

This paper addresses the benefits of accurate water control using dedicated water monitoring focused on relevant measurement of heads of water and flow rates. The sections cover how water moves into a block cave, how to design a dewatering system and how to set targets and monitor success.

2 How water moves into a block cave

Water moves from high to low pressure, gravitating to the lowest point in a mine. Water also takes the easiest and shortest route, also known as the path of least resistance. The main sources of water flowing into a block cave are:

- Rainwater - direct or indirect such as stormwater runoff.
- Seepage from surface impoundments such as waste rock dumps or tailings storage facilities (TSF).
- Water in the zone of relaxation (ZOR) around and within an overlying open pit.
- Groundwater (including near surface, fractured and deep aquifers).
- Recycled water including leakage from underground sumps, settlers, and dams.

The various sources of water arrive in the underground sumps at different times. Figure 1 is a diagram of the concentric cylinders of water sources (provenance).

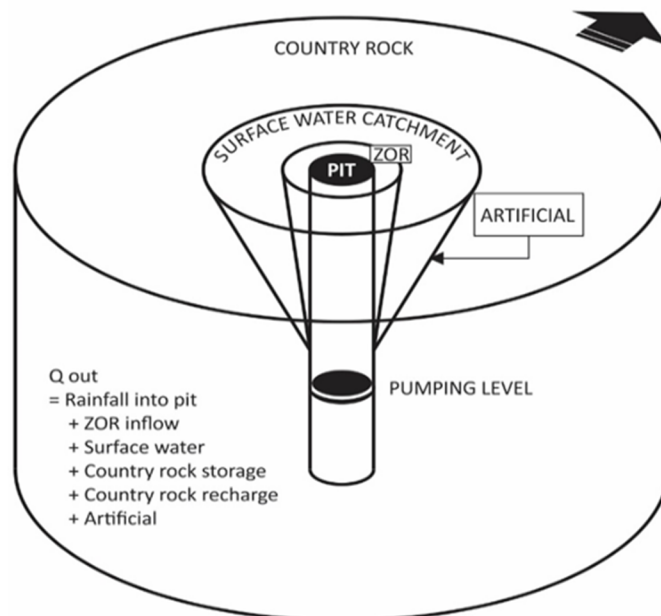


Figure 1 Diagram of sources (provenance) of water reaching a caving (pumping level) in an underground mine below an open pit (Morton 2008)

As the inflows arrive at different times the pumping rates from the mine sumps increase depending on travel time. The example in Figure 1 is for an underground mine with an overlying open pit. The pit acts as a funnel collecting and directing water into the cave below. If there is no pit then the rainfall makes it way to the underground mine via access routes, declines, shafts, geological structures and old exploration coreholes. Figure 2 is a graph of pumping rates from underground caused by the impact of two rainfall events.

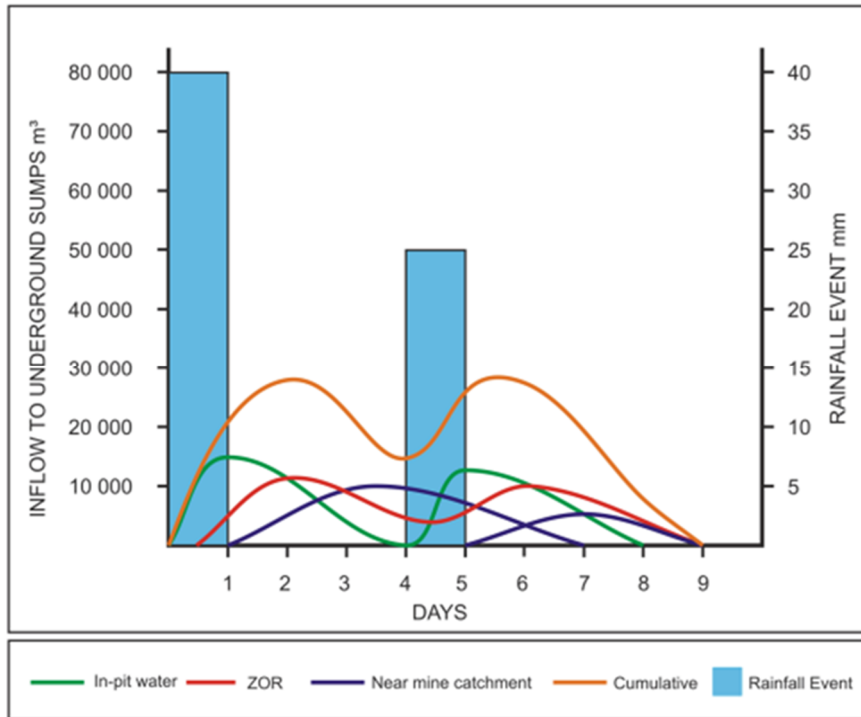


Figure 2 Pulsed arrival of water from each source into the mine, assuming two rainfall events (Morton 2008)

The movement of water through materials is governed by D’Arcy’s law where simply:

$$Q = KiA \tag{1}$$

where:

- Q = inflow (m³/day).
- K = hydraulic conductivity (m/day) also known as permeability for water at 25°C.
- I = groundwater gradient (m head /m length) also can be written as Δh.
- A = cross-sectional area (m²).

