BHP

Orebody 29, 30 and 35

Detailed Hydrogeological Assessment

Version: 1.0

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Contents

Figures

1. Introduction

1.1. Overview

The Mount (Mt) Whaleback Operation is located approximately 5 kilometres (km) west of Newman township in the Pilbara region of Western Australia (WA) (Figure 1.1). The existing operations comprises the Mt Whaleback pit and the Orebody (OB) 29, OB30 and OB35 pits (OB29/30/35) and is situated on the Mining Lease (ML) 244SA. The approved Western Ridge project is located immediately south west and west of these operations and is situated on ML244SA, Mineral Lease (M) 266SA and Lease (L) 52/199 (Figure 1.2).

The Mt Whaleback Operations (including OB29/30/35) and Western Ridge are situated in the East Pilbara – Fractured Rock subarea of the Pilbara Groundwater Allocation Plan (DoW, 2013).

BHP proposes to increase the dewatering volume from OB29/30/35, from the current approved volume of 8,000,000 Kilolitres per annum (kL/a) or 22 Megalitres per day (ML/d) to 24,500,000 kL/a or 67 ML/d. This will enable the continued mining below the water table within these mineral deposits (herewith referred to as the Project).

This H3 level detailed hydrogeological assessment report has been prepared for OB29/30/35 in accordance with the Department of Water and Environmental Regulation guidelines *Operational Policy 5.12 Hydrogeological reporting associated with a groundwater well licence* (DoW, 2009). It supports the assessment process under the *Rights in Water and Irrigation Act 1914* (RiWI Act) and Part IV of the *Environmental Protection Act 1986* (EP Act).

This report includes a discussion of the regional setting and provides conceptual and numerical modelling information to support the assessment of impacts from the increase in dewatering of OB29/30/35 on the environment, the water resources and other nearby groundwater users. The information presented in this report is an update of information presented as a Detailed Hydrogeological Assessment supporting document to the Newman Hub (Western Ridge) Derived Proposal submission (BHP Iron Ore, 2022).

1.2. Licences

Groundwater abstraction at OB29/30/35 is currently regulated through the RiWI Act 5c License to Take Water GWL160418(8) which allows the annual abstraction of 8,000,000 kilolitres per annum (kL/a) or 8 GL/a, for the purpose of:

- Dewatering for mining purposes.
- Dust suppression for earthworks and construction purposes.
- Earthworks and construction purposes.
- Mineral ore processing and other mining purposes.
- Mining camp purposes.

BHP is seeking to amend the 5c licence (GWL160418(8)) to increase the dewatering volumes for continued mining below water table, as follows:

- Increase groundwater abstraction via dewatering from 8,000,000 to 24,500,000 kL/a (rounded to nearest whole kL from 67 ML/d).

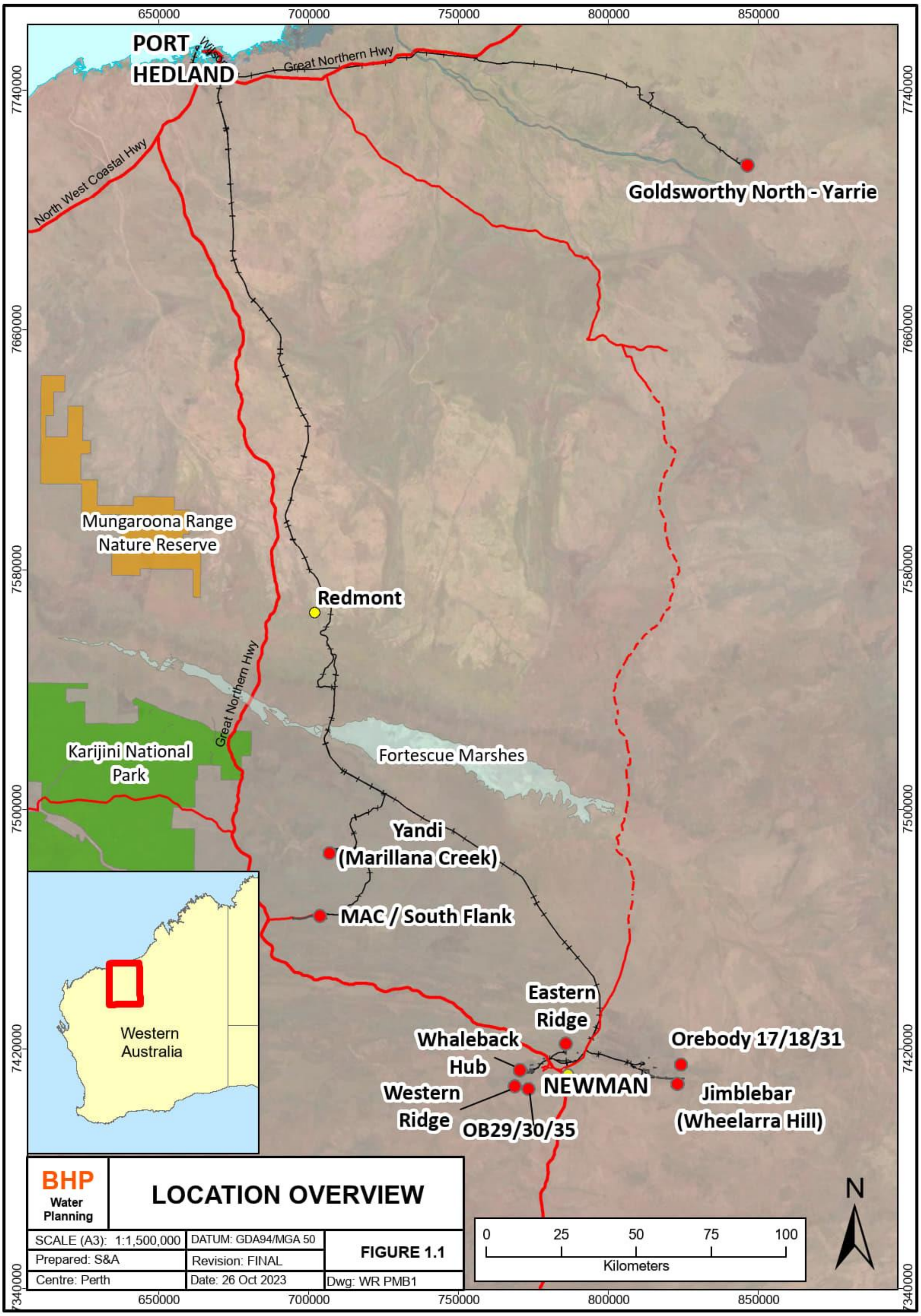

Figure 1.1: BHP operations in the Pilbara region of WA

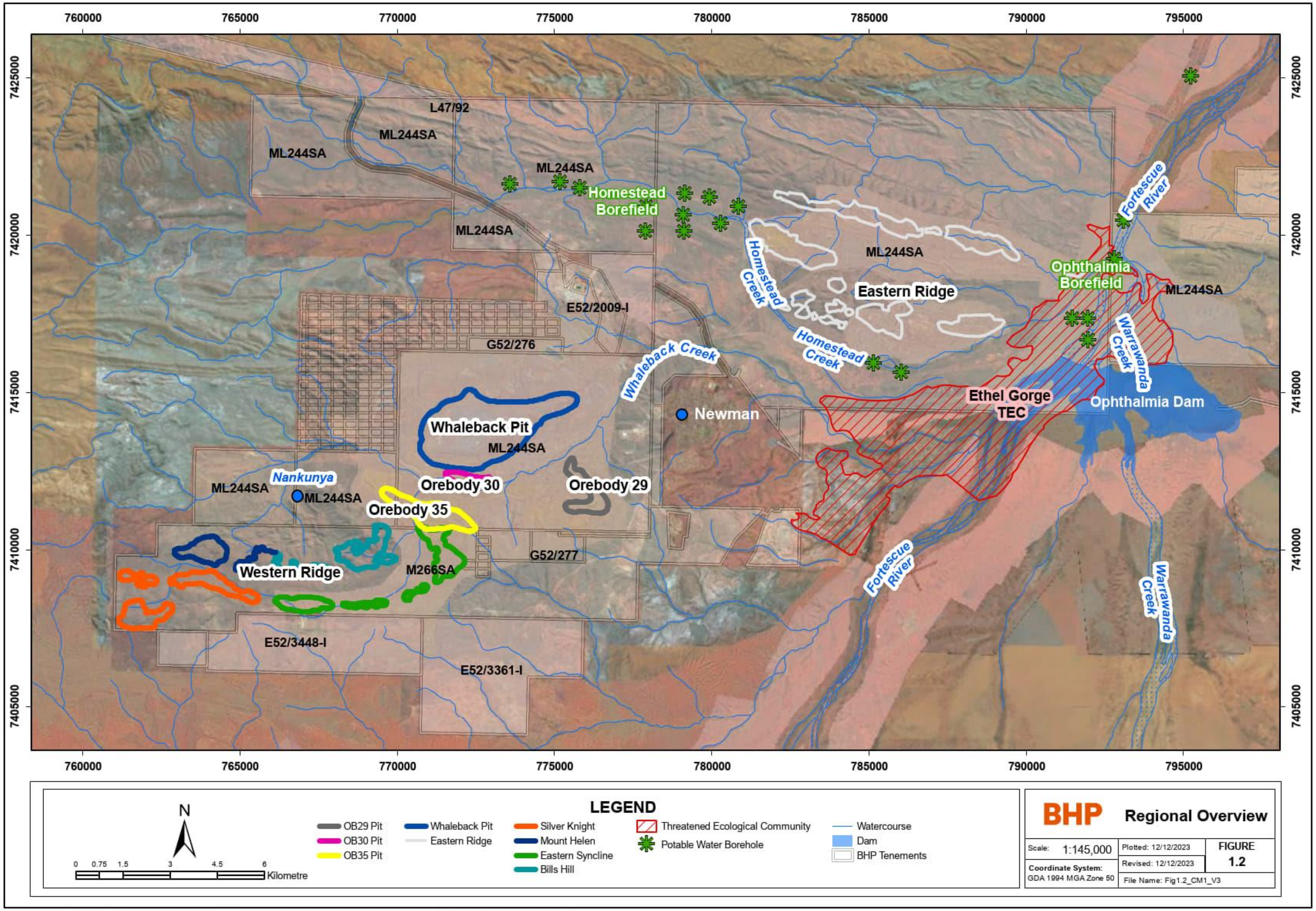

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Figure 1.2: OB29/30/35 and surrounds regional overview

2. Climate/Rainfall

The Pilbara climate and subsequent rainfall is typically dominated by the influence of subtropical highs located to the south of the Pilbara. During summer (November to April), the high pressure cell moves further south, resulting in the Pilbara receiving approximately 70% of its annual precipitation during these summer months. Annual precipitation figures for these zones are much less than the annual potential evaporation.

The mean annual distribution of rainfall across the Pilbara (during the period 1911 to 2011) shows a gradual reduction from north to south, typically 300 to 350 millimetres (mm) in the north, decreasing to less than 250 mm in the south. The OB29/30/35 borefields are located in the Southern Pilbara region, which has a mean annual rainfall of around 275 to 325 mm per year (mm/yr) (Charles *et al*, 2015).

The Pilbara is characterised by high local evaporation rates and a generally low soil infiltration capacity. This results in recharge occurring exclusively during major rainfall events (15 - 25 mm per day (mm/d)). Within the Upper Fortescue region, this is thought to occur primarily through leakage from streambeds (McFarlane *et al*, 2015). The closest station that records evaporation is the Wittenoom BoM station, located approximately 190 km northwest of Newman. Annual average evaporation for Wittenoom is 3,142 mm/yr, which exceeds annual rainfall by as much as 2,800 mm/yr.

Newman rainfall over the period 1970 to 2023 (collected at the Newman Aero gauging station) is shown in Figure 2.1. Data for 1992-1994 and 1996 was either not recorded or incorrectly recorded at the gauging station.

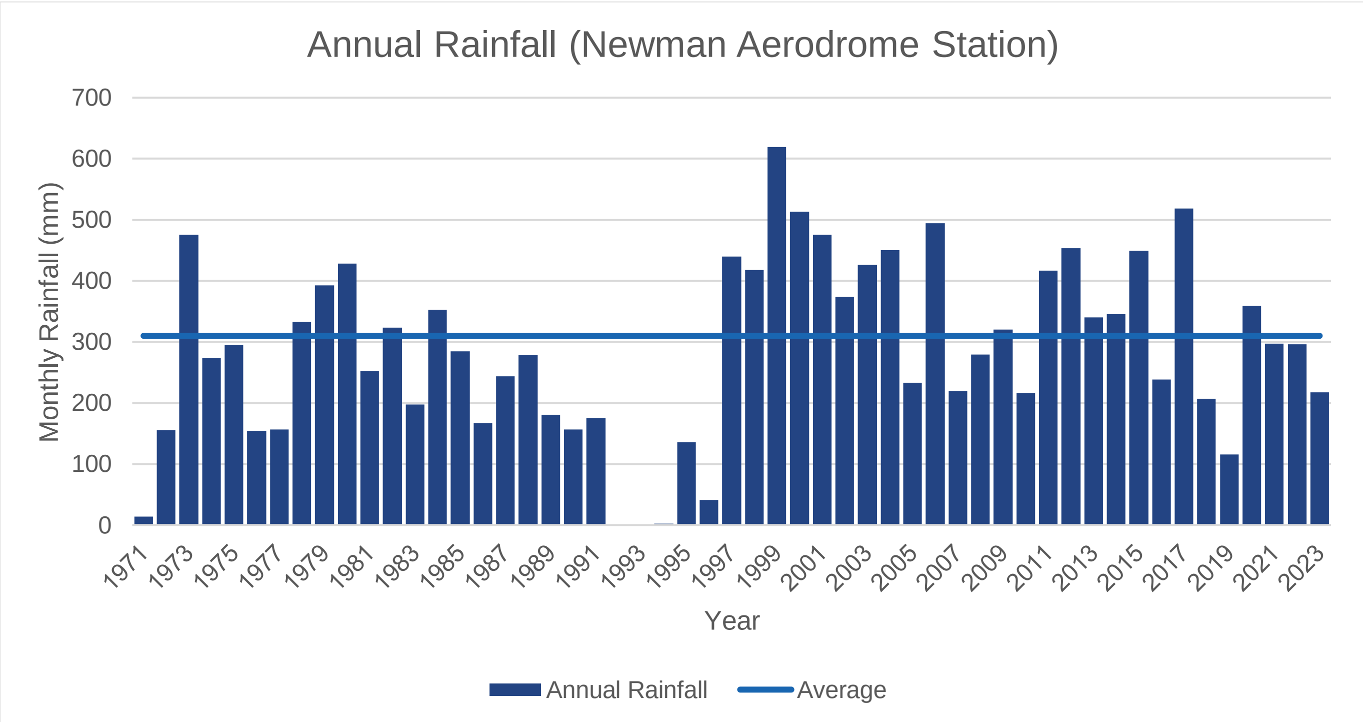

Figure 2.1: Rainfall measured at the Newman Aerodrome Gauging Station (BoM, 2023)

3. Hydrogeology

3.1. Introduction

An overview of the regional setting, conceptual model and key uncertainties is provided in the following sections. The focus of the report is predominantly on increased dewatering at the OB29/30/35 deposits, however as the OB29/30/35 and Western Ridge area forms a larger semi-continuous aquifer compartment with flow barriers to the south, north and west and a leaky flow barrier to the east, the Western Ridge area is included.

This work builds on numerous investigations and assessments carried out since the 1970s, which are referenced where relevant.

3.2. Topography and surface water drainage

The study area is located within the Whaleback Creek catchment. The main drainage features are the Whaleback Creek, which flows in a north easterly direction across the study area, and its southern tributary which drains the Western Ridge area (referred to as Southern Creek) (Figure 3.1). Downstream of the study area, the Whaleback Creek drains into the Fortescue River and towards Ophthalmia Dam.

The Ethel Gorge aquifer is located at the confluence of Homestead, Shovelanna and Warrawanda Creeks, which merge within the Fortescue River and flow through the Ophthalmia Range in a northerly direction. The Ethel Gorge aquifer has been identified as a key ecohydrological receptor as it supports a shallow groundwater system which hosts the Ethel Gorge Aquifer Stygobiont Community Threatened Ecological Community (Ethel Gorge TEC). Ethel Gorge aquifer is located approximately 15-20 km to the east of the Mt Whaleback operations.

The topography of the Mt Whaleback operations area is influenced by the regional geology. The hills bounding the southern sides of the valleys tend to be low-lying and are formed from the Marra Mamba Iron (Marra Mamba) and Jeerinah Formations, whilst the higher, more scarp slopes on the northern margins of the valleys (i.e. Mt Whaleback and Western Ridge) are formed from the Brockman Iron (Brockman) Formation.

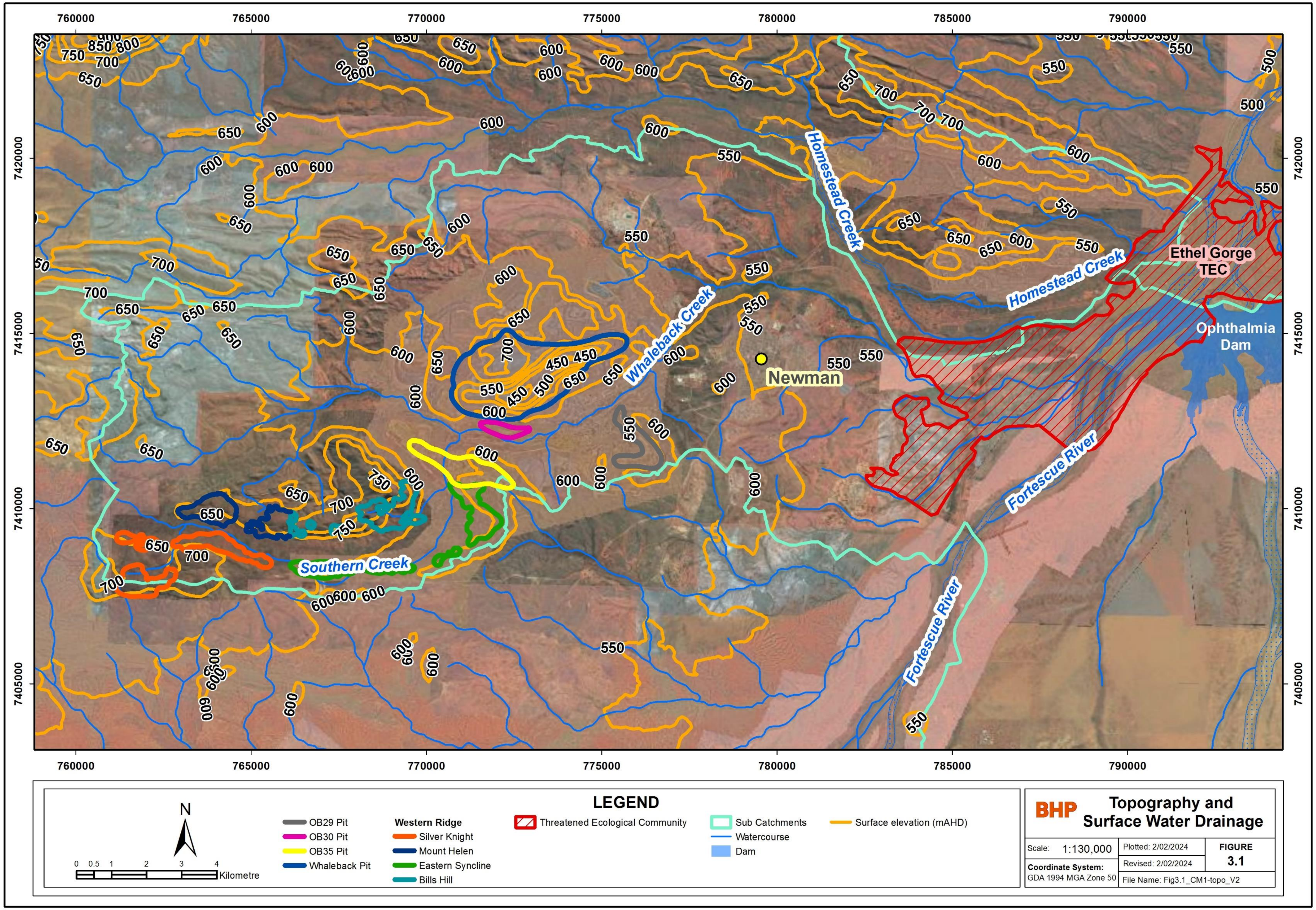

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Figure 3.1: Topography and surface water drainage of the OB29/30/35 area and surrounds

3.3. Conceptual Model

3.3.1. Hydrostratigraphy and relationships

The study area is structurally complex, comprising a series of anticlines and synclines, cross-cut and offset by a regional fault system.

The Mt Whaleback orebody is hosted in the Brockman Formation in two steeply-dipping and overturned synclines that have been displaced by a series of low-angle faults (splays of the regional Whaleback Fault). Another broad syncline dominates the Western Ridge area with the Brockman Formation (hosting the Mount Helen and Bills Hill deposits) located towards the centre of this syncline. The Marra Mamba forms the outer (southern) edges of both the Whaleback and Western Ridge synclines, hosting the Silver Knight, Eastern Syncline, OB29, OB30 and OB35 deposits. These deposits are further complicated by additional, local-scale folding and faulting which is expected to influence the hydrogeological properties of the individual deposits (Figure 3.2).

There are two main aquifer types within the OB29/30/35 and Western Ridge area:

- *The regional aquifers*; which generally comprise weathered dolomite of the Paraburdoo Member of the Wittenoom Formation which occurs in sub-crop along the Whaleback and Southern Creek valleys. The overlying Tertiary detritals are above the water table through much of the study area, but where they are saturated, they also form part of the regional aquifer system. The thickest sequence of Tertiary detritals (more than 150 m) is found to the west of the Whaleback Pit with other notable areas of thickness occurring south of the Mount Helen deposit (Western Ridge) and northeast of OB29 in the vicinity of the rail loop.
- *The orebody aquifers*; which comprise the mineralised Brockman that make up the Mt Whaleback, Bill's Hill and Mount Helen orebodies and the mineralised Marra Mamba that make up the OB29/30/35, Silver Knight and Eastern Syncline orebodies. The orebody aquifers are usually well delineated by the extent of the high-grade ore (assumed high permeability), with a halo of lower grade ore (assumed moderate permeability) around it. In this case the depth of the high-grade ore is:
    - OB29: About 400 metres Australian Height Datum (mAHD) in the central area and as deep as 200 mAHD in the east (close to HEOP0808P)
    - OB35: About 440 mAHD
    - OB30: About 320 mAHD
    - Eastern Syncline: 360 mAHD
    - Silver Knight: 490 mAHD
    - Bill's Hill: 490 mAHD
    - Mount Helen: 380 mAHD

In the north-eastern corner of the study area, to the north-west of Newman, the Whaleback Creek valley narrows significantly. It is possible that the dolomite aquifer (i.e. Paraburdoo Member) may not be present in sub-crop in this area due to the Marra Mamba being up-thrusted on the north side of the valley along a splay of the Whaleback Fault. As such, groundwater flow in this area may be through the alluvium (if saturated) or more likely through secondary permeability (developed as a result of mineralisation or faulting) within the Marra Mamba/West Angela Member.

Geological and conceptual cross sections are provided in Figures 3.3 and 3.4. These illustrate the main geological relationships in the area.

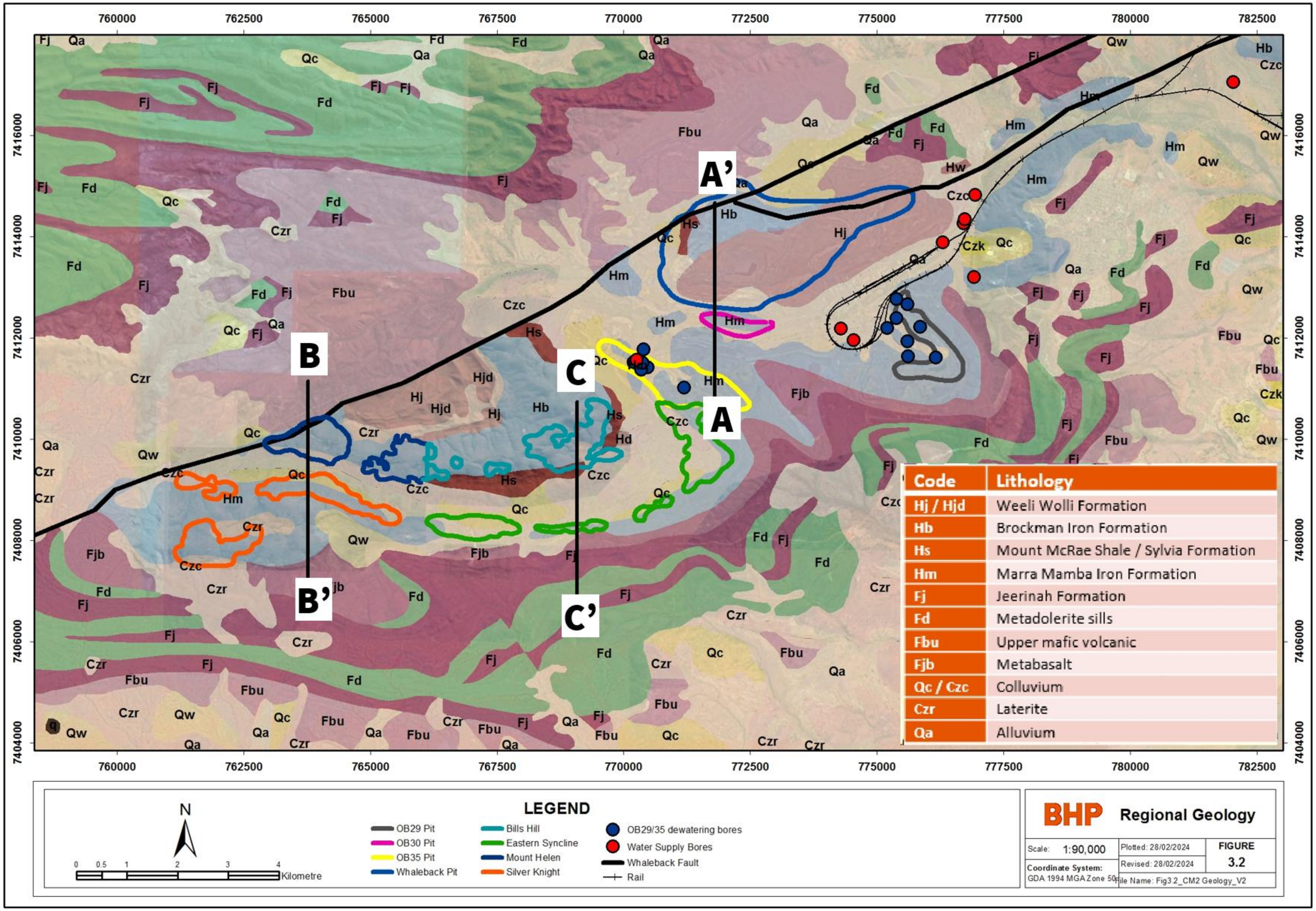

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Figure 3.2: Regional geology of OB29/30/35 area and surrounds

