The use of mineral exploration drilling to kickstart hydrogeology data collection for Pre-Feasibility mining studies and beyond.

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Abstract

Valuable groundwater information becomes available as soon as drilling starts, particularly during early mineral exploration campaigns. Often the information is not collected as the value does not become evident until the exploration sites become a mine. This paper describes what information can be collected very inexpensively during exploration drilling and how drill holes can be used to create an early monitoring network for the collection of water levels across the site. Examples of logging sheets, daily drill records and construction designs for monitoring boreholes are provided.

During drilling and logging of exploration coreholes the emphasis is all on characterising the orebody. Drilling methods include rotary, air percussion and core drilling. All encounter water and, with very little effort, the information on water intersections, drilling fluid circulation losses, basic water chemistry and rest water levels can be collected by the drilling contractor and the site geologist, under direction from the project managers.

If the basic information is captured, then this significantly reduces the cost of the initial hydrogeological study for the pre -feasibility reports. Some of the holes can be equipped for use as water level monitoring boreholes or preserved for use at a later stage. Old core holes that are not sealed can create conduits for underground inflows when the mine is developed. Decision criteria are provided for the use of the hole after drilling to optimise information from all drillholes and reduce risk when mining commences.

Keywords water / mine design / inflow / flood / precipitation/ PFS

Introduction

Valuable groundwater information becomes available as soon as drilling starts, particularly during early mineral exploration campaigns. Often the information is not collected because the value of groundwater information does not become evident until the exploration sites become under scrutiny for development as a mine.

This paper describes what information can be collected very inexpensively during drilling and how drill holes can be used to create an early monitoring network for the collection of water levels across the site. Examples of logging sheets, daily drill records and construction designs for monitoring boreholes are provided.

During drilling and logging of exploration coreholes emphasis is on characterising the orebody, sometimes even the overburden (future waste-stripping) is not logged. Drilling methods include rotary, air percussion and core drilling. If the basic information is captured, then this significantly reduces the cost of the initial hydrogeological study for the pre -feasibility reports. The information can be valuable at Pre-feasibility, Bankable feasibility, Full feasibility, during construction, during mining and at closure and beyond. Economic sustainability of the mine site can depend on the availability of groundwater, therefore the greater the coverage and longer the record of water levels and groundwater occurrence the better for design, operation and closure.

All holes usually encounter water ranging from damp to undrillable, with very little effort the information on water intersections, drilling fluid circulation losses, basic water chemistry and rest water levels can be collected by the drilling contractor, the site geologist under direction of the project managers.

Some of the holes can be equipped for use as water level monitoring boreholes or preserved for use at a later stage. Before drilling a hole, it is important to envisage all future uses, risks and impacts, old core holes that are not sealed can create conduits for underground inflows when the mine is developed thus creating unnecessary hazards. Decision criteria are needed prior to drilling for the use of the hole after drilling and should be used to optimise information from all drillholes and reduce risk when mining commences.

Exploration drilling can provide a wealth of information on groundwater that is very valuable for Pre-Feasibility Studies (PFS) and beyond. Each drill hole is capable of being used to determine the depth of the water table, if aquifers are confined or unconfined and then used for water level monitoring, water chemistry information and a long-term record of water level movement prior to mining. The exploration drillholes provide baseline data on the groundwater for very little additional cost or effort. Drillers record a lot of information on water strikes, water levels and drilling fluid loss circulation records which give important information on zone(s) of high permeability. All this information is significant for early mine planning and can reduce the cost of the design of water supply, dewatering and environmental studies. The use of the exploration drill holes as long-term monitoring sites can provide an early monitoring network which will add value to the mine design and planning as well as provide background information critical to the success of the mine.

Often a planned mine area has a very high density of drillholes used for exploration but if these holes have not been used to measure water levels, then additional new holes will have to be drilled at Pre-feasibility stage thus creating an additional high cost to the PFS. During exploration drilling the knowledge and experience of the driller and site geologist should be used to collect the easily available groundwater information and store ready for PFS and beyond.