Q is the usual unknown as the mine wants to know how much water will enter the workings and needs to be pumped out. K is usually known as an order of magnitude for different rock types (Freeze & Cherry 1979).

The equation is very relevant for underground water control (and simple enough to be understood by all the parties involved in the execution of a mine dewatering design). It shows that hydraulic conductivity (K), groundwater gradient (i) and A are all of equal importance for calculating inflow (Q). Often Q is measured, and K is known but Δh is not measured. This means there is an incomplete understanding of the direction and sources of inflows. Once water levels and pressure gradients are plotted the flow lines to the extraction level can be drawn. Figure 3 shows theoretical flowlines and equipotentials (lines of equal pressure) for an underground excavation or cave.

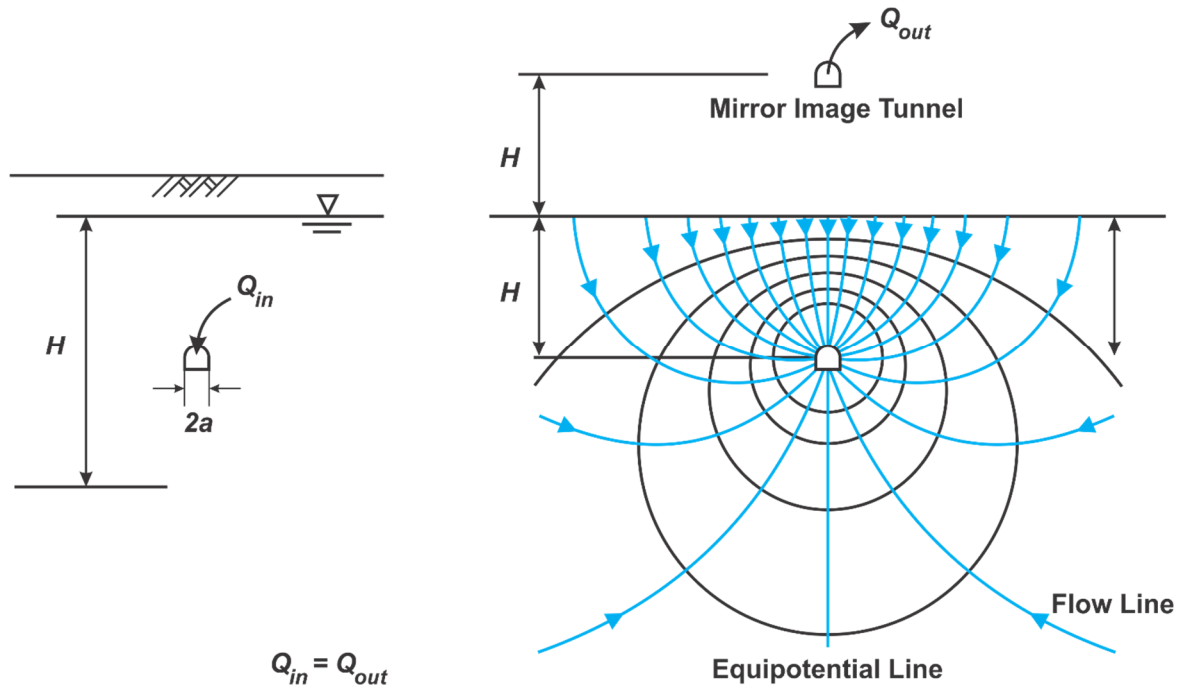


Figure 3 Equipotentials and flow lines showing flow to an underground cave in a uniform, isotropic media

Accurate groundwater level and pressure monitoring enables the plotting of groundwater gradients around a block cave which then allows understanding of groundwater flow directions. Once the flow directions are known they can be diverted away from the active caving areas to reduce risk of inflow and mud rushes and thus maintain or de-risk production. In many cases reduced water impacts underground result in increased production as it frees the operations from water related delays. Typical methods of diversion are equipping large diameter boreholes drilled underground in geological structures linked to the working area with pumps. The pumping creates a lower pressure than at the working area and therefore drains the incoming water towards the borehole(s).

Flow rates vary for different rock types and climatic conditions. Figure 4 is a graph of some of the wettest mines in the world, where block caves are marked with an asterisk (*).

