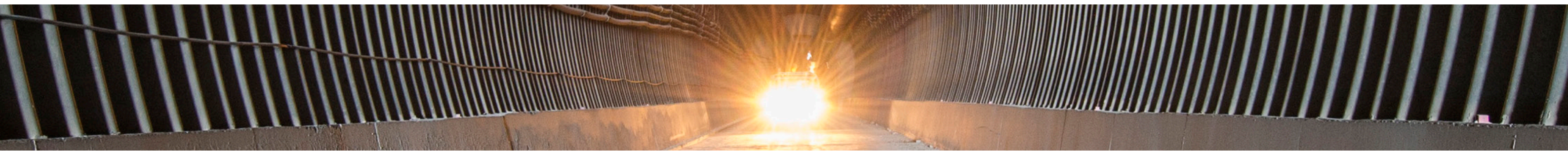
Appendix 10

Groundwater impacts from Ranger 3 Deeps



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TECHNICAL MEMORANDUM

DATE: 28 April 2014

FROM: John Sigda and John Pickens
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TO: Stephen Booth and Peter Anderson
Energy Resources of Australia, Ltd

SUBJECT: Groundwater Impacts from R3 Deeps

1.0 INTRODUCTION

Energy Resources of Australia Ltd (ERA) engaged INTERA Incorporated (INTERA) to assess potential impacts to groundwater from depressurization of the proposed R3 Deeps (R3D) underground uranium mine, located at the Ranger mine site near Jabiru, Northern Territory, Australia. Construction of the R3D mine decline began in late 2012 and is expected to be completed in early 2015. Mining of ore is planned to begin in mid-2015 and continue to the end of 2020. This memorandum describes the approach used to determine the potential impacts and the results of the analyses.

For the purposes of this document, depressurisation refers to the decrease in groundwater head caused by the presence of atmospheric conditions and water extraction (dewatering) during underground mining operations. Depressurisation of underground mines in low-permeability rock effectively removes water from in and around the mine workings but does not require that any overlying water table be lowered down to the elevation of the mine workings. Mine dewatering causes depressurisation of a volume of rock within the formations surrounding the mine. This volume of depressurisation increases during the period that the mine is open and decreases during the post-closure period to approach no-mining conditions.

The objective of this assessment is to evaluate potential groundwater impacts of the R3D mine workings during construction, operations, closure, and post-closure stages. Potential groundwater impacts are defined by three performance measures: drawdown, groundwater discharge to Magela Creek, and the amount of time needed for shallow groundwater heads to recover near to no-mining conditions. Drawdown is defined as the reduction in groundwater heads caused by mine depressurisation. The discharge of groundwater into Magela Creek surface water is the most important interaction between groundwater and surface water for this assessment. A reduction in groundwater discharge to Magela Creek that is attributable to depressurisation of the R3D workings may constitute a potential impact. The amount of time necessary for groundwater heads to recover to values near to no-mining conditions, defined as drawdown that is less than 5% of its maximum, following completion of mining is also considered as a performance measure.

2.0 APPROACH

INTERA carried out simulations of groundwater flow with and without the R3D mine workings present to determine potential impacts as defined by the performance measures. The three-dimensional groundwater flow model developed to quantify solute egress from integrated closure of Pit 3 and R3 Deeps (INTERA, 2014) was adapted to simulate mine depressurisation and quantify the performance measures. The modelling approach used in this assessment follows the same approach used to simulate post-closure groundwater flow and transport for integrated closure of Pit 3 and R3 Deeps (INTERA, 2014). Model boundary conditions representing recharge, evapotranspiration, and creek stages were identical to those in the INTERA (2014) model. Barring changes needed to represent the open mine workings, hydraulic properties were identical to those in the INTERA (2014) model. The following sub-sections describe how the INTERA (2014) groundwater flow model was revised and used to carry out the impact assessment.

2.1 Modelling Mine Depressurisation

Construction of the entire R3D mine was conservatively assumed to be complete on 1 January 2013 and left open until the end of 2020. In actuality, mining of stopes is planned to occur from mid-2015 to the end of 2020, during which time, mined out stopes will be immediately backfilled with a cemented paste aggregate fill with tailings (cemented PAF with tailings). Consequently, this is a “worst case” assumption because all of the R3D mine workings are assumed to be open, thus requiring depressurisation, for longer periods than will be required for mining.

The depressurisation model was constructed using the INTERA (2014) groundwater flow model. Boundary conditions were added to implement the depressurisation and the hydraulic properties of model cells with workings were changed as needed to represent the removal of rock from mining.

Drain boundary conditions were assigned to each model cell containing a stope, a tunnel, or a section of the decline. The drain stage was set to the bottom elevation of the model cell. The decline and tunnels were assumed to be covered with shotcrete. The drain conductance for decline and tunnel cells was calculated using the geometric average of shotcrete hydraulic conductivity values from Jeoung et al. (2008), 1 x 10^{-4} m/day, if the hydraulic conductivity of the host rock was higher; otherwise the drain conductance was calculated using the host rock hydraulic conductivity. The drain conductance for a stope was assumed to equal the host rock hydraulic conductivity.

Hydraulic conductivity values were specified for each model cell containing mine workings based on whether it contained a stope, tunnel, or decline. Cells with stopes were assigned a large hydraulic conductivity value of 10,000 m/day because all or nearly all of the cell volume will be mined out. Tunnels and decline sections occupy roughly 6% of the volume of model cells used to represent them. Host rock conductivity was used for decline and tunnel cells for two reasons. First, no water flows through the mine void, but is instead removed from the cell by the drain. Second, groundwater must flow through the host rock to reach the void. Hydraulic properties for all other model cells remained identical to those in the INTERA (2014) model.

Initial groundwater head values for the mining period simulation were determined by simulating groundwater flow in the absence of R3D mine workings (no-mining conditions) and taking the final head values at the end of a 10,000-year simulation period. The resulting initial head value, called the no-mining head values, represent the groundwater system in the absence of the R3D workings. No-mining conditions are defined for the purpose of this assessment as resulting from a groundwater flow system that is in equilibrium with the climate and the final post-closure landform. No-mining conditions provide a conservative estimate of the potential impacts because the no-mining groundwater heads are much higher around Pit 3 and the R3D workings than the present day groundwater heads, which have been lowered through drainage to Pit 3.

The model was run as a transient system to allow heads surrounding the R3D mine to change over the 8-year mining period. Drawdown was calculated as the difference between the simulated head and the no-mining head for each model cell.

