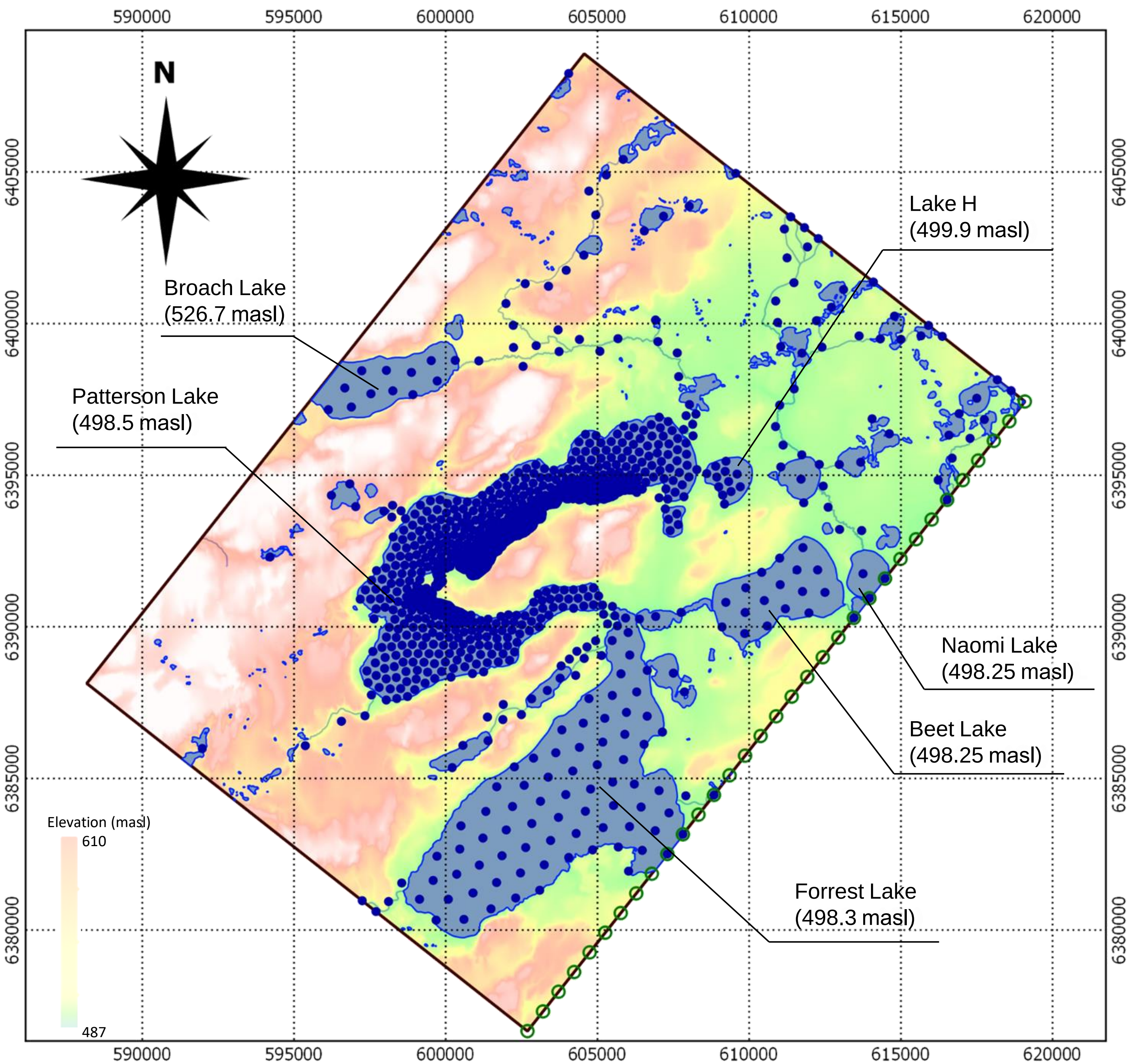
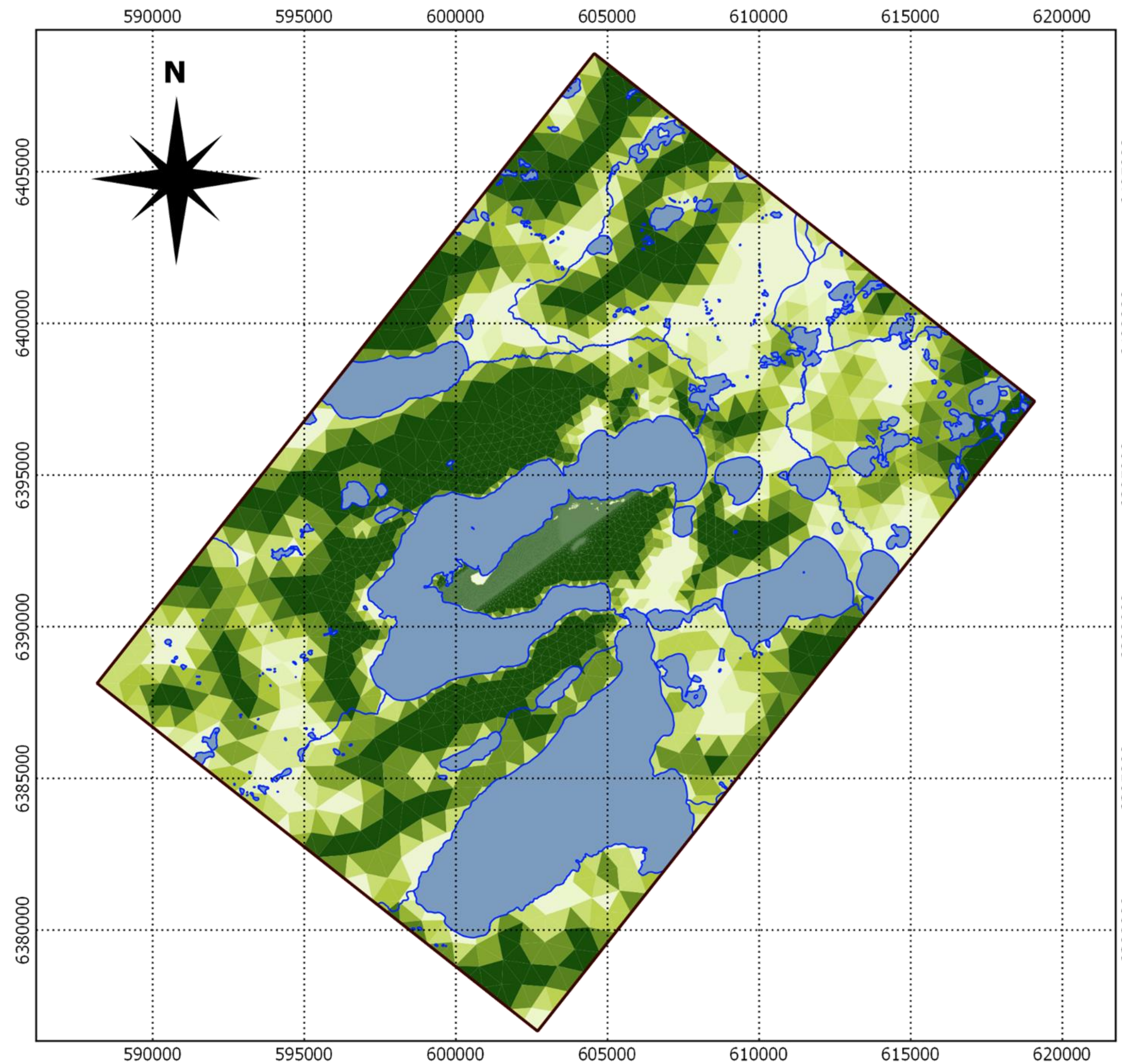
TITLE
CONCEPTUAL HYDROGEOLOGICAL MODEL
GROUNDWATER CONTOUR MAPS (DEEP MINE LEVEL)

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-6c

GROUNDWATER FLOW BOUNDARIES



SURFICIAL RECHARGE DISTRIBUTION



0 2 4 6 8 km

LEGEND

- Watercourse
- Waterbody
- Domain
- Lakes and streams
- Constant head Slice 6 to 39

Net Recharge (mm/yr)

0 - 10	60 - 70	120 - 130
10 - 20	70 - 80	130 - 140
20 - 30	80 - 90	140
30 - 40	90 - 100	
40 - 50	100 - 110	
50 - 60	110 - 120	

NOTES

1. Lake and stream constant head boundaries are placed on model slice 1. Specified elevations correspond to ground surface for streams, and fixed head for lakes.
2. The model recharge distribution was determined by applying a uniform infiltration rate of 140 mm/yr, and allowing the model to remove excess infiltration in the event that groundwater elevations rise above ground surface. Refer to Section 3.3 of the report for additional details.

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PROJECT

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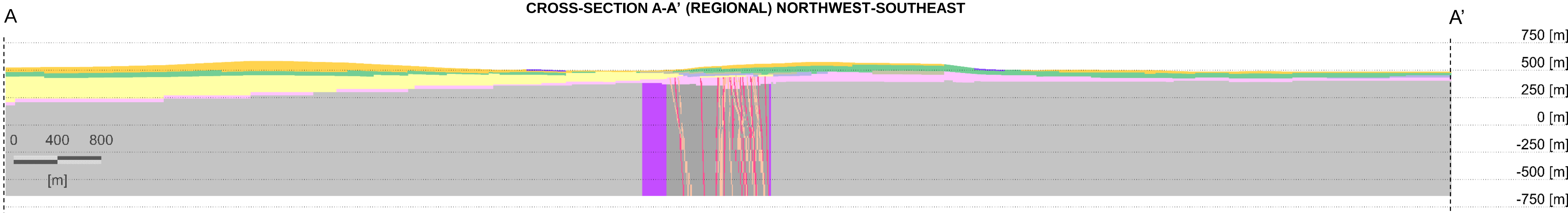
TITLE

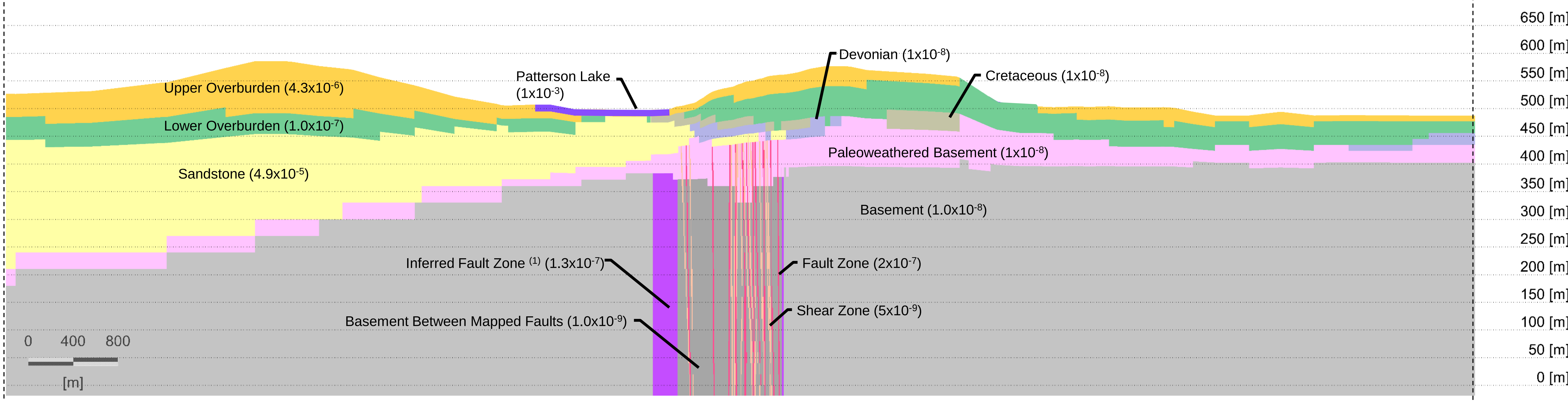
MODEL BOUNDARY CONDITIONS AND RECHARGE RATES (CURRENT CONDITIONS)

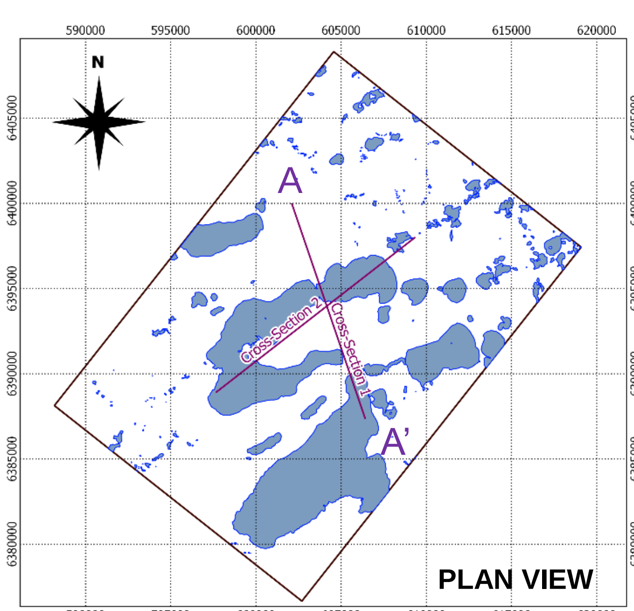
PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-7

CROSS-SECTION A-A' (REGIONAL) NORTHWEST-SOUTHEAST



CROSS-SECTION A-A' (REGIONAL) NORTHWEST-SOUTHEAST (DETAIL ABOVE 0 MASL, VERTICAL EXAGGERATION 5:1)





Unit	Horizontal Hydraulic Conductivity (Kh, m/s)	Vertical Hydraulic Conductivity (Kv, m/s)	Kh:Kv	Porosity (-)
Lake	1.0E-3	1.0E-3	1	1
Upper Overburden	4.3E-06	5.0E-08	87	0.2
Lower Overburden (Till)	1.0E-07	1.4E-09	74	0.2
Cretaceous Bedrock	1.0E-08	5.0E-11	200	0.1
Devonian Bedrock	1.5E-07	5.0E-11	2943	0.1
Sandstone Bedrock	4.9E-05	5.0E-06	9.8	0.1
Paleoweathered Bedrock	1.0E-08	9.5E-10	11	0.05
Basement Bedrock	1.0E-08	8.3E-10	12	0.01
Fault Zone	2.0E-07	1.0E-08	20	0.05
Shear Zones	8.3E-09	1.0E-08	0.8	0.05
Inferred Fault Zone (1)	1.3E-07	1.9E-09	70	0.05
Inner Basement	1.0E-09	1.0E-10	10	0.01

Note:
1) Inferred fault zone refers to the area interpreted to encompass the fault zones and shear zones present in the local 3D geological model. This zone extends approximately 4 km to the southwest from the mine area, and approximately 700 m to the northeast. Preferential horizontal hydraulic conductivity is applied at an angle of 43 degrees from north. Refer to section 4.5.2.4 of the text.