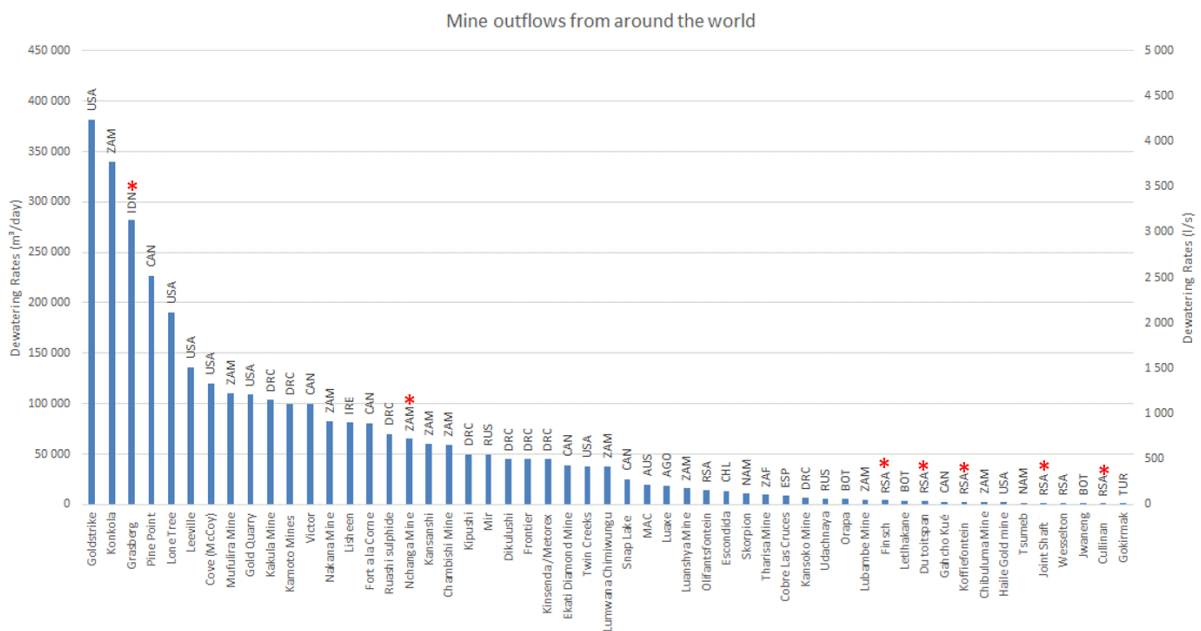


Figure 4 Mine outflows from around the world (acknowledgement to Dr LC Atkinson)

2.1 Hydrochemistry

Knowledge of the chemistry of the different water types found underground can be used to plot the sources and direction of underground flow. Groundwater takes on the chemical characteristics of the rocks it passes through. Sampling of pH, temperature and electrical conductivity (EC) underground using hand-held meters can be used to determine the sources of water intercepted underground. For example, alkaline water may indicate a dolomite or limestone source whereas acidic water may indicate seepage from the orebody or surface rock dumps. Laboratory analysis of cations/anions and isotopes can provide more detailed interpretation of sources of water with isotopes used to measure the age of the water and therefore probable travel time or length of residence. Isotopes can also be used to identify seepage of evaporative type waters from TSFs.

3 How to design a dewatering system

Figure 5 shows the iterative process to design an accurate dewatering system.

