Cost Effective Method to Depressurise Perched Aquifers to Prevent Slope Failures in Open-Pit Mines, South Africa

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Abstract

Effective depressurising and/or dewatering of localised perched aquifers at open pit mines is often overlooked. An investigation was initiated to develop a practical and cost-effective solution to depressurise a localised perched aquifer and if successful develop a step-by-step guide for similar scenarios. The depressurisation system was designed and installed based on the conceptual model that was constructed by conducting a detailed survey of seepage zones along the highwall of the open pit mine and reviewing available geological, hydrogeological, and geotechnical data. The investigation concluded that it is possible to develop a practical and cost-effective solution to depressurise localised perched aquifers.

Keywords: Depressurisation, slope failure, perch aquifer, open pit mine

Introduction

The depressurising and/or dewatering of localised perched aquifers at open pit mines is often overlooked. The focus generally remains on lowering the regional groundwater level to below the lowest mining elevation. Perched aquifers within the study area have led to seepage zones directly linked to slope failures within the softer geological layers/units, causing a risk to mine safety and production. A perched aquifer is an aquifer that is isolated from the regional water table and is generally a relatively small body of water with an impermeable base underlain by an unsaturated zone (DWA 2011).

Conventional depressurising systems (such as in-pit horizontal drain holes and sumps) requires large capital expenses. A practical and cost-effective solution was required to abstract and dispose of the groundwater at the source.

Materials and Methods

A desktop study was completed to understand the nature of the highwall failures by reviewing the available hydrogeological-, geotechnical-, and geological conceptual site models in conjunction with pit face mapping. This information was used to design a practical and cost-effective depressurisation system.

A cost-benefit analysis was conducted that compared the capital expenditure between the proposed depressurisation system and conventional slope protection mechanisms at high-risk slope failure areas. The capital expenditure required for rehabilitation if single-and multi-bench failures was also included in the analysis.

The depressurisation system installed, consisted of abstraction, injection, and monitoring boreholes. The pore pressures at the study area were monitored for a period of nine months (baseline data) before the pumps for groundwater abstraction was commissioned. Abstraction took place over a period of 26 months.

Site Description

Topography and Climate

The surface elevation at the mining site ranges between 1210 and 1305 mamsl and slopes towards the south. To the west of the mining area, prominent hills striking north to south, rise above the plains.

Climatic conditions are semi-arid, with an annual rainfall (MAP) that ranges between 300 mm and 500 mm. Rainfall is received in the summer months and generally in the form of thunderstorms. The average maximum temperature ranges between 17 and 31 and the average minimum temperature ranges between 6 and 21 (South African Weather Service 2019)

Regional Geology

The study area lies geologically within the Paleoproterozoic Transvaal Supergroup, deposited within two distinct fault-controlled basins known as the Transvaal- and the Griqualand West Basins(Alchin and Botha 2006). The basins formed on the rocks of the Archean Kaapvaal craton during the intracratonic extension on the stable Kaapvaal-Limpopo-Zimbabwe block. The Transvaal basin contains a succession of siliciclastic and volcanic rocks, while the Griqualand West basin consists mainly of volcanic rocks and chemical sediments such as the Postmasburg Group (fig.1).

Local Geology

The study area is located within the Griqualand West Basin of the Transvaal Supergroup at the southern tip of a narrow north-south trending belt of iron- and manganese-bearing lithologies within the southern extent of the Maremane Dome and the western edge of the Kaapvaal Craton (fig. 2). The underlying geology of the region was subjected to protracted series of events (Thomas and Basson 2015) such as intensive structural