2.2 Modelling Depressurisation Recovery

The recovery model was constructed by running the INTERA (2014) post-closure flow model with hydraulic properties for mine elements representing post-closure conditions and the final head values from the depressurisation model described above as initial head conditions. R3D stopes are simulated as having been backfilled with cemented PAF with tailings and decline sections were simulated as having been backfilled with cemented rock fill. Groundwater heads from the depressurisation model's final time step, i.e., the end of 2020, were used as the initial conditions for the recovery model. Drawdown was calculated as the difference between the simulated head and the no-mining head for each model cell.

2.3 Quantifying Performance Measures

Model results were used to quantify each of the three performance measures. Drawdown and groundwater discharge to Magela Creek were quantified using the depressurisation simulation. The amount of time necessary for groundwater heads to recover to near to no-mining conditions was quantified using the recovery simulation.

Maximum drawdown was calculated for each model cell by subtracting the groundwater head in a cell from the depressurisation simulation at the end of 2020 from the pre-mining groundwater head for that cell. Contours of maximum drawdown were plotted for model layer 1 and along model column 72, which represents the stopes nearest to Magela Creek, and column 90, which represents the deeper stopes (Figure 1).

Changes in groundwater discharge were determined by calculating the volumetric flux into the reach of Magela Creek immediately downgradient from the mine workings. The R3D discharge zone (Figure 1) represents the reach of Magela Creek that is downgradient from the R3D mine and so is most likely to be affected by R3D depressurisation. In the INTERA (2014) model, transfers between groundwater and Magela Creek surface water are simulated using the General Head Boundary (GHB) boundary condition. The Magela Creek GHB cells in layer 1 simulate groundwater discharge to Magela Creek surface water by removing groundwater at a rate defined by Darcy's law when groundwater head exceeds the surface water stage. Volumetric groundwater flux leaving the GHB cells in the R3D discharge zone was calculated using the boundary reach reporting tool in the Groundwater Vistas graphical user interface (Rumbaugh and Rumbaugh, 2007) to extract and sum the appropriate cell-by-cell fluxes from the .CBB output file. Groundwater discharge to the R3D discharge zone was calculated for the no-mining model and for the depressurisation model using the output values for the end of 2020.

The amount of time necessary for shallow groundwater heads to recover was determined by examining layer 1 drawdown from the recovery simulation over time. Recovery is assumed to be attained when layer 1 drawdown is less than 5% of the maximum drawdown from the depressurisation simulation.

3.0 RESULTS

3.1 Mine Depressurisation

Figures 2A and 2B compare the pre-mining heads for the shallow groundwater flow system, represented by model layer 1, with those from the depressurisation simulation at the end of 2020. Groundwater heads show no significant differences over the entire domain except near the entrance to the decline (Figure 2A). Depressurisation locally altered the shallow groundwater flow system within a very small area near the decline entrance (Figure 2B).

Drawdown in the shallow groundwater system at the end of 2020 is approximately 11 m at the decline entrance, but the 0.01-m (1-centimetre) drawdown contour remains far (roughly 400 m or more) from Magela Creek (Figure 3). At the depths of the stopes, drawdown is much greater than that in the shallow groundwater system. Drawdown is more than 200 m near the deep stopes and tunnels shown along model column 72, but the maximum drawdown is less than 0.01 m at depths of 16 to 20 m below the Magela Creek sediments (Figure 4). Along column 90, maximum drawdown is more than 400 m in the deep mine workings, but it is less than 0.01 m within 400 m of Magela Creek (Figure 5).

As drawdown varies with depth, the overall lateral extent of drawdown also varies. A drawdown envelope was created from model results across all depths to show the farthest lateral extent of 0.01 metres of drawdown (Figure 6). The envelope is the largest possible outline of all 0.01-m drawdown values; all drawdown values outside the envelope are less than 0.01 m. The 0.01-m drawdown envelope is more than 2 kilometres (km) from the Brockman and Magela borefields, demonstrating that R3D depressurisation will not cause any measureable drawdown at the water supply bores.

Groundwater discharge to Magela Creek within the R3D discharge zone (Figure 1) is about 35 litres per minute (L/min) for the no-mining conditions simulation (Figure 7). This flux rate represents a “baseline” groundwater discharge from model cells that represent the portion of Magela Creek that is downgradient from the proposed R3D mine footprint. With R3D depressurisation, the groundwater discharge to Magela Creek within the R3D discharge zone remains at about the baseline flux rate of 35 L/min (Figure 7), deceasing by less than 0.03% (0.01 L/min) from the baseline flux rate over the entire mining period.

3.2 Groundwater Recovery

The groundwater recovery simulation revealed that drawdown in the shallow groundwater system caused by R3D depressurisation quickly recovers. Eight years after closure of the R3D workings, drawdown in the shallow groundwater flow system has decreased to slightly more than 0.1 m at the decline entrance (Figure 8A), which is approximately 1% of the 11-m maximum drawdown observed in the same location at the end of mining (Figure 3). Drawdown is on the order of 0.03 m at the decline entrance 16 years after closure of R3 Deeps (Figure 8B).

4.0 SUMMARY

A conservative modelling approach was implemented with the assumption that the entire R3D mine would be fully open from 1 January 2013 through 31 December 2020 for the mining period simulation. Stopes and the decline were simulated as having been backfilled for the subsequent post-closure recovery simulation. Modelling results demonstrated the following:

- The maximum changes in shallow groundwater heads (drawdown) during the mining period occurred only in the vicinity of the entrance to the R3D decline and did not exceed 12 m.

- There were no measureable impacts to groundwater levels at and near Magela Creek. The 0.01-m (1-centimeter) drawdown contour in the shallow groundwater system is predicted to extend no closer than 400 m from Magela Creek.

- Simulated depressurisation of the R3D mine caused a negligible (less than 0.03%, which is equal to 0.01 L/min) change in groundwater discharge to Magela Creek.

- Measureable impacts from R3D mine depressurisation to groundwater levels at and near the Magela Borefield and the Brockman Borefield are very unlikely because the borefields are located at large distances, greater than 2 km, from the 0.01-m drawdown envelope resulting from R3 Deeps depressurisation.

- Groundwater levels recover quickly after closure of the R3 Deeps mine. Drawdown in the shallow groundwater system decreased to 0.1 m, roughly 1% of the maximum drawdown, within 8 years after closure of R3 Deeps, and to 0.03 m within 16 years after closure.

5.0 REFERENCES

INTERA. 2014. *Solute Egress Modelling for ERA Ranger R3 Deeps Mine Closure*. Prepared for Energy Resources of Australia Ltd. by INTERA Incorporated, Albuquerque, NM USA, 15 March 2014.

Jeoung, J., Lee, S., Lee, G. 2008. Evaluation of Hydraulic Conductivity of Shotcrete Lining Samples. World Tunnel Congress 2008 - Underground Facilities for Better Environment and Safety, India, pp 1703-1710.

