Caramulla MAR Injection Modelling

5 June 2019

Contents

Introduction

BHP Iron Ore (BHPIO) is developing a Managed Aquifer Recharge (MAR) scheme to inject surplus water into the regional aquifer at Caramulla, east of the South Jimblebar, Wheelarra and Hashimoto mining areas (Figure 1).

Objectives

The objective of this study was to investigate the likely capacity and mounding behaviour of MAR in the regional aquifer in the Caramulla Area.

This was done by:

1. Analysing the available data (pre-development heads and FY19 drilling)
2. Using a numerical model to test the response to MAR considering parameter and conceptual uncertainty. This was done by:
    - Incorporating recent drilling data into the hydrostratigraphic representation in the model
    - Considering uncertainty in terms of hydraulic parameters and conceptualisation
    - Considering two continuous 10 year injection rates of 15 ML/d and 30 ML/d

Hydrogeology

The Caramulla site is characterised by a roughly East-West trending palaeovalley (filled with Tertiary detritals) underlain by the Paraburdoo Dolomite Member of the Wittenoom Formation. Orebodies lie both to the north and south of the palaeovalley and are probably in relatively good hydraulic connection along strike and with the regional aquifers. The unmineralised Brockman Iron Formation probably forms a flow barrier to the north of the orebodies and the Jeerinah formation forms a barrier to the south. Based on preliminary exploration drilling programs which mainly concentrated on the northern and southern ridges for mineralised deposits, it is understood that the sedimentary units are dipping to the north.

To enhance the hydrogeological understanding of the area, the drilling of 25 Monitoring Bores was undertaken in early 2019 (Figure 2). Drilling conditions and geological logging of these holes suggests that:

- A Tertiary detrital sequence extends from 0 m to 85 mbgl.
- The Tertiary detrital contains a clay unit from 20 to 70 mbgl, which appears to be behaving as a confining unit on the aquifers beneath it.
- A vuggy breccia unit is intersected beneath the clay. This forms the detrital base unit, has a variable thickness and was found to extend to over 100 mbgl in places. It is hydraulically connected to underlying Dolomite.
- A dolomite is present below the Tertiary detritals and is weathered within the upper 10 to 20 m.
- Groundwater is intersected at depth ranging from 70 – 90 mbgl, however the standing water levels measured in the bores after construction are recorded at ~50 mbgl.

Previous Modelling

Numerical groundwater modelling was most recently undertaken in FY17 to support the request for an increase to the 5C Licence to abstract up to 22 GL/a (BHP, 2017) and then in FY19 to support internal BHPIO infrastructure decisions (BHP, 2019). Compared to the FY17 model, the latest model has:

- The western hydraulic compartment removed (i.e. everything west of the Central Fault), which is not hydraulically connected to the eastern compartment.
- Changes to hydraulic parameters assigned to the WHASH and the western part of South Jimblebar orebodies and the regional aquifer between them.
- No changes in the Caramulla area.

The model domain is shown in Figure 2.

Hydrogeological Uncertainty

From the drilling results then, one of the key controlling factors in terms of MAR capacity (and major uncertainty) appears to be the occurrence of the clay unit in the majority of holes. Uncertainty associated with this includes the clay layer's:

- Lateral extent,
- Hydraulic parameters and heterogeneity, and
- Continuity

The response to MAR will also be controlled by the hydraulic conductivity of the regional aquifers beneath the clay and also the specific yield of the non-clay Tertiary detritals where the confining clay is not present.

The pre-development heads (Figure 2) are very consistent throughout the area (i.e. a flat water table at about 462 – 464 mAHD) and are in agreement with the heads observed during the latest drilling. Only 15 km to the east do they appear to change (increase) significantly. This suggests the presence of a north-south trending flow barrier in this area which may bound the groundwater system available for mounding.

Modelling Strategy and Set-Up

The FY19 model was simplified by:

- Removing all historical and future mine dewatering and injection
- Introducing new hydrostratigraphic units to assess the uncertainty described above:
    - A clay layer (with different configurations as required; Small, Large and Patchy (Figure 3)) in model layer 1
    - A vuggy breccia / undefined Tertiary detrital zone in layer 2 (and layer 1 either side of the clay)
    - A dolomite zone of uniform thickness (100 m) beneath the Tertiary detritals (in model layers 3 to 5).
- Introducing 4 MAR wells in the weathered dolomite (Figure 4).

