CONFIDENTIAL

REPORT

Eagle Mine Phase 4 Crown Pillar Engineering

Report in Support of Permit Condition E8

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Executive Summary

The design of crown pillars for underground mines typically advances in phases. Initial assessment is normally based on data collected from core, using surface diamond drilling and then underground mapping as a mine is developed. As more data is collected from additional drilling campaigns and the mapping of underground development, subsequent phases of crown pillar assessment and engineering design are conducted and refined based on this improved knowledge of the crown pillar volume.

Two phases of crown pillar assessment were completed prior to the permitting of the Eagle Mine. The mine permit application proposed that a third phase of evaluation be undertaken prior to mining above a given threshold elevation, which was established at 327.5 m above sea level (MASL). Mining up to this elevation would result in a crown pillar thickness of 87.5 m that the Phase 2 assessment showed would be stable. It was also proposed that following the approval of the mining permit, additional data would be gathered during mine construction to refine the assessments of a Phase 3 crown pillar geometry. This concept was defended through the Contested Case Court hearings with the premise that this third phase of evaluation would be based on additional data gathered from exposure of the actual rock mass conditions in underground excavations. This approach was accepted by the Court and by the Michigan Department of Environmental Quality (MDEQ) and formed the basis for issue of condition (E8) to the permit, outlining the aspects to be addressed before mining could proceed above 327.5 MASL.

In 2016, Golder Associates Ltd. (Golder) completed the Phase 3 Crown Pillar assessment (Phase 3) as planned (Golder, 2016a). During Phase 3, additional information was collected, including geotechnical, geological, and hydrogeological data. This information was used to create a soft-coupled 3D model that integrated the Engineering-Geology (EG) model, the numerical stress model, the hydrogeological model, and the discrete fracture network (DFN) model. The crown pillar was assessed for stability, and the water inflows were estimated based on the change in stresses as a result of mining. This assessment supported the proposed mining approach above 327.5 MASL that included two additional levels of development at elevations of 352 MASL and 381 MASL (352 level and 381 level, respectively), and one additional level of production stoping on the 323 level (between the 323 level and the 352 level). Eagle Mine development levels are named after the elevation of the floor in MASL; and when a stope is referred to be on a particular mine level, the mine level referenced is the one that accesses the bottom of the stope.

The MDEQ reviewed and accepted the report prepared by Golder summarizing the Phase 3 work (Golder, 2016a), which has allowed Eagle Mine LLC (Eagle) to progress with development to 381 MASL, and progress with stoping between 323 MASL and 352 MASL. As planned at the end of Phase 3, Eagle and Golder have continued to collect data and advance the assessment of the crown pillar as additional mining was completed. These efforts have been described as the Phase 4 crown pillar work. After the Phase 3 work was accepted by the MDEQ, development was advanced to the 381 level, above the current maximum allowable production elevation, in order to collect additional geotechnical and hydrogeological information to be used for the Phase 4 crown pillar assessments. The intent of this work has been to improve the understanding and characterization of the crown pillar zone, to refine mining plans above 352 MASL, and to assess the stability of these mining plans, in order to address the seven requirements set out in the mine permit condition E8 to approach the ultimate crown pillar thickness as follows:

1) **Collect in Situ Stress Data** – After the completion of Phase 3, additional in situ stress measurements were collected on the 172 level in 2016, and on the 381 level in 2019 by Golder. This additional information allowed the Phase 3 stresses to be refined for use in the Phase 4 assessments. When in situ stresses were assessed for Phase 4, stress measurements from three depths within the mine were available. This allowed stress gradients with respect to depth, and locked in stresses to be estimated, resulting in an improved stress regime interpretation compared to that of Phase 3, when only measurements from one depth were available. Locked in stresses are expressed as a constant rather than a gradient. The Phase 4 stress regime is expressed as follows:

$$\sigma_1 = 0.030\text{*depth} + 2.70 \text{ (MPa)}$$
$$\sigma_2 = 0.028\text{*depth} + 1.13 \text{ (MPa)}$$
$$\sigma_3 = 0.018\text{*depth (MPa)}$$

2) **Supplemental Drilling to Fill in Data Gaps** – Eagle has drilled 337 (20,646 m) additional diamond core drillholes from underground since the completion of Phase 3. No additional drilling has been completed from surface since the completion of Phase 3.

3) **Standard Geologic Data** – Additional geologic data has been collected from additional diamond drill core and through mapping of the underground development completed to date. Most notably, since the completion of Phase 3, the mine has conducted development on the 294, 323, 352, and 381 levels.

4) **Geotechnical Data** – Additional geotechnical data has been collected from 63 (7,043 m) of the additional diamond core drillholes since the completion of Phase 3. Portions of specific diamond core drillholes were selected for geotechnical data collection to reduce the gaps in geotechnical data that existed at the end of Phase 3.

   Mapping of the underground development has been completed to collect structural fabric and rock mass quality information. Most notably, since the completion of Phase 3, the mine has conducted development on the 294, 323, 352, and 381 levels. No additional oriented core or televiewer data was collected as part of Phase 4.

   The Phase 4 rock mass characterization for the crown pillar is consistent with the previous phases of characterization. While the Phase 4 work has improved the characterization by adding more data and underground coverage, the rock mass characterization is within the range of conditions estimated during Phase 3 and previous phases of the project.

5) **Hydrologic Data** – Since the permit was issued in 2007, piezometers and groundwater monitoring wells were installed near the crown pillar and have been continuously monitored. The mine has been collecting daily pumping inflow and outflow rates since development of the mine started, and this was used to estimate the groundwater inflow into the mine and calibrate the groundwater flow model.

6) **Physical 3-Dimensional Model** – The soft-coupled 3D model was updated to include additional data added to the EG model, the numerical stress model, the hydrogeological model, and the DFN model.

   Information from the EG was used to generate the DFN and was also used in the numerical stress model. The numerical stress model data was applied to the fractures in the DFN in order to estimate changes in the hydraulic conductivity of the crown pillar during mining. The soft-coupled model forecasted inflows to be 10 to 34 USgpm at the end of mine life. Based on the results of the soft-coupled model, the crown pillar is not anticipated to be affected by changes to inflow due to stress changes in the crown pillar as a result of mining.

7) **Evaluate Rock Stability** – The physical stability of the crown pillar was assessed by means of a Scaled Span assessment and the numerical stress modeling results. The performance of the stope stability to date was examined using the Mathews Stability Graph method (Golder, 1981). The performance of the backfill to date was examined based on cavity monitoring surveys, visual observations, and laboratory strength testing of the backfill. The stope stability and backfill performance to date have shown that the mine has good practices related to stope stability and backfilling. This information indicates that the stability of the overall crown pillar footprint is not of concern, and as such, stability assessments have focused on an “open ground” effect (e.g., stope-by-stope stability assessment as opposed to overall crown pillar footprint). The justification for this approach is that the stope walls are stable for the range of conditions encountered at Eagle Mine, and the crown pillar will be supported by the stope backfill.

Since the completion of Phase 3, the mine has developed a Crown Pillar Management Plan (CPMP), which includes a detailed monitoring plan, a Trigger Action Response Plan (TARP) for groundwater inflows and ground movement monitoring, a backfill management and Quality Assurance (QA)/ Quality Control (QC) plan, and a stope reconciliation process, in addition to the Ground Control Management Plan (GCMP) that has been in place since the start of mining.

The Phase 4 crown pillar assessment completed by Golder supports the proposed mining approach to achieve the last level of production stoping between the 352 level and the 381 level. As described in this report, it is considered that the completed work satisfies the requirements identified in condition E8.

Study Limitations

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by Lundin Mining's Eagle Mine LLC (Eagle) to complete an update to the crown pillar engineering, referred to as the Phase 4 Crown Pillar Engineering Project. The objective is to confirm the assessments performed in the previous stage of crown pillar engineering (Phase 3), using updated data collected from directly below the proposed crown pillar.

2.0 PROPOSED MINING APPROACH

The final mine design for Eagle includes one additional level of production stoping (between the 352 level and the 381 level) beyond the approved Phase 3 limits, as shown on Figure 1. Development on the 381 level and the 352 level, and production stoping between the 323 level and 352 level, were previously approved following of the Phase 3 assessment work. This permit action is for permission to complete the additional level of stoping between the 352 level and the 381 level. This is the final request for permission under the mine permit, as Phase 4 will result in the mine reaching the ultimate crown pillar thickness/elevation (29 m/386 MASL), as specified in the mine permit. Eagle Mine development levels are named after the elevation of the floor in MASL; and when a stope is referred to be on a particular mine level, the mine level referenced is the one that accesses the bottom of the stope.

The mine is currently developed on each of the planned horizons (145, 172, 190, 215, 240, 250, 265, 294, 352 and 381 levels [MASL]). Primary stopes have currently been extracted on the 145, 172, 190, 215, 240, 265, 294, and 323 levels of the mine and backfilled with Cemented Rock Fill (CRF), and secondary stopes have currently been extracted on the 145, 172, 190, 215, 240, and 265 levels of the mine and backfilled with non-cemented waste rock.

2.1 Crown Pillar Plans, Controls, and Monitoring

The Phase 4 crown pillar assessment supports the proposed additional level of production (between the 352L and 381L), as shown on Figure 1. An important aspect of successfully mining in the upper levels of the mine is to connect the Phase 4 assessments and recommendations with the day to day activities at the mine. This will facilitate the completion of mining activities in a planned and controlled manner. Eagle, with support from Golder, have developed a Crown Pillar Management Plan (CPMP) to manage key activities related to mining above the elevation restriction in the permit condition E8 (327.5 MASL). The CPMP consists of the following six sub-plans:

1) **Detailed Monitoring Plan** – Prior to the start of developing of the mine, Eagle developed a monitoring plan that includes two multi-point borehole extensometers installed from surface, surveying of monitoring stations on surface located within the footprint of the crown pillar, continuous water level logging of six bedrock piezometers, nine quaternary (overburden) monitoring wells, six wetland monitoring wells, and visual monitoring and data collection from the underground development (e.g., features that result in water inflows >5 USgpm). Eagle intends to continue to develop and improve the existing monitoring plan for the crown pillar. Eagle has also installed seven multi-point borehole extensometers (MPBX's) in key locations in the crown pillar area from underground, prior to mining the stopes above the 323 level. The MPBX's are 12 m long, monitor six points, and are installed vertically above primary sill drives on the 381, 352, and 323 levels.

2) **Trigger Action Response Plan (TARP)** – Eagle has developed a TARP that relates to the detailed monitoring plan. This includes setting thresholds below and at the regulatory required action thresholds for groundwater monitoring, inflow monitoring, and displacement monitoring, and respective responses for if each threshold were to be reached.

3) **Backfill Management and Quality Assurance/Quality Control (QA/QC) Plan** – Backfilling is an important aspect to maintaining stability in open stoping areas, including in the crown pillar area. Given the primary-secondary, bottom-up sequence at the Eagle Mine, the effective employment of CRF is critical to achieve the desired mining targets, while maintaining the stability of the rock. In order to confirm the effectiveness of the backfill, a QA/QC plan has been developed that involves regular visual monitoring of the components of the backfill (aggregate, sand, and binder) and strength testing of backfill samples in order to confirm that the design target of 1.5 MPa backfill strength is reached at 28 days of curing. Since implementation, the mine has maintained this testing program and intends to continue with testing throughout the mining of the primary and secondary stopes, continually building the knowledge and experience base. Jam filling has been completed on the 145, 190, 265, and 294 levels of the mine to date. Jam filling is also used in some primary stope bottom sills to close the brow of the stope and confirm that the sill is tightly filled. Golder has observed jammed and non-jammed fill that has been exposed by adjacent drifting, and the backfill is observed to stand up well and there are no records of fill failure in these areas.

4) **Stope Reconciliation Process and Database** – The mine has developed a process to collect and assess data on a regular basis related to production data, backfill records, cavity monitor surveys (CMS), volume/overbreak reconciliation, and maintaining a record of stope stability using the Stability Graph method (Golder, 1981). As part of the Phase 4 work, Golder reviewed this data in order to assess the performance of the stopes and backfilling to date, as this is the best indication of anticipated performance of the stopes and backfill between the 352 level and 381 level.

5) **Ground Control Management Plan (GCMP)** – Eagle has developed a GCMP that includes minimum ground control standards for the mine and describes how these standards are to be implemented. The GCMP defines the communication protocols between the operations team and the engineering department (i.e., communication of unusual ground conditions, identification of areas that may require rehabilitation, and any rock mechanics observations made each day).

6) **Crown Pillar Risk Register** – Eagle has developed and maintained a risk register related to the crown pillar. The risk register was developed at the end of Phase 3 and has been updated regularly as mining progressed towards the 381 level and continues to be updated on an ongoing basis as new information is collected and an improved understanding of the crown pillar conditions are gained. In addition to this, enhanced monitoring and trigger-action response plans have been implemented, which have decreased the risk associated with the crown pillar since the original risk register was created at the completion of Phase 3.

Taken together, the above six sub-plans form the CPMP. The CPMP is used to guide day-to-day activities at the mine. Progress with the CPMP is reviewed monthly by management and operations staff at Eagle Mine. Golder is included in these reviews as needed.

3.0 PERMIT CONDITION E8

Included in the mining permit for the Eagle Mine is Condition E8, which restricts mining to below 327.5 MASL. This condition includes seven aspects relating to the crown pillar for the mine to address before additional stoping above 327.5 MASL is approved by the regulator. The conditions are as follows:

1) Collect in situ stress data.
2) Supplemental drilling to fill in data gaps.
3) Collect standard geologic data.
4) Collect geotechnical data.
5) Collect hydrologic data.
6) Physical 3-dimensional model.
7) Evaluate rock stability.

The following sub-sections (3.1 through 3.7) provide a summary of each aspect of the permit condition, and describes the work completed in order to address each component of condition E8 above.

3.1 Collect In Situ Stress Data

In situ stress measurements were completed at Eagle Mine for Phase 4 to supplement the measurements completed in 2013 in support of Phase 3. In addition to providing useful information for the engineering of the mine, this testing program fulfilled sub-condition (1) of permit condition E8. The collected in situ stress data provided measurements to better define the stress regime of the mine.

During the Phase 4 data collection period (e.g., after the completion of Phase 3), Golder completed overcoring stress measurement programs on the 381 level in 2019 and the 172 level in 2016. Testing was conducted using CSIRO Hollow Inclusion Stress Cells (HI Cells). The tests were completed at two sites on the 381 level of the mine, as shown on Figure 2, and at one site on the 172 level of the mine, as shown on Figure 3. The stress measurement results were summarized into major, intermediate, and minor principal stresses with a trend and plunge orientation, as shown in Table 1.

Table 1: Overcoring Stress Measurement Testing Summary

Level	Test #	σ_1 – Major Principal Stress			σ_2 – Intermediate Principal Stress			σ_3 – Minor Principal Stress		
		MPa	Trend (°)	Plunge (°)	MPa	Trend (°)	Plunge (°)	MPa	Trend (°)	Plunge (°)
381 L	SM11	6.0	188	11	0.7	095	12	-1.6	320	74
	SM12	2.8	228	34	1.9	326	02	-0.5	071	54
	SM13	4.9	186	31	2.5	285	15	1.7	037	55
	SM21	2.0	003	88	0.7	242	01	0.4	152	01
	SM22	3.0	223	17	1.3	133	00	0.5	042	73
	SM31	9.3	200	04	2.9	109	14	1.2	308	76
	SM32	4.6	221	03	3.6	312	12	1.9	115	77
	SM33	3.0	030	19	1.2	270	55	0.0	130	28
	SM41	2.9	346	10	1.8	254	09	-0.1	123	76
172 L	OC2	9.0	058	07	5.0	148	15	4.0	290	76
	OC3	13.0	253	00	7.0	343	07	4.0	164	84
	OC4	14.0	184	29	9.0	288	24	2.0	053	50

The overcoring stress measurements collected in 2013 during the Phase 3 crown pillar assessment were interpreted along with the overcoring stress measurements collected during the Phase 4 assessment, and input into the numerical stress modeling software FLAC3D. The stress measurements were used to calibrate the numerical stress model, considering the mining completed at the time of each measurement, the rock mass characterization for Phase 4, and the geologic setting of the measurement locations. A series of modeling scenarios were completed for the calibration process.

As part of the calibration process, the Phase 3 stress measurements were reviewed. As part of this review, it was identified that the Phase 3 stress measurements were within an area with a localized stress rotation and magnitude, as a result of the shape of the peridotite-sediment contact at the locations of the tests, as shown on Figure 4. In the Phase 3 Crown Pillar Engineering report, it was acknowledged that the stress measurements completed in 2013 were on the higher end of the range of anticipated stresses. The Phase 4 stress measurements confirmed this notion and allowed for the development of a more refined stress regime. The stress regime determined for Phase 4 is summarized in Table 2.

Table 2: Phase 4 Stress Tensor Summary

	Estimated Stress Magnitude at 30 m Depth (MPa)	Trend	Plunge	Phase 4 Principal Stress (MPa)
Major (σ_1)	3.6	214°	14°	σ_1 = 0.030*depth + 2.70
Intermediate (σ_2)	2.0	304°	10°	σ_2 = 0.028*depth + 1.13
Minor (σ_3)	0.5	041°	73°	σ_3 = 0.018*depth

In addition to stress measurements, Eagle and Golder staff regularly perform inspections of Eagle Mine development, which includes recording observations relating to stress induced damage. As part of Phase 4, Golder completed a site visit to collect stress observations. During this site visit, there were no observations of damage surrounding underground development as the result of high in situ stresses recorded in Eagle Mine. Observations of potential stress damage were recorded by Golder in the decline to Eagle East, at a depth of approximately 850 m below ground surface (approximately 580 m below Eagle Mine). These observations are consistent with the stress magnitudes interpreted from the stress measurements relative to the rock strength.

3.2 Drilling to Fill in Data Gaps

Ongoing data collection is a standard industry practice conducted as mines are developed, which allows geological and geotechnical models to be refined and improved for subsequent assessment. The Phase 3 crown pillar assessment was completed based on orebody delineation diamond drill holes that were geotechnically logged, and underground development mapping. During Phase 3, six shallow dipping drillholes (12EA301, 12EA302, 12EA303, 12EA304, 12EA305, and 12EA306) were drilled through the crown pillar zone above the planned 381 MASL stoping and development workings, and each was geotechnically logged (Golder, 2016a). For Phase 3 and prior Phases, a total of 43,850 m of core in 127 diamond core holes were geotechnically logged.

In order to fulfill sub-condition (2) of permit condition E8, the mine has made an explicit effort to identify potential data gaps and drill additional boreholes to collect information throughout the crown pillar and fill these gaps. For Phase 4, an additional 20,646 m of core in 337 diamond core holes were drilled. From this, 7,043 m of core from 63 diamond core holes was geotechnically logged. The portions of holes selected for logging were determined by comparing the new drilling to the overall drilling previously completed to identify areas of holes that would provide valuable geotechnical data to fill data gaps that existed after Phase 3.

3.3 Standard Geologic Data

In order to fulfill sub-condition (3) of permit condition E8 and mine the last level of stopes (between 352 MASL and 381 MASL), the mine was required to collect standard geologic data. Since the permit was issued in 2007, the mine developed a decline from surface to the 145 level, and development has been completed on the planned levels of the mine. Primary stopes have currently been extracted on the 145, 172, 190, 215, 240, 265, 294, and 323 levels of the mine. The mine has geologically mapped the exposed developments on the 145, 172, 190, 215, 240, 265, 294, 323, 352, and 381 levels.

For Phase 4, additional drillholes (more than 337 diamond core drillholes) were drilled from underground, with approximately 20 drillholes providing data in the crown pillar zone. This mapping and drilling data have been used to update and improve the Eagle Mine geological models. With this additional data, there were no changes in the geologic interpretation at the Eagle Mine since the interpretation completed in Phase 3. The geologic units at Eagle Mine consist of: Overburden, Sedimentary, Intrusive, and Sulphide. The composition of these geologic domains remains the same as Phase 3 (Golder, 2016a).

3.4 Geotechnical Data

In order to fulfill sub-condition (4) of permit condition E8 and mine the last level of stopes (between 352 MASL and 381 MASL), the mine was required to collect geotechnical data. This aspect has been addressed primarily through geotechnical logging of additional diamond core drilling and underground geotechnical mapping for the collection of rock mass parameters.

For Phase 4, an additional 7,043 m in 63 diamond core holes were geotechnically logged. The portions of holes selected for logging were determined by comparing the new drilling to the overall drilling previously completed to identify areas of holes that would provide geotechnical data to fill data gaps that existed after Phase 3. Furthermore, Golder provided recommendations to Eagle to log core in any of the non-geotechnical holes if low RQD zones (RQD < 50%) or major structures (e.g., faults) were intersected. Eagle noted that no low RQD zones or major structures were identified in any of the completed holes.

3.4.1 Updated Geotechnical Characterization

The updated crown pillar geotechnical characterization was completed based on data collected from geotechnically logged drill core and geotechnical mapping of the underground development. This consisted of intact rock strength, rock mass structural fabric data, and rock mass quality data as outlined in the following sub-sections, in conjunction with the geological interpretation provided by Eagle. As part of Phase 3, Golder created a geotechnical RQD and Rock Mass Rating 1976 (RMR_{76}) block model using the geotechnical drillhole data available at the time (Golder, 2016a); and as described in Section 3.6.1, the Phase 4 assessment has focused on comparison of the additional drilling and underground mapping data to the Phase 3 block model in an effort to confirm the Phase 3 block model. The rationale for continuing to use Bieniawski (1976) rather than Bieniawski (1989) is that it constitutes the basic reference for the application of the Hoek-Brown (H-B) criteria (Hoek et al., 1995).

3.4.1.1 Intact Rock Strength Testing

In Phase 3, laboratory testing from 2006 (Coleman Engineering, 2006) and 2014 (Earth Mechanics Institute, 2014) were used to characterize the intact rock strength. Results of the average values from the laboratory strength testing are presented in Table 3. Details of the uniaxial and triaxial compressive strength tests are presented in the Phase 3 Crown Pillar Engineering Report (Golder, 2016a).

Table 3: Phase 3 Uniaxial Compressive Strength Testing Summary (After Golder, 2016a)

Simplified Lithology	Coleman Engineering (2006) Data		EMI (2014) Data	
	Average UCS (MPa)	Standard Deviation	Average UCS (MPa)	Standard Deviation
Intrusive	114	56	158	9
Sulphide	81	41	124	56
Sedimentary	93	60	190	39

Additional UCS testing was not completed for Phase 4, however, point load index tests were completed on some of the geotechnically logged Phase 4 core. A comparison of the Phase 3 and Phase 4 point load strength index results for each geotechnical domain are summarized in Figure 5. This comparison shows that the Phase 4 point load index test results for the lithologies and domains are consistent with the Phase 3 results.

3.4.1.2 Rock Mass Structural Fabric

The Phase 3 rock mass structural fabric was largely based on geotechnical drilling and televiewer data, supplemented with mapping data of underground development. The rock mass structural fabric has been updated in Phase 4 using additional mapping data from underground development. No additional oriented core or televiewer data collection has been completed as part of Phase 4.

Phase 4 underground scanline mapping was used to assess the structural fabric of each rock type. Structures observed underground and in core include: joints, bedding, foliation/cleavage, shearing, veins, faults, and contacts. Terzaghi Weighting was used throughout this assessment to account for the bias caused by N-S and E-W development. Terzaghi Weighting is a method of weighting structure orientation measurements, relative to their likelihood of being encountered based on the orientation of the traverse (such as a borehole or mapping scanline) that the structure was recorded along, to reduce the bias that is introduced because of the orientation of the traverse. This is particularly important for the Intrusives and Sulphides which were predominantly encountered in N-S oriented excavations as a result of how the orebody is accessed. Field observations during a 2019 site visit to Eagle Mine were also used for interpretation of the rock mass fabric. The mapping for Sedimentary and Intrusive geotechnical domains remains the same as Phase 3, as summarized in Table 4 and shown on Figure 6.

It is noted that no mapping data had been completed in the Sulphide geotechnical domain at the time of Phase 3, since no development had been completed into the Sulphides at the time. Since that time, there has been development into the Sulphides, and as a result mapping data is now available. Two new sets were identified in the Sulphides: one dipping south sub-vertically and one dipping west sub-vertically. It is noted that the west dipping set is unique to the Sulphides.

Table 4: Underground Mapping - Dominant Feature Average Orientation by Geotechnical Domain

Feature Set	Sedimentary	Intrusive	Sulphide
Horizontal (Dip/Dip Dir.)	10°/176°	-	-
South Dipping, Sub-Vertical (Dip/Dip Dir.)	54°/188°	74°/194°	84°/199°
North Dipping, Sub-Vertical (Dip/Dip Dir.)	79°/317°	72°/331°	-
West Dipping, Sub-Vertical (Dip/Dip Dir.)	-	-	88°/267°
North-East Dipping, Mid-Vertical Dip (Dip/Dip Dir.)	-	53°/059°	

3.4.1.3 Rock Mass Quality (Classification)

Golder used the geotechnical core logs to update the crown pillar rock mass classification using the RMR_{76} (Bieniawski, 1976) and Q (Barton, Lien, & Lunde, 1974) rock mass quality rating systems. The rationale for continuing to use Bieniawski (1976) rather than Bieniawski (1989) is that it constitutes the basic reference for the application of the RMR system, and allows for conversion to other classification systems. Accordingly, the ground water component of RMR_{76} (A5 rating) has been set to 10 (dry) to allow for conversion between the RMR_{76} and Q' systems (Hoek et al., 1995). Where RMR_{76} has been used to estimate Q', the resulting Q' value is referred to as $Q'_{equivalent}$. Golder utilized a statistical estimation of each of the parameters in both systems using the following terminology that has been adopted for this report:

- Lower Bound Value – This value represents the approximate 16% cumulative frequency of the data, which is approximately the average (mean) value minus 1 standard deviation.
- Upper Bound Value – This value represents the approximate 84% cumulative frequency of the data, which is approximately the average (mean) value plus 1 standard deviation.
- Typical – This represents the most commonly occurring value, equivalent to the mode.

The average (mean) and standard deviation for the RMR_{76} parameters were estimated, assuming the data to be representative and normally distributed. General statistical treatment (average and standard deviation) of RMR_{76} and each individual parameter is applicable because RMR_{76} is a linear function. These values have been converted to $Q'_{equivalent}$ and $Q_{equivalent}$ to estimate the range of Q conditions, as summarized in Table 5.

Table 5: Crown Pillar Characterization – RMR_{76} and Q' equivalent

RMR_{76} Parameter	Lower Bound		Typical		Upper Bound		Average		
	Value	Rating	Value	Rating	Value	Rating	Value	Std. Dev.	Rating
A1: Strength Index (Is50)	3 MPa	7	5 MPa	11	>8 MPa	15	5 MPa	3 MPa	11 ± 7
A2: RQD Index	75%	15	100%	20	100%	20	89%	16%	18 ± 3
A3: Discontinuity Spacing	1 m	20	1 m	20	3 m	30	1 m	0.1 m	22 ± 6
A4: Jc Rating	-	6	-	6	-	12	-	-	-
A5: Groundwater	-	10	-	10	-	10	-	-	10
RMR_{76} (A1+A2+A3+A4+A5)	58		67		87		67	13	-
$Q'_{equivalent}$ [a]	4.7		12.9		118.8		12.8	-	
J_w / SRF[b]	0.5 / 2.5		0.5 / 2.5		0.5 / 2.5		0.5 / 2.5	-	
$Q_{equivalent}$[c]	1		3		24		3	-	

Notes: [a] $Q'_{equivalent}$ conversion used as $Q' = e^{\frac{RMR_{76}-44}{9}}$
[b] SRF estimated from traditional Q tables (Barton et al., 1974)
[c] $Q_{equivalent}$ has been rounded to the nearest whole number

The RMR_{76} values for the crown pillar are estimated to range from 58 (lower bound) to 87 (upper bound), with a typical value of 67, and average of 67 ± 13. This is consistent with the Phase 3 characterization. Based on the average RMR_{76} value of 67 and the RMR_{76} to Q' conversion (Hoek et al., 1995), the average $Q'_{equivalent}$ is estimated as 13. Considering a standard deviation of 13 RMR_{76} units, the $Q'_{equivalent}$ is estimated to vary from 3 to 55 for the crown pillar, which is also consistent with the Phase 3 characterization.