LEGEND
- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INFERED FAULT ZONE
- BASEMENT BETWEEN MAPPED FAULTS
- LAKE

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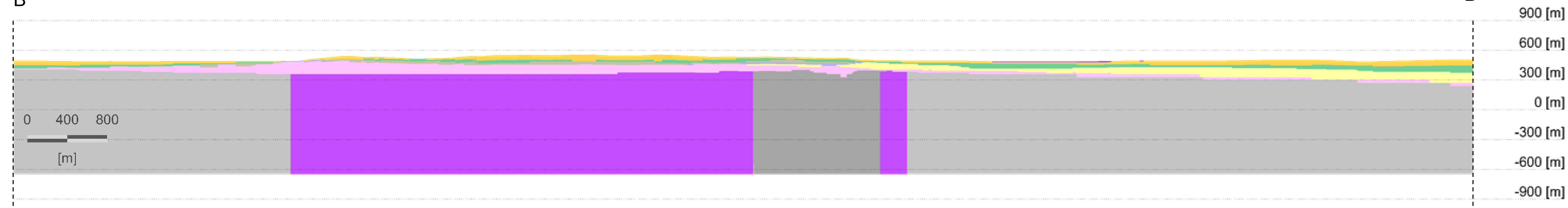
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

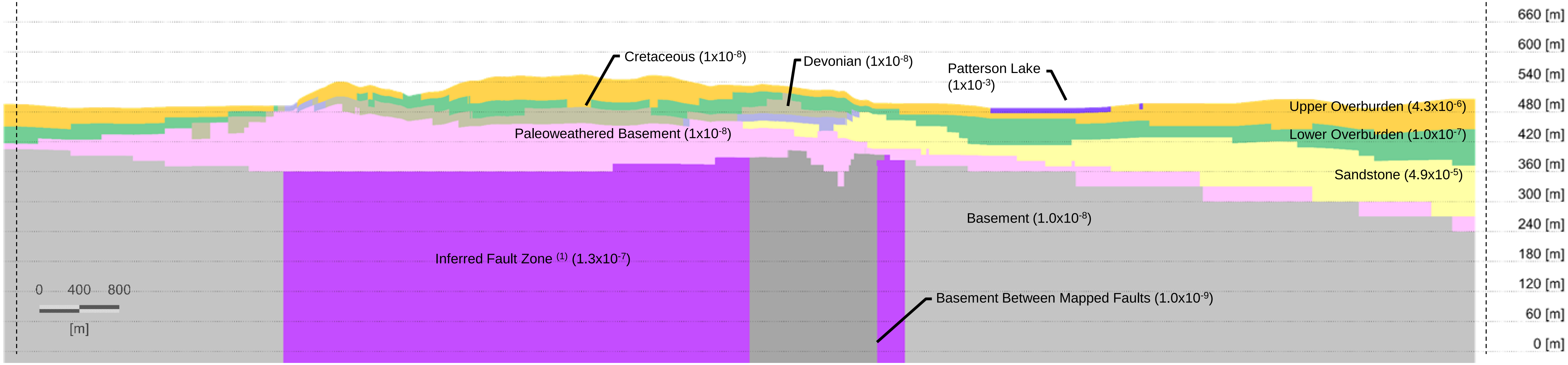
TITLE
CALIBRATED MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION
CROSS-SECTION A-A' (REGIONAL) NORTHWEST-SOUTHEAST

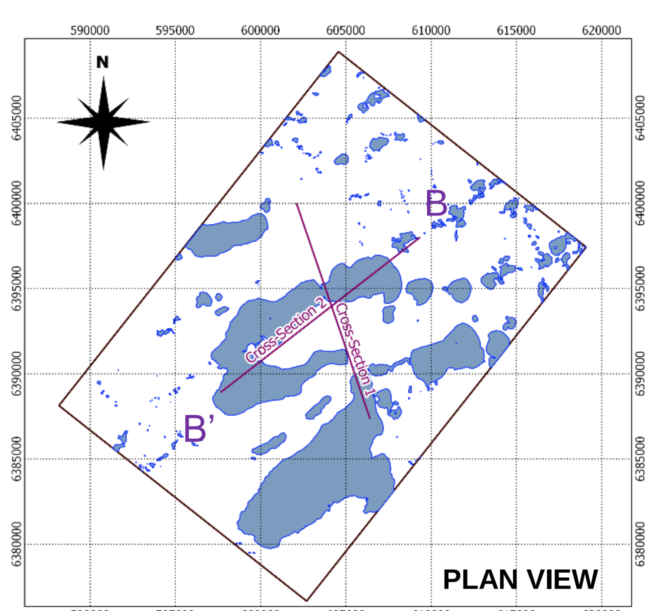
PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-8

CROSS-SECTION B-B' (REGIONAL) SOUTHWEST-NORTHEAST



CROSS-SECTION B-B' (REGIONAL) SOUTHWEST-NORTHEAST (DETAIL ABOVE 0 MASL, VERTICAL EXAGGERATION 5:1)





Unit	Horizontal Hydraulic Conductivity (Kh, m/s)	Vertical Hydraulic Conductivity (Kv, m/s)	Kh:Kv	Porosity (-)
Lake	1.0E-3	1.0E-3	1	1
Upper Overburden	4.3E-06	5.0E-08	87	0.2
Lower Overburden (Till)	1.0E-07	1.4E-09	74	0.2
Cretaceous Bedrock	1.0E-08	5.0E-11	200	0.1
Devonian Bedrock	1.5E-07	5.0E-11	2943	0.1
Sandstone Bedrock	4.9E-05	5.0E-06	9.8	0.1
Paleoweathered Bedrock	1.0E-08	9.5E-10	11	0.05
Basement Bedrock	1.0E-08	8.3E-10	12	0.01
Fault Zone	2.0E-07	1.0E-08	20	0.05
Shear Zones	8.3E-09	1.0E-08	0.8	0.05
Inferred Fault Zone (1)	1.3E-07	1.9E-09	70	0.05
Inner Basement	1.0E-09	1.0E-10	10	0.01

Note:
1) Inferred fault zone refers to the area interpreted to encompass the fault zones and shear zones present in the local 3D geological model. This zone extends approximately 4 km to the southwest from the mine area, and approximately 700 m to the northeast. Preferential horizontal hydraulic conductivity is applied at an angle of 43 degrees from north. Refer to section 4.5.2.4 of the text.

LEGEND
- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INFERED FAULT ZONE
- BASEMENT BETWEEN MAPPED FAULTS
- LAKE

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DESIGN	GI
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PROJECT
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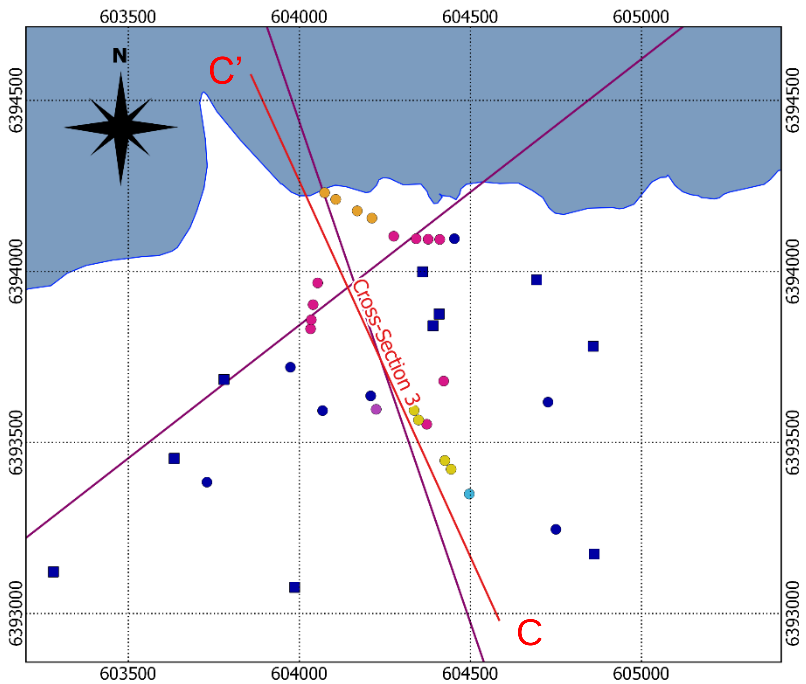
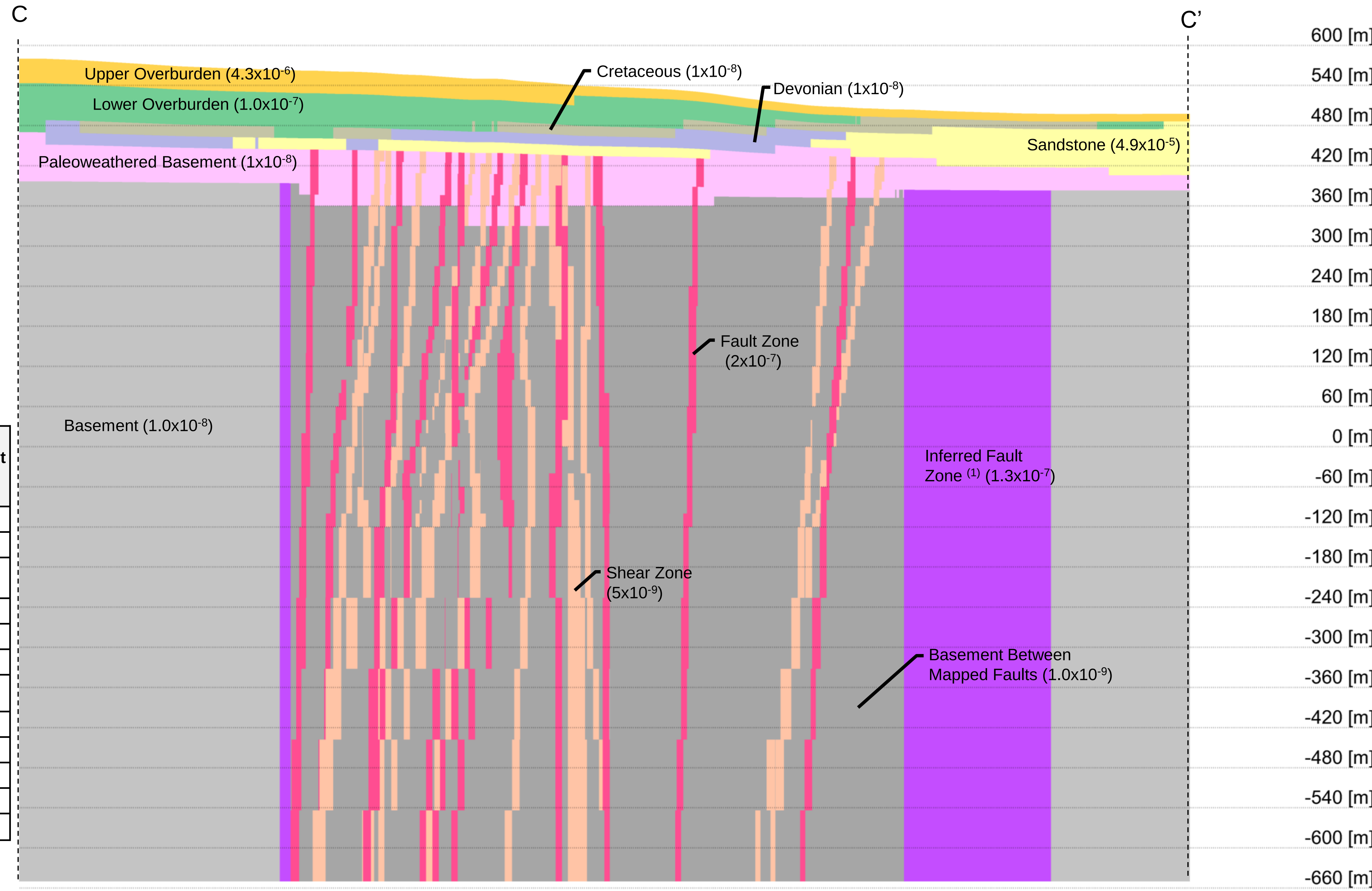
TITLE
CALIBRATED MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION
CROSS-SECTION B-B' (REGIONAL) SOUTHWEST-NORTHEAST

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-9

PLAN VIEW



CROSS-SECTION C-C' (LOCAL) MINE AREA TO PATTERSON LAKE



Unit	Horizontal Hydraulic Conductivity (Kh, m/s)	Vertical Hydraulic Conductivit y (Kv, m/s)	Kh:Kv	Porosit y (-)
Lake	1.0E-3	1.0E-3	1	1
Upper Overburden	4.3E-06	5.0E-08	87	0.2
Lower Overburden (Till)	1.0E-07	1.4E-09	74	0.2
Cretaceous Bedrock	1.0E-08	5.0E-11	200	0.1
Devonian Bedrock	1.5E-07	5.0E-11	2943	0.1
Sandstone Bedrock	4.9E-05	5.0E-06	9.8	0.1
Paleoweathered Bedrock	1.0E-08	9.5E-10	11	0.05
Basement Bedrock	1.0E-08	8.3E-10	12	0.01
Fault Zone	2.0E-07	1.0E-08	20	0.05
Shear Zones	8.3E-09	1.0E-08	0.8	0.05
Inferred Fault Zone (1)	1.3E-07	1.9E-09	70	0.05
Inner Basement	1.0E-09	1.0E-10	10	0.01

Note:
1) Inferred fault zone refers to the area interpreted to encompass the fault zones and shear zones present in the local 3D geological model. This zone extends approximately 4 km to the southwest from the mine area, and approximately 700 m to the northeast. Preferential horizontal hydraulic conductivity is applied at an angle of 43 degrees from north. Refer to section 3.4 of the text.

LEGEND

- UPPER OVERBURDEN
- LOWER OVERBURDEN (TILL)
- CRETACEOUS BEDROCK
- DEVONIAN BEDROCK
- SANDSTONE BEDROCK
- PALEOWEATHERED BASEMENT ROCK
- BASEMENT ROCK
- SHEAR ZONE
- FAULT ZONE
- INFERED FAULT ZONE
- BASEMENT BETWEEN MAPPED FAULTS
- LAKE

NOTES

1. Plan view maps shows boreholes for reference. Refer to Figure 5 to check the corresponding name.

CLIENT
NexGen Energy Ltd.

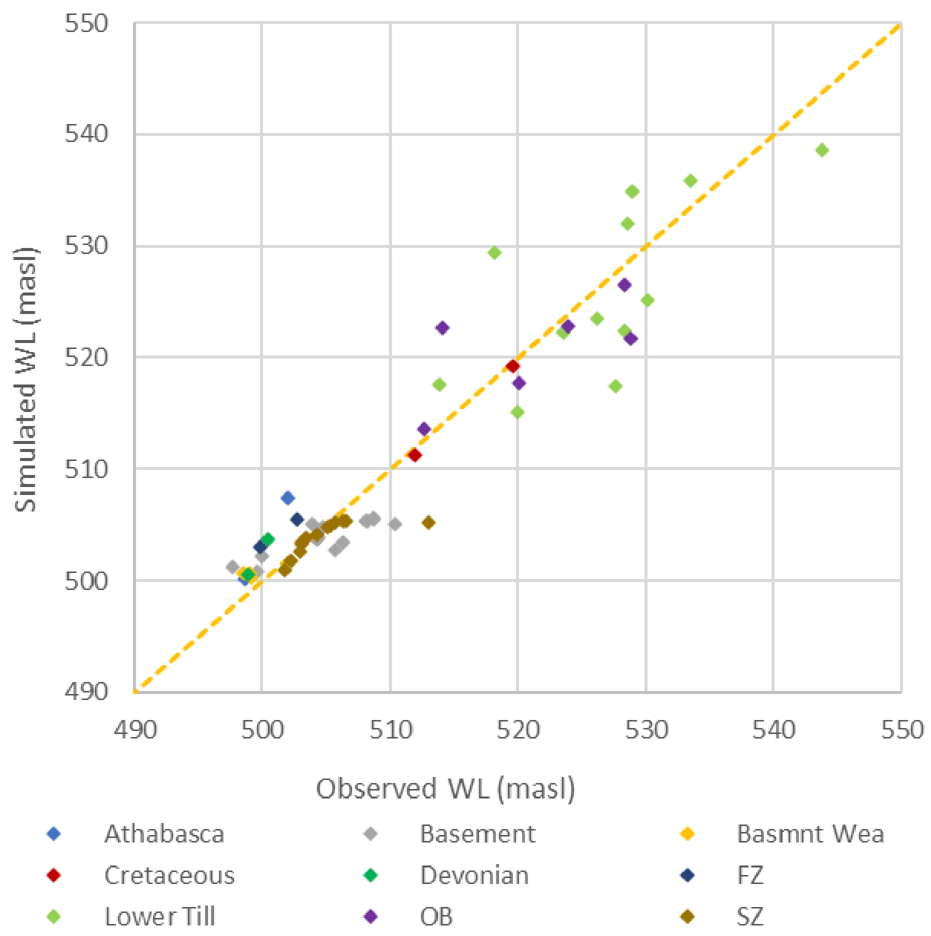
CONSULTANT
GOLDER

YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
CALIBRATED MODEL HYDRAULIC CONDUCTIVITY DISTRIBUTION CROSS-SECTION C-C' (LOCAL) MINE AREA TO PATTERSON LAKE

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-10



Calibration statistics

# Observation points	57
Mean error (m)	-0.3
Root mean squared error (m)	3.7
Normalizaed RMSE (%)	8.1%

LEGEND

RESIDUAL ERROR – (SIMULATED MINUS OBSERVED GROUNDWATER ELEVATION (m)

- <-5
- -5 to -2
- -2 to 2
- 2 to 5
- >5

NOTAS

1. Simulated against observed heads graph shows observations based on measured hydrogeological unit.
2. Residual error distribution graph uses brackets to show elevation at nested piezometers
3. Marker size shows the magnitude of the difference between observation and simulated head

CLIENT

NexGen Energy Ltd.