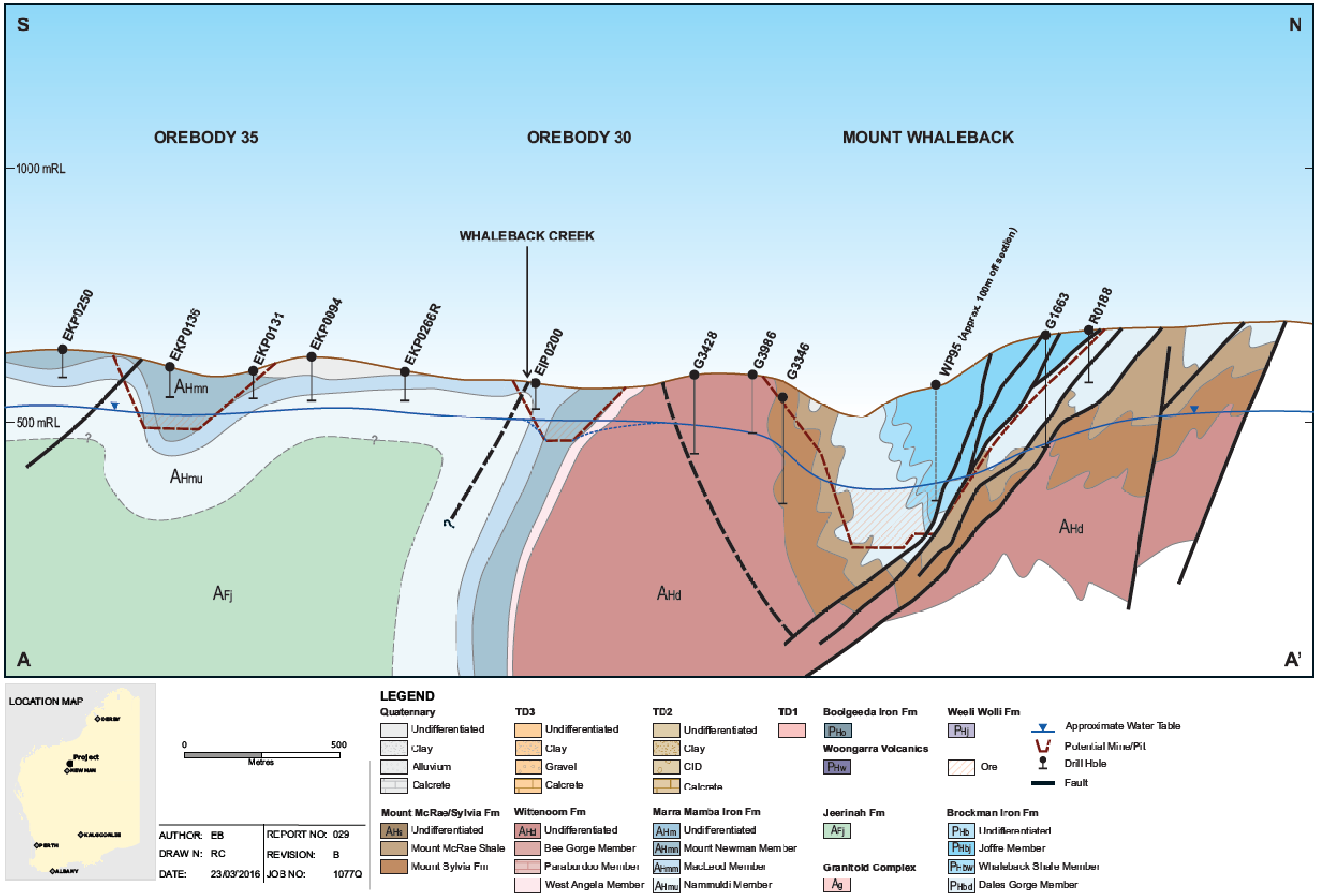

Figure 3.3: Geological cross section A

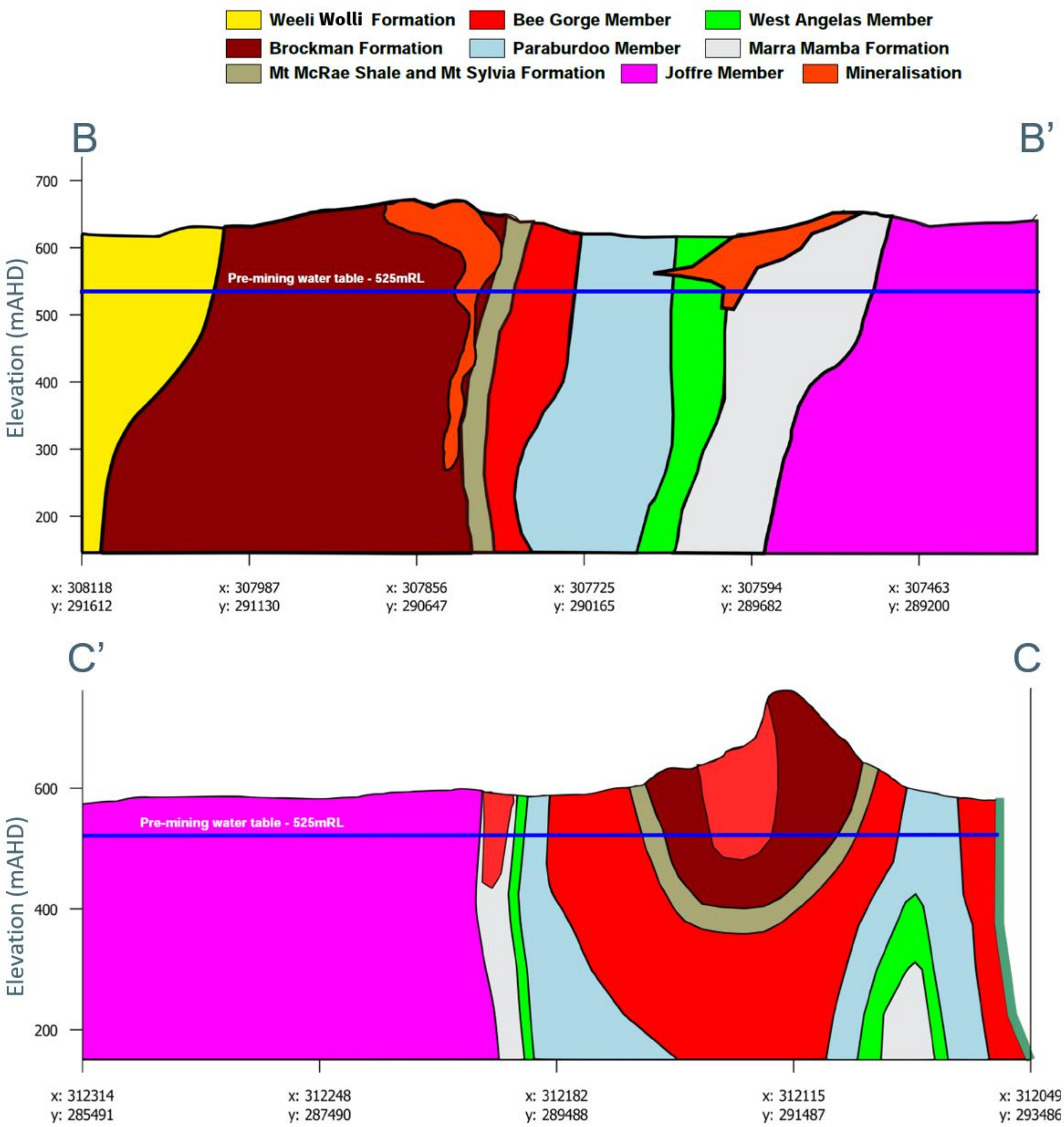

Figure 3.4: Geological cross sections B and C

3.3.2. Pre-development groundwater levels

Observed water levels prior to the OB29 Hydrodynamic Trial (HDT) and dewatering at OB29 and OB35 are shown in Figure 3.5. These are comprised of the following datasets:

- Exploration drill hole water levels collected between 2006 and 2015; and
- Monitoring bore water levels recorded in December 2014.

In the area of OB29/30/35, between 2006 and 2014, levels varied from a minimum of 519 mAHD to a maximum of almost 526 mAHD. This is likely the result of natural fluctuations (local rainfall recharge and long-term trends) as well as water supply pumping. Developing a single pre-development groundwater level for the whole area is therefore difficult and will incorporate these variations depending on when the observations were taken.

The data does suggest however that:

- Heads in the orebody and regional aquifers throughout the study area are consistently between about 519 and 524 mAHD. In more detail:
    - Around OB29 heads are mostly 523 mAHD, but some lower values are recorded to the northeast (the range is 520 to 524 mAHD).
    - Around OB30 heads are very variable and include what appear to be some spurious data. However, most observations are between 519 and 523 mAHD.
    - Water level observations are limited to a small area in OB35, and these are between 520 and 523 mAHD.
    - Heads in the Western Ridge orebodies are between 519 mAHD and 522 mAHD. However, some orebodies are not represented in the data.
- Heads in the unmineralised Brockman to the north of Bill's Hill are much higher (>580 mAHD)
- Heads in the southern part of the Silver Knight (Marra Mamba) orebody are also higher (>570 mAHD)
- Heads to the northwest of OB30 are consistently lower (<480 mAHD). This is likely the area impacted by dewatering of the Whaleback orebody and is not part of the OB29/30/35 regional or local aquifer systems.

The water levels just east of OB29 are high in bores north of the Whaleback Fault (>535 mAHD) but consistent at about 523 mAHD in the regional aquifer. Further to the east the water level is lower (518 mAHD). This signifies the transition from the levels of 519 to 523 mAHD in the Western Ridge / OB29/30/35 area to the lower water levels in the Ethel Gorge aquifer (roughly 505 mAHD before Ophthalmia Dam was constructed and water supply abstraction was occurring in that area).

The data show that water levels are very consistent through almost all the aquifer systems in this area. Given the variation in levels through time however, care must be taken not to conclude too much from this data, but the levels do not delineate a clear flow of water from the west to the east (which is the assumption given the only obvious natural discharge is towards Ethel Gorge in the east). In fact, the highest heads appear to be in the east (OB29), if only by a metre or so. This could indicate that Whaleback dewatering may be having some effect, although minor, on the system to the west.

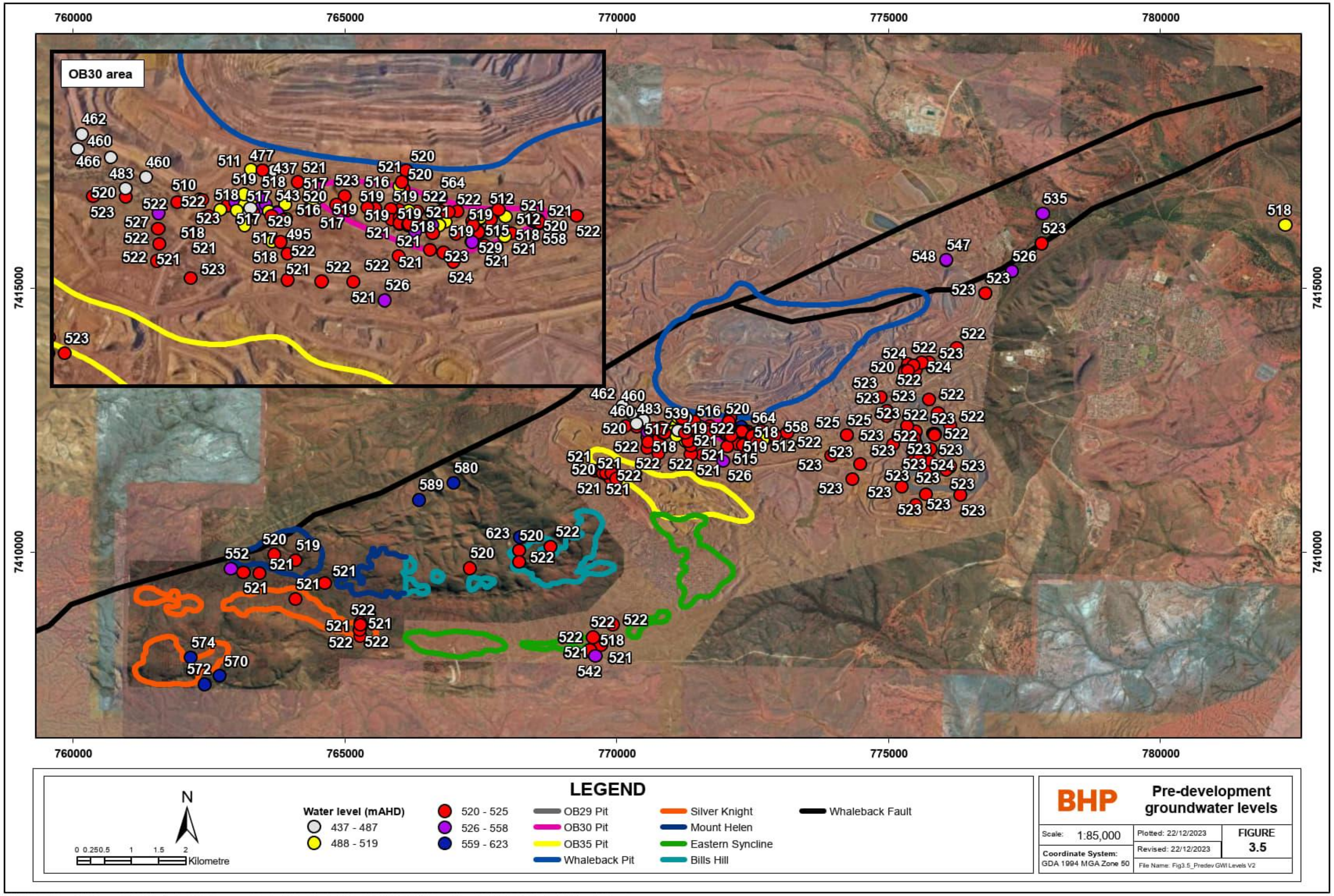

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Figure 3.5: Orebody 29/30/35 and Western Ridge pre-development water levels (mAHD)

3.3.3. Time variant groundwater response

The groundwater level dataset has been organised into two groups to assist in the analysis:

- Long term monitoring bores: Comprising locations with data between 1968 and 2015. During this period there were no groundwater level observations west of the OB29/30/35 area (near Western Ridge). All monitoring in this period was east of OB35 (as shown in Figure 3.6).
- Post 2015 monitoring bores: Comprising locations with data within the period of the OB29 HDT and OB29 and OB35 dewatering (i.e. from February 2015 onwards). Monitoring bores in the OB29/30/35 area are shown in Figure 3.6.

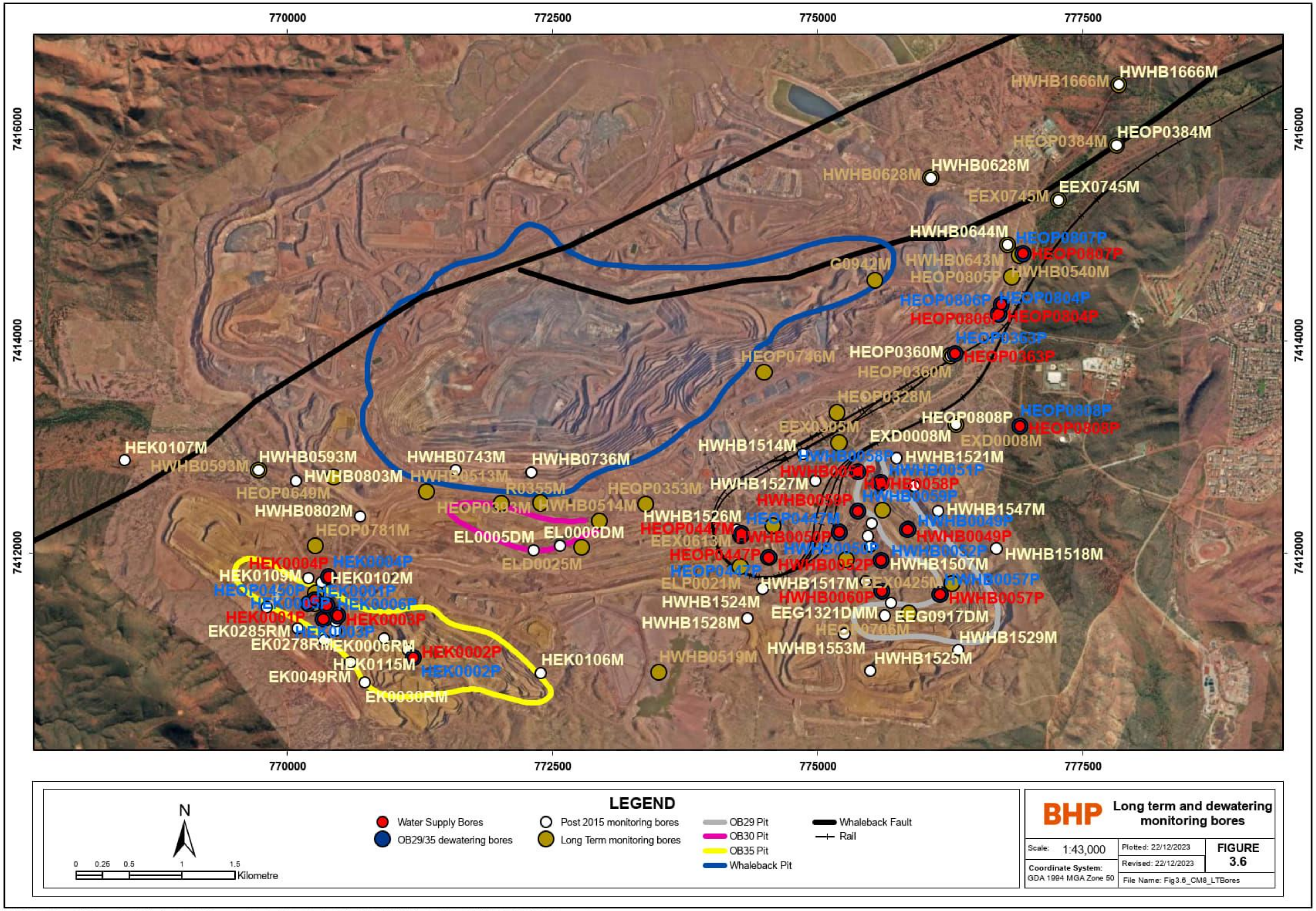

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Figure 3.6: Long term monitoring and dewatering bores around OB29/30/35

3.3.3.1. Long term groundwater levels (1968 to 2015)

Analysis

Groundwater level monitoring has occurred over a very long time period in the Newman area (since the early 1970s). This was originally associated with water supply for the Whaleback mining operation and potable water supply for the Newman township (the Ophthalmia borefield). As mining expanded to include other orebodies, for example Orebody 23 (OB23) and Orebody 25 (OB25) in the Eastern Ridge operations, associated water management infrastructure has also increased. This included the construction of Ophthalmia Dam in the early 1980s. The influence of these activities has been recorded in the water level fluctuations at the many observation bores in the area.

The locations and groundwater levels from the monitoring bores with long term data are shown in Figure 3.7. Abstraction from the water supply bores in the area is shown in Figure 3.8, along with their locations.

Some abstraction data may be missing from the BHPBIO digital records between 1985 and 1991, however, even with this uncertainty, analysis of the long term response of the groundwater system provides an insight into the main hydraulic characteristics of the regional and local aquifers in the area.

There are three main types of responses over this period (as shown in Figure 3.7):

- **Group A**: in the area between and including OB29, OB30 and OB35 (blue in the map and hydrographs).
- **Group B:** generally to the north-east of OB29 (green in the map and hydrographs).
- **Group C**: In the periphery of the main flow systems, a miscellaneous group that show significant variability and conform to neither of the groups above (brown in the map and hydrographs).

Their geographical spread suggests that the first two groups, Group A and B, are representative of the main regional and local flow systems in the area (i.e. aquifer type responses). All of these are located in Marra Mamba or Wittenoom (dolomite) Formations. The Group C is likely drawn from bores located in lower permeability material on the edges of the flow system or from bores situated on the other side of significant flow barriers (i.e. non aquifer type).

Hydrographs from boreholes in Groups A and B are shown in Figure 3.9 and their behaviour is described and contrasted in Table 1.

The contrasts between these two type responses provide strong evidence that the regional aquifer system is hydraulically separated by a geological feature (referred to as a leaky flow barrier) between HEOP0360M and EXD0008M (and shown in the Figures, e.g. Figure 3.7). Hinted at by a small head difference at start of monitoring, further evidence is provided by the distinct behaviour of groundwater levels either side of the feature through time. For example, the western compartment seems quite unaffected by head changes occurring to the east (through whatever mechanism, up or down).

All areas experienced a very strong water level response to rainfall from eight cyclones crossing the eastern Pilbara area in the 1999/2000 season. This indicates that very large amounts of recharge can occur if the rainfall events are of sufficient duration and magnitude. Heads throughout the aquifer system associated with Group A (i.e. the main OB29/30/35 system) are very similar from east to west, suggesting that the regional aquifer in this area is well connected and has high permeability and that the regional and local aquifers are in hydraulic connection.

Boreholes that do not conform to Group A or B responses are in the minority (Figure 3.7 – Group C). In fact, the location of boreholes that return “aquifer type” responses extend right up to the southern boundary of Whaleback, including all bores in a line from HWHB0513M in the west to HEOP0353M in the east. The two other long-term observation bores in this area are both in the west; HWHB0593M (Wittenoom Formation), which returns a head about 20 m higher than the main group and does not show any obvious connection to the Whaleback abstraction, and HWHB0649M which was only monitored for a short time period, but during that time returned a head roughly equal to the Group A and B bores, although with a different trend towards the end (downwards instead of stable).

The other Group C bores are either located in conceptually low permeability rock material in the area between OB29 and OB35 (i.e. HWHB0519M (Jeerinah Formation)) or to the north east of the apparent leaky flow barrier, but in the Wittenoom Formation. Three bores fall into the latter category; HWHB0628M, HWHB1666M and EEX0745M. The first two of these return high water levels that from first observations don’t appear to react to anything other than seasonal changes (i.e. they are not well connected to either the Whaleback or OB29/30/35 aquifer systems). The third, EEX0745M has returned a relatively stable long term groundwater level but with more seasonal variation than most other locations. All three locations are either to the north of, or very close to the Whaleback Fault, which behaves as a significant flow barrier in other parts of the catchment and, judging by these observations, is likely to do so here.

Table 1. Analysis and comparison of the historical groundwater levels west and east of OB29.

Period	West (Group A)	East (Group B)
Abstraction (1970 – 2015)	Records suggest that abstraction was quite limited in these areas. Most was from HEOP0450P in the Western sector and from HEOP0808P on the eastern side.	
Initial ~1970	518 mAHD	512 mAHD
	Gradient west to east.	
1970 – 1979	Stable until 1979.	Falling by 2 to 3 m by 1980, probably due to water supply abstraction from further to the east (Ophthalmia borefield).
1979 - 1989	Falling 2 to 3 m due to abstraction from this sector (mainly HEOP0450P and HEOP0808P) until 1984/1985. Then slight recovery when abstraction stops. Possible response to same event that drives rapid increase observed to east seen only at 1 bore (HEOP0328M) and nowhere else.	Stable, then from 1982 rapid increase of about 10 m to maximum in 1987. This does not seem to be associated with a rainfall event and is isolated to the eastern compartment. It could be due to discharge of excess / s**urplus** water from Whaleback operations into the creek in this area during initial dewatering at Mt Whaleback. At the peak the sub-regional flow gradient observed in 1970 was reversed (now from east to west in this area) Water level recession starts after this.
1990 - 1999	Relatively stable at between 516 mAHD and 519 mAHD. Slight rising trend through period. Abstraction from HEOP0808P seen in heads at EXD0008M between 1994 and 1998 but limited effect elsewhere.	Other than rapid fall and recovery in 1992/1993 (with no record of any significant abstraction at the same time) the levels are quite stable at 519 mAHD (western end) and 516 mAHD (eastern end).
2000 - 2010	Starts with increase of 4 to 8 m in all locations. Major recharge following 1999/2000 cyclones. The response is towards the lower range in Group A (to the west) and higher range in Group B (to the east). All stay at elevated levels for about 3 years, then recession occurs from 2003 to 2008 when levels stabilise.	
	Heads peak at about 523 mAHD but end the period at about 519 mAHD.	Heads peak at about 526 mAHD but end the period at about 519 mAHD. Local gradient reversal maintained through this period – with heads higher in the east (HWHB0384M) than the west (HWHB0360M).
2010 - 2015	Relatively stable period (data more limited in the chosen bores however). EXD0008M shows significant variation.	Stable, some variation in HWHB0360M.

Note – monitoring bores mentioned in the table are clearly marked in Figure 3.9

Conclusion

The long-term data clearly delineate a zone of high conductivity (and strong hydraulic connectivity) throughout the regional and local aquifers in the immediate OB29/30/35 area which is distinct from what seems to be a lower quality aquifer system to the east. They also provide evidence for the existence of a leaky flow barrier just east of OB29 and the barrier parallel to the flow direction formed by the Whaleback Fault in the east and the lower permeability unmineralised material both to the south and north of OB29/30/35.

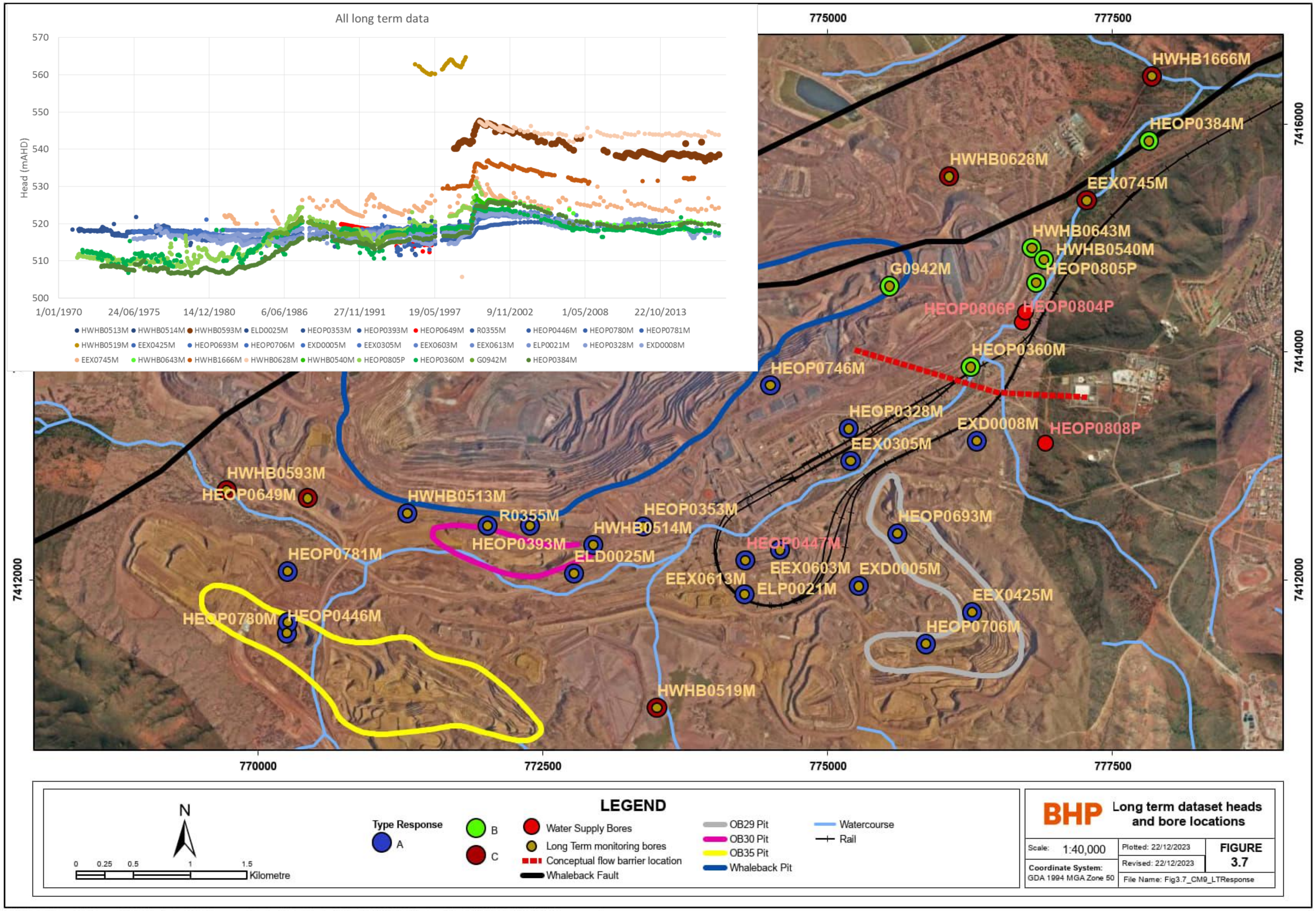

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Figure 3.7: Long-term dataset, heads and associated bore locations

