A Real Challenge in Mine Water Management in High Precipitation Area, Grasberg Mine

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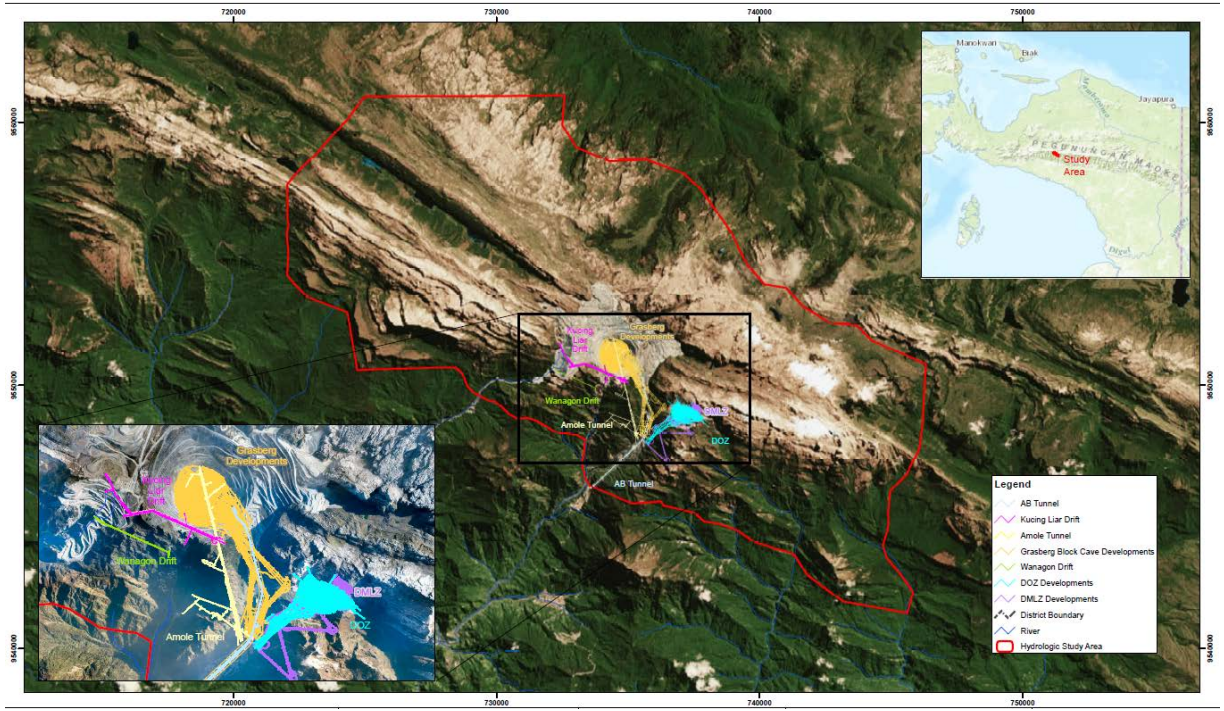
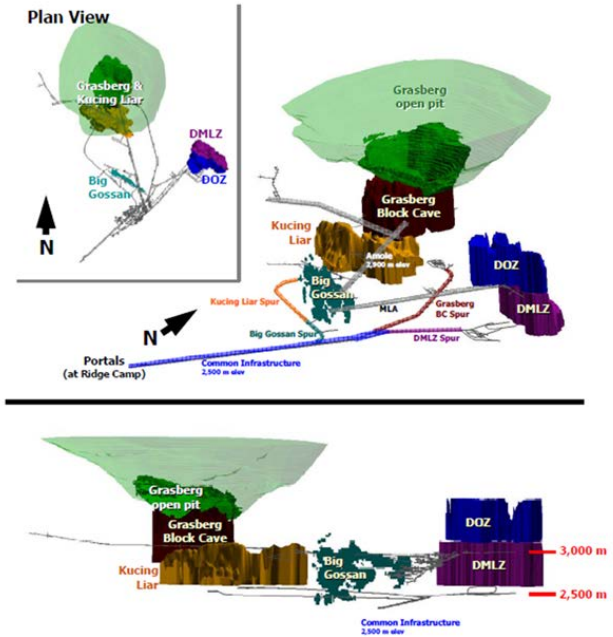
Hydrogeological Study Area





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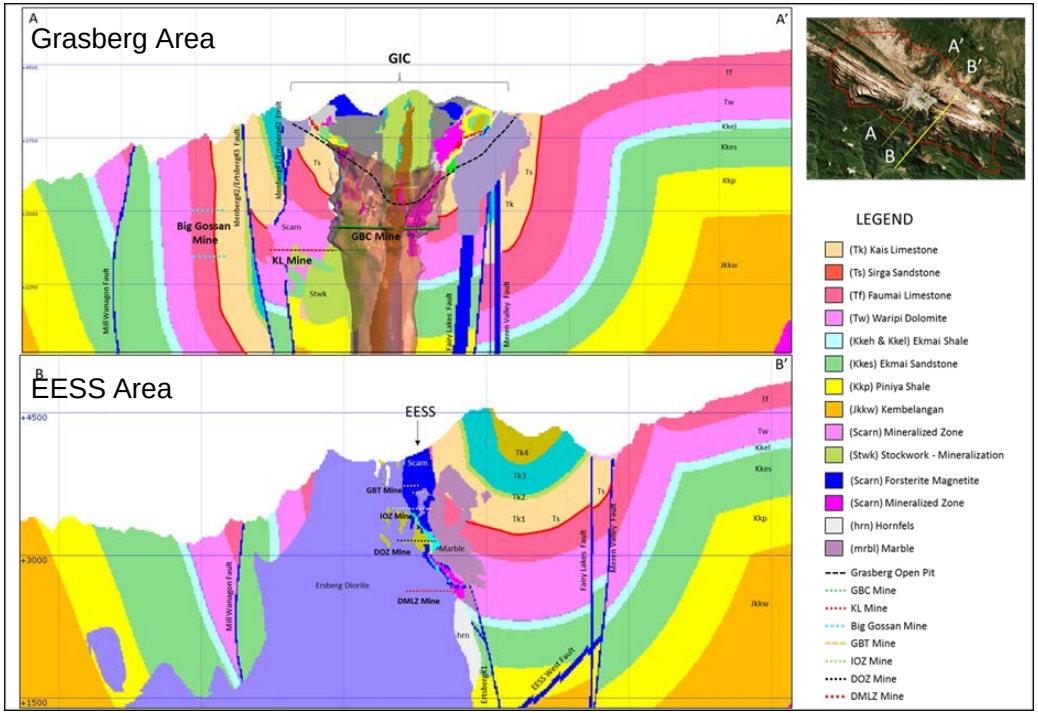
Purpose of Study

- Identify the sources and geologic controls of groundwater flowing through the mining area;
- Develop conceptual hydrogeologic models of the three block cave mines within the framework of the regional hydrogeology;
- Develop the numerical groundwater flow model and calibrate it to observed groundwater intersections/mine water flows and changes in water levels observed during more than 30 year period; and
- Predict groundwater inflows to the GBC, DMLZ, and KL Block Caves and ancillary drifts and water level changes due to mining.