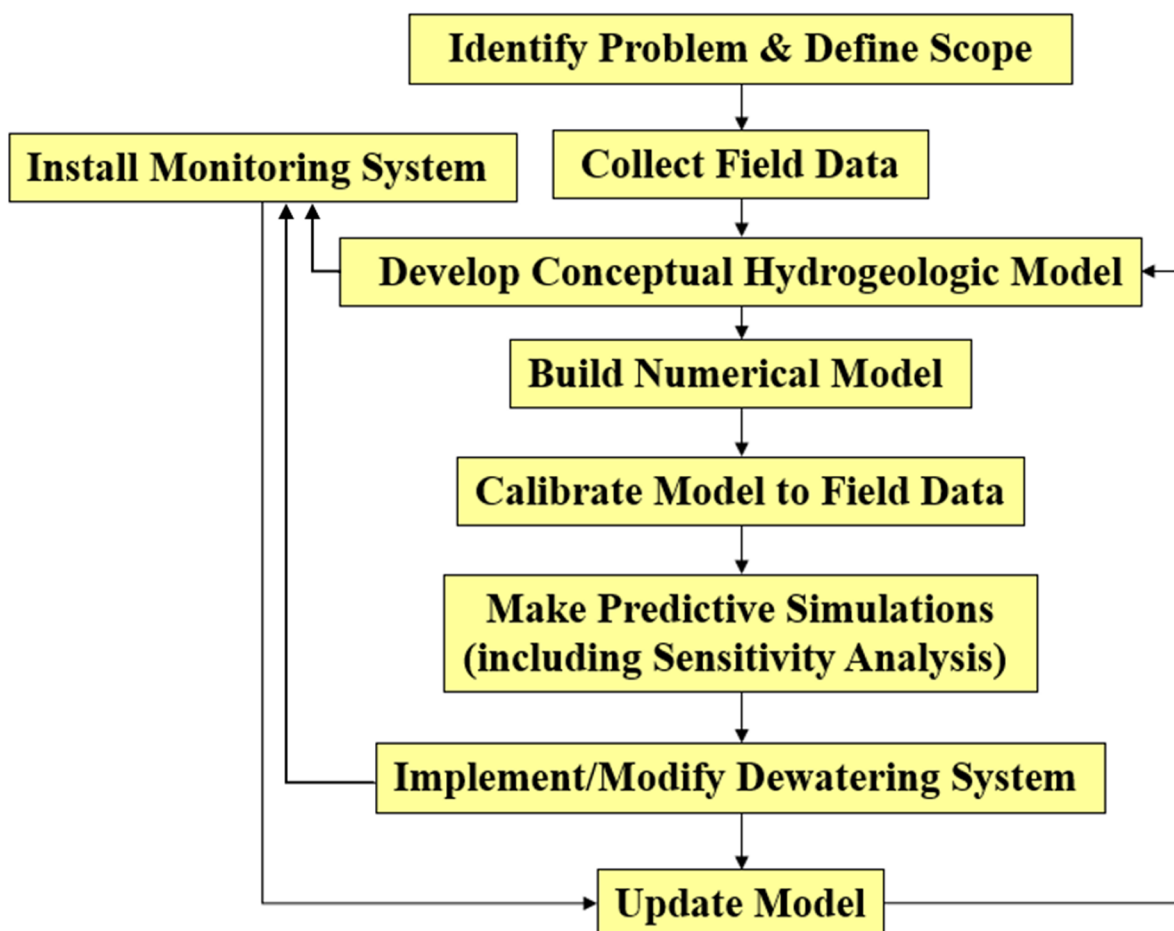


Figure 5 Iterative process of hydrogeologic field investigations and numerical modelling

The actual work programme (described in Figure 5) which is implemented depends on the stage of mining. At pre-feasibility level the implementation will emphasise the collection of basic information and the implementation of an initial monitoring network.

The article 'The use of mineral exploration drilling to kickstart hydrology data collection for pre-feasibility mining studies and beyond' published in Core Magazine details the use of early monitoring networks (Morton 2022).

At later stages in a cave design the modelling becomes more important so as to evaluate different dewatering scenarios.

Key to the design is the conceptual hydrogeological model, based on definition of hydrogeological units (HUs). Measurement of that describes the sources of water, flow paths and areas of storage. Hydrogeological values such as K (hydraulic conductivity), T (transmissivity) b (aquifer thickness) and h (water pressure or water level) should be assigned to each hydrogeological unit.

A numerical hydrogeological model is first constructed and calibrated then used to simulate different dewatering scenarios. Once twinned with the mine schedule, it is used to set targets for water levels to be achieved for specific sectors in advance of mining. Pumping and drainage are used to create a gradient that diverts water from the mining areas.

The monitoring network which has provided the initial heads around the mine for use in the model is then expanded to form a production-oriented feedback monitoring network. A dashboard is used to show different levels of management, the status of the dewatering levels, and provide guidance on allocation of resources to maintain or decrease measured heads.

At the implementation stage the regular updating of the action-response feedback loop is important using target water pressures.

4 Setting targets and monitoring success

The monitoring network is essential to accurately manage flows into a block cave through reduction of heads in active working areas.

Pressure heads are measured using vibrating wire transducers (VWTs) or pressure gauges installed on coreholes as illustrated in Figure 6.

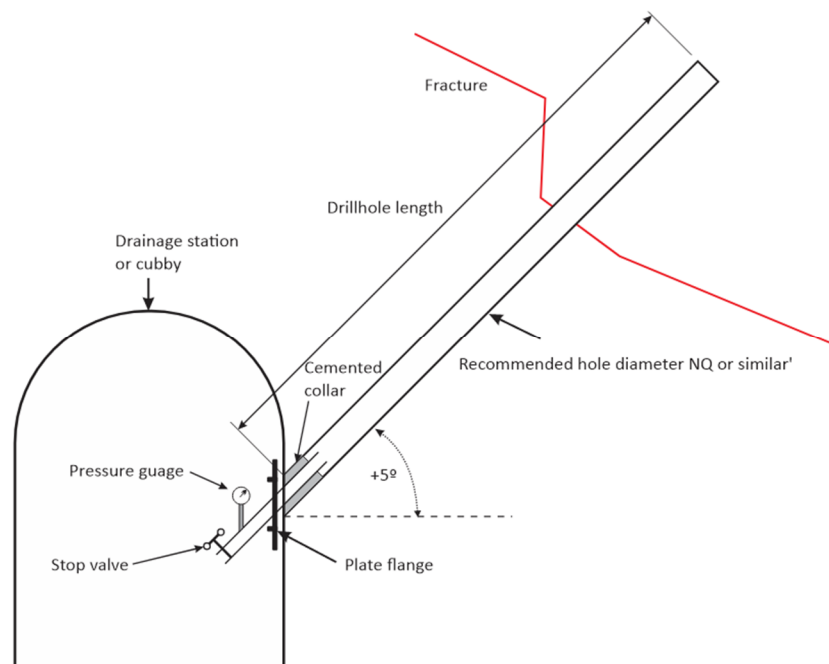


Figure 6 Measurement of pressure from underground single open hole

Multiple VWTs can be installed in one hole to give h with distance from the access tunnel. Figure 7 shows three VWTs installed in one corehole.