Rumbaugh, J. and Rumbaugh, D. 2007. Groundwater Vistas, Version 6.26, Build 24.

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FIGURES

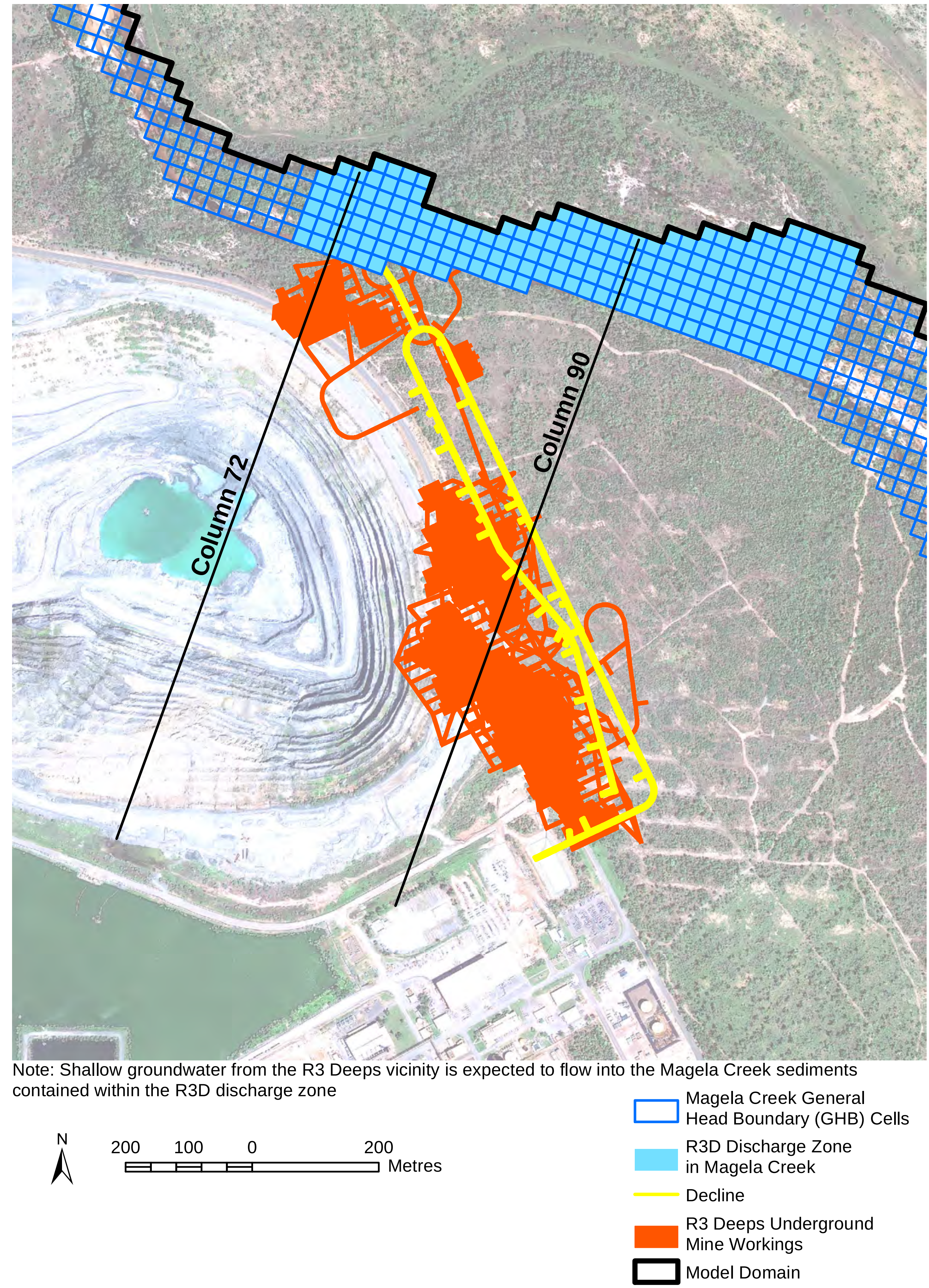

Figure 1: Location of R3 Deeps Underground Mine Workings and Magela Creek

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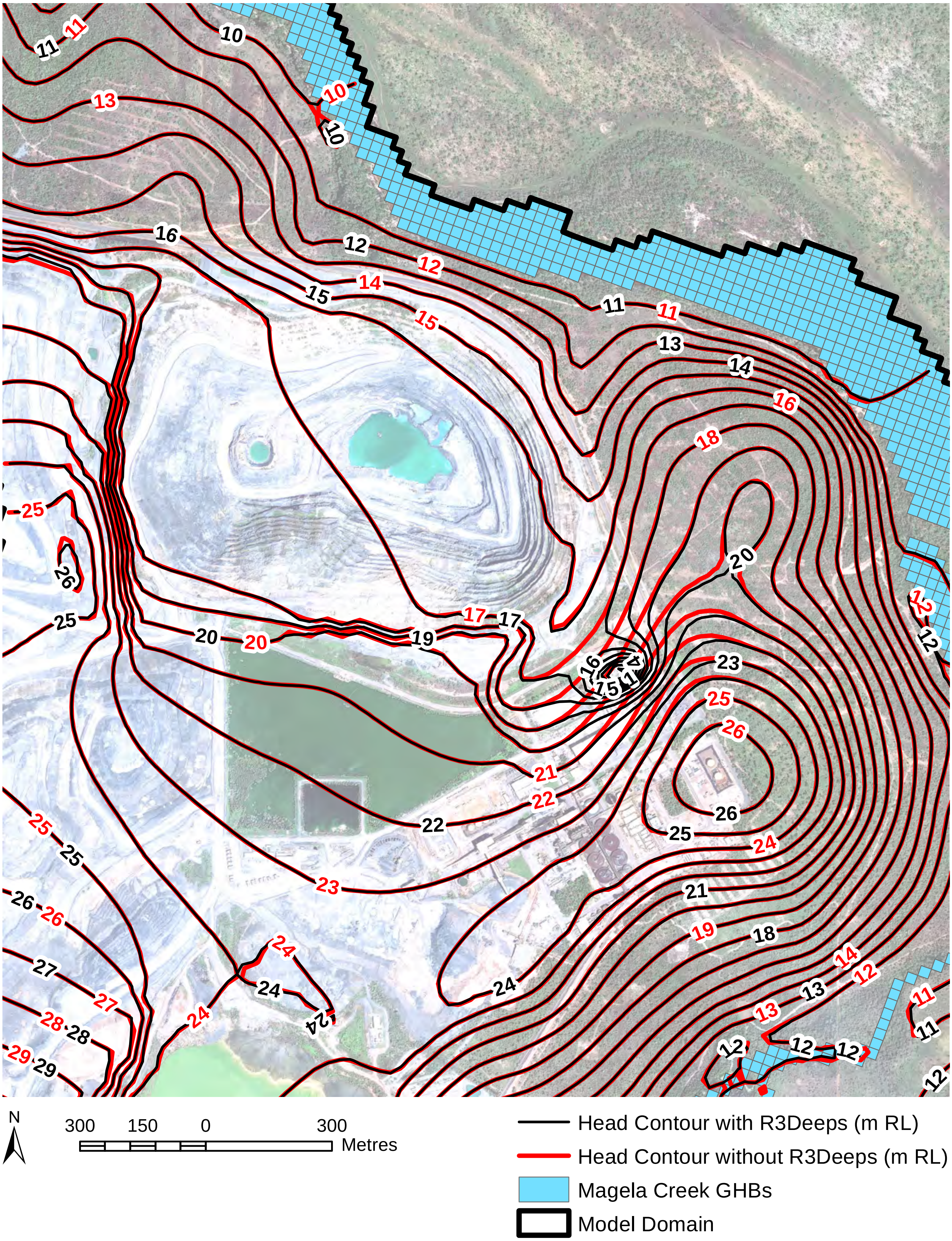