- Removing the need for steady state and time variant calibration models by setting the initial heads at a uniform 462 mAHD and running MAR from this starting point.
- Extending the model to the east to coincide with the area where heads indicate the presence of a hydraulic flow barrier.
- Modifying the model run time to 10 years.
- Setting Layers 2 to 7 as confined.

All other model settings were unchanged from the previous version.

Model parameters

The hydraulic parameters of the three key hydrostratigraphies in terms of the response of the groundwater system to MAR are shown in Table 1.

Table 1. Key hydraulic parameters

Hydrostratigraphy	Hydraulic conductivity (m/d)	Specific Yield (%)
Clay	1×10^{-5}	1
Vuggy breccia / non-clay detritals	1 - 20	1 - 15
Weathered dolomite	5 – 20 (T =500 – 2000 m^2/d)	N/A

* The clay parameters were not varied.

The ranges presented for the vuggy breccia and the weathered dolomite are considered to be roughly at the upper and lower bound of what can be expected at Caramulla.

Predictive uncertainty scenarios were constructed based on:

- The three variable hydraulic parameters; one with the high values combined, the other with the low values
- The three clay extent realisations
- Two MAR injection rates: 15 ML/d (5.5 GL/a) and 30 ML/d (11 GL/a).

This required for the running of 12 distinct scenarios, as shown in Table 2.

Table 2. Predictive uncertainty scenarios

Run	Clay	VB / TD K m/d	VB / TD Sy	Dolomite T m^2/d	Injection rate ML/d
1	Large	High (=20)	High (=15%)	High (=2,000)	High (=30 ML/d)
2	Large	Low (=1)	Low (=1%)	Low (=500)	High
3	Large	High	High	High	Low (=15 ML/d)
4	Large	Low	Low	Low	Low
5	Small	High	High	High	High
6	Small	Low	Low	Low	High
7	Small	High	High	High	Low
8	Small	Low	Low	Low	Low
9	Patchy	High	High	High	High
10	Patchy	Low	Low	Low	High
11	Patchy	High	High	High	Low
12	Patchy	Low	Low	Low	Low

Results

The results of injection modelling are provided as hydrographs (Figures 5 and 6) of groundwater level at a hypothetical observation bore (shown in Figure 8) in the regional aquifer beneath the clay in the centre of the MAR borefield. The range of likely outcomes are shaded in the plots. The scenarios correspond to the limit of the expected range, so the most likely result is expected somewhere between them (i.e. in the shaded area).

The limit of mounding is set at 25 m below ground level to avoid impacts to facultative phreatophytes species (i.e. *Eucalyptus victrix* and *E. camaldulensis*) occurring in the area, which are estimated to be able to access groundwater at depths of 20 m bgl The shaded area is also restricted by the 25 mbgl limit to groundwater mounding. This means that the upper limit of mounding is about 495 mAHD. With the heads at 463 mAHD in the MAR borefield area this leaves an available unsaturated thickness for mounding of just over 30 m.

The plots show that:

- There is a high likelihood (greater than 80%) that injection at 15 ML/d can be sustained for at least 3 or 4 years and about a 30% chance that it can be sustained for 10 years.
- There is a much lower likelihood that injection at 30 ML/d will be sustainable for any significant time period.

An example of the predicted mounding in layer 1 (the clay) is shown in Figure 8. This shows that the head in the clay, if it behaves as assumed in the modelling, will increase more slowly than the head in the underlying aquifers. If this is the case, the clay water level will not reach the 25 mbgl mounding limit as rapidly as described above. At this stage in the project however, given the high uncertainty over the lateral continuity and the hydraulic parameters of the clay, this mechanism has not been factored into the assessment.

Conclusions

BHP has analysed a range of possible mounding scenarios, given that the data with which to assess the response of the groundwater system at Caramulla to MAR is limited and therefore predictive uncertainty is very high. This is reflected in the outcomes which suggest that:

- The available mounding thickness is just over 30 m (based on a 25 m bgl cut-off threshold).
- A significant amount of clay has been encountered in the recent drilling exercise in the area of the proposed MAR borefield. Whether this is laterally continuous and how far beyond the drilling it may extend is unknown. Currently it has been assumed to behave as a confining unit to the regional aquifers below.
- The likelihood of mounding from MAR at 15 ML/d staying below the 495 mAHD (25 mbgl) threshold is high for the first few years but becomes less than 50% by 10 years of continuous injection.
- The likelihood of mounding from MAR at 30 ML/d staying below the 495 mAHD threshold is low.