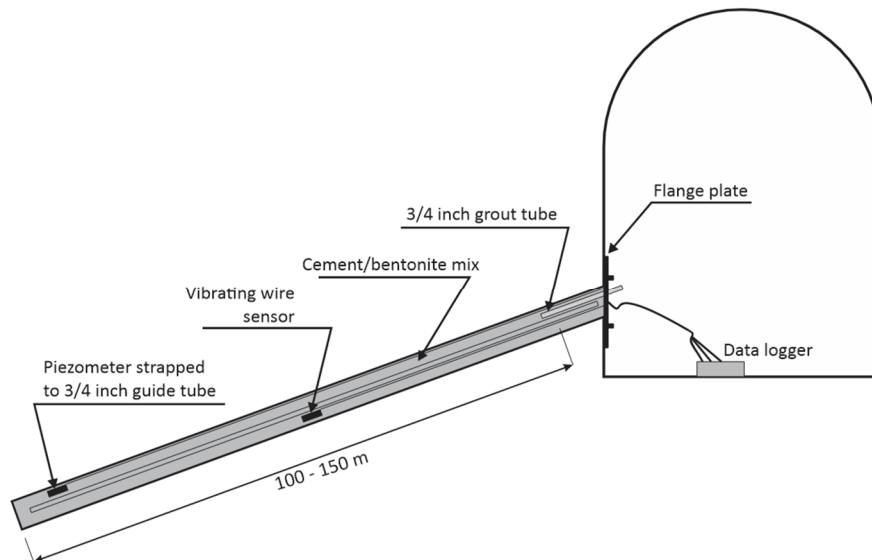


Figure 7 Multiple VWTs in a single core hole

The measured water pressures are used to evaluate the impact of pumping and/ or drainage on specific hydrological sectors of underground mines. The interpreted hydraulic values are used to update numerical models.

5 Method for using pressure release tests to obtain hydraulic parameters

The same monitoring coreholes can be used to run pressure release tests to indicate the speed of pressure decrease when an area is drained. The test provides data for the calculation of K.

The layout of a pressure release test comprises at least three long drill holes fitted with pressure gauges and valves. The central drillhole is opened, and the other two holes are used to record change in pressure. The pressure release test data can be used to calculate K, T and estimate the Q required to lower the pressure head (Δh) in advance of mining. The lower the pressure the lower the Q.

Figure 8 shows the layout of a pressure release test using three drill holes that intercept a fissure.

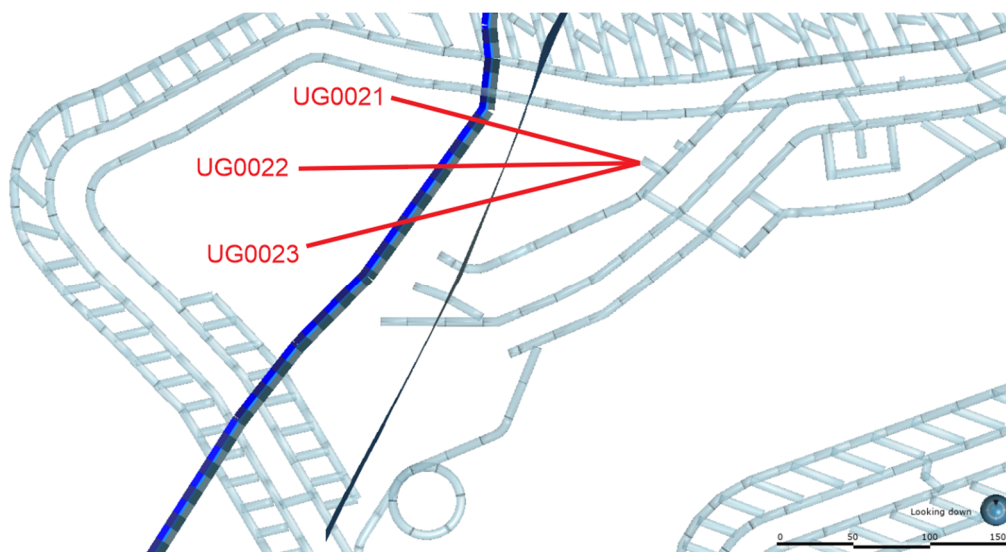


Figure 8 Location plan of pressure release test drillholes

Figure 9 shows the results of a pressure release test as pressure changeover time.