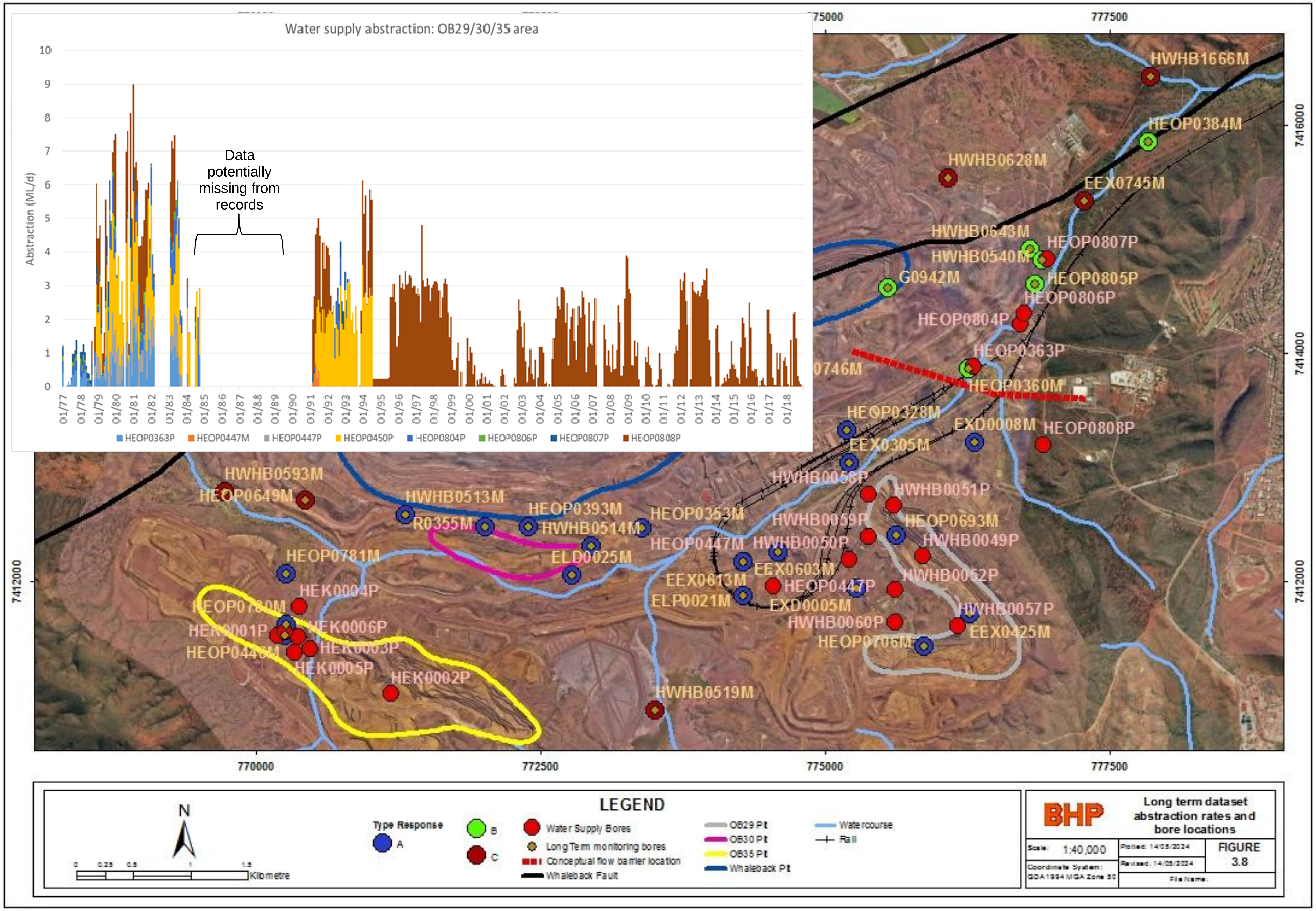

Figure 3.8: Long-term dataset, abstraction rates and bore locations

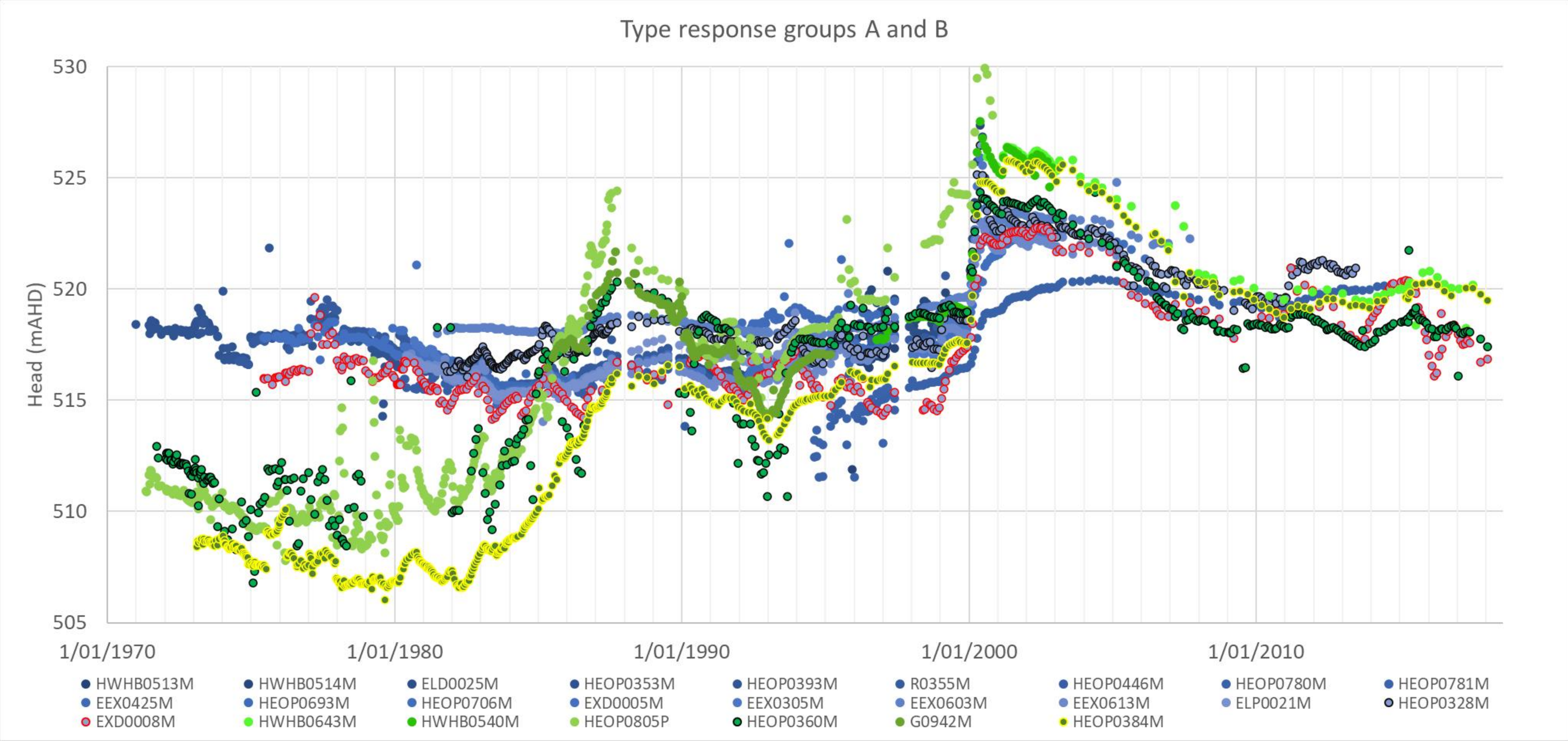

Figure 3.9: Groundwater levels in "Type Response Groups A and B"

3.3.3.2. Post 2015 (OB29 and OB35 dewatering)

Introduction

Knowledge of the OB29, OB30, OB35 and Western Ridge groundwater flow systems has been advanced significantly by undertaking an HDT at OB29 and subsequent dewatering at both OB29 and OB35. The production bore locations and abstraction rates are shown in Figure 3.10 and can be summarised as:

- First Phase: Abstraction (via HDT) from OB29 only from March 2015 to March 2016 at an average of nearly 8 ML/d.
- Recovery Phase: no abstraction between the start of April 2016 until the end of October 2016 (7 months).
- Second Phase: Dewatering from both OB29 and OB35 (averaging 17 ML/d). This began in November 2016 and finished (with the final ramp down of OB29 abstraction) in November 2020.
- Third Phase: From December 2020, dewatering only from OB35, averaging 20 ML/d up to April 2022.

The collection of groundwater level data during the first period was concentrated around OB29 to monitor the response to the HDT. Monitoring in and around OB35 was limited to just a few locations at this time, until dewatering of this orebody commenced, and additional monitoring was installed. Monitoring at Western Ridge commenced in May 2017 with a single round of dips, then with loggers from mid-2018. The borehole locations are shown in Figure 3.11.

Figure 3.12 shows that the vast majority of groundwater levels in the area are very similar. Just before dewatering commences at OB29 (i.e. early 2015), the levels are between 518 mAHD and 526 mAHD. Those that are not, are also shown in Figure 3.12. These responses help delineate the extent of the regional / orebody aquifer system.

The dataset pertaining to the regional / orebody aquifer system can be divided into 5 groups based on their response to dewatering. These are shown in Figures 3.13 to 3.15.

A more detailed analysis of this data follows.

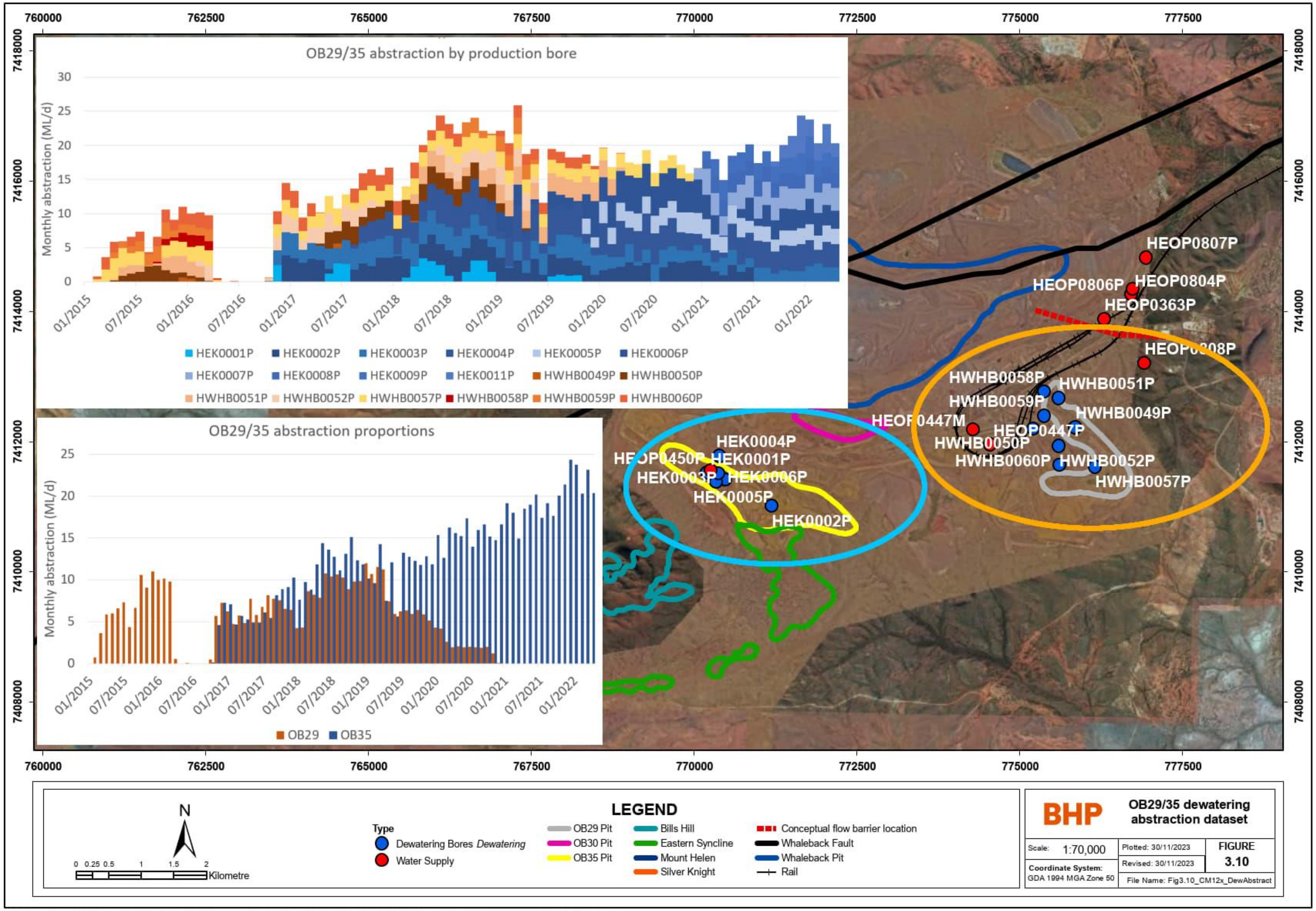

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Figure 3.10: OB29 and 35 dewatering abstraction volumes by production bore and deposit

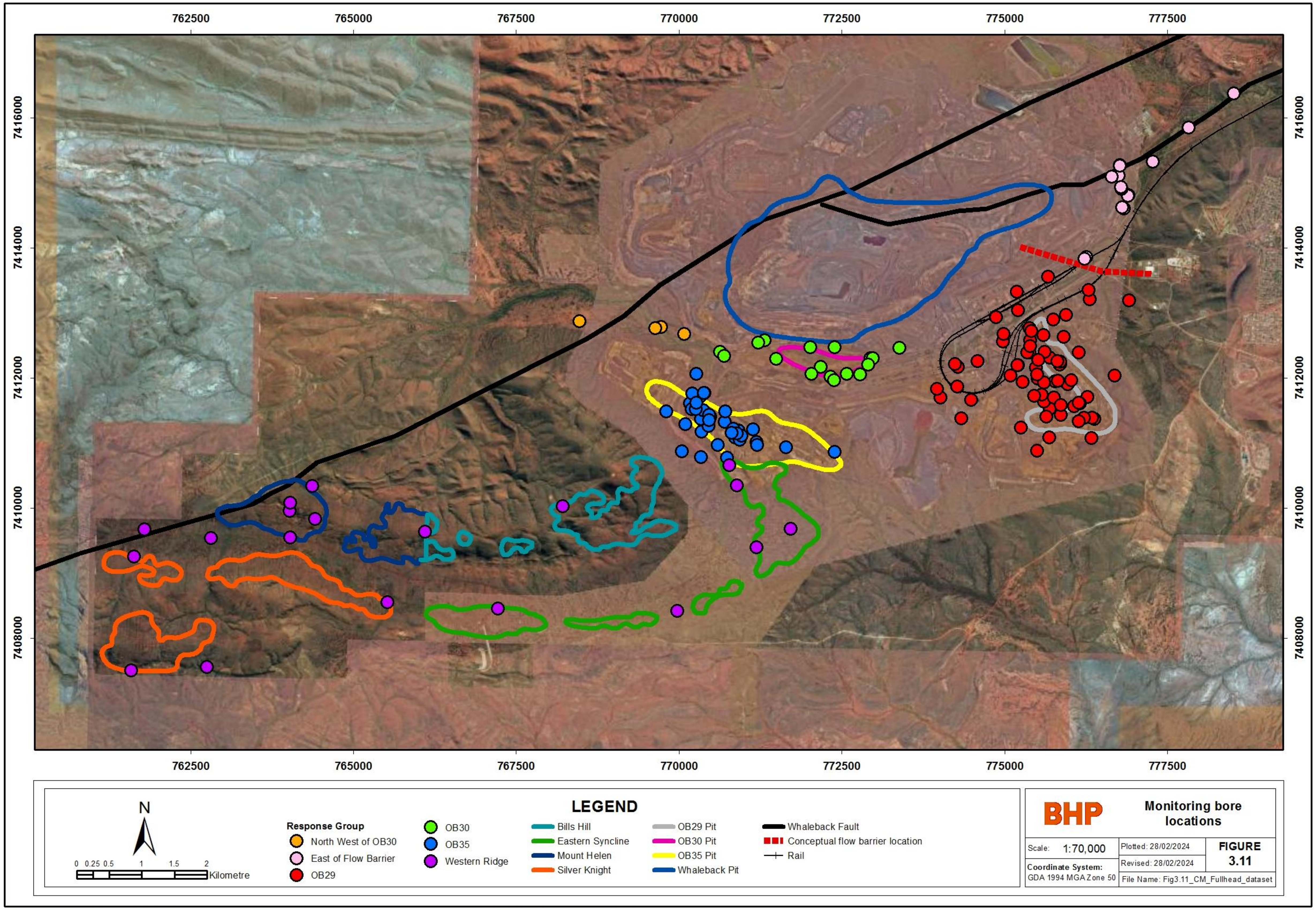

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Figure 3.11: Groundwater level monitoring bores for OB29/30/35 and surrounds (Post-2015)

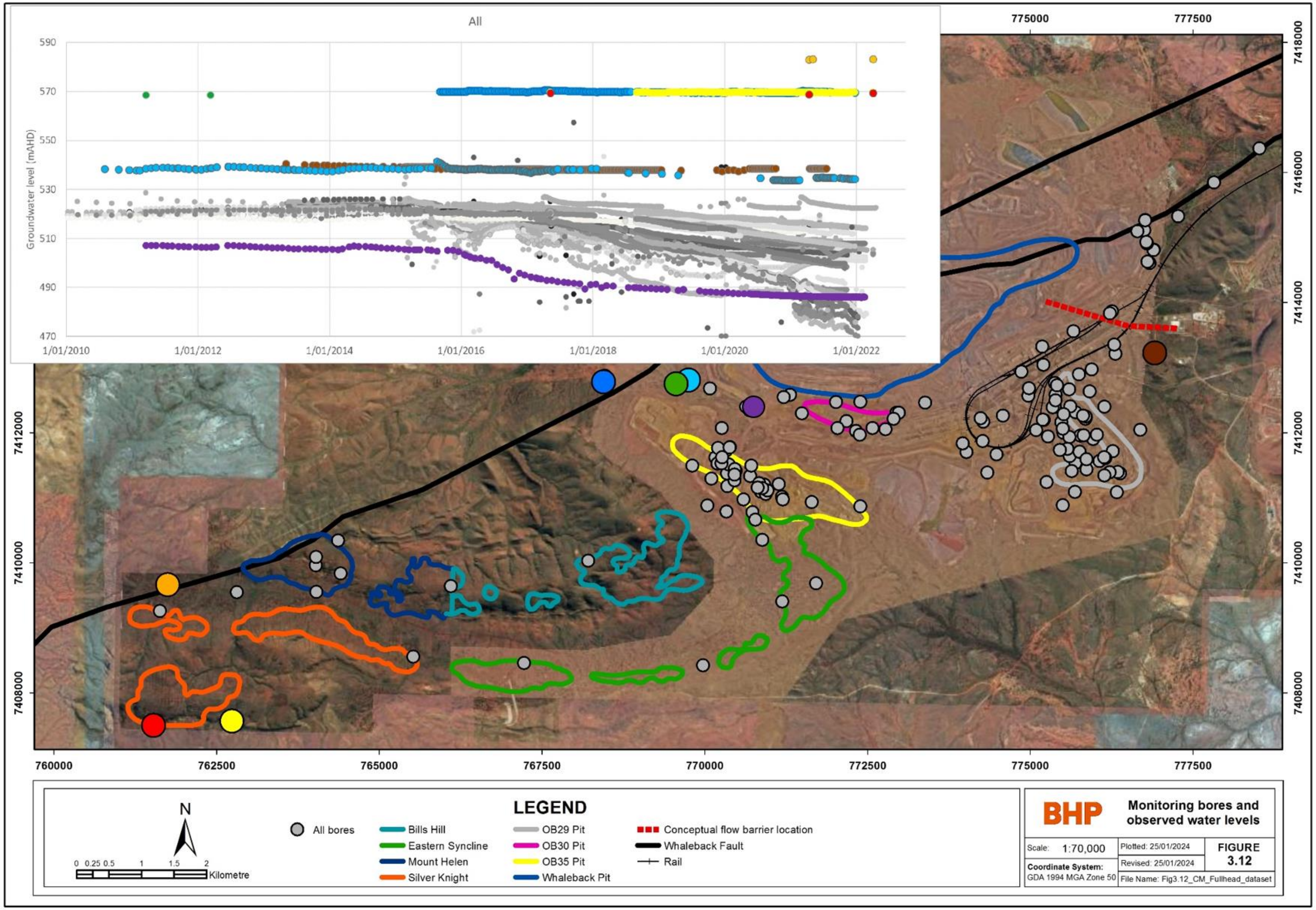

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Figure 3.12: Groundwater levels (2010 to 2022)

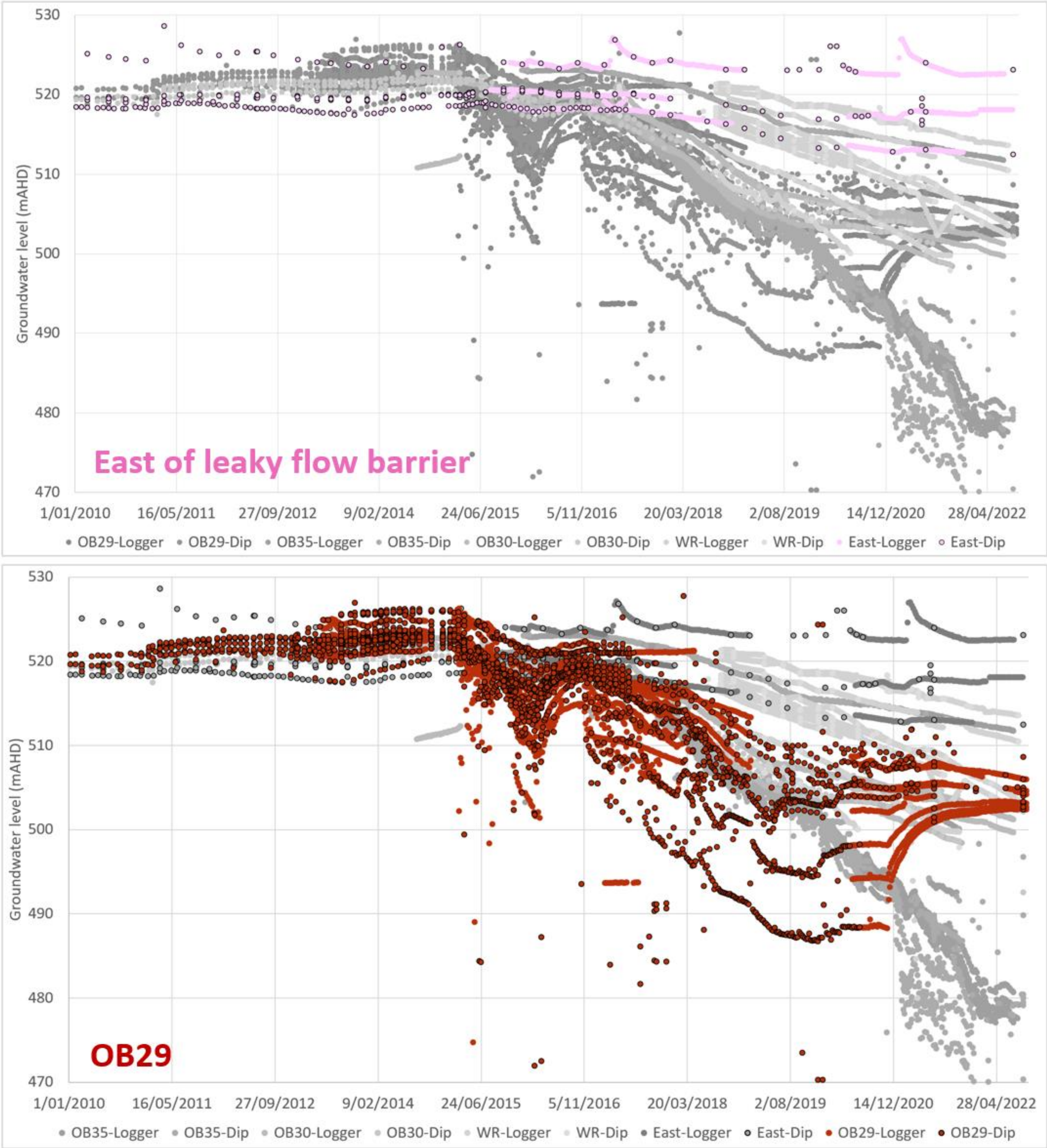

Figure 3.13: Groundwater levels east of leaky flow barrier and in OB29

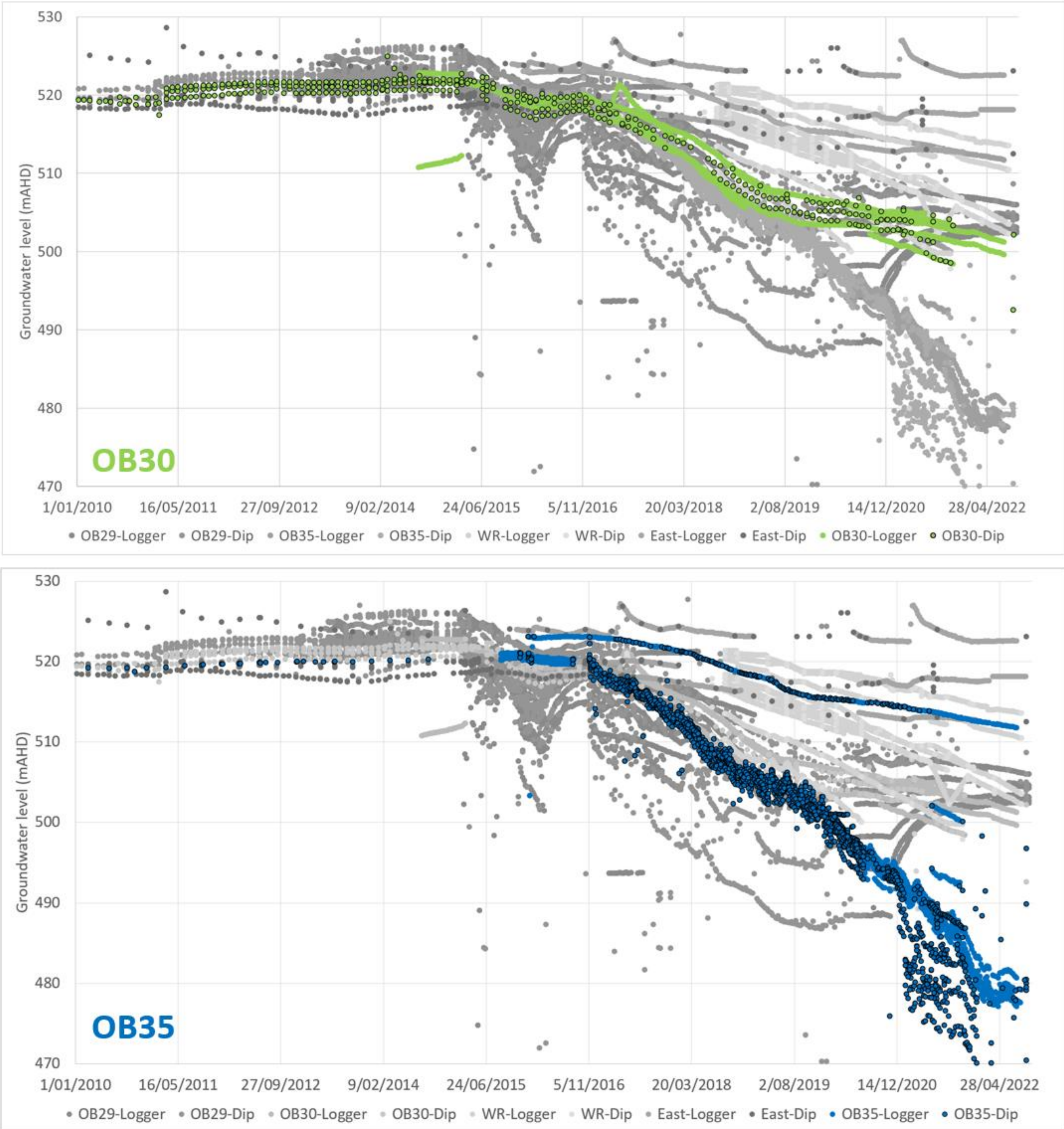

Figure 3.14: Groundwater levels in OB30 and OB35

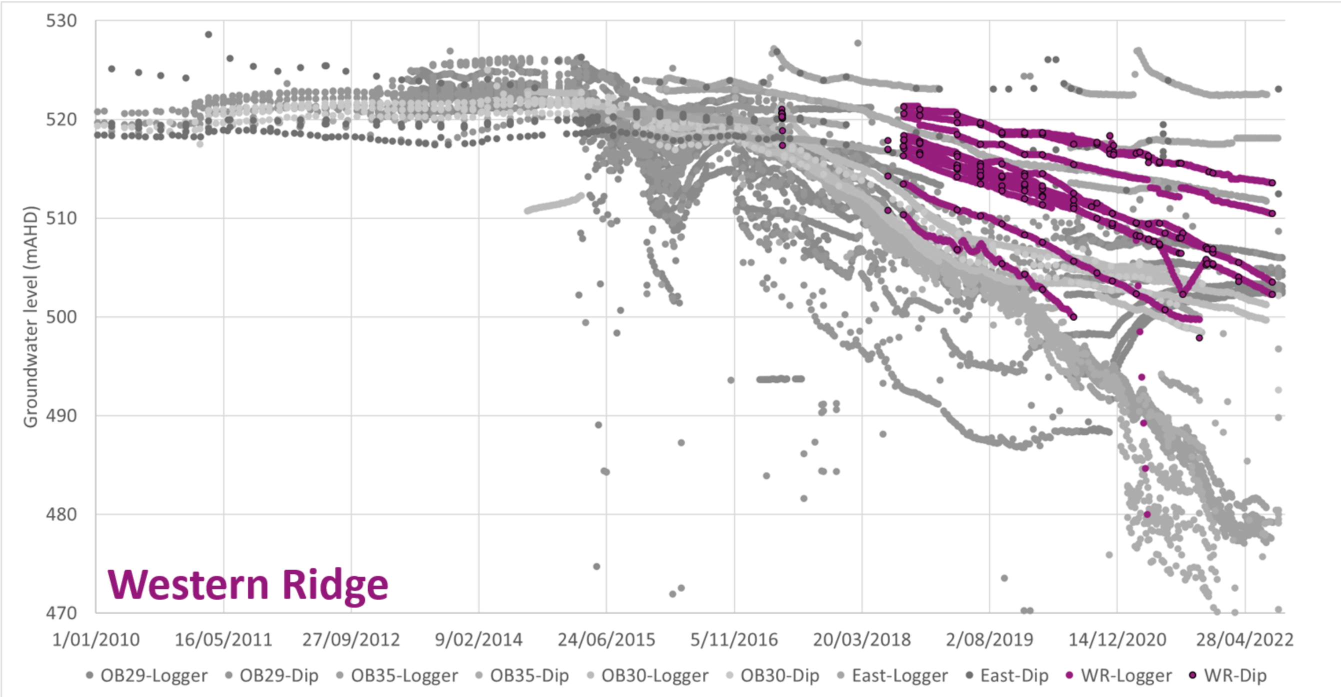

Figure 3.15: Groundwater levels at Western Ridge

OB29 and surrounds

Introduction

The observed heads around OB29 are shown in Figures 3.16 to 3.18. The data show that:

- all but one location has recorded a large response to dewatering.
- the range of initial water levels was quite large (almost 10 m).
- the range of drawdown in the orebody aquifer by 2020 was quite high (between about 20 m to 35 m).
- drawdown was greatest in bores in the southern part of the orebody compared to those in the north (Figures 3.17 and 3.18).
- the regional aquifer responds in a similar way to the northern part of the OB29 orebody aquifer.