Figure 1 shows an example of drillhole density for a project in plan.

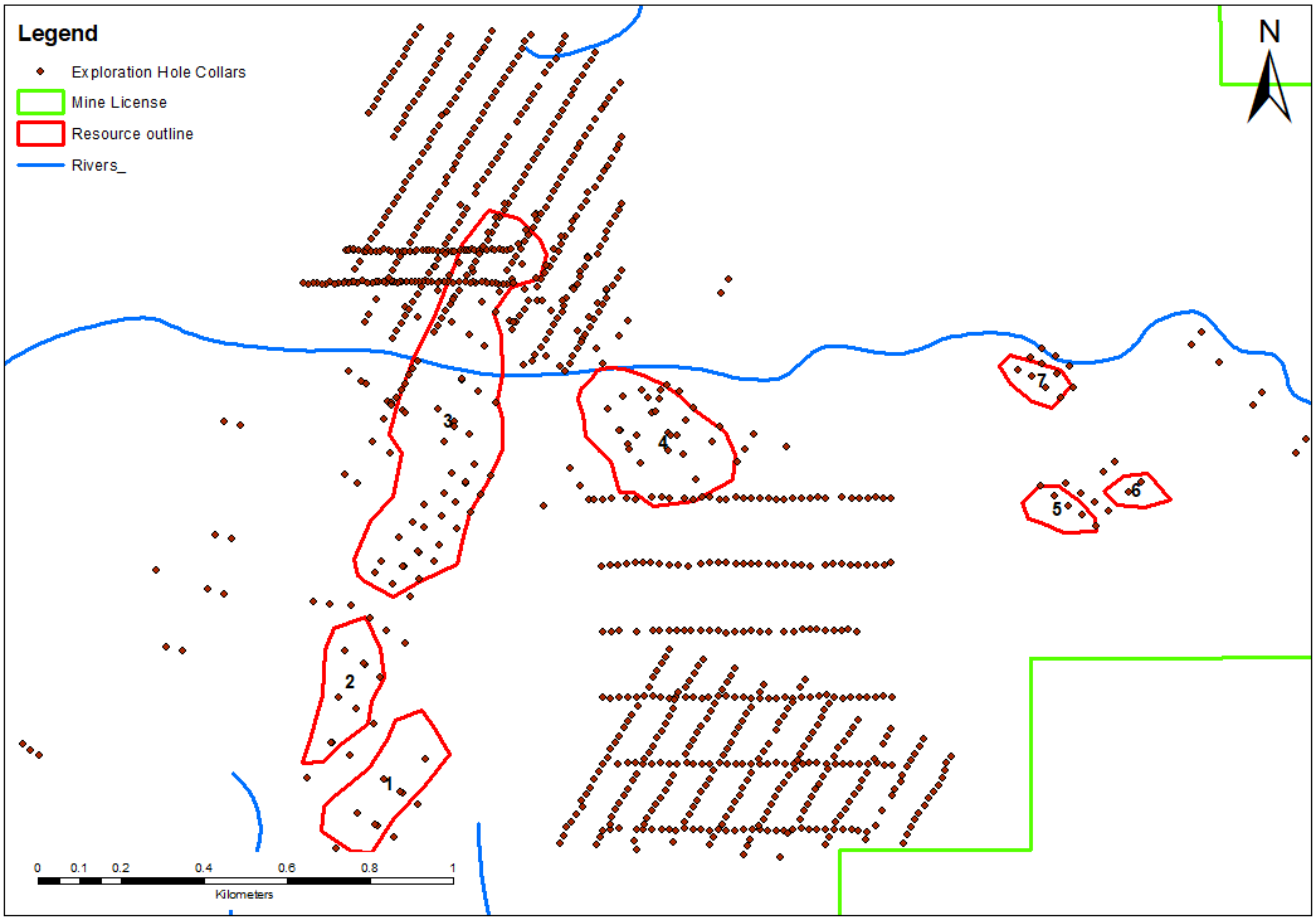

Fig. 1 Typical exploration drilling density in plan and isometric

Drill holes are expensive, therefore it is important to extract as much groundwater information from them to enable decisions on sealing (to protect the future mine) or converted to monitoring holes as contribution to a better understanding of the future mine hydrology.