References

BHP, 2017. Jimblebar Detailed Hydrogeological Assessment

BHP, 2019. WHASH data analysis and FY20 dewatering prediction update (Internal document)

Figures

Figure 1. Location map.

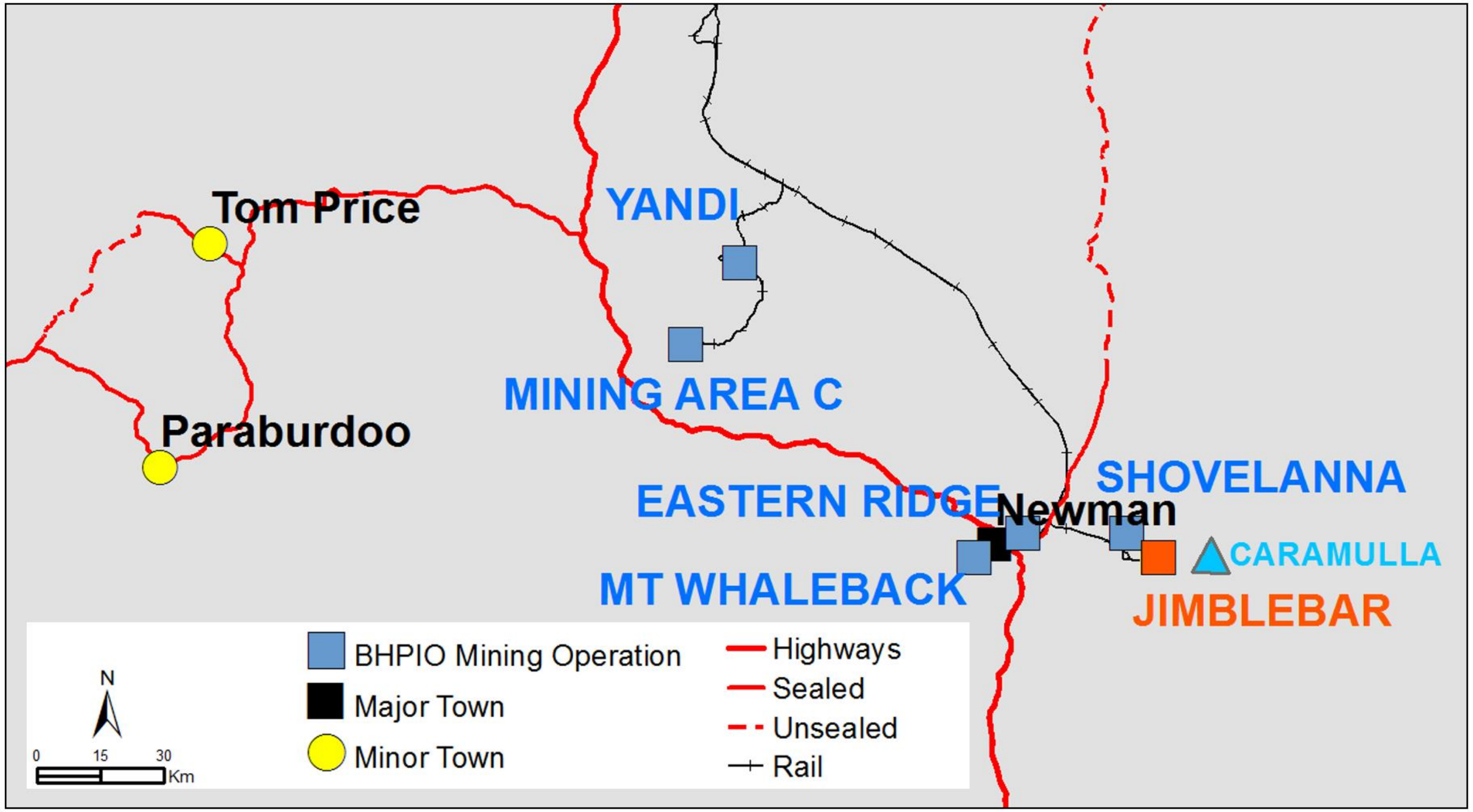

Figure 2. Groundwater levels and recent drilling locations

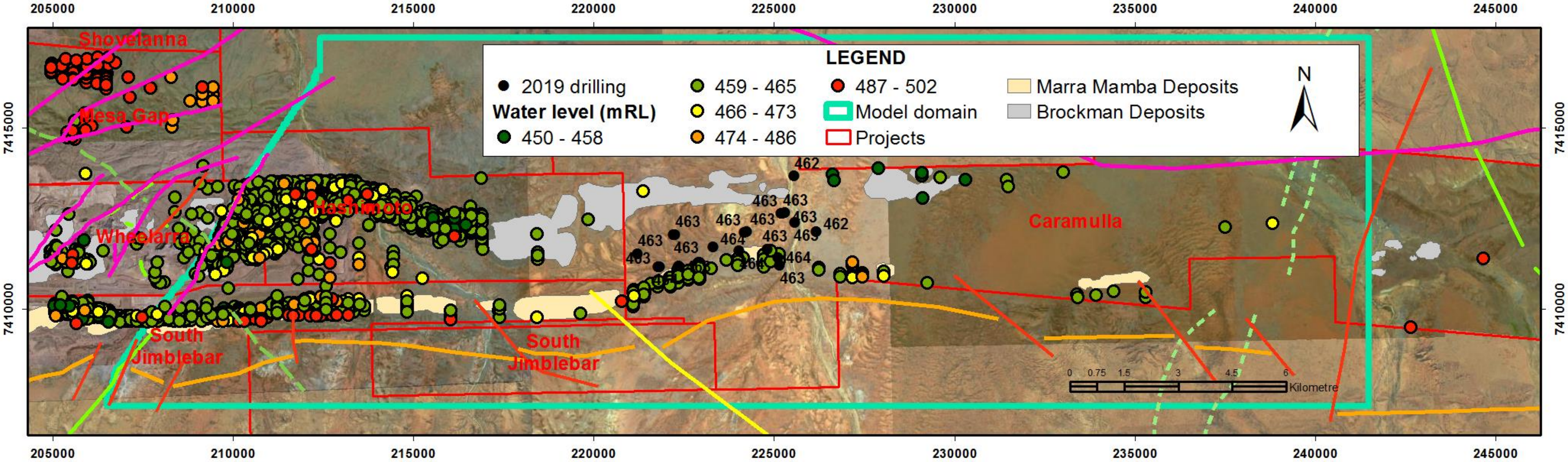

Figure 3. Simulated clay extents.