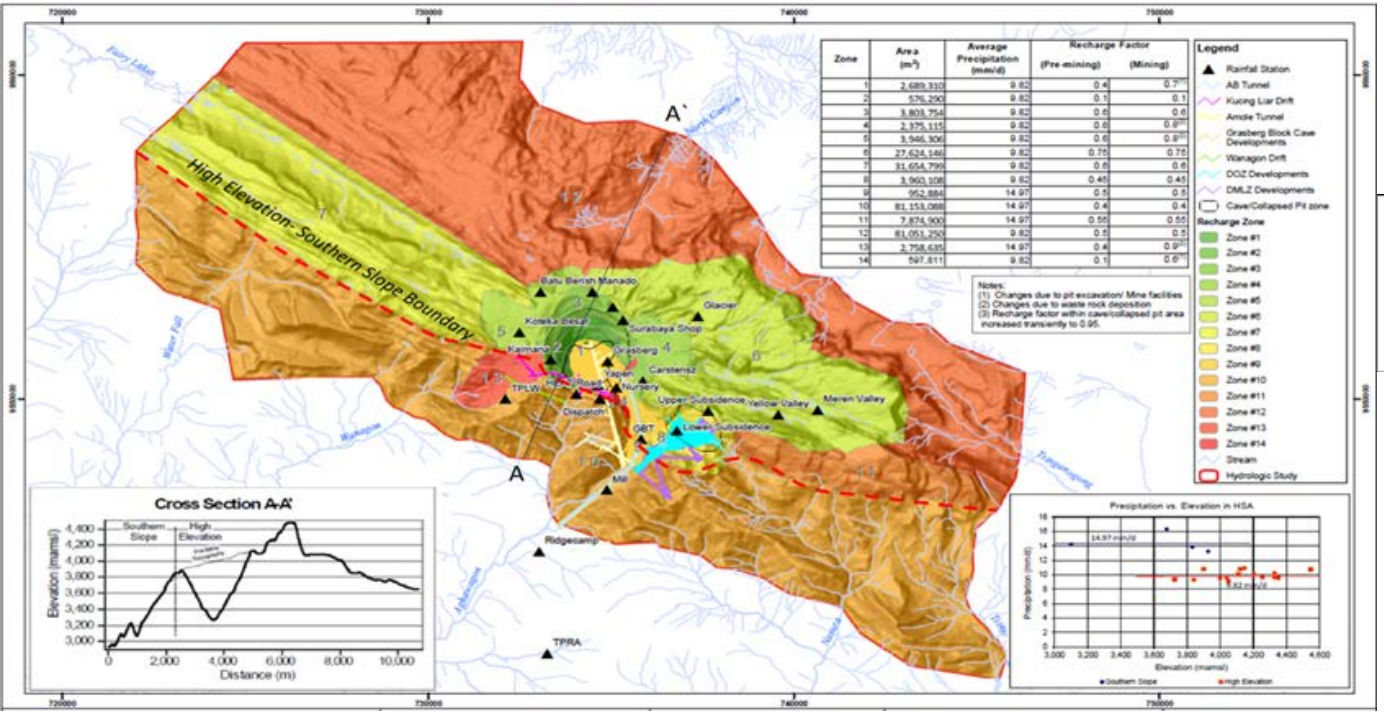
Hydrogeological Challenges

- Complex geology;
- Karstic features and sinkholes holes in mine vicinity;
- Permeable regional faults and hydrogeologic contacts controlling groundwater flow;
- High but variable in time precipitation (effecting by El Nino);
- Large scale dewatering system based on passive inflow to underground drainholes;
- Deep open pit currently in transition into block cave operation (Grasberg area);
- Multiple and staged block cave operation (EESS area);
- Cave and fracture zone propagations in time changing initial hydrogeological conditions;
- Large set of hydrogeological data and difficulties to model groundwater system and predict mine inflows.

Geology of Grasberg and EESS Mines Shown in Cross-Sections

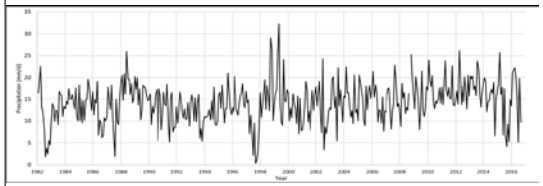


Recharge From Precipitation Key Hydrogeologic Input



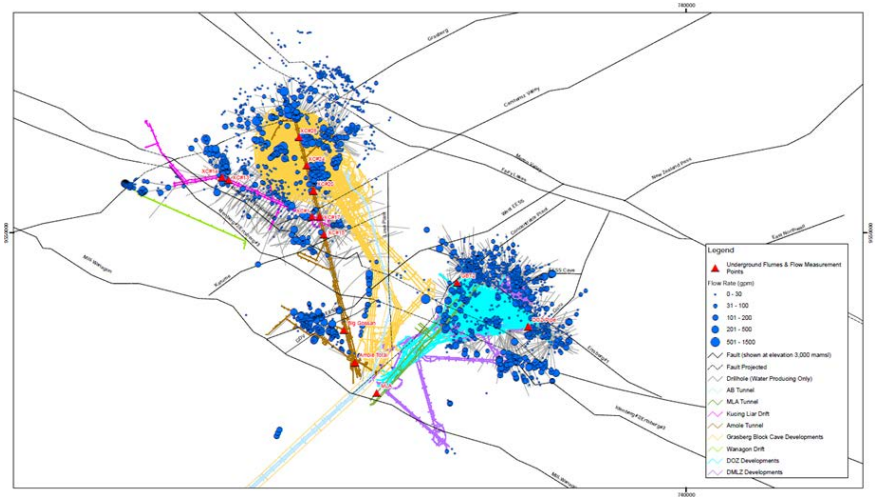
Zone	Area (m^2)	Average Precipitation (mm/d)	Recharge Factor (Pre-mining)	Recharge Factor (Mining)
1	2,689,310	9.82	0.4	0.7
2	576,290	9.82	0.1	0.1
3	3,803,754	9.82	0.6	0.6
4	2,375,115	9.82	0.6	0.8
5	3,946,906	9.82	0.6	0.8
6	27,624,146	9.82	0.75	0.75
7	31,654,799	9.82	0.6	0.6
8	3,960,108	9.82	0.45	0.45
9	952,884	14.97	0.5	0.5
10	81,153,088	14.97	0.4	0.4
11	7,874,900	14.97	0.55	0.55
12	81,051,250	9.82	0.5	0.5
13	2,758,635	14.97	0.4	0.9
14	597,811	9.82	0.1	0.6