Best practice is to seal drillholes so that they cannot become conduits for flow into mine workings but where possible the drillholes should be sealed using cemented-in vibrating wire piezometers (VWP) to provide 3D monitoring of the ground water prior to and during mining. Modern automation techniques can be used to collect long term water level records which will be of vital interest to PFS groundwater studies and, for very little additional cost, reduce the water risk to the planned and operational mine.

Advantages for ground water can be obtained at all stages of exploration drilling. This valuable information can be used in dewatering design, water supply, water balance reporting, environmental impact studies, closure design and post closure planning.

Drilling stage

Exploration drillholes usually comprise core drilling and sometimes, if there is about 20m+ of weathered material the core holes are usually collared using air percussion or rotary percussion drilling. Reverse Circulation drilling (RC) is also extensively used in exploration, and often the progress of drilling is impacted by the presence of groundwater. The exploration geologist is primarily interested in the ore body and hanging and footwall however it is very important to log the depth of weathering as this can be a significant aquifer or water susceptible zone when the mine is designed. Geotechnical engineers are also interested in the depth and types of weathering. These can be recorded on the standard drilling and geological logs.

During core drilling the driller monitors a minimum of three gauges on a drill rig: water pressure, feed pressure and torque pressure. They are integrated onto the control panel. When the water table is encountered the driller notices that water pressure will start to increase. Also when lowering the overshot to lift the core tube there will be slack in the line, this is also the sign of a water table in front of the core bit. The web site http://drilling.fordia.com/essential-guide-to-drilling-parameters describes all the parameters monitored by a driller and their use in recording the water encountered in the formation.

During drilling by any method, the depth of the first water strike should be recorded by the driller on daily drill logs and the drill sheets. Most drill sheets are primarily focussed on details for invoicing the client however it can be specified in the drilling contract that all water strikes, water losses and water levels must also be recorded and shared with the site geologist.

Normally all drill hole collars are surveyed within 0.5cm accuracy for x,y,z. The z needs to be specified for water level measurement which, although measured in metres below ground (or drillhole collar), should be reported in metres above mean sea level (mamsl) as the hydrogeologist is primarily interested in head measurements and groundwater gradient to plot flow lines.

During drilling, the driller can see, very easily, the depth at which water is encountered thus giving a plot of the water table for the area. Water strikes and the subsequent measurement of water levels can indicate the presence of confined aquifers. When encountered in confined aquifers the resultant water level is the phreatic or pressure surface for the area. Both measurements; of water strike and of water level are very important for the understanding of the groundwater conditions and possible impact on the proposed mine.

Figure 2 shows water level intersection of an unconfined aquifer and of a confined aquifer.

