Horizontal scavenger borehole system for plume containment

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Abstract

While scavenger boreholes have been proposed for groundwater remediation for a number of Mine Residue Deposits throughout Southern Africa, a limited number of case studies are available. Furthermore, the use of horizontal scavenger boreholes for site remediation is common in the northern hemisphere but is an emerging technology in South Africa. This paper presents results and lessons learnt from implementing the first horizontal scavenger borehole system for the hydraulic containment of a seepage plume emanating from an unlined Tailings Storage Facility (TSF).

Keywords: ICARD | IMWA | MWD 2018, hydraulic plume containment, horizontal scavenger boreholes.

Introduction

The Horizontal Directional Drilling (HDD) Industry in South Africa is largely focused on the installation of underground utilities mainly within the overburden. As a result, directional drilling companies are not familiar with the drilling and equipping of horizontal boreholes for hydraulic plume containment, just as very few hydrogeologists have experience in the design and installation of horizontal boreholes. In this case study, two horizontal scavenger boreholes were drilled, screened and commissioned to intercept a seepage plume emanating from a Tailings Storage Facility (TSF) and associated Return Water Dam (RWD). The study area is located in the eastern limb of the Bushveld Igneous Complex, 25 km south west of Steelpoort in the Limpopo Province, South Africa. The area is underlain by massive to poorly layered pyroxenites and norites of the Rustenburg Layered Suite, intruded by numerous dykes. In-situ weathered and unconsolidated transported overburden covers most of the valley bottom and lower and mid slopes of the valley sides, forming a typical Basement aquifer system. Tailings deposition (from a Platinum Group Metals Concentrator) onto the TSF started in October 2006 and surface- and groundwater monitoring data showed a deterioration of water qualities downstream of the TSF and RWD. Highly elevated nitrate, ammonia, sulphate and sodium concentrations in the seepage water from the TSF contribute to a saline mine drainage chemistry. The current plume (represented in fig. 1 by sulphate) emanating from the 60 Ha TSF migrates preferentially in zones of deeper weathering along 'pre-facility' drainage courses to the east and south-east towards a large perennial river. The vertical plume migration is limited by the underlying fresh bedrock with significantly lower permeability compared to the upper weathered overburden with associated higher flow rates. Results from a site specific numerical groundwater flow and transport model indicated that the plume could be intercepted before reaching the receptors, in this case regarded as the southern tributary and the perennial river to the east. The sulphate concentration limit for the river is 70 mg/L based on the instream flow requirement. Scenario modelling concluded that two horizontal wells could in theory be more effective than 10 conventional boreholes, reducing the Capex and eventually the long-term Opex cost for the predicted minimum pumping rate of 15 years post-closure (expected for 2019).

Methods

Following an initial plume characterisation study, additional monitoring boreholes were drilled during the plume interception study to establish sub-surface conditions along the

Figure 1 *Simulated sulphate plume extent.*

proposed horizontal borehole path. The drilling was preceded by ground geophysical surveys, including earth resistivity imaging, and electromagnetic and magnetic traverses adjacent and downstream of the TSF. The main aim of the survey was to:

- confirm dyke positions inferred from regional aeromagnetic data,
- investigate geological structures and deep weathering zones as potential preferential flow paths,
- optimize the selection of drilling sites for scavenger wells.

Ultimately a total of nine geophysical traverses were conducted with a total length of 1 918 m. Based on the resistivity survey results, the resistive basement (bedrock) varies in depth from 4 m to approximately 18m below surface. Overburden and soil cover varies from absent (rock outcrops) to 1-2 m thickness. The resistivity results were also used to delineate areas associated with deep seepage, indicating saturated conditions immediately downstream of the TSF and RWD.

Boreholes drilled along the proposed horizontal borehole paths were used to confirm