Figure 2A: Comparison of Layer 1 Groundwater Heads at End of 2020 for Simulations with and without R3D Depressurisation

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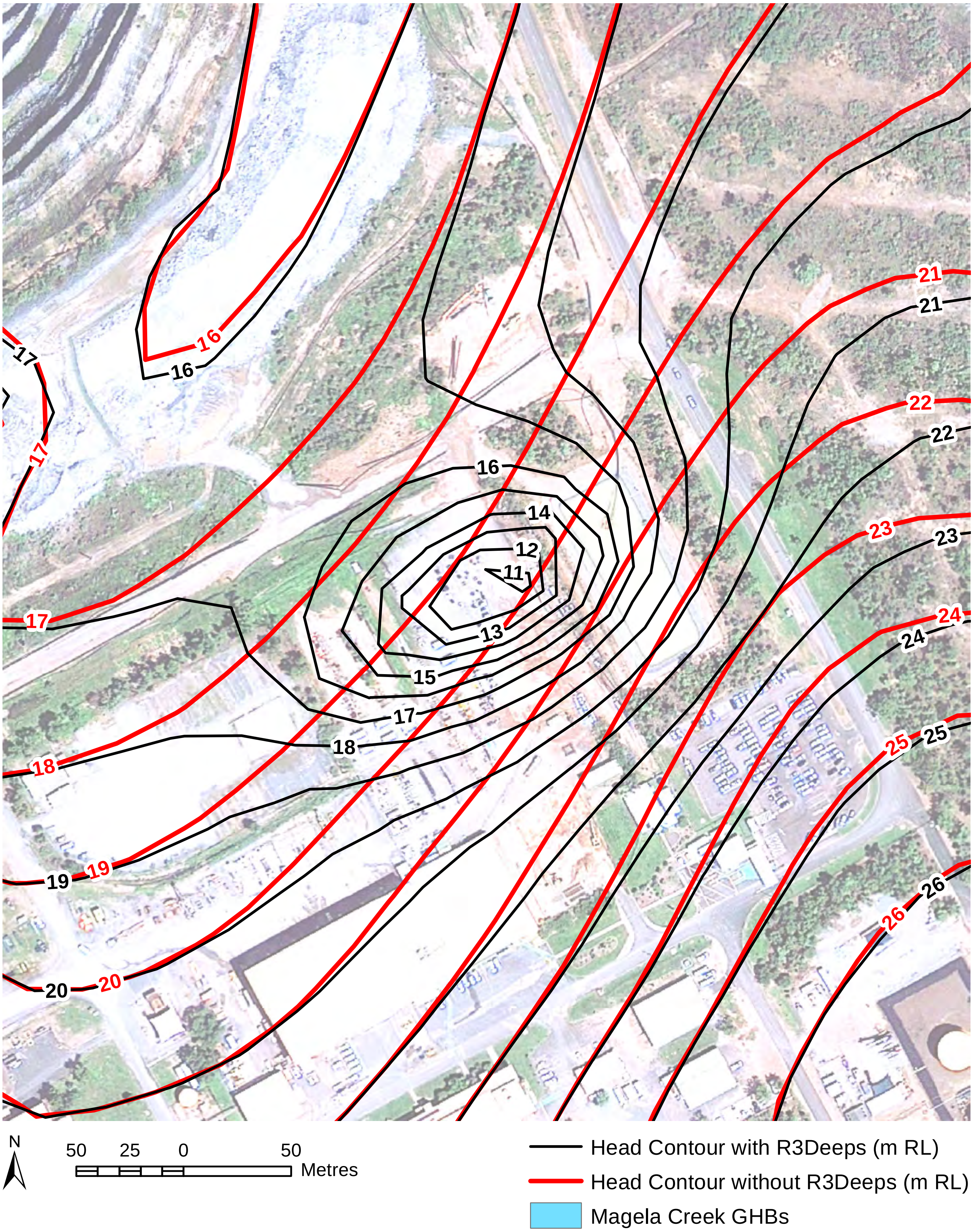

Figure 2B: Comparison of Layer 1 Groundwater Heads in Area with Greatest Drawdown at End of 2020 for Simulations with and without R3D Depressurisation