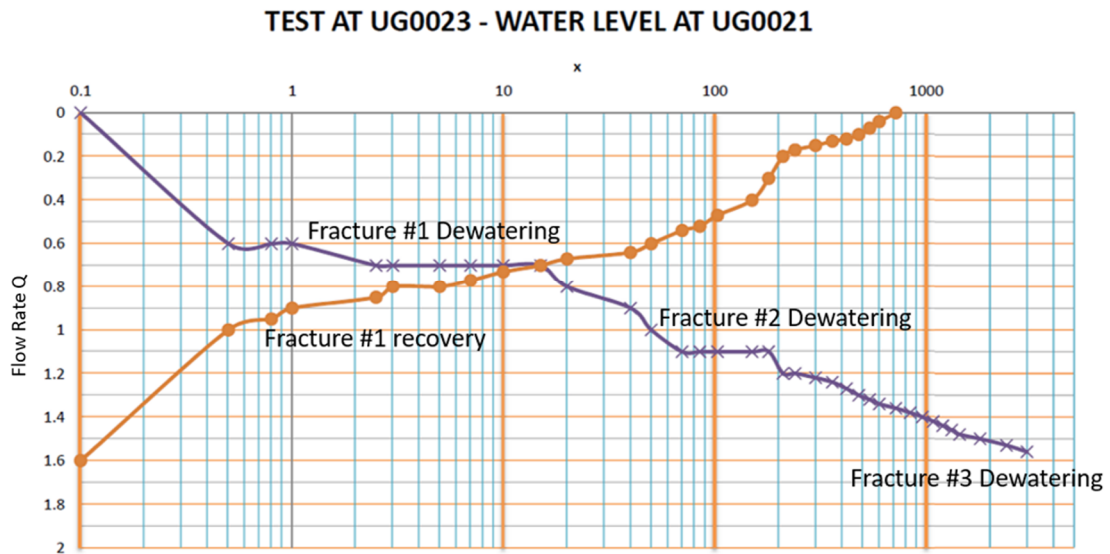


Figure 9 Results of a pressure release test from an underground corehole

Standard pumping test analyses methods are used to calculate K, T and S (storativity).

6 Examples of block caves with dewatering monitoring

Two generic examples are presented; Finsch diamond mine in the Northern Cape, South Africa, and Grasberg gold/copper mine in Indonesia.

6.1 Finsch mine

Finsch mine set up a monitoring network using point piezometers to measure the pressure head of water around the planned block cave below 650 mL. Eight pumping boreholes drilled from 65 L (650 m below ground) were used to dewater the block cave below 65 level. Figure 10 shows the graph of one of the piezometers and the target level of 65 mL. It can be seen the piezometer level continually decreases and is kept below 65 L by continuous pumping.

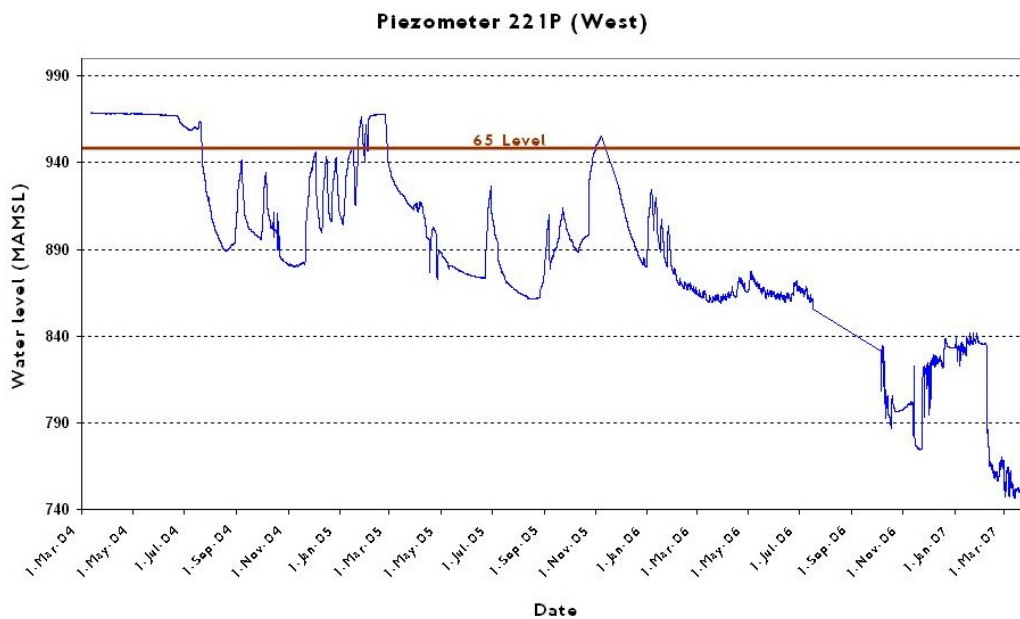


Figure 10 Piezometer 221P west – plot of pressure in an observation corehole over time

Figure 11 shows the location of the observation hole 221P West located to the northwest of the 65 L conveyor belt level that encircled the kimberlite.