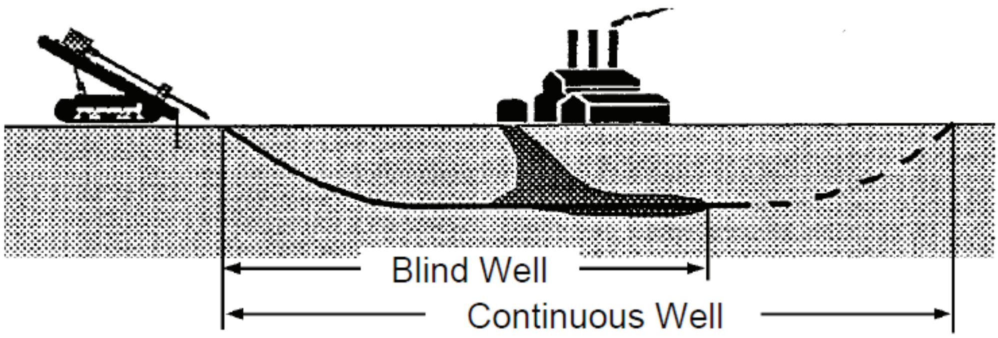

Figure 2 *Horizontal well used to intercept a plume. The solid line represents a blind well; the solid line plus the dashed line represents a continuous well. (EPA, 1994).*

the depth to bedrock, likely lithologies and groundwater qualities to optimise the horizontal borehole profile. These observation boreholes also aid in assessing and monitoring the drawdown of the water levels during testing and commissioning. Additional monitoring boreholes were drilled further downstream of the horizontal boreholes to assess the effectiveness of the hydraulic containment system. Based on hydraulic test results, the hydraulic conductivity varies from 0.1 to 0.8 m/d for the area with the highest contaminant concentrations (south of the TSF and RWD).

The information was used to establish a horizontal profile to be followed during the horizontal drilling process. The target depths were essentially the weathered-bedrock interface zones perpendicular to the preferential groundwater flow path. Directional drilling methods use specialized bits to curve bores in a controlled arc which enables bores to be initiated at a relatively shallow angle from the ground surface and gradually curve to horizontal (EPA, 1994). While blind horizontal boreholes terminate in the subsurface, in most cases the borehole is turned back towards the surface and returns to the ground to form a continuous well (Figure 2).

A summary of the pre-drilling design criteria is provided in Table 1, while the initial design considerations are given below:

- The original aim was to drill the horizontal boreholes from surface to surface along the pre-planned path so that the well screen portion of the borehole is flat or inclined at a specified grade at the desired location.
- Once the drill head (with a diameter of 165 mm) has re-emerged at the surface, it is removed from the drill string and the 110 mm OD sleeves (screened and solids) are attached directly behind the drill head and pulled into the borehole.
- A walk-over system consisting of a radio beacon-receiver measures surface location up to a depth of 16 to 18 mbgl to ensure the boreholes follow the correct path.

Results

Drilling was carried out using an American Augers DD-10 percussion rig with an air percussion hammer head. Each drill entry point was excavated to around 1 m below surface. Steering of the drill head remained below 2 % per 6 m rod length, which prevented the borehole being completed back to surface. As a result, the two horizontal boreholes were

Table 1 *Design criteria of the horizontal scavenger borehole system*

Borehole	Deepest target depth (m)	Length to target depth (m)	Total length (m)	Sulphate (concentrations)
HWELL-B1	18	70	140	450
HWELL-B1	9	50	110	96

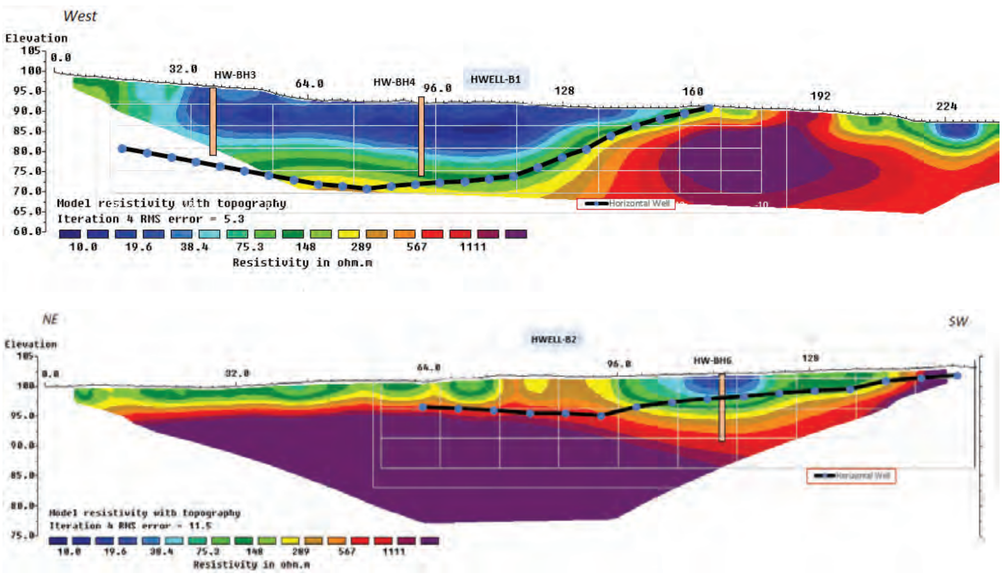

Figure 3 *Horizontal borehole profiles in relation to the closest resistivity results.*

completed as blind wells. The final drilled horizontal borehole profiles, in relation to the closest geophysical profile and vertical monitoring boreholes, is shown in fig. 3.