Notes:
(1) Changes due to pit excavation/ Mine facilities
(2) Changes due to waste rock deposition
(3) Recharge factor within cave/collapsed pit area increased transiently to 0.95.

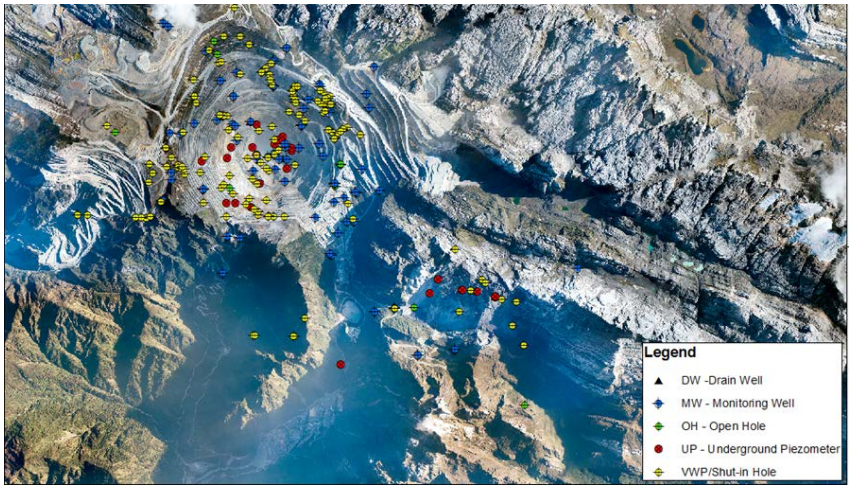


Flow and Water Level Measurements

Groundwater Intersections and Flow Stations

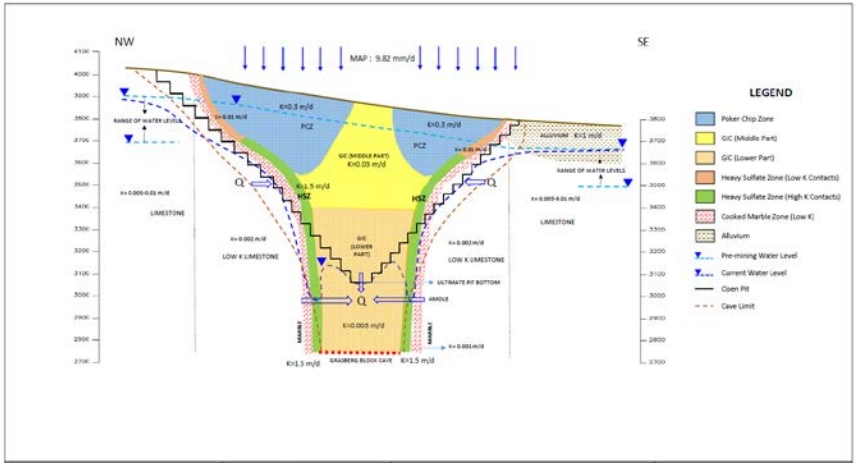


Monitoring Wells and Piezometers

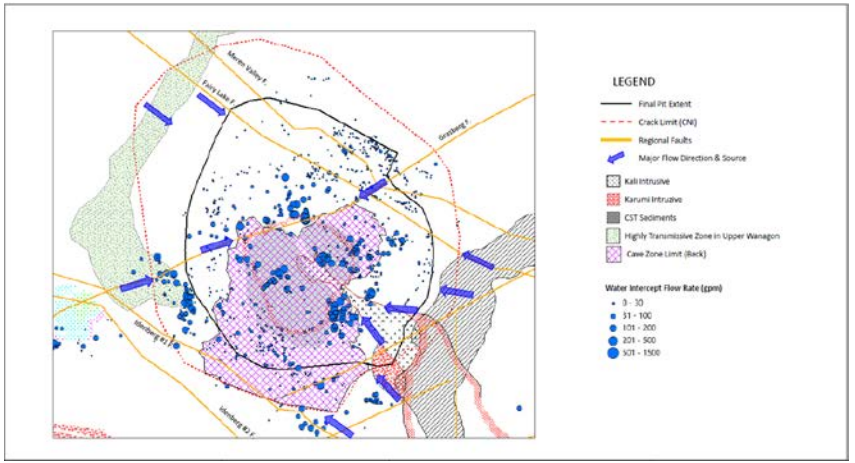


Grasberg Conceptual Hydrogeologic Model

Cross-Section

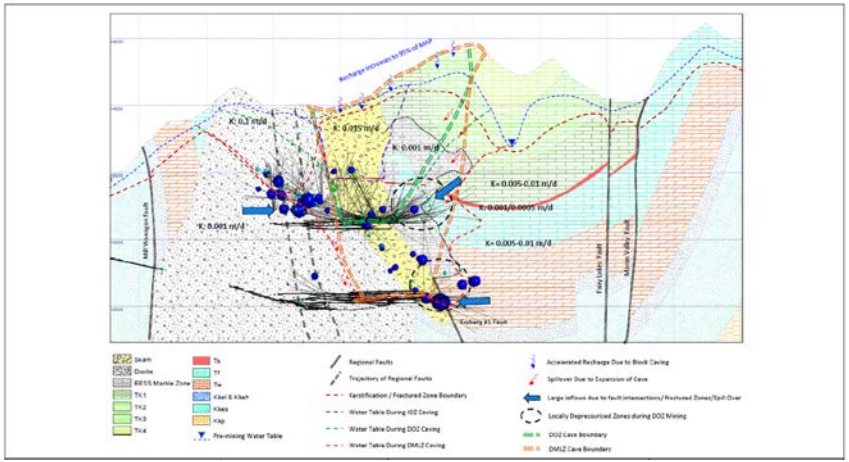


Plan View

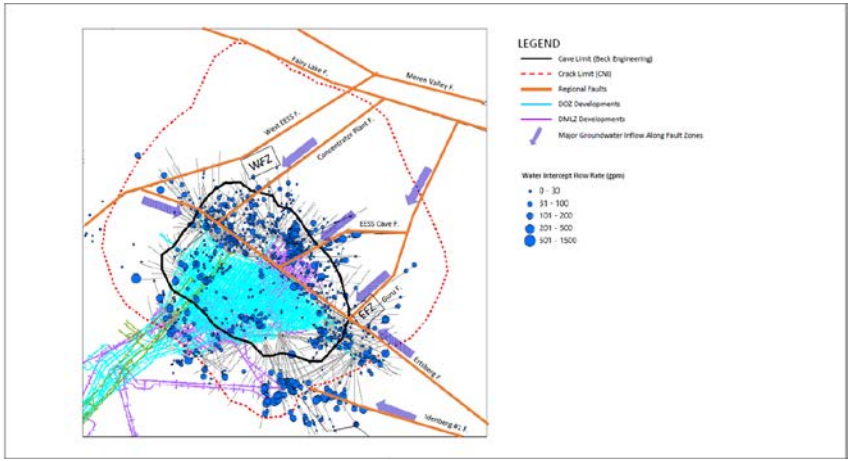


EESS Conceptual Hydrogeologic Model

Cross-Section



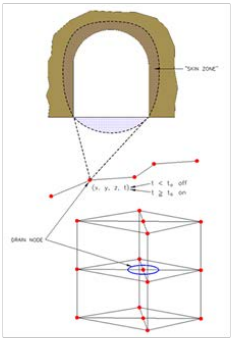
Plan View

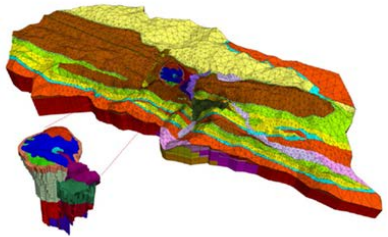