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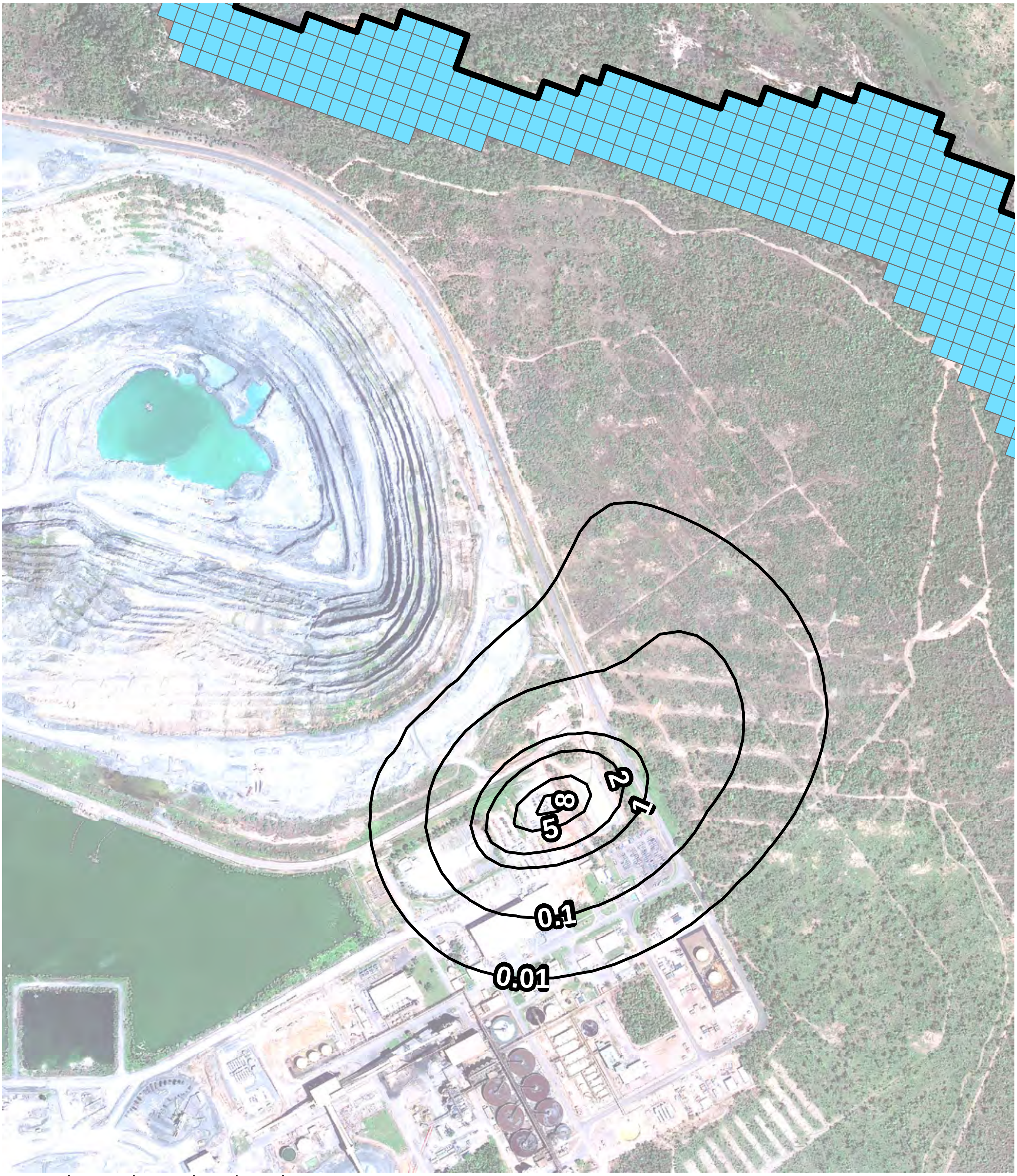

Note: The maximum drawdown is 11.1 metres

Figure 3: Drawdown in Layer 1 at End of 2020

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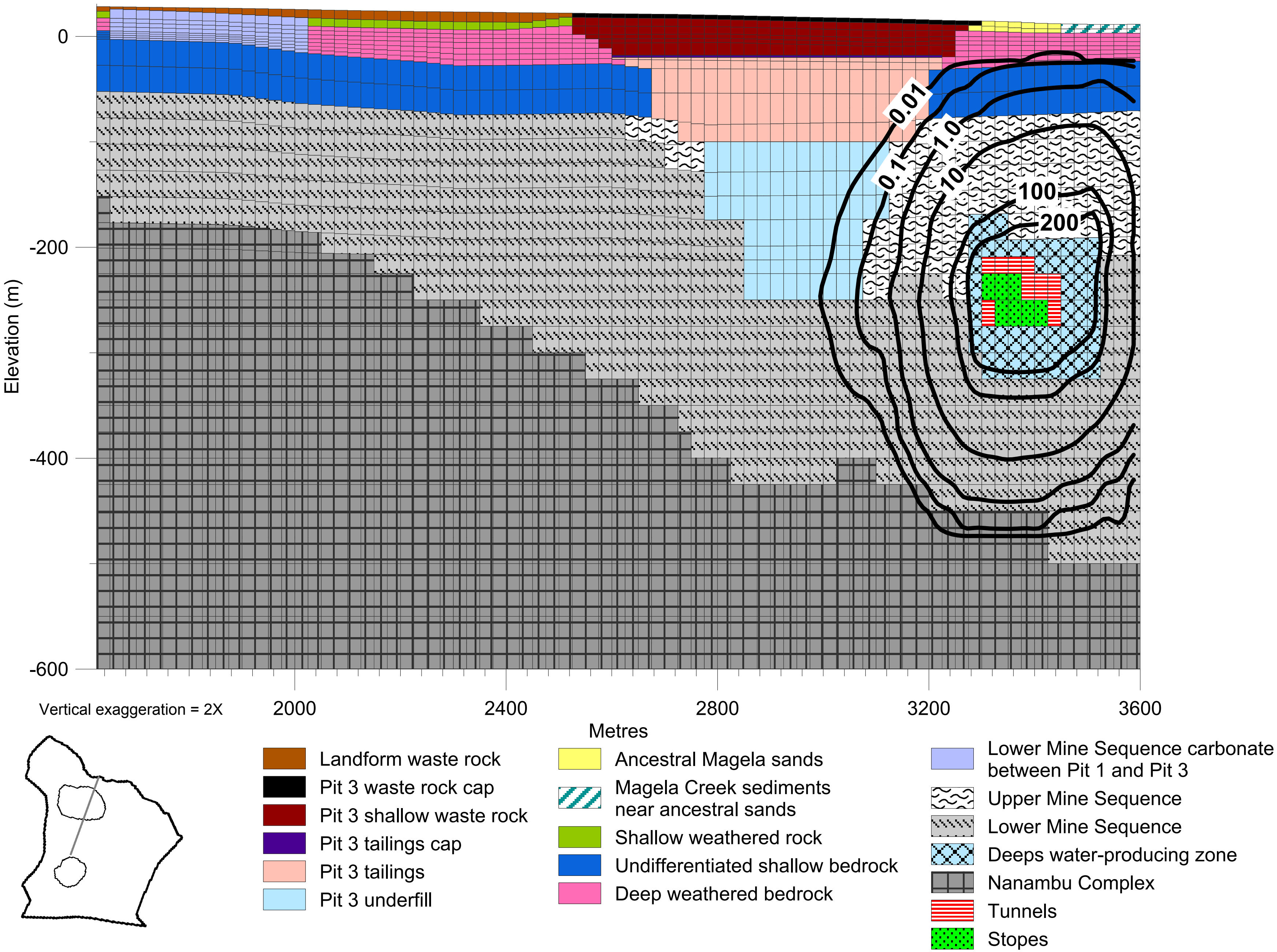