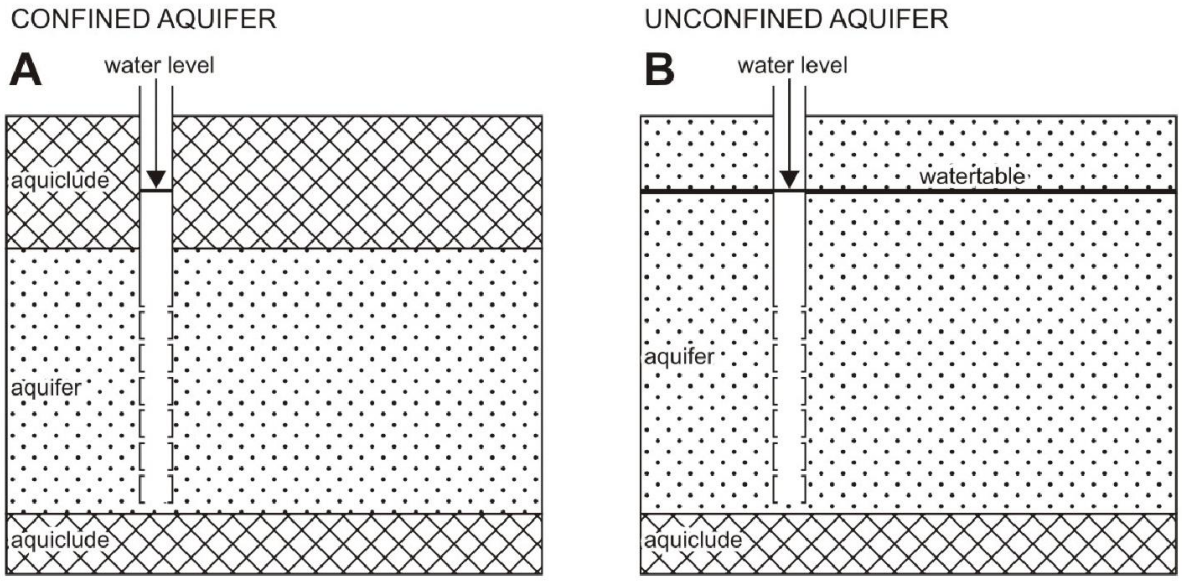

Fig. 2 Water level intersection of an unconfined aquifer and of a confined aquifer

Air percussion and rotary drilling can be used to measure the yield of a water strike in litres per second (l/sec) or metres cubed per hour (m^3/hr). Core drilling does not enable the measurement of yield, however, if a permeable zone (possibly an aquifer or water bearing fracture) is intercepted the driller will note circulation losses and need to top up the corehole with water and drilling fluids. The more water and fluid used indicates the greater the permeability. This provides a guide for the possible groundwater characteristics and pumping yields at the corehole location. Heinz, in his Diamond drilling handbook (1989) describes all the formations that can be noted from circulation losses including:

- Sands and gravels

- Cavernous or vugular limestone and dolomite
- Naturally fractured/fissured rocks
- Induced fractures in solid rocks

It is very valuable to have a record of the drilling circulation losses. Appendix A is a recommended daily drill log. It is important to state in the drilling contract that the information on water strikes, circulation losses and water levels and must be collected.

During core drilling the level of drilling fluid in the core hole represents the hydraulic pressure being maintained by the driller to keep the hole open, the bit lubricated and optimise the efficiency of the drilling. If the drilling is stopped for any reason (e.g. a drillers' break weekend or at the end of the hole) the fluid level will equilibrate to the actual groundwater level. This is essential information and should be recorded with a hole depth and date. As the drill hole deepens different aquifers, with different groundwater pressures may be encountered therefore the level of fluid in the corehole should be measured after any cessation of drilling over 24 hours. It is possible that artesian conditions, where the fluid flows out of the core hole, may be encountered and these too should be noted on the drilling log with date and corehole depth.

During drilling the pH and the electrical conductivity of the water encountered may change indicating interception of different aquifers. Some drilling companies such as Geomechanics (Pty) Ltd ("Geomechanics") offer automated logs of drilling information. Figure 2 is an example of a log created by Geomechanics.