Benefits of Using *MINEDW* for Grasberg Groundwater Model

MINEDW simulates key hydrogeological features presented at Grasberg Mine:

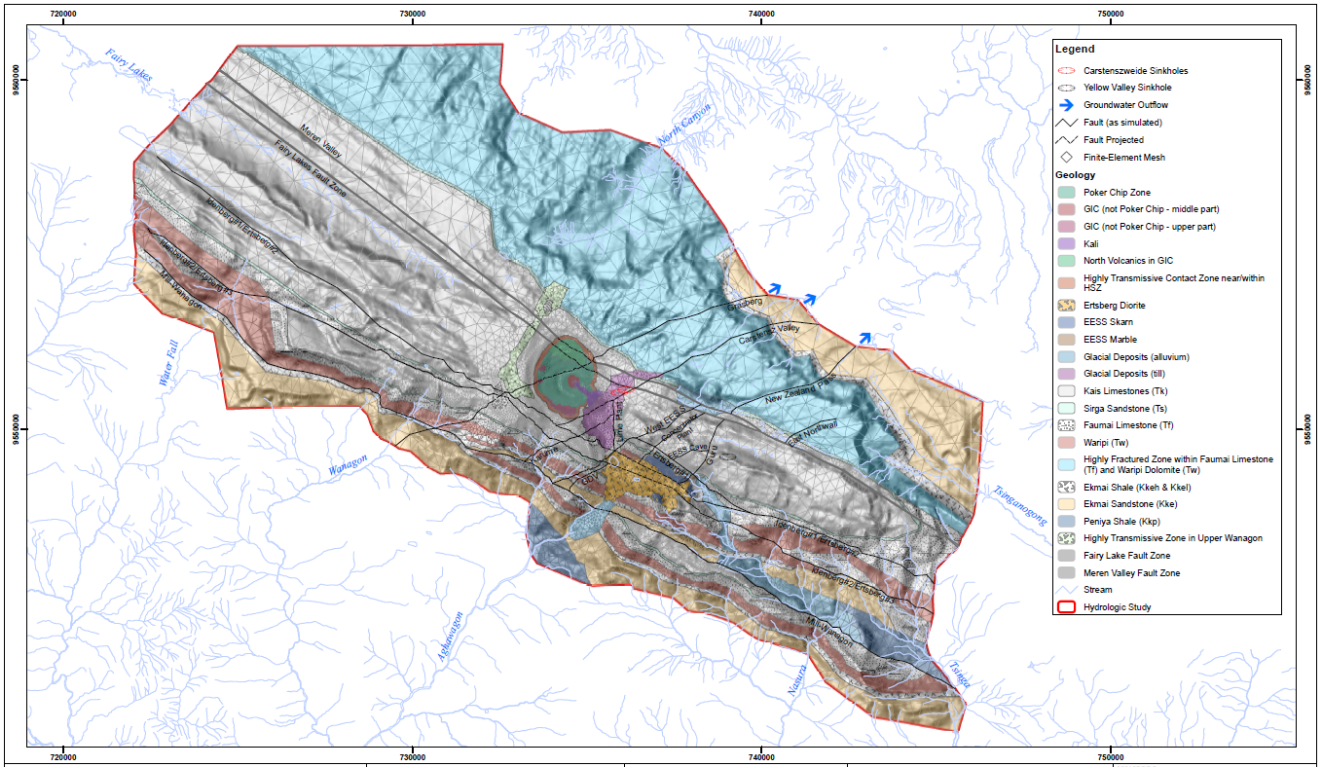
- Complex hydrogeological settings with high contrast in hydraulic parameters and highly variable recharge from precipitation;
- Transmissive faults by fault linked nodes without additional mesh discretization;
- Non-Darcian flow in the transmissive faults;
- Underground developments using drain nodes with head dependent leakance factor;
- Open pit excavation by using of collapsing mesh;
- Zone of relaxation around the pit (automatic setup); and
- Block cave propagation by changing hydraulic parameters in time (automatic setup).