Figure 4: Drawdown (in Metres) Along Column 72 at the End of 2020

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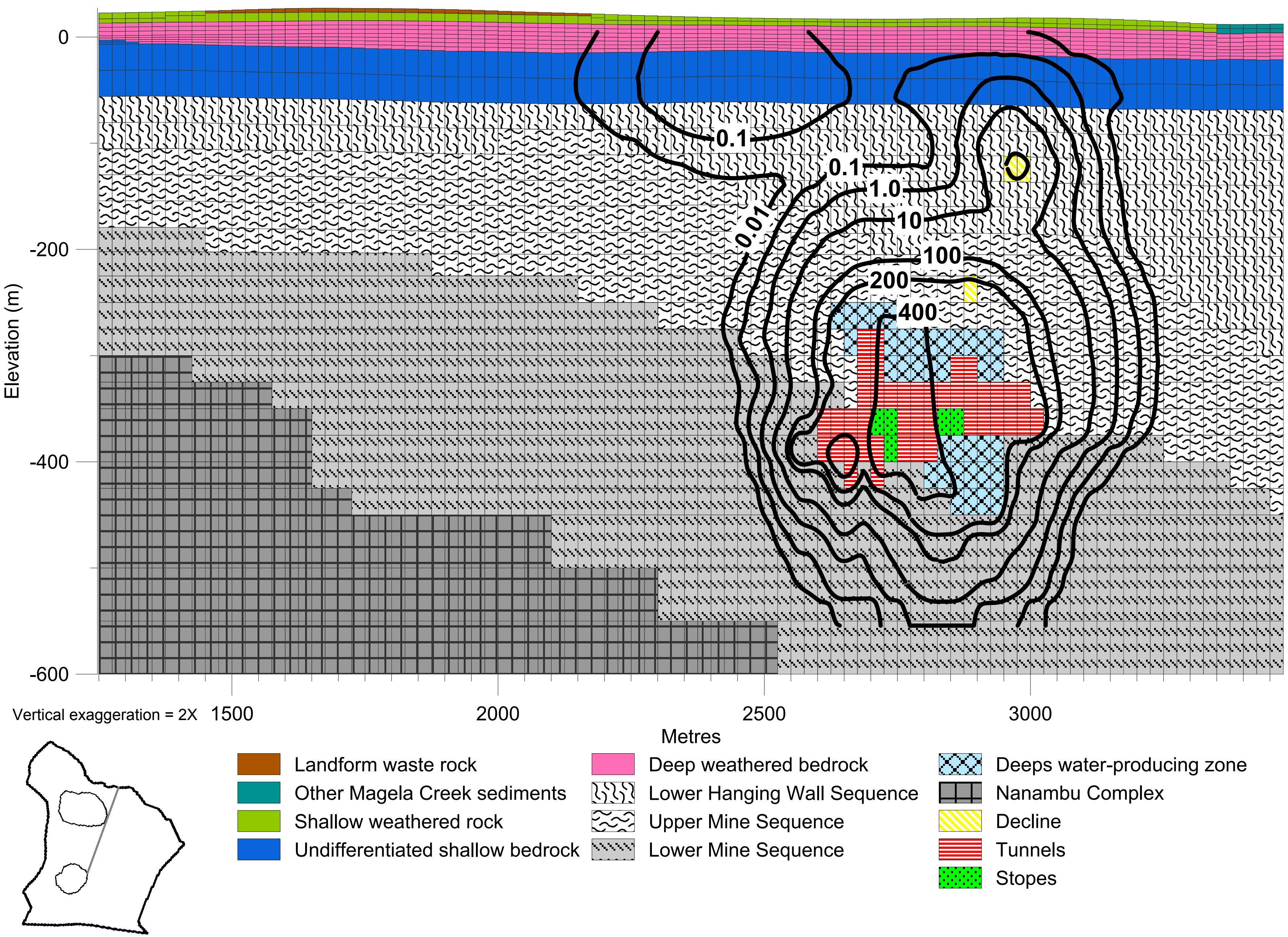

Figure 5: Drawdown (in Metres) Along Column 90 at the End of 2020

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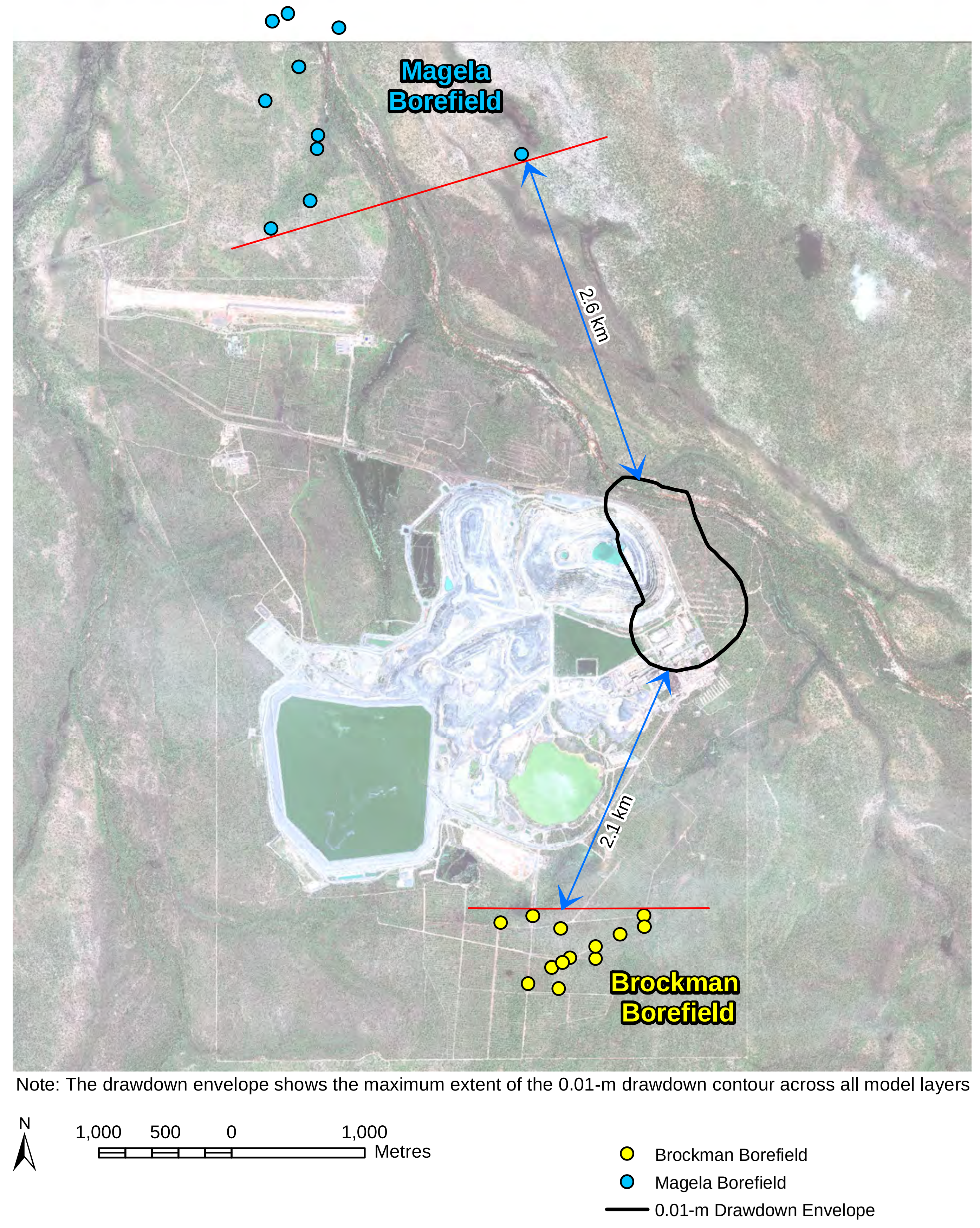