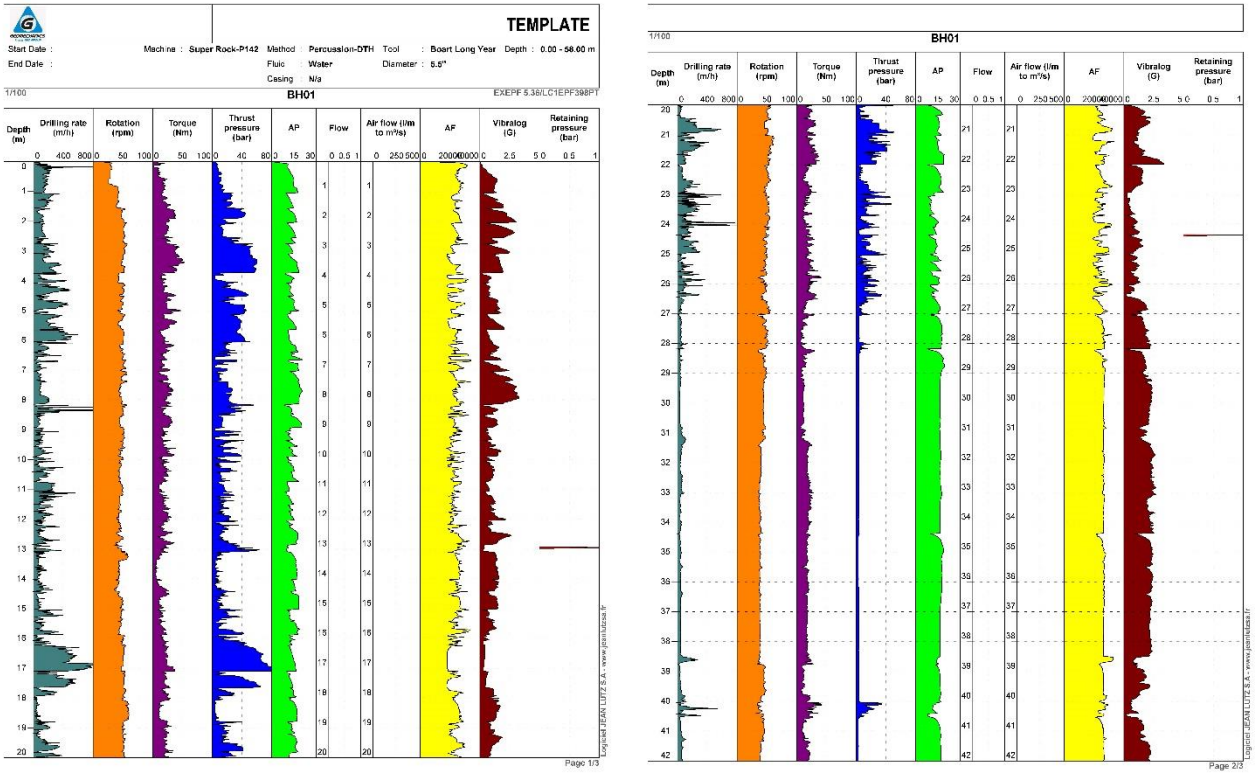

Fig. 3 Example of automated drilling log (Geomechanics).

When plotted with the geological log the information can highlight more permeable zones and give guidance to the next stage of hydrogeological investigation.

Down -the- hole geophysics

On completion of a drillhole, exploration coreholes are often surveyed using down-the-hole (dth) geophysical probes to record information on the ore body. The dth logging probes can also provide information on the aquifers encountered in the corehole (Bouw and Morton 1987). At the very least the probes will record when water is entered and thus provide a record of the water level in the corehole on a specific date. Gamma-gamma and resistivity probes can record information on porosity and permeability. Temperature and electrical conductivity probes indicate zones of water flow or different aquifers. Groundwater geophysical logging can be piggybacked on the mineral exploration dth logging and requires discussion with the dth contractors and hydrogeologist to choose the most suitable probes.

Drill hole closure

Following drilling, the hole is often contaminated with mud, grease, and oil. This needs to be cleaned out to unclog the side walls and enable the hole to be used for monitoring either as a temporary (it will collapse if not kept open) open hole or as a permanent water level monitoring hole. A hole can be kept open using plastic conduit or more robust casing. Often both are easily available. It is important the conduit/casing is slotted (can be hand slotted), capped at the bottom and protected at surface. Figure 4 shows a recommended design for an open hole – often called a piezometer.