Plan View of Finite-Different Mesh

- Simulated Geology in Uppermost Layer and Faults



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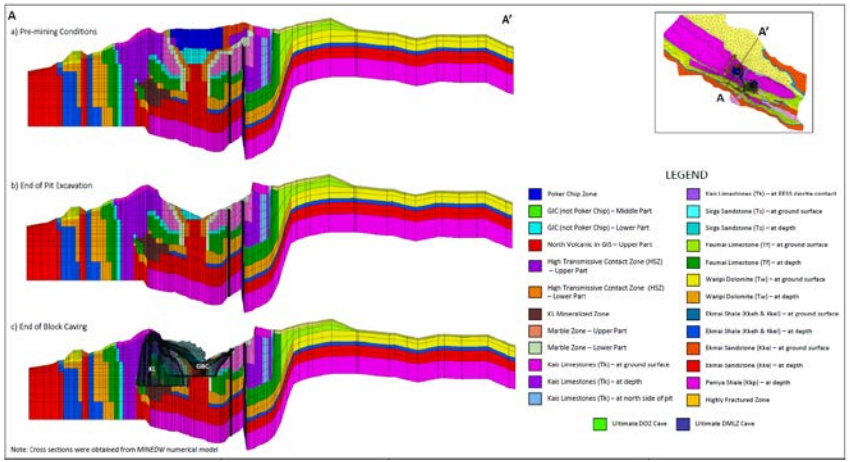
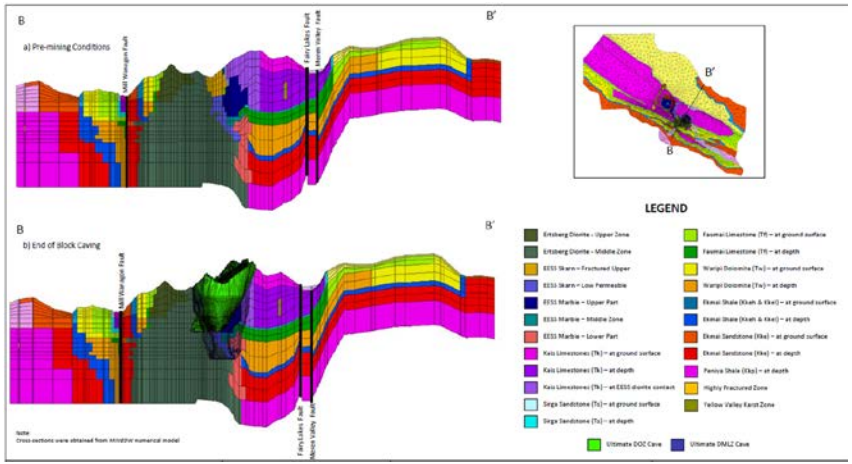
Modeled Cross Sections