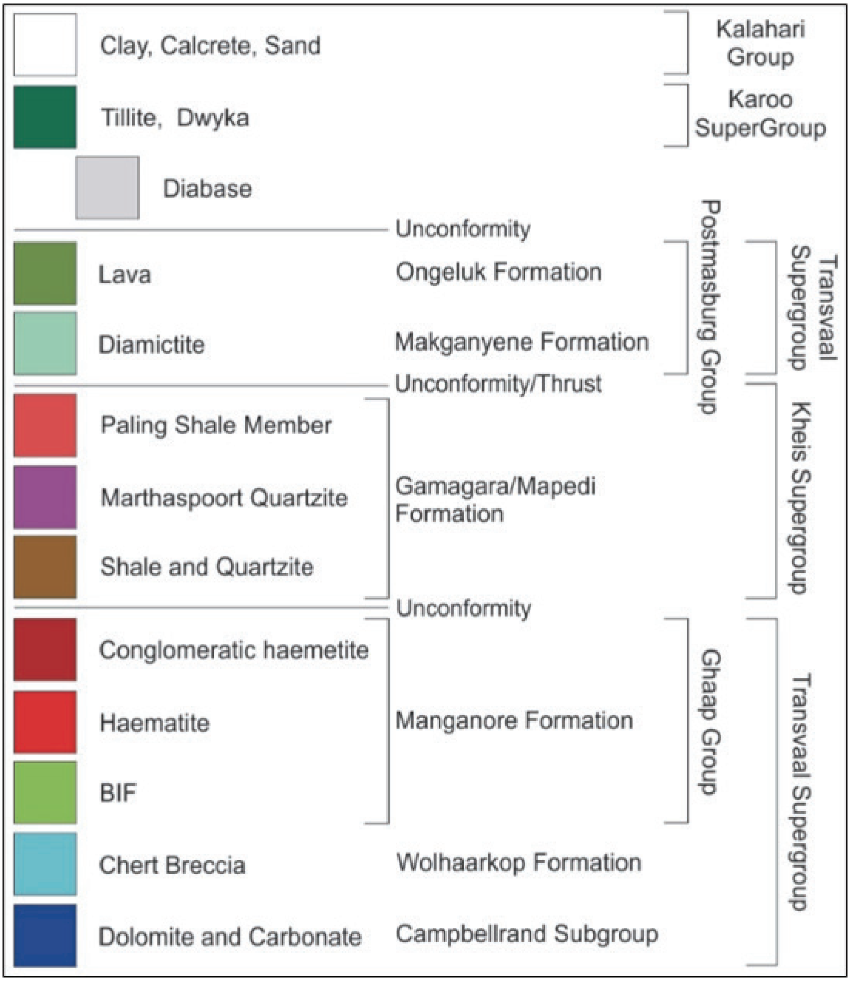

***Figure 1** Simplified lithostratigraphy (Steenekamp 2005)*

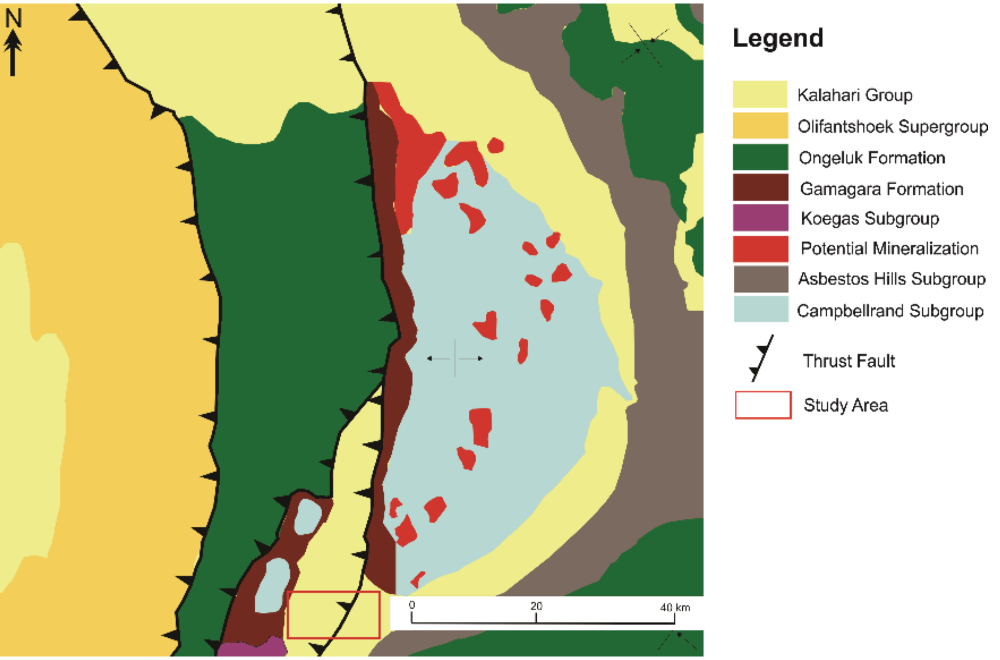

Figure 2 *Simplified geology map (modified from Carney and Mienie 2003)*

deformation in the form of thrusting, folding, and faulting that led to a series of northwest-southeast (NW-SE) striking fracture zones (Carney and Mienie 2003).

Hydrogeology

Three significant aquifers have been identified in the area (fig. 3) (Viljoen 2006). The first is the upper semiconfined to unconfined primary aquifers that occur in the sand and calcrete underlain by a clay mainly tillite in most cases with yields of less than 2 L/s. The aquifer usually develops on contact between the calcrete and the underlying clay formation of the Kalahari Group. The surrounding communities mainly use this aquifer for potable, and livestock water and the groundwater are on average 0-60 mbgl. This investigation focuses on the perched aquifers within the Kalahari Group, which mainly comprises the calcrete cut off from the fractured rock aquifers below by the tillite that acts as an aquitard.

The second aquifer is associated with fractures, fissures and joints, and other discontinuities within the older Transvaal Supergroup geology, primarily within the banded iron formation, hematite, gabbro, and chert breccia. The yield consistently pumps within the fractured rock aquifers varies from 1 L/s to 40 L/s at an average depth from 60 m to 120 m.

The third and highest yielding aquifer is located within the permeable dolomite. Groundwater is found within an interconnected karst and fractured rock dolomitic aquifer that produces yields from 20 L/s – 60 L/s at depths of between 120 m to 400 m.

The natural groundwater level has been lowered, and the absence of seepage into dry monitoring boreholes indicates that the geology has been dewatered to below 200 mbgl in the vicinity of the mine pit. The groundwater intercepted in the pit is predominantly situated within dolomitic fractures. The water level drawdown from the mine dewatering programme is relatively homogeneous within a two-kilometre radius around the study area. The natural groundwater flow direction is in a north to south direction. The main water-bearing geological structures feeding the fractured rock aquifers were found to be vertical or near-vertical northwest to southeast (NW-SE) faults (fig. 4).