To look in more detail at these responses, the following discussion has been divided into three sections:

- OB29 orebody aquifer.
- Regional aquifer.
- Jeerinah around OB29.

OB29 Orebody aquifer (Figures 3.16 and 3.17)

All bores in the orebody show a response to the HDT (abstraction and recovery), dewatering and switching all OB29 abstraction to OB35.

There is however a large amount of variability spatially. From 2014 to the start of 2020 the water level had fallen from about 525 mAHD to about 505 mAHD (20 m drawdown) in the northern part of the orebody (i.e. HWHB1549M) but to as low as 490 mAHD (35 m drawdown) in the southern part (EEG1048RM). The distance between these two locations is roughly 900 m. Furthermore, EEG0917DM, located 370 m to the west of EEG1048RM, reached a minimum of about 500 mAHD. This indicates some localised heterogeneity within the OB29 orebody aquifer.

From June 2018 to April 2019, abstraction from OB29 was relatively consistent at an average of 11 ML/d. From May 2019 to February 2020 abstraction was reduced and averaged of 6 ML/d. The response within the orebody aquifer to this reduction was a levelling off of drawdown. In the last few months, some recovery was observed in the southern bores (EEG1048RM and EEG0917DM), but this was not seen in the northern bores. This could either be because of production bores in the south reducing abstraction (i.e. HWHB0060P has been reduced from 1.6 ML/d to almost nothing) or because of localised rainfall recharge in the southern area.

The northern part of the orebody aquifer showed a limited recovery once abstraction ceased in that area and also when abstraction ceased in the whole of OB29. The southern part (which was drawdown much further) showed a large and rapid recovery once abstraction completely finished (November 2020) but recovered to a level just below the recovery level in the northern part. This recovery level in the northern and southern areas of the orebody was about 15 to 20 m lower than the pre-dewatering level.

Regional aquifer (Figure 3.18)

Bores HWHB1514M and HWHB1526M are located in the regional dolomite aquifer to the northwest and west of OB29. They show that the regional aquifer in this area has also responded to the OB29 HDT (both abstraction and recovery) and subsequent dewatering. The response has been very consistent between the two bores and with drawdown reaching about 16 m at the start of 2020. This compares to the 20 m drawdown observed in the northern part of the OB29 orebody and suggests good hydraulic connection between the regional and orebody aquifers in this area and a high transmissivity regional aquifer system (the two bores are almost 1 km apart).

Post-dewatering at OB29 these bores have recovered a little (a few metres) but have remained roughly flat since the middle of 2020 (actually before abstraction ceased completely).

Leaky flow barrier east of OB29 (Figure 3.19)

Several bores east of OB29 provide evidence for a leaky flow barrier across the regional aquifer in that location. The area is shown in Figure 3.19 and the evidence provided from bores HEOP0360M, HWHB0644M and HEOP0384M.

The observations at these three bores diverge from the orebody and other regional aquifer observations in two important ways:

- The initial levels (2014) range from 521 to 522 mAHD. These were 4 or 5 m lower than the observations at the other OB29 area bores (i.e. HWHB1514M).
- The response to the OB29 HDT and dewatering was subdued compared to the orebody and other regional aquifer bores. By February 2020 (when water levels had stabilised in response to the reduction in OB29 dewatering) drawdown in HEOP0360M reached about 3.5 m, compared to the 16.0 m in HWHB1514M.

Even though this bore is further from the dewatering wells, roughly 1.4 km from the nearest, the reason for the subdued response at HEOP0360M is most likely due to a geological structure cutting through the regional aquifer to the west of this bore or a change in the average hydraulic properties of the dolomite to the east of OB29. The monitoring here does not inform on the nature of the disconnection, but it does show the magnitude.

Jeerinah around OB29 (Figure 3.17)

A single monitoring bore (HWHB1518M) is located in the Jeerinah, directly to the east of OB29 (Figure 3.17). The data from this bore suggests that the Jeerinah here is very low permeability because:

- Water levels fall by about 1 m between 2014 and 2020 (although they were falling at roughly that rate before abstraction started)
- The water level is much higher here (542 mAHD) than in the aquifer bores (524 to 528 mAHD).

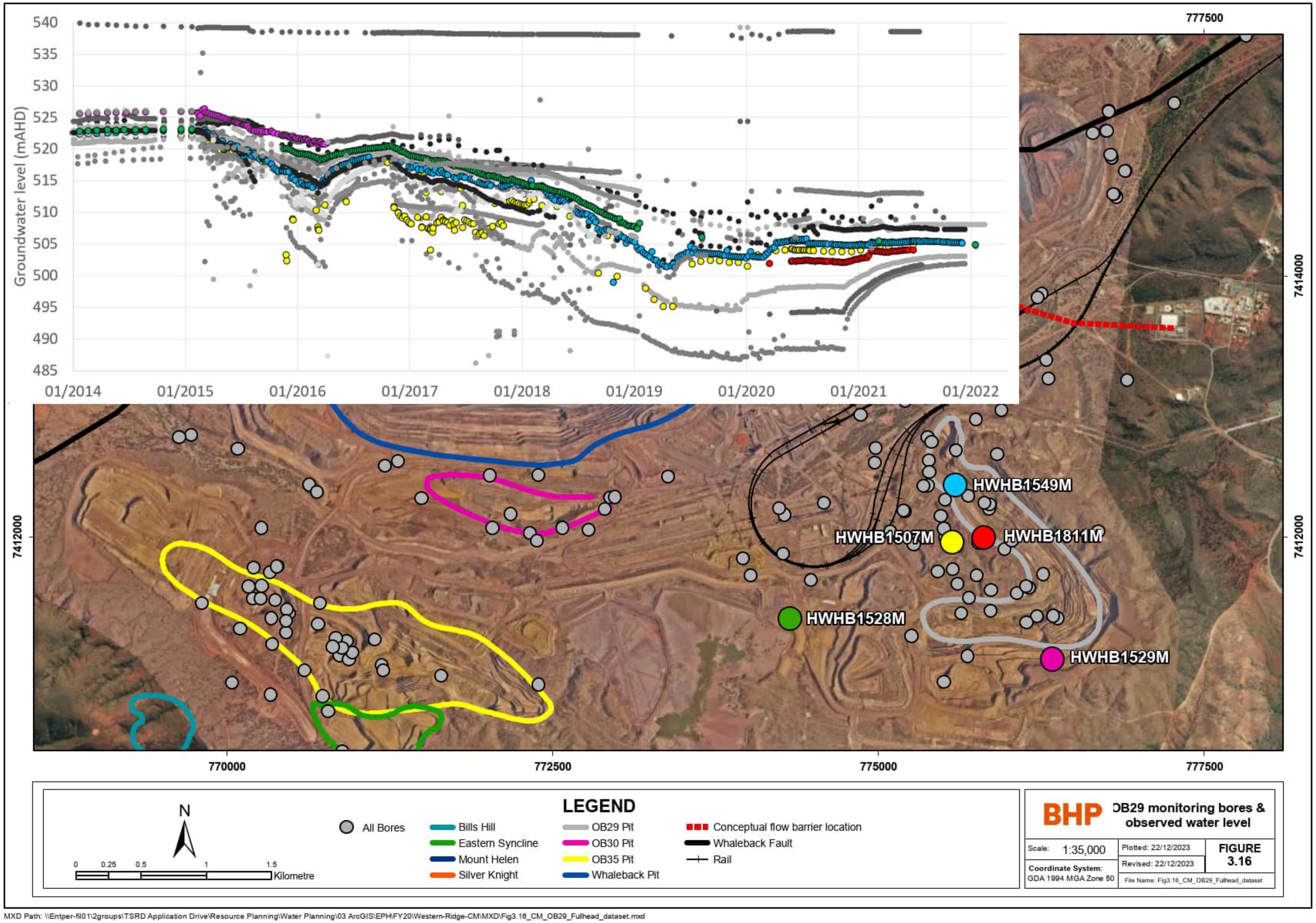

Figure 3.16: Observed groundwater levels in the OB29 aquifer (1)

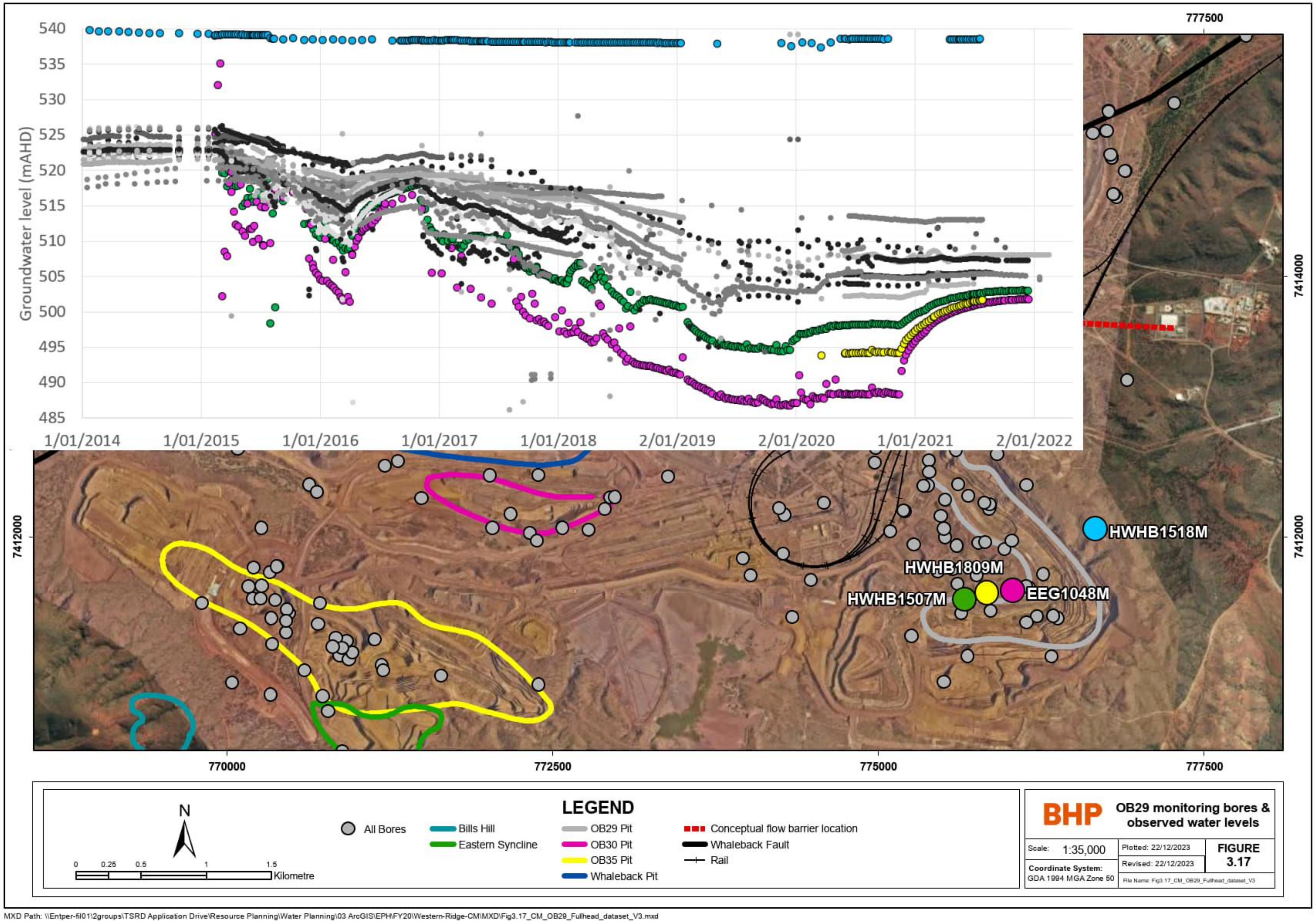

Figure 3.17: Observed groundwater levels in the OB29 aquifer (2)

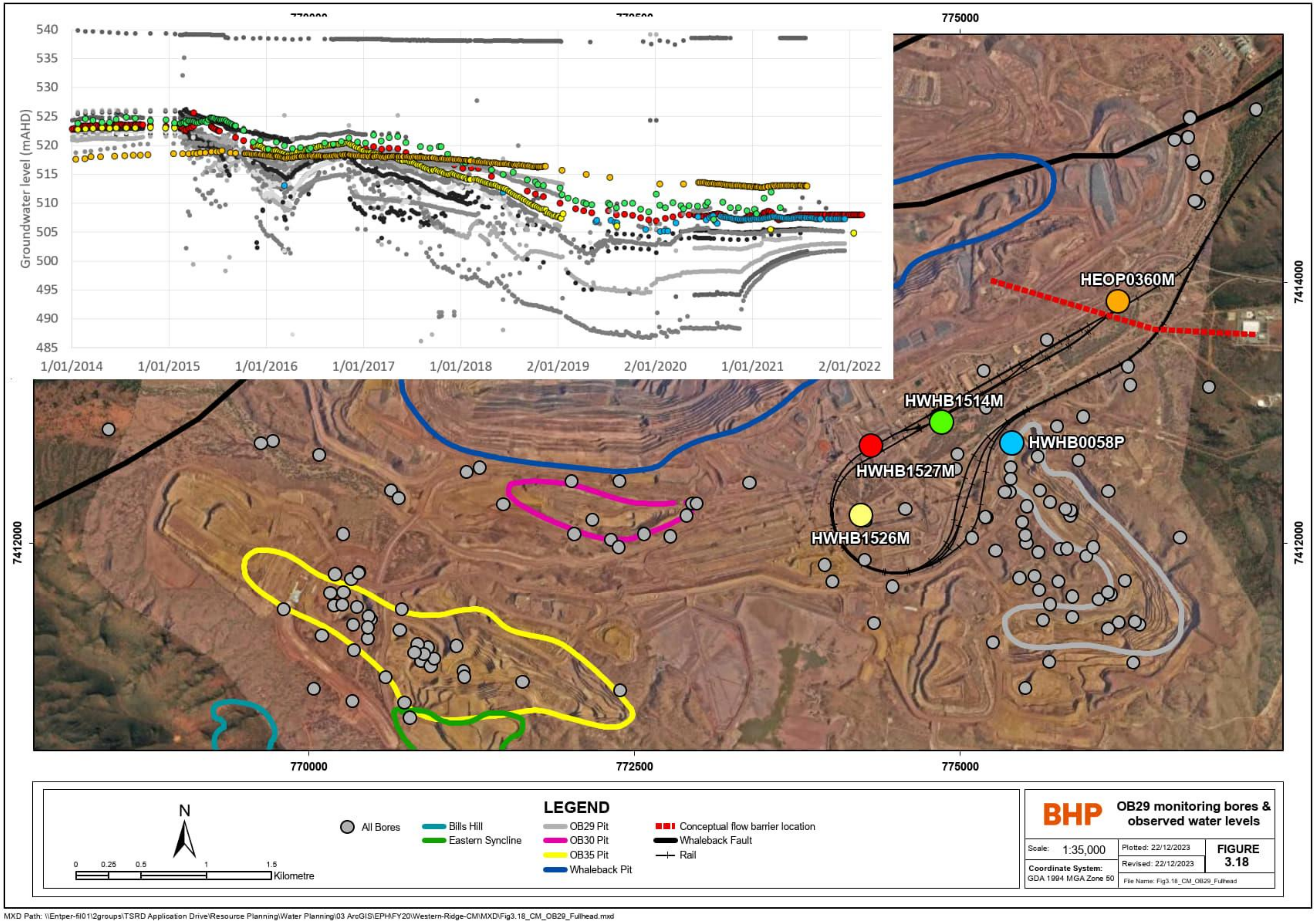

Figure 3.18: Observed groundwater levels in the regional aquifer north of OB29

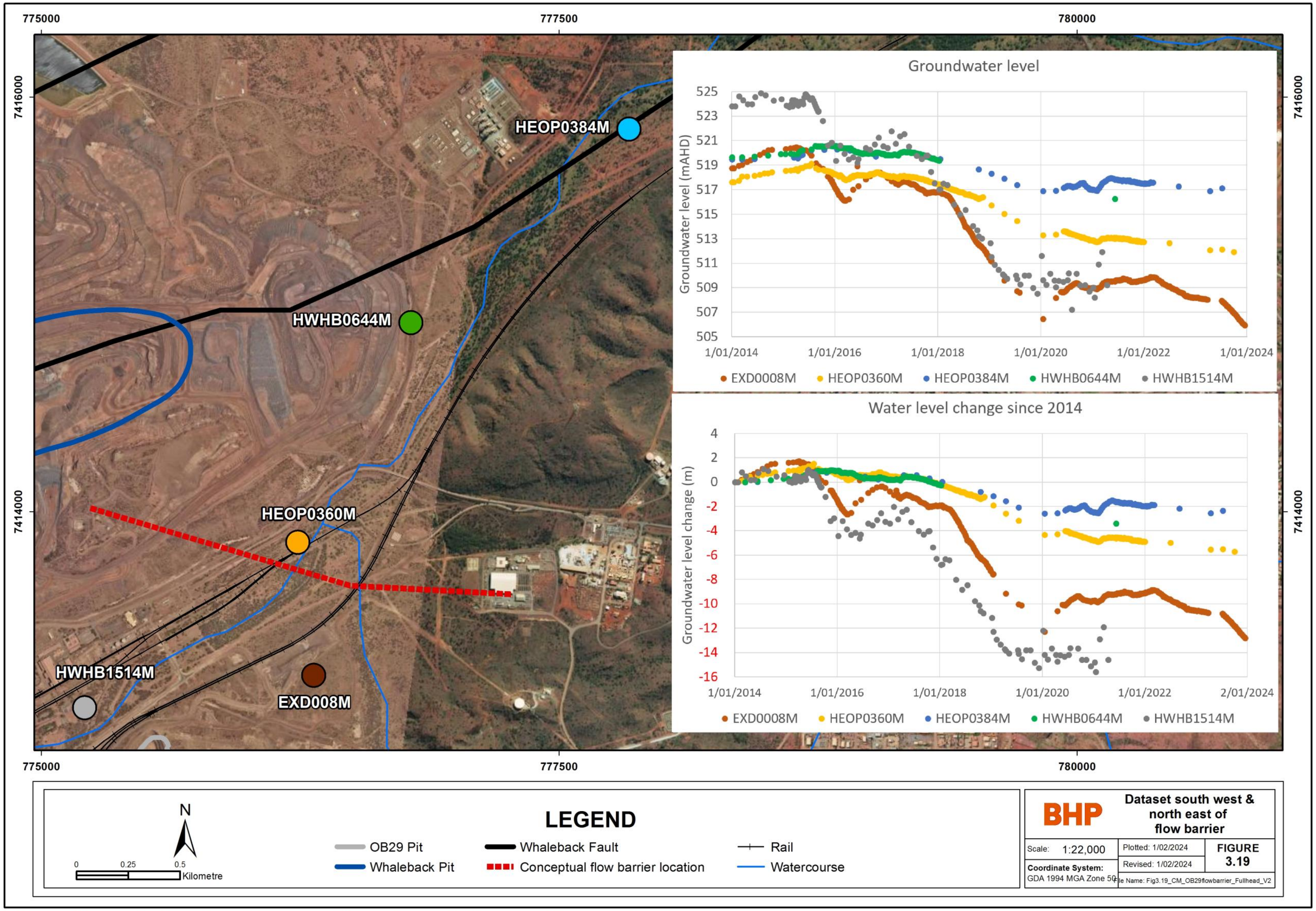

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Figure 3.19: Observed groundwater levels either side of the leaky flow barrier east of OB29

OB30 and surrounds

Figure 3.20 shows the water levels in the vicinity of OB30 and to the north west and representative locations in OB35 and the regional dolomite north of OB29. The data show that:

- The OB30 aquifer responds very consistently to the dewatering from the east (OB29) and southwest (OB35). This suggests that the area covered by these monitoring bores presents high transmissivity.
- The OB30 water levels start to diverge from the regional water levels (dolomite) north of OB29 and the OB35 water levels from the start of 2020. From this point on (in response to OB29 abstraction reducing then stopping) the OB35 water levels fall more rapidly and the regional OB29 levels recover slightly. The OB30 levels continue to drawdown post-2019, but at a reduced gradient.

This suggests that the OB30 aquifer is very well hydraulically connected to the OB29 regional and / or orebody aquifers and has some degree of hydraulic separation from the OB35 aquifer.

The data also show that the water levels are more variable to the north west of OB30. They are discussed in more detail below (in the "Connection to Whaleback aquifer system" section), but it is worthwhile noting here that the water levels are very different to those seen throughout the regional and orebody aquifer systems around OB29/30 and OB35 and range significantly (from 540 mAHD to 510 mAHD) prior to abstraction and show no obvious response when abstraction does commence.

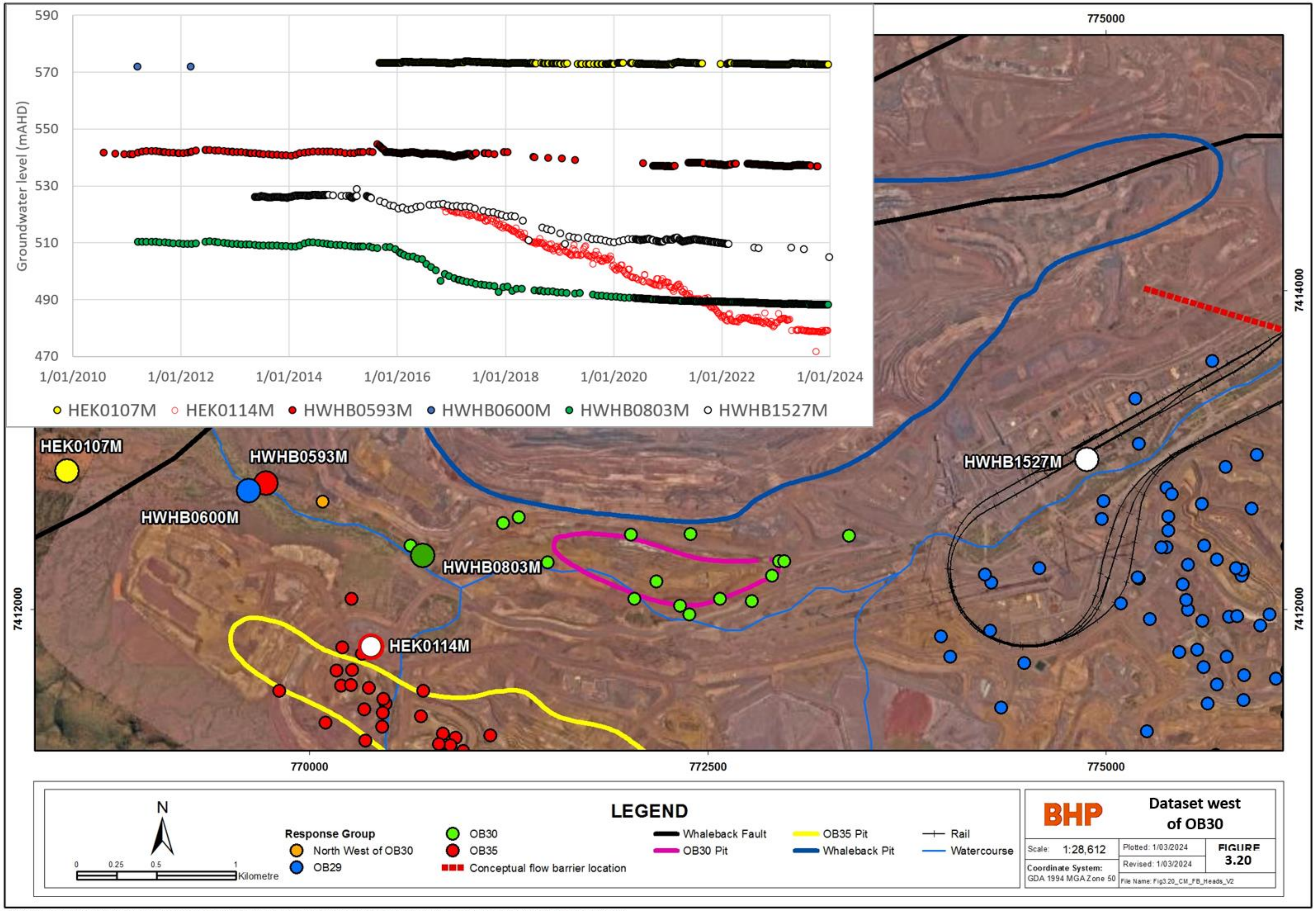

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Figure 3.20: Groundwater levels west of Orebody 30

OB35 and surrounds

The groundwater levels and monitoring bores around OB35 are shown in Figures 3.21 to 3.23. These show the locations of all observations, the main OB35 aquifer group and the outliers. They show that:

- Monitoring was limited around OB35 during the OB29 HDT (2015-2016). Of the few bores that were monitored during this time, the observations suggest that OB35 water levels may have been reduced in the order of a metre of so in response to OB29 abstraction. The response was far less than that seen at OB30, however.
- The response to dewatering is very consistent throughout the orebody. This is indicative of a highly transmissive orebody aquifer. By 2022 groundwater levels in the orebody and regional system to the north have fallen to about 480 mAHD. Assuming an initial level of 520 mAHD, drawdown has therefore been 40 m.
- Several bores along the northern edge of the OB35 orebody are constructed in the dolomite. These return identical heads to the orebody bores, suggesting a direct connection between the orebody and regional aquifers in this direction.
- Monitoring in the regional aquifer is limited to just two bores (HEK131M and HEK132M – see Figures 3.22 and 3.33) to the west of OB35. These bores return a clear response to dewatering, but it is subdued compared to the orebody response. There is also a significant difference between them, HEK131M is drawn down about 10 m less than the orebody (therefore 30 m by the start of 2022) and HEK132M about 20 m less than the orebody (therefore 20 m by the start of 2022).
- HEK0106M in the east (Figures 3.22 and 3.23) shows a very different response compared to the orebody aquifer. Whilst this bore is screened in the Marra Mamba, it falls outside the low and high grade orebody and:
    - provides evidence that the hydraulic conductivity of the unmineralised Marra Mamba is relatively low.
    - is initially (2015) higher than the surrounding water levels, potentially indicating seepage from the tailings facility, although this could also be a function of the lower hydraulic conductivity.
    - shows an inflection at roughly the time that the OB29 production bores are switched off. This indicates that it may be hydraulically connected in some way to the OB29 orebody aquifer.
- After diverging slightly during the OB29 HDT, the water levels in OB35 and OB30 converge and remain the same until mid-2019. From this point the downward gradient hardly changes in OB35 (even though abstraction steadily increases) but at OB30 the drawdown ceases altogether, with water levels remaining stable for almost 2 years before falling again (although at a slower rate than before) at the start of 2021. This suggests that there is a significant degree of hydraulic disconnection between these two orebody aquifers.
- From January 2020, when dewatering has been almost exclusively from OB35, water levels in OB35 and the northern regional aquifer have fallen consistently and uniformly. The rate of drawdown was about 10 m/yr in 2020 and 2021.
- There is also a clear response to dewatering in the Eastern Syncline orebody. However, the response reduces steadily with distance from the OB35 orebody aquifer. In the southern part of Eastern Syncline orebody, water levels are drawn down by almost 15 m by 2022 (WSR0911M), compared to the 40 m in OB35 and between 20 and 30 m in the regional aquifer to the west of OB35. This, added to the presence of a distinct groundwater gradient within the Eastern Syncline orebody suggests that:
    - The hydraulic connection between the OB35 and Eastern Syncline orebody aquifers is limited; and / or
    - The Eastern Syncline orebody comprises lower quality aquifer material (i.e. lower hydraulic conductivity) than the OB35 orebody; and / or
    - The main hydraulic connection with the southern part of the Eastern Syncline orebody aquifer is via the regional dolomite (given that the drawdown at WSR1029M is (slightly) greater than that at WSR0911M – the former being the closest to the regional aquifer).