3.4.1.4 Rock Mass Strength Estimate

Two strength criteria have been considered for modeling purposes, based on the range of rock mass classification ratings GSI, where GSI is estimated as GSI ≈ RMR_{76} for RMR_{76} > 18 (Hoek et al., 1995), for the three geotechnical domains as follows:

- Where the GSI ≥ 65, the rock mass is massive to moderately jointed, and most likely to respond in a brittle manner to loading (Diederichs, 2007; Cai & Kaiser, 2014). The failure process associated with brittle failure is dominated by fracturing through rock, and thus a strength criterion relevant for this failure process as per Diederichs (2007) needs to be adopted.
- Where the GSI < 65, the rock mass is blocky and sufficiently jointed to fail via block rotation and shear along joints. The failure processes of blocky rock masses are suitable for strength estimation using the HB-GSI rock mass strength scaling equations (Hoek & Brown, 2018).

It should be noted that in this study, elastic parameters are of interest for the primary calibration approach using stress measurement data in the elastic domain. Material parameters used in this study are summarized in Table 6. The strength envelopes for the brittle and non-brittle rock mass cases are provided in Figure 7.

Table 6: Numerical Stress Model Material Parameters

Parameters	Intrusive		Sulphide		Sedimentary		Backfill
Density (kg/m^3)	3200		4300		2700		2000
Rock Mass Modulus, E_{rm} (GPa)	50-85		30-50		40-60		1.0
Poisson's Ratio	0.19		0.17		0.19		0.20
Estimated GSI from RMR_{76}	71	80	71	80	66	80	-
Failure Criteria	HB-GSI	Brittle	HB-GSI	Brittle	HB-GSI	Brittle	Elastic
Peak Tensile Strength (MPa)	1.1	4.0	0.6	2.1	1.0	5.0	-
Plastic Shear Strain (%)	0.25		0.25		0.05		-
UCS (MPa)	120		133		150		-
Peak mb parameter	4.2		9.0		3.6		-
Peak s parameter	0.038		0.042		0.023		-
a parameter	0.501		0.501		0.502		-
Residual mb parameter	2.1		4.5		1.8		-
Residual s parameter	0.001		0.001		0.001		-
Peak Cohesion (MPa)	-	15	-	12	-	15	-
Peak Friction Angle (°)	-	25	-	35	-	30	-
Residual Cohesion (MPa)	-	0	-	0	-	0	-
Residual Friction Angle (°)	-	60	-	60	-	60	-

3.5 Hydrologic Data

In order to fulfill sub-condition (5) of permit condition E8 and mine the last level of stopes (between 352 MASL and 381 MASL), the mine was required to collect hydrologic data from specified piezometers and groundwater monitoring wells located within and adjacent to the crown pillar footprint, as well as background stations from outside of the crown pillar area. Since the permit was issued in 2007, piezometers and ground water monitoring wells were installed near the planned crown pillar, in order to monitor water levels in the bedrock and overburden, as shown on Figure 12 and listed in Table 7. The Phase 4 assessment considers monitoring data collected from June 2011 through October 2018 for the wetland (Figure 13) and quaternary (Figure 14) monitoring wells, and from November 2012 through October 2018 for the bedrock monitoring wells (Figure 15).

Table 7: Bedrock, Quaternary, and Wetland Monitoring Wells with Continuous Water Level Measurements

Bedrock Monitoring Wells			Quaternary Monitoring Wells		Wetland Monitoring Well	
Drillhole	**Piezometer Elevation (MASL)**	**Collar Location**	**Drillhole**	**Screened Horizon**	**Drillhole**	**Screened Horizon**
04EA-074	245.8	Footwall	QAL004	A	WLD002	
	412.5			D	WLD022	4.5
04EA-077	252.5	Eastern Zone	QAL008	A	WLD023	4.5
	388.6			D	WLD025	4.5
12EA291	369.8	Crown Pillar	QAL023	4.5		9.5
	388.6			B	WLD026	4.5
	403.4		QAL024	A		9.5
12EA301	379.1	Crown Pillar	QAL043	4.5	WLD027	4.5
	387.4			B		9.5
	409.0		QAL044	B	WLD028	4.5
12EA304	366.7	Crown Pillar	QAL064	D		
	382.3		QAL065	D		
	416.2		QAL066	D		
YD02-20	418.8	Decline and Portal Ramp				

For Phase 4, the historical groundwater level data was compiled into continuous time series plots for the 19 available monitoring wells at the site (Figure 13 to Figure 15). These data were plotted alongside daily precipitation (site specific provided by Eagle, augmented by U.S. Climate data from Big Bay Michigan), Quaternary pumping wells commencement, and mine events to determine what trends are present, and potential causes from a visual assessment. Precipitation data was reviewed on an annual basis to evaluate for interannual trends related to longer term climate effects (Figure 16). Monthly production volumes from the two Quaternary source wells were plotted (Figure 17). Review of the Wetland Monitoring Wells in conjunction with the precipitation data show that there are two seasonal trends, as follows:

- Two wells (WLD027-4.5 and WLD028-4.5) show strong seasonal variation indicating a strong hydraulic connection to surface water bodies and seasonal precipitation events (Figure 13). Highs in groundwater levels typically occur in May-June, while lows typically occur in late summer/early fall months. These wells are both near the surface projection of the crown pillar, as shown on Figure 12. There is no apparent correlation to groundwater level trends and underground mine development (Figure 13).

- Two wells, WLD025-4.5 and WLD026-4.5, located in closer proximity to Main Branch of the Salmon Trout River (Figure 12) show more muted seasonal variations compared to WLD027-4.5 and WLD028-4.5. In WLD025-4.5, there is recognizable interannual downward trend but muted (i.e., less than 0.3 m) starting between 2014/2015 and continuing through to the end of the review period in 2018.

In the reviewed wells completed in the deeper Quaternary sediments (i.e., Quaternary Wells), a seasonal variation is observed (Figure 14), but smaller magnitude than those observed in Wetland Wells WLD027-4.5 and WLD028-4.5; that is consistent with these wells being deeper and more isolated from surface water bodies. QAL024A shows a strong seasonal trend and no obvious correlation to underground development. Most of the Quaternary wells show a recognizable interannual downward trend starting in 2014/2015 and continuing to end of reviewed period in 2018 in the magnitude of 0.15 to 0.3 m.

The eight bedrock monitoring wells show no trends or variations that could be interpreted as a result of seasonal climate variations (Figure 15). This is consistent with relatively poor hydraulic communication between the bedrock and Quaternary sediments by virtue of the low bedrock hydraulic conductivity. The bedrock wells consistently show no correlation to pumping in the Quaternary wells, which would be recognized as a gradual decline. In-turn, the low bedrock hydraulic conductivity is consistent with the very low groundwater inflows measured to date at Eagle Mine. Also, no interannual trends could be identified that would be the result of longer-term annual precipitation variations (Figure 16). The bedrock monitoring wells show a strong correlation to underground development, with sudden pressure changes, that is consistent with a low storativity and low bulk hydraulic conductivity system. The groundwater levels are expected to recover following the end of mining.

Pumping from two Quaternary supply wells will lower water levels and result in a cone of depression. Pumping from the two wells commenced at the beginning of 2012 and continues to the present day. The annual volumes and equivalent volumetric averaged flow rates are shown in Table 8.

Table 8: Summary of Well Production from Quaternary Supply Wells

Year	QALPSW001 Annual volume (USgal)	QALPSW001 Pumping rate (USgpm)	QAL011D Annual volume (USgal)	QAL011D Pumping rate (USgpm)
2012	3,889,600	7.40	8,904,200	16.93
2013	2,489,700	4.73	12,061,900	22.93
2014	4,513,800	8.58	14,970,100	28.46
2015	3,572,400	6.79	21,594,500	41.06
2016	7,214,384	13.72	23,258,113	44.22
2017	7,198,344	13.69	32,822,978	62.41
2018	3,948,600	7.51	37,087,048	70.51

Well QALPSW001 is used as a potable well, and well QAL011D is used as the utility well. Pumping from well QAL011D has increased since 2012 to 2018, from 17 US gallons per minute (USgpm) to 70 USgpm (Table 8, Figure 17), as a result of increased demand during the increase of mining operations. Well QALPSW001 has remained relatively stable since 2012, producing between 5 USgpm and 14 USgpm. Figure 17 shows the monthly production of the to Quaternary supply wells, and the location of the wells is shown on Figure 12.

3.5.1 Hydrologic Data Assessment Summary

Lines of converging evidence continue to support poor hydraulic connection between the wetland wells and the bedrock: 1) bedrock groundwater levels show no seasonal variations while the Quaternary wells show seasonal variations, 2) the hydraulic testing to date and low inflows to the underground to date support a low hydraulic conductivity for the bedrock (i.e., < 10^{-8} m/s), 3) the Quaternary strata includes low permeability strata that will impede upward propagation of pressure transients, and 4) the bedrock shows no correlation to pumping in the two Quaternary wells.

Quaternary wells show seasonal variations and select wells show a muted interannual downward trend in the magnitude of 0.3 m (1 foot) or less between 2014/15 and continuing to the end of the data review period in 2018 (Figure 14). Because of the relatively muted trend and multiple potential sources for the trend, no unequivocal cause and effect relation can be hypothesized. However, the trend is unlikely related to underground development due to the evidence discussed above that continues to support poor hydraulic connection between the wetland wells and the bedrock.

Wetland wells WLD027-4.5 and WLD028-4.5 show strong seasonal variations and no correlation to underground development (Figure 13). There is a correlation between annual low precipitation years and lows in groundwater levels in these wells; during low precipitation years in 2012 and 2015 (Figure 16), the groundwater levels approached the regulatory trigger water level elevation for additional assessment (Figure 13) that appeared to be unrelated to underground development. This correlation will be important when interpreting the data for future years with below normal precipitation. The evaluation indicates that water levels may reach triggers that are unrelated to underground development; therefore, if a trigger is reached, the additional assessment should include a review of climate data and pumping from Quaternary wells.

3.6 Physical 3-Dimensional Model

The purpose of the physical 3-dimensional model was to assess the potential changes in water inflow due to mining induced stress changes in the crown pillar. More specifically, the assessment addressed the potential effect of stress induced changes to rock mass permeability and inflows to the mine.

In order to fulfill sub-condition (6) of permit condition E8 and mine the last level of stopes (between 352 MASL and 381 MASL), the mine was required to create a physical 3-dimensional model. As part of the Phase 3 assessment, Golder identified different approaches to fulfill this requirement, and proposed an approach of creating a soft-coupled 3D model that integrated the following components:

- Engineering geology model
- Numerical stress model
- Hydrogeological model
- Discrete fracture network (DFN) model

For Phase 4, these components were updated and/or calibrated based on measurements collected and/or observations in the mine since the start of mining. The following sub-sections describe the four components of the 3D physical model and how they were integrated into the soft-coupled hydro-mechanical model.

3.6.1 Engineering-Geology Model

As part of Phase 3, an EG model was created based on data from geotechnical drilling, geotechnical domaining, the geotechnical RQD and RMR_{76} block models, and the underground mapping data. The EG model was refined to consider patterns of mapped structures, and inferences with respect to position and extent of contact zones (as estimated based on lower RQD zones), geotechnical domains, underground mapping, and observed fabric trends.

The drilling completed after Phase 3 was from underground, and the primary focus was to collect additional geological information to support the mine design process. Some of the additional holes were selected for geotechnical logging, as outlined in Section 3.4. Geotechnical mapping of the levels of the mine has also been completed since the completion of Phase 3, as outlined in Section 3.4.

The focus of the Phase 4 work was to review the additional drilling and mapping data against the Phase 3 geotechnical block model. Figures showing the new drilling plotted against the Phase 3 block model for the 352 level and 381 level are shown on Figure 18 and Figure 19, respectively. As shown in these figures, the additional rock mass quality information collected from drilling completed in Phase 4 is consistent or generally of better RQD when compared to the Phase 3 geotechnical block model values in the same location. As such, the geotechnical block model has not been updated.

Most notably, in Phase 3, the presence of major crown pillar bounding structures was not found (Golder, 2016a). Instead, it was thought that the low rock mass quality zones bounding the crown pillar were likely to be related to the contact between geotechnical domains. As part of the Phase 4 work, Golder inspected the development in the areas that crossed the contact and these large (30 m wide) low rock mass quality zones were indicated in the geotechnical block model. As shown on Figure 20, there is a small zone (less than 5 m in width) of low RQD at the contact. This suggests that geotechnical block model and geotechnical drilling are likely conservative and underestimate the true RQD and rock mass quality of the host rock and crown pillar.

3.6.2 Numerical Stress Model

A numerical stress model was created for the stopes and development mined to date and the remaining planned stopes and development using the FLAC3D modeling software. The elastic, Boundary Element Method (BEM) numerical stress modeling Map3D was used in Phase 3; however, FLAC3D was used for Phase 4 to allow for the assessment of plastic behavior in the crown pillar, and better stress calibration. CMS surveys of the completed development and stoping were imported into FLAC3D, as well as representative wireframes of the remaining sills, stopes, and bedrock surface, as shown on Figure 21. The time-step sequence (at a high level) for the numerical stress model and subsequent hydro-mechanical model is shown on Figure 22 and Figure 23, respectively.

3.6.3 Hydrogeological Model

The groundwater flow model for Eagle was updated in 2018 in support of work that Golder completed for the Eagle East deposit. The access ramp to Eagle East begins at the 145 level of Eagle Mine, and the deposit is approximately 800 m below and approximately 1 km east of Eagle Mine. This model was used as the starting point for the Phase 4 assessment work. The model was reconfigured to represent the following three scenarios to compare simulated inflows to measured inflows:

- **Scenario 1 – Base Case** – This scenario assumes the same hydrogeological conceptualization as developed under the previous assessment, with the exception that the hydraulic conductivity of the upper bedrock unit (the upper 90 m of bedrock) was lowered by a factor of 3 (i.e., from 2.0×10^{-8} m/s to 6.7×10^{-9} m/s), in an effort to improve the match between measured and simulated inflows to the mine. This scenario also includes 11 water conductive features in the vicinity of the Eagle Mine development, which extend laterally over approximately 145 m in the north-south direction throughout the Lower Bedrock (top of bedrock to 90 m vertical depth) to the base of the Eagle Mine. The transmissivity of these features was assumed to be 1×10^{-6} m^2/s. Hydraulic properties and distribution were based on packer testing. To accommodate the potential influence of localized stress-induced fracturing, the model was configured such that the hydraulic conductivity of the rock in the immediate area of the mine workings was increased by a factor of 3, upon activation of the boundaries representing the workings. This scenario is viewed as conservative, considering the estimation of inflow volumes to the mine and the absence of observations of stress induced fracturing surrounding mine development.
- **Scenario 2** – **Water Conductive Features Removed** – This scenario is identical to Scenario 1, with the exception that the eleven water conductive features within the Lower Bedrock were removed to further improve the match between measured and simulated inflows to the mine, particularly in more recent stages of mine operations.
- **Scenario 3 – Water Conductive Features Removed, Reduce Lower Bedrock K** – This scenario is identical to Scenario 2, with the exception that the hydraulic conductivity of the Lower Bedrock was reduced by a factor of 5 to further improve the match between measured and simulated inflows to the mine.

Each of the scenarios described above was run using the model, and groundwater inflows to the workings were tracked throughout the simulation period, which included the period of mine operation from August 2011 through December 2017 based on current mine development information provided by Eagle, and January 2018 through to 2024 based on planned future mine development information provided by Eagle. It should be noted that the focus of the current work was on the Eagle Mine, as crown pillar stress effects will be limited to this portion of the mine. Though the model includes active boundaries to represent the connector ramp and Eagle East developments, the simulated inflows to these features were not assessed as a part of the current work.

The simulated and measured groundwater inflows to the underground workings were compared to each other from the onset of development through to December 2018, as shown on Figure 24. This figure shows estimates of the measured groundwater inflows to the mine that take into consideration the lower bound and upper bound evaporation losses (equivalent to 5 USgpm and 10 USgpm, respectively).

The modeling results show that the simulated ground water inflows for Scenario 3 are more consistent with the lower bound and upper bound estimates of inflows (with evaporation losses considered) than the other two simulations (Scenario 1 and Scenario 2), with the exception of the years 2013 and 2014, when the inflows were typically below the average measured values. Scenario 1 was found to be generally consistent with the upper bound estimates of measured inflows (accounting for evaporation losses) from the beginning of the simulation (2011) through 2013, after which, the Scenario 1 model over forecasted the groundwater inflows by a factor of approximately 3. Scenario 2 was found to be generally consistent with the lower bound estimates of measured inflows (accounting for evaporation losses) from the beginning of the simulation (2011) through 2012, and in 2013 and 2014 the simulated inflows for Scenario 2 were generally consistent with the measured values (neglecting evaporation losses), after which, the simulated inflows were consistent with the upper bound estimate of measured inflows (i.e., Scenario 1).

3.6.4 Discrete Fracture Network (DFN) Model

As part of Phase 3, a Discrete Fracture Network (DFN) model was created for the crown pillar at Eagle Mine in order to model the natural crown pillar rock mass fabric and fracture system in more realistic ways than is possible using an equivalent porous media approach. The DFN development allowed description of the fracture geometry within the crown pillar rock mass driven by confirmable data acquired from the core logging and drift mapping.

DFN models, in general, seek to describe the heterogeneous nature of fractured rock masses by explicitly representing key elements of the fracture system as discrete 2D objects in space with appropriately defined geometries and properties. By building geologically realistic models that combine the larger observed deterministic structures with smaller stochastically inferred fractures, DFN models capture both the geometry and connectivity of the fracture network, as well as the geometry of the associated intact rock blocks.

The aim of the DFN modelling was to condition the fracture model as much as was possible to the available data, including building in several of the fracture systems as deterministic wireframes, and then using Monte Carlo simulations to quantify the uncertainty of extrapolation of the remainder of the fracture pattern throughout the upper part of the mine volume, including the crown pillar. The methodology for fracture generation in the bulk of the modelled rock mass was thus stochastic, allowing multiple but equi-probable realizations to be created.

The DFN model was created within Golder's FracMan 7 code using properties derived from the crown pillar rock mass characterization, utilizing the work flow outlined in Figure 25. There were six key properties used to create the DFN model, as follows:

- **Fracture Orientation Distribution** – The data from seven televiewer drillholes were used to condition the orientation distribution. FracMan used a technique known as bootstrapping, which uses the directionally corrected televiewer data to guide the assignment of fracture orientations to the model. Thus, the DFN model can accurately reproduce the same observed orientation trends as seen in the data without the complicated need to assign the data to different fracture sets. This methodology was used because it has been found to provide the most accurate reproduction of dispersed orientation data.
- **Fracture Size Distribution** – The underground mapping data has been used to define the fracture size properties. A Pareto distribution was found to provide a reasonable description of structural size and has been used to define the fracture size distribution of fractures in the DFN for the crown pillar.
- **Fracture Intensity Distribution** – Fracture frequency, P10 (fractures/m) from geotechnical drillholes, and televiewer drillholes were used to estimate the fracture intensity distribution in the DFN for the crown pillar. These values were calculated by plotting borehole fracture data on cumulative fracture intensity (CFI) plots

to calculate the rock mass P10. For the actual DFN modelling, these directionally sensitive fracture frequency (P10) values were converted to a volumetric fracture intensity property known as P32 (fracture area per unit volume), using the methodology of Wang (2005).

- **Spatial Variation of Fracture Intensity** – The spatially located volumetric fracture intensity (P32) properties were compared to the RQD block model and the distance to contact zones, in order to determine if there was any spatial variation of the fracture intensity. No relationship was found, and therefore a simple random (Poisson) process was used with no explicit spatial variation in volumetric fracture frequency (P32) for creating the DFN for the crown pillar. The actual fracture intensity in the model was constrained from a corrected P10 (fractures per unit length) value. Fractures were generated until the modified P10 on the target boreholes was best matched. The actual P10 target was reduced to account for the fact that only larger and more transmissive fractures were being generated.
- **Contact Zones** – It should be noted that in keeping with the observations described in Section 3.6.1, major structures were not included in the DFN model. This is the main change to the DFN model from Phase 3.
- **Fracture Transmissivity Distribution** – An iterative Oxfilet assessment (Osnes Extraction from Fixed Interval Length Effective Transmissivities, Osnes et al. (1988)) has been used to derive the fracture transmissivity distribution and frequency of conductive fractures from the packer test data conducted from within the crown pillar. The fracture transmissivity distributions used for the Intrusives and Sulphides are provided in Figure 26.

A summary of the final properties input into the DFN model of the crown pillar is shown in Table 9.

Table 9: DFN Model Definitions and Justifications

Fracture Property	Distribution	Justification
Fracture Orientation	Bootstrapped distribution from ATV logged data.	Most accurate reproduction of dispersed orientation data.
Fracture Size	Power Law Distribution Gradient 3.8, Min Size = 5, Max = 500	Defined from analysis of mapping data in drifts and raise.
Fracture Intensity	Average P10 = 3 x 10%	Average intensity defined from CFI analysis, reduced to 10% to account for minimum size and transmissivity.
Spatial Variation	Random (Poisson Process) Only	No relationship between interpreted P10 values and RQD block model or distance to major structures, so no explicit spatial variation utilized.
Fracture Transmissivity	Correlated to Size	Three different relationships for Intrusives, Sulphides, and contacts.

3.6.5 Soft-Coupled Hydro-Mechanical Model

As mining advances to the upper areas of the orebody, there were concerns that a reduction in the thickness of the crown pillar may have impacts to the groundwater regime in the rock mass above the mine. In order to address this, a methodology has been developed to rationally quantify future forecasted changes in rock mass permeability in the crown pillar that might occur during mining, as a result of stress re-distribution. There are different approaches to assess this potential change in rock mass permeability and hydraulic conductivity. Golder felt that it was of most importance to capture changes in hydraulic conductivity through a calibrated hydraulic model of the crown pillar, and this was therefore the focus of the modelling effort. Accordingly, in order to implement a methodology that is clear, pragmatic, and defensible, an approach has been developed that couples the stress modelling results from FLAC3D with FracMan's ability to spatially model fracture transmissivity throughout the crown pillar rock mass. The forecasted bulk permeability change of the crown pillar was then utilized in the model to forecast the mine inflows and drawdown cones.

The main workflow steps followed in this analysis were:

- Take the DFN model with derived fracture transmissivity distributions assigned from the previous mining sequence step.
- Apply stresses from Flac3D for the next mining sequence step and compute the changed apertures resulting from mining.
- Take the modified DFN fracture file with adjusted fracture apertures and run a flow simulation through the model for that mining sequence step to derive the change in crown pillar permeability for the last mining sequence step.

The primary justifications for adopting this methodology were:

- The assignment of initial fracture transmissivities is particularly important and not possible outside the DFN or discrete modelling environment.
- The response of the conductive fractures to mining stresses is a geometric problem, so without the explicit representation of discrete fracture objects it is difficult to define the change in hydraulic response of the rock mass.
- As mining approaches the ultimate elevation, the crown pillar thickness has been designed to limit rock mass deformation, such that the behavior of the crown pillar is anticipated to be elastic (i.e., it is assumed there will be no permanent non-recoverable plastic deformation at the bedrock contact), thus utilizing the stresses computed from within the FLAC3D model is sensible and reasonable.
- Coupling the DFN geometry and the FLAC3D stresses together, therefore, allows the geometric complexity of the fracture system to be coupled with the stresses in a defensible way.

Starting with an initial DFN model, the stresses were applied such that the normal and shear stress of each fracture could be determined (Bandis et al., 1983; Barton et al., 1985; Barton et al., 1995). A total of ten stochastic realizations of the DFN model were generated in FracMan, in order to evaluate the stochastic variability associated with the modelling inputs. The transmissivity of the crown pillar was estimated based on the following routine:

- The stress data was applied to the DFN model, with the resolved shear and normal stresses on each fracture being calculated. Each fracture was then tested to determine if it was initially critically stressed (i.e., the stress applied to a fracture was greater than its shear strength as defined by the Mohr Coulomb failure criterion), became critically stressed during mining, or was never critically stressed.
- Based on the stress state of the fracture, a conservative approach was used to modify the aperture, as follows:
  - **Critically Stressed Initially -** If the fracture was critically stressed under initial conditions, the aperture was set to remain unchanged throughout the mining sequence.
  - **Critically Stressed During Mining -** If the fracture became critically stressed at any time between the initial step and the current step, the aperture was increased by $10^{1/2}$ from the initial aperture and would then remain that way throughout the remainder of the mining sequence. This is the equivalent to an order of magnitude increase in transmissivity.
  - **Not Critically Stressed -** If the fracture was not critically stressed, the aperture was adjusted based on a two-part function depending on whether the normal stresses were positive or negative.
- The transmissivity of the fracture was modified based on the updated aperture.
- The fractures in the DFN were subsequently converted into a finite element flow mesh with modified aperture and transmissivity properties, and then a steady state flow simulation was carried out through the DFN model.
- The equivalent hydraulic conductivity was calculated for the crown pillar based upon the flow rate through the crown pillar.
- The process was repeated for each step of mining.

A summary of the forecasted evolution of bulk hydraulic conductivities of the crown pillar, for each mining step, is provided in Figure 27 for each of the ten stochastic realizations. The geometric mean bulk hydraulic conductivity for the crown pillar is shown on Figure 27, and is estimated to range from 1.05×10^{-8} m/s initially (year 1) to 4×10^{-8} m/s in year 12.

3.6.6 Updated Mine Inflow Forecast as a Result of the Soft-Coupled Analysis

Given that the Scenario 3 simulated inflows are in better agreement with the measured inflows, it was used as the base model for forecast simulation modeling. An additional scenario was considered for the forecast modeling, as follows:

- **Scenario 4 – Increase in Hydraulic Conductivity in the Crown Pillar to Account for Stress Changes** – This scenario is identical to Scenario 3, with the exception that the hydraulic conductivity of the bedrock in the crown pillar was adjusted to reflect the effects of stress-induced changes to permeability. Based on the results of the stress modelling, the hydraulic conductivity of the upper bedrock in the vicinity of the crown pillar (including the area above the ramp) was gradually increased by a factor of 3 (i.e., from 6.7×10^{-9} m/s to 2×10^{-8} m/s) between mid-2016 and early-2021. This represents the upper end of the simulated range in hydraulic conductivity increases resulting from the assessment of stress effects. In order to avoid "double counting" of the increases in hydraulic conductivity related to stress effects, the localized increase in hydraulic conductivity in the immediate area of the mine workings was removed for the portion of the mine situated in the Upper Bedrock unit. Due to the timing of the stress effects in the crown pillar (i.e., most of the increases to hydraulic conductivity occur later in mine development), this scenario was only evaluated for the forecast period and not as a part of the comparison between simulated and measured inflows.

The simulated groundwater inflows throughout the mine life for Scenario 3, which provided the best match to measured rates of groundwater inflows, and Scenario 4, are shown in Figure 28. Because the objective of this work was to estimate the influence of the stress effects on groundwater inflows in the crown pillar area, the groundwater inflows presented on Figure 28 include only the component of flow reporting to the entrance ramp and Eagle Mine development; groundwater inflows to the lower ramp, connector ramp to Eagle East, and Eagle East development are not included. As such, the results presented on Figure 28 are not comparable to those presented on Figure 24 for the period following development of the lower ramp and connector ramp, which began mid-2016. Changes in flows, shown on Figure 28, that occur after December 2017, reflect the future development at Eagle Mine (it is acknowledged that at the present time part of this development has been completed).

For Scenario 3 (discrete features removed, 5x reduction in lower bedrock hydraulic conductivity, and no changes to the crown pillar), the simulated groundwater inflows to the Eagle Mine Development, during the forecast period were approximately 10 USgpm to 13 USgpm (55 m^3/d to 71 m^3/d). For Scenario 4, the increase in hydraulic conductivity in the crown pillar and upper ramp area resulted in a gradual increase in groundwater inflows throughout the early forecast period, until 2021 when it was assumed that the maximum stress state (and hydraulic conductivity increase) was reached. At this point, the simulated groundwater inflows were steady around 34 USgpm (i.e., approximately two to three times higher than Scenario 3 where stress effects were implemented only locally in the vicinity of the mine workings).

The simulated drawdown at the end of mining (end of year 2023) at the lower bedrock horizon (elevation 355 MASL) for Scenarios 3 and 4 are shown on Figure 29. The maximum extent of drawdown (as defined by the 0.5 m drawdown contour) was similar for both cases, extending approximately 200 m beyond the mine workings. Less depressurization (up to 2 m) was noted for Scenario 4 in the area of the crown pillar, which occurred as a result of the increase in hydraulic conductivity.