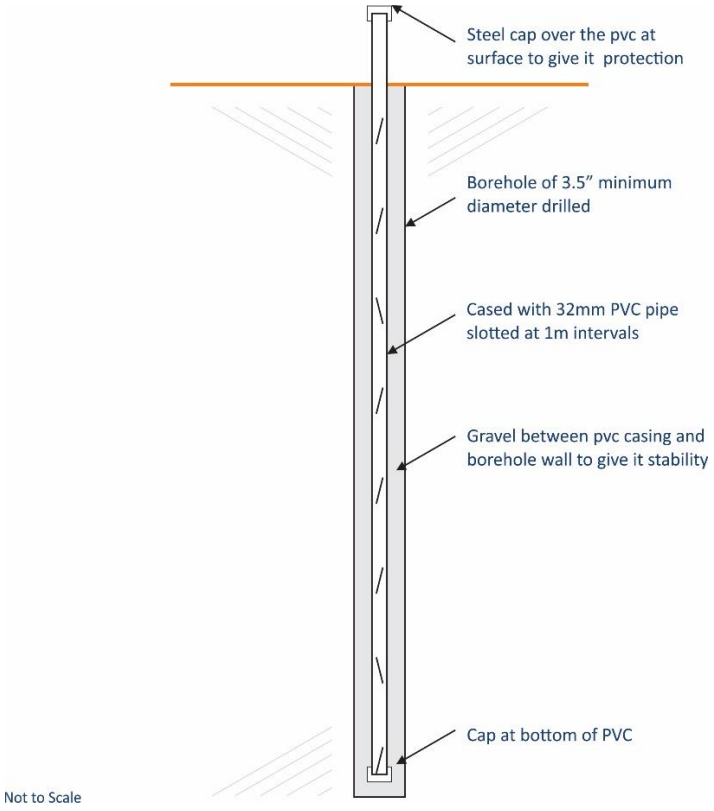

Fig. 4 Simple open hole piezometer construction to create a monitoring borehole.

When water strikes or multiple aquifers have been encountered during drilling then multi-stage open piezometers can be installed. Figure 5 shows a multi open hole piezometer constructed in one hole or using several holes.

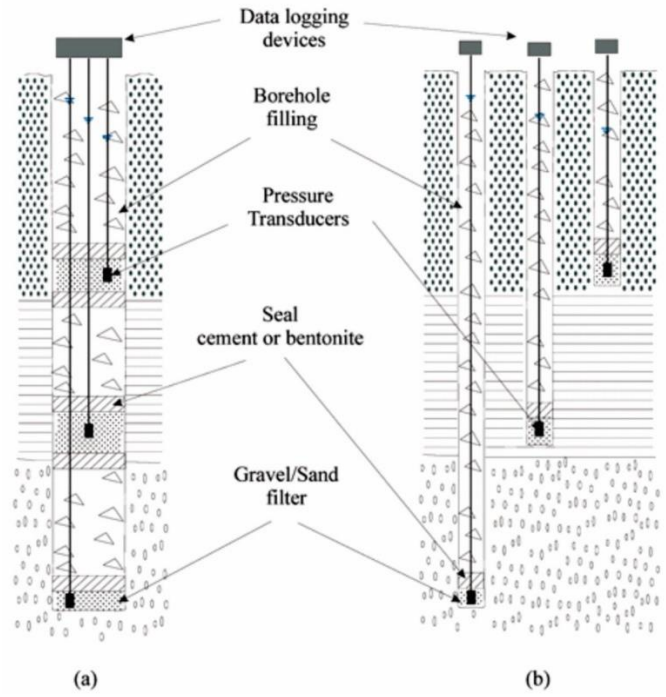

Fig. 5 Multistage open hole piezometers in one or multiple boreholes

If open pit mine or underground mine dewatering is anticipated, then sealed vibrating wire piezometers (VWP) are recommended as these measure groundwater pressure for known depths. A network of VWP's will give the distribution of pressure and plot flowlines in 3D providing valuable information for the interception of mine water and accurate dewatering design. Figure 5 shows the construction of a vibrating wire type point piezometer and data logger sealed into the backfilled core hole using a tremie pipe.