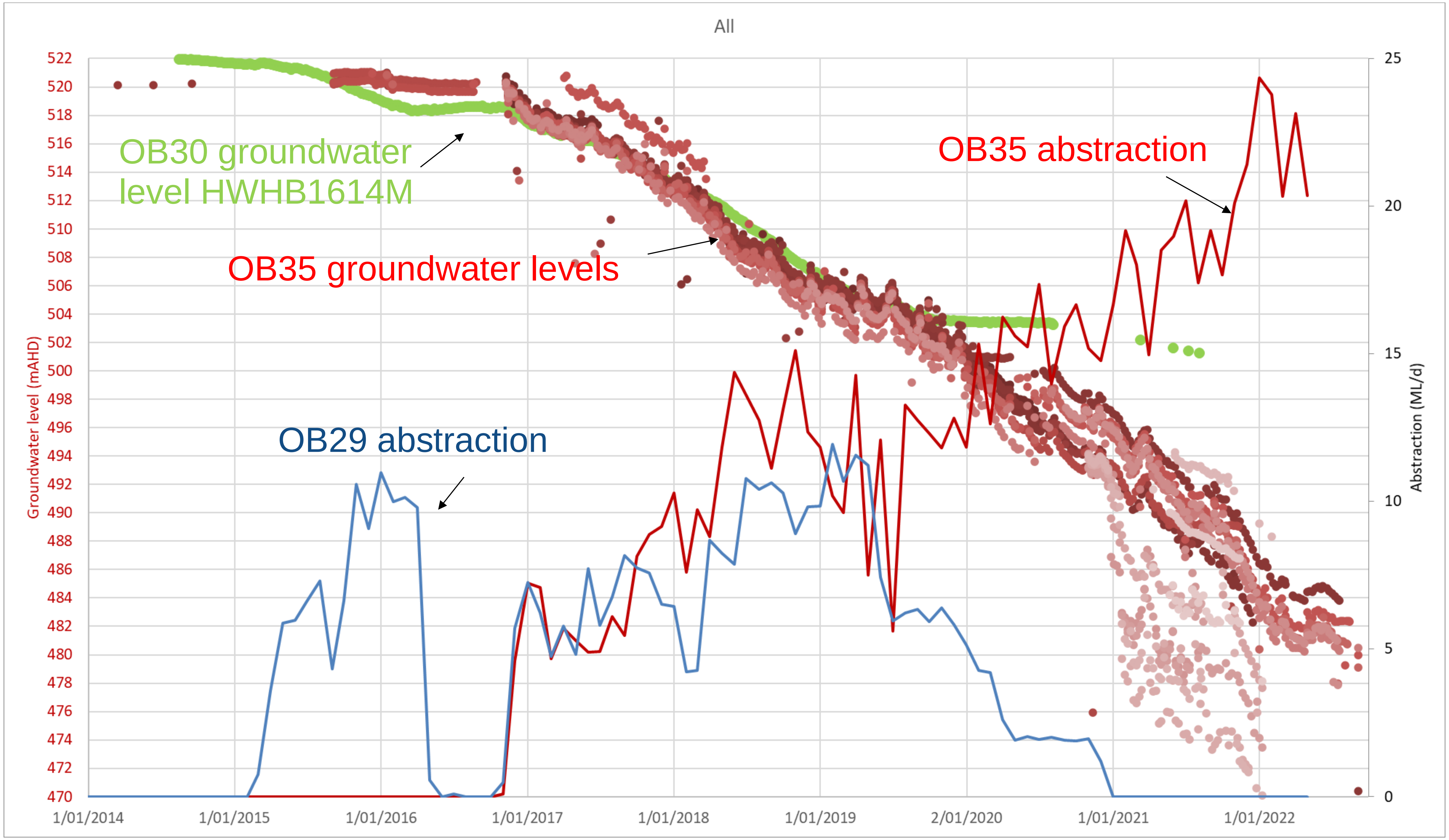

Figure 3.21: Observed groundwater levels in OB35 and OB29 / OB35 abstraction rates

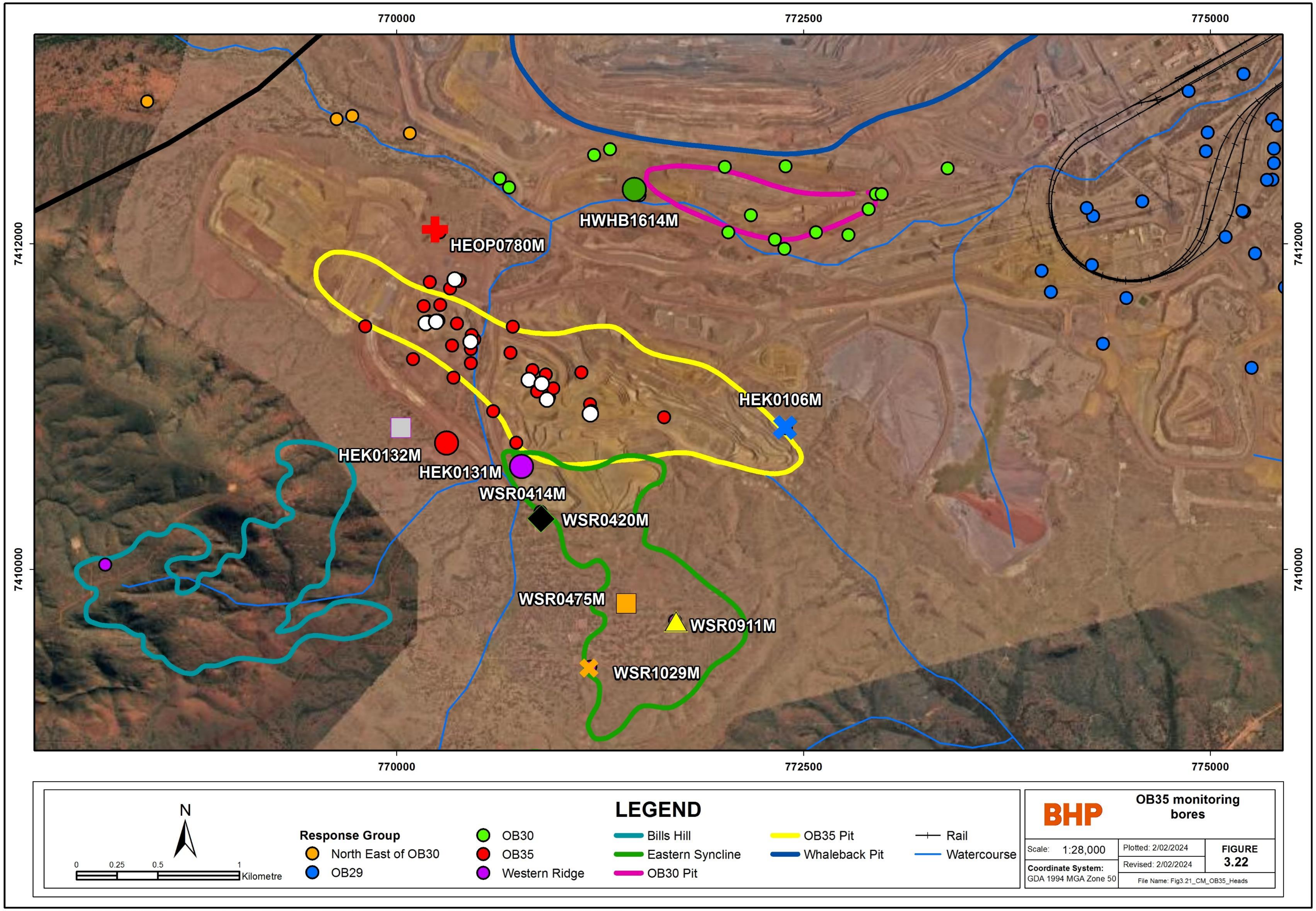

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Figure 3.22: Selected OB35 and Eastern Syncline monitoring bores

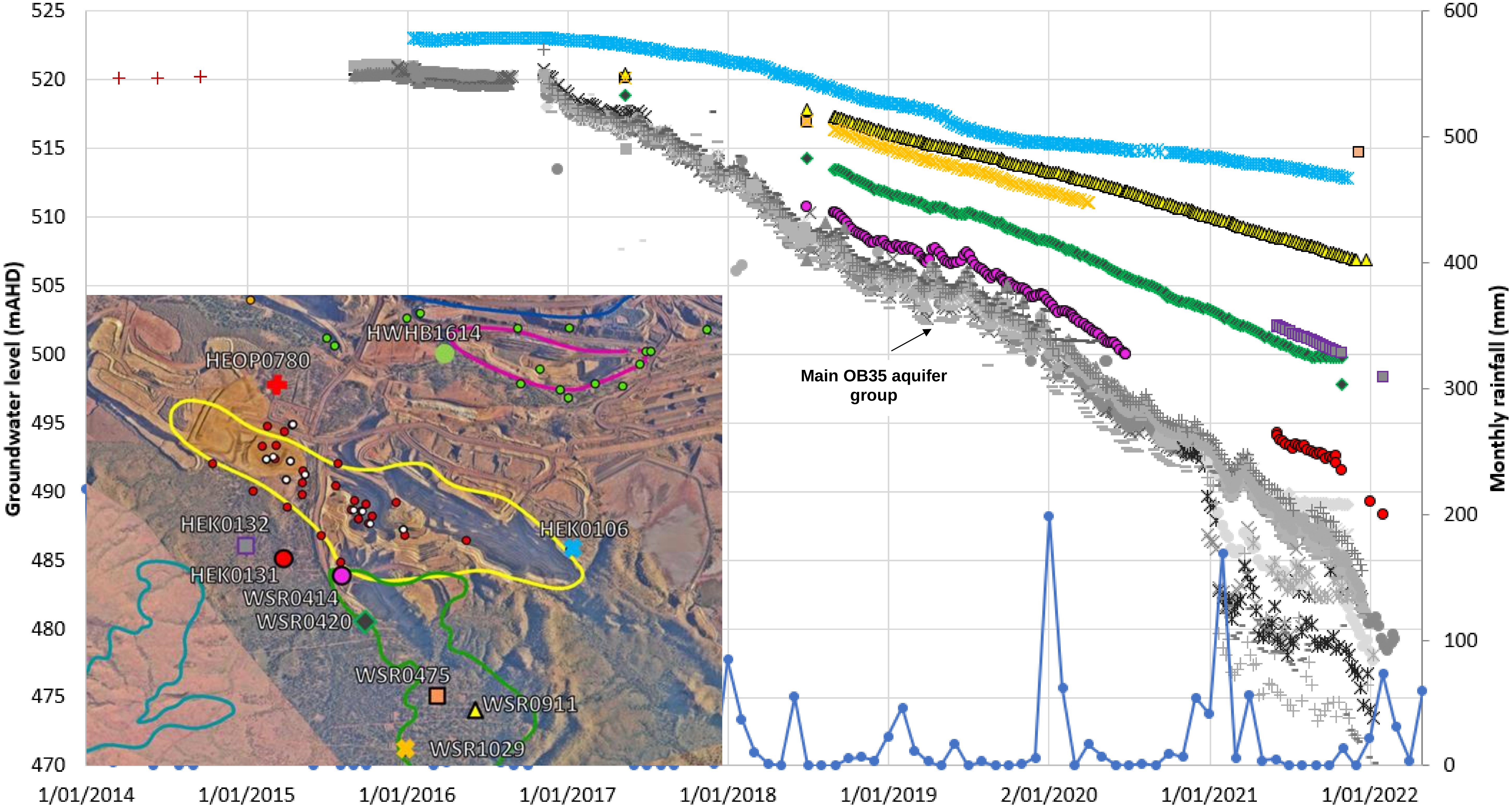

Figure 3.23: Observed groundwater levels at selected OB35 and Eastern Syncline

Western Ridge

The Western Ridge monitoring dataset is presented in Figures 3.24 to 3.25. The data show that:

- The Western Ridge aquifer compartment is bound to the west by the Whaleback Fault. Groundwater levels at HWSR0019M are 583 mAHD. Water levels are available in 2021 and 2022 and show no signs of falling in response to dewatering at OB35 and OB29. In 2022 the water level here is 80 m higher than the water level just east of the Whaleback Fault (WSR0296RM).
- All initial observations (May 2017) are at roughly the same level (~520 mAHD) as that seen in OB35 (e.g. at HEK0111M). The only exceptions are at WSR1139RM and WSR1193RM, both of which return the much higher level of 570 mAHD.
- The water levels in all locations (apart from WSR1139RM and WSR1193RM) experience drawdown throughout the monitored period (from 2017 to 2022).
- WSR1139RM and WSR1193RM experience no drawdown at all and are located in the southern part of the Silver Knight orebody. Monitoring in the northern part of this orebody experiences the same drawdown as elsewhere, suggesting a significant flow barrier between the northern and southern Silver Knight orebodies.
- The monitoring in the regional aquifer and southern orebodies is limited somewhat spatially and temporally. However, the data is suggestive of a very uniform and high transmissivity regional aquifer, well connected to the southern orebody aquifers. The recorded drawdown at the western end of the system (defined by the Whaleback Fault) and the eastern end (the southern part of the Eastern Syncline orebody) is very similar. By the start of 2022 for example, it is roughly 17 m in the west (regional aquifer (WSR0296RM)) and 15 m in the east (Eastern Syncline aquifer (WSR0911RM)).
- The drawdown is just under half that observed in OB35 but considering the length of the flow path to the western boundary (roughly 9 km), this is significant.

In summary, the Western Ridge groundwater system is defined by:

- A regional aquifer extending from OB35 in the east to the Whaleback Fault in the west. This presents a very high transmissivity.
- The regional aquifer is very well hydraulically connected to the orebody aquifers in the south (Silver Knight and Eastern Syncline).
- The regional aquifer is less well connected to the orebody aquifers to the north (Bill's Hill and Mount Helen).
- The southern orebody of Silver Knight is hydraulically disconnected from the northern Silver Knight orebodies.

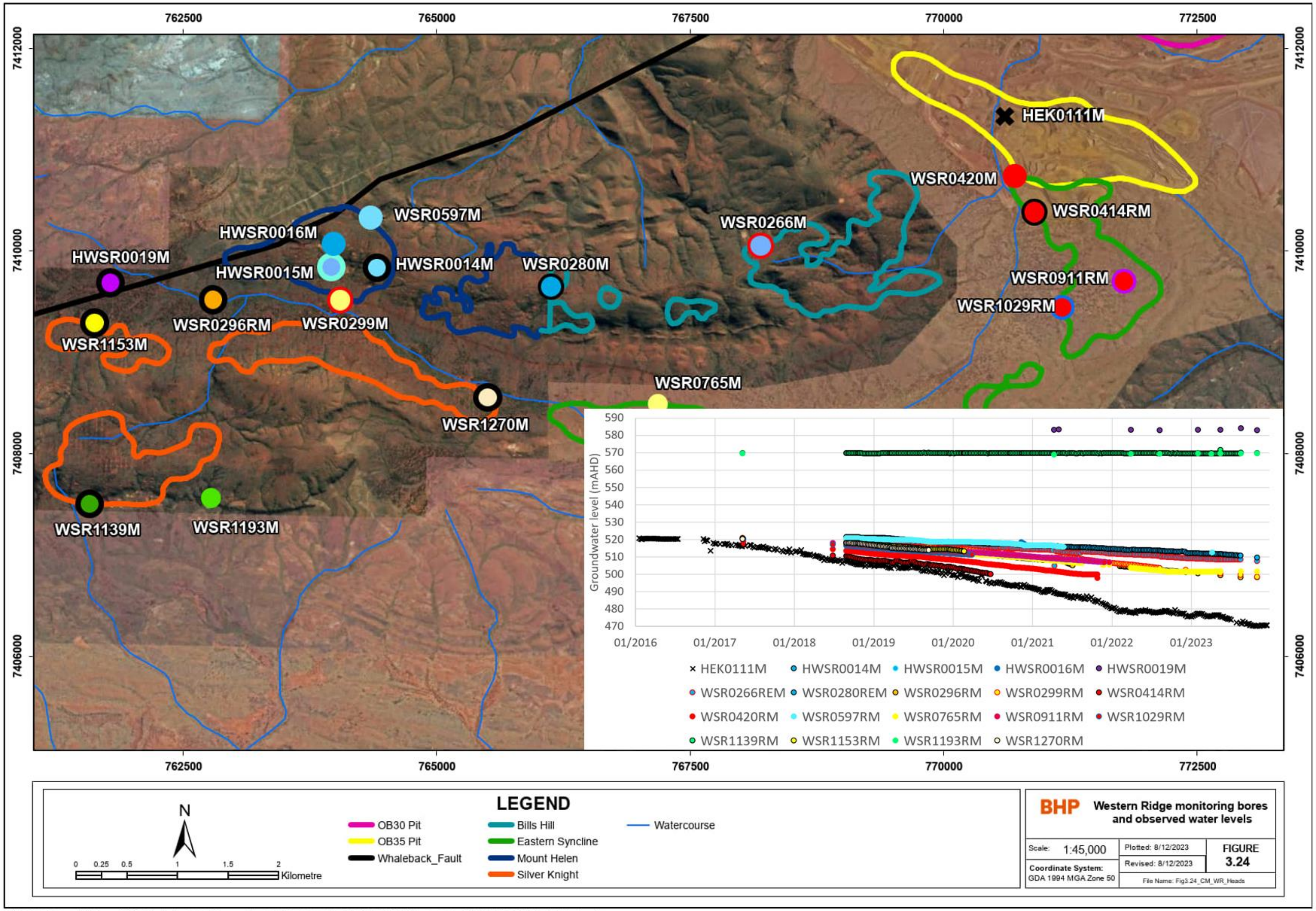

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Figure 3.24: Western Ridge monitoring bores and observed water levels

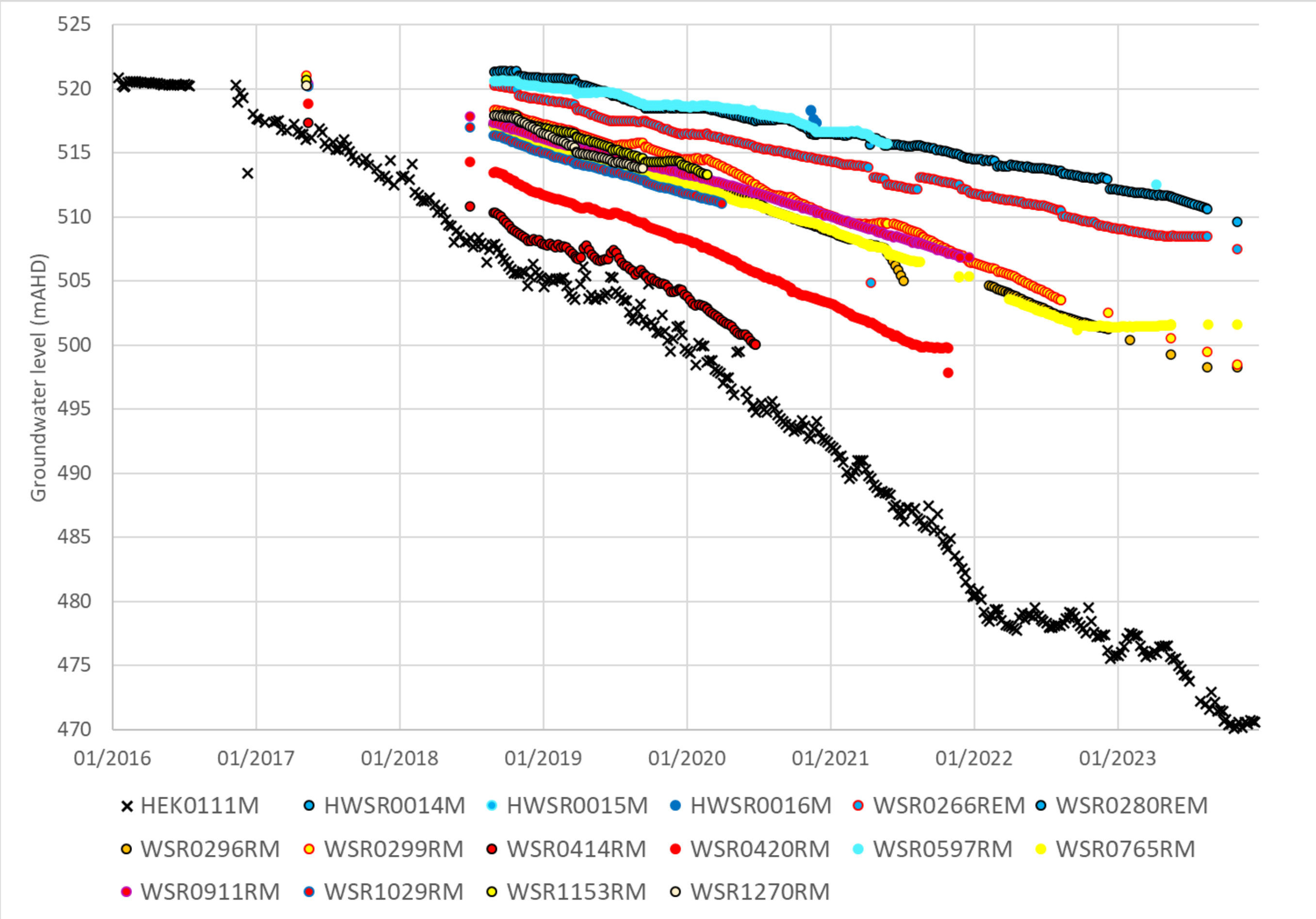

Figure 3.25: Western Ridge observed water levels (bore locations shown in Figure 3.24)

Conclusions

OB29 / OB30 area

The OB29 and OB30 orebody aquifers are well connected to the regional aquifer. The OB29 orebody aquifer shows some heterogeneity, with potentially compartmentalisation or lower hydraulic conductivity in the southern half.

The regional dolomite is likely to present both a high transmissivity and high storage. There is no obvious disconnection to the regional aquifer between OB29 and OB30. There is evidence of the presence of leaky flow barriers at either end of this system though; one between OB35 and OB30 and one just to the east of OB29. To varying extents these barriers interrupt groundwater flow through this system.

OB35 / Western Ridge area

The OB35 orebody and adjacent regional aquifers are very well connected through the northern part of the OB35 aquifer and both appear to be hydraulically homogeneous in the local area.

The Western Ridge area is characterised by the high transmissivity of the regional aquifer which continues all the way to the Whaleback Fault in the west. The Marra Mamba orebodies in the south, Silver Knight (excluding the southernmost orebody) and Eastern Syncline, are hydraulically connected to this regional system as the observed drawdown response so far is indistinguishable between the two aquifer types. There is a degree of hydraulic disconnection between the adjacent OB35 and Eastern Syncline orebodies, and / or the Eastern Syncline orebody aquifer has a lower transmissivity. The Brockman orebodies in the north appear to have some connection to the regional aquifers but less than the Marra Mambas in the south. This is most likely due to the presence of significant thickness of Mt McRae Shale and Mt Sylvia Formations in this area.

3.3.3.3. Connection to the Whaleback Aquifer system

Analysis

For this analysis both the long-term and dewatering datasets have been considered. The locations of pertinent bores are shown in Figure 3.26 along with the historical Whaleback abstraction rates. Hydrographs from monitoring bores in the south west (i.e. north of OB30) are shown in Figures 3.27 and 3.28 and from those in the east (i.e. north of OB29) in Figure 3.29.

The Whaleback orebody hydrogeology is complex, characterised by many fault blocks that host disconnected orebody aquifers. A detailed analysis of this system is not warranted here, however, in relation to the OB29/30/35 aquifer system, the following can be concluded:

- Pre-mining groundwater head reported to be about 525 mAHD (AGC, 1985)
- Heads in central and eastern parts of the Whaleback pit have been reduced to around 370 mAHD and lower.
- Heads in the south western compartment have remained at higher levels (between 470 and 510 mAHD) until abstraction commenced in a nearby production bore (HWHB0071P). Operation of this bore from the start of 2016 has clearly affected the south-western compartment, reducing heads in this area by at least 20 m.
- The heads in the OB29/30/35 aquifer system show no signs of reducing due to the head gradient anywhere along the southern walls of the Whaleback pit (Figure 3.27).
    - In the east the gradient is as much as 150 m and before dewatering started at OB29/35 there was no sign of this drawing down heads to the south (i.e. in the OB29/30/35 system)
    - In the west the gradient was smaller before dewatering of OB29/35 (10 to 20 m). However here as in the east, there was no obvious drawdown occurring to the south before dewatering commenced. Unfortunately, dewatering from the Whaleback bore HWHB0071P started in 2016, after the HDT at OB29, so it is not possible to see whether there was a response in the OB29/30/35 aquifer system to this stress as the groundwater level response is dominated by the HDT. If there was a response, it was certainly very small.
- Heads in bores further to the west (HWHB0593M (Wittenoom Formation) and HEK0107M (Jeerinah Formation) are much higher than those in the regional system, 540 and 570 mAHD respectively, and show

no signs of reacting to either Whaleback or OB29/35 dewatering. HEK0107M (not shown in the Figure) is located on the northern side of the Whaleback Fault.

- To the east of Whaleback there are again no signs of dewatering of Whaleback influencing the OB29/30/35 system (Figure 3.29). The bore HWHB0628M (Wittenoom Formation) has maintained a high head (540 mAHD) throughout both Whaleback and OB29/35 dewatering and G0942M in the south eastern Whaleback pit wall recorded no obvious connection to the Whaleback system when it was monitored between 1985 and 1995 and when the Whaleback orebody just to the north was being dewatered, with heads falling to as low as 460 mAHD.

Conclusion

These data suggest that there is either no connection between the Whaleback and OB29/30/35 aquifer systems, or, if there is, it is very limited, with a low maximum potential flow rate. If the connection were significant, it is unlikely that such a head gradient (with no sign of reduction) would be possible between the two systems.