3.7 Evaluate Rock Stability

In order to fulfill sub-condition (7) of permit condition E8 and mine the last level of stopes (between 352 MASL and 381 MASL), the mine was required to evaluate the rock stability based on the updated characterization from the additional data collected. This work has been completed and includes the following:

- A review of the hangingwall and footwall stability of stopes mined to date has been completed as outlined in Section 3.7.1. This review shows that there have been no hanging wall or stope sidewall failures to date.
- A review of the cemented rock backfill (CRF) performance has been completed as outlined in Section 3.7.2. This review shows that the CRF has been achieving the required strengths, and backfill has performed as expected to date.
- Crown pillar stability assessments for the 29 m thick ultimate crown pillar has been completed using the Scaled Span method, as outlined in Section 3.7.4. This assessment shows that the crown pillar will be stable

for the duration required by the mining cycle, and that long-term stability of the crown pillar will be achieved by tight filling of the stopes with CRF.

- The numerical stress modeling was used to estimate the confinement and depth of yield in the crown pillar and estimate the crown pillar displacement at the bedrock contact, as outlined in Section 3.7.5. This assessment, in consideration of the above assessments of the CRF and Scaled Span assessment, shows the short-term crown pillar stability will be achieved by installation of cable bolts, and that the crown pillar displacement is estimated to be less than the maximum amount allowable in the mine permit.

The following sections provide a summary of these stability assessments, which were completed based on the rock mass characterization and the EG model described earlier in Section 3.4.1 and 3.6.1, respectively.

When completing the Phase 4 rock stability assessments, Golder considered the same five potential crown pillar failure mechanisms considered for the Phase 3 assessments, as indentified from back analysis of case histories of crown pillar failures (Golder, 1990). For each failure mechanism, there are multiple methods to assess the stability of the crown pillar, as follows:

- *Plug failure* – Analytical Plug, Scaled Span, and numerical stress modelling assessments.
- *Chimneying* – Chimney/Cave, Scaled Span, Voussoir limit equilibrium, and numerical stress modelling assessments.
- *Caving* – Mathews-Potvin/Laubscher Stability, Scaled Span, and numerical stress modelling assessments.
- *Unravelling* – Numerical methods for simulating unravelling, Kinematic & Scaled Span Assessments, Discrete Fracture Network (DFN) modeling, and other sophisticated forms of numerical modelling.
- *Delamination* – Numerical Modelling, limit equilibrium plate solutions & Scaled Span Assessments.

The failure mechanisms listed above can be assessed using the empirical Scaled Span methodology, as failure case records matching each mechanism were included within the original database from which the method was developed.

For chimneying, caving, or unraveling failure mechanisms to occur, an adequate void space below the crown pillar is required in order to allow the crown pillar to fail and bulk into. Failure will be limited in the short-term by ground support, including cable bolts installed in the drill level development at the top level of the mine, and will be limited in the long-term by tightly filling the void space. Accordingly, no specific analytical calculations were undertaken to evaluate these mechanisms, with the understanding that the empirical Scaled Span assessments would explicitly also encompass the chimneying, caving, and unraveling failure mechanisms. Additionally, it was considered that unravelling could be checked for by interpretation of the numerical stress modeling.

For the delamination failure mechanism to occur, the crown pillar must consist of a dominant weak horizontally bedded or foliated rock mass. Based on a review of the geological information for the crown pillar, this is not the case for Eagle Mine, and as such, the potential for the delamination failure mechanism is not present at Eagle Mine.

3.7.1 Stope Stability

Data for Eagle Mine's stopes were plotted on the empirical Stope Stability Graph as shown on Figure 8, developed by Golder (1981) and updated by Potvin (1988) amongst others. Empirical trend lines for estimating Equivalent Linear Overbreak/Slough (ELOS) were added to the Stope Stability Graph by Clark and Pakalnis (1997), and then alternative empirical trend lines were added by Capes & Milne (2008). ELOS has been estimated by the volume of stope overbreak for a specific stope wall, divided by the area of the wall, and is often used to estimate the amount of unplanned dilution. Both sets of ELOS trend lines are plotted in on Figure 8 to show that although the two sets of trend lines differ, they both indicate that Eagle Mine's stopes are anticipated to experience less than ~0.5 m of ELOS.

Eagle records stope stability parameters, and details of overbreak and backfill for each stope. There have been no hanging wall, footwall, or sidewall failures recorded at Eagle Mine in the 272 primary and secondary stope panels excavated since the start of production. Of the 272 primary and secondary stope panels, there have been no stope roof failures in 271 panels. One roof failure occurred in a secondary stope on the 215 level in August 2016. Eagle, in addition to supporting the stope backs with cable bolts, has further mitigated the potential for stope roof instability by only excavating a 5 m wide sill below the secondary stope panels. Since this change has been made, 72 stope panels have been excavated and no stope roof instabilities have occurred.

The stope stability parameters and details of overbreak were used to plot Eagle Mine stope Hanging Walls (HW) and Footwalls (FW) on the Stope Stability Graph presented in Figure 8. Stopes at Eagle Mine are generally found to be stable, based on visual observations by Eagle and Golder staff and from CMSs, which is in agreement with where they plot on the graph relative to Potvin's stability transition zones presented in Figure 8. Most stopes experience less than ~0.5 m of ELOS, which is what the empirical trends from Clark and Pakalnis and Capes and Milne forecast; however, there are some stopes that have experienced larger amounts of ELOS. As such, there is not a clear trend between ELOS and the modified stability number (N'), or the hydraulic radius (HR). The recorded ELOS is within the normal anticipated ranges for overbreak, considering the methods used to excavate the stopes (longhole blasting practices).

Stope roof data was not plotted on the stope stability graph because the stope roofs are supported by cable bolts and the stability is assessed by the Scaled Span assessment outlined in Section 3.7.4. The stope roof support design is outlined in Eagle's Ground Control Management Plan (GCMP).

3.7.2 Backfill Performance

Eagle uses CRF to fill primary stopes and unconsolidated rock fill for secondary stopes below the 323 level. Above the 323 level, each primary and secondary stope will be filled with CRF. The sills on the 381 level will be tightly filled by jamming the CRF with a jamming attachment on a Load-Haul-Dump (LHD) piece of heavy mobile equipment, which is a front-end loader with modifications, making it better suited to working underground.

A backfill management plan has been developed by the mine that outlines the required QA/QC testing. QA/QC performed on cast cylinders of Eagle Mine's CRF is presented in Figure 9. It shows that the backfill performs as it should with strength gains following a logarithmic trend with respect to curing time. The distribution of the data is relatively large, which may be due to the inherit difficulty of testing CRF with large aggregates. The design strength of the CRF is 1.5 MPa, which is reached by the logarithmic best fit lines for binder contents ranging from 3% to 5.25% in less than two days.

Secondary stope sidewalls at Eagle Mine (where primary stope CRF is exposed) tend to be stable, with ELOS values of less than approximately 0.2 m. The low ELOS values show that the backfill used at Eagle Mine performs as designed. This agrees with visual observations collected by Eagle and Golder of exposed backfill during the mining of secondary stopes.

Jam filling has been completed on the 145, 190, 265, and 294 levels of the mine to date. Where the jamming technique has been employed in primary stope top sills, the top sills of adjacent secondary stopes did not experience additional overbreak, compared to when the standard stoping sequence was used.

Jam filling is also used in some primary stope bottom sills to close the brow of the stope and confirm that the sill is tightly filled. Golder has observed jammed and non-jammed fill that has been exposed by adjacent drifting, and the backfill is observed to stand up well and there are no records of fill failure in these areas. An example of jammed primary stope CRF that has been exposed by adjacent secondary stoping activities is provided in Figure 11.

Based on the testing data and visual observations, the backfill has performed as expected to date. This indicates that the backfilling plan for the 381 level will be achievable as planned.

3.7.3 Acceptable Crown Pillar Stability Guidelines

Acceptable guidelines for crown pillar stability in the context of mining use and public access, as shown in Table 10, have been presented in various publications since the mid 1990's. More recently, specific risk classes have been derived from a relationship of the Scaled Span (Cs) to the Probability of Failure (PoF) based on logistic regression of the crown pillar failure database (Carter et al., 2008). Acceptable Factors of Safety (FOS) and anticipated serviceable life for a given crown pillar, as outlined by Carter and Miller (1995), are also shown in this table. For closure purposes, Classes E to G (< 5% PoF) are generally considered acceptable from a regulatory standpoint. Long-term stability (i.e., Class E to G) of the crown pillar at Eagle is planned to be achieved through tight filling of the upper level mine workings.

Table 10: Acceptable Crown Pillar Risk Exposure Guidelines (Carter et al, 2008 after Carter & Miller, 1995)

Class	PoF (%)	Minimum FOS	Design Guidelines for Pillar Acceptability/Serviceable Life of Crown Pillar				
			Serviceable Life	Years	Public Access	Regulatory Position on Closure	Operating Surveillance Required
A	50-100	< 1	Effectively zero	< 0.5	Forbidden	Totally unacceptable	Ineffective
B	20-50	1.0	Very, very short-term (temporary mining purposes only; unacceptable risk of failure for temporary civil tunnel portals)	1.0	Forcibly prevented	Not acceptable	Continuous sophisticated monitoring
C	10-20	1.2	Very short-term (quasi-temporary stope crowns; undesirable risk of failure for temporary civil works)	2-5	Actively prevented	High level of concern	Continuous monitoring with instruments

Class	PoF (%)	Minimum FOS	Design Guidelines for Pillar Acceptability/Serviceable Life of Crown Pillar				
			Serviceable Life	Years	Public Access	Regulatory Position on Closure	Operating Surveillance Required
D	5-10	1.5	Short-term (semi-temporary crowns, e.g., under non-sensitive mine infrastructure	5-10	Prevented	Moderate level of concern	Continuous simple monitoring
E	1.5-5	1.8	Medium-term (semi-permanent crowns, civil portals, possibly under structures)	15-20	Discouraged	Low level of concern	Conscious superficial monitoring
F	0.5-1.5	2	Long-term (quasi-permanent crowns, civil portals, near-surface sewer tunnels)	50-100	Allowed	Of limited concern	Incidental superficial monitoring
G	< 0.5	> 2.0	Very long-term (permanent crowns over civil tunnels)	> 100	Free	Of no concern	No monitoring required

3.7.4 Scaled Span Assessment

The Scaled Span approach has been developed from empirical evidence of failed and stable crown pillar case records, initially from more than 200 cases with over 30 failures, to now with over 500 cases with more than 70 failures. The method is empirical, but provides a means for assessing crown pillar geometries for the failure mechanisms discussed in Section 3.7. This assessment was therefore used as a primary evaluation tool for checking the dimensions proposed for the stoping sequence for mining the crown pillar. The Scaled Span assessment method (Golder, 1990; Carter, 1992; Carter & Miller, 1995; Carter et al., 2008), which has been in use for more than two decades, is based on crown pillar geometry and rock mass quality where the crown pillar stability can be estimated empirically by comparing rock mass quality using the Q system against a scaled crown pillar span, C_S, which attempts to characterize the geometry of the crown pillar with overlying overburden and/or incompetent rock accounted for in the density term. No consideration of groundwater and/or clamping stress is included in the Scaled Span geometry definition. Rock mass quality (Q), which includes consideration of water and stress (i.e., the Jw and SRF value parameters), is defined for the stability controlling rock mass domain (Carter, 1992; Carter et al., 2008). This is then evaluated based on the critical span at which failure for any given rock quality, Q, might be expected to occur (PoF = 50%). Based on the ongoing database of case histories, the critical span, Sc, was established to be slightly non-linear in logarithmic space for extremely competent crowns.

The crown pillar stability was assessed using the Scaled Span method considering two scenarios:

1) A Stope-by-Stope assessment that considers the geometry of the crown pillar over each individual stope for a final crown pillar of 29 m thick. This assessment considers that the stopes are 100% tightly filled and the backfill is sufficiently stiff to support the crown pillar. The performance of the backfill and stope stability since the start of mining, described in Section 3.7.2 above, demonstrate that the CRF is tightly filled and can be expected to provide the required support to the crown pillar. A summary of the Scaled Span assessment for each stope is provided in Table 11.

2) A sensitivity assessment was completed by increasing the span from 10 m to 20 m and varying the strike from 10 m to 100 m. The variation on span is to account for minor portions of adjacent stopes that may not be tightly filled, and the variation on strike is to account for the different stope transverse lengths. A summary of the sensitivity assessment is provided in Table 12.

Table 11: Scaled Span Assessment for 29 m Thick Crown Pillar (Stope-By-Stope Assessment)

Stope Crown Pillar	Crown Pillar Geometry				Rock Mass Quality		Scaled Span Assessment				
	Strike (m)	Span (m)	Thick (m)	T/S	Jw / SRF	$Q_{equivalent}$	Scaled Span (Cs)	Critical Span (Sc)	FoS	PoF (%)	Class (Ref. Table 1)
381-1405	32	10	29	2.9	0.5/2.5	3.1	2.7	5.9	1.6	4	E
381-1415	42.5	10	29	2.9	0.5/2.5	3.1	2.8	5.9	1.6	4	E
381-1425	57.5	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	4	E
381-1435	80	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	4	E
381-1445	90.5	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	5	E
381-1455	89	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	5	E
381-1465	75	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	4	E
381-1475	65	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	4	E
381-1485	66.5	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	4	E
381-1495	58.5	10	29	2.9	0.5/2.5	3.1	2.9	5.9	1.5	4	E
381-1505	40.5	10	29	2.9	0.5/2.5	3.1	2.8	5.9	1.6	4	E
381-1515	32	10	29	2.9	0.5/2.5	3.1	2.7	5.9	1.6	4	E

Table 12: Sensitivity Analysis for the Scaled Scan Assessment (Crown Pillar Thickness = 29 m)

Case	Crown Pillar Geometry				Rock Mass Quality		Scaled Span Assessment				
	Strike (m)	Span (m)	Thick (m)	T/S	Jw / SRF	$Q_{equivalent}$	Scaled Span (Cs)	Critical Span (Sc)	FoS	PoF (%)	Class (Ref. Table 1)
1	10	20	29	1.5	0.5/2.5	3.1	3.6	5.9	1.3	8	D
2	20	20	29	1.5	0.5/2.5	3.1	4.4	5.9	1.2	17	C
3	30	20	29	1.5	0.5/2.5	3.1	4.8	5.9	1.1	25	B
4	40	20	29	1.5	0.5/2.5	3.1	5.1	5.9	1.1	30	B
5	50	20	29	1.5	0.5/2.5	3.1	5.3	5.9	1.1	34	B

Case	Crown Pillar Geometry				Rock Mass Quality		Scaled Span Assessment				
	Strike (m)	Span (m)	Thick (m)	T/S	Jw / SRF	$Q_{equivalent}$	Scaled Span (Cs)	Critical Span (Sc)	FoS	PoF (%)	Class (Ref. Table 1)
6	60	20	29	1.5	0.5/2.5	3.1	5.4	5.9	1.1	37	B
7	70	20	29	1.5	0.5/2.5	3.1	5.5	5.9	1.0	39	B
8	80	20	29	1.5	0.5/2.5	3.1	5.6	5.9	1.0	41	B
9	90	20	29	1.5	0.5/2.5	3.1	5.6	5.9	1.0	43	B
10	100	20	29	1.5	0.5/2.5	3.1	5.7	5.9	1.0	44	B

The Scaled Span assessments above indicate that the individual stope crown pillars have a manageable probability of failure for a 29 m crown pillar thickness. The sensitivity analysis indicates that if the stope span were to increase from 10 m to 20 m, the probability of failure will still be acceptable for the short duration that the stopes are planned to be open for, before they are backfilled; however, 20 m spans were only assessed for the sensitivity analysis, and Eagle is not planning on excavating stopes with spans of 20 m. The probabilities of failure presented in the above table are consistent with other operating mines that employ tight-filling practices for long-term closure. During Phase 3, the probability of failure of a 29 m think crown pillar had been estimated to be less than 6.5%, whereas the updated data incorporated into Phase 4 resulted in the estimated probability of failure of a 29 m thick crown pillar to be less than 5%.

3.7.5 Numerical Stress Modeling Assessment

As outlined in Section 3.6.2, a numerical stress model created in FLAC3D was used to estimate the stress changes in the crown pillar throughout the life of mine. As outlined in Section 3.4.1.4, two scenarios with different strength behaviors were considered for the three geotechnical units in the model (i.e., Sedimentary, Sulphide, and Intrusives). In the first scenario, a higher quality rock mass was assumed (i.e., GSI > 65), with brittle behavior. In the second scenario, a lower quality rock mass was assumed (i.e., GSI < 65), with HB-GSI blocky rock mass behavior. The numerical stress model results were used to assess the crown pillar stability, as follows:

- Crown pillar confinement
  - The evolution of crown pillar confinement via three iso-surfaces of 0, 0.5, and 1 MPa are shown in Figure 31. The confinement in the crown pillar at the end of 2018 is estimated to range from 0.5 to 1.5 MPa. Prior to mining stopes between the 352 level and the 381 level, the crown pillar confinement is estimated to decrease to below 1 MPa, and gradually decrease to 0.5 MPa as stoping progresses above the 352 level.
  - Non-continuous zero-confinement zones above the 352 level, stopes between the 352 level and 381 level, were found to develop locally above primary stopes as they were mined-out and filled in the model. These local non-continuous zero-confinement zones are estimated to start to gradually become

connected by the end of July 2023, when over 90% of primary stopes were mined-out and filled. At this stage, the zero-confinement zone locally grew to 10-13 m (the blue iso-surface in Figure 31b) into the crown pillar. As secondary stoping progressed after this point, the zero-confinement zone is estimated to grow as more discontinuous zones become connected, creating a larger area of zero-confinement (e.g., the blue iso-surface in the modeled mining sequence in Figure 31c). At the end of mining, the zero-confinement zone is estimated to grow to 427 MASL, which is approximately 5-7 m below the bedrock surface, as shown in Figure 31d.

  - In both primary and secondary stope sills on the 381 level, 6 m long cable bolts are planned to be installed as secondary support, prior to excavation of the associated stope. This will limit the potential for unravelling of the zero confinement zone, as the cable bolts and mesh will act to retain and hold the rock mass until the stope is backfilled, at which point there is insufficient void space below the crown pillar to allow for unravelling of the rock mass in the crown pillar above a stope.

- Depth of yield in the crown pillar
  - The modeling results for the brittle rock mass behavior show that the crown pillar is currently in the elastic domain at the end of 2018, where stoping has been completed below the 294 level. As stoping progresses upwards towards the ultimate crown pillar (i.e., the 381 level), the crown pillar is forecasted to incrementally develop tensile yield in the back of the 381 level, over an area of approximately 5 m x 15 m, to a maximum depth of yield of 3 m when the stopes between the 352 level and the 381 level are completely extracted and backfilled, as shown in Figure 30a.
  - The modeling results for the HB-GSI rock mass behavior show that the crown pillar is within the elastic domain at the end of 2018, where stoping has been completed below the 294 level. As stoping progresses upwards towards the ultimate crown pillar (i.e., the 381 level), the crown pillar is forecasted to develop a larger depth of yield in the back of the 381 level, over an area of approximately 70 m x 80 m, with a maximum depth of yield of 12 m when the stopes between the 352 level and the 381 level are completely extracted and backfilled, as shown in Figure 30b.
  - For both cases, 6 m long cable bolts are planned to be installed as secondary support in each of the primary and secondary sills on the 381 level, prior to excavation of the associated stope. This will limit the potential for unravelling of the yielded zone, as the cable bolts and mesh will act to retain and hold the rock mass until the stope is backfilled, at which point there is insufficient void space below the crown pillar to allow for unravelling of the rock mass in the crown pillar above a stope.

- Crown pillar displacement at the bedrock overburden contact
  - During previous Phases of crown pillar assessment, Golder estimated that plastic deformation of the crown pillar would not occur and that elastic deformation would be limited to a maximum of 2 cm at the bedrock-overburden contact (Golder, 2006a). This point was discussed during the contested case and has been included in the mine permit as a requirement to monitor.
  - As part of the Phase 4 assessment, Golder reviewed the displacement measurements recorded from the two multi-point borehole extensometers (MPBXs) installed from surface prior to mining compared to displacement forecasted from the numerical stress modeling, as shown on Figure 32. At the end of 2018,

the model showed negligible displacement (i.e., approximately < 0.6 mm), and this is in agreement with measurements recorded in the MPBXs.

- The numerical stress model was used to estimate displacement in the MPBXs, as shown on Figure 32, as well as at the bedrock surface, as shown on Figure 33. Displacements in the virtual MPBXs are estimated to be less than 2 mm at the end of mining, as shown on Figure 32. Displacement at the bedrock contact is estimated to be less than the 2 cm limit as outlined in the mine permit.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The work completed as part of the Phase 4 assessment addresses the seven aspects in condition E8 of the mining permit and support the proposed mining approach for the final additional level of production stoping between the 381 level and the 352 level. The outcome of this work can be summarized as follows:

1) **Collect in Situ Stress Data** – After the completion of Phase 3, additional in situ stress measurements were collected on the 172 level in 2016, and on the 381 level in 2019, by Golder. This additional information allowed the Phase 3 stresses to be refined for use in the Phase 4 assessments. When in situ stresses were assessed for Phase 4, stress measurements from three depths within the mine were available. This allowed stress gradients with respect to depth, and locked in stresses to be estimated, resulting in an improved stress regime interpretation compared to that of Phase 3, when only measurements from one depth were available. The Phase 4 stress regime is expressed as follows:

$$\sigma_1 = 0.030*\text{depth} + 2.70 \text{ (MPa)}$$
$$\sigma_2 = 0.028*\text{depth} + 1.13 \text{ (MPa)}$$
$$\sigma_3 = 0.018*\text{depth} \text{ (MPa)}$$

2) **Supplemental Drilling to Fill in Data Gaps** – Eagle has drilled 337 (20,646 m) additional diamond core drillholes from underground since the completion of Phase 3. No additional drilling has been completed from surface since the completion of Phase 3.

3) **Standard Geologic Data** – Additional geologic data has been collected from the additional diamond drill core and through mapping of the underground development completed to date. Most notably, since the completion of Phase 3, the mine has conducted development on the 294, 323, 352, and 381 levels.

4) **Geotechnical Data** – Additional geotechnical data has been collected from 63 (7,043 m) of the additional diamond core drillholes since the completion of Phase 3. Portions of specific diamond core drillholes were selected for geotechnical data collection to reduce the gaps in geotechnical data that existed at the end of Phase 3.

   Mapping of the underground development has been completed to collect structural fabric and rock mass quality information. Most notably, since the completion of Phase 3, the mine has conducted development on the 294, 323, 352, and 381 levels. No additional oriented core or televiewer data was collected as part of Phase 4.

   The Phase 4 rock mass characterization for the crown pillar is consistent with the previous phases of characterization. While the Phase 4 work has improved the characterization by adding more data and underground coverage, the rock mass characterization is within the range of conditions estimated during Phase 3 and previous phases of the project.

5) **Hydrologic Data** – Since the permit was issued in 2007, piezometers and groundwater monitoring wells were installed near the planned crown pillar and have been continuously monitored. The mine has been collecting daily pumping inflow and outflow rates since development of the mine started, and this was used to estimate the groundwater inflow into the mine and calibrate the groundwater flow model.

6) **Physical 3-Dimensional Model** – Golder completed a soft-coupled 3D model that included the following five components:

   - **Engineering-Geology Model** – As part of Phase 3, Golder created an Engineering-Geology (EG) model using data from geotechnical drilling, simplified lithological domaining, underground mapping, and a geotechnical block model. For Phase 4, the rock mass quality and structural fabric were updated based on additional drilling and underground mapping. These were compared against the Phase 3 geotechnical block model and determined that the additional data would not change the block model results.

   - **Numerical Stress Model –** Golder created a numerical stress model of the mine sequence using the industry standard FLAC3D modeling software. The model input parameters were based on the updated crown pillar characterization completed as part of the Phase 4 work described in this report, and the mine geometry/sequence were based on the life of mine design/plan available at the time that the work was completed.

   - **Hydrogeological Model –** Golder used the measured data collected since the start of mining to compare the forecasted inflows and calibrate the bedrock flow model. Three scenarios were examined, as outlined in Section 3.5, to forecast the groundwater inflows since the start of mining until the end of 2018. These forecasted values were compared against the measured values, and determined that one of these scenarios is generally consistent with the lower bound and upper bound estimates of inflows; this model was used as the basis for the forecast modeling.

   - **DFN Model –** Golder updated the DFN model of the crown pillar created as part of Phase 3, which has allowed a stochastic representation of the rock mass fracturing, as determined from available drilling, to be evaluated from the viewpoint of identifying interconnected fracture conductivity and flow path evolution. The model built for the Eagle Mine crown pillar has been confirmed using structural orientation information based on the ATV data: the fracture size distribution based on the mapping data, the fracture intensity defined based on the ATV data (and conditioned relative the required conductive fracture frequency), and the fracture transmissivity based on assessments of packer testing data, and also correlated with fracture size. Specific sampling of the DFN model confirmed the reasonableness of the model.

   - **Soft-Coupled Hydro-Mechanical Model –** Golder used numerical stress results estimated from the stress modelling to apply a stress to each fracture in the DFN for each step of mining. This stress stepping was used as the basis for estimating the change in transmissivity of each fracture, and in turn, the bulk conductivity of the crown pillar throughout mine development. The modelling results suggest an average increase in crown pillar hydraulic conductivity in the order of 3.5×10^{-9} m/s, over the life of mine. The stochastic model has allowed multiple equi-probable realizations of the crown pillar

DFN to be generated, and the evolving hydraulic conductivity to be calculated during the mining sequence. This relates to a forecasted maximum inflow at end of mining of approximately 10 to 34 USgpm.

7) **Evaluate Rock Stability** – The physical stability of the crown pillar was assessed by means of a Scaled Span assessment and the numerical stress modeling results. The performance of the stope stability to date was examined using the Mathews Stability Graph method. The performance of the backfill to date was examined based on cavity surveys, visual observations, and lab testing of the backfill. The stope stability and backfill performance to date have shown that the mine has good practices related to stope stability and backfilling. This information indicates that the stability of the overall crown pillar footprint is not of concern, and as such, stability assessments have focused on an “open ground” effect (e.g., stope-by-stope stability assessment as opposed to overall crown pillar footprint). The justification for this approach is that the stope walls are stable for the range of conditions encountered at Eagle Mine, and the crown pillar will be supported by the jammed backfill and temporarily by cable bolts in the stope backs.

As outlined above, the Phase 4 crown pillar engineering work completed supports the mine planning approach described in Section 2.0, which will result in a 29 m thick crown pillar above the production stopes and development drifts. As mining progresses, Eagle with the support from Golder, will continue to collect information and adjust the mining activities based on this information. This will include the following:

- Continue to maintain the CPMP as described in Section 2.1, including the detailed monitoring plan, trigger action response plans (TARPS), backfill management and QA/QC plan, stope reconciliation process, ground control management plan, and crown pillar risk register.
- Continuing to collect geotechnical information, primarily from underground mapping, in order to confirm that the rock mass is within the range of expected conditions as development and stoping progresses.
- The mine will continue to confirm the reliability of the groundwater model by periodically checking it against measured inflow data and revise as needed to improve the calibration. Key information that will continue to be collected as the mining advances includes: total inflow to the mine, location and magnitude of any significant inflows (greater than approximately 5 USgpm), and drawdown response in the available piezometers.

The Phase 4 crown pillar assessment completed by Golder supports the proposed mining of one additional level of production stoping (between the 381 level and the 352 level). As described in this report, the completed work satisfies the requirements identified in condition E8.

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6.0 CLOSURE

We trust that this report adequately describes the Phase 4 crown pillar engineering work. Should you have any questions or comments, please do not hesitate to contact the undersigned.

Golder Associates Ltd.