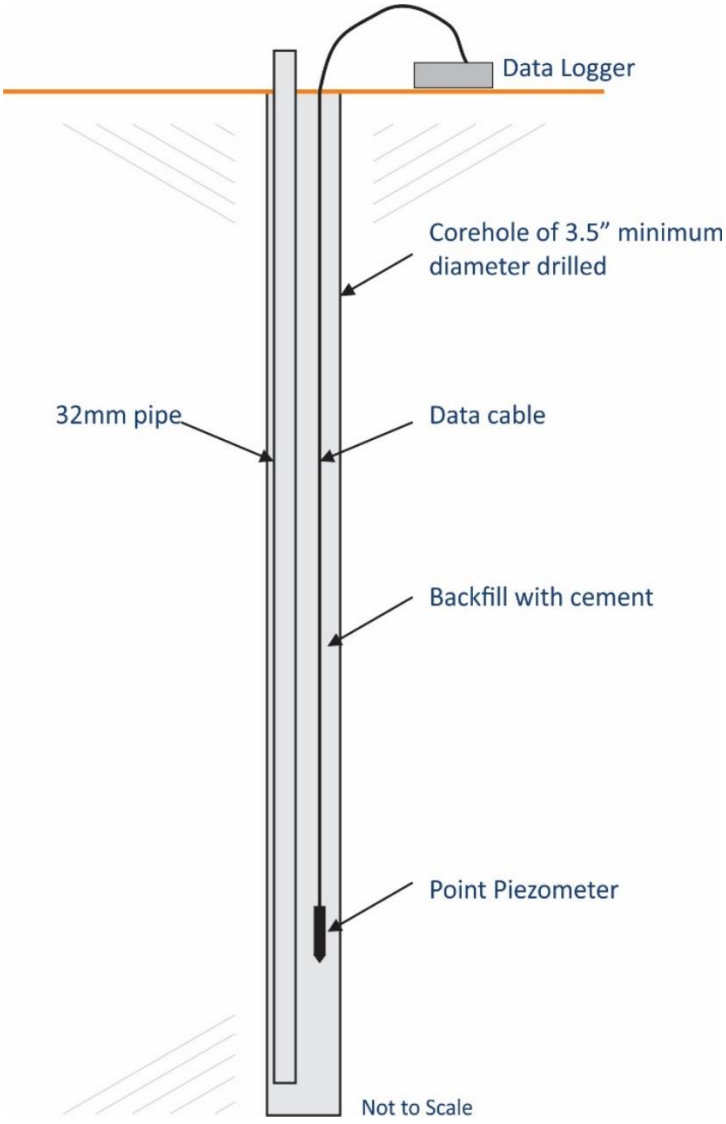

Fig. 5 Vibrating wire piezometer in a corehole backfilled with Cement.

Appendix B holds an example of a drilling sign-off log. This was developed at De Beers Group for use prior to the drilling of all holes. The document shows the layout and length of the planned hole, its construction and planned use. Then the design is shared with all interested parties such as Geology, Geotechnical, Engineering, Mining and Environmental department heads for sign off before the hole is drilled. This ensure all stakeholders are informed of any new hole and get the opportunity to use the hole for their investigations.

Post exploration

Once exploration is complete, or at least the first phase, the project is evaluated at either Pre-feasibility (PF) or Feasibility levels to obtain funding for either further exploration to improve confidence or to design and open the mine. There is now opportunity to use the initial monitoring network and some of the cleaned out coreholes to collect monthly groundwater levels. This valuable information adds confidence to the studies needed for environmental permitting, water supply and mine dewatering designs. For very little expenditure the monthly plotting of groundwater level fluctuations significantly increase the understanding of the groundwater regime and provide essential data for use in modelling and calibration of the water flow for the planned mine.

As the mine project advances and new exploration holes are added, then the monitoring network can be expanded, and data collection frequency increased. The more hydrological seasons that are covered by monitoring the higher the confidence in the conceptual hydrogeological model and therefore the improved confidence in numerical modelling and the initial water control, water supply and dewatering designs.

Data management

During exploration and PF levels a lot of information is collected by a variety of site staff. It is important that the groundwater information is filed in a dedicated data base for use later in the project development.

AcQuire® and QuickLog® are two of the geological logging programmes that can also store water level and water strike information. Other water data packages can be used and can include water chemistry information. It is vital that a chronology of data collection is maintained and back up of data supported.

The data needs to be easily accessible and attached to the dates measured for use in the conceptual and numerical modelling.