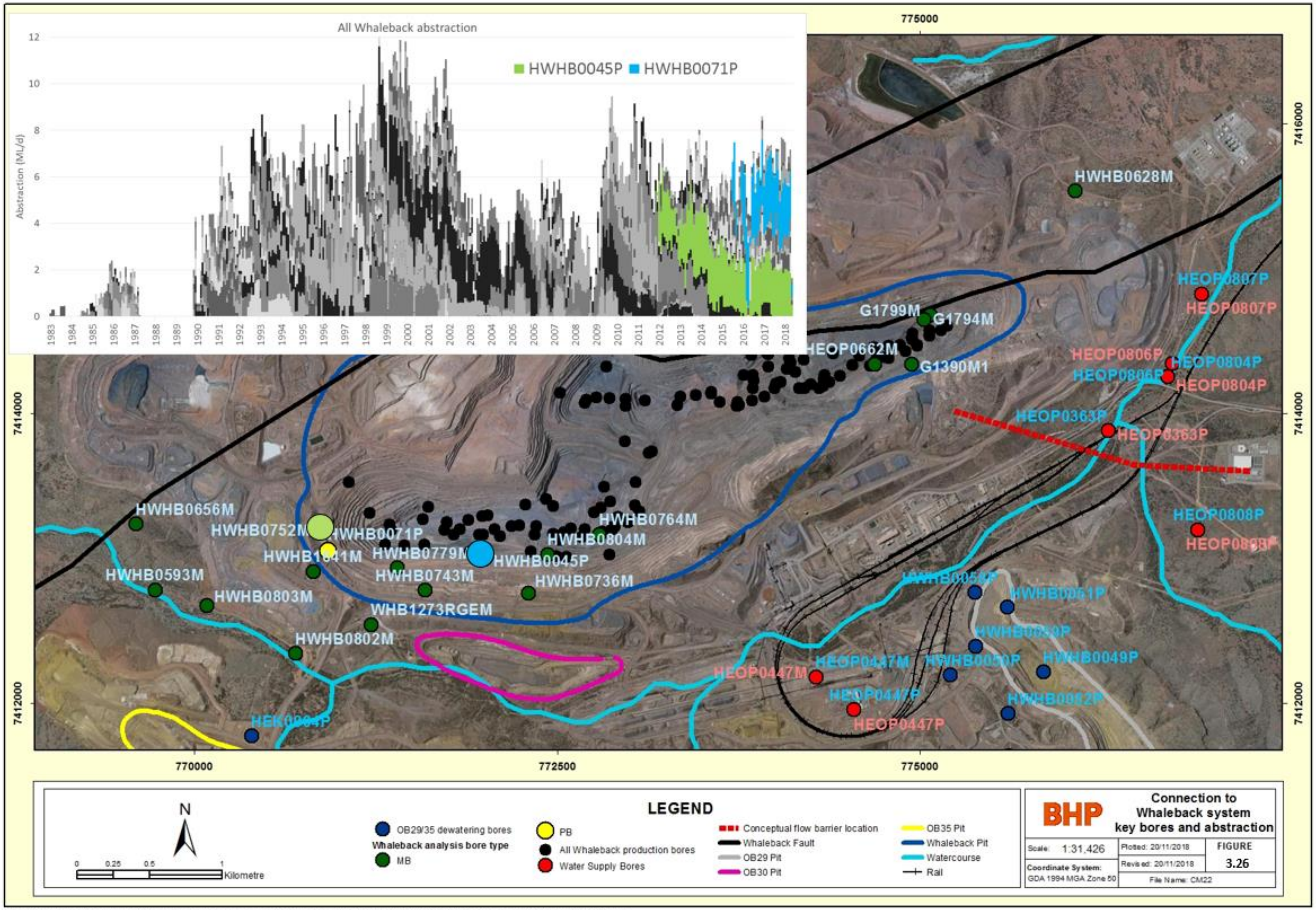

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Figure 3.26: Connection to Whaleback system – key bores and abstraction

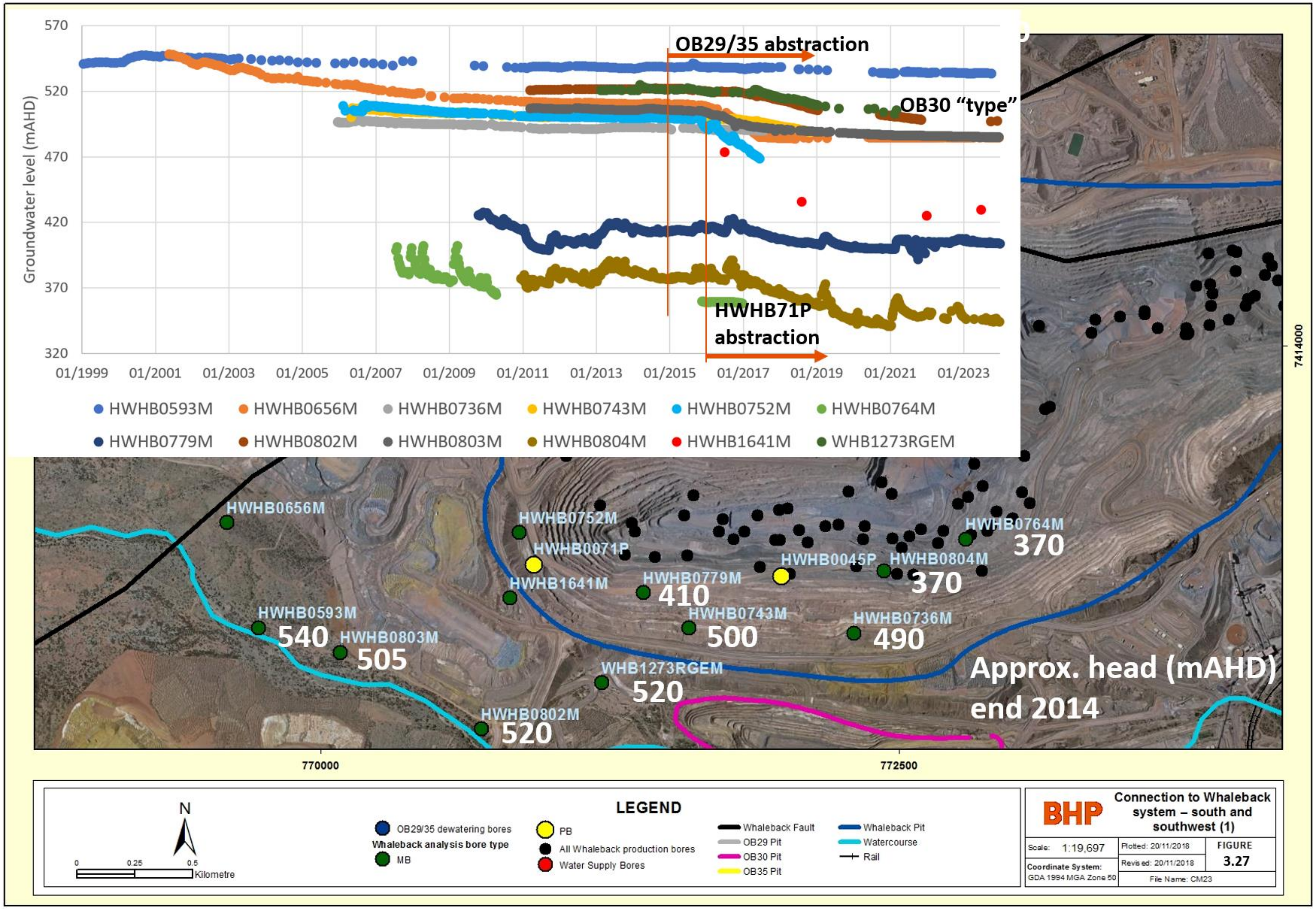

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Figure 3.27: Connection to Whaleback system – south and south west (1)

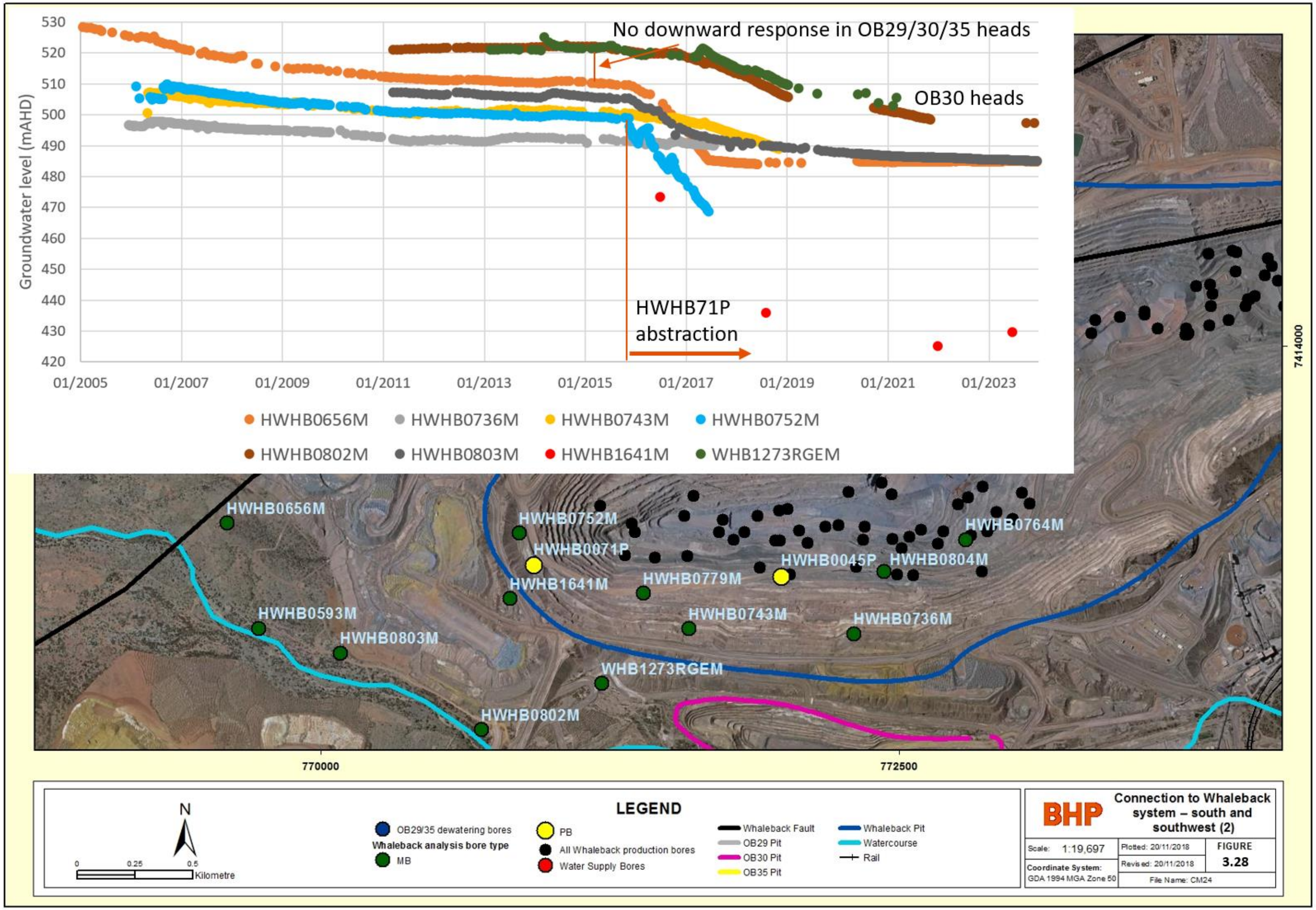

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Figure 3.28: Connection to Whaleback system – south and south west (2)

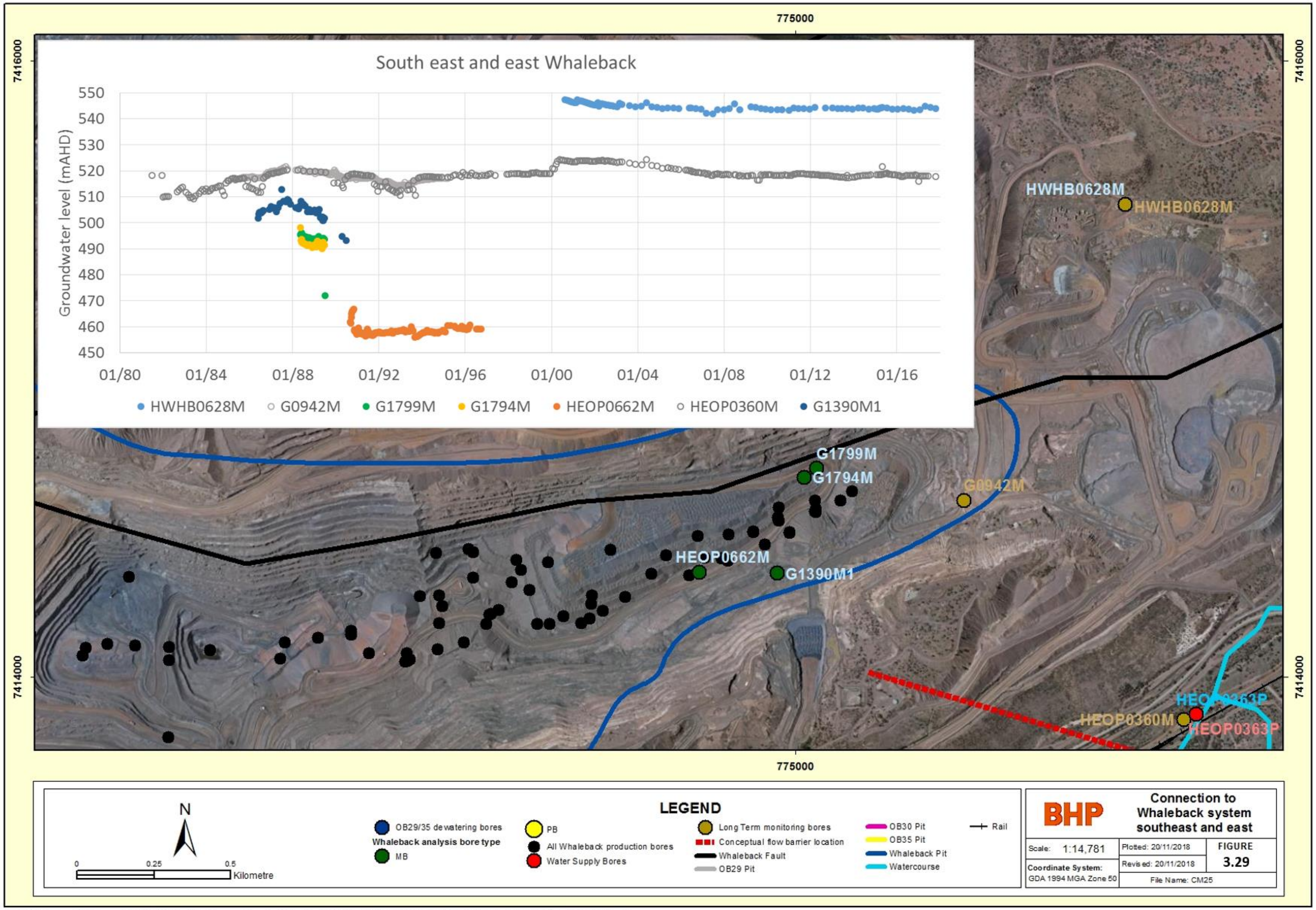

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Figure 3.29: Connection to Whaleback system south east and east

3.3.3.4. Connection east towards Ethel Gorge

Analysis

The evidence for the existence of a leaky flow barrier through the regional aquifer just to the east of OB29 is provided in the observed groundwater fluctuations over both the long-term and in response to OB29/35 dewatering. As it seems likely that the water level fall observed in the last 24 months just east of the barrier (HEOP0360M) is derived from abstraction from OB29 and OB35, it is necessary to expand the hydrogeological analysis to the east, to gauge the potential for future dewatering of the OB29/30/35 system to influence groundwater levels towards the Ethel Gorge TEC.

As a conservative assumption, the regional Tertiary Detrital / dolomite aquifers are assumed to be continuous from OB29 to the Ethel Gorge system. The aquifers pass north of Newman then turn south east, passing to the south of OB25 and merging with the western side of the Ethel Gorge system (west of Ophthalmia Dam). The locations of monitoring bores with long term data within this area and the historical production bores are shown in Figure 3.30. Historical abstraction is shown in the same figure and groundwater levels are shown in Figure 3.31 and 3.32. Figure 1.2 shows the location of Ethel Gorge TEC relative to operational areas.

These data show that the area has had a complex past, with many anthropogenic and natural stresses acting on the groundwater system resulting in head changes in some parts of the regional aquifers being more than 20 m, over approximately 50 years of monitoring. In terms of the potential for drawdown moving from just across the OB29 leaky flow barrier to Ethel Gorge, the following can be surmised from these data:

- The OB29/30/35 (Figure 3.31 red zone) and the Ethel Gorge aquifer systems (Figure 3.31 blue zone) maintain very homogeneous groundwater levels throughout their individual extents. Bearing in mind this is only a part of the full Ethel Gorge system, the heads vary only by 2 m over 7 km of lateral aquifer extent, from about 500 to 502 mAHD (as observed in the early 1970s, before significant water supply abstraction occurred (Figures 3.31 and 3.32)).
- Between these aquifer systems (Figure 3.31 green zone) there is a gradient between the heads just east of the OB29 barrier (i.e. HEOP0360M) and the western extent of the Ethel Gorge aquifer system (i.e. HEOP0317M). The gradual change in heads between these two points suggest that there is a change in rock mass properties or geometry (i.e. reduction in permeability, saturated thickness, aquifer width and therefore ultimately aquifer transmissivity) rather than structural controls (although this is also possible).
- There seems to be a distinct change (indicating a flow barrier of unknown type and efficacy) in heads where the green zone (i.e. HEOP0432M) and blue zone (HEOP0322M) meet. These bores are 500 m apart, but the head is about 5 m lower in the eastern bore (prior to the installation of the dam).
- The drawdown resulting from water supply abstraction from the Ophthalmia Borefield in the Ethel Gorge aquifer prior to the construction and operation of Ophthalmia Dam in the early 1980s appears to be replicated (at an ever decreasing rate towards the west) all the way to the OB29 leaky flow barrier. Whether this response crosses the barrier is difficult to tell but if it does the effect is very small.
- Since operation of the dam, the Ethel Gorge system has responded to several different types of stress, often at the same time (seepage from the dam, dewatering of OB23, Orebody 24 (OB24) and OB25, continued abstraction from the Ophthalmia borefield and rainfall recharge). Using this data to build an understanding of a relationship between volume and drawdown is problematic. However, looking at the data from before the dam, abstraction from the Ethel Gorge system of about 10 ML/d (Ophthalmia borefield) reduced the head in the Ethel Gorge aquifer by about 1 m/year (i.e. 7 m in 7 years between 1974 (~501 mAHD) and 1980 (~494 mAHD)).
- As mentioned previously, the aquifer just to the east of OB29 experienced a rapid increase in heads from 1982 until 1987 (up to 10 m), probably from discharge of surplus water from the Whaleback mining operation during early dewatering and / or leakage from two pit lakes at the eastern end of the Whaleback pit. This mounding did not spread west across the OB29 leaky flow barrier, but this data shows that heads increased in a similar manner as far east as HEOP0414M (although in this area, seepage from the Newman Waste Water Treatment Plant could be responsible), just to the west of the main Ethel Gorge aquifer system. What effect this had on the heads in the Ethel Gorge aquifer is hard to tell because it coincided with operation of the dam and associated increases in heads in that area. Nonetheless, the gradient increased between the two areas, which confirms a level of disconnection between them.

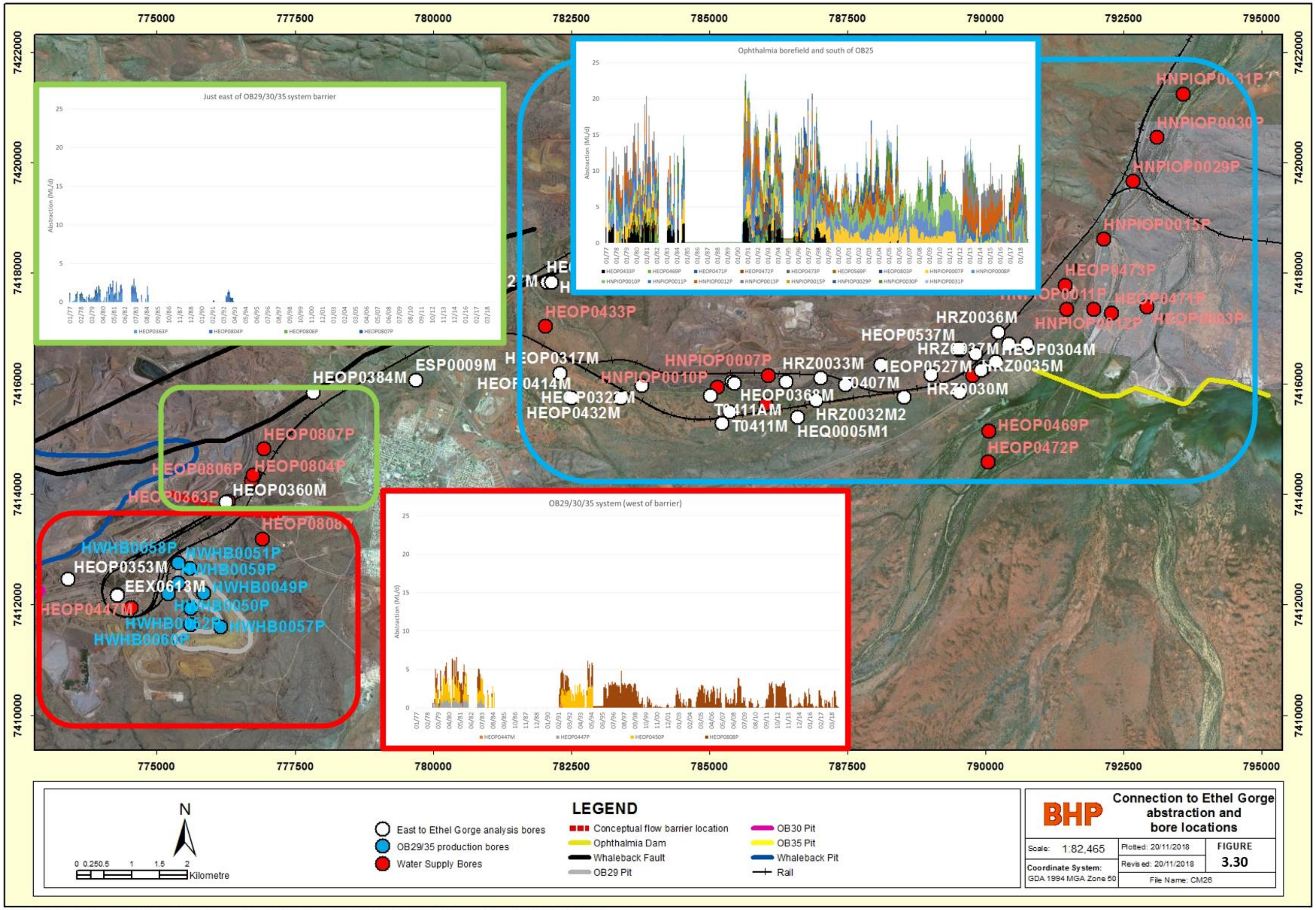

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Figure 3.30: Connection to Ethel Gorge – abstraction and monitoring bores (long-term data)

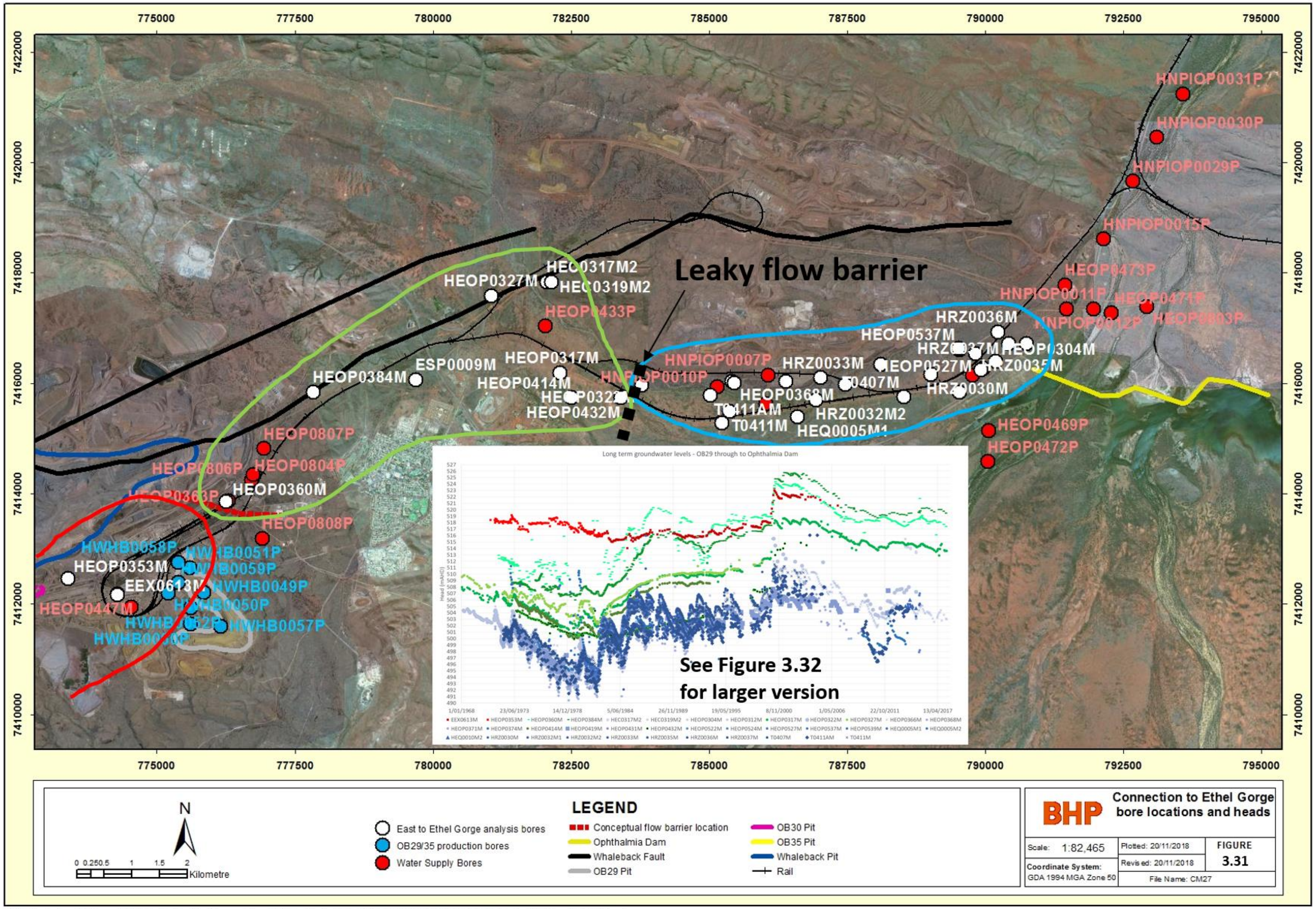

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Figure 3.31: Connection to Ethel Gorge; bore locations and observed groundwater levels (1968 to 2017)

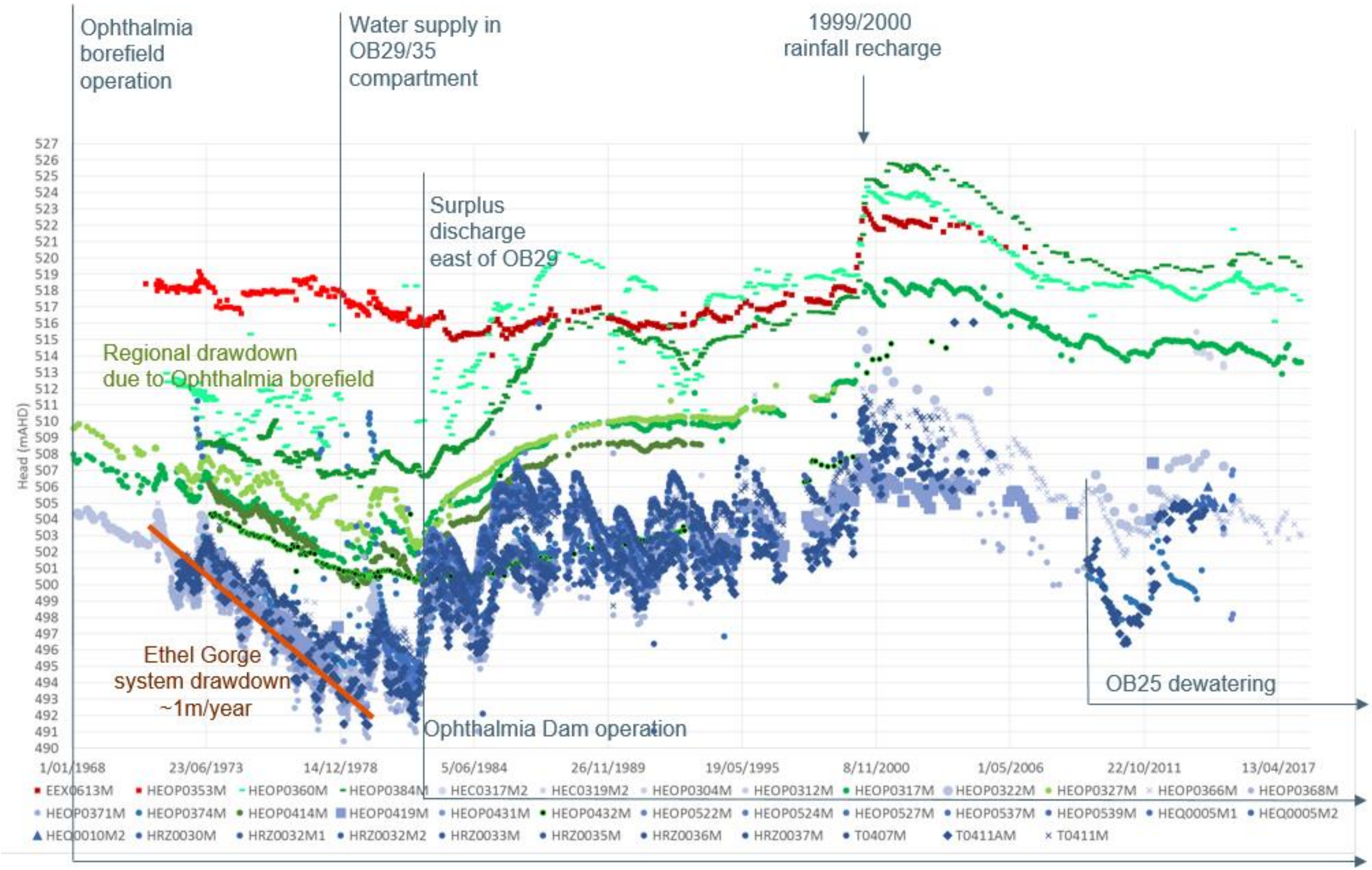

Figure 3.32: Connection to Ethel Gorge – observed groundwater levels

Throughflow estimate

Throughflow from the area just east of OB29 to the Ethel Gorge aquifer can be estimated based on the data described above. Unfortunately, all of the key assumptions into the Darcy equation are uncertain, and all play a significant role in the outcome. However, even when a range is used for some of these parameters, the result gives an idea as to the order of magnitude that is likely. Using the equation:

$$Q = K\frac{dh}{dl}A$$

Where,

K = hydraulic conductivity – assumed to be 100 m^2/d (although may be lower given head gradients that have built up periodically in this area).

dl = length over which head change is observed – 3,600 m (from HEOP0360M to HEOP0327M)

dh = head change over area of interest – 10 m (roughly, in 1970)

A = cross sectional area through which flow occurs (m^2) – unknown, but width limited to about 100 m and depth (of significant K) likely anywhere between 20 and 100 m.