Grasberg Area

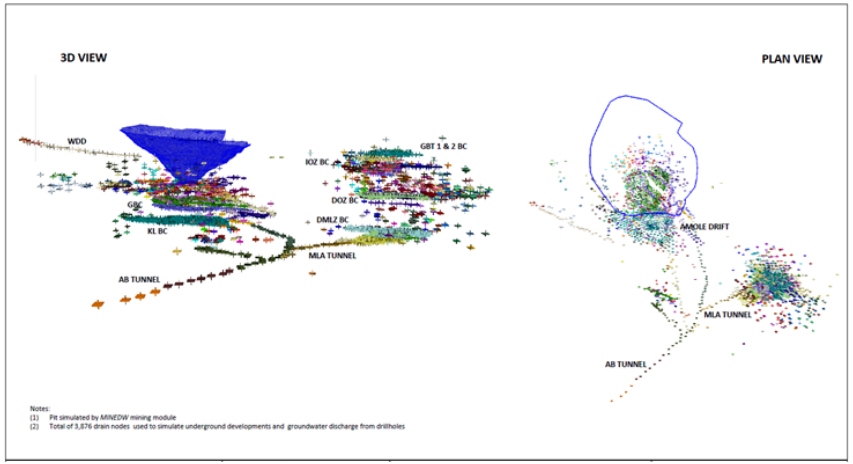


EESS Area

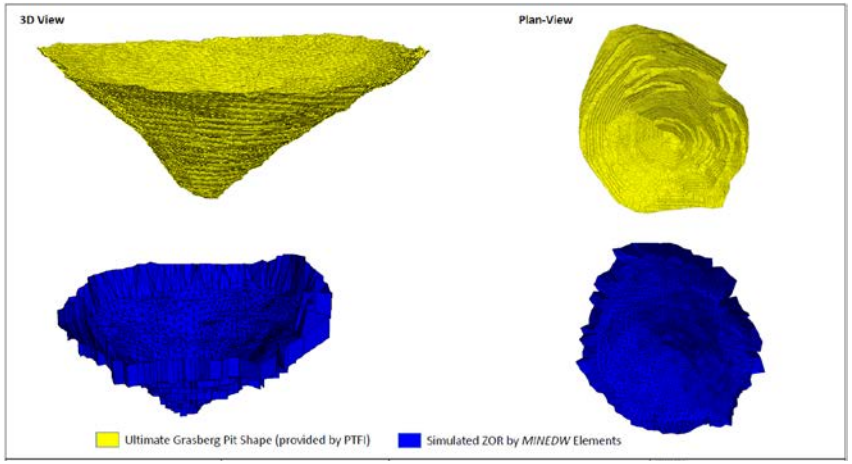


Simulation of Mining

Underground/Pit Developments and GW interceptions

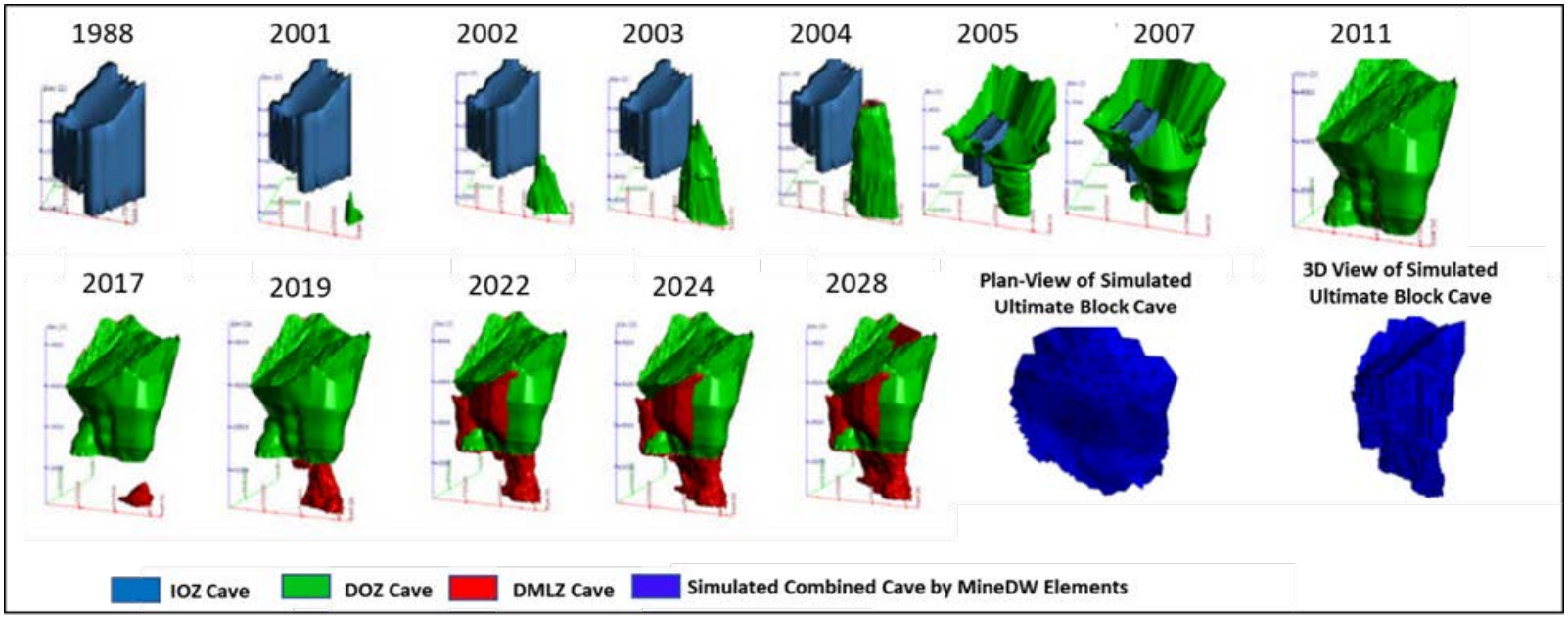


Zone of Relaxation around Pit



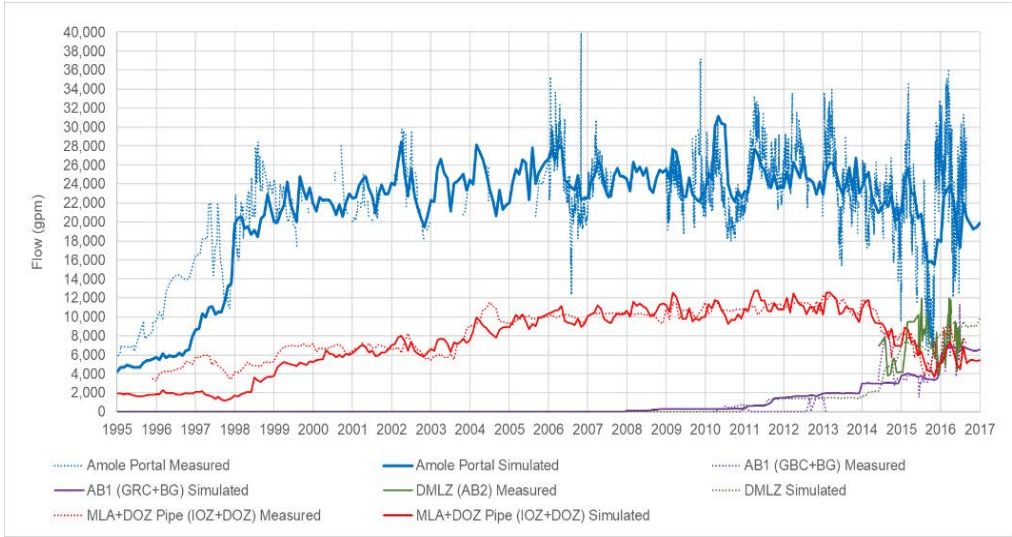
Simulation of Mining

EESS Cave Zones Propagation

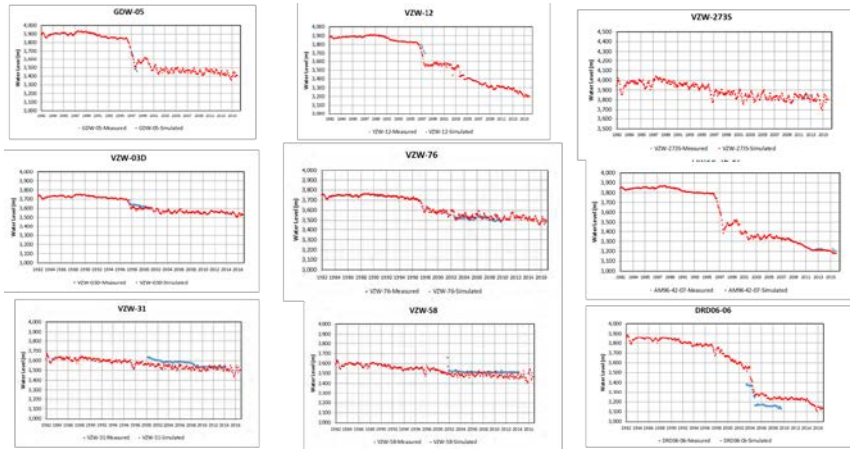