Figure 6: Extent of Drawdown at End of 2020 and Regional Borefields

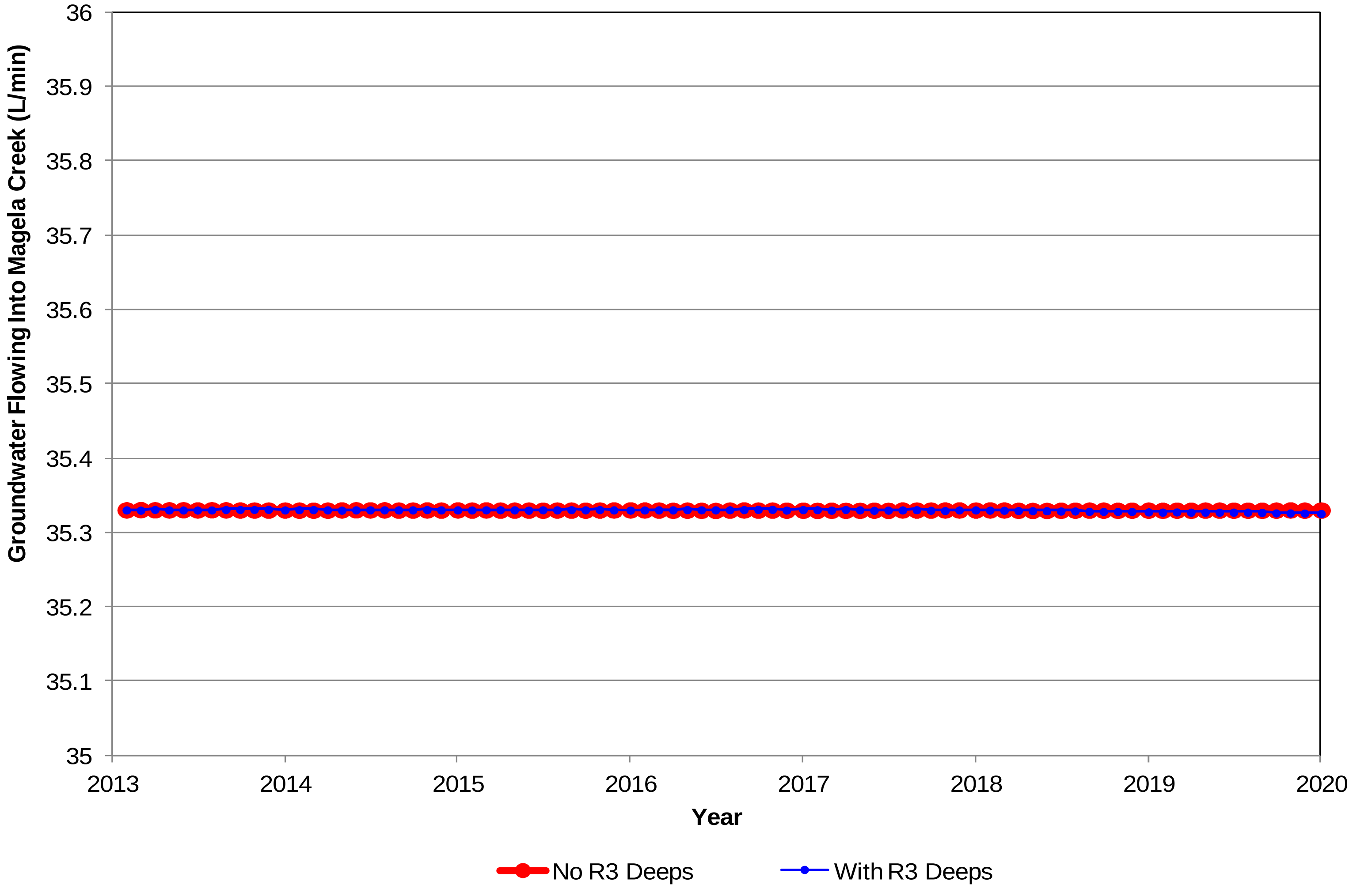

Figure 7: Groundwater Discharge Rate to R3D Discharge Zone in Magela Creek with and without R3D Depressurisation