John Wozniewicz
Principal, Senior Hydrogeologist

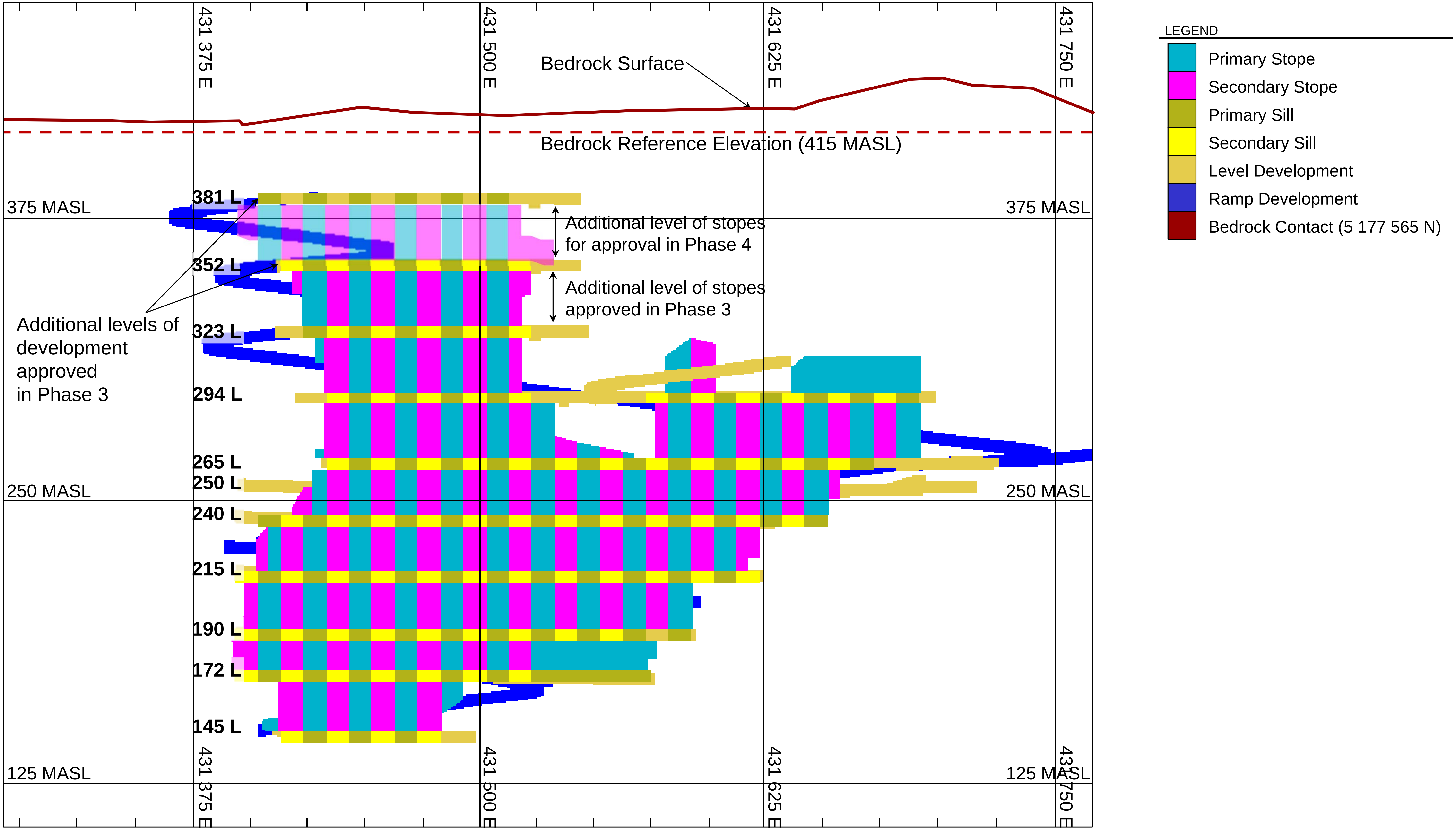
Jonathon Taylor
Senior Mining Engineer

Rob Bewick, Ph.D.
Associate, Senior Rock Mechanics Engineer

JJT/RB/sm/sb

https://golderassociates.sharepoint.com/sites/33550g/deliverables/008 phase 4 report/rev1/18109752-008-r-rev1-eagle phase 4 report 05jul_2019.docx

Figures



CLIENT
Eagle Mine LLC

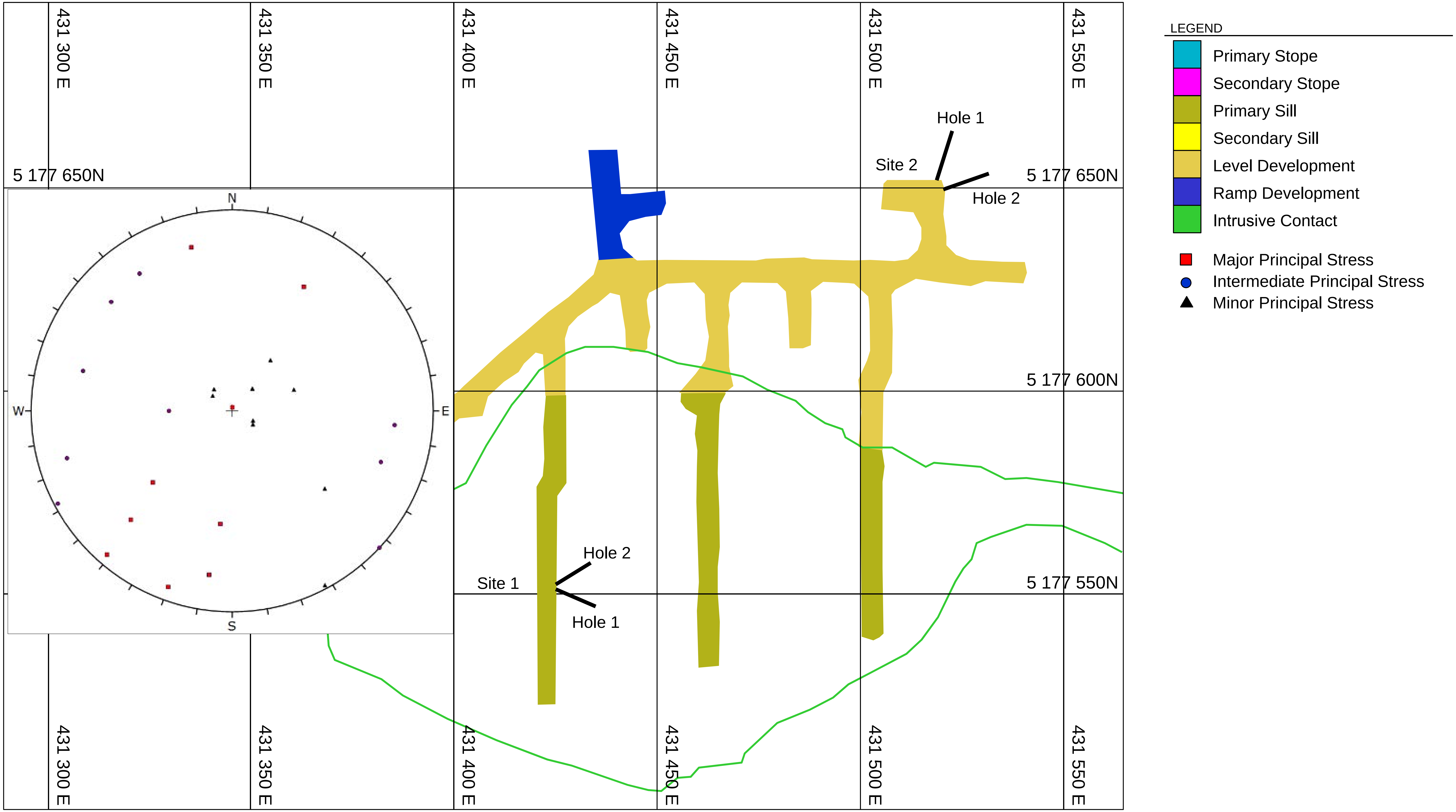
PROJECT
Phase 4 Crown Pillar Assessment

CONSULTANT
GOLDER

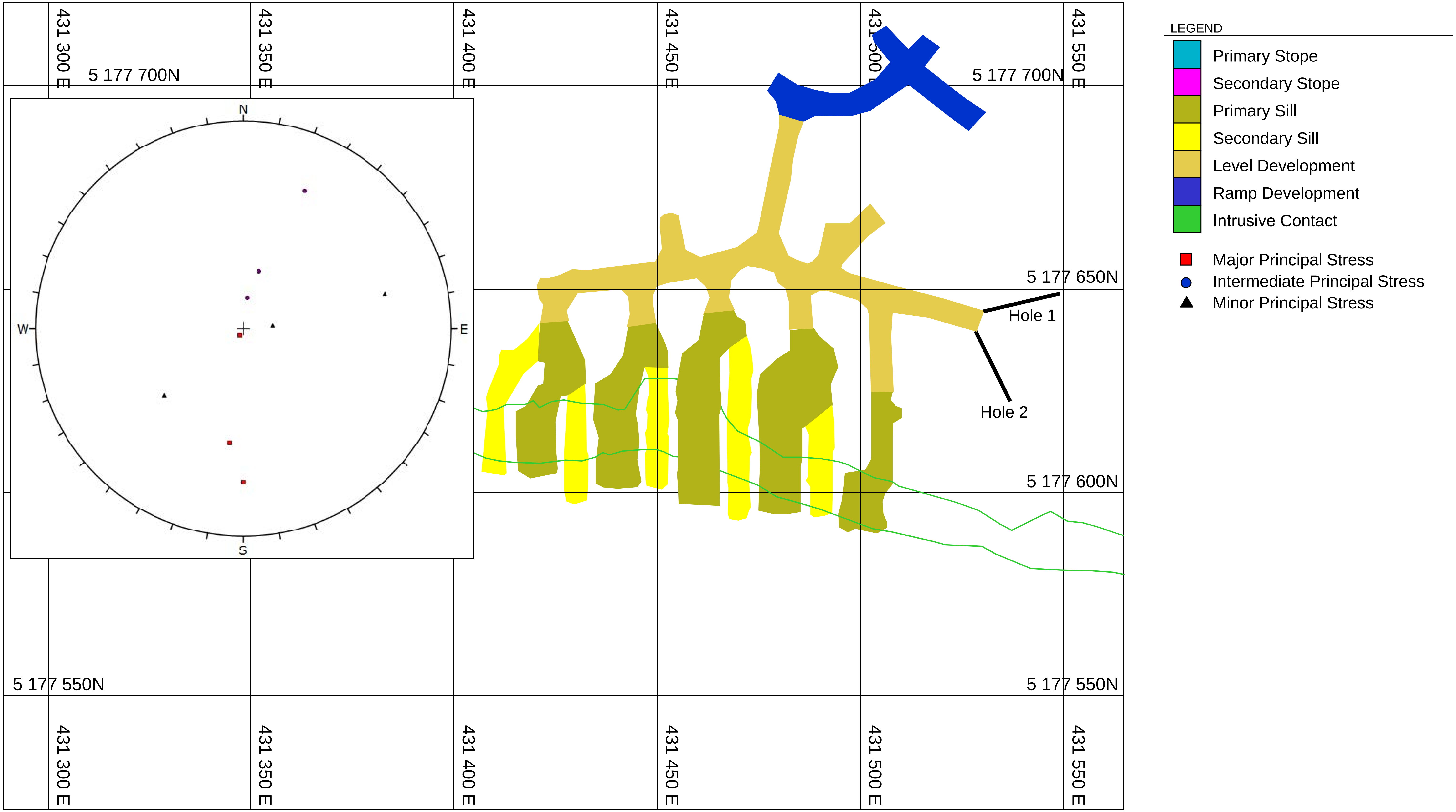
YYYY-MM-DD	2019-07-02
DESIGNED	JJT
PREPARED	JJT
REVIEWED	RPB
APPROVED	RPB

TITLE
Mine Longitudinal Projection

PROJECT No.	Rev.	Figure.
18109752-008	1	1



CLIENT Eagle Mine LLC		PROJECT Phase 4 Crown Pillar Assessment	
CONSULTANT	YYYY-MM-DD	2019-07-02	TITLE 381 L Overcoring Stress Measurement Locations
GOLDER	DESIGNED	JJT	
	PREPARED	JJT	
	REVIEWED	RPB	PROJECT No. 18109752-008 Rev. 1 Figure. 2
	APPROVED	RPB	



CLIENT	PROJECT
Eagle Mine LLC	Phase 4 Crown Pillar Assessment

CONSULTANT

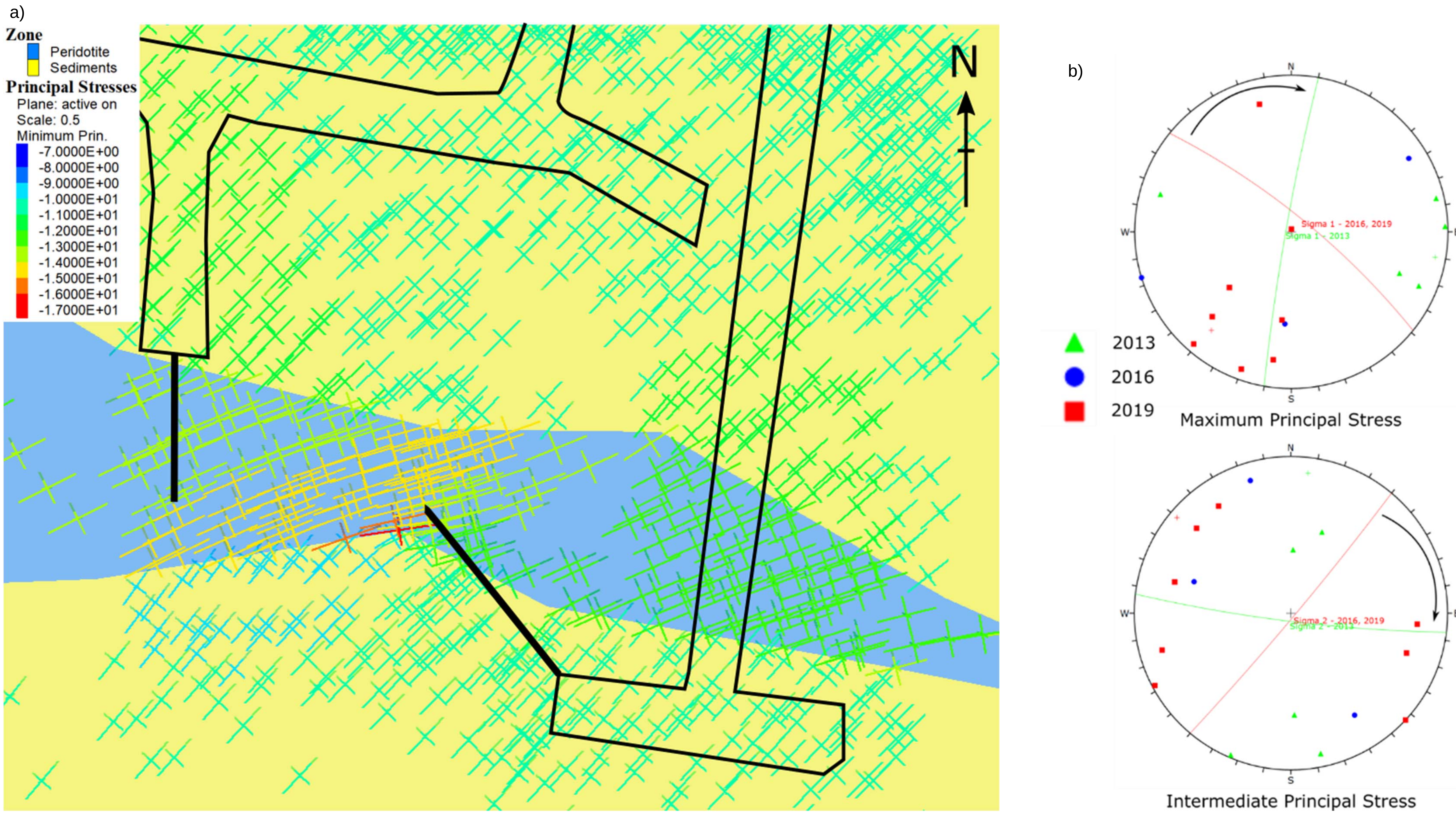
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	JJT
PREPARED	JJT
REVIEWED	RPB
APPROVED	RPB

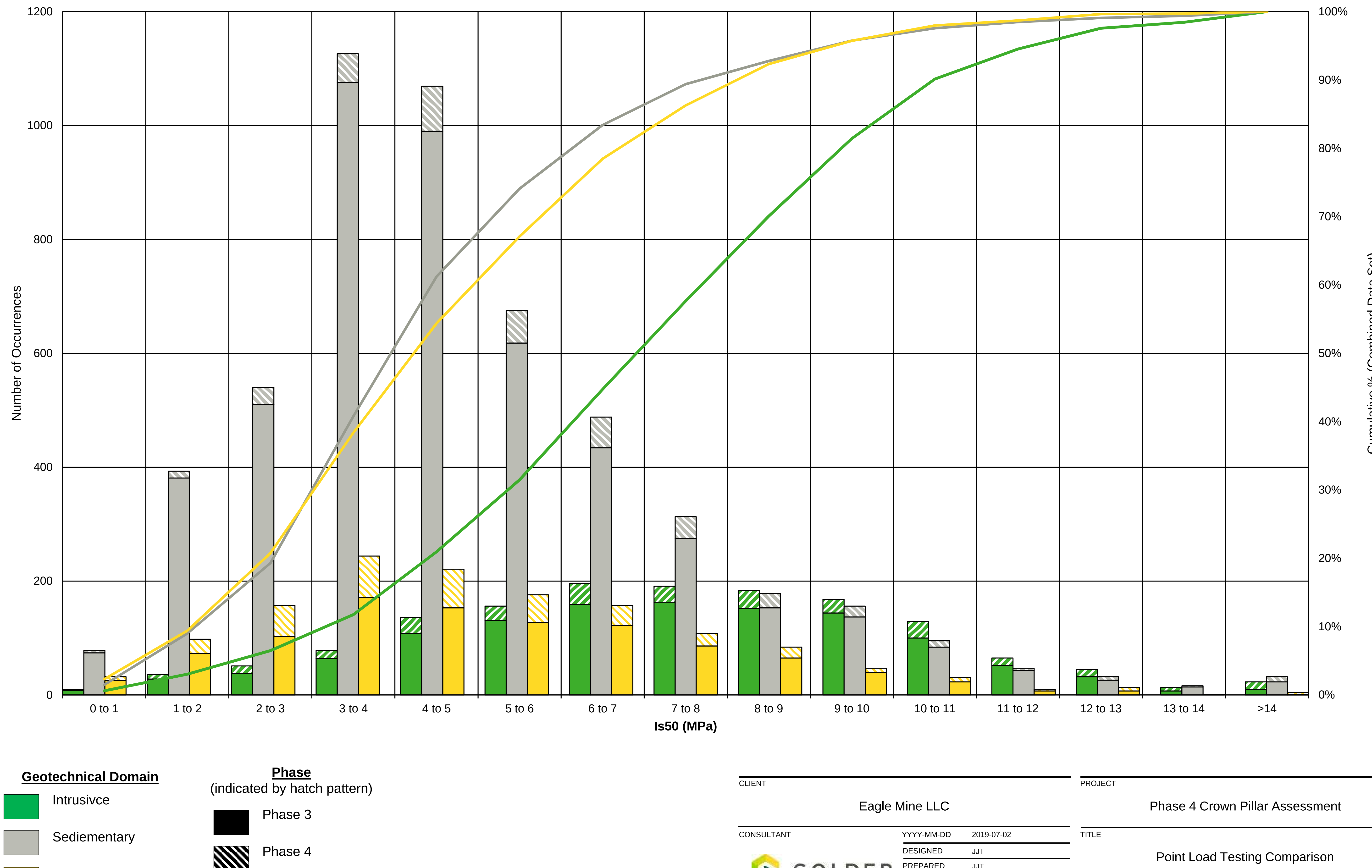
TITLE

172 L Overcoring Stress Measurement Locations

PROJECT No.	Rev.	Figure.
18109752-008	1	3



CLIENT Eagle Mine LLC		PROJECT Phase 4 Crown Pillar Assessment	
CONSULTANT GOLDER	YYYY-MM-DD 2019-07-02 DESIGNED ACM PREPARED JJT REVIEWED RPB APPROVED RPB	TITLE In Situ Stress Calibration	
		PROJECT No. 18109752-008	Rev. 1 / Figure. 4



CLIENT

Eagle Mine LLC

PROJECT

Phase 4 Crown Pillar Assessment

CONSULTANT

GOLDER

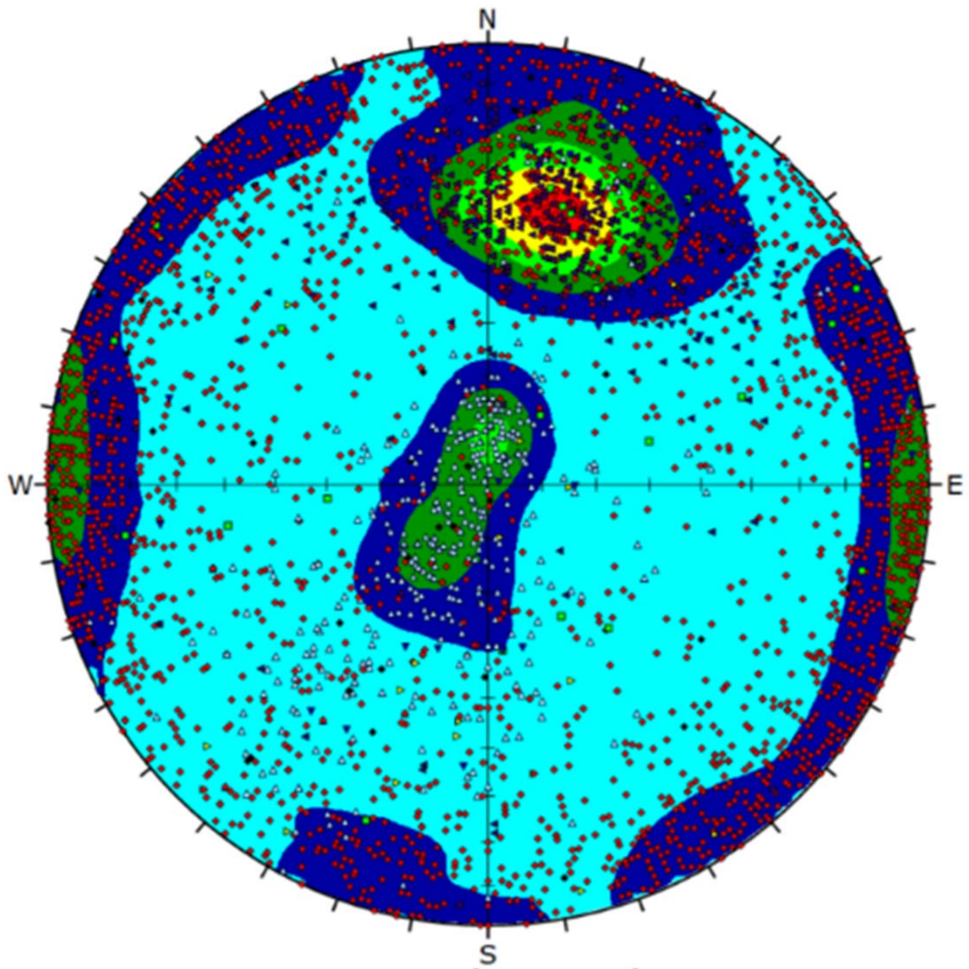
YYYY-MM-DD	2019-07-02
DESIGNED	JJT
PREPARED	JJT
REVIEWED	RPB
APPROVED	RPB

TITLE

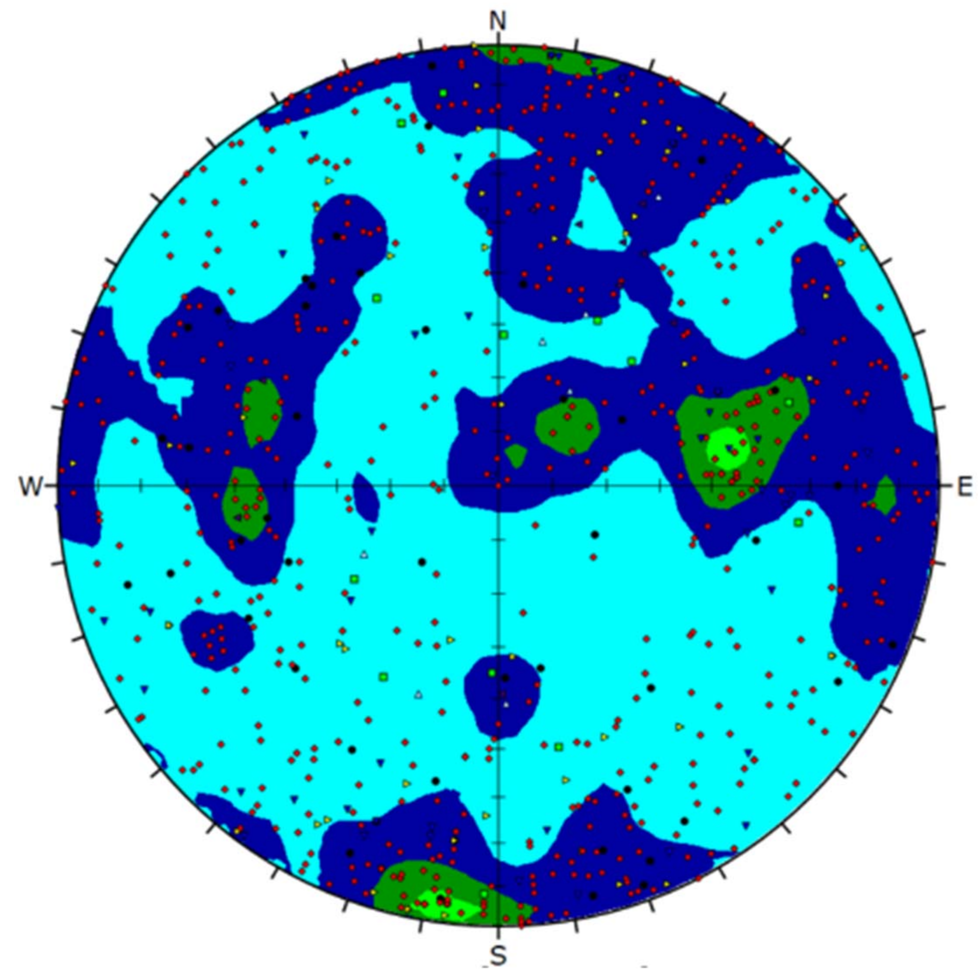
Point Load Testing Comparison

PROJECT No.	Rev.	Figure.
18109752-008	1	5

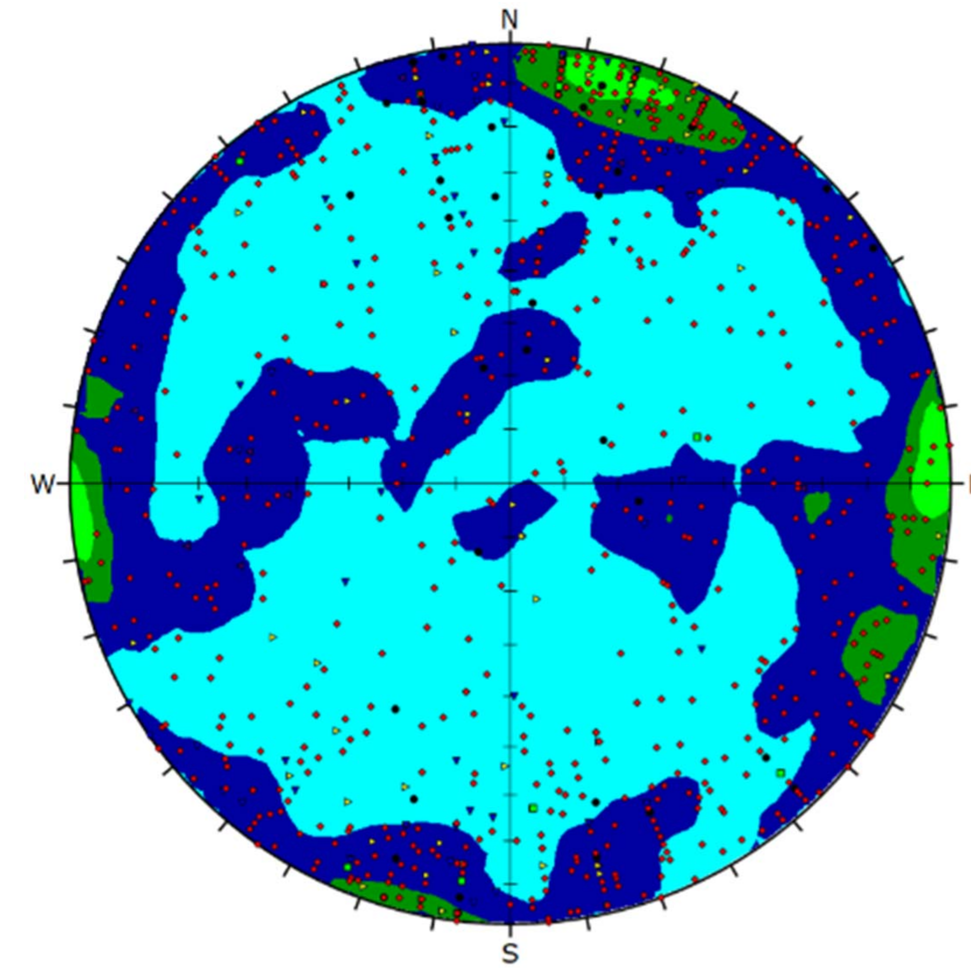
Sedimentary



Intrusives



Sulphides



LEGEND

Fisher Concentrations
% of total per 1.0% area

0.00 ~ 1.00 %
1.00 ~ 2.00 %
2.00 ~ 3.00 %
3.00 ~ 4.00 %
4.00 ~ 5.00 %
5.00 ~ 6.00 %
> 6.00 %