With these inputs, and varying the depth of significant K (20, 50 and 100 m), the simple analysis estimates flow through the aquifer at this location to be 280 m^3/d, 700 m^3/d or 1,400 m^3/d.

Other than aquifer depth, the other potential variations will have the following impact on these estimates:

- Reduced flow: Lower K (higher not thought probable), smaller aquifer width, lower head gradient
- Increased flow: Greater aquifer width, higher head gradient

Conclusion

It seems likely that flow within the regional aquifer is inhibited (i.e. within the low transmissivity zone described by the green coloured zone in Figure 3.31) between the local OB29/30/35 aquifer system in the west and Ethel Gorge aquifer system in the east. The western boundary of this low transmissivity zone is formed by the leaky flow barrier that exists just to the east of OB29 and the eastern boundary occurs somewhere around HEOP0432M (just south west of OB25). The water level data show that head changes originating in the Ethel Gorge aquifer do however pass westwards, all the way to the OB29 leaky flow barrier. The data also suggest that head changes originating in the intervening area may pass into the Ethel Gorge aquifer but have very little overall effect. These observations are likely to characterise the relationship between two very different aquifer systems, one with high storage and transmissivity (the Ethel Gorge system) and the other with a low storage and transmissivity (the system up to the barrier at OB29). A conceptual illustration is shown in Figure 3.33.

The rough estimates of throughflow described above, whilst uncertain, suggest that flow from the west to east could be in the range of 100 to 2,000 m^3/d (0.1 to 2 ML/d).

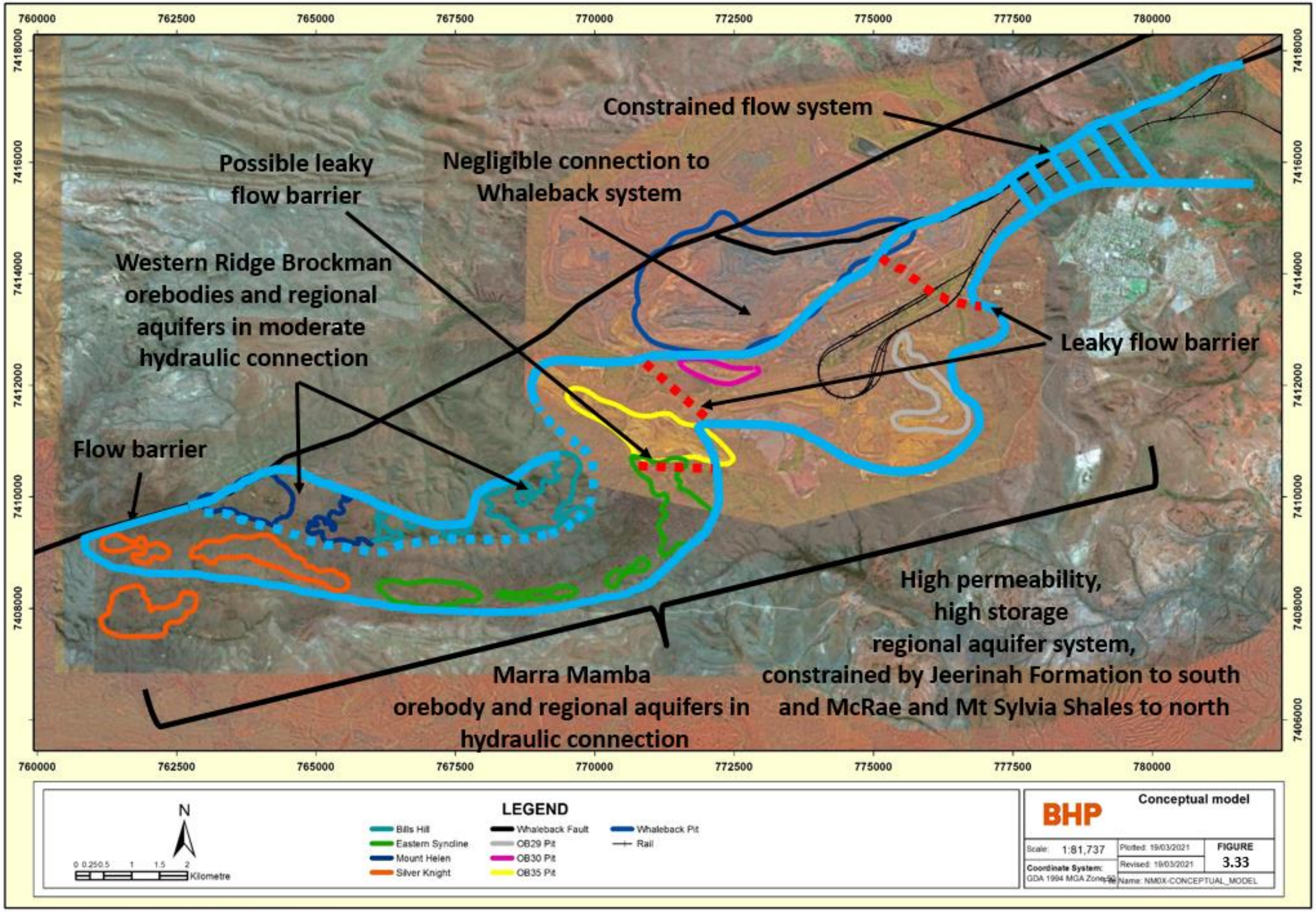

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Figure 3.33: Conceptual groundwater flow model

3.3.4. Recharge mechanisms

Recharge is expected to occur primarily via the base of drainage lines including Whaleback Creek and associated tributaries. Diffuse recharge is considered to be low and likely to be more prevalent in areas where bedrock is exposed. A significant aquifer response was observed during 1999/2000 wet season and numerous smaller responses observed relating to smaller scale rainfall events.

Depth to groundwater in the regional aquifers in this area ranges from a minimum of about 30 mbgl around OB29 to a maximum of about 90 mbgl towards the western end of Western Ridge.

Throughflow from upstream aquifers to the west is considered to be minimal due to the isolating effects of the Whaleback fault. Similarly, throughflow from the north and south of the study area is unlikely due to presence of low permeability shales.

3.3.5. Discharge mechanisms

The area has a very long history of groundwater abstraction, initially associated with water supply for the Whaleback mine and associated infrastructure (known as the V-Line borefield), then dewatering of the Whaleback pits and more recently dewatering of the OB29 and OB35 pits.

Mining commenced at Mt Whaleback in 1969 with below water table mining commencing in 1984. Dewatering requirements have progressively increased as the pit has developed both laterally and vertically with approximately 6-10 ML/d being abstracted in recent years. Most abstraction is derived from in-pit dewatering bores and sumps within the orebody aquifers, with lesser amounts derived from pit wall dewatering / depressurisation systems.

Mining commenced at OB29 in 1980 and at OB30 in 1999. However, mining below water table at OB29 has only started recently, with dewatering (initially as a HDT) starting in February 2015. Preparation for below water table mining at OB35 began with dewatering in October 2016.

Abstraction at OB29 has been undertaken in two phases, separated by a period of about 7 months to allow system recovery for analysis (as part of the HDT). The first phase, with most abstraction between March 2015 and March 2016 averaged nearly 8 ML/d. The second commenced in November 2016 and averaged about 7 ML/d to July 2018, decreasing to 0 ML/d by November 2020 (Figures 3.10).

Abstraction at OB35 has averaged 13 ML/d since it started in October 2016 to April 2022 (Figure 3.10). From December 2021 to April 2022 dewatering at OB35 averaged 20 ML/d.

The water supply for the mining area is predominantly sourced from local dewatering and additional raw water has historically been sourced from the Newman water supply system, which includes excess water from OB23 and OB25 at the Eastern Ridge operations. Historically water was also sourced from production bores installed in the Whaleback Creek valley (V Line Borefield) and one bore near the OB35 deposit, HEOP0450P (formerly known as V16). These bores intersected aquifers in the Paraburdoo Member dolomite and Marra Mamba. However, due to insufficient supply an alternate water supply was developed via the Ophthalmia borefield. Only one of the original V Line bores, HEOP0808P (formerly known as V18), which provides process water to the Yarnima Power Station, currently remains operational. This bore has been used since 1978 and at times reached a maximum rate of 3 ML/d. Between 2015 and 2017 this bore has been pumped at an average of 0.8 ML/d.

3.3.6. Groundwater chemistry

There is limited water chemistry data in the Western Ridge area with a single sample from bore HWSR0021P in the west end of the project area. Data from that sample shows the water quality to be similar to OB35, fresh with a dolomite signature. Given the strong hydraulic connection and common aquifer material, it is expected water quality will be similar in future sampling. The OB35 aquifers to the east however contain fresh water with TDS typically less than 600 mg/L. Groundwater in the Whaleback area is dominated by bicarbonate with no dominant cations. Expanded Durov plots, completed in the 2018 Annual Aquifer Review (AAR) are shown in Figure 3.34 and show a differentiation between water in the Mt Whaleback aquifer compartment compared with the study area hosted in the Marra Mamba and Wittenoom dolomite compartment to the south. There are slight but distinct groupings for water in the two regions with the slightly more evolved waters associated with the Brockman showing generally higher TDS (~800 mg/L) and tendency toward Mg where the Marra Mamba waters show a tendency toward Ca. Both water types are generally associated with recharge and the lower TDS indicates that the Marra Mamba and dolomite aquifers have a more active recharge regime. The distinct boundaries between the water types also suggests little to no mixing which supports the idea that these two compartments are poorly connected.

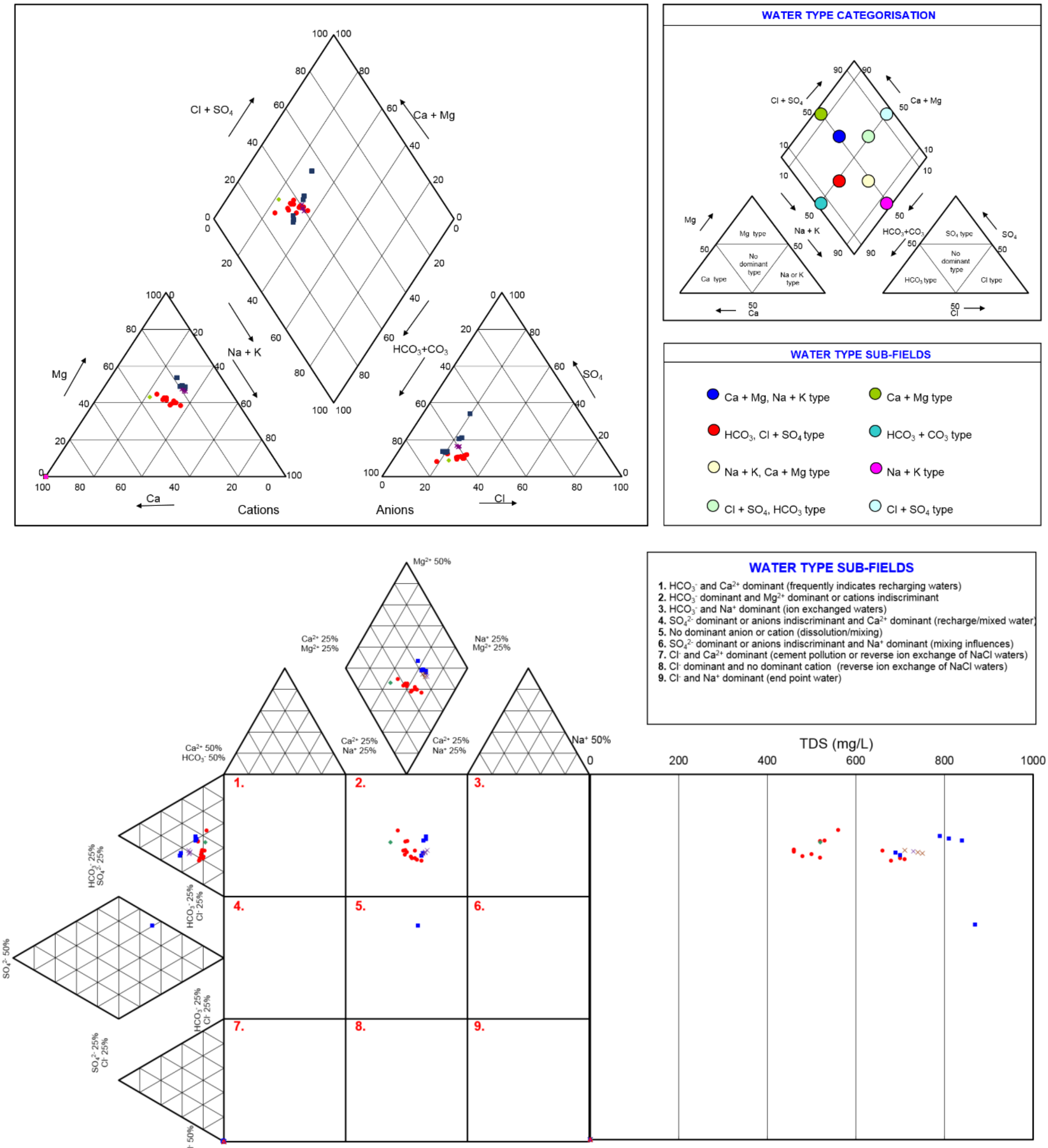

Figure 3.34: Expanded Durov plots completed during the 2018 AAR

3.3.7. Receptors

3.3.7.1 Groundwater receptors

The main groundwater receptors that have been identified within the OB29/30/35 area are:

- The Ethel Gorge Aquifer Stygobiont TEC, located approximately 15-20 km to the east (Figure 1.2). Further explanation of the TEC can be found in Sections 4.1.1 and 10.2.1.
- The P1 Newman Water Reserve Public Drinking Water Source Area, which overlaps the OB29/30/35 area. The reserve was proclaimed to protect the Newman town water supply, which is currently sourced from the Homestead and Ophthalmia borefields, located approximately 6-9 km north and 15 km northeast of OB29/30/35 respectively. Further explanation is provided in Section 4.2.
- Other groundwater users (BHP operated and third party), discussed further in Section 4.2 and 4.3.

3.3.7.2 Non-groundwater receptors

An area of pools located within a gorge, known as Nankunya (formerly Afghan Springs) is located approximately 4 km west/northwest of the OB35 area (Figure 1.2).

The current hydrogeological conceptualisation indicates the pools associated with Nankunya are supported by a combination of surface water runoff, infiltration of surface water to a local, perched, fractured rock aquifer and is disconnected from the orebody and regional aquifer systems.

For this reason, it is not considered as a receptor, for assessment, going forward.

3.3.8. Conceptual model Summary

A plan view of the conceptual groundwater flow model is provided in Figure 3.33. The area is characterised by hydraulically connected regional (weathered dolomite and some tertiary detritals) and Marra Mamba orebody aquifers. The connection of the regional aquifer to the Marra Mamba orebodies is either through mineralisation of the West Angela Shale, or the absence of it.

The regional dolomite aquifer over much of the area is likely to have both high storage (most likely karstic) and high hydraulic conductivity.

These aquifers are bounded by the low permeability Mt Sylvia Formation and Mt McRae Shale to the north (isolating this system from Whaleback orebody aquifer) and the low permeability Jeerinah Formation to the south. There is no evidence of any significant connection between the Whaleback orebody aquifer and the regional aquifers. The Mt Sylvia Formation and Mt McRae Shale appear to be less of a barrier to flow in the west however, allowing some flow between the regional aquifer and the Brockman orebody aquifers (Bill's Hill and Mount Helen).

The regional aquifer system appears to be interrupted by at least two leaky flow barriers. One between OB30 and OB35 and the other just to the east of OB29. The western side of the Whaleback Fault consists of the Jeerinah Formation which is considered very low permeability and presents a no flow boundary. The exact nature of the flow barrier to the east of OB29 is unknown (it may be rock mass or structural) and some flow does appear to occur across it. Between this barrier and the main Ethel Gorge aquifer system (about 9 km along the flow path to the east) there is evidence of a reduced regional aquifer transmissivity (which could be due to the reduction in aquifer width, reduced dolomite permeability or structural features) and another leaky flow barrier just south of OB25. The mechanism controlling the leaky flow barrier between OB30 and OB35 is unknown.

All the orebody aquifers are potentially high permeability and high storage. So far, only OB29 has shown signs of compartmentalisation and heterogeneity, but this may be due to the maturity of dewatering at this location and the large amount of monitoring.

Aquifer recharge following rainfall is a regular occurrence. Extremely high recharge rates are possible as evidenced by the response to the 1999/2000 wet season. This has happened once within the almost 50 years of observation history, but, given the apparent high hydraulic conductivity and storage of the dolomite and orebody aquifers, this event resulted in very significant amount of recharge to the system.

The high depth to groundwater (between 30 and 90 m for the aquifers) throughout the area suggests that groundwater/surface water interaction and evapotranspiration do not occur in this area.

Prior to dewatering at OB29 and OB35, groundwater flow was from west to east; from Western Ridge towards OB29. From OB29 flow would continue towards Ethel Gorge.

The target water levels for the study are shown in Figure 3.35. This study excludes the planned dewatering for Western Ridge described in the hydrogeological assessment for Western Ridge (BHP Iron Ore, 2022).

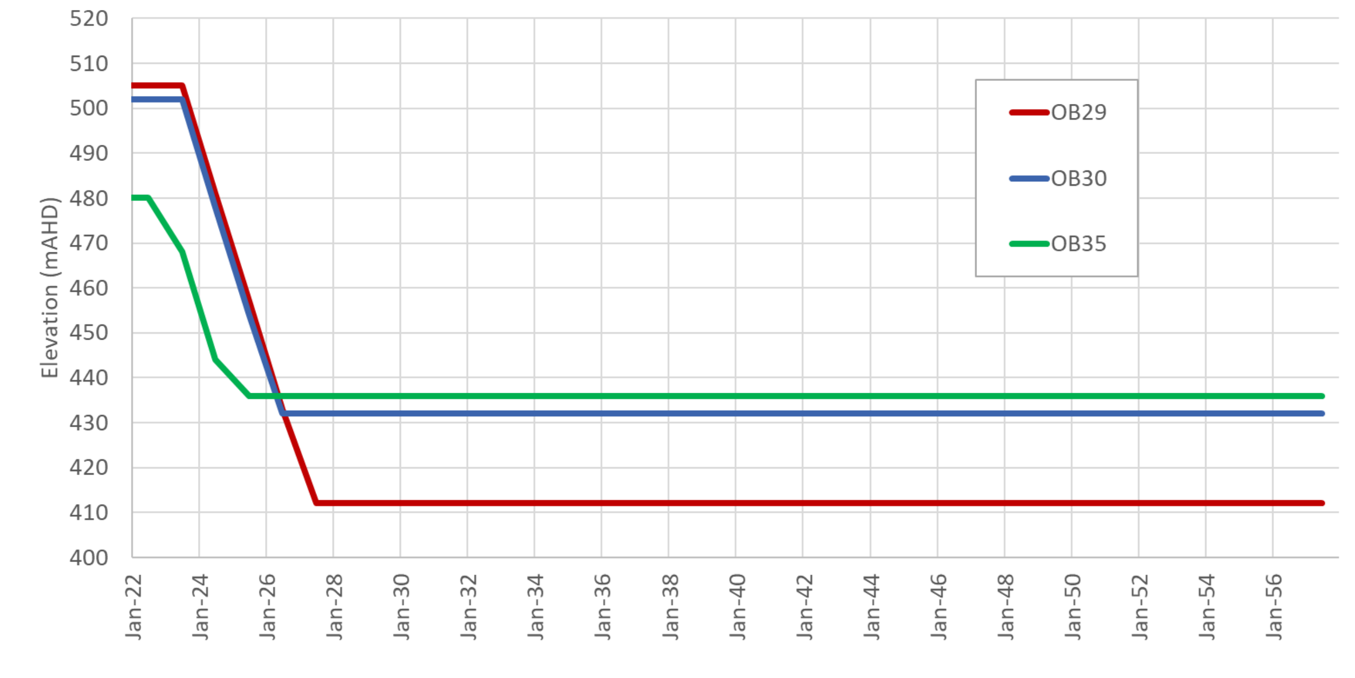

Figure 3.35: Target water levels

3.4. Data gaps and uncertainties

The hydrogeological conceptualisation is based on the observed groundwater levels, water chemistry, rainfall and geology from numerous boreholes. The main uncertainties remaining in the area that are relevant to future dewatering requirements and drawdown predictions are:

- **Behaviour of the leaky flow barriers as dewatering continues and water levels fall** – particularly the barrier east of OB29 and the potential barrier between OB30 and OB35.
- **Nature of connection to east** – historic data suggests a limited and shallow connection through the Whaleback Creek valley however connection at depth may be possible. Ongoing monitoring of deep and shallow bores along potential drawdown pathways will resolve this question.
- **Nature of the hydrogeology around OB30** – this includes the size and location of the dolomite and potential hydraulic structures between OB30 and OB29, of which there is some evidence from drilling.
- **Depth of karstic dolomite** - karstic dolomite is assumed to extend to depth but it may be a shallow feature. Understanding of this will develop over time as dewatering continues.
- **The connection and hydraulic parameters of the Western Ridge orebody aquifers** – constraining data is limited at the present time, so uncertainty is high.
- **The mine plan** – always subject to change, especially in timing and mining speed.

4. Receptors

4.1. Ecological

4.1.1. Ethel Gorge Aquifer Stygobiont Community

The Ethel Gorge aquifer is located approximately 10 km north-east of Newman and approximately 15 km north-east of OB29/30/35 (Figure 4.1). It is an important feature of the Eastern Pilbara hydrological system, located at the convergence of surface and groundwater flows from the upstream catchment (Section 3.2). The gorge itself is a valley incised into the Ophthalmia Range by the Fortescue River although the name is also used to refer to the alluvial and palaeochannel aquifers in the area.

The area is characterised as a receiving environment, comprising channels, flood plains and calcretes of the river and land systems that dissect ridges of bedrock. It has groundwater levels of less than 10 m below ground level (mbgl) in the valleys which allows interactions between the groundwater and terrestrial environments (through surface water connection and vegetation).

The Ethel Gorge Aquifer Stygobiont Community TEC is listed as a Critically Endangered ecological community under the *Biodiversity Conservation Act 2016* (WA), due to the diverse assemblage of stygofauna species inhabiting the shallow aquifers within Ethel Gorge and downstream of the gorge for approximately 5 km (Bennelongia, 2013 and DBCA, 2023).

The stygofauna community is hosted in shallow alluvial aquifers (notably calcrete) and their habitat is maintained by saturation of these aquifers. Changes to groundwater levels or quality, therefore, may have an impact on the TEC. Ophthalmia Dam, some 3 km upstream of Ethel Gorge, was designed as a Managed Aquifer Recharge (MAR) facility to offset drawdown from the Ophthalmia Borefield and has an important influence on the hydrological condition in Ethel Gorge. Recharge to the shallow groundwater system occurs as seepage from Ophthalmia Dam and associated infiltration structures as well as direct infiltration from channel flow events.

The hydraulic behaviour of the gorge groundwater system has been dominated by Ophthalmia Dam since it was commissioned in 1981. The dam impounds and retards flood waters in the Fortescue River to allow larger volumes of infiltration over a prolonged period. Consequently, the dam has maintained groundwater levels nearer natural conditions, as groundwater levels would have declined without the dam due to the operation of the Ophthalmia Borefield.

4.2. Other BHP operations

As detailed previously, the Mt Whaleback dewatering operations are located immediately north of the study area.

The conceptual model and long-term time-series monitoring data suggests little to no hydraulic connection between Mt Whaleback and the OB29/30/35 operations. Regionally, a number of BHP owned and operated potable and non-potable borefields and dewatering activities are located in the vicinity including:

- Homestead potable water supply borefield.
- Eastern Ridge mine dewatering borefields.
- Ophthalmia potable water supply borefield.

The OB29/30/35 area and the borefields described above are located within the Priority 1 Public Drinking Water Source Area of the Newman Water Reserve (Figure 4.1). Groundwater is abstracted from the BHP operated Ophthalmia and Homestead borefields, to provide drinking water for the Newman town water supply.

The borefields described above are considered hydraulically disconnected from the OB29/30/35 and Western Ridge area, providing a very low risk of detrimental change to the water supply at these receptors.

4.3. Third Party Groundwater Users

Groundwater users identified from the DWER Water Register (DWER, 2023a) and Water Information Reporting tool (DWER, 2023b) within 5 km from OB29/30/35 are limited to BHP Iron Ore, with the exception of three groundwater users that have a Groundwater Licence (GWL) for abstraction. These are:

- Newman Hotel located on Lot 1 Newman Drive, within the Newman townsite (GWL203493 for 13,000 kL/a);

- Department of Primary Industries and Regional Development located on Lot 300 and 301 on Plan 46156 within the Newman townsite (GWL201936 for 25,000 kL/a); and
- Holcim (Australia) Pty Ltd located on G52/15, M52/59, L52/115, G52/278, G52/18; M52/59; G52/15, north east of OB29/30/35 (GWL101965 for 150,000 kL/a).

Within a 10 km radius from OB29/30/35, additional third party groundwater users are:

- Pilbara Iron Services with four GWLs for exploration tenements E48/470 and E52/1894 (with GWL110695 (100,000 kL/a), GWL158835 (100,000 kL/a), GWL167618 (45,000 kL/a) and GWL171851 (45,000 kL/a).
- Shire of East Pilbara located at the Newman Airport with GWL204602 (11,000 kL/a).

Figure 4.1 illustrates the nearby BHP groundwater users and third party groundwater users.