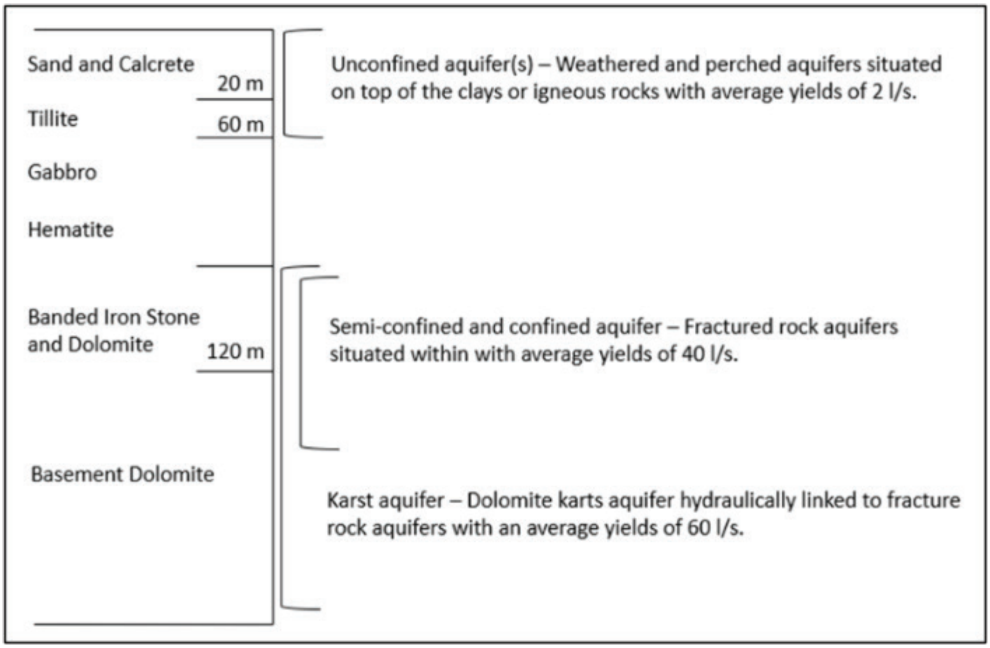

Figure 3 Aquifers and associated lithological units

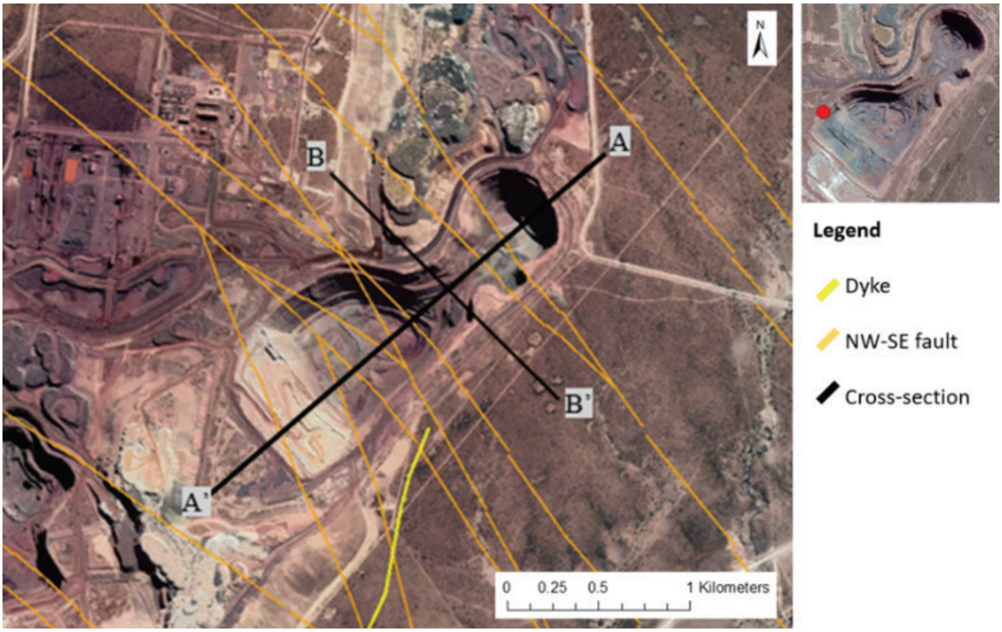

Figure 4 Major geological structure superimposed on the mining pit

Results and Discussion

The perched aquifer has been identified as isolated pockets of groundwater situated within the unconfined upper weathered aquifer with two phreatic zones within the Calcrete (Phreatic Level1) and Clay/Tillite (Phreatic Level 2) lithologies on the western side of the mine pit (fig.5). The regional water level within the mining area has been lowered to 250 mbgl. The phreatic zones indicated that the shallow groundwater levels of 8 mbgl in the calcrete and 55 mbgl in the clay/tillite show that the perched aquifer is disconnected from the major fracture rock aquifers and can be identified as perched as per the definition.

Face Mapping

The face-mapping identified six main seepage zones on the third, fourth, and fifth bench (10 m benches) of the western wall of the mining pit (fig. 6). A series of slope-parallel faults also occurs (fig. 6). It was estimated that there was at least 200 kPa driving pressure along the highwall before failure occurred (Beale 2017).