CONSULTANT

GOLDER

YYYY-MM-DD	2021-06-28
PREPARED	GI
DESIGN	GI
REVIEW	NB
APPROVED	MT

PROJECT

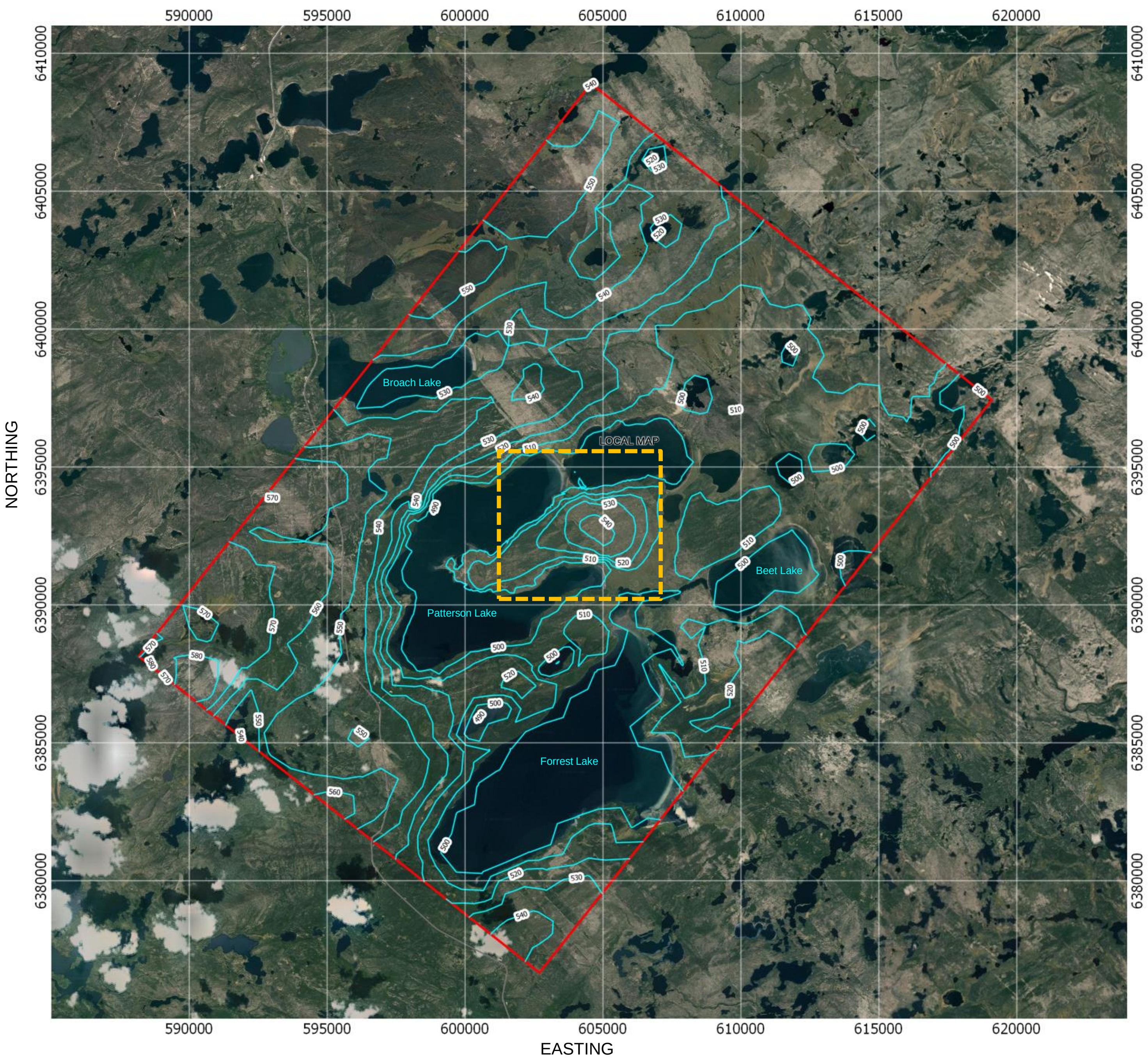
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

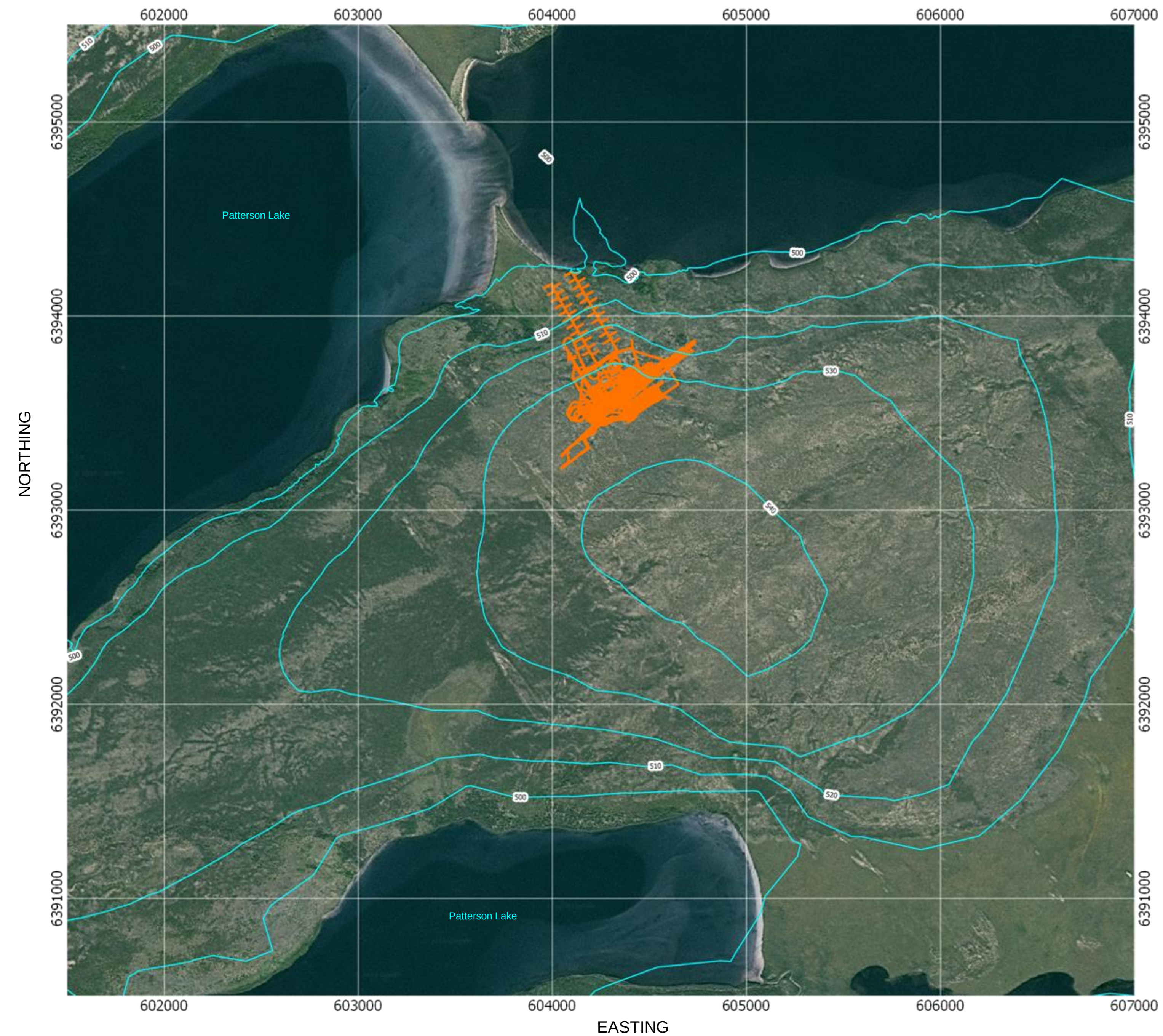
MODEL CALIBRATION

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-11

REGIONAL SCALE - FULL MODEL DOMAIN



LOCAL SCALE – MINE AREA



LEGEND

- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Notes:
1) Simulated overburden groundwater elevations correspond to model slice 2 (approx. elevation 520 mASL in the mine area).

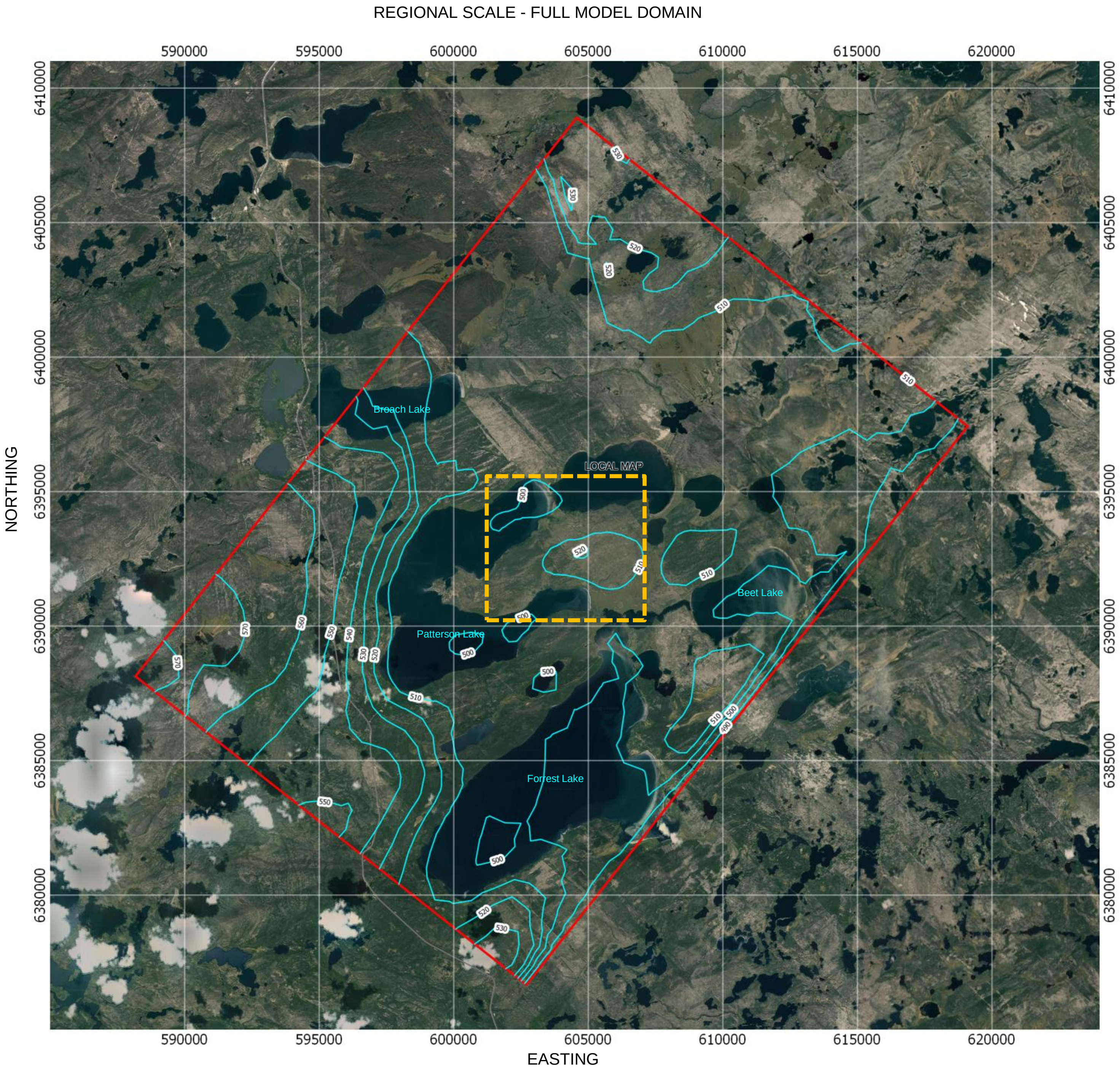
2) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

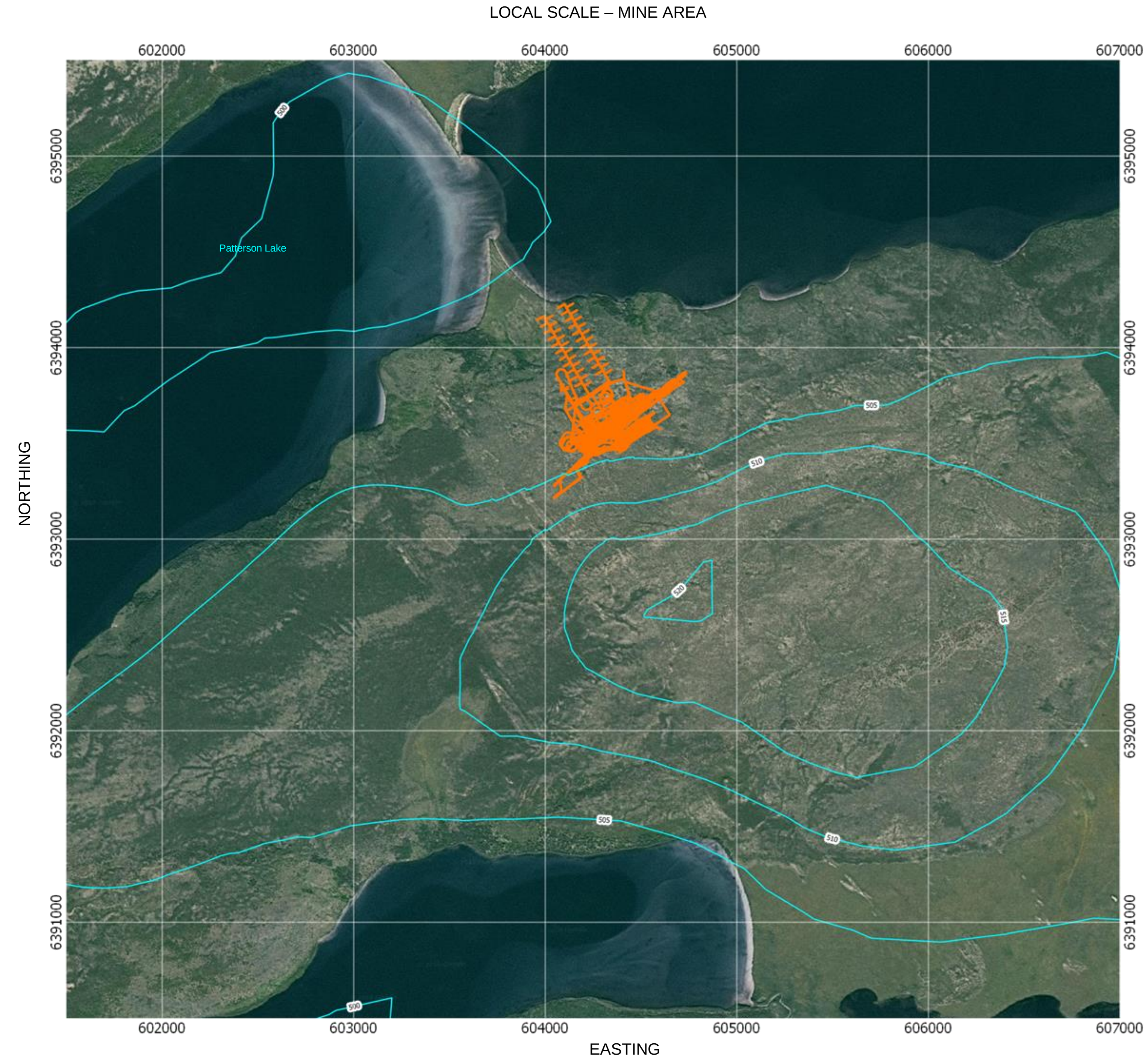
CLIENT	NexGen Energy Ltd.
CONSULTANT	GOLDER
YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED GROUNDWATER FLOW ELEVATIONS FOR CURRENT (PREDEVELOPMENT) CONDITIONS – GLACIAL DRIFT