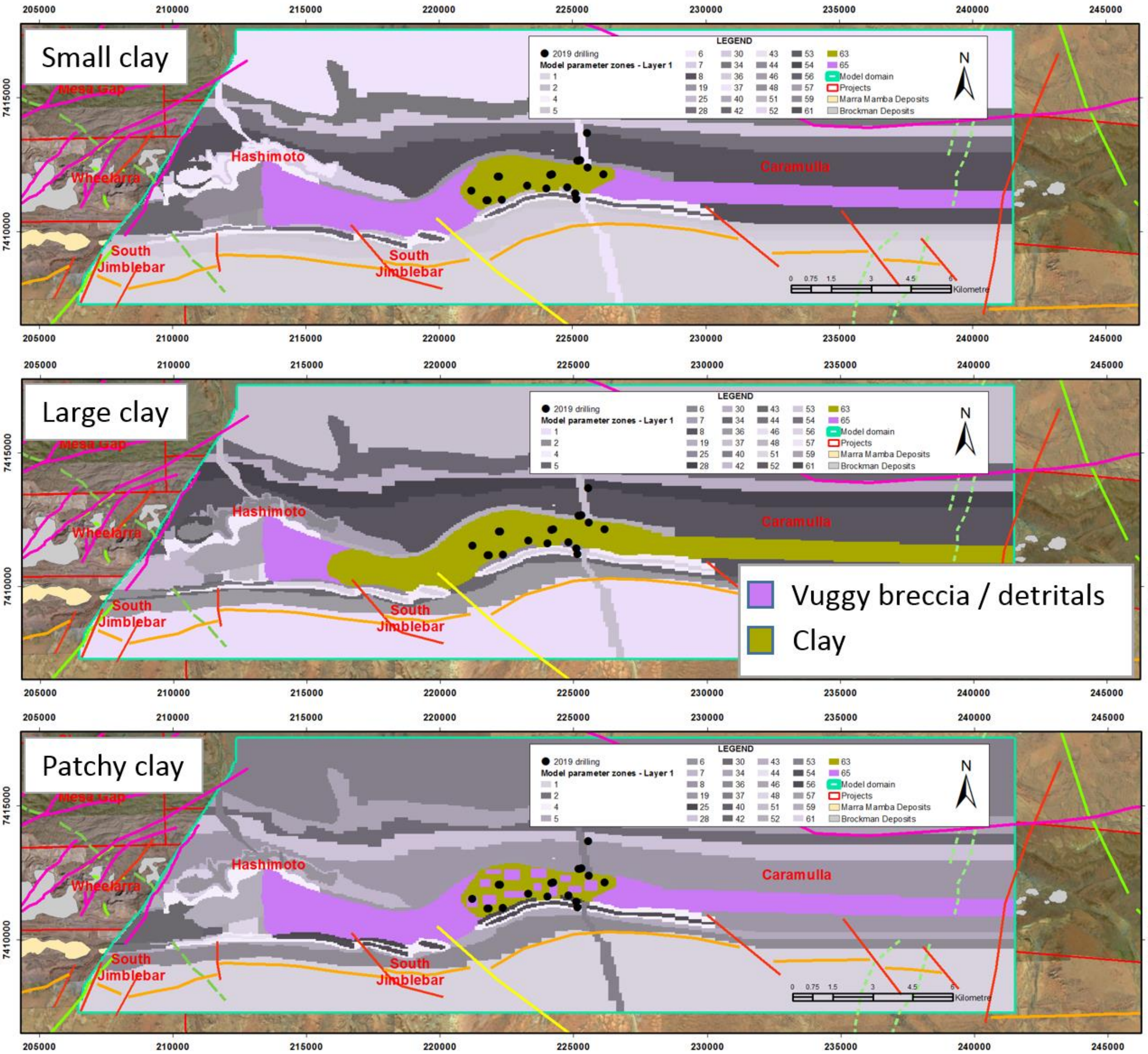

Figure 4. MAR borefield

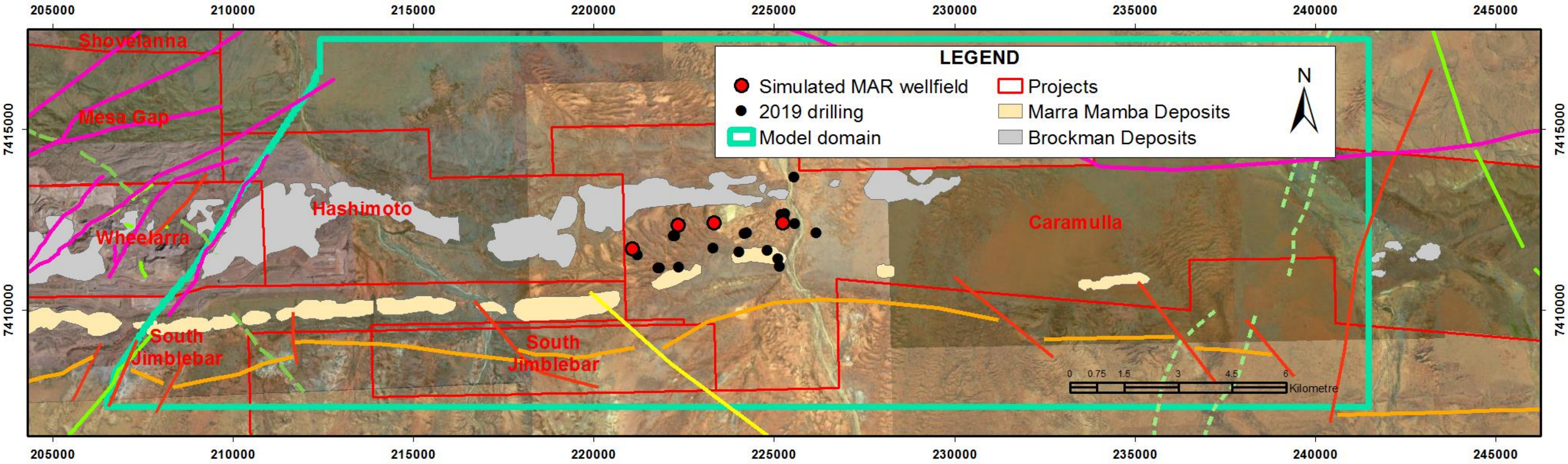