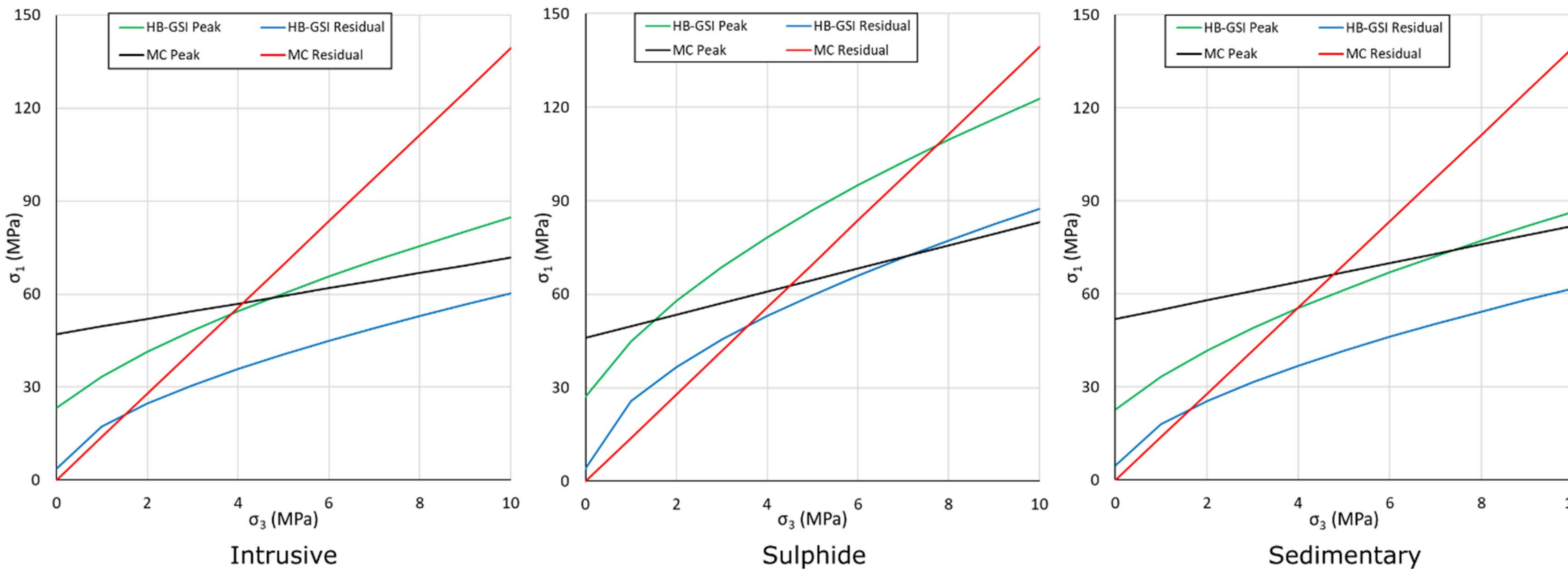
Terzaghi Correction
Min. Bias Angle = 15°

Equal Area
Lower Hemisphere

Feature Type

△ Bedding
▷ Contact
▼ Fault
◀ Foliation
◆ Joint
■ Shear
● Vein

CLIENT	Eagle Mine LLC	PROJECT	Phase 4 Crown Pillar Assessment
CONSULTANT	YYYY-MM-DD: 2019-07-02	TITLE	Mapping Stereonets
GOLDER	DESIGNED: ACM		
	PREPARED: ACM		
	REVIEWED: RPB	PROJECT No. 18109752-008	Rev. 1
	APPROVED: RPB	Figure. 6	



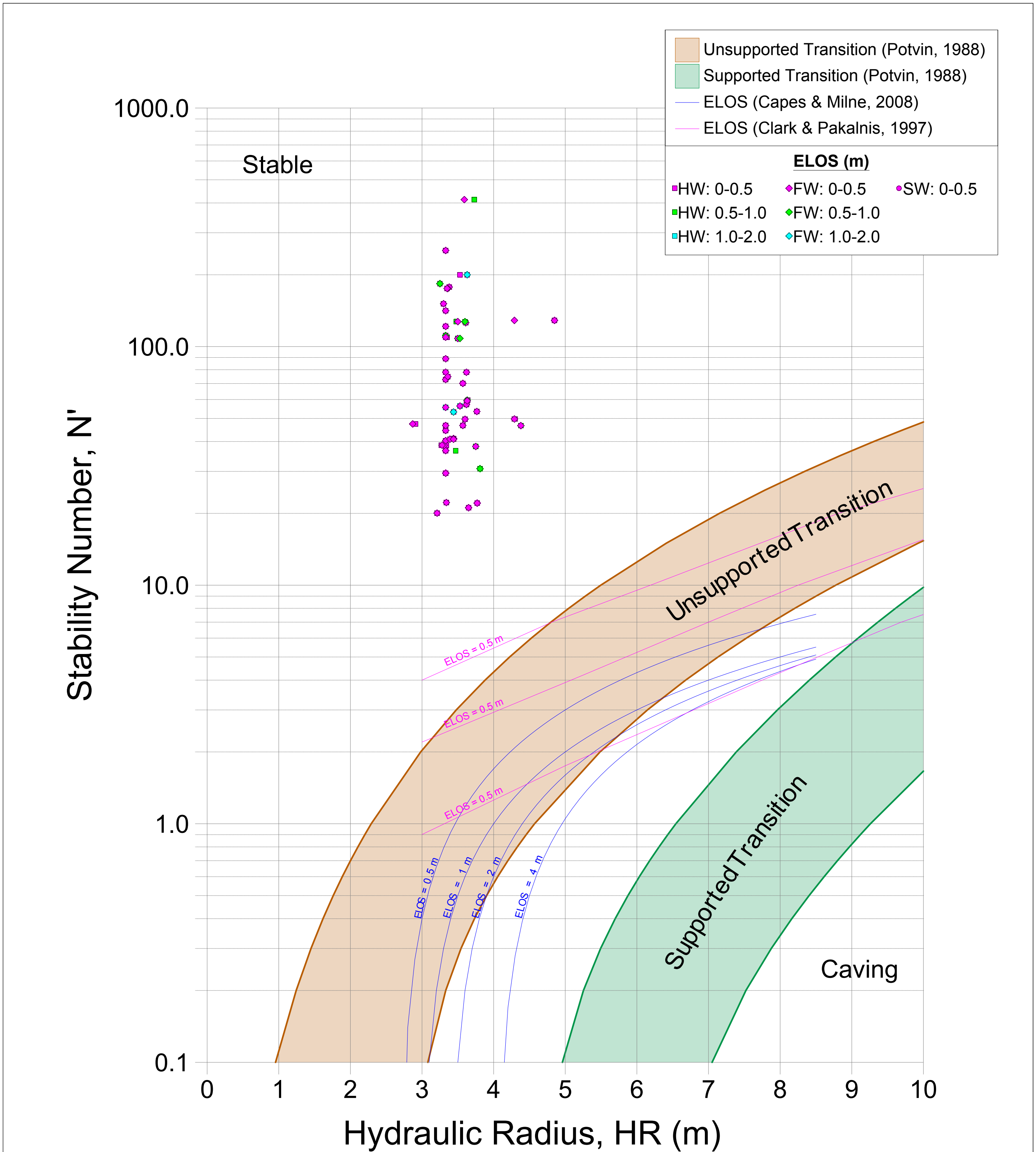
CLIENT Eagle Mine LLC	PROJECT Phase 4 Crown Pillar Assessment

CONSULTANT	YYYY-MM-DD	2019-07-02
GOLDER	DESIGNED	BM
	PREPARED	BM
	REVIEWED	RPB
	APPROVED	RPB

TITLE

Rock Mass Strength Envelopes

PROJECT No.	Rev.	Figure.
18109752-008	1	7



CLIENT		PROJECT
Eagle Mine LLC		Phase 4 Crown Pillar Assessment

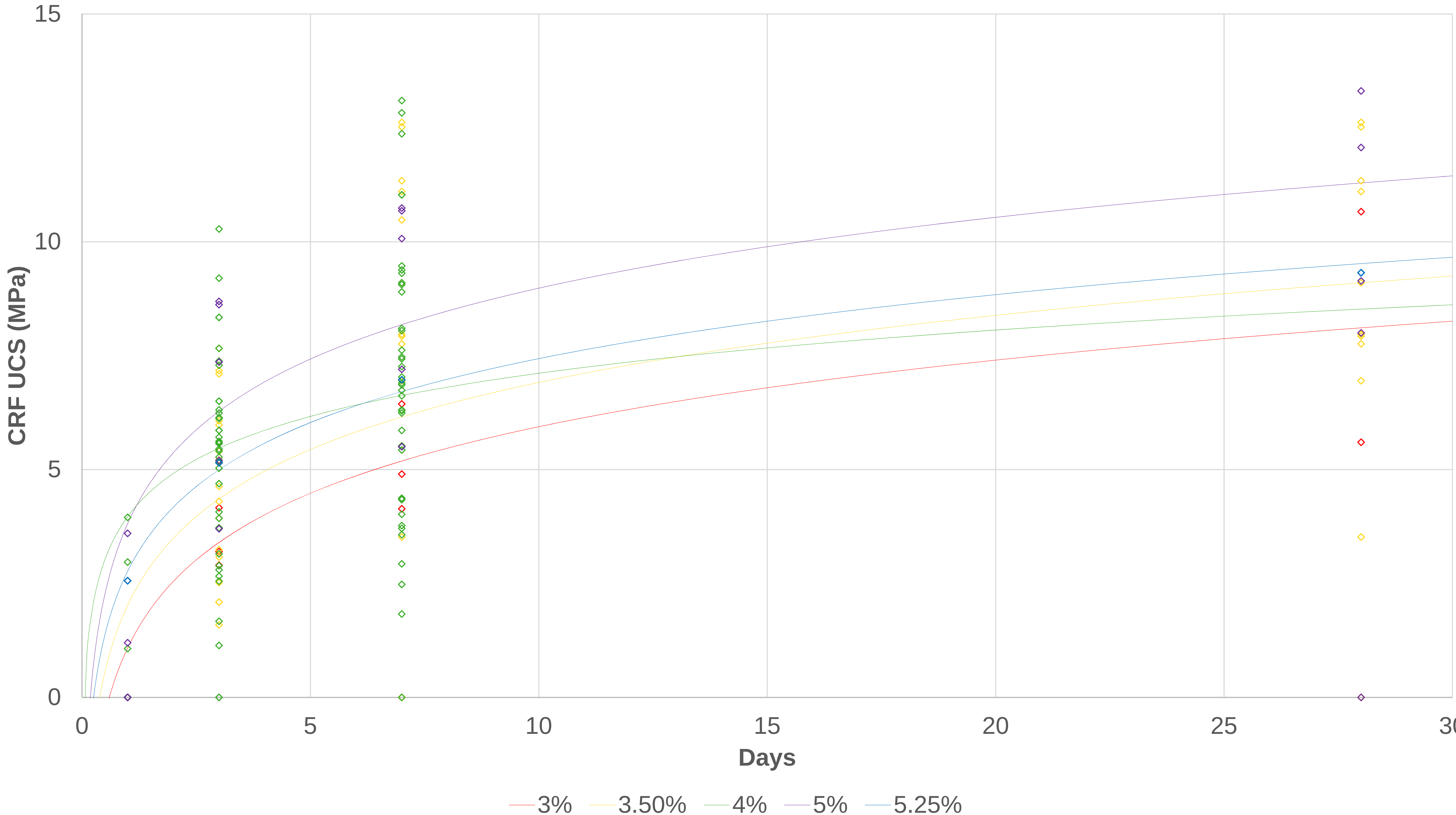
CONSULTANT: GOLDER

YYYY-MM-DD	2019-07-02	
DESIGNED	ACM	
PREPARED	CG	
REVIEWED	JJT	
APPROVED	RPB	

TITLE

Stope Stability Graph

PROJECT NO.	REV.	FIGURE
18109752-008	1	8



CLIENT

Eagle Mine LLC

PROJECT

Phase 4 Crown Pillar Assessment

CONSULTANT

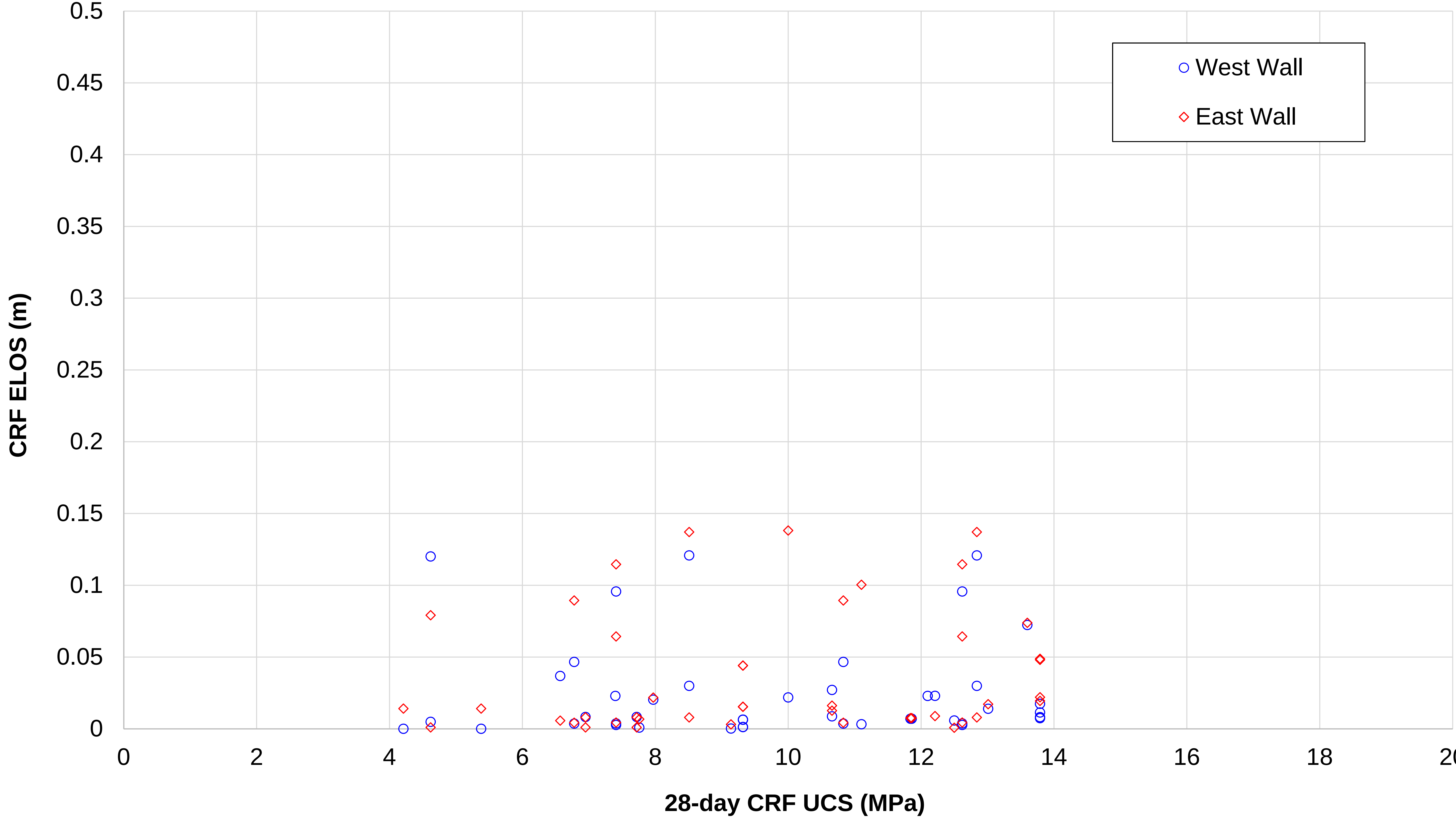
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	BM
PREPARED	BM
REVIEWED	RPB
APPROVED	RPB

TITLE

CRF strength vs. curing time data, with logarithmic trends for various binder contents

PROJECT No.	Rev.	Figure.
18109752-008	1	9



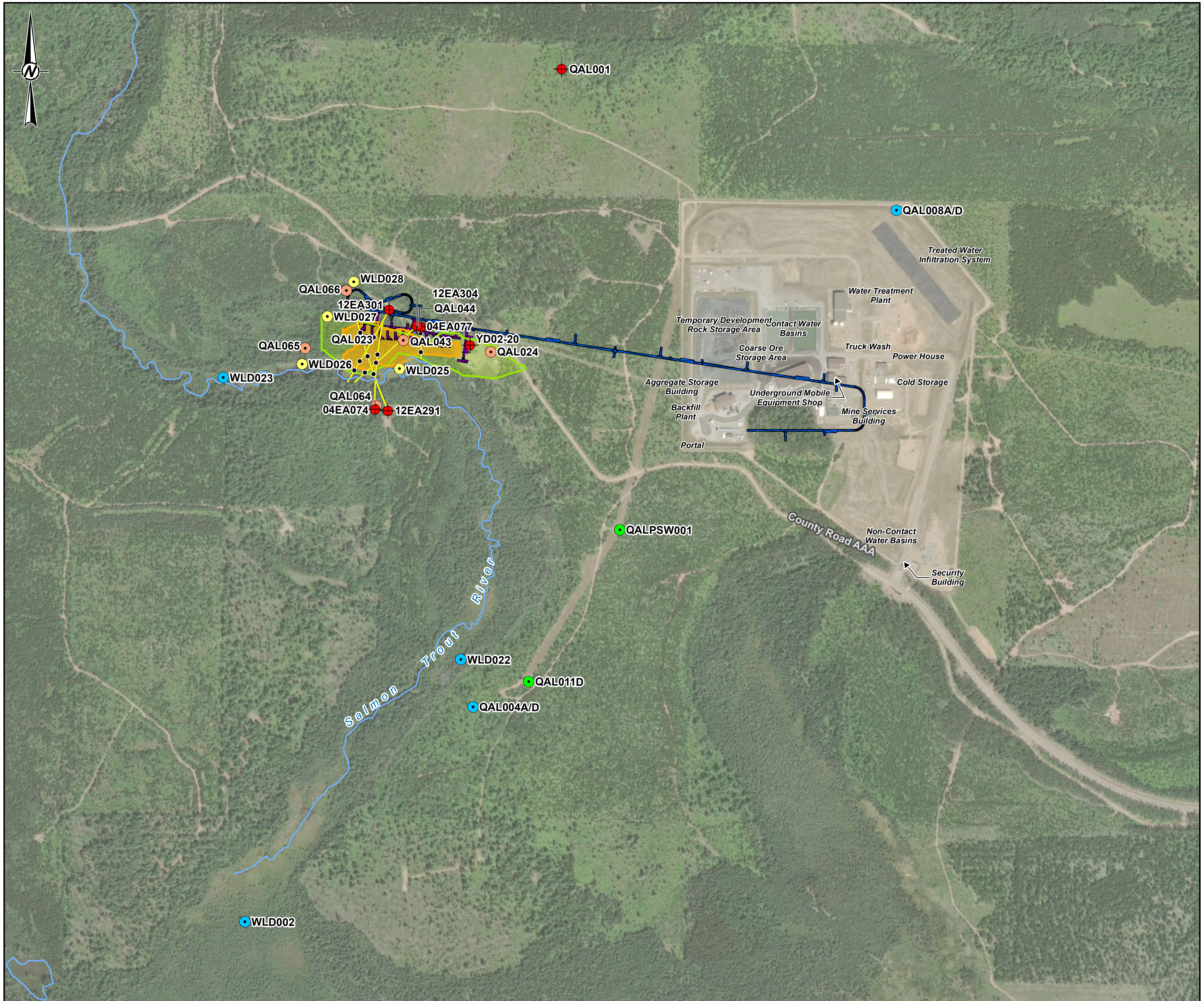
CLIENT		PROJECT	
Eagle Mine LLC		Phase 4 Crown Pillar Assessment	
CONSULTANT	YYYY-MM-DD 2019-07-02	TITLE	
GOLDER	DESIGNED BM	Secondary stope end wall ELOS vs. 28-day CRF strength	
	PREPARED BM		
	REVIEWED RPB	PROJECT No. 18109752-008	Rev. 1 · Figure. 10
	APPROVED RPB		

CLIENT			PROJECT		
Eagle Mine LLC			Phase 4 Crown Pillar Assessment		
CONSULTANT	YYYY-MM-DD	2019-07-02	TITLE		
GOLDER	DESIGNED	JJT	Example of Primary Stope CRF Exposed by Adjacent Drifting		
	PREPARED	JJT			
	REVIEWED	RPB	PROJECT No.	Rev.	Figure.
	APPROVED	RPB	18109752-008	1	11

25 mm

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

0



LEGEND

- Grouted-In Piezometers
- Pumping Wells
- Continuous Groundwater Monitoring
- Quaternary Wells
- Wetland Wells
- Transducer Locations Along Borehole Trace
- Borehole Traces
- Crown Pillar
- Peridotite projection
- Underground Ramp
- Underground Workings
- Crown Pillar Projection
- Peridotite Projection

0 200 400
1:10,000 METRES

NOTE(S)
THIS FIGURE IS TO BE READ IN CONJUNCTION WITH THE ACCOMPANYING GOLDER ASSOCIATES LTD. REPORT NO. 18109752-005

REFERENCE(S)
CONTAINS INFORMATION LICENSED UNDER THE OPEN GOVERNMENT LICENCE – ONTARIO.
HTTPS://WWW.ONTARIO.CA/GOVERNMENT/OPEN-GOVERNMENT-LICENCE-ONTARIO
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD 83
COORDINATE SYSTEM: UTM ZONE 17 VERTICAL DATUM: CGVD28

CLIENT
EAGLE MINE
A SUBSIDIARY OF LUNDING MINING

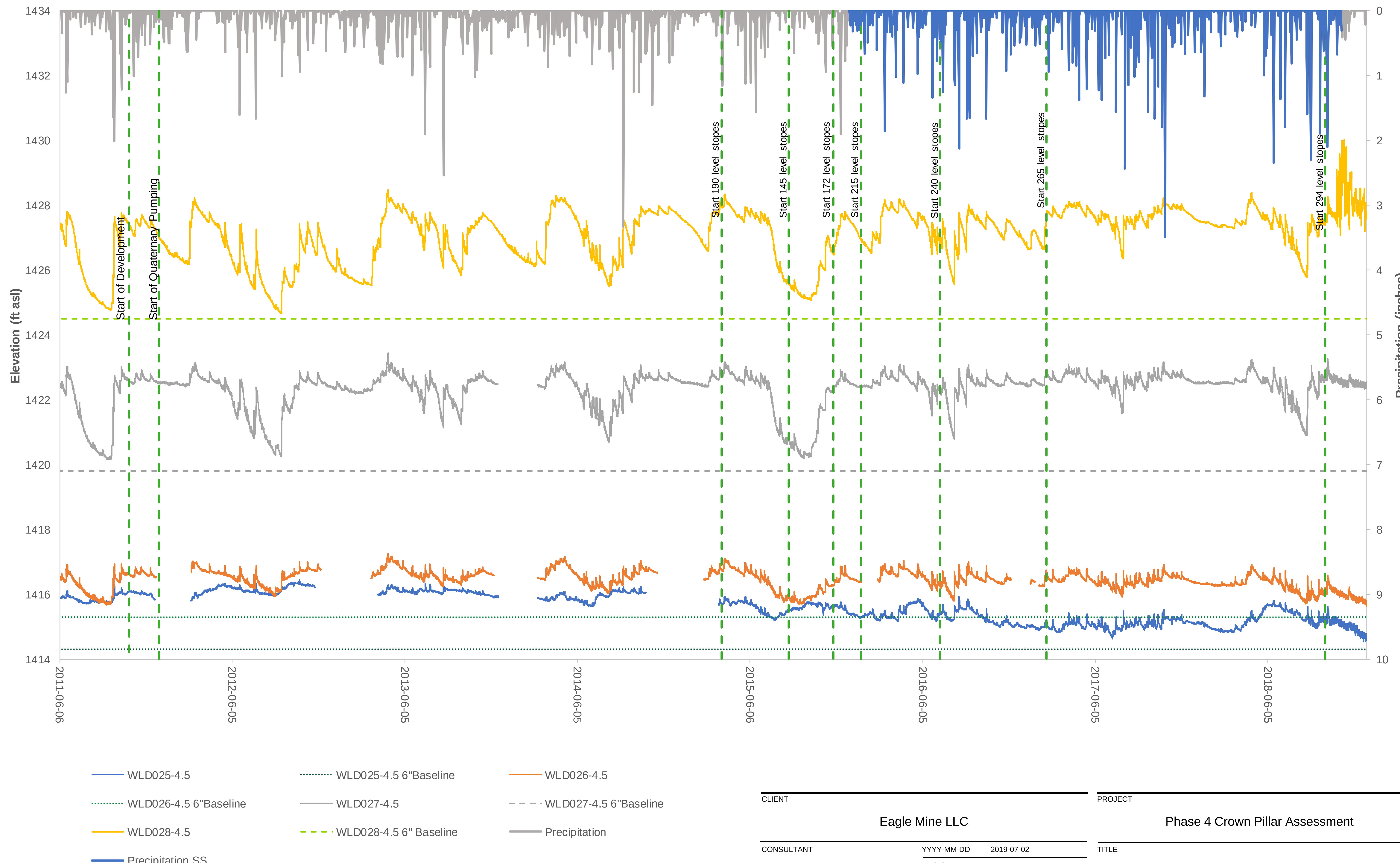
PROJECT
PHASE 4 CROWN PILLAR ENGINEERING STUDY
EAGLE MINE

TITLE
MONITORING WELL LOCATIONS

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	EQ
PREPARED	RRD
REVIEWED	JW
APPROVED	JW