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-12





LEGEND

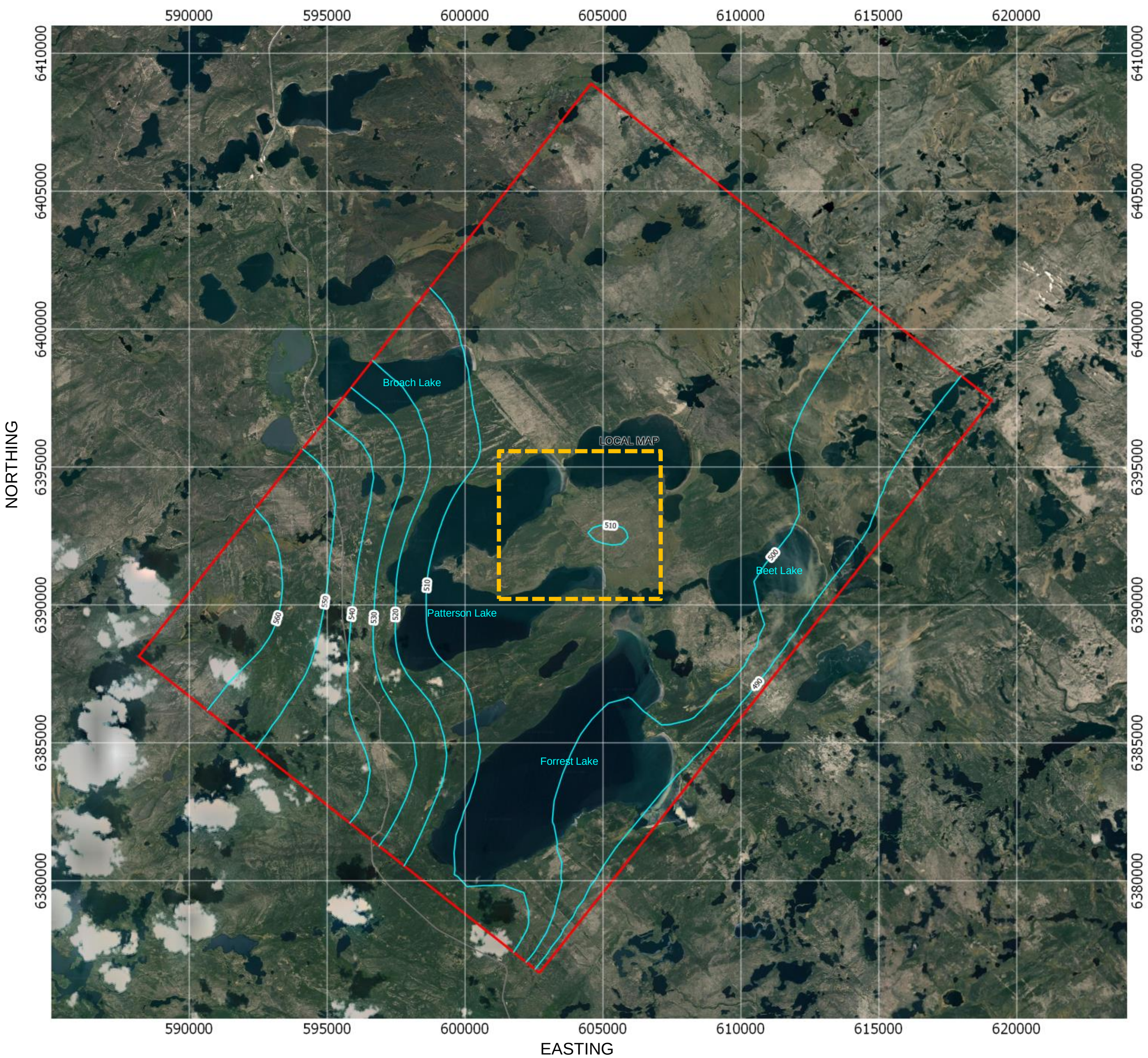
- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Notes:
1) Simulated shallow bedrock groundwater elevations correspond to model slice 10 (approx. elevation 405 mASL in the mine area)

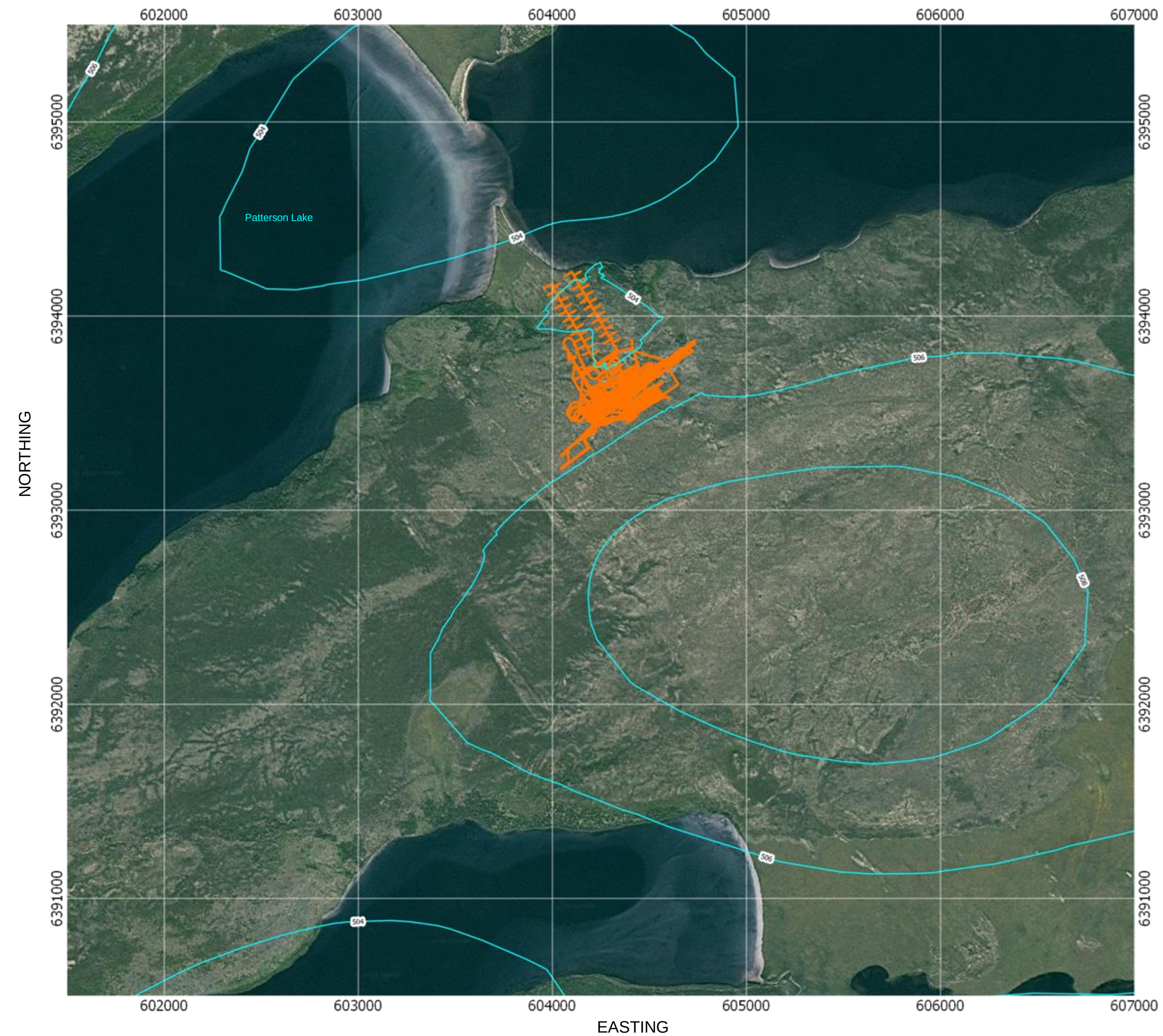
2) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

CLIENT	NexGen Energy Ltd.	PROJECT	NEXGEN ENERGY LTD. ROOK I PROJECT
CONSULTANT	GOLDER	TITLE	SIMULATED GROUNDWATER FLOW ELEVATION FOR CURRENT (PREDEVELOPMENT) CONDITIONS – SHALLOW BEDROCK
YYYY-MM-DD	2021-06-28	PROJECT No.	20144150
PREPARED	NB	PHASE	3104
DESIGN	NB	Rev.	1
REVIEW	MT	FIGURE	A-13
APPROVED	MT		

REGIONAL SCALE - FULL MODEL DOMAIN



LOCAL SCALE – MINE AREA



LEGEND

- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Notes:

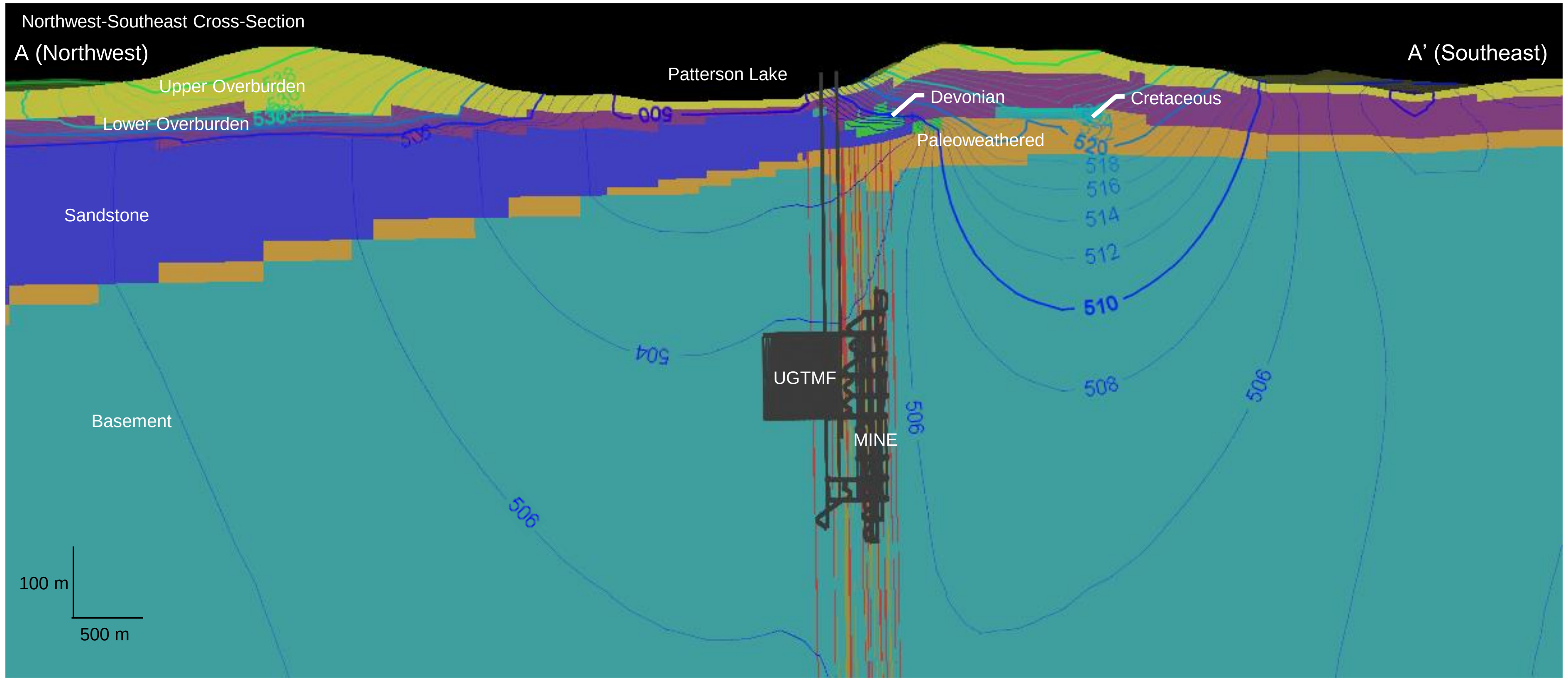
1) Simulated deep bedrock groundwater elevations correspond to model slice 20 (elevation 160 mASL).
2) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

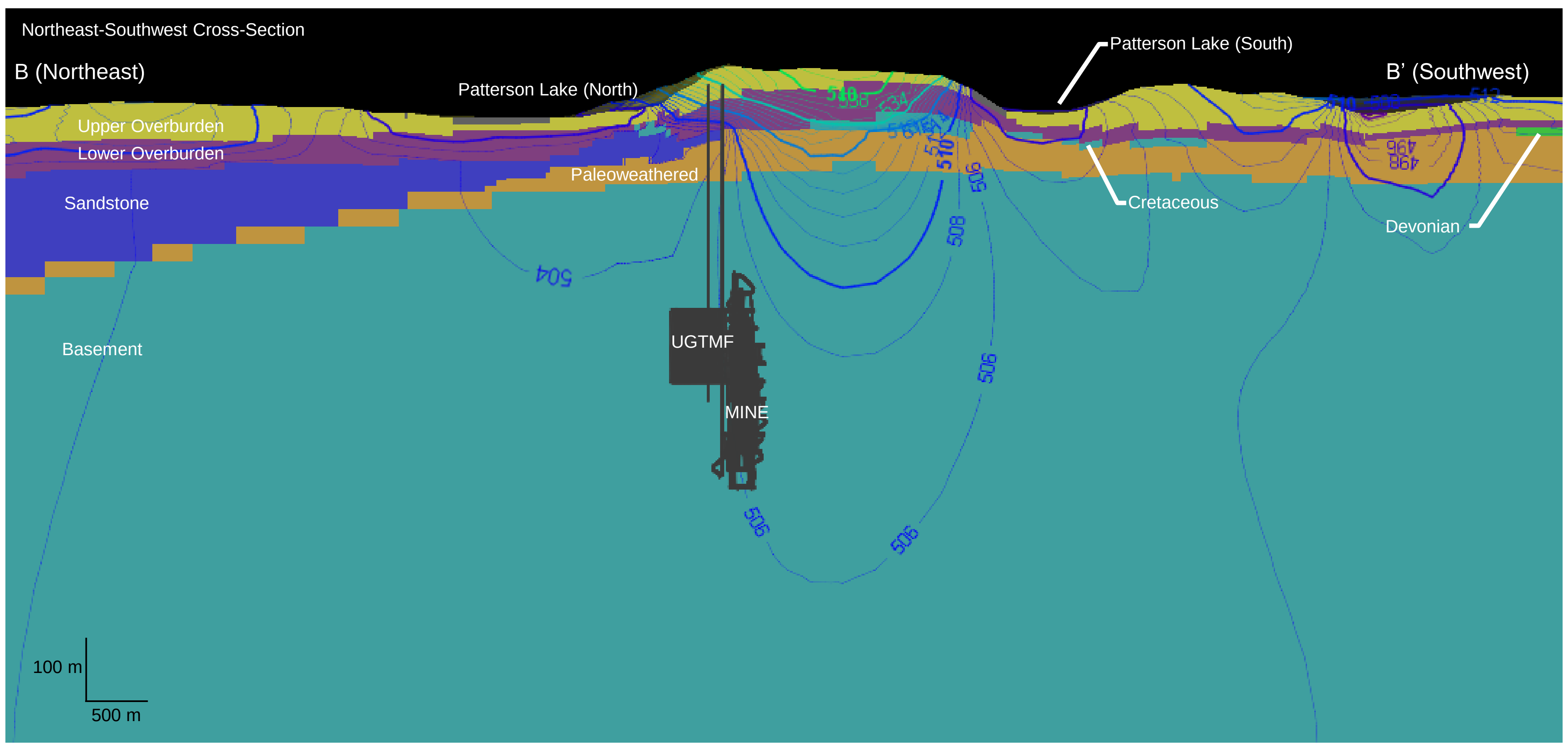
CLIENT	NexGen Energy Ltd.
CONSULTANT	GOLDER
YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