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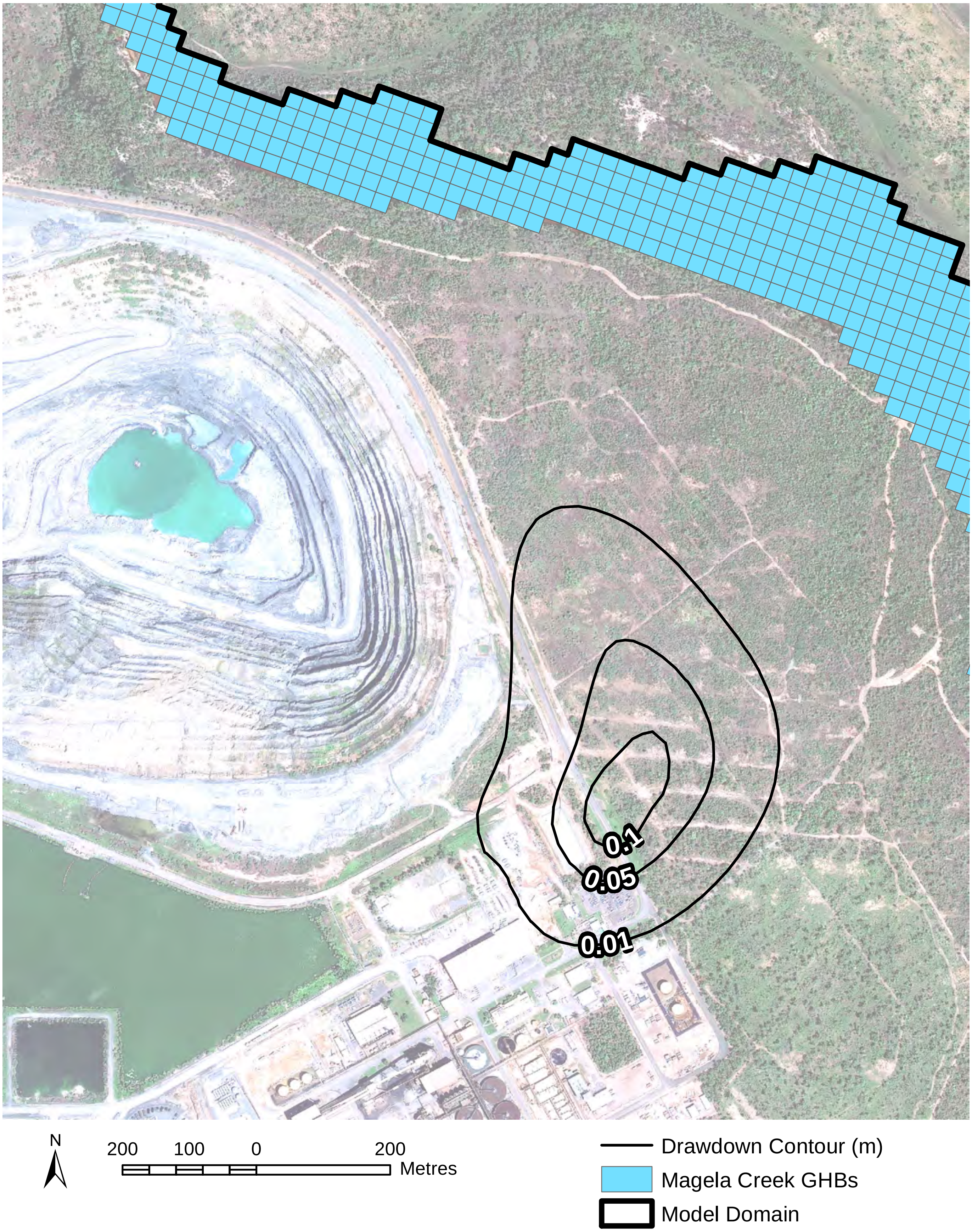

Figure 8A: Drawdown in Layer 1 at 8 years after End of R3D Depressurisation

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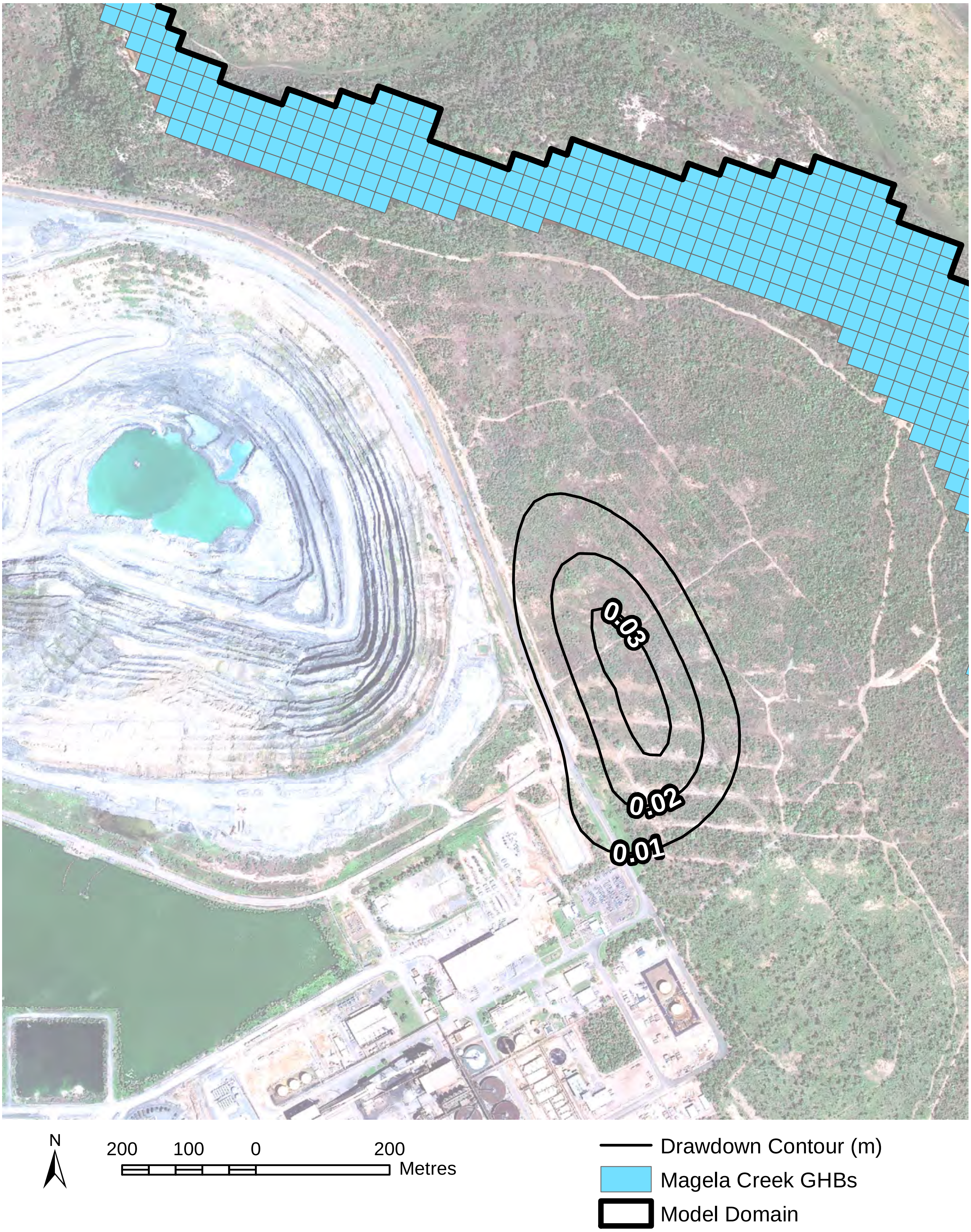

Figure 8B: Drawdown in Layer 1 at 16 years after End of R3D Depressurisation