After a horizontal borehole was drilled it was developed using a smaller reamer forcing air and water into the horizontal borehole, flushing soft sandy overburden material from the open hole. The drill rods were moved back and forth along the entire screened section until the discharged water was relatively free of suspended material. The HDPE sleeve was pushed into the hole with the screened sections installed along the target area. Solid sleeves were used in the upper overburden. The hole opening with the protruding starter sleeve fitting over the riser HDPE pipe was sealed with a bentonite-based cement block.

The preliminary pumping tests of the horizontal boreholes included limited step tests and constant discharge tests followed by a recovery monitoring period, mainly to determine the potential yields of the boreholes and to determine the specifications for the submersible pumps for the installation. The detailed schedule of the constant discharge tests is provided in Table 2.

Based on the results, the horizontal boreholes were equipped with 3-inch submersible pumps which run through an inverter, allowing for variable discharge rates. Based on the tests conducted and the limitation of the 3-inch pump diameter, the following ranges are obtainable form the current installation.

- HWELL-B1: 0.1 L/s to 0.9 L/s (at 75 m horizontal distance)
- HWELL-B2: 0.1 L/s to 0.6 L/s (at 60 m horizontal distance)

During the time of the study, the reticulation system to the Pollution Control Dam was yet to be installed. Although no formal monitoring programme was implemented yet, the time was used to test the pumps and reticulation up to a transfer dam. Two piezometric data loggers were installed within the

Table 2 *Pumping test summary*

Borehole	Screened section (m)	Pump intake (horizontal) distance (m)	Constant discharge rate (L/s)	Time (m)	Max. drawdown (m) at pump intake
HWELL-B1	102	47	0.84	480	4.23
HWELL-B1	66	45	0.54	960	5.05