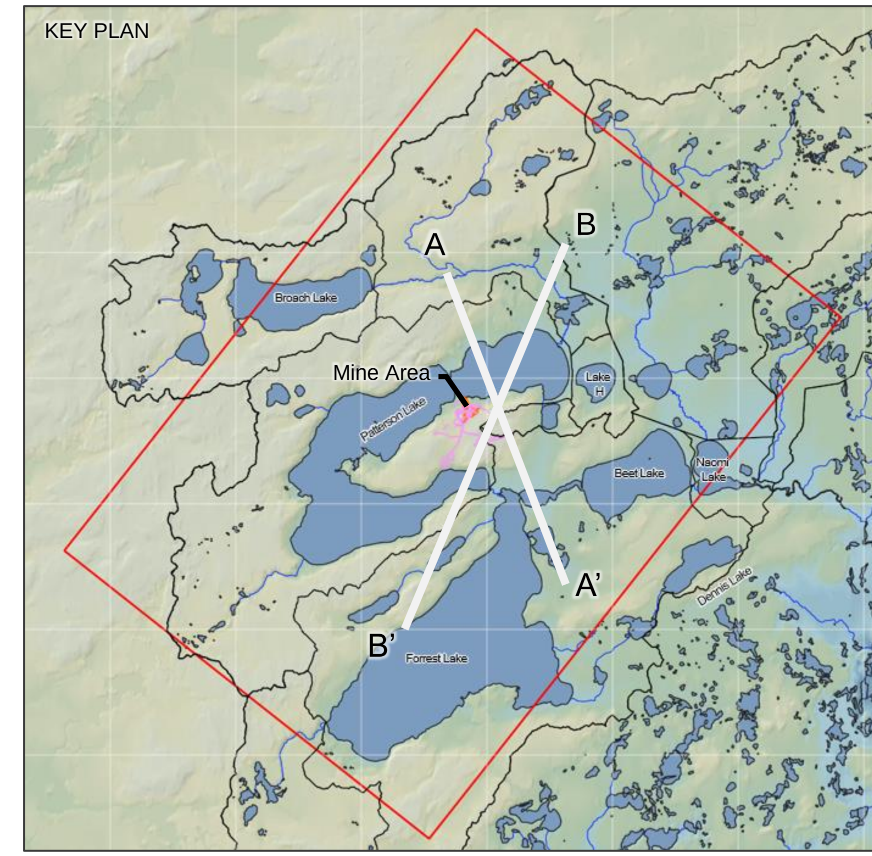
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED GROUNDWATER FLOW ELEVATIONS FOR CURRENT (PREDEVELOPMENT) CONDITIONS – DEEP BEDROCK

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-14







LEGEND

- MODEL DOMAIN
- SIMULATED GROUNDWATER ELEVATION (mASL)
- UNDERGROUND DEVELOPMENT

Note:
1) 3-D mine plan files for the underground workings provided by NexGen (November 19, 2020).

CLIENT
NexGen Energy Ltd.

CONSULTANT
GOLDER

YYYY-MM-DD	2021-06-28
PREPARED	NB
DESIGN	NB
REVIEW	MT
APPROVED	MT

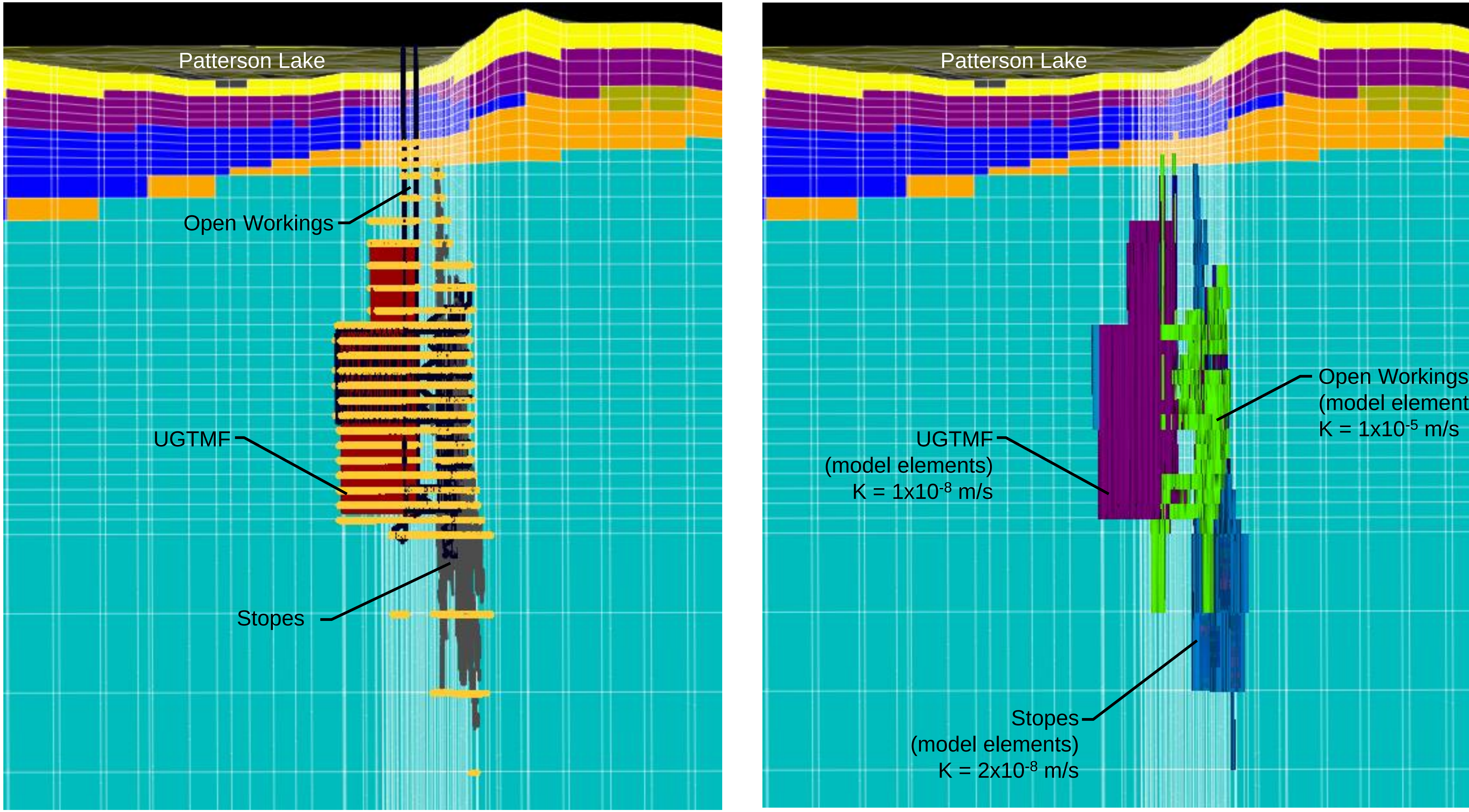
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED GROUNDWATER FLOW ELEVATIONS FOR CURRENT (PREDEVELOPMENT) CONDITIONS – CROSS SECTIONS

PROJECT No.	PHASE	Rev.	FIGURE
20144150	3104	1	A-15

Operations Configuration

Post-Closure Configuration



LEGEND

- MODEL SEEPAGE NODE BOUNDARY
- BASEMENT ROCK
- PALEOWEATHERED BASEMENT ROCK
- SANDSTONE
- DEVONIAN ROCK
- LOWER OVERBURDEN (TILL)
- UPPER OVERBURDEN

CLIENT
NexGen Energy Ltd.

CONSULTANT
GOLDER MEMBER OF WSP

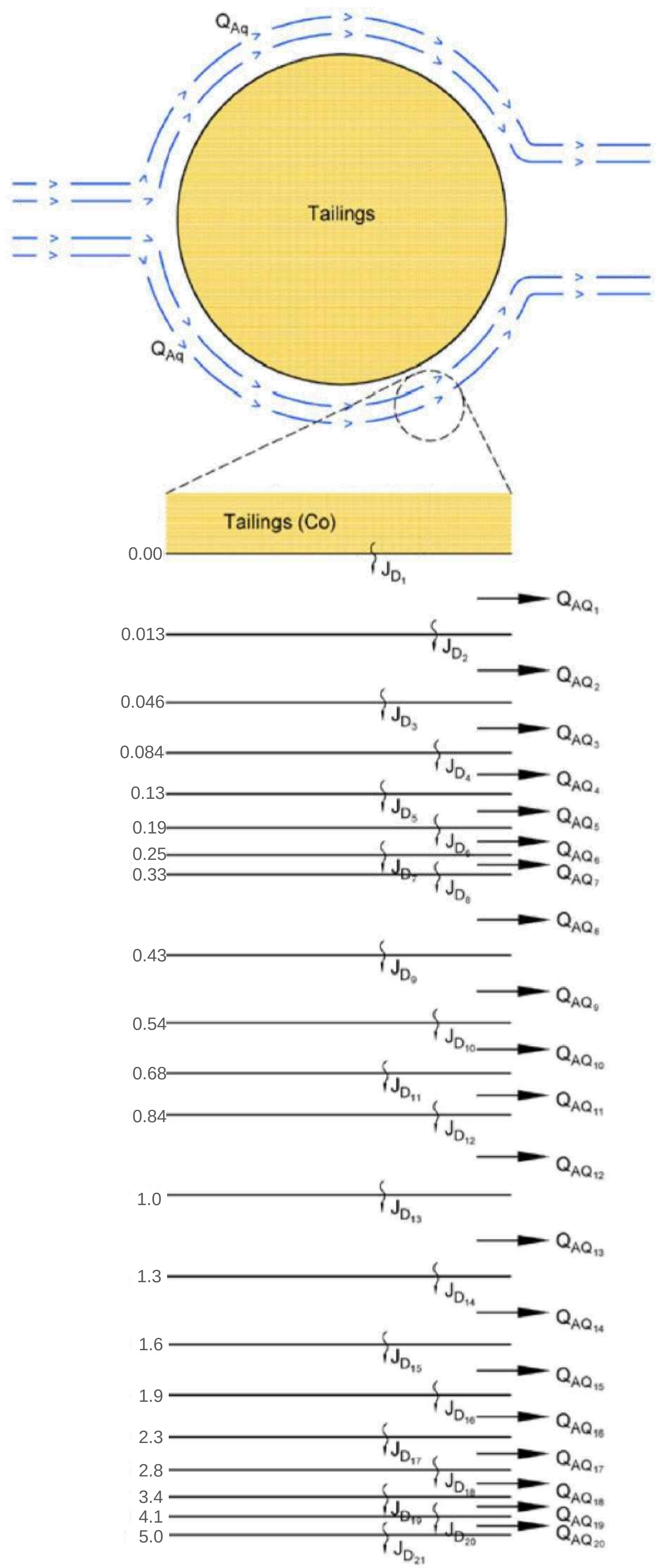
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

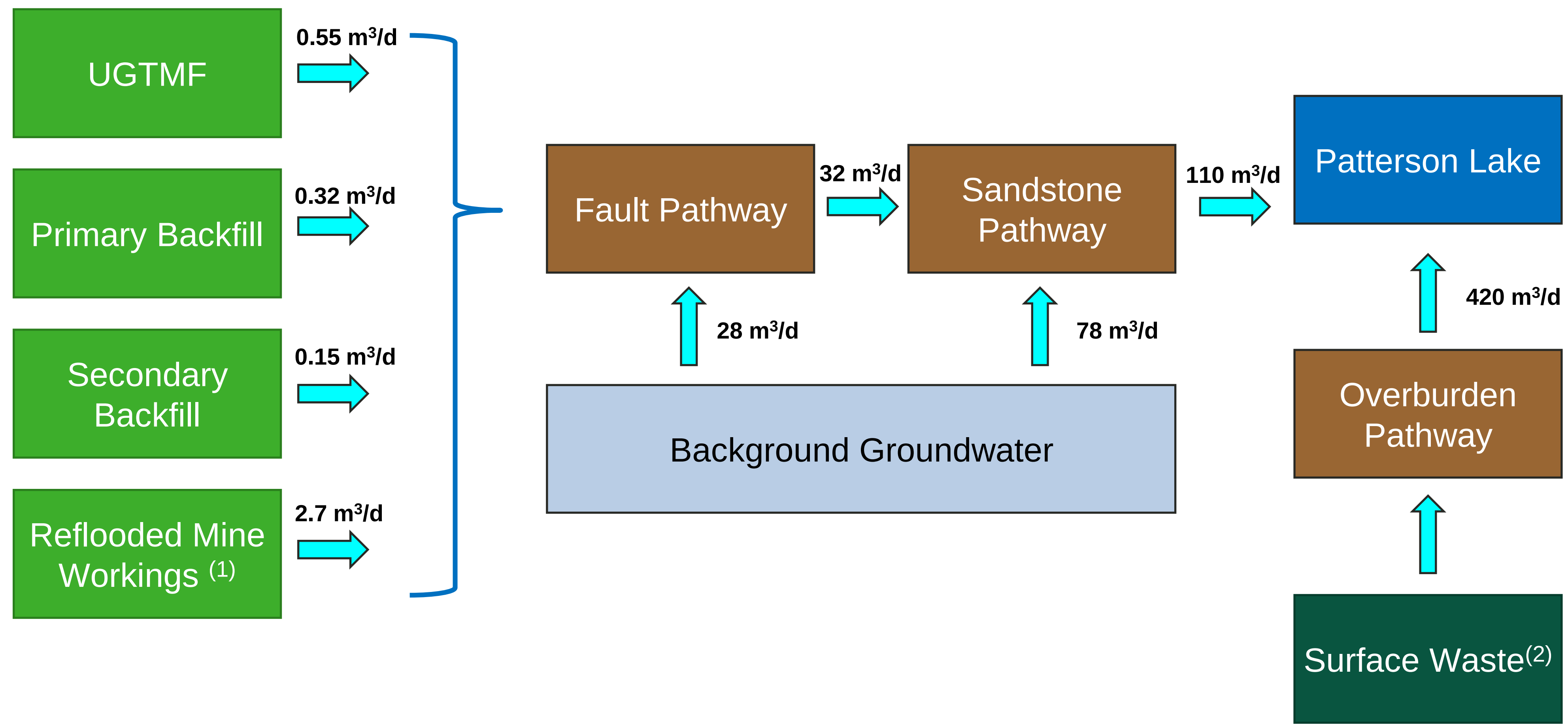
TITLE
IMPLEMENTATION OF UNDERGROUND DEVELOPMENT IN THE PREDICTIVE MODEL

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	1	A-16

Diffusive Flux



Advective Flux



LEGEND

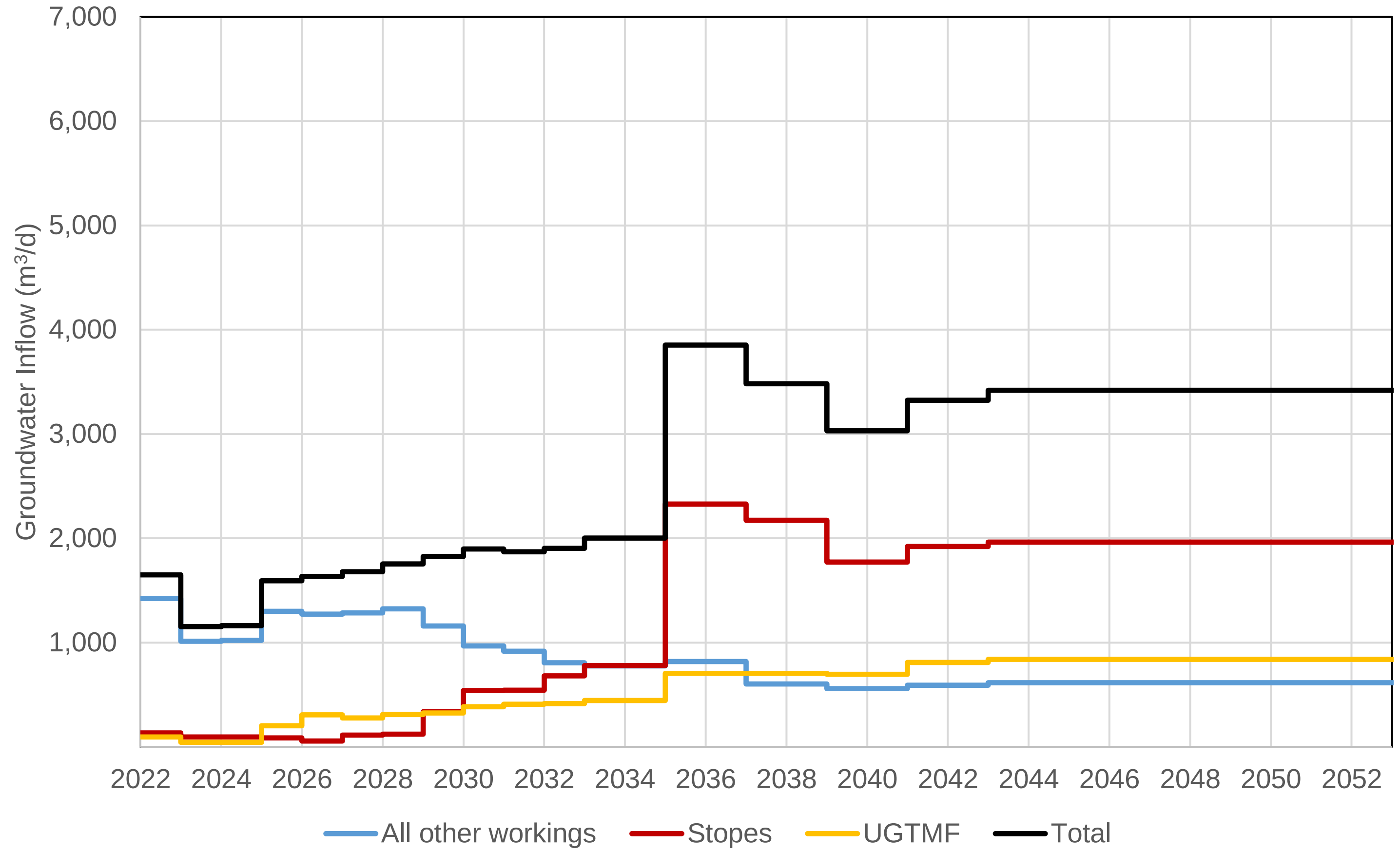
- UNDERGROUND WASTE SOURCE
- SURFACE WASTE SOURCE
- GEOLOGICAL PATHWAY
- RECEPTOR
- BACKGROUND