Figure 5. Results from the 15 ML/d simulations

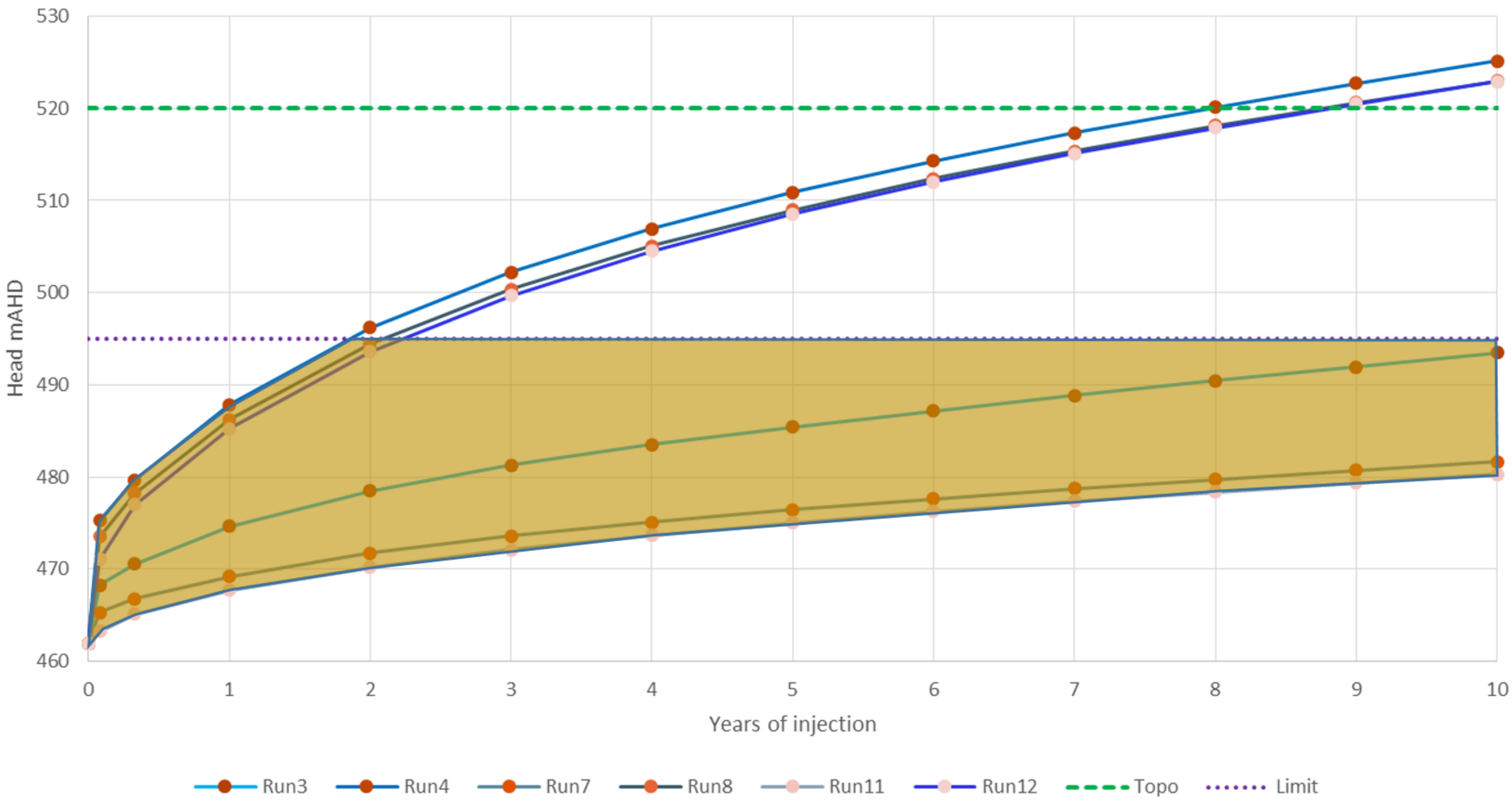

Figure 6. Results from the 30 ML/d simulations