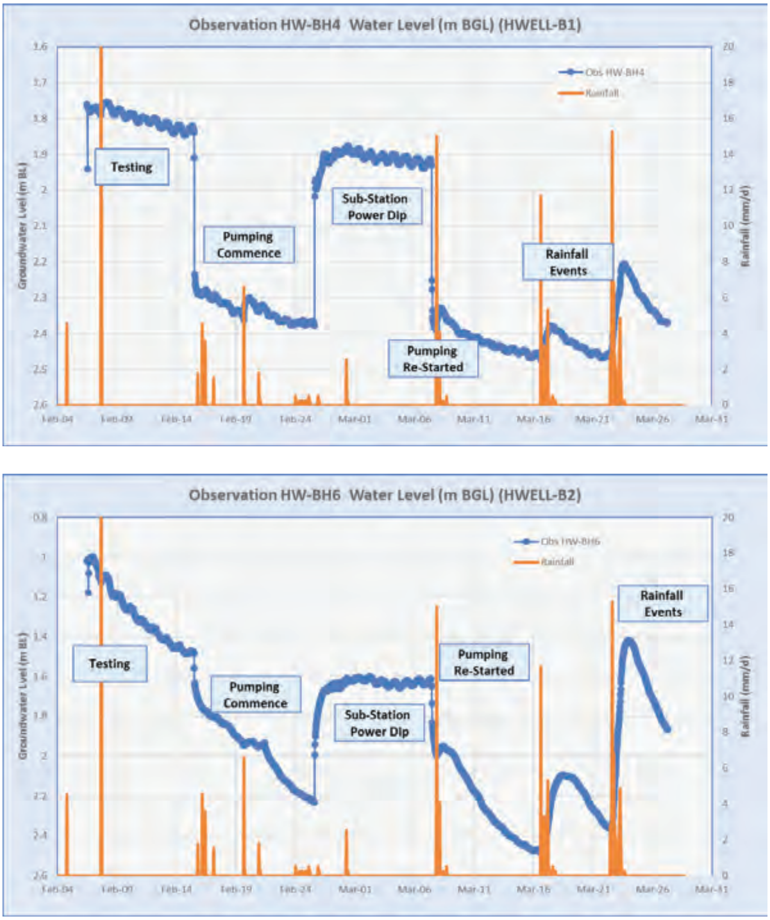

Figure 4 *Drawdown results from longer term tests.*

observation boreholes closest to the completed horizontal boreholes. Pumping rates were commissioned on preliminary licensed abstraction figures (established pre-drilling of the horizontal boreholes), namely 0.54 L/s for HWELL-B1 and 0.23 L/s for HWELL-B2. The drawdown results for the longer-term testing period are shown in Figure 4. No continuous pumping of the horizontal boreholes was possible due to power surges in the substation providing electricity to the pumps, resulting in a recovery of water levels during down-time. The system is currently being investigated to ensure an uninterrupted power supply to the pumps. While the results indicate drawdowns within the perimeter of the horizontal borehole, the larger zone of influence will only be determined once the site-specific monitoring programme becomes operational.

Updated post-closure model predictions indicate that pumping should continue beyond 15 years post closure, until source depletion (i.e. reduction of seepage rate once active deposition onto the TSF cedes and the TSF is rehabilitated) and natural attenuation of the remaining plume after pumping ceased prevents unacceptable plume concentrations reporting to the receptor (tributary). Figure 5 depicts the seepage plume with a cut-off value of 70 mg/L after 15 years post closure with the commissioning of the two existing horizontal wells. While it appears that the distribution and pumping rates assigned are sufficient to limit the plume migration, it's only with ongoing monitoring and post-audits that model predictions can be verified.

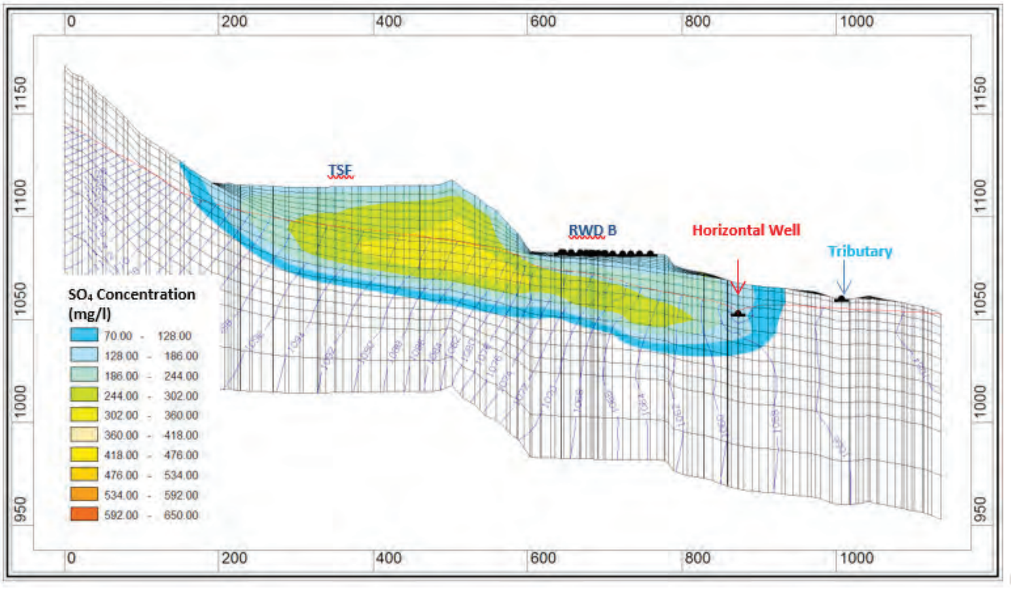

Figure 5 *Cross section showing simulated plume extent 15 years after hydraulic plume containment using horizontal boreholes commenced.*

Conclusions

Hydraulic containment of seepage plumes emanating from an unlined TSF and RWD in the eastern limb of the Bushveld Igneous Complex was required to prevent impacts on a downstream river and ensure legal compliance. Detailed geophysical and intrusive investigations as well as numerical modelling assisted in the delineation of zones of preferential weathering and ultimately groundwater flow and transport pathways. These were intercepted using two horizontal scavenger boreholes. Current pumping rates are based on licensed abstraction limits, but will be adjusted once a site-specific monitoring programme is initiated to delineate the zone of influence and to determine the effectiveness of the scavenger system.

References

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