Notes:

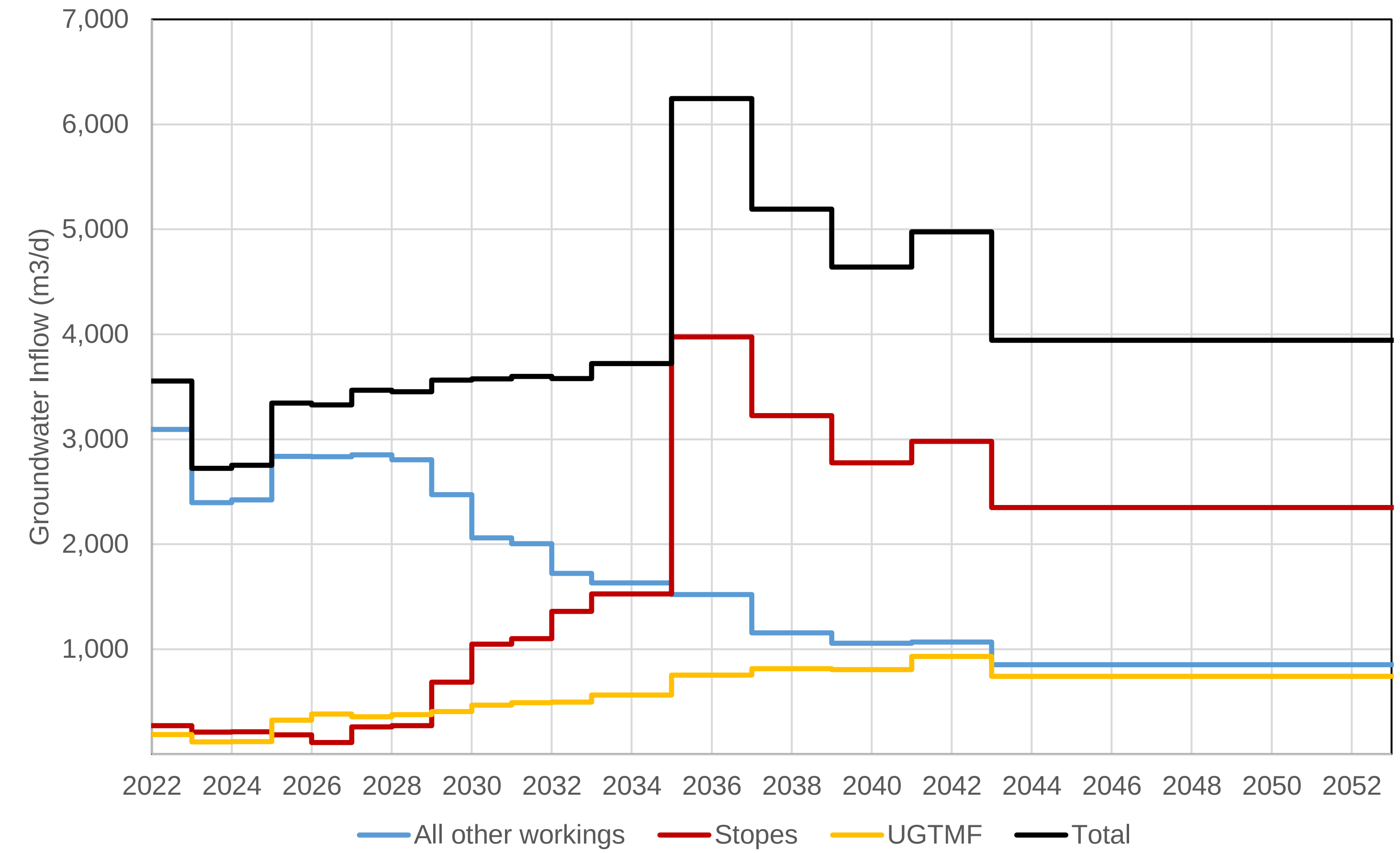
1) Mass loading rates from reflooded mine workings provided by SRK (November 30, 2020).
2) Mass loading rates from surface waste provided by SRK (November 26, 2020). The model is configured using the "Option 2 Engineered" scenario. No flow rate associated with this source (i.e., mass loading rates only)
3) Q_{AQ} refers to flow component through the bedrock adjacent to the tailings; Co refers to concentration at the tailings; J_D refers to diffusive mass flux

CLIENT	NexGen Energy Ltd.	PROJECT	NEXGEN ENERGY LTD. ROOK I PROJECT
CONSULTANT	GOLDER MEMBER OF WSP	TITLE	SOLUTE TRANSPORT MODEL SCHEMATIC
YYYY-MM-DD	2021-07-24	PROJECT No.	20144150
PREPARED	NB	PHASE	XXXX
DESIGN	NB	Rev.	1
REVIEW	SD	FIGURE	A-17
APPROVED	MT		

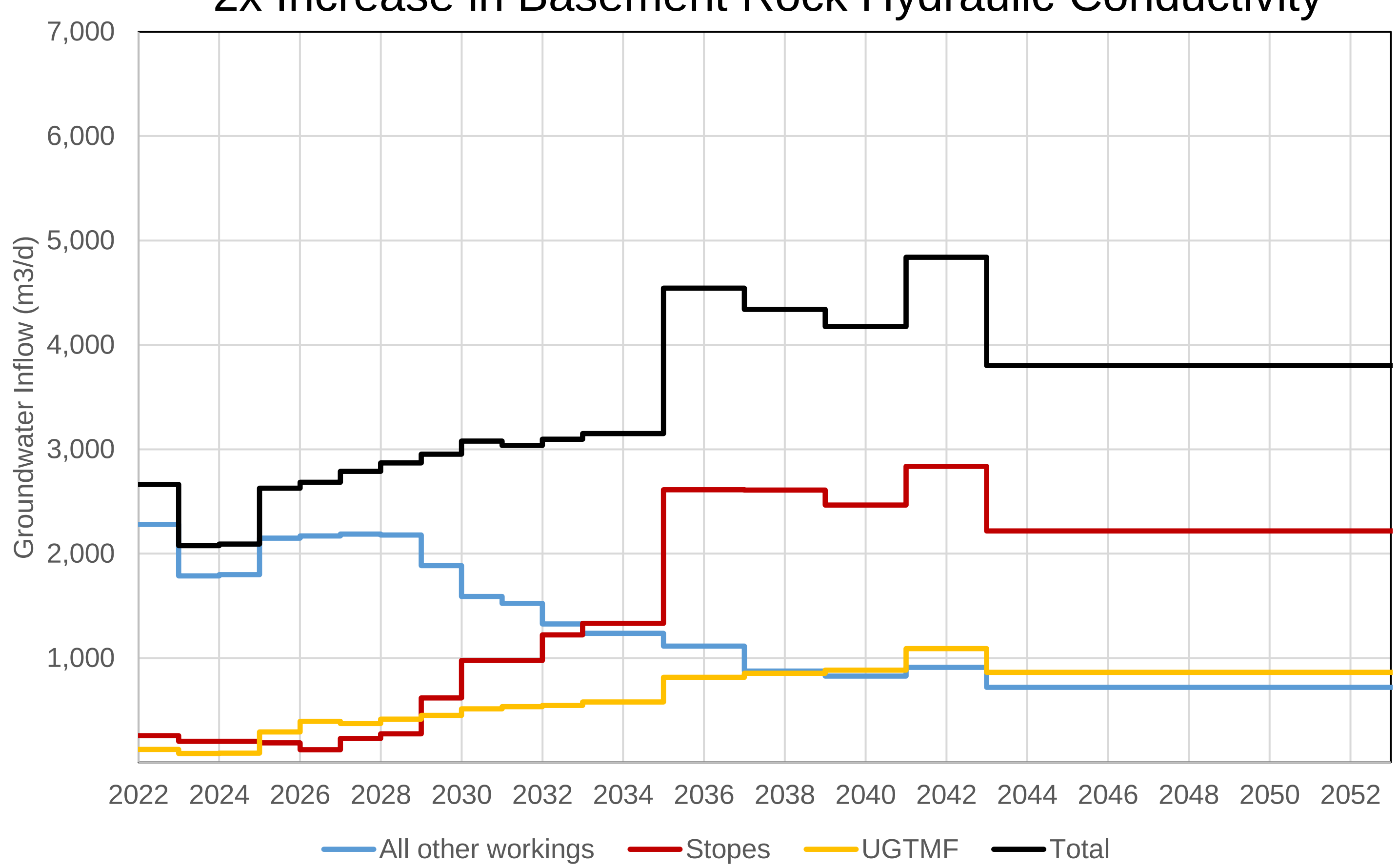
Base Case Simulation



5x Increase in Fault Zone Hydraulic Conductivity



2x Increase in Basement Rock Hydraulic Conductivity



Year	Annual Average (m^3/d)		
	Base Case	5x Increase in Fault Zone K	2x Increase in Basement K
2022	1651	3554	2664
2023	1153	2724	2078
2024	1162	2752	2091
2025	1594	3344	2628
2026	1636	3327	2683
2027	1679	3466	2788
2028	1755	3452	2869
2029	1826	3563	2954
2030	1897	3575	3079
2031	1870	3597	3036
2032	1903	3579	3096
2033	2001	3720	3150
2035	3852	6246	4544
2037	3483	5193	4341
2039	3031	4641	4177
2041	3325	4977	4839
2043	3420	3943	3802