Model Calibration

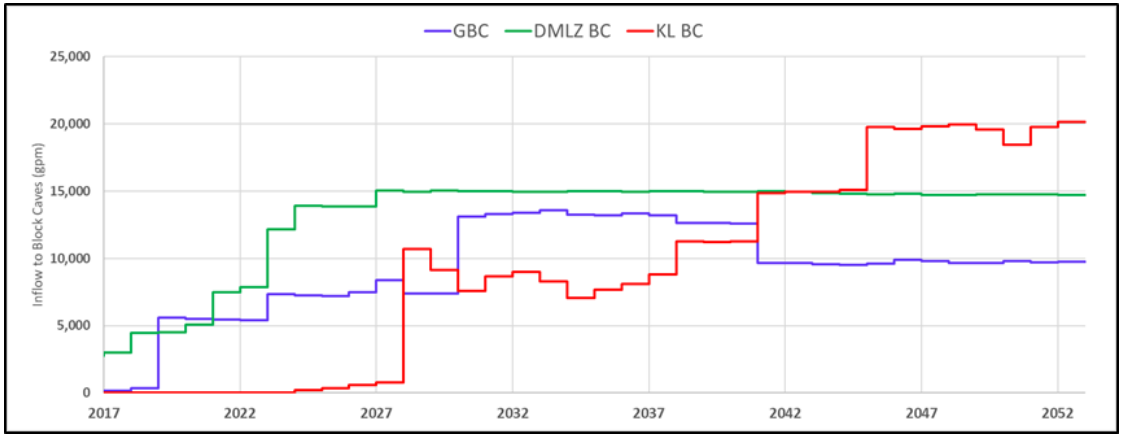
To Measured Flows

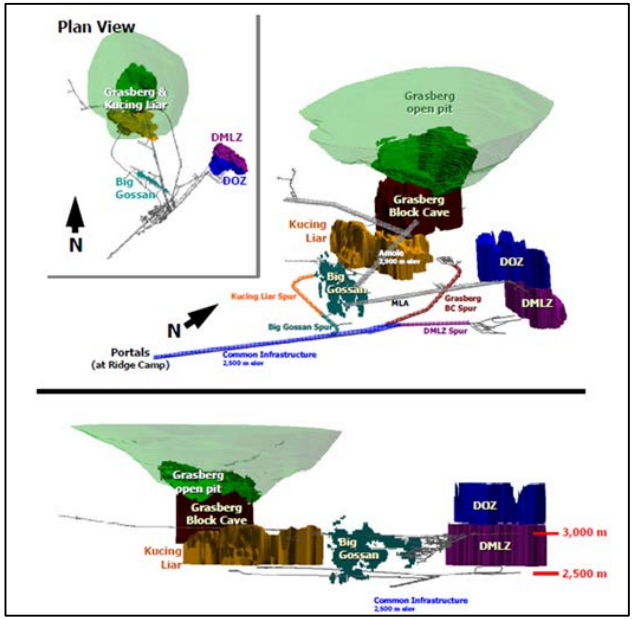


To Measured Water Levels



Predicted Inflows to Block Caves

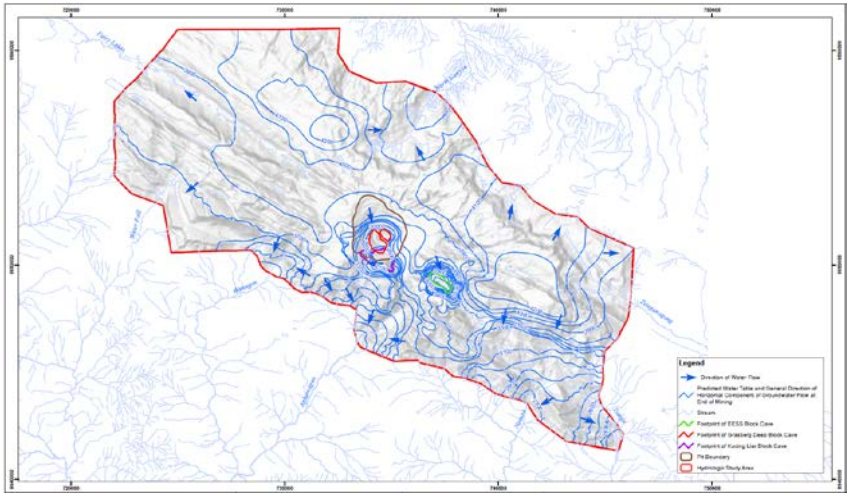




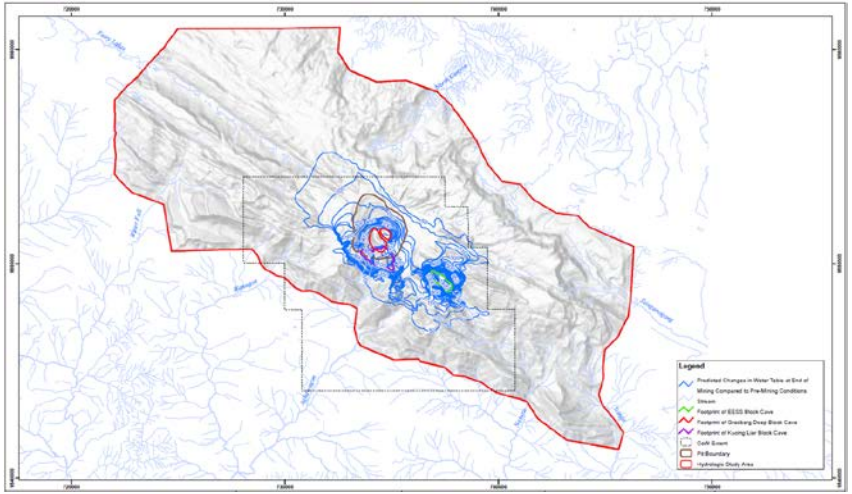
- Maximum predicted inflows under average rainfall conditions:
  - GBC – 12,800 gpm
  - DMLZ – 15,000 gpm
  - KL BC – 20,000 gpm