CONCLUSIONS

Exploration drilling programmes can be used, at very little extra cost, to collect information on groundwater including water strikes, possible zones of increased permeability and water levels. The drill holes can be used to create an initial monitoring network for the collection of water levels. The longer the monitoring record the greater the confidence in the conceptual and numerical models needed to design the water management strategy and obtain permissions for mining. Ground water data can be obtained at all stages of drilling and provides valuable information for project water supply, mine dewatering design, water balance reporting, mine water management, environmental impact studies and ongoing monitoring for eventual closure design and post closure planning.

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References

Bouw, P C and MORTON K L, (1987). "The importance of geophysical logging of boreholes". **Borehole water Journal Vol 6. South Africa**

Heinz WF 1989 Diamond drilling handbook Johannesburg, South Africa ISBN 0-620-13785-1

Appendices

Appendix A

Drilling log for core holes which include capture of circulation losses.

Appendix B

Sign-off document for all new core and drill holes.

Appendix A - Drilling log for core holes which include capture of circulation losses.

Appendix B - Sign-off document for all new core and drill holes.

DAILY DRILLING REPORT

No. xxxxx

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Date:	Contract Name:		Rig No:	Machine start hour:	
Weather:	Client:	Inclination:	Rig Type:	Machine end hour:	
Contract no.	BH-no:	Direction:	Pump Type:	Diesel received:	
Water Used: Litres	Water Carted: Kilometers				

Nature of Core Classification: **FR**-FRESH, **WR**- WEATHERED, **B**-BOULDERS, **S**-SOILS, **G**-GRAVELS

Legend **Run length: Depth to - Depth from = Run length** **Bit type eg.**: NWD4/ TNW/ NQ/ HMLC etc **Drilling response**: FAST/ SLOW/ EVEN/ UNEVEN

Inclination: Horizontal, Vertical, Inclined deg(45) **Direction:** Compass reading (or from Geologist)

Depth from	Depth to	Run Length	Core Recovered	Core loss	Run Duration [min]	Bit type	Casing Depth	SPT Blow count 0.075	0.150	0.225	0.300	0.375	0.450	Sample recovered - SPT, Undisturbed	Drill Fluid	Water return % / Pressure psi	Colour	Drilling response	FR/WR/B/S /G	Rock type	Bit NO.	Accum bit meters

Borehole complete?	Yes		No		Core boxes:	of	Corewriter Name:	Signature:
Water level:	m	Time:	am		Water level:	m	Time: pm	Supervisor Name:	Signature:

Instruction by Geologist:	**Comment on Water Intersection**
Equipment replaced:	
Equipment lost:	

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COREHOLE PLANNING AND SIGN OFF DOCUMENT (PRE DRILLING)

DATE	
ORIGIN	
NAME OF RESPONSIBLE PERSON	
name	

COREHOLE NUMBER		COORDINATES		
IMAGE OF COREHOLE IN 3D Showing known geology, ramp and ug, geology structures, existing holes and illustrating reason for the location of the new hole		ELEVATION		
		LOCATION		
		OBJECTIVES OF COREHOLE *eg. To determine structures in ? Direction for ? Block*		

COREHOLE CONSTRUCTION					
SIZE		LENGTH		ORIENTATION	

COREHOLE LOGGING	
RESPONSIBILITY:	DTH GEOPHYSICS REQUIRED

PACKER TESTING	
PROPOSED INTERVALS	TEST DESCRIPTION
	eg. Single / double & test duration

POST COMPLETION USE (LIST MONITORING NEEDS)
eg. Equip with point piezometer in approximate depths ?, ?and ??? geological Horizons Equip with tensiometers at ??, Equip with mining markers at ?? Depths/lengths

SIGN OFF AGREEMENT ON LOCATION, TESTING AND PURPOSE			
DEPARTMENT	NAME AND TITLE	COMMENTS	SIGNATURE
GEOLOGY			
GEOTECHNICAL			
HYDROGEOLOGY			
SHE/ENVIRONMENTAL			
MINE PLANNING			
MINE MANAGER			