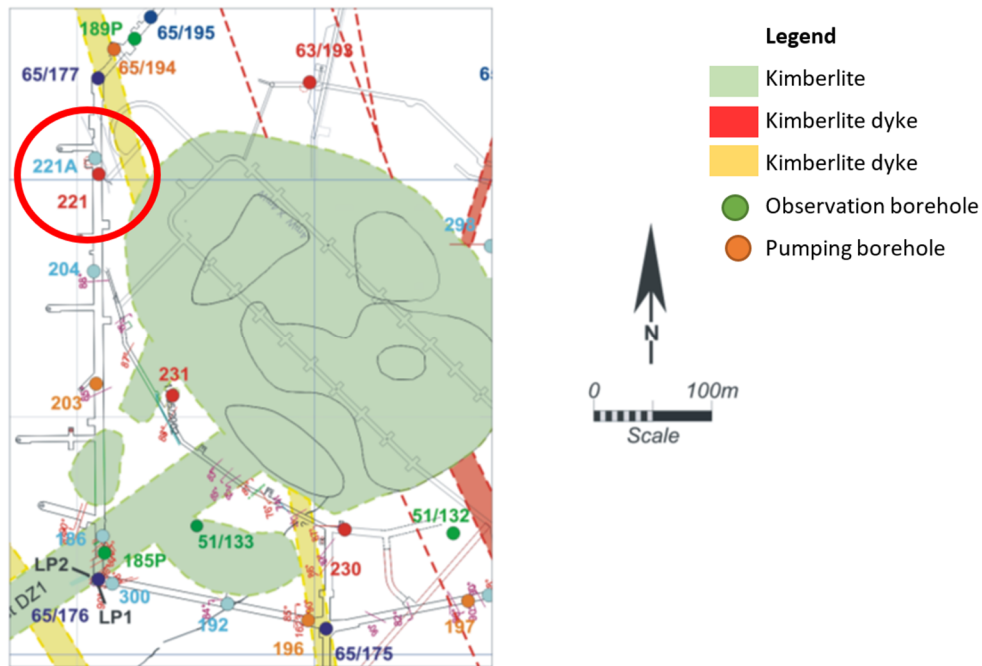


Figure 11 Location of 221P

The observation coreholes were equipped with VWTs and used to check the pumping network kept the water levels below 65 L.

6.2 Grasberg mine

Grasberg is a multiple block cave mine in Indonesia. As with other caves Grasberg will receive water from rainfall (over 5 m per year) (Mining Minerals and Sustainable Development 2002), surface runoff, groundwater, leakage from waste rock dumps and loose tailings on surface. Figure 12 illustrates the areas of provenance for caves and Figure 13 illustrates the direction of flow reaching the cave, superimposed on the geology (Rinaldi et al. 2018).