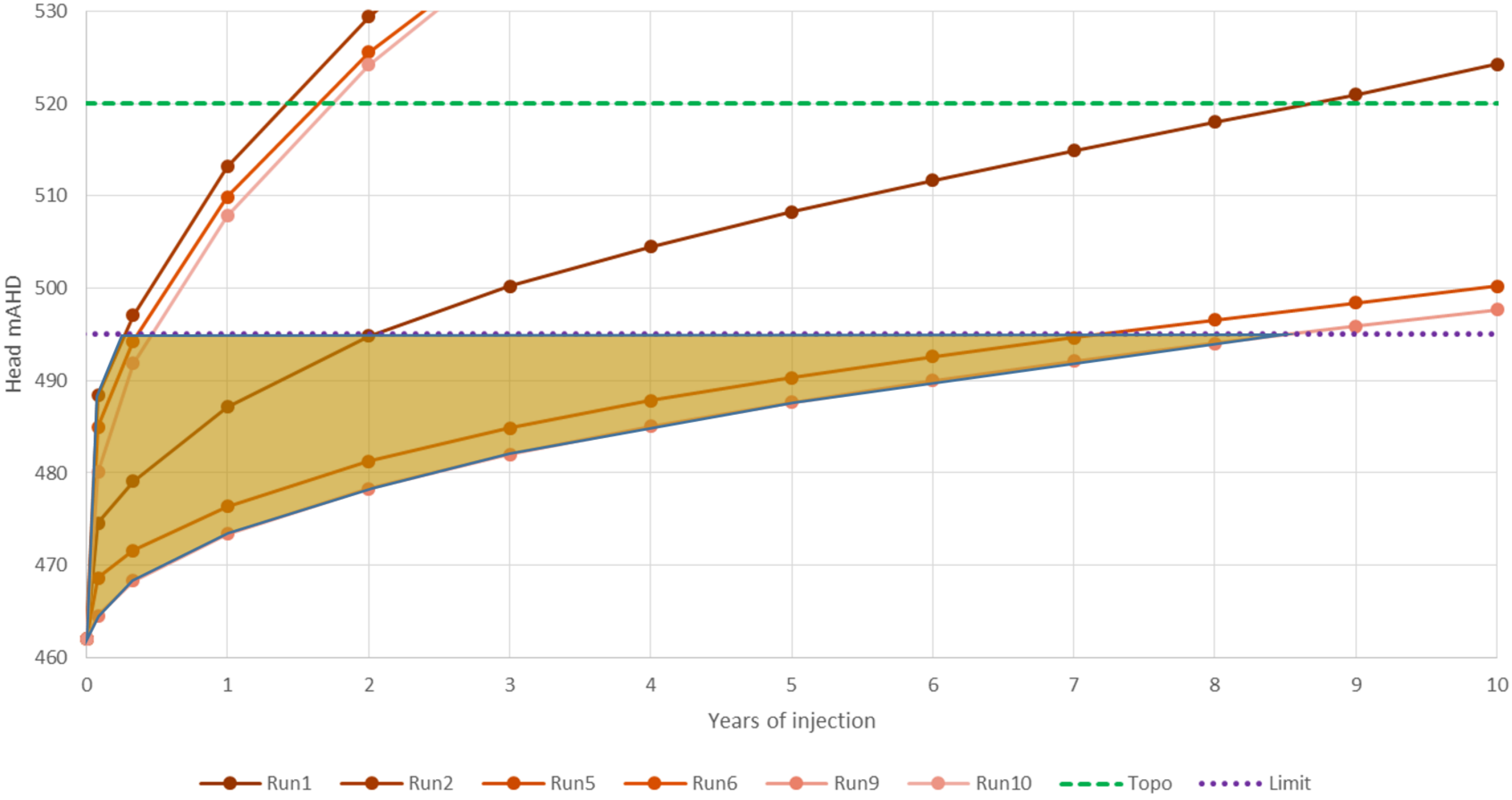

Figure 7. Predicted groundwater mounding after 4 and 10 years (Scenario 1).