PROJECT NO.	CONTROL	REV.	FIGURE
18109752-008	0001	1	12



CLIENT

Eagle Mine LLC

PROJECT

Phase 4 Crown Pillar Assessment

CONSULTANT

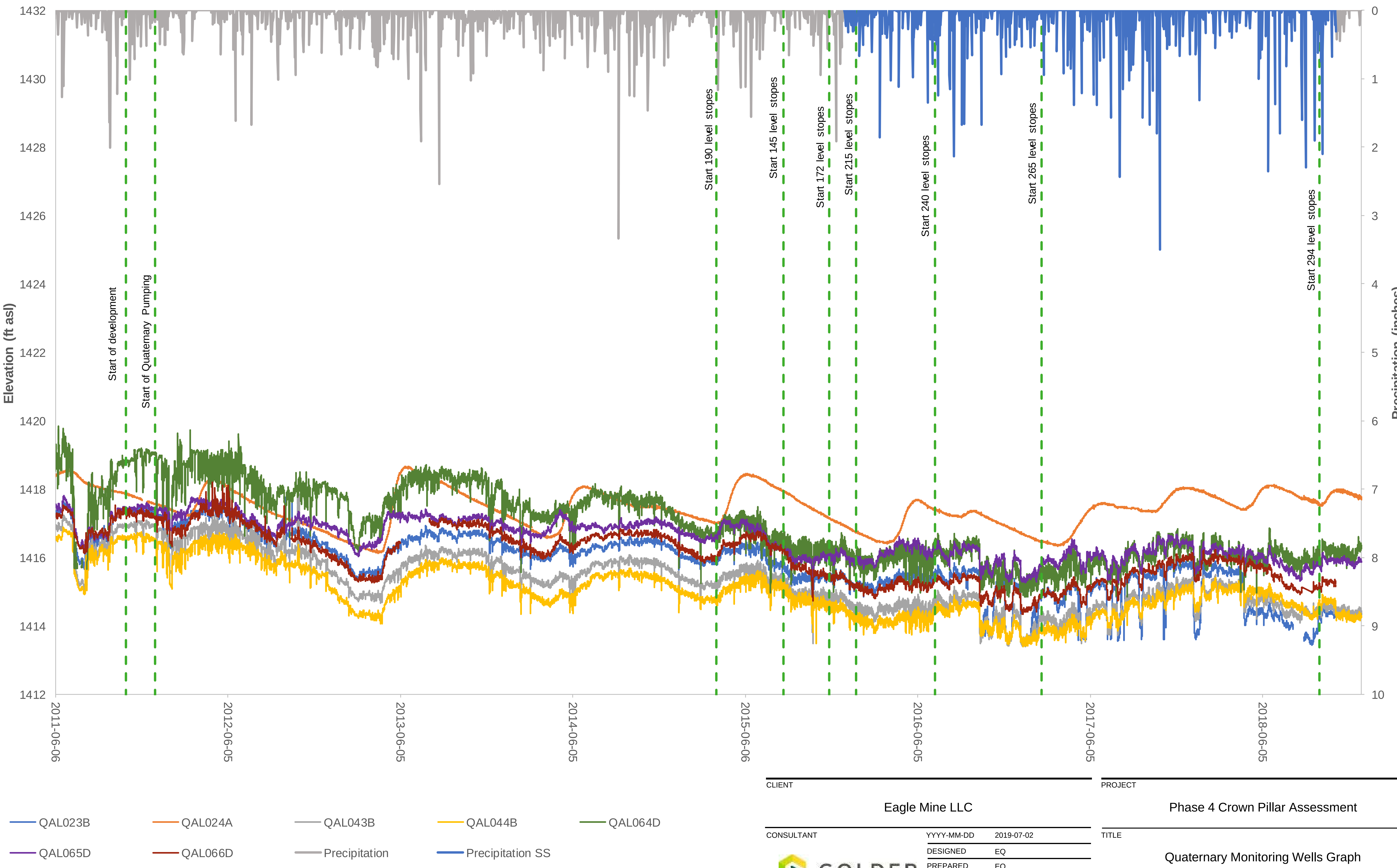
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	EQ
PREPARED	EQ
REVIEWED	JW
APPROVED	JW

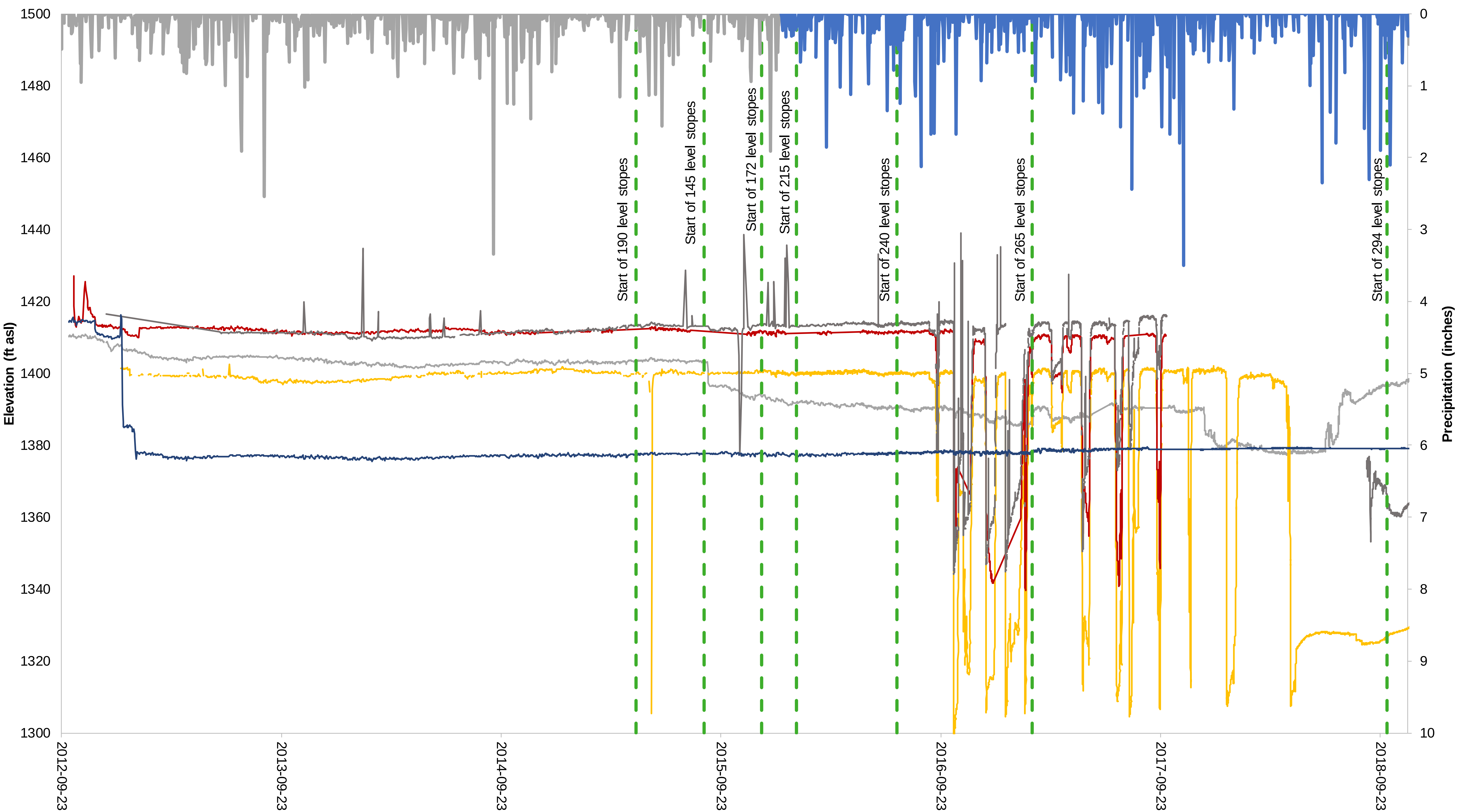
TITLE

Wetland Monitoring Wells Graph

PROJECT No.	Rev.	Figure.
18109752-008	1	13



CLIENT		PROJECT		
Eagle Mine LLC		Phase 4 Crown Pillar Assessment		
CONSULTANT	YYYY-MM-DD 2019-07-02	TITLE		
GOLDER	DESIGNED EQ	Quaternary Monitoring Wells Graph		
	PREPARED EQ			
	REVIEWED JW	PROJECT No. 18109752-008	Rev. 1	Figure. 14
	APPROVED JW			



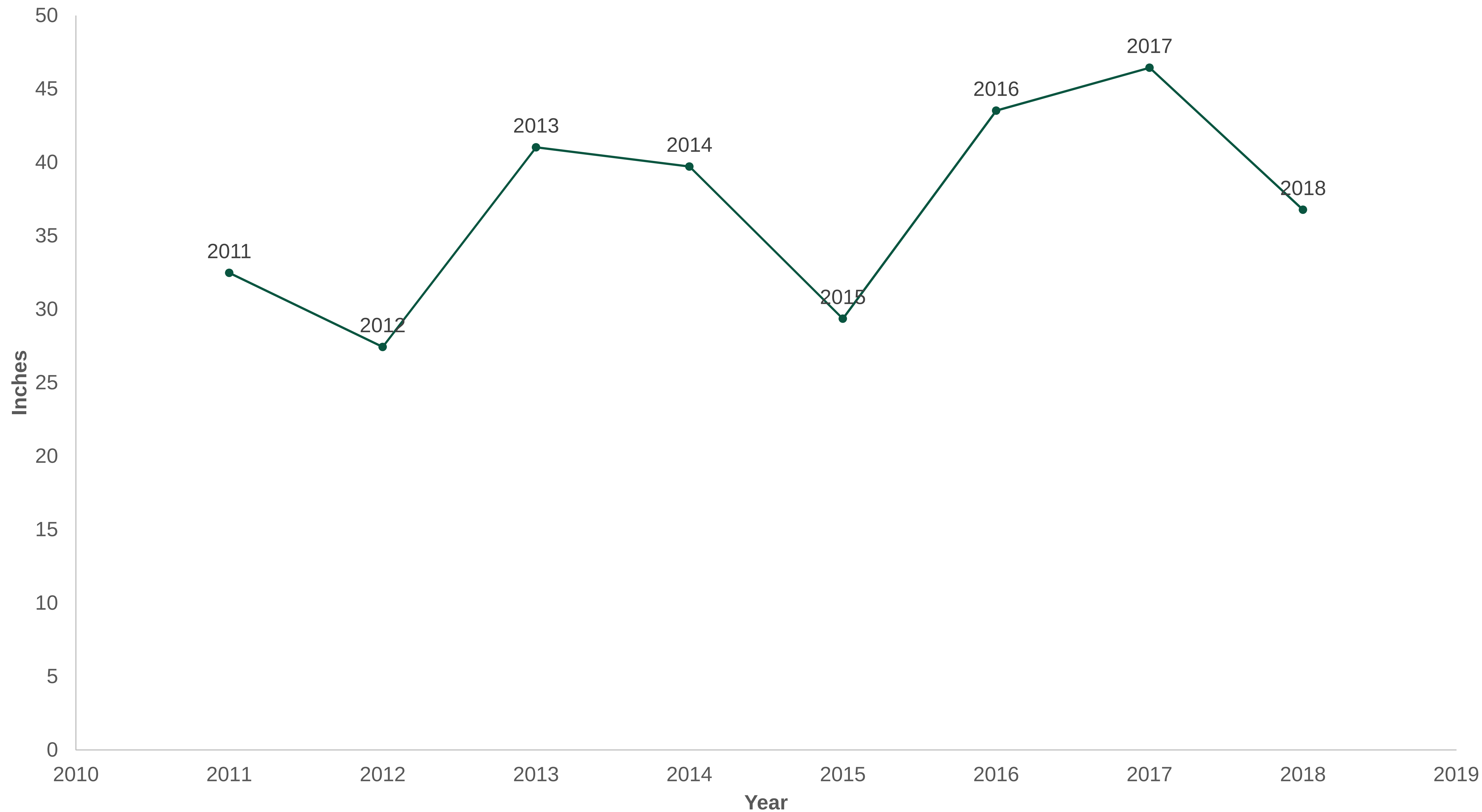
CLIENT	PROJECT
Eagle Mine LLC	Phase 4 Crown Pillar Assessment

CONSULTANT			TITLE
GOLDER	YYYY-MM-DD	2019-07-02	Bedrock Monitoring Wells Graph
	DESIGNED	EQ	
	PREPARED	EQ	
	REVIEWED	JW	
	APPROVED	JW	

PROJECT No.	Rev.	Figure.
18109752-008	1	15

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25 mm



CLIENT	PROJECT
Eagle Mine LLC	Phase 4 Crown Pillar Assessment

CONSULTANT

GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	EQ
PREPARED	EQ
REVIEWED	JW
APPROVED	JW

TITLE

Annual Precipitation

PROJECT No.	Rev.	Figure.
18109752-008	1	16

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25 mm

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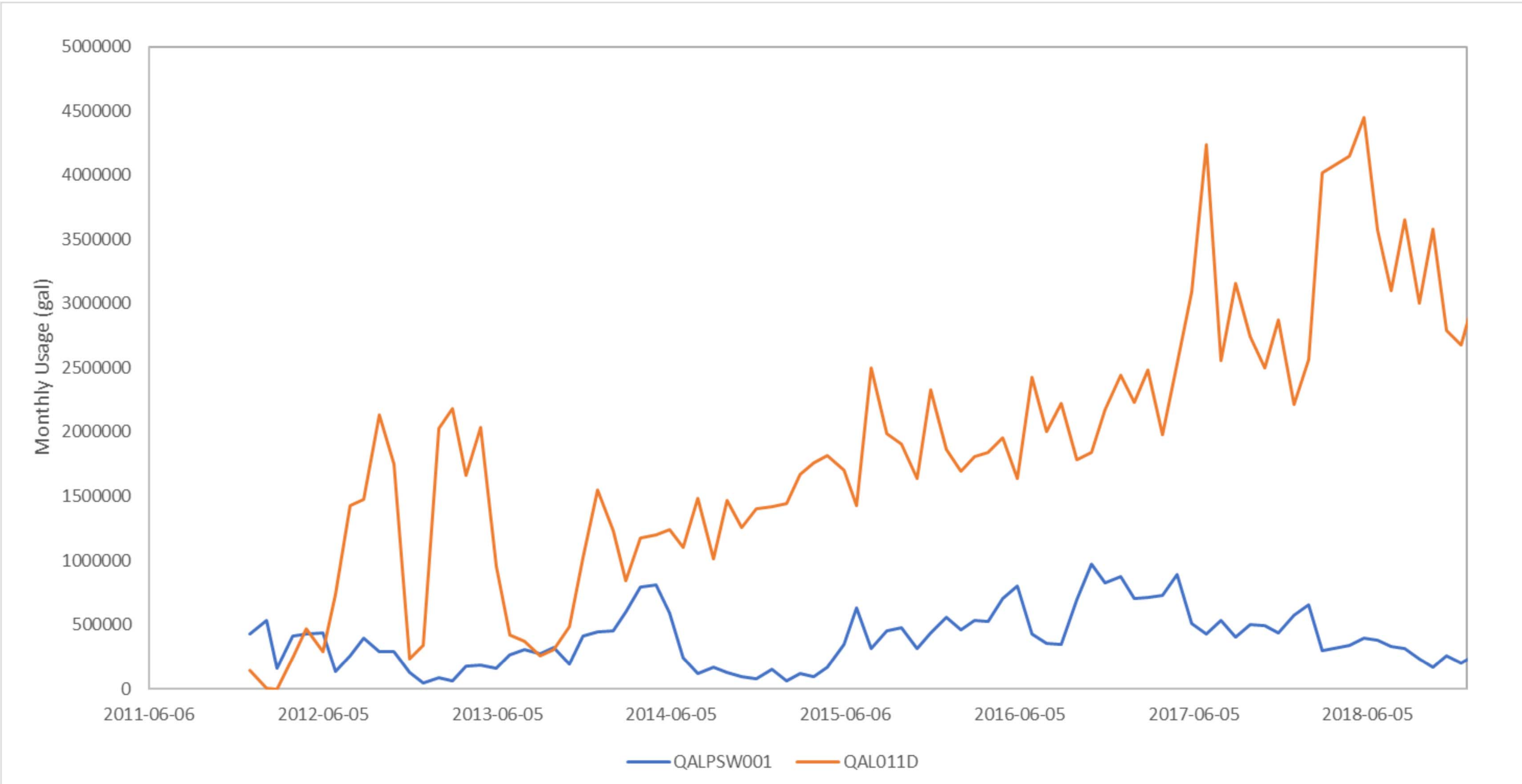
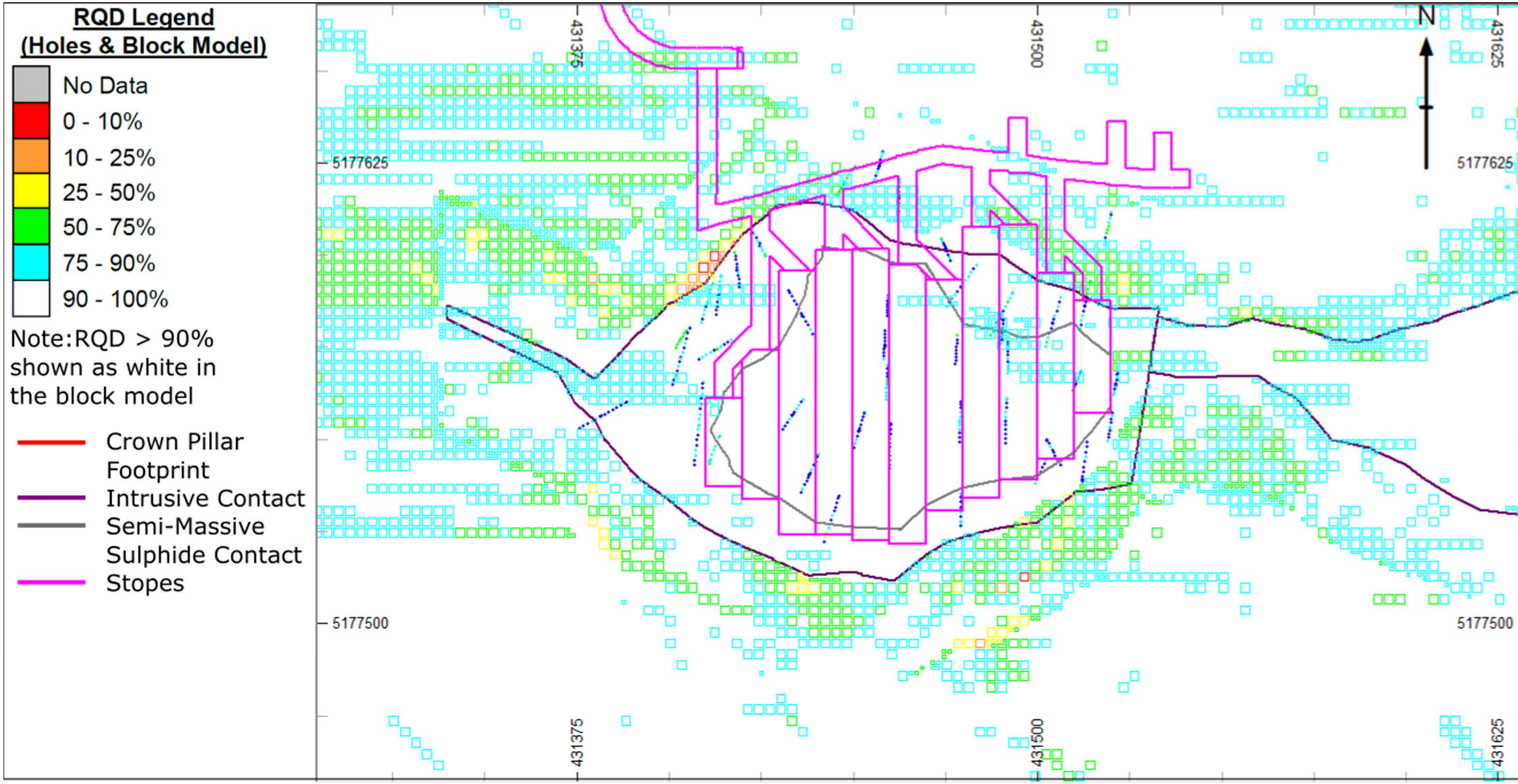


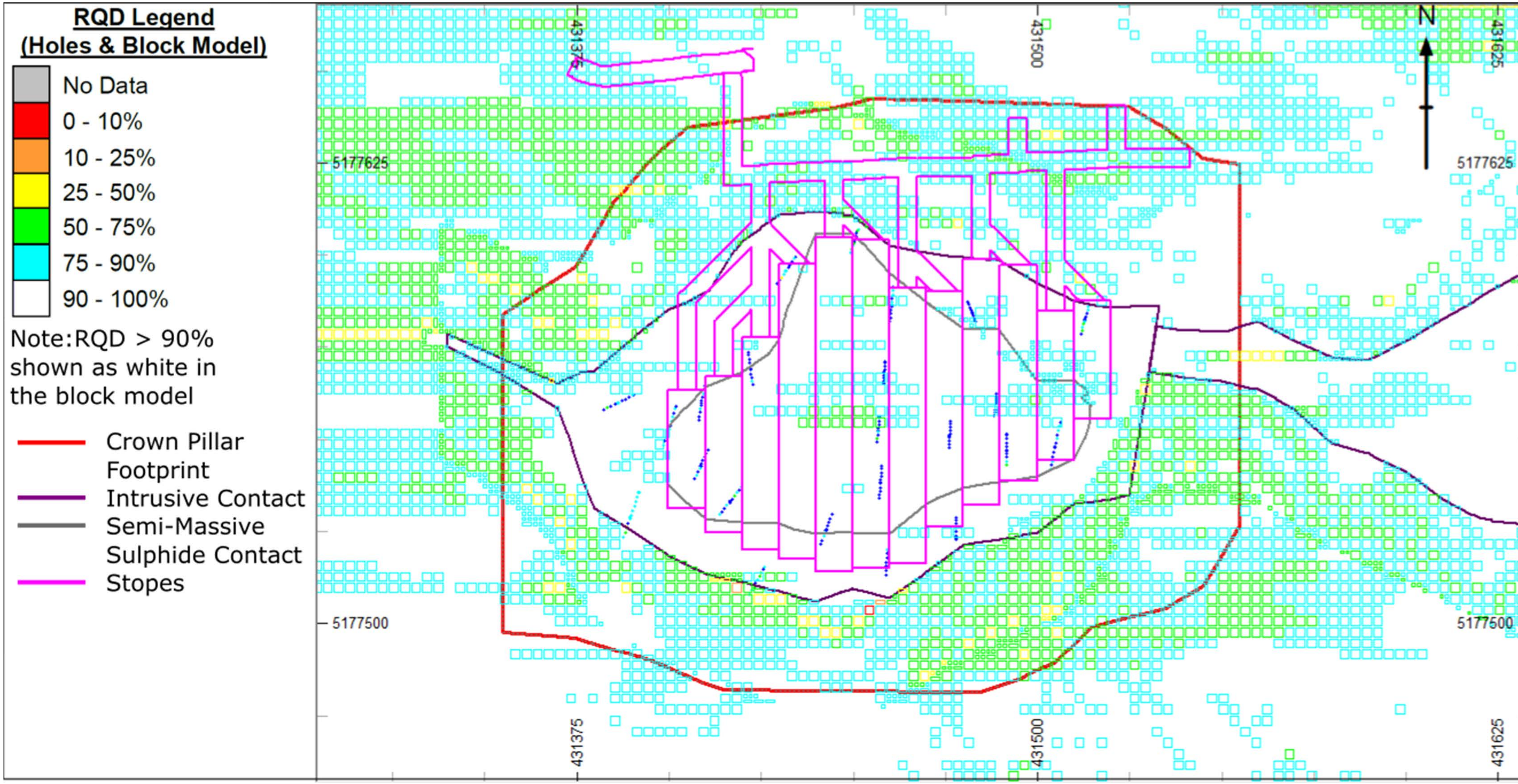
CLIENT		PROJECT		
Eagle Mine LLC		Phase 4 Crown Pillar Assessment		
CONSULTANT	YYYY-MM-DD 2019-07-02	TITLE		
GOLDER	DESIGNED EQ	Monthly Pumping Volumes from Quaternary Wells		
	PREPARED EQ			
	REVIEWED JW	PROJECT No. 18109752-008	Rev. 1	Figure. 17
	APPROVED JW			



CLIENT		PROJECT		
Eagle Mine LLC		Phase 4 Crown Pillar Assessment		
CONSULTANT	YYYY-MM-DD 2019-07-02	TITLE		
GOLDER	DESIGNED ACM	Block model RQD at an elevation of 352 level, with an overlay of Phase 4 drillhole RQD		
	PREPARED ACM			
	REVIEWED JJT	PROJECT No.	Rev.	Figure.
	APPROVED RPB	18109752-008	1	18

25 mm

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



CLIENT	PROJECT
Eagle Mine LLC	Phase 4 Crown Pillar Assessment

CONSULTANT	YYYY-MM-DD	2019-07-02
GOLDER	DESIGNED	ACM
	PREPARED	ACM
	REVIEWED	JJT
	APPROVED	RPB

TITLE
Block model RQD at an elevation of 387.381 level with an overlay of Phase 4 drillhole RQD

PROJECT No.	Rev.	Figure.
18109752-008	1	19

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B
25 mm

381L

352L

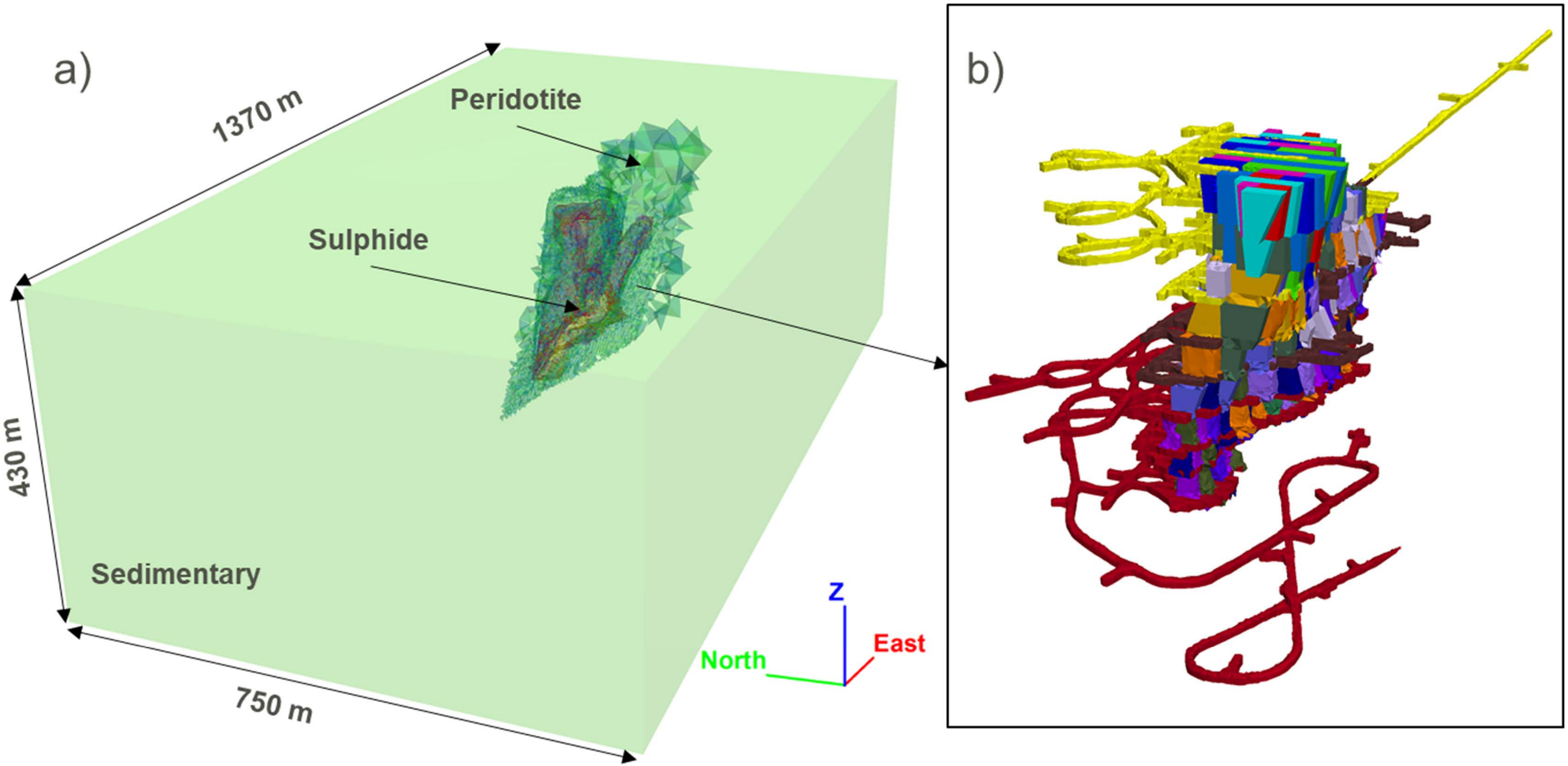
CLIENT	
Eagle Mine LLC	

CONSULTANT	YYYY-MM-DD	2019-07-02
GOLDER	DESIGNED	JJT
	PREPARED	JJT
	REVIEWED	RPB
	APPROVED	RPB

PROJECT		
Phase 4 Crown Pillar Assessment		
TITLE		
Photos of Contact		
PROJECT No.	Rev.	Figure.
18109752-008	1	20