CLIENT

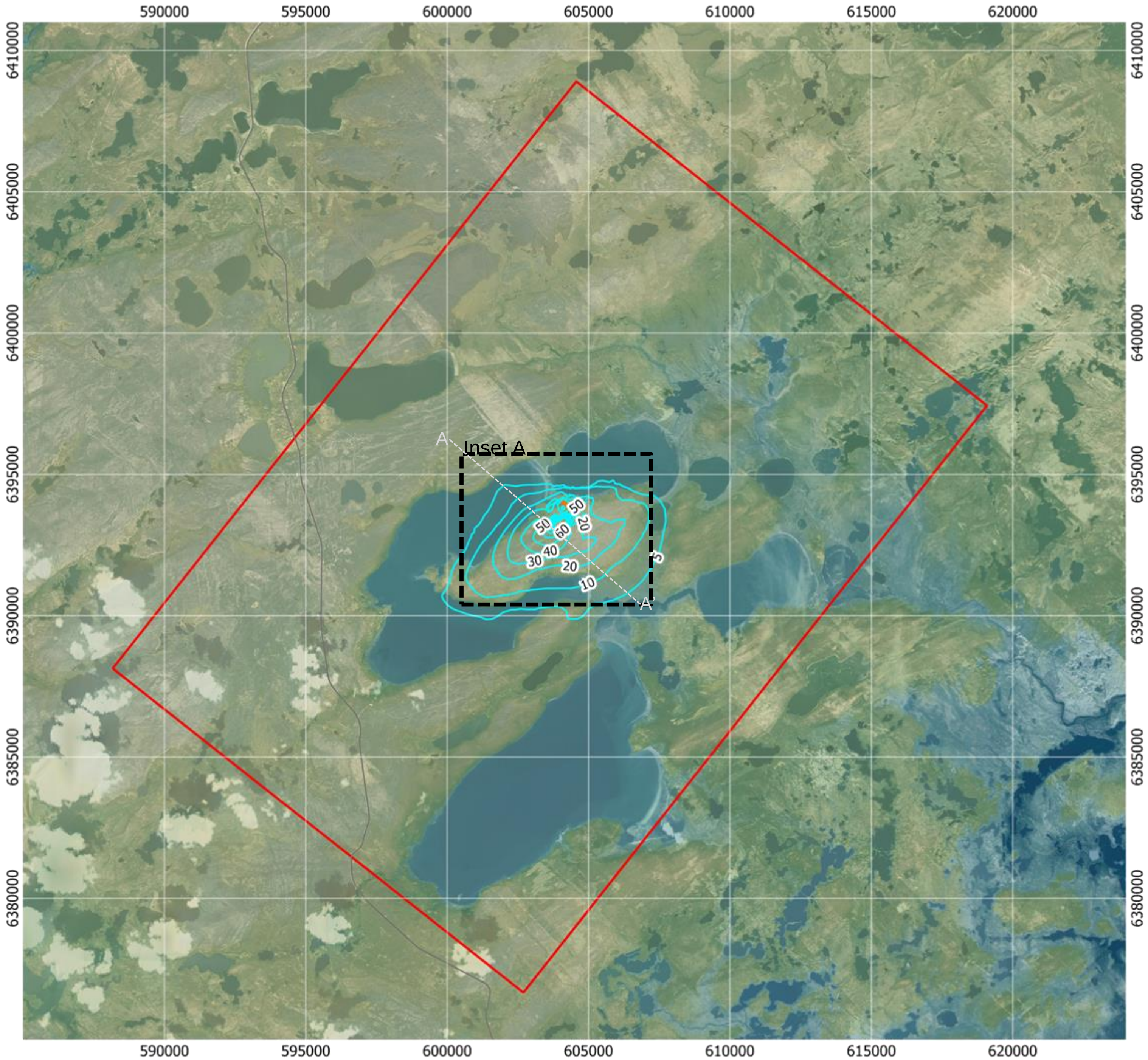
CONSULTANT

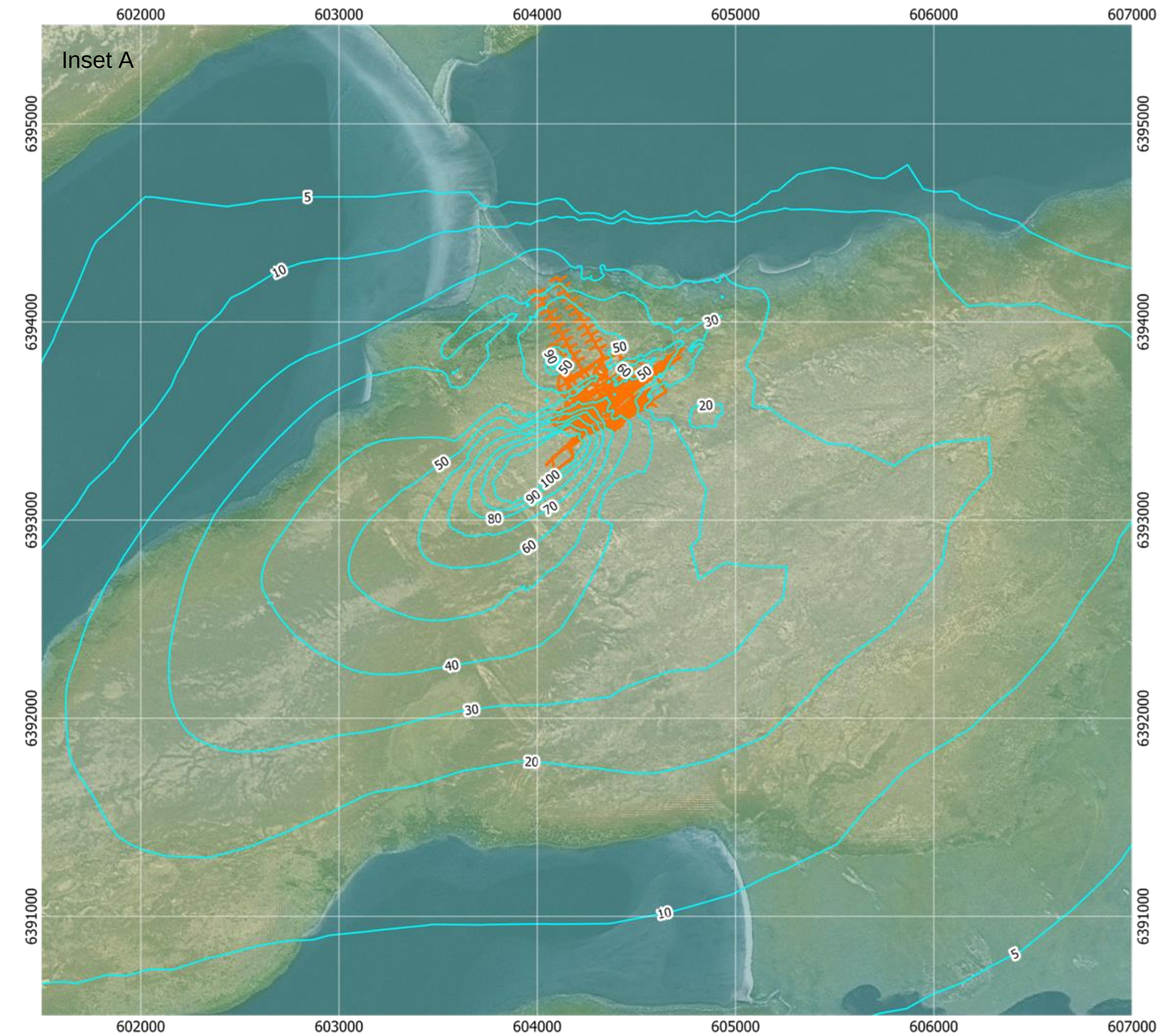
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

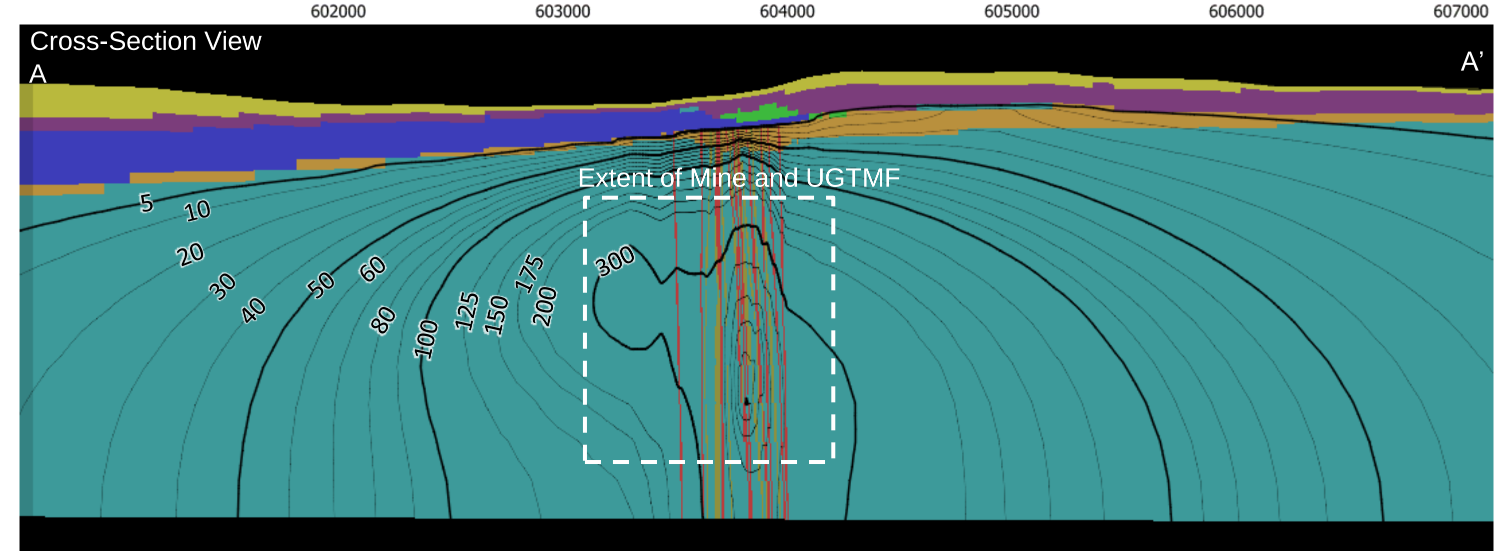
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED GROUNDWATER INFLOWS TO THE MINE

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	1	A-18







LEGEND

- MODEL DOMAIN
- UNDERGROUND WORKINGS
- SIMULATED GROUNDWATER DRAWDOWN CONTOUR (m)

Notes:

1) Groundwater drawdown shown for basement rock at elevation 330 mASL, approximately 200 m below ground surface.

CLIENT

NexGen Energy Ltd.

CONSULTANT

GOLDER MEMBER OF WSP

YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

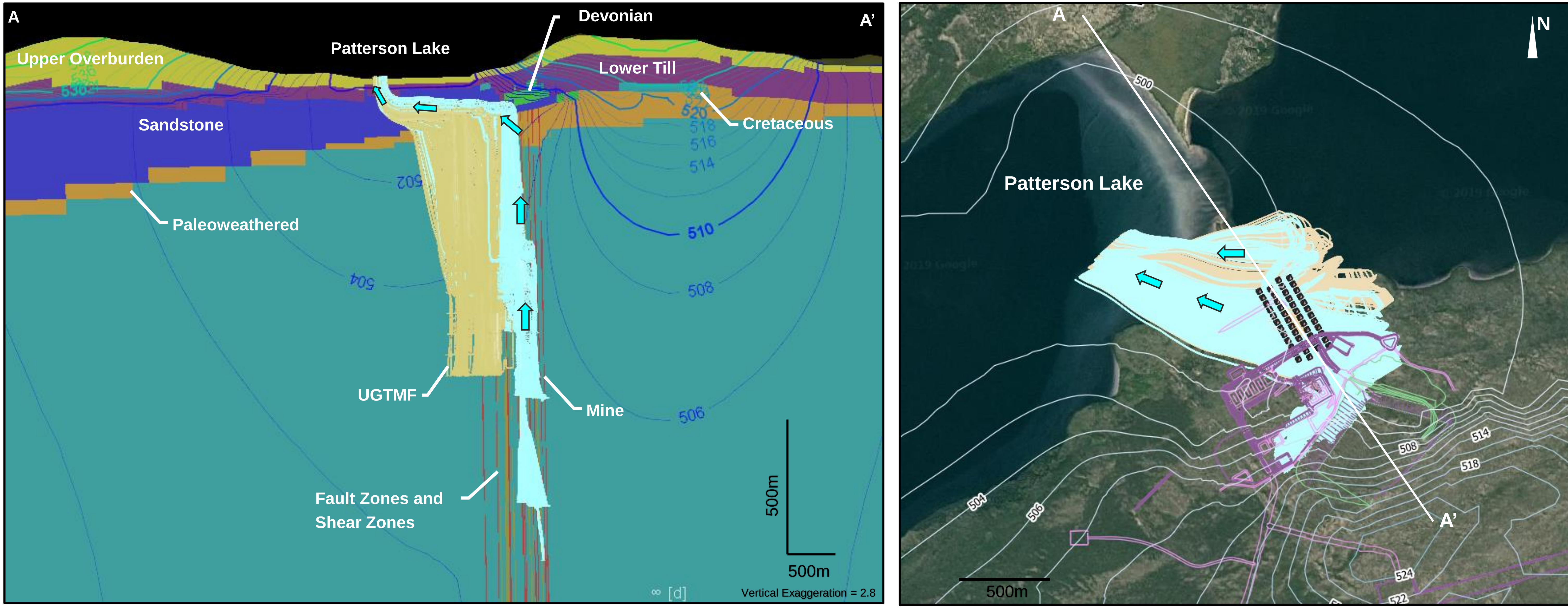
PROJECT

NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE

SIMULATED GROUNDWATER DRAWDOWN AT THE END OF OPERATIONS

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	1	A-19



LEGEND

- SIMULATED GROUNDWATER HEAD CONTOUR – SECTION VIEW (m)
- SIMULATED GROUNDWATER HEAD CONTOUR – PLAN VIEW (m)
- SIMULATED GROUNDWATER FLOW PATHWAY (UGTMF)
- SIMULATED GROUNDWATER FLOW PATHWAY (BACKFILL)
- BASEMENT ROCK
- PALEOWEATHERED BASEMENT ROCK
- SANDSTONE
- DEVONIAN ROCK
- CRETACEOUS ROCK
- LOWER OVERBURDEN (TILL)
- UPPER OVERBURDEN

Notes:
1) Arrows indicate direction of groundwater flow pathway
2) Simulated groundwater head contours reflect long-term post-closure conditions.

CLIENT NexGen Energy Ltd.		PROJECT NEXGEN ENERGY LTD. ROOK I PROJECT	
CONSULTANT GOLDER MEMBER OF WSP	YYYY-MM-DD 2021-07-24	TITLE PARTICLE TRACKING ANALYSIS – GROUNDWATER FLOW PATHWAYS FOR UNDERGROUND SOURCES	
	PREPARED NB		
	DESIGN NB		
	REVIEW SD	PROJECT No. 20144150	PHASE XXXX
	APPROVED MT	Rev. 1	FIGURE A-20a

LEGEND

- SIMULATED GROUNDWATER FLOW CONTOUR – PLAN VIEW (m)
- SIMULATED GROUNDWATER FLOW PATHWAY
- SURFACE WASTE FACILITIES (WRSA, INCLUDING PAG AND NPAG)
- SURFACE MINE INFRASTRUCTURE

Notes:

1) Arrows indicate direction of groundwater flow pathway
2) Simulated groundwater head contours reflect long-term post-closure conditions.

CLIENT
NexGen Energy Ltd.

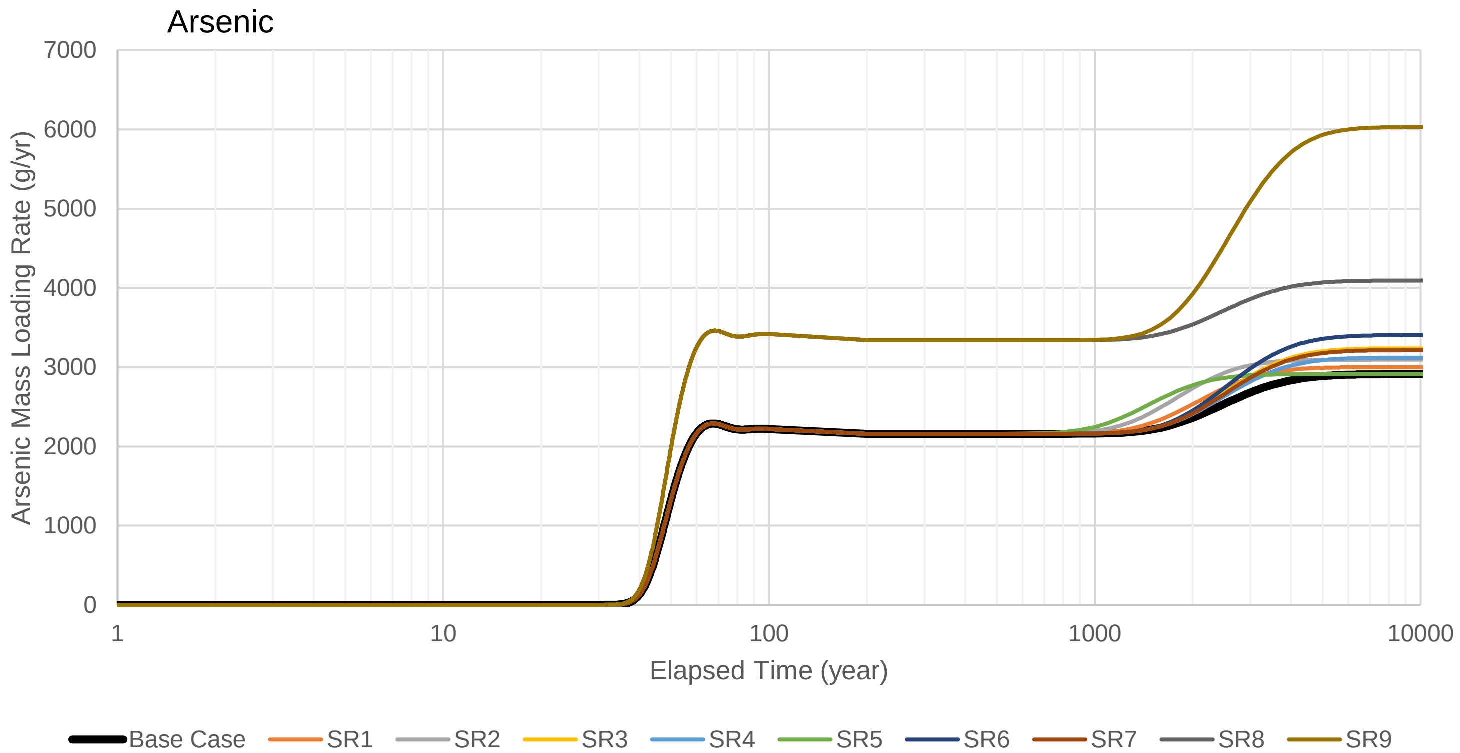
CONSULTANT
GOLDER MEMBER OF WSP

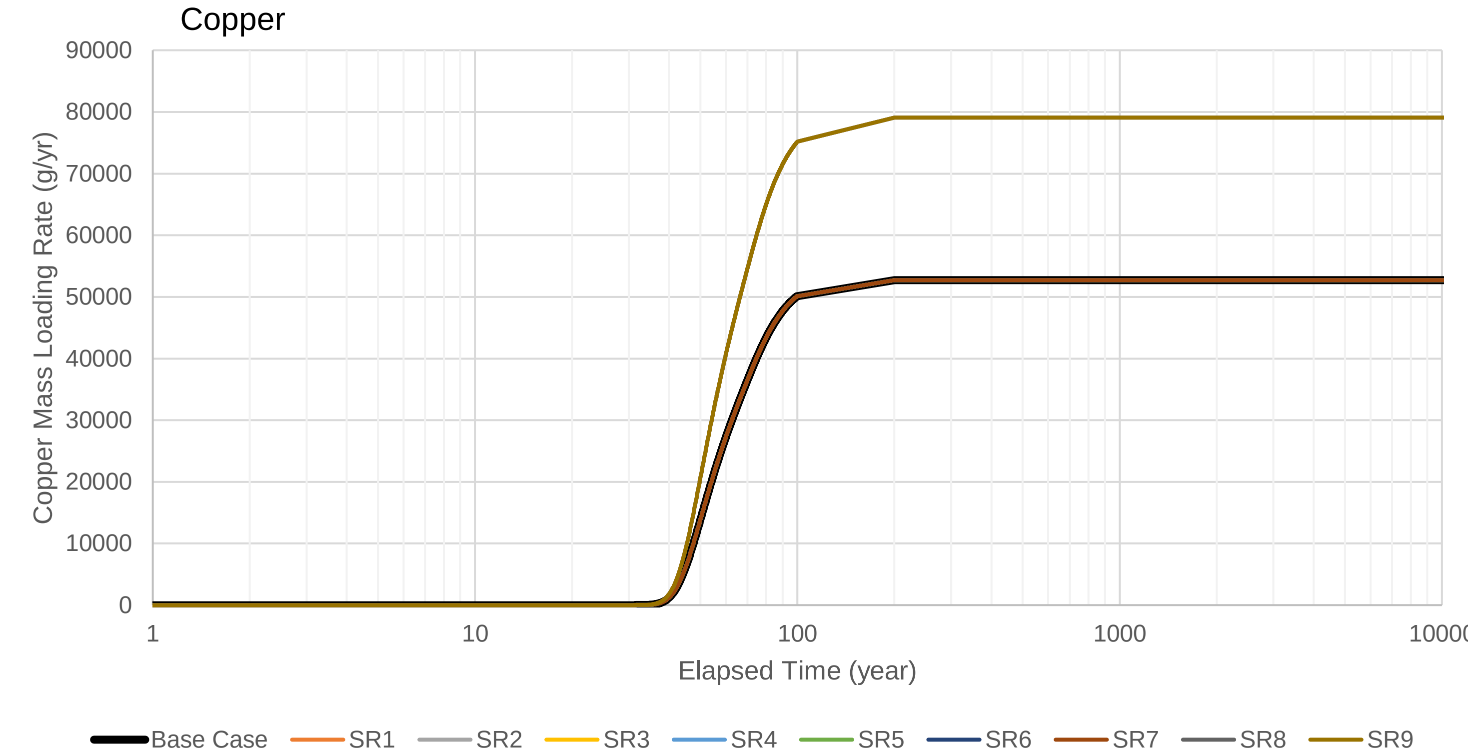
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