Predicted Water Table and Drawdown at End of Mining

Water Table

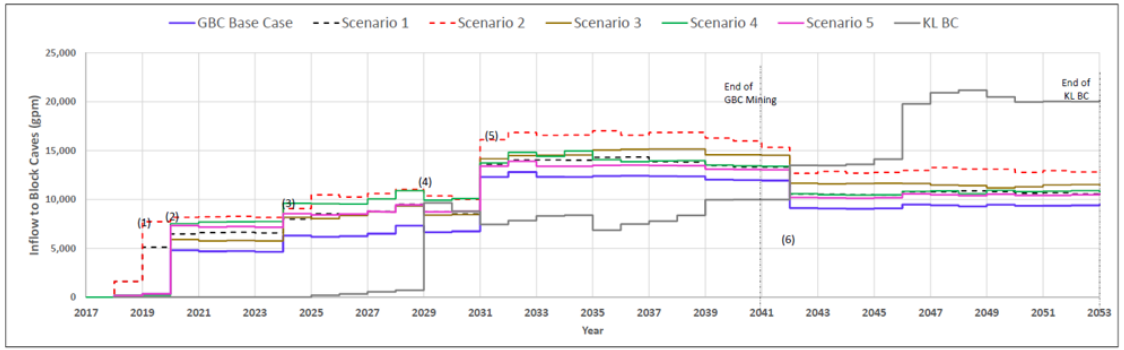


Drawdown

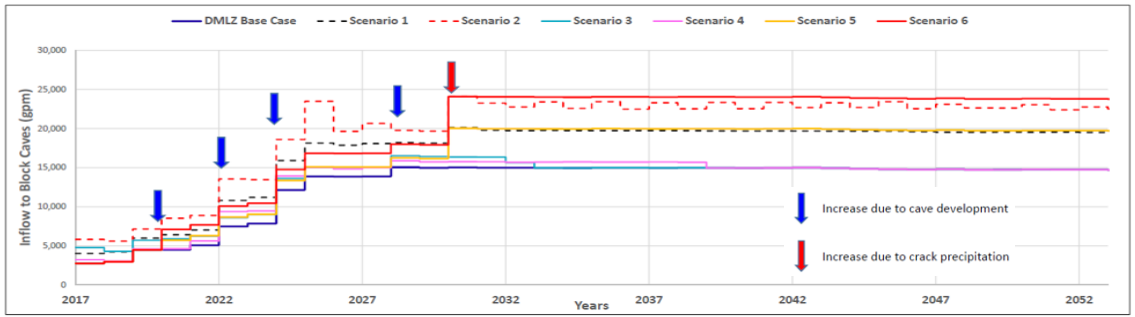


Results of Sensitivity Analysis – Predicted Cave Inflows

GBC



DMLZ BC



Variable Parameters:

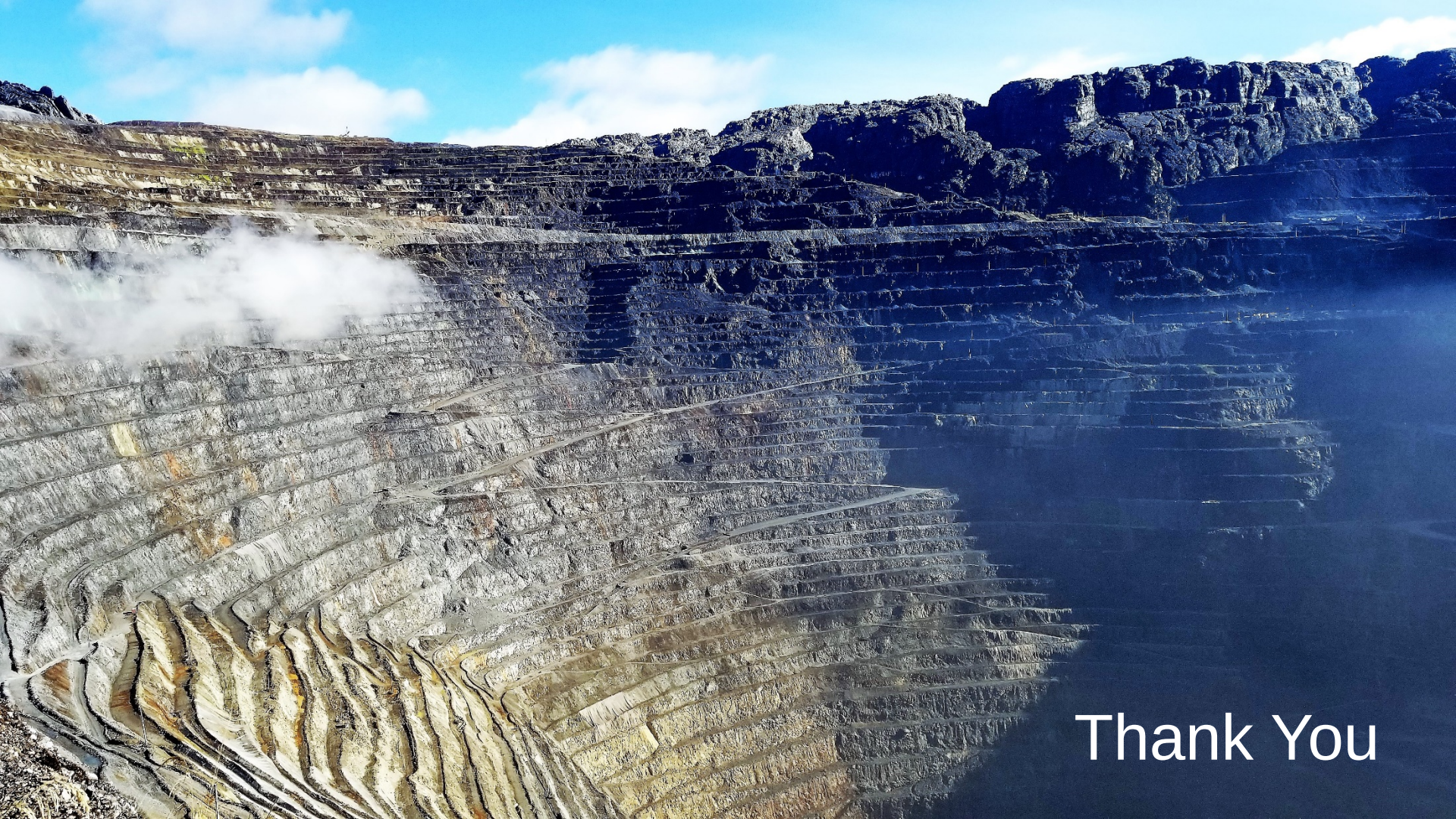
- **Shapes of cave and fractured zones**
- Recharge factors
- Transmissivity of faults; and
- Hydraulic conductivity of key HGU

Conclusions – Addressed Challenges

- Development of conceptual and numerical hydrogeological models including:
  - Complex lithology, presence of transmissive features with spatial contrasts in hydraulic conductivity distribution;
  - Extremes in recharge rates from precipitation and their drastically variability in time and space;
  - Presence of karstic zones (sinkholes) and highly permeable faults with non- linear flow;
- Simulation groundwater discharge to drainholes and underground developments by drain nodes with head dependent leakance factors and considering non-Darcian flow in permeable faults;
- Handling of large amounts of monitoring data (groundwater flows and water levels) with model calibration to more than 30 years transient mining conditions;

Conclusions – Addressed Challenges (Cont'd)

- Simulation of complex mining developments including required detailed handling of transient hydraulic parameters modification in time and space:
  - Grasberg Pit with dynamic changes in open pit elevation;
  - Propagation of ZoR around the pit;
  - GBC operation below ultimate Grasberg Pit; and
  - Five stages of cave and fractured zone propagations in the EESS.
- Use specialized finite-element groundwater modeling MINEDW code (which was modified by developer several times during process of the modeling by author requests) to minimize numerical problems in the process of the transient simulations.


Thank You