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

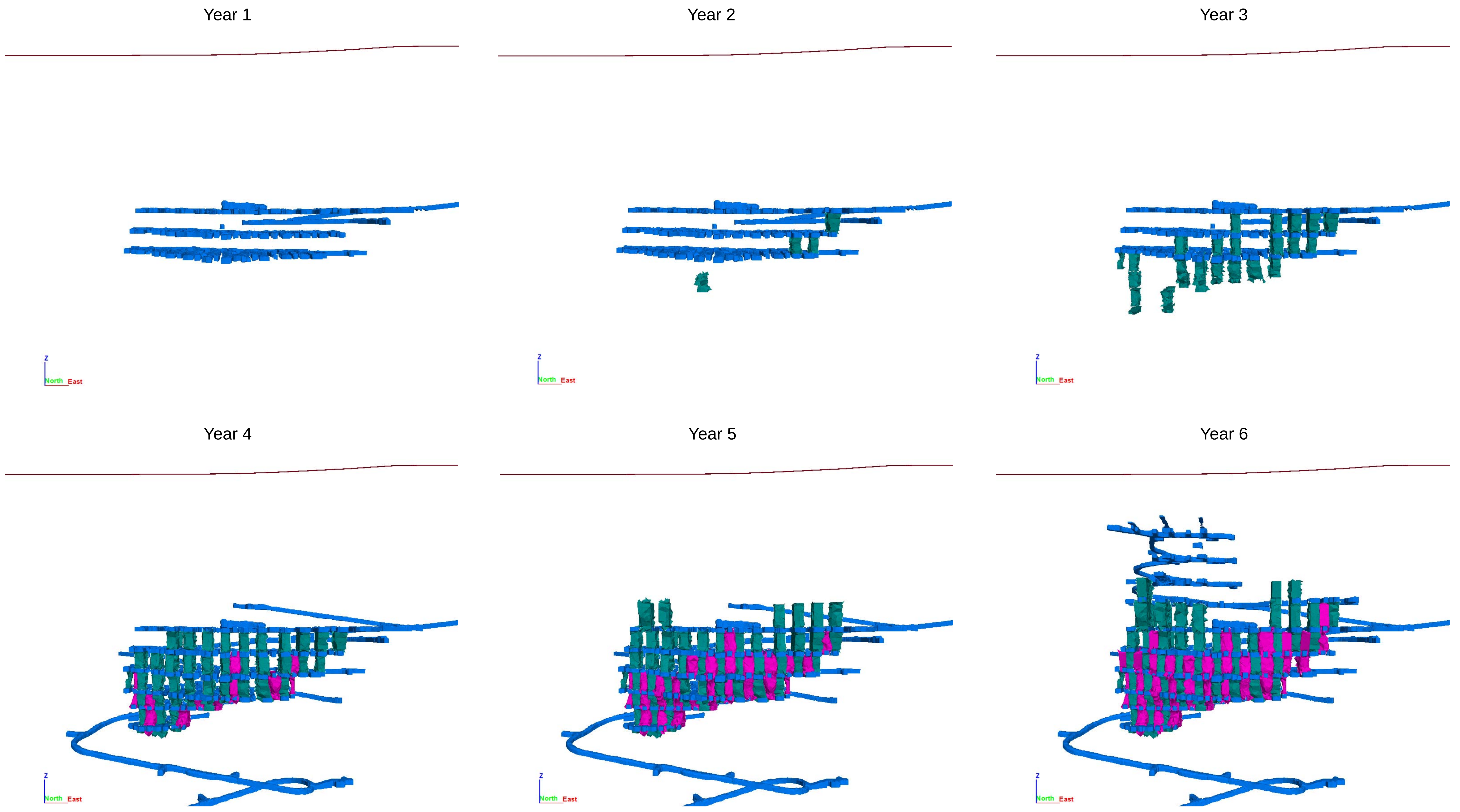
25 mm



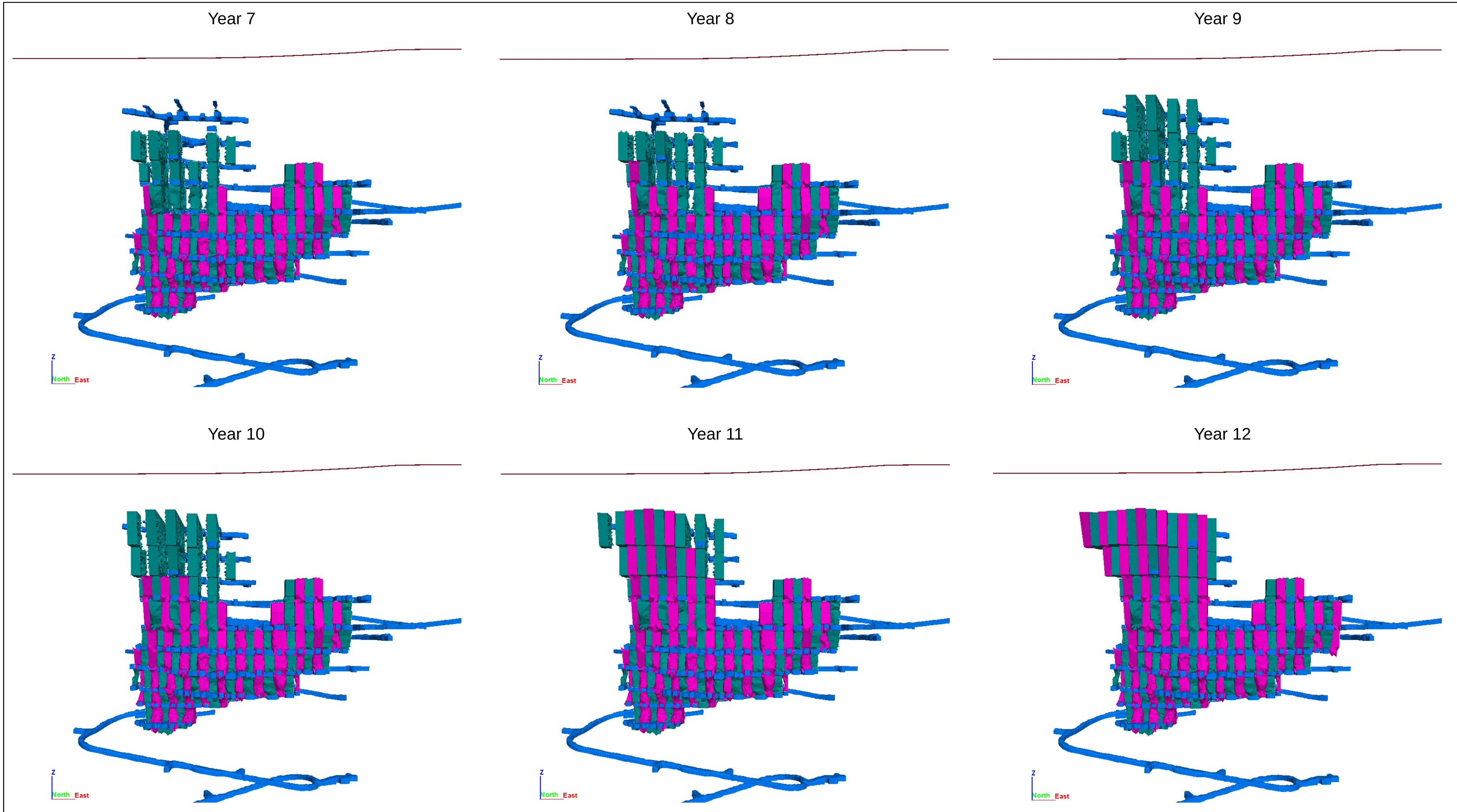
CLIENT	PROJECT
Eagle Mine LLC	Phase 4 Crown Pillar Assessment

CONSULTANT	YYYY-MM-DD	2019-07-02	TITLE
GOLDER	DESIGNED	BM	FLAC3D Model Wireframe
	PREPARED	BM	
	REVIEWED	RPB	
	APPROVED	RPB	

PROJECT No.	Rev.	Figure.
18109752-008	1	21



CLIENT	Eagle Mine LLC
PROJECT	Phase 4 Crown Pillar Assessment
CONSULTANT	GOLDER
YYYY-MM-DD	2019-07-02
DESIGNED	BM
PREPARED	BM
REVIEWED	RPB
APPROVED	RPB
TITLE	FLAC3D Sequence Time Steps (1 of 2)
PROJECT No.	18109752-008
Rev.	1
Figure.	22



CLIENT

Eagle Mine LLC

PROJECT

Phase 4 Crown Pillar Assessment

CONSULTANT

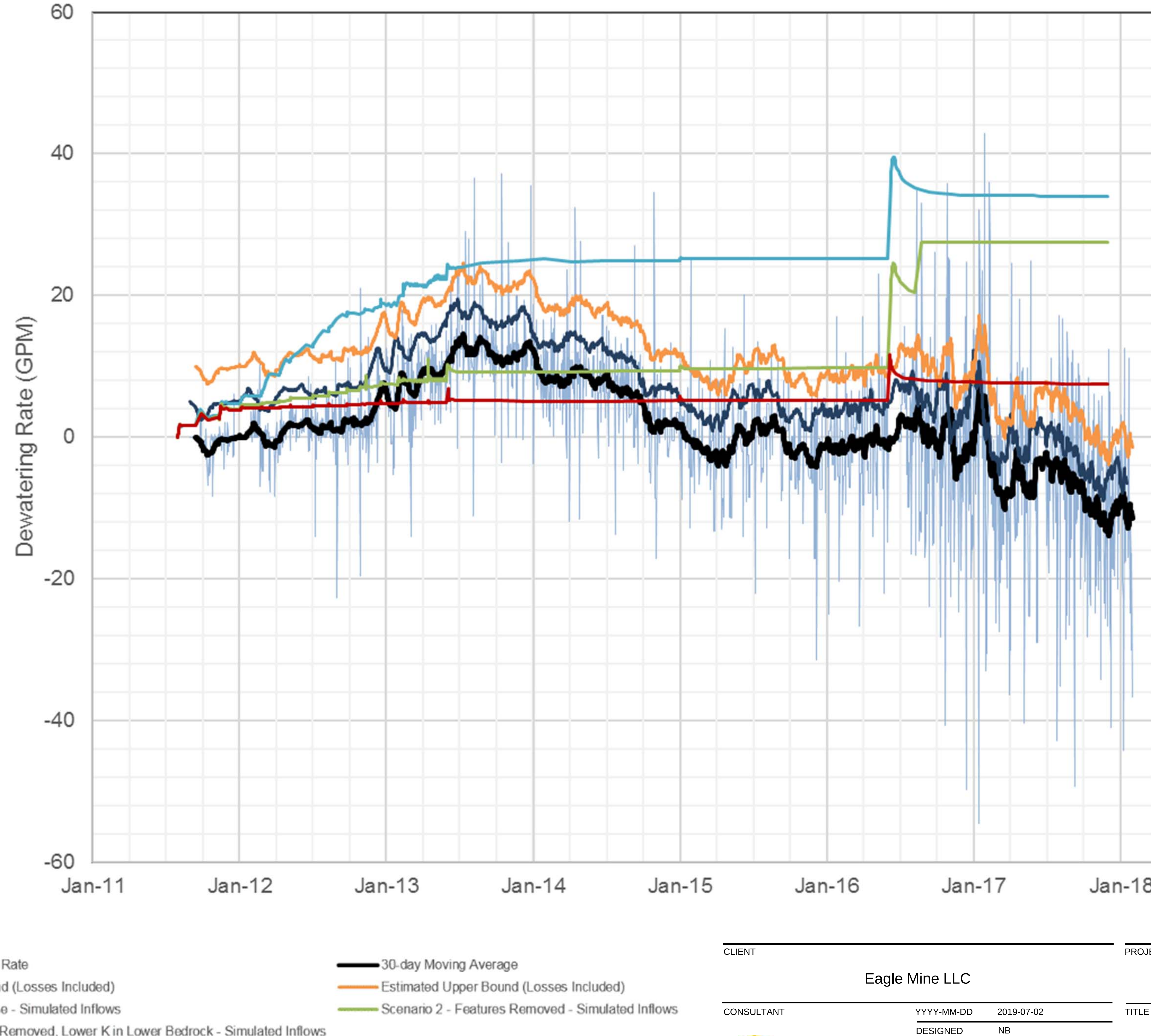
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	BM
PREPARED	BM
REVIEWED	RPB
APPROVED	RPB

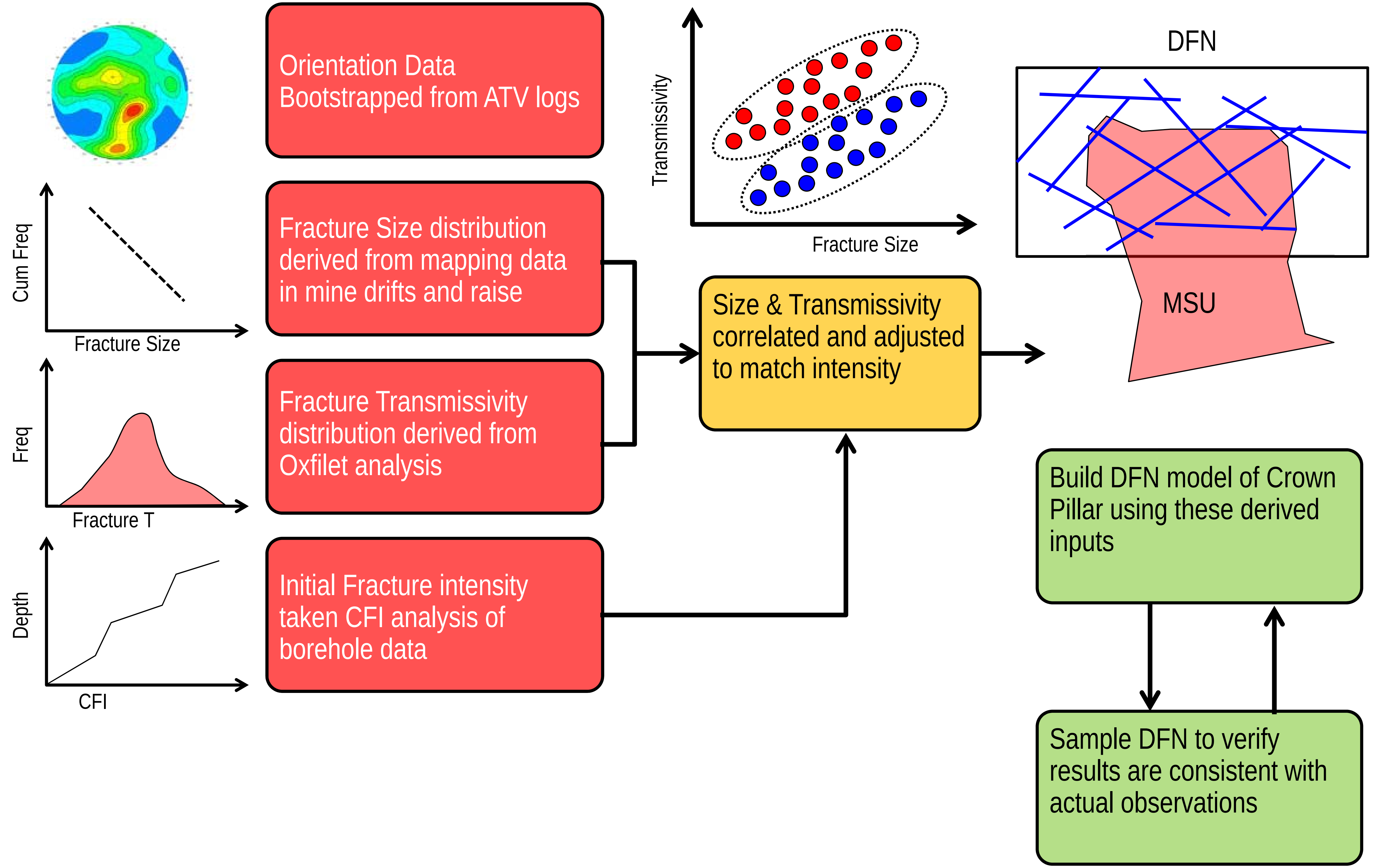
TITLE

FLAC3D Sequence Time Steps (2 of 2)

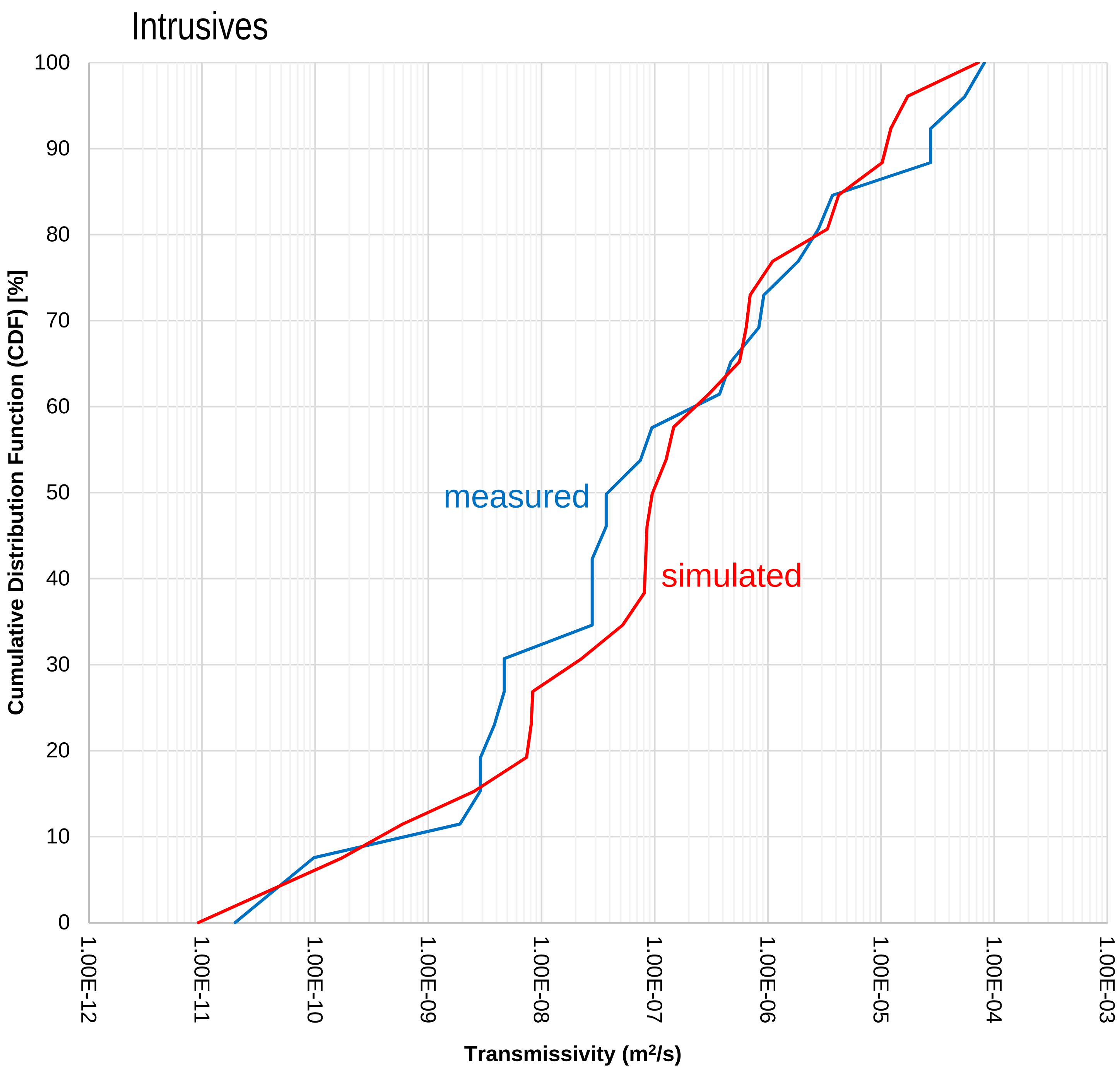
PROJECT No.	Rev.	Figure.
18109752-008	1	23



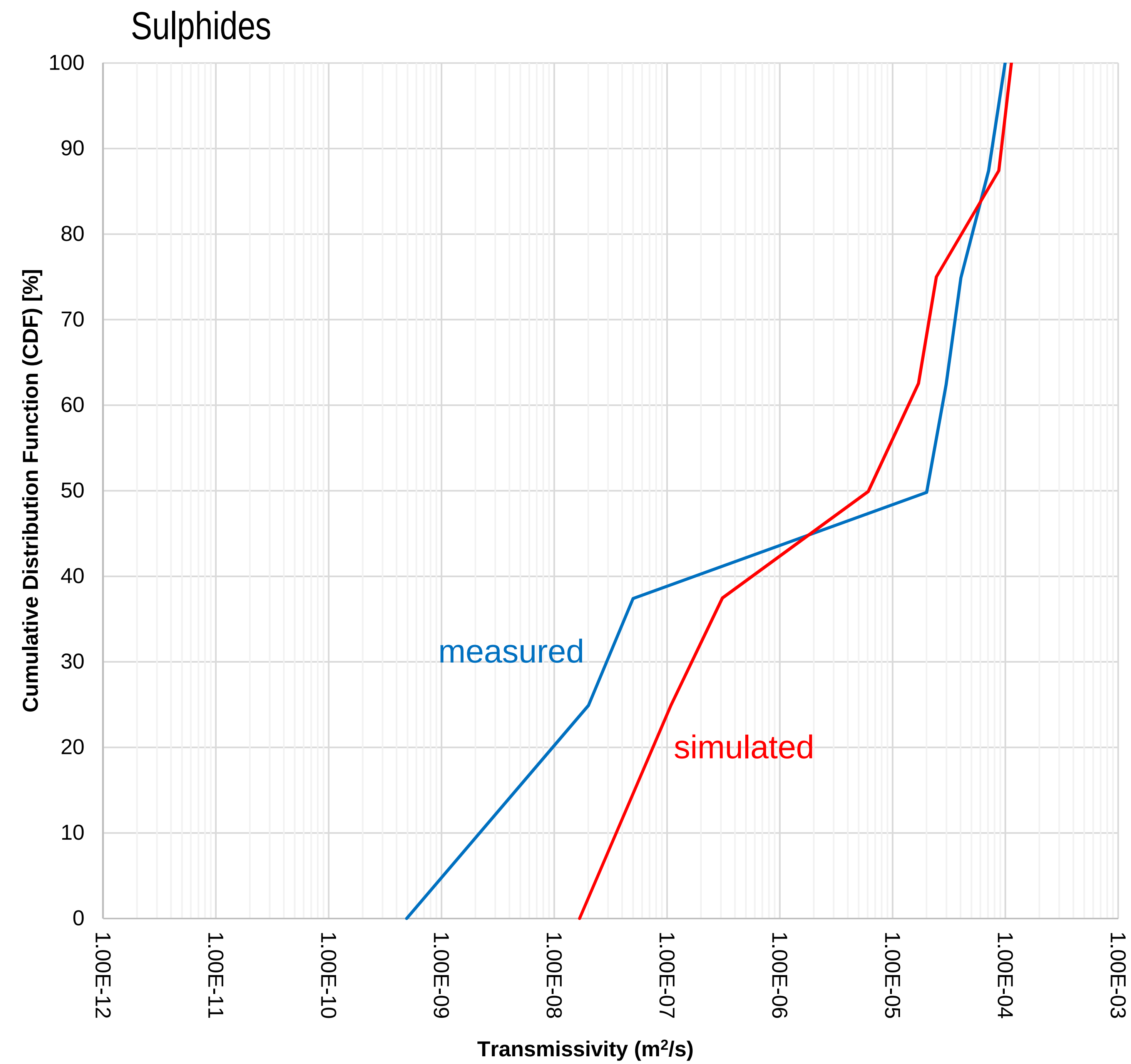
CLIENT		PROJECT		
Eagle Mine LLC		Phase 4 Crown Pillar Assessment		
CONSULTANT	YYYY-MM-DD: 2019-07-02	TITLE		
GOLDER	DESIGNED: NB	Comparison of Simulated and Measured Groundwater Inflows to Eagle Mine		
	PREPARED: NB			
	REVIEWED: JW	PROJECT No. 18109752-008	Rev. 1	Figure. 24
	APPROVED: JW			



CLIENT Eagle Mine LLC	PROJECT Phase 4 Crown Pillar Assessment
CONSULTANT: GOLDER YYYY-MM-DD 2019-07-02 DESIGNED SR PREPARED SR REVIEWED RPB APPROVED RPB	TITLE DFN Model Building Workflow PROJECT No. 18109752-008 Rev. 1 Figure. 25



Min Flow capacity (m²/s)	Mean T (m²/s)	Stdev (m²/s)	P10 (m-1)	Seed #
1e-11	5e-06	0.2	0.3	155072655



Min Flow capacity (m²/s)	Mean T (m²/s)	Stdev (m²/s)	P10 (m-1)	Seed #
1e-11	7e-06	0.003	0.3	1030220268

CLIENT
Eagle Mine LLC

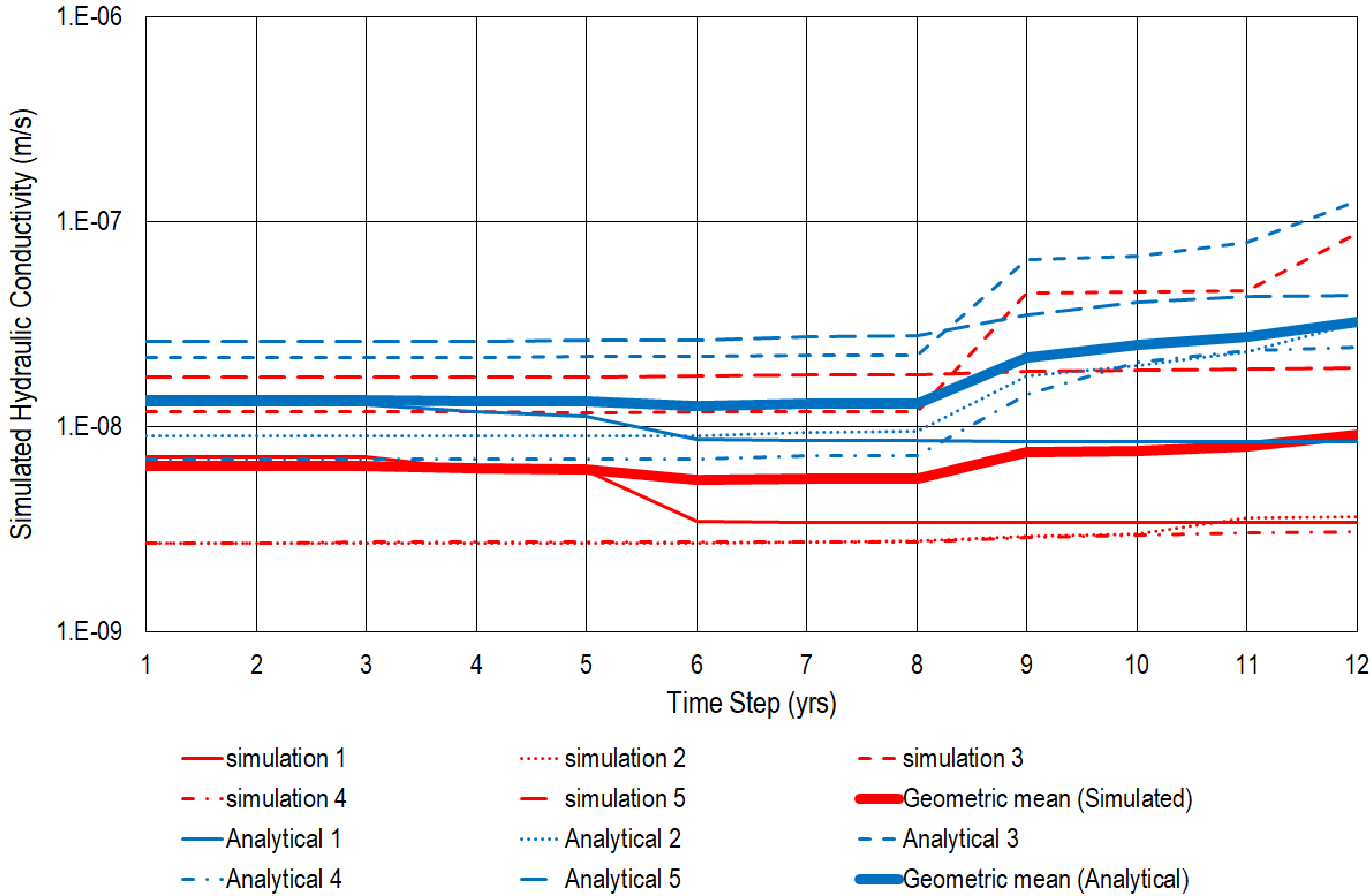
PROJECT
Phase 4 Crown Pillar Assessment

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	SR
PREPARED	SR
REVIEWED	RPB
APPROVED	RPB