Depressurisation System Design

The depressurisation system was designed based on the seepage zones identified. The system design is illustrated by fig. 7. The basic system is designed to allow for water to be abstracted at the abstraction boreholes and then injected at injection boreholes which targets dolomitic aquifer. The water levels and pore pressures response to abstraction can then be measured with the vibrating wire piezometers (VWP) installed in the monitoring boreholes.

Cost Benefit Analysis

Based on a high probability of failure for the study area, the financial expenditure was calculated, and three options were considered: i. No mitigatory actions and allow for slope failure repair should a controlled failure take place; ii. install geotechnical controls in the form of catch fence and wire mesh to control rockfall, and iii. Installing a slope depressurisation system to reduce the probability of failure to acceptable levels. The comparison between the different approaches indicates that installing a depressurisation system is more cost-effective than the other approaches (tab. 1).

Depressurisation System Results

The pressure head in both the calcrete and tillite indicated a sharp decline when the depressurisation system was commissioned

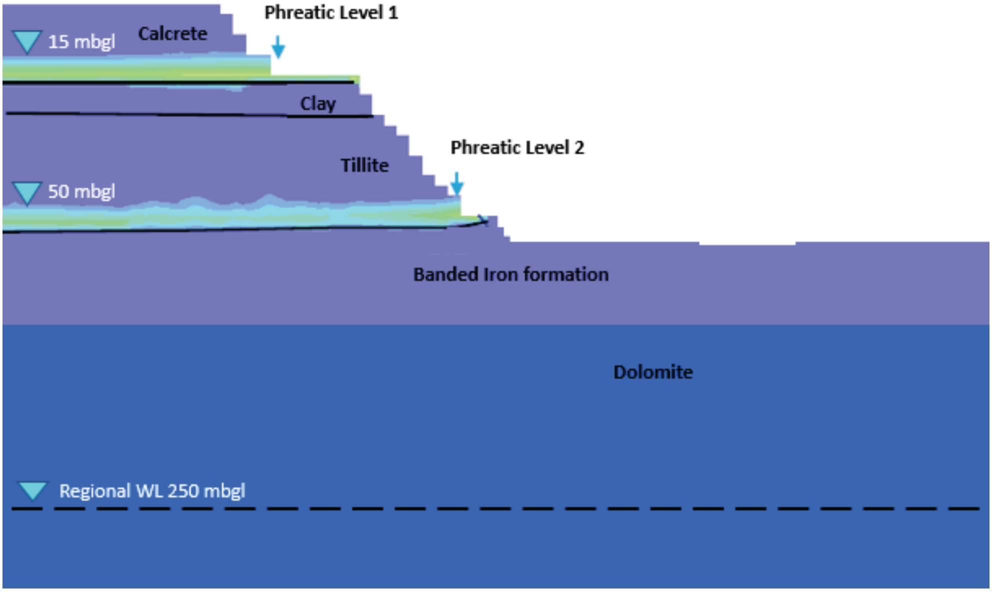

Figure 5 *Perched aquifers phreatic zones*

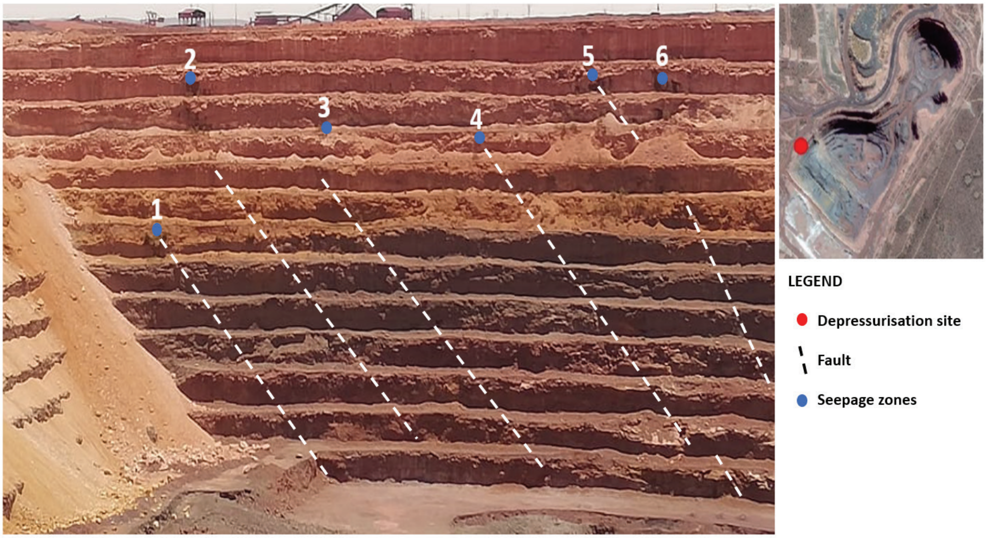

Figure 6 *Seepage zones along the western wall*

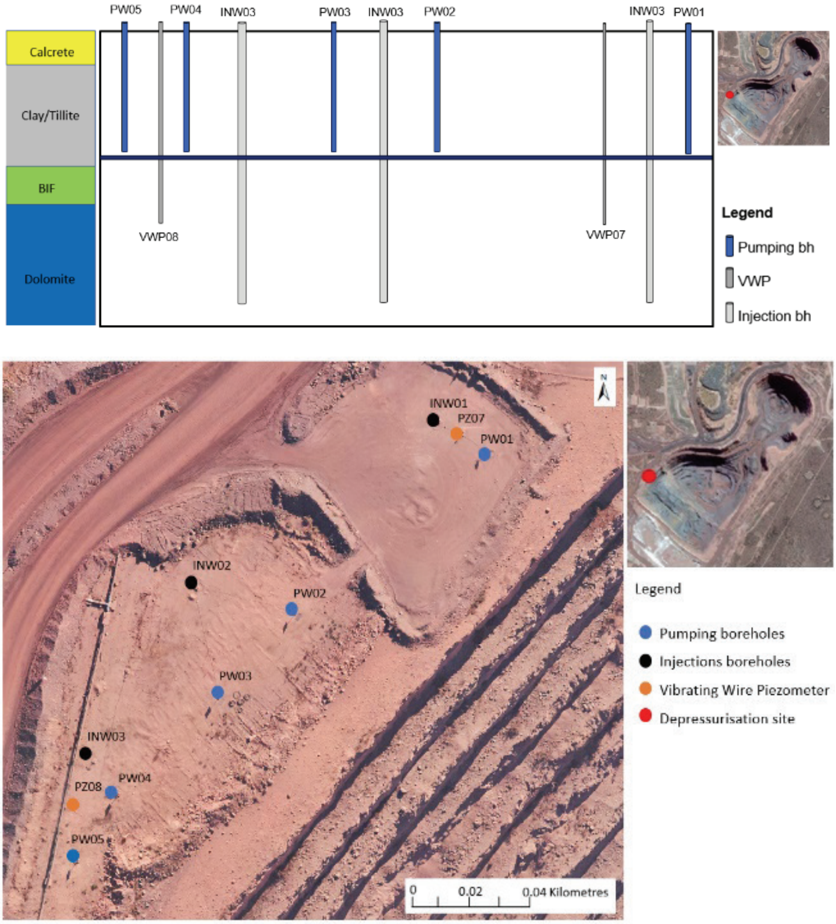

Figure 7 *Depressurisation system design*

Table 1 *Estimated expenditure comparison*

Item	Single bench	Double bench	Triple bench
Slope Failure Rehabilitation			
Slope failure repair – material removal	R 2 400 000	R 4 800 000	R 7 200 000
Gross revenue loss – no expit ore	R 12 849 315	R 19 273 972	R 25 698 630
Total	R 15 249 315	R 24 073 972	R 32 898 630
Installing geotechnical controls			
Geotechnical Catch Fence	R 4 000 000	R 4 000 000	R 4 000 000
Geotechnical Wire Mesh	R 560 000	R 1 120 000	R 1 680 000
Radar Deployment and monitoring	R 5 000 000	R 5 000 000	R 5 000 000
Total	R 9 560 000	R 10 120 000	R 10 680 000
Depressurisation System			
Drilling Cost			R 4 788 000
Equipment -Vibrating Wire Piezometers			R 800 000
Equipment - Solar Pumps			R 175 000
Installation			R 250 000
Total			R 6 013 000