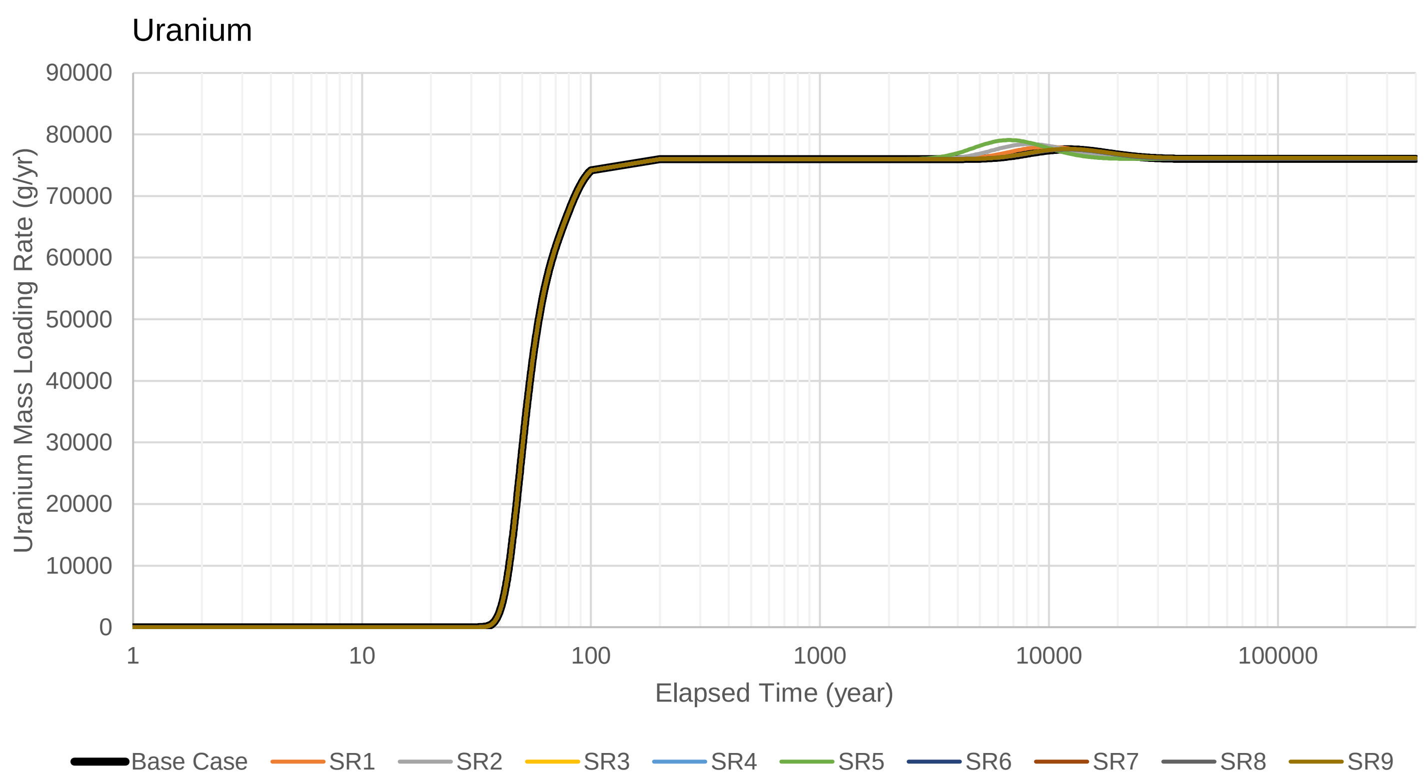
PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

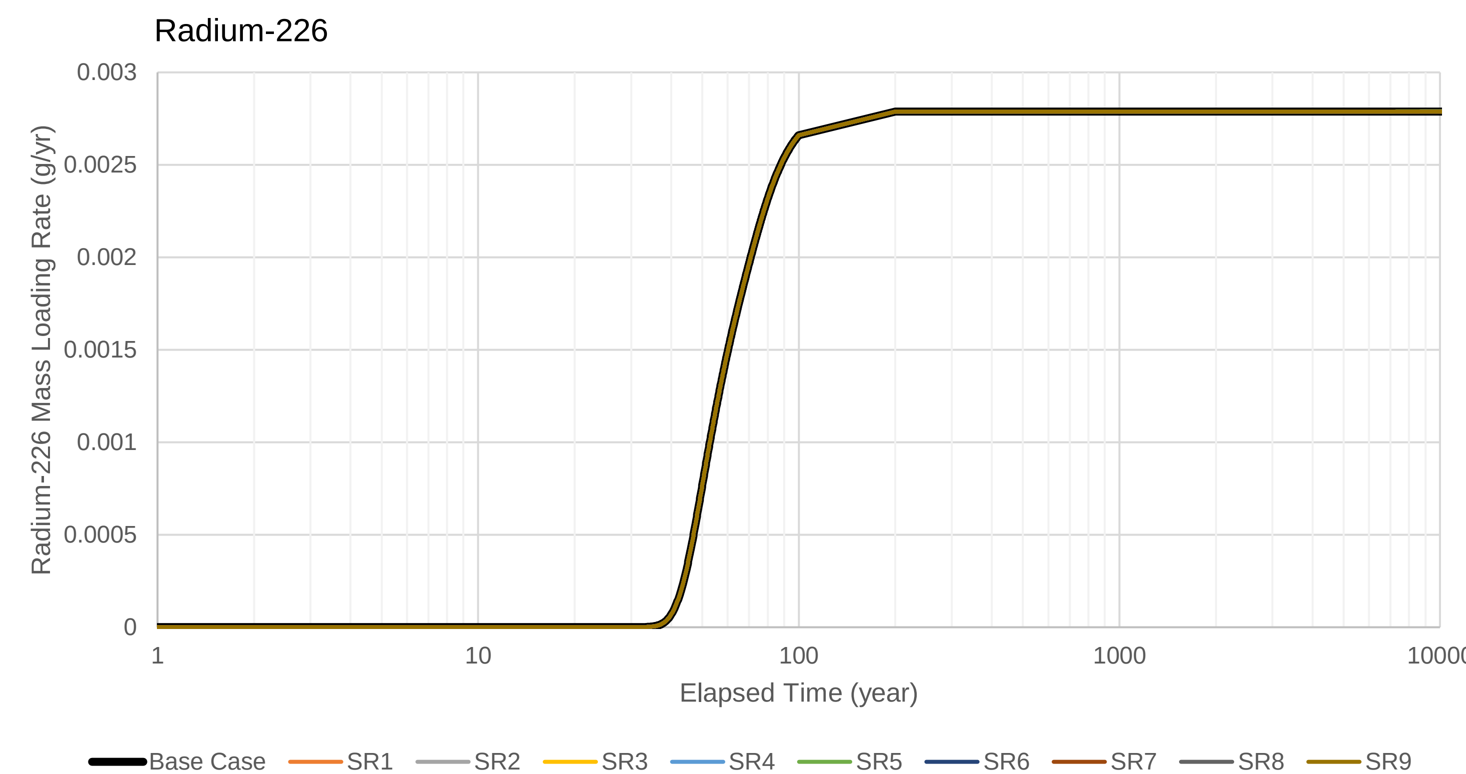
TITLE
PARTICLE TRACKING ANALYSIS – GROUNDWATER FLOW PATHWAYS FOR ABOVE GROUND SOURCES

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	1	A-20b









CLIENT
NexGen Energy Ltd.

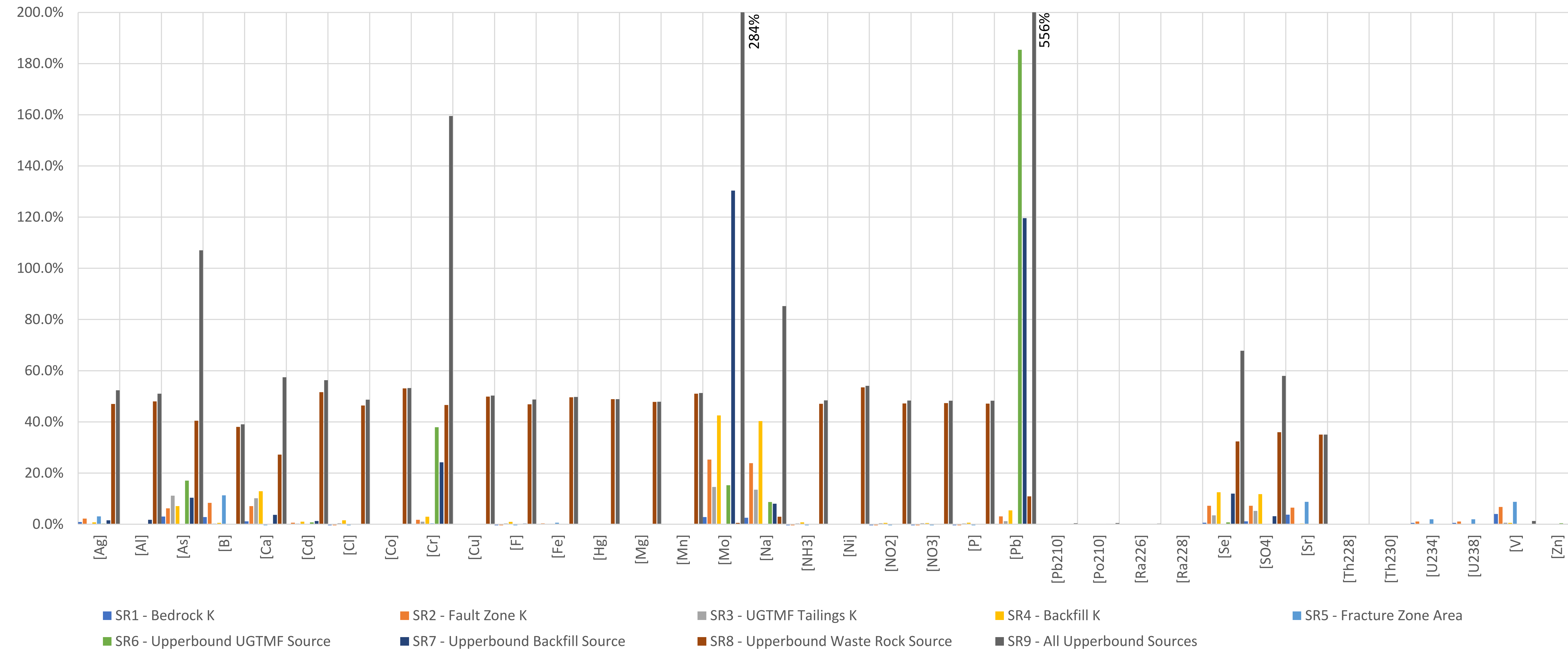
CONSULTANT
GOLDER
MEMBER OF WSP

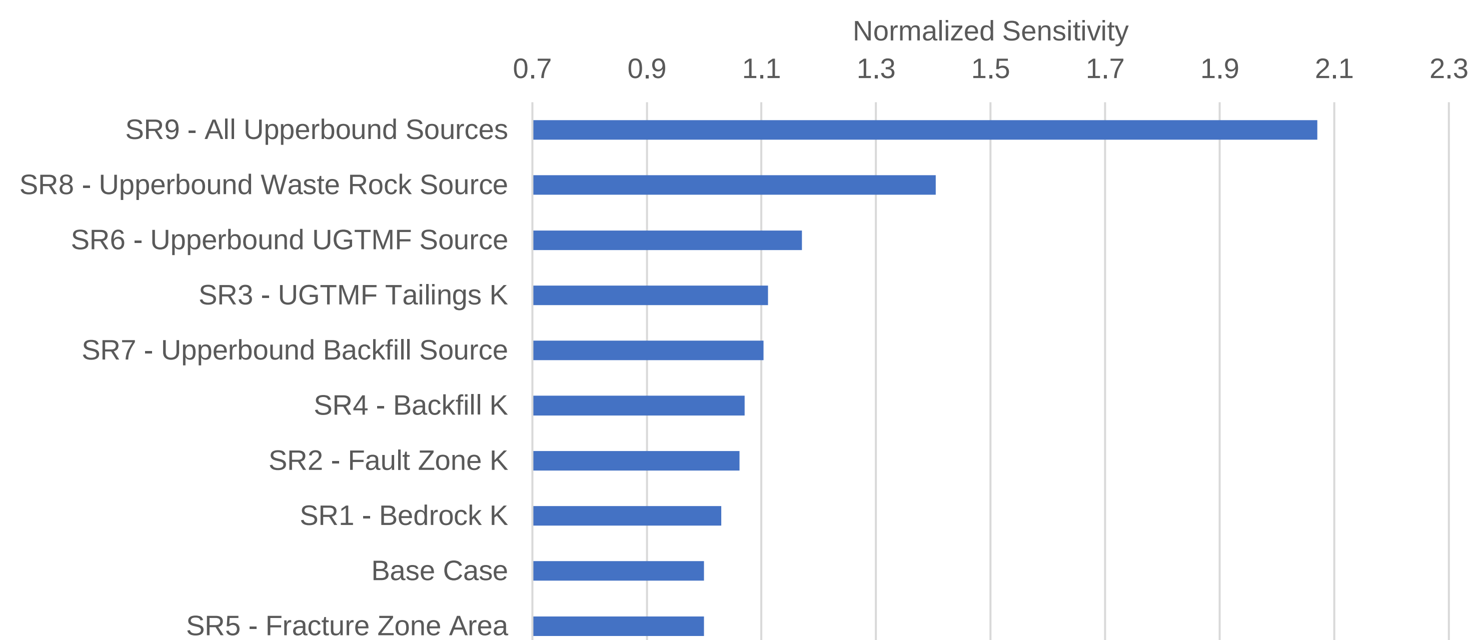
YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SIMULATED MASS LOADING RATES TO PATTERSON LAKE – PLOTS FOR SELECT SOLUTES

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	1	A-21





CLIENT
NexGen Energy Ltd.

CONSULTANT
GOLDER
MEMBER OF WSP

YYYY-MM-DD	2021-07-24
PREPARED	NB
DESIGN	NB
REVIEW	SD
APPROVED	MT

PROJECT
NEXGEN ENERGY LTD.
ROOK I PROJECT

TITLE
SOLUTE TRANSPORT MODEL – RESULTS OF SENSITIVITY SIMULATIONS

PROJECT No.	PHASE	Rev.	FIGURE
20144150	XXXX	1	A-22