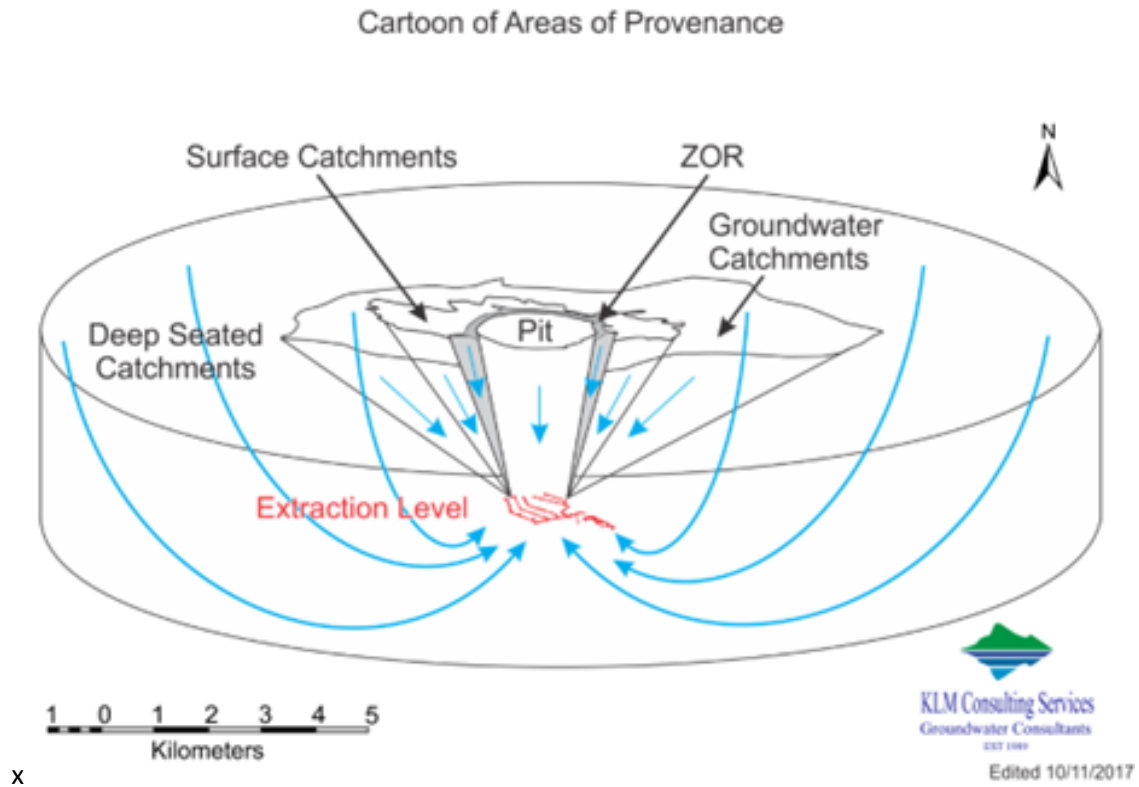


Figure 12 Areas of provenance supplying water to block caves (modified from Morton 2008)

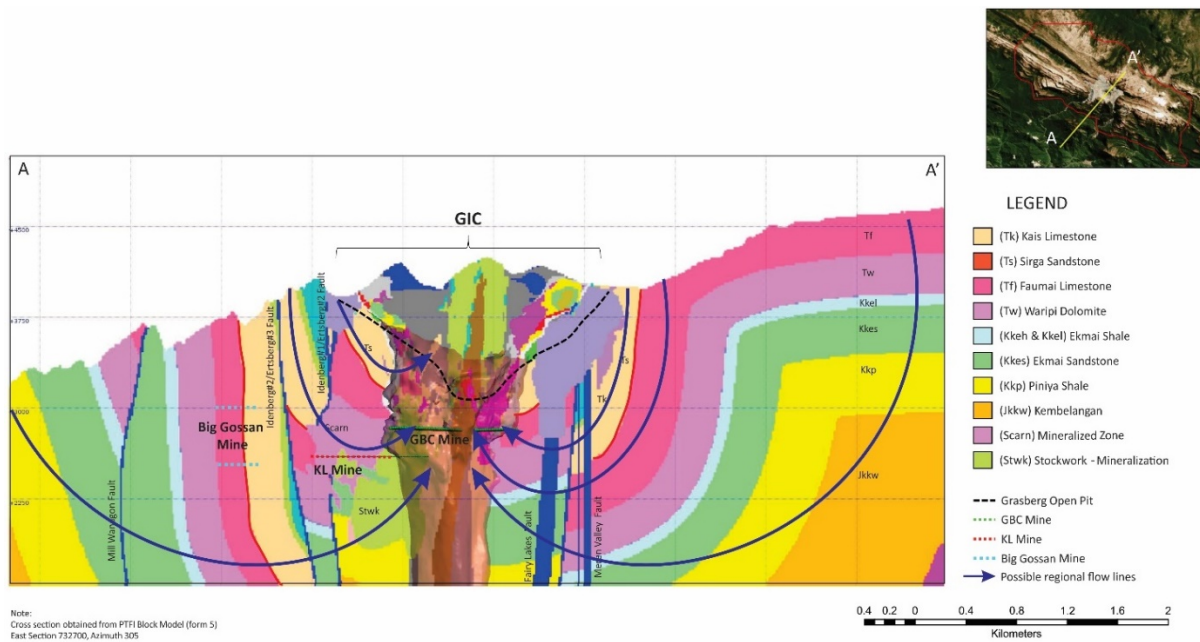


Figure 13 Cross-section of geology and probable flow lines for Grasberg (geology from Rinaldi et al. (2018) and flow lines drawn by KLMCS)

Grasberg has an advantage in that it is about 4 km above sea level (Rinaldi et al. 2018). Therefore, dewatering of the block is achieved by drainage using a ring of upward coreholes drilled into the country rock which then drain into tunnels below the block cave and daylight into the valley (Rinaldi et al. 2018). The water levels above the cave are monitored using a network of coreholes equipped with VWTs (Rinaldi et al. 2018).

Dashboards showing the daily pressure readings can be used to manage the flows into the cave. Additional coreholes are used when drainage needs to be increased (Rinaldi et al. 2018).

7 Conclusion

Monitoring of water levels above and around a block cave can be used to measure the heads of water driving water into the block cave. By twinning the measurement of water levels with measurement of flow, the block cave can be dewatered using a design which sets targets for water pressures and manages the inflows by diverting away from the working area.

Acknowledgement

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