TITLE
Oxflet Results by Lithology

PROJECT No.	Rev.	Figure.
18109752-008	1	26



CLIENT
Eagle Mine LLC

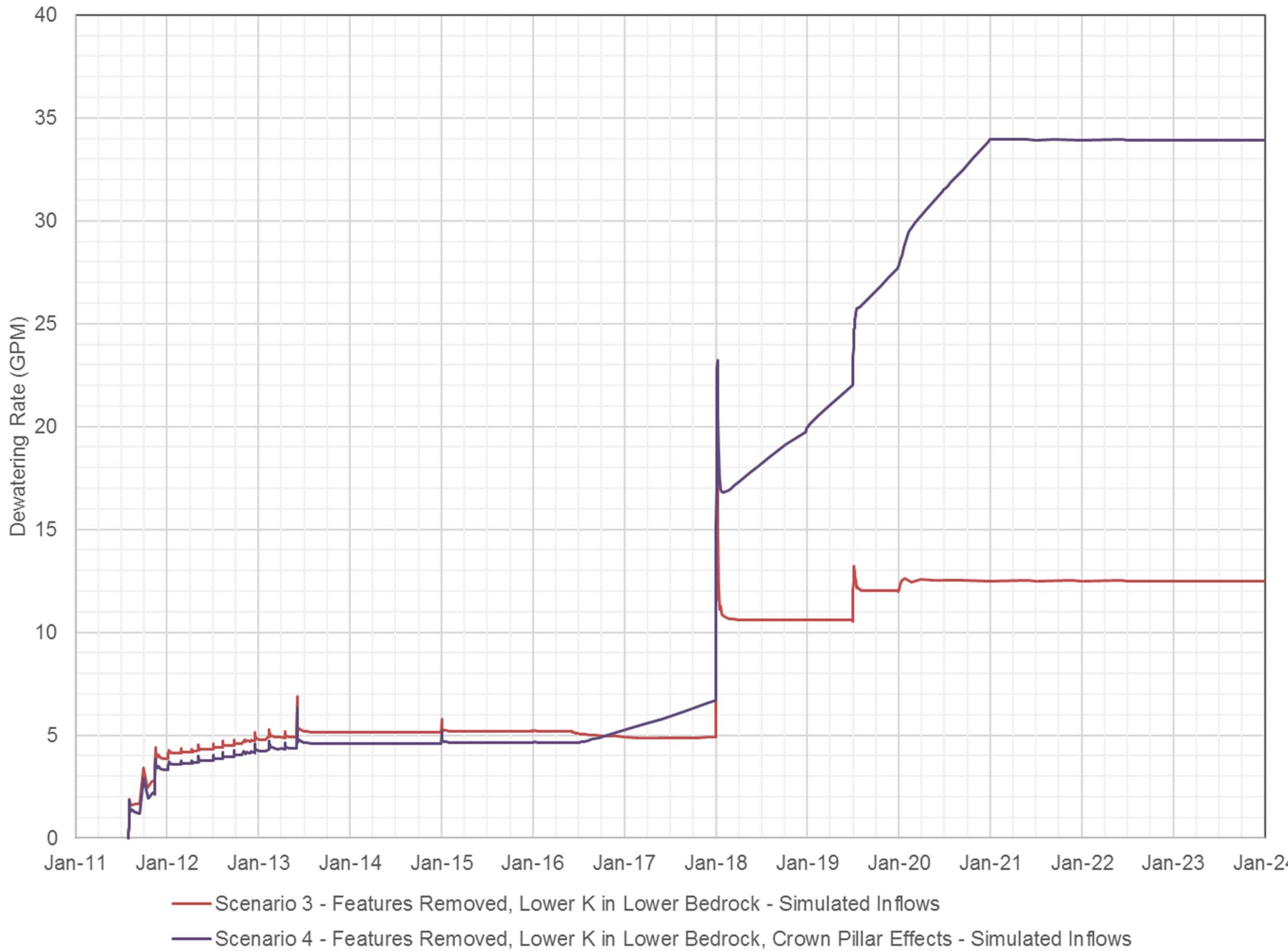
PROJECT
Phase 4 Crown Pillar Assessment

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	SR
PREPARED	SR
REVIEWED	RPB
APPROVED	RPB

TITLE
Calculated average hydraulic conductivity in vertical direction, simulated and analytical results

PROJECT No.	Rev.	Figure.
18109752-008	1	27



Note:
The simulated groundwater inflows for each scenario include the ramps and stopes of the Eagle Mine development, excluding the lower ramp and connector ramp to Eagle East, as well as the Eagle East development.

CLIENT
Eagle Mine LLC

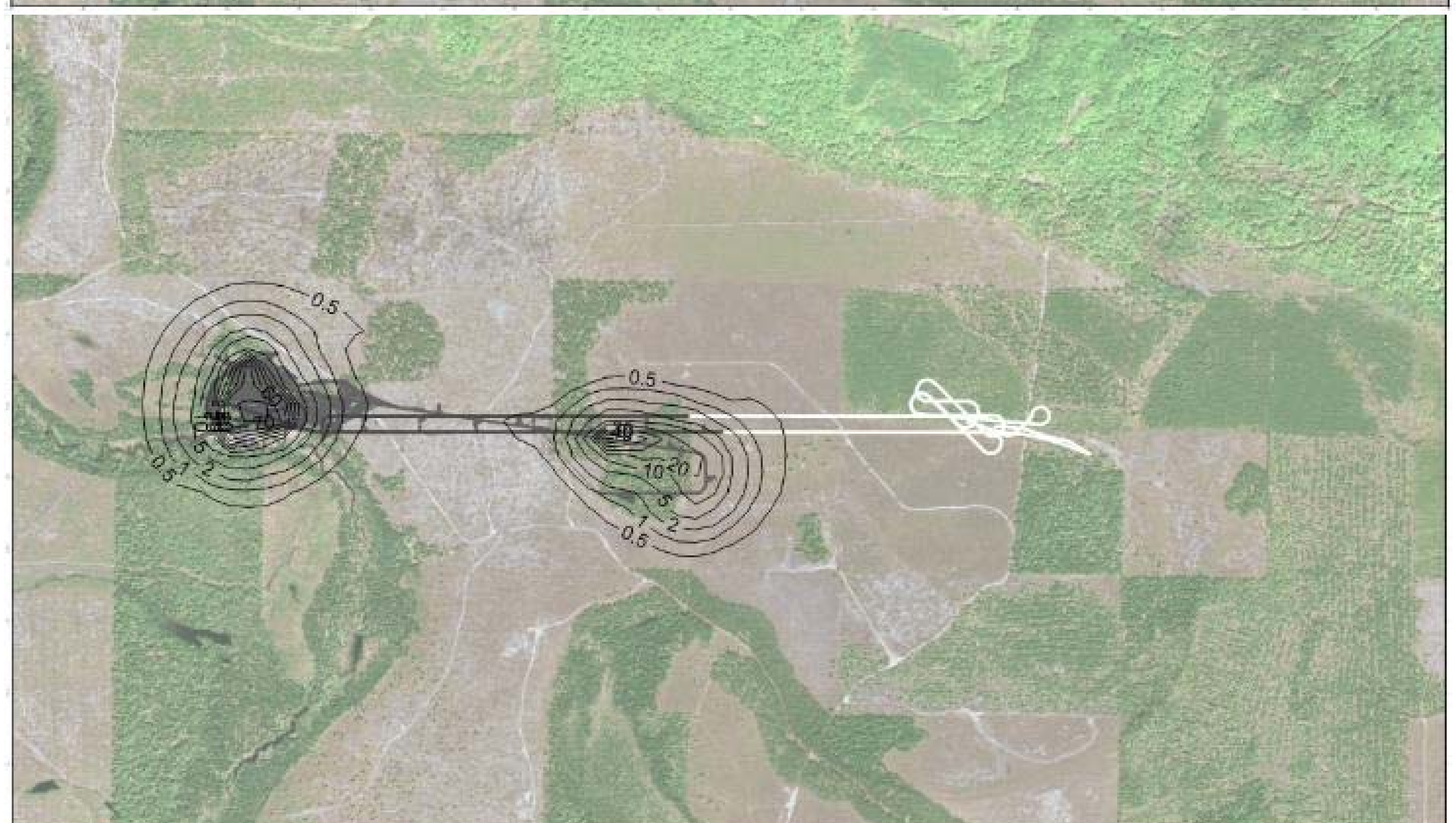
PROJECT
Phase 4 Crown Pillar Assessment

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	NB
PREPARED	NB
REVIEWED	JW
APPROVED	JW

TITLE
Simulated Groundwater Inflows To Eagle Mine
(Excluding Connector Ramp And Eagle East)

PROJECT No.	Rev.	Figure.
18109752-008	1	28

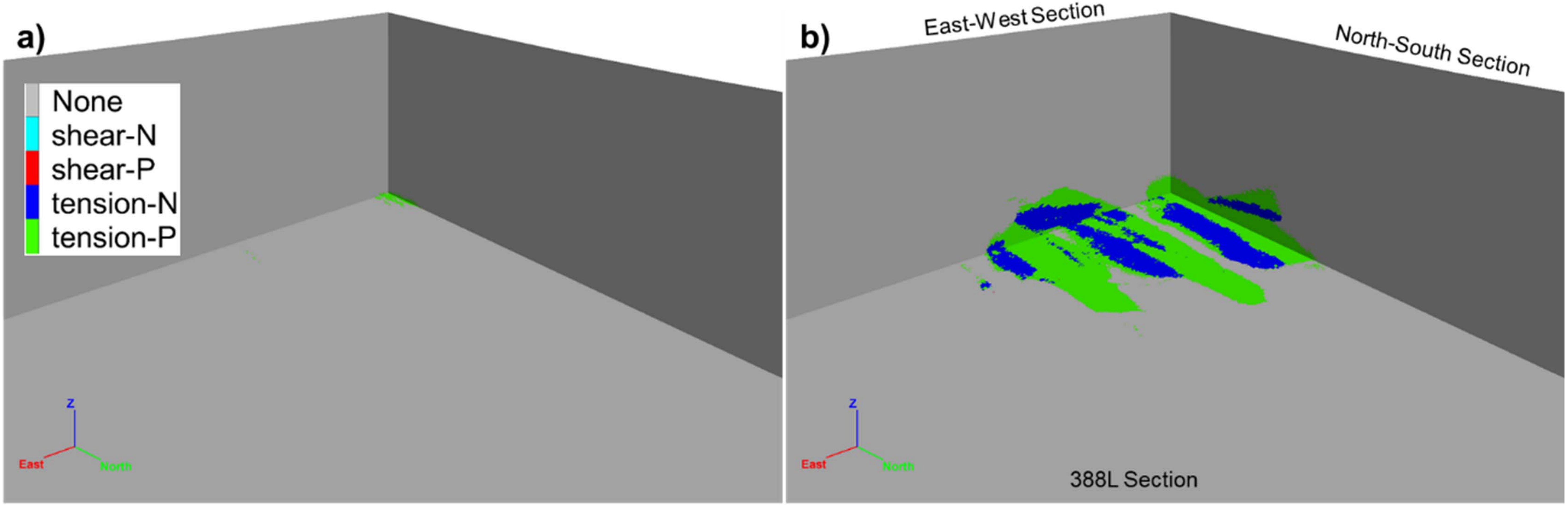


Note:
Drawdown contours (black lines) expressed in units of metres. Images represent drawdown at the top of the lower bedrock unit (elevation 355 mASL).

CLIENT			PROJECT		
Eagle Mine LLC			Phase 4 Crown Pillar Assessment		
CONSULTANT	YYYY-MM-DD	2019-07-02	TITLE		
GOLDER	DESIGNED	NB	Simulated Groundwater Depressurization in Deep Bedrock at End of Mining		
	PREPARED	NB			
	REVIEWED	JW	PROJECT No.	Rev.	Figure.
	APPROVED	JW	18109752-008	1	29

Brittle Strength Scenario

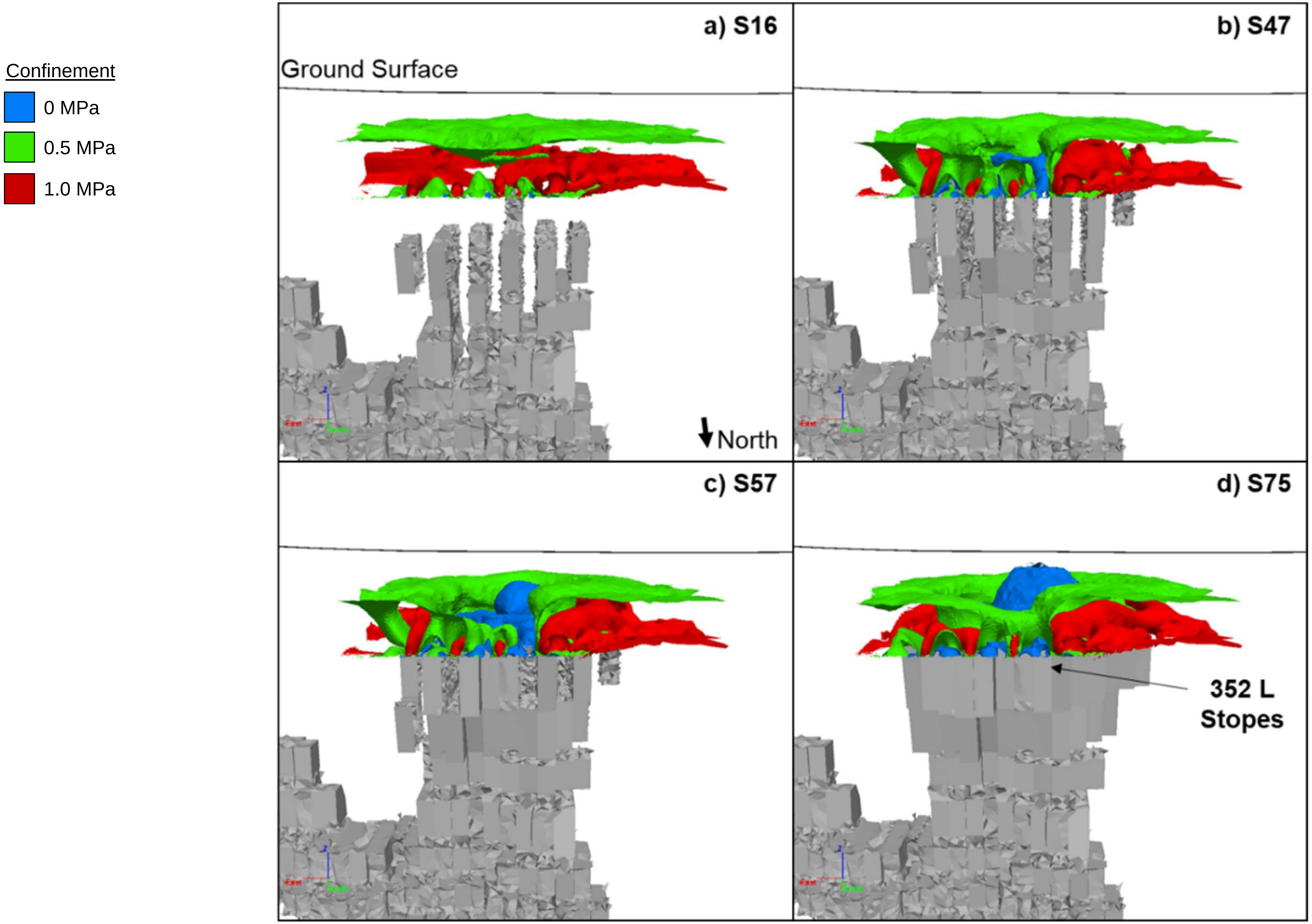
HB-GSI Behavior Scenario



CLIENT			PROJECT	
Eagle Mine LLC			Phase 4 Crown Pillar Assessment	
CONSULTANT	YYYY-MM-DD	2019-07-02	TITLE	
GOLDER	DESIGNED	BM	Depth of Yield in the Crown Pillar	
	PREPARED	BM		
	REVIEWED	RPB	PROJECT No. 18109752-008	Rev. 1 / Figure. 30
	APPROVED	RPB		

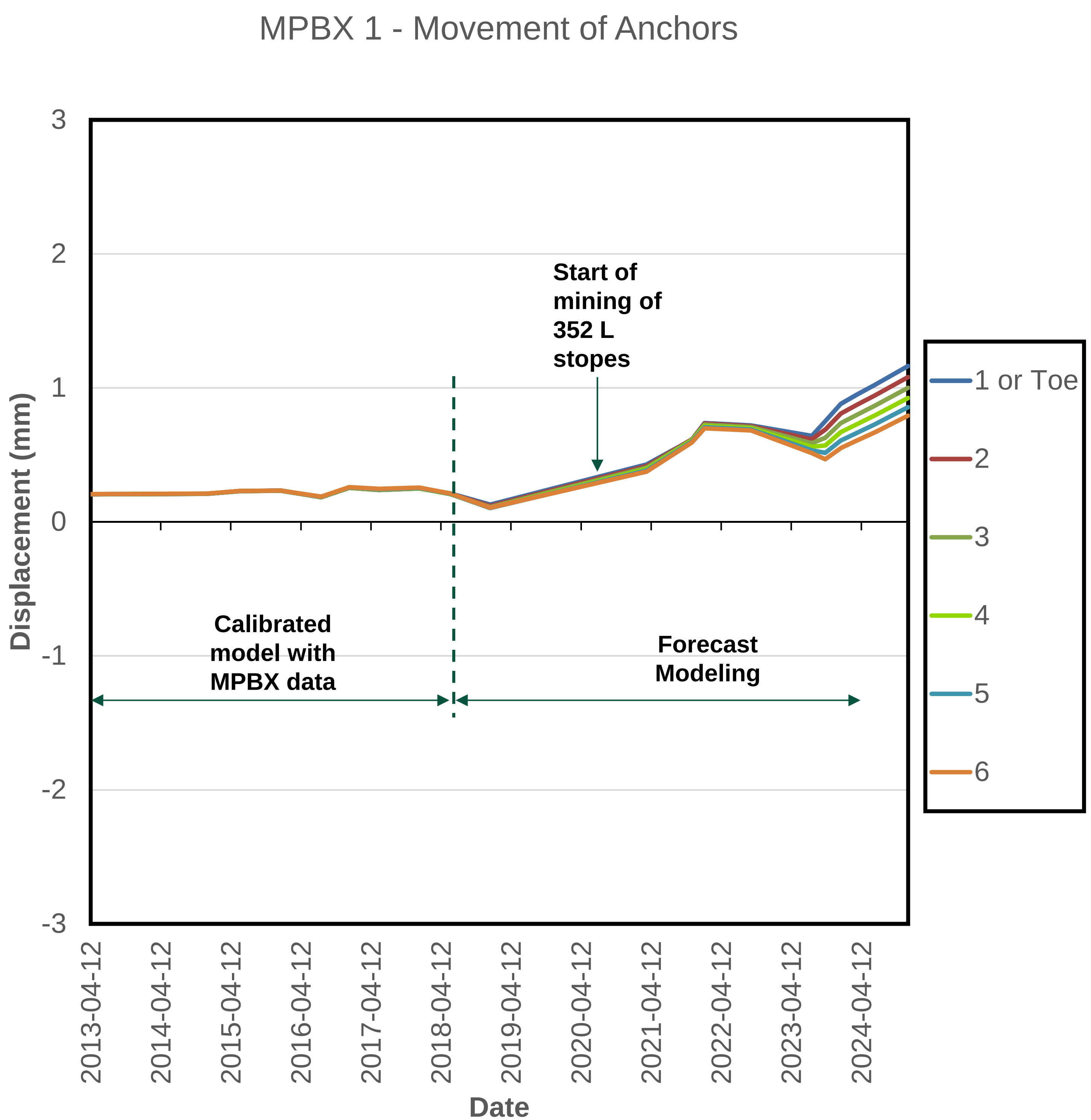
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

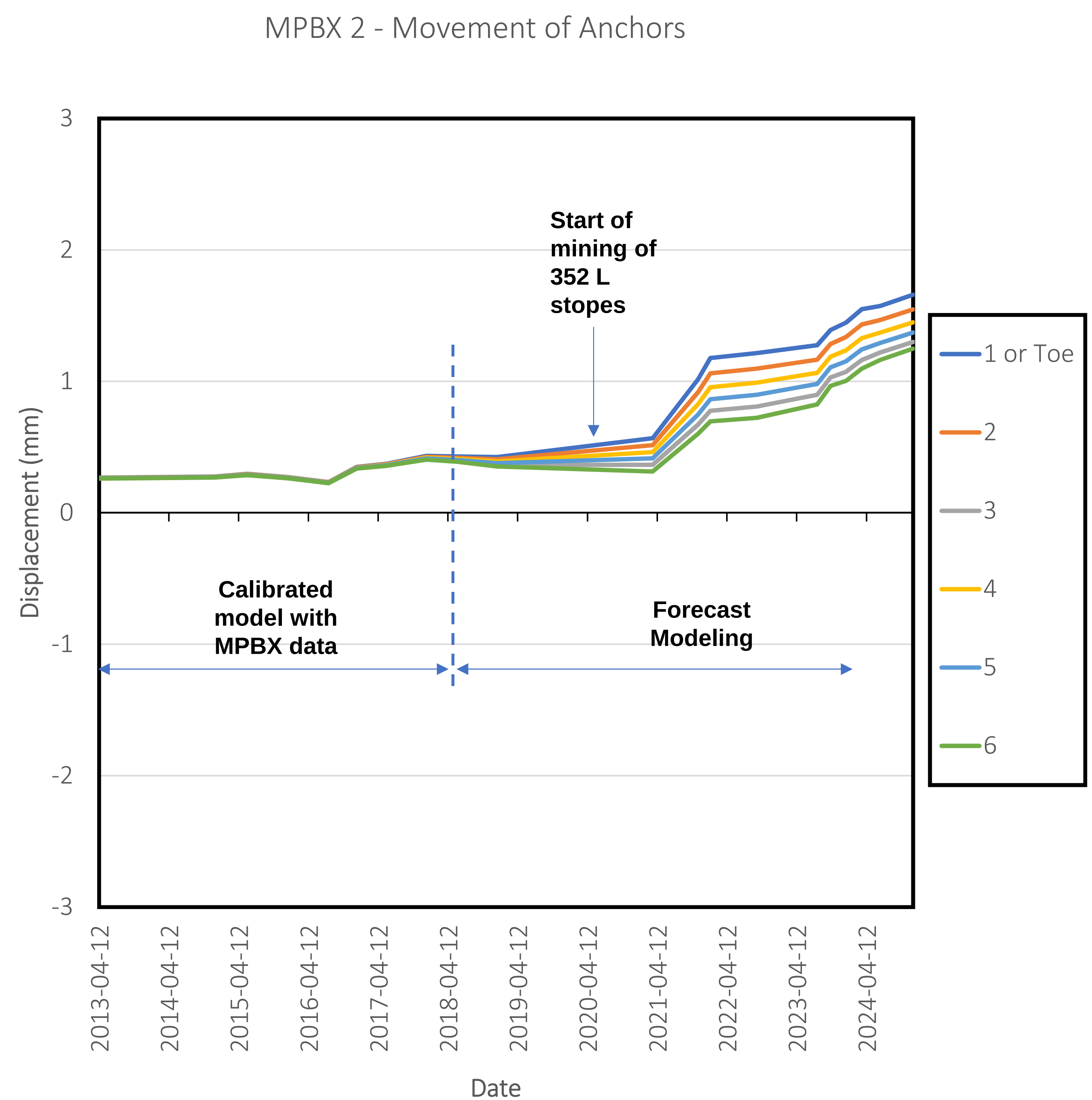
25 mm



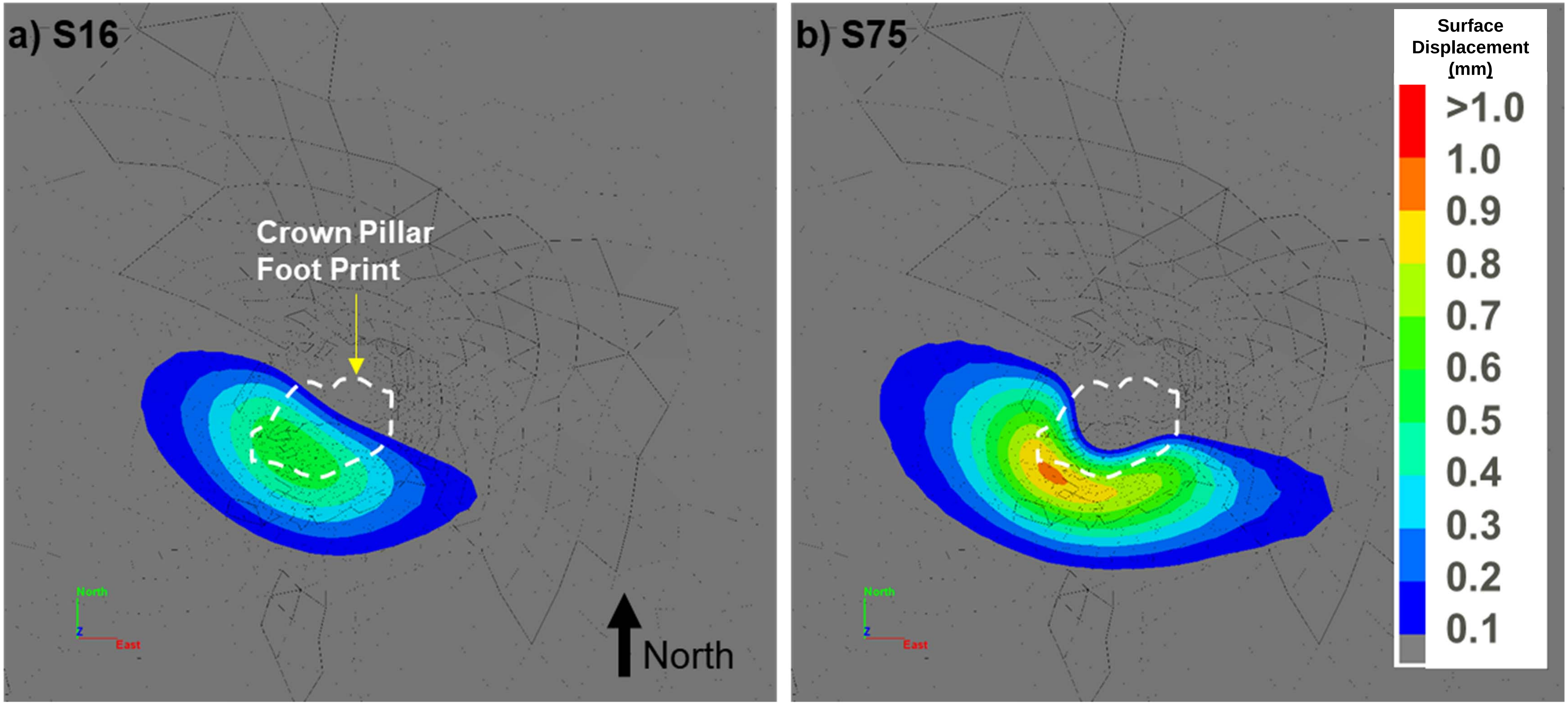
CLIENT	PROJECT
Eagle Mine LLC	Phase 4 Crown Pillar Assessment

CONSULTANT			TITLE
GOLDER	YYYY-MM-DD	2019-07-02	Evolution of Confinement Iso-Surfaces (Looking South)
	DESIGNED	BM	
	PREPARED	BM	PROJECT No. 18109752-008 · Rev. 1 · Figure. 31
	REVIEWED	RPB	
	APPROVED	RPB	





CLIENT	Eagle Mine LLC	PROJECT	Phase 4 Crown Pillar Assessment
CONSULTANT	GOLDER	TITLE	Modeled Displacement of the Crown Pillar at the Location of Two MPBXs Installed in the Crown Pillar
YYYY-MM-DD	2019-07-02	PROJECT No.	18109752-008
DESIGNED	BM	Rev.	1
PREPARED	BM	Figure.	32
REVIEWED	RPB		
APPROVED	RPB		



CLIENT
Eagle Mine LLC

PROJECT
Phase 4 Crown Pillar Assessment

CONSULTANT
GOLDER

YYYY-MM-DD	2019-07-02
DESIGNED	BM
PREPARED	BM
REVIEWED	RPB
APPROVED	RPB

TITLE
Surface Displacement at Two Modeled Mining Sequence Stages

PROJECT No.	Rev.	Figure.
18109752-008	1	33

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