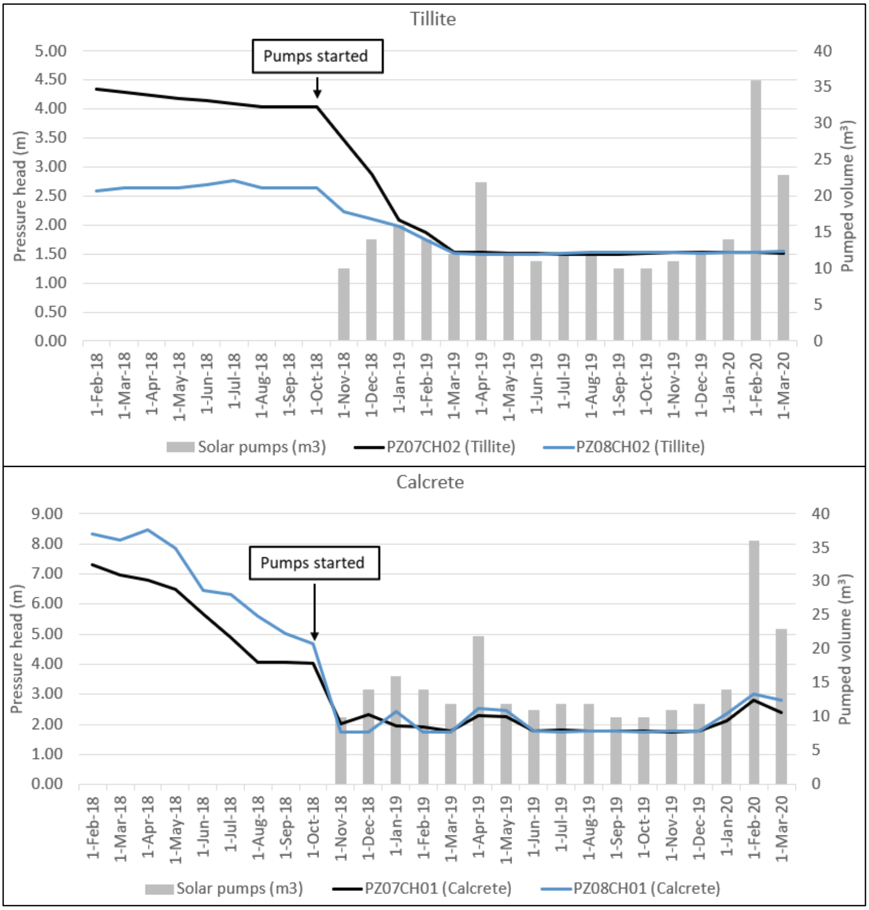

Figure 8 *Pressure head change in the calcrete and tillite*

(fig. 8). After the initial decline, the pressure head in the calcrete and tillite remained stable, therefore indicating that the pore pressures could be lowered and maintained at acceptable levels. These results prove that the depressurisation system is effective and can reduce the risk of slope failures.

Conclusions

The depressurisation system effectively reduced and maintained the highwall pore pressures to acceptable levels, therefor illustrating that it is possible to develop a practical and cost-effective solution to depressurise localise perched aquifers.

The lessons learned from the investigation were used to develop a step-by-step guide to plan, finance, implement, and monitor a depressurisation system in similar hydrogeological and geotechnical conditions. Hydrogeologists and mining engineers can use these guidelines as a generic plan when planning a depressurisation system.

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