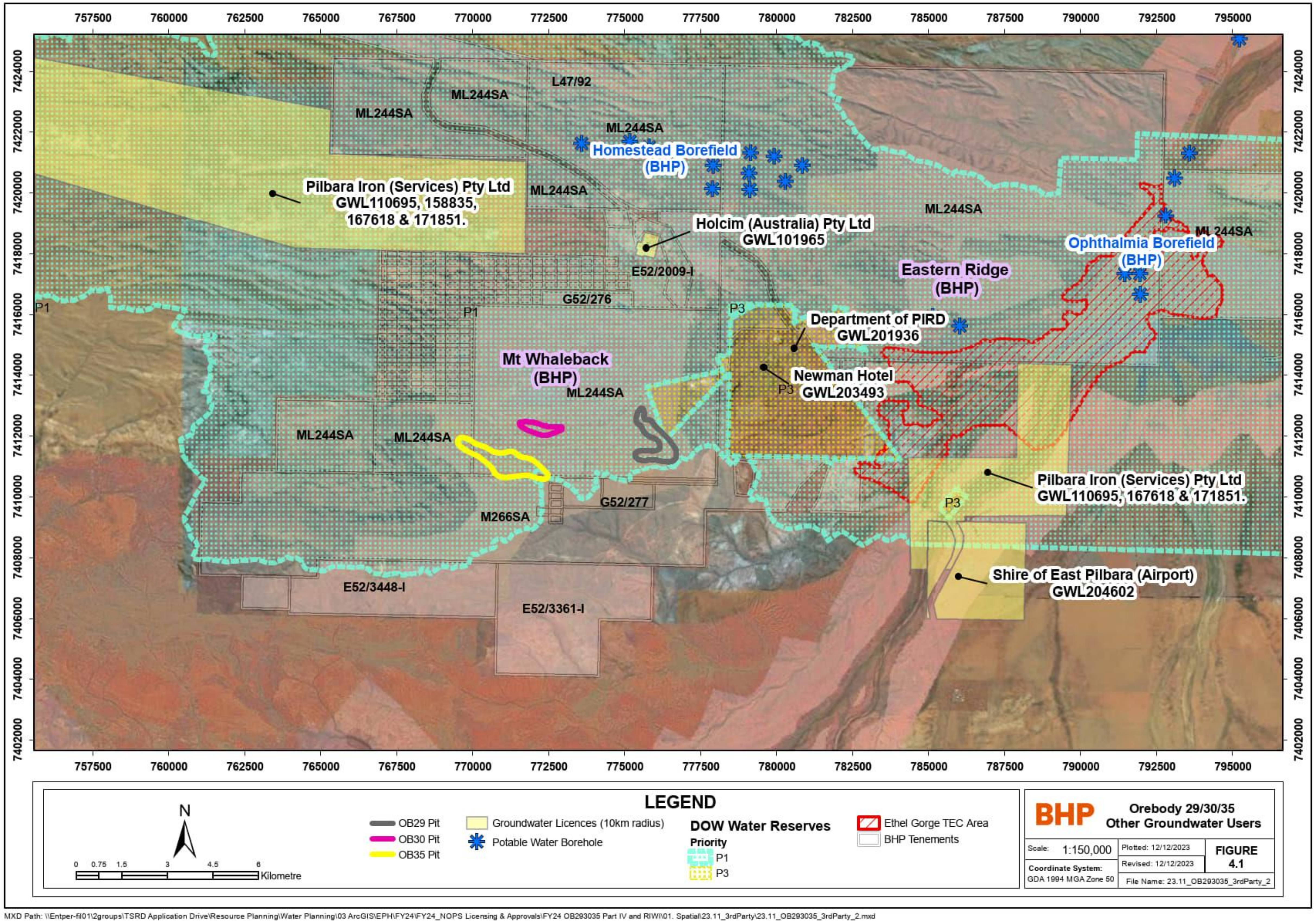

Figure 4.1: Key receptors and BHP and third party groundwater users surrounding OB29/30/35

5. Groundwater Investigations

Groundwater investigations in the catchment around Mt Whaleback began in the late 1960's and were initially focused on finding water supply close to the operations. Several generations of investigation and production bores were drilled targeting dolomite in the valley between Mt Whaleback and OB29. Supply bores were installed in the valley dolomites east of Mt Whaleback (HEOP0804P, HEOP0806P, and HEOP0807P) and were known as the V-line bores. These were typically low yielding and used to supply the processing plant. Investigations of the dolomites in the valley directly south of Mt Whaleback in 1974 found little water (yields between 1 and 6 L/s) and concluded, incorrectly, that the valley was a poor prospect for water supply (Mt Newman Mining Company, 1974). Water level monitoring has been carried out more or less continuously ever since with some attrition of points and new bores being added during each successive phase of work.

In the early to mid-1980's groundwater investigations were focused on Mt Whaleback as the operation began to go below water table. Water supply for dust suppression and processing was subsequently sourced from dewatering from around 1986.

Initial investigations into the Marra Mamba orebodies began in mid 2000's with ore moisture studies beginning in 2006 to understand potential processing issues of wet Marra Mamba and drainage characteristics. A test bore (HWHB0049P), and an array of monitoring bores were drilled in the north of OB29. Pumping was undertaken with the aim of dewatering adjacent ore prior to diamond drilling. A constant rate test and analysis was undertaken at this stage but was confined to the local area (Aquaterra, 2009).

In 2012, a preliminary hydrogeological review was carried out (RPS-Aquaterra, 2012) to estimate potential dewatering ranges from the OB29, OB30 and OB35 orebodies. Analytical models were used to develop a range of dewatering volumes for each deposit.

In 2013 a desktop assessment was carried out to assess potential impacts of below water table mining at OB29/30/35 (RPS-Aquaterra, 2013). This report built on the 2012 work and estimated a drawdown footprint as well as dewatering volumes. This report was submitted in support of the Part IV below water table assessment for OB29/30/35.

In 2015, BHP began a HDT at OB29 with the objective to improve understanding of dewatering volumes and water balance predictions, potential drawdown extent, water quality parameters, and mining and processing of below water table ore. 17 monitoring bores and 8 production bores were installed in OB29, from which ~2 GL was pumped over the course of 10 months in 2015. The work was reported via internal memo in 2016 (BHP Iron Ore, 2016a), key findings included that drawdown propagated a significant distance to the west following the dolomites in the valley. This information was used to update the conceptual model and subsequent numerical model that forms the basis of current work.

In addition to these groundwater investigations more work has been conducted to date within the Western Ridge exploration area:

The most recent groundwater model of the area was developed in 2019 to support the application of the current groundwater license at OB29/30/35 (BHP Iron Ore, 2019) but model calibration didn't focus on the Western Ridge area. The updated model conceptualisation and numerical models of the Western Ridge area are described further in sections 9.1 and 9.11.

6. Drilling

As described in Section 5 there have been numerous phases of hydrogeological drilling work within OB29/30/35.

7. Test Pumping

Operational water data and long-term monitoring is presented in lieu of test pumping.

8. Groundwater Chemistry

See Section 3.3.6.

9. Groundwater Modelling

9.1. Introduction

9.1.1. Model basis

The numerical groundwater flow model used here is taken from the modelling undertaken to support the assessment of Western Ridge in 2022 (BHP Iron Ore, 2022).

The model domain is shown in Figure 9.0. The model does not extend all the way to the Ethel Gorge aquifer system. Whilst this may seem contrary to the objectives (i.e. predicting the full extent of drawdown), this is required to ensure that the model remains focussed on the main system response (i.e. OB29/30/35). Including this area would require the simulation of far more processes, and over a much larger area, than the current model. For example, the Ethel Gorge aquifer system is affected by:

- Infiltration from the Dam,
- Water supply pumping from Ophthalmia borefield,
- Dewatering of OB25, and
- Backfilling of OB23.

If the model were extended to include these elements, it would have to be made considerably larger and it is likely that the predictive capability around OB29/30/35 would be compromised as a result.

Furthermore, analysis of the data has shown that the characteristics of the regional aquifer between OB29 and Ethel Gorge present a constriction in the flow system and significantly reduce the potential for throughflow from west to east. The model is able to predict the drawdown that may occur across the leaky flow barrier and this will be combined with the conceptual understanding of the flow system between the barrier and Ethel Gorge to provide estimates of the potential for drawdown to move in that direction.

9.1.2. Model updates

No major changes to the Western Ridge numerical model were required for these purposes. Instead, the update was centred around:

- Adding the local scale modifications to the north of OB29 that came from the PFAS modelling in that area (BHP Iron Ore, in preparation).
- Adjusting parameter values to improve the fit between simulated and observed groundwater levels (given that a year had passed since the last model calibration).

These changes are outlined in the sections below.

9.1.3. Modelling strategy

The modelling strategy adopted for this study was to:

- Update the existing model with the relevant abstraction and recharge data and any changes in conceptualisation since the last iteration.
- Develop a base case model with the best possible match (using the PEST (Doherty, 2015) software suite) to observed data (history matched).
- Use this model to test the uncertainty of both history matching performance and predictive dewatering.

9.1.4. Model types

Three model versions were used in the study. They were:

- A history match model (1st January 2015 to 1st May 2022). This was used to:
    - Calibrate model hydraulic parameters.
    - Explore model sensitivities / uncertainties.

    - Develop uncertainty cases.
- A predictive dewatering model (from 1st May 2022 to 3rd July 2056 (24 years)), which was used to:
    - Predict dewatering rates.
    - Predict drawdown migration
    - Investigate uncertainty in predictions.
- A predictive dewatering model extension (from 2056 to 2065) to reflect the mine life according to the current mine plan which also includes a 2 m deeper target dewatering target at OB30, which was used to compare results to the 2056 predictions.
- A predictive closure model (from 3rd July 2056 to 1st January 2650 (600 years)), which was used to:
    - Predict final recovery water levels
    - Predict speed of recovery

9.2. Model setup

9.2.1. Introduction

The model was developed using the Modflow 2005 code operating under the Groundwater Vistas graphical user interface (Version 8.23 Rumbaugh and Rumbaugh, 1996 – 2011).

The pertinent aspects of model setup are described in Table 9.1 and discussed in more detail below.

Table 9.1. Basic numerical model settings

Aspect	Setting
Model code	Modflow 2005
Graphical user interface	Groundwater Vistas V8.23 Build 48 (Rumbaugh, J O and Rumbaugh, D N, 2011)
Solver	PCG2
Stress periods	Post-2015 model – 88 (monthly) Predictive dewatering model – 70 (half yearly) Predictive closure model – 1200 (half yearly)
Coordinate system	GDA94 Zone 50 (with elevations in mAHD)
Model grid	Rotated 26 degrees clockwise Minimum (orebody areas): 50 x 50 m Maximum: 350 x 500 m Rows: 157, Columns: 312, Layers: 6 Active cells: 202,083 Total cells: 293,904
Model dimensions (active area)	8 km north-south / 24 km east-west

The hydrogeology is represented by six, flat-lying, layers. The base of the model was set at a constant elevation of 150 mAHD. The updated hydrostratigraphy is shown in Figures 9.1 to 9.6 for the whole model domain, and in Figures 9.7 to 9.9 for the upper 3 layers for the OB29/30/35 area.

The extent of the orebodies was assigned consistent with high grade (typically >57% Fe) and low grade (typically >48% Fe) shells. The term “regional aquifer” predominantly represents the weathered dolomite of the Paraburdoo Member, although in the vicinity of OB35 a highly permeable fault / fracture zone to the north of the orebody is anticipated to be the main aquifer unit in hydraulic connection with dolomite aquifer.

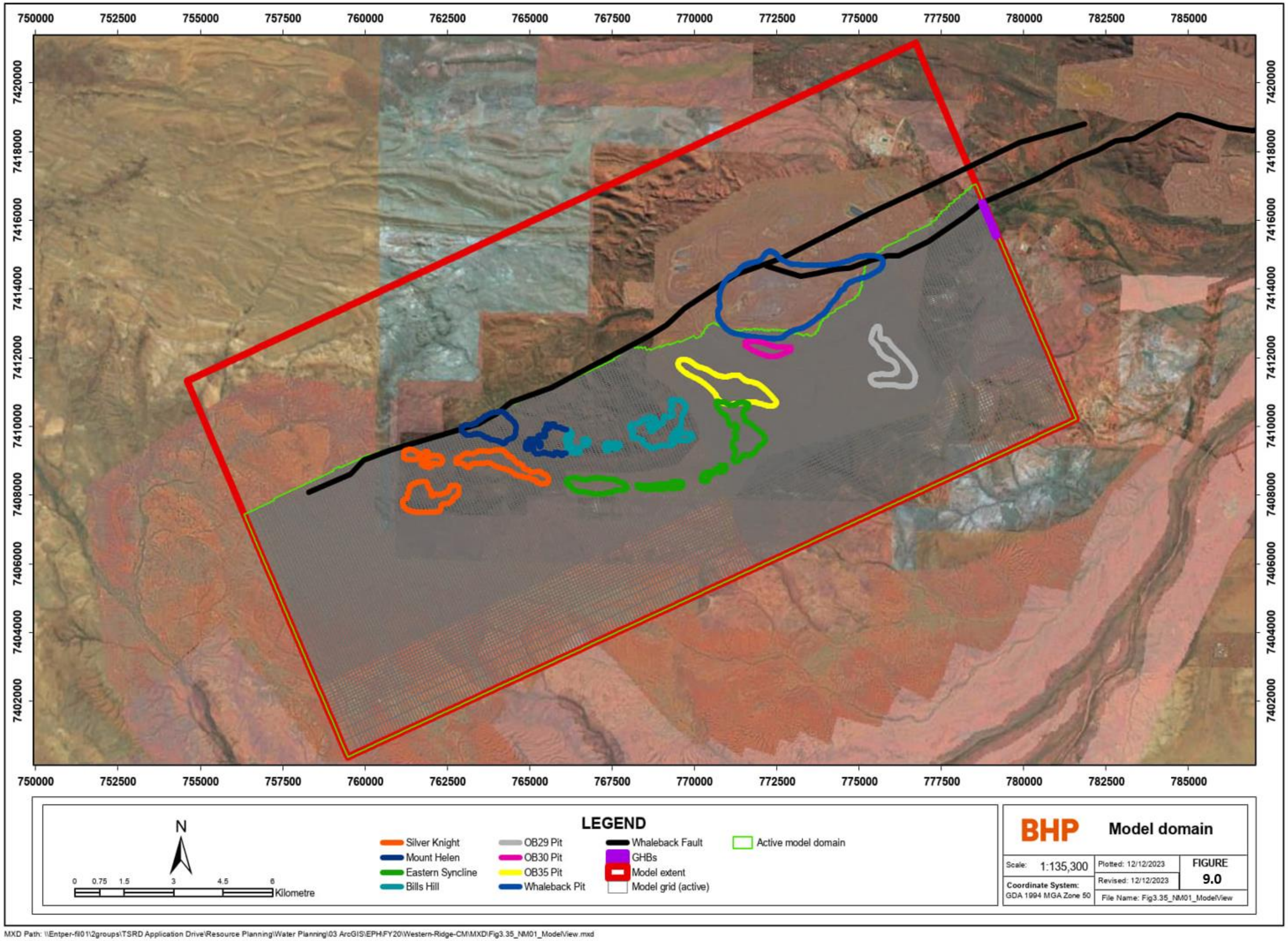

Figure 9.0: Groundwater Model Domain

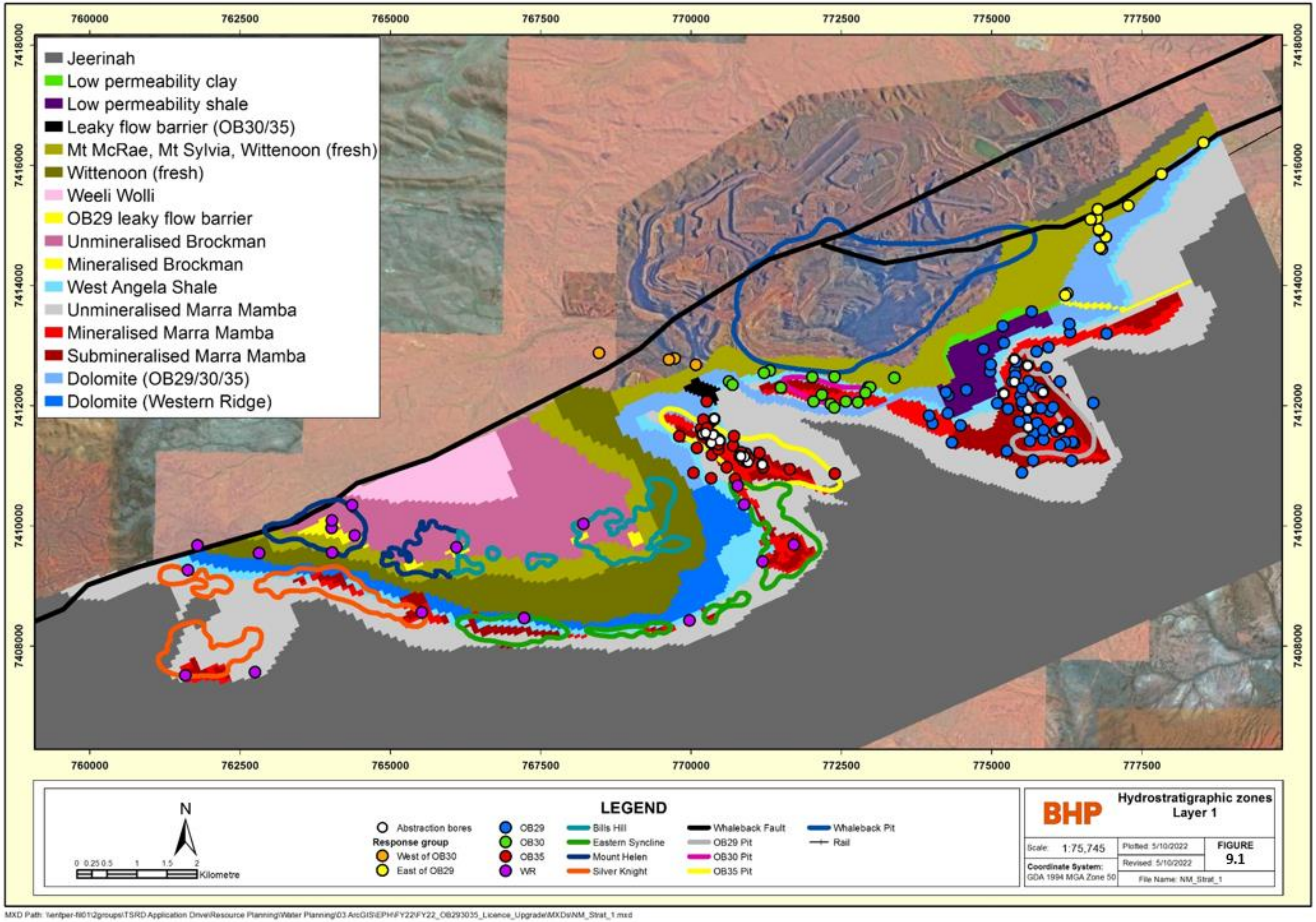

Figure 9.1: Hydrostratigraphic zones, Layer 1

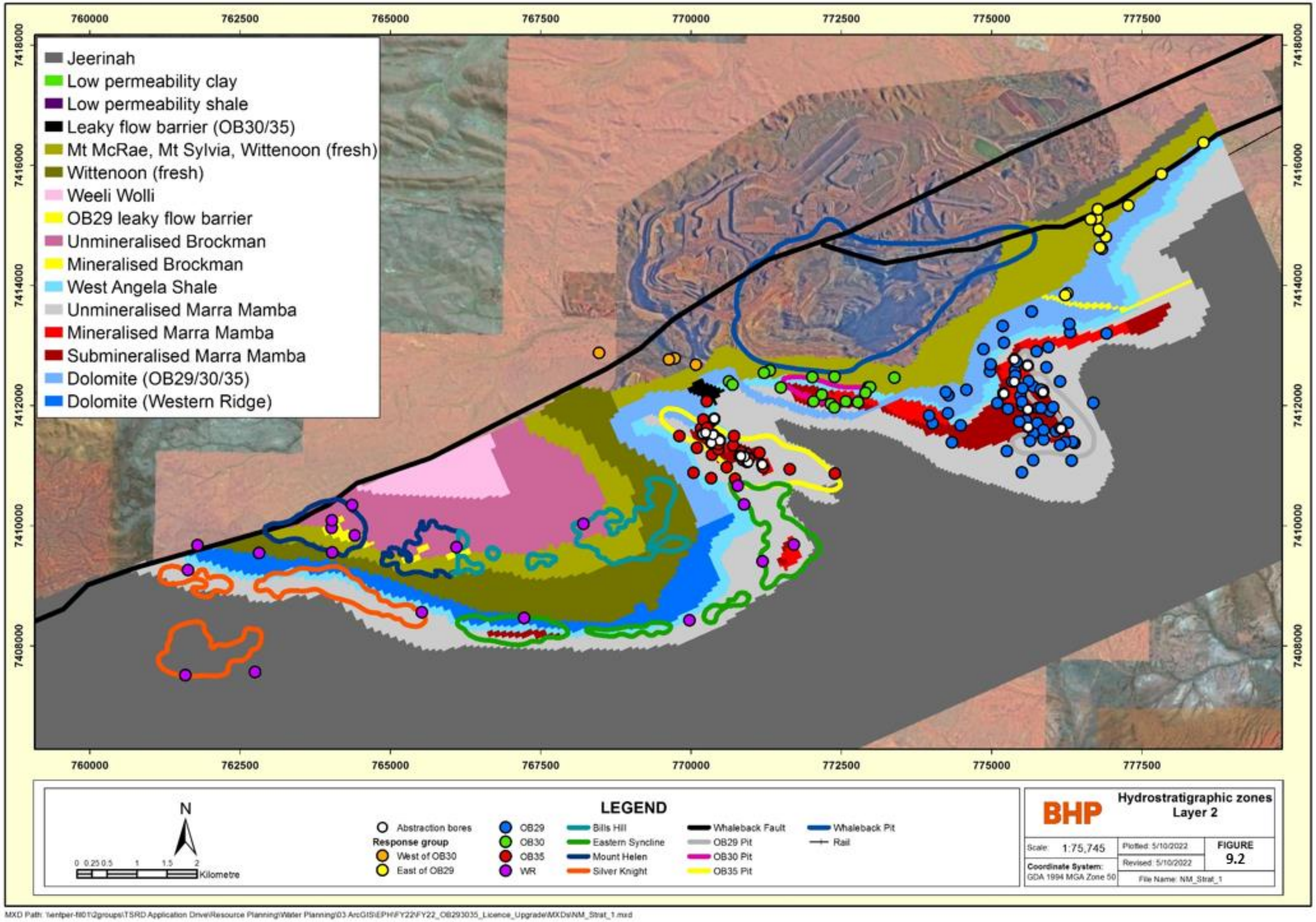

Figure 9.2: Hydrostratigraphic zones, Layer 2

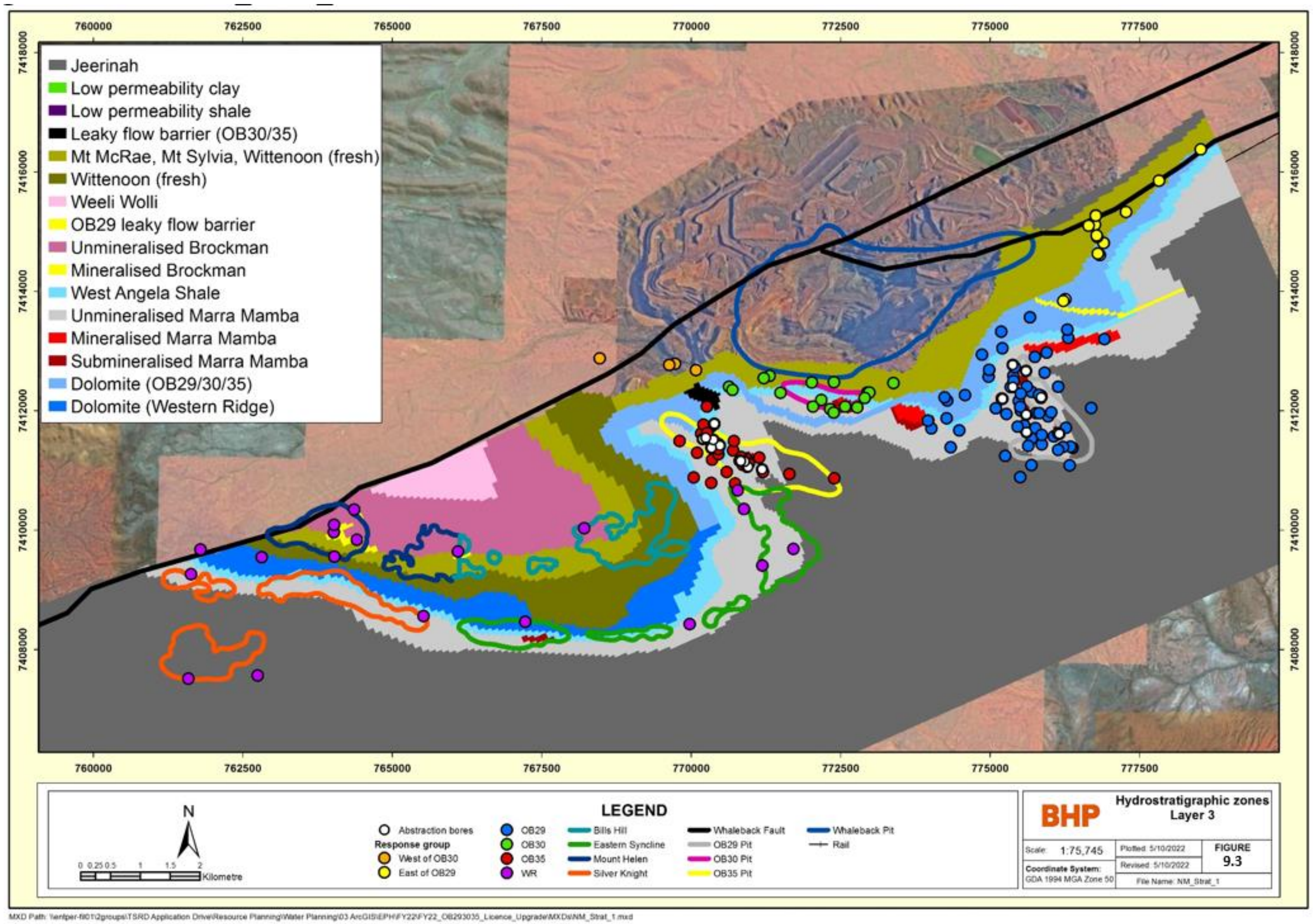

Figure 9.3: Hydrostratigraphic zones, Layer 3

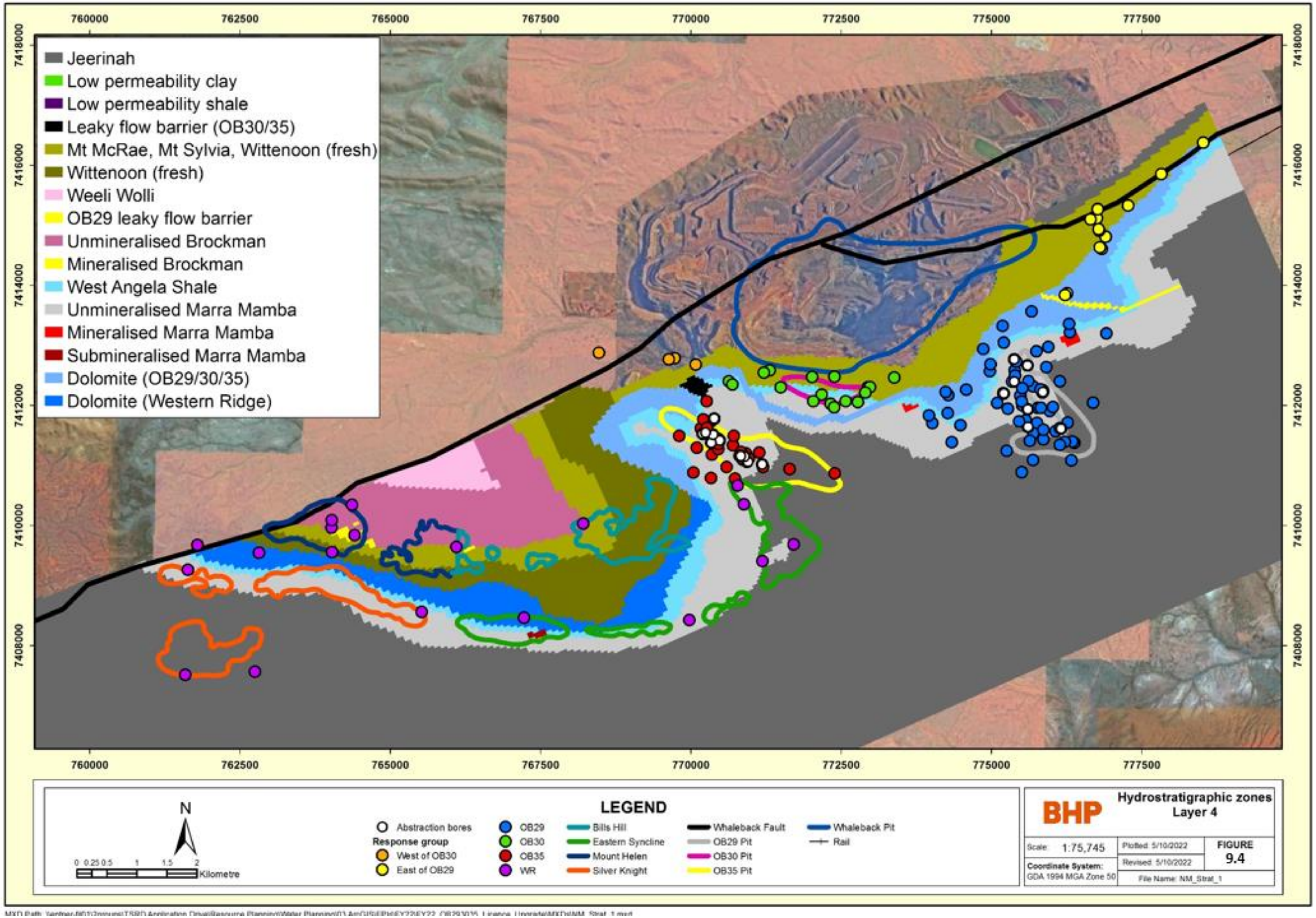

Figure 9.4: Hydrostratigraphic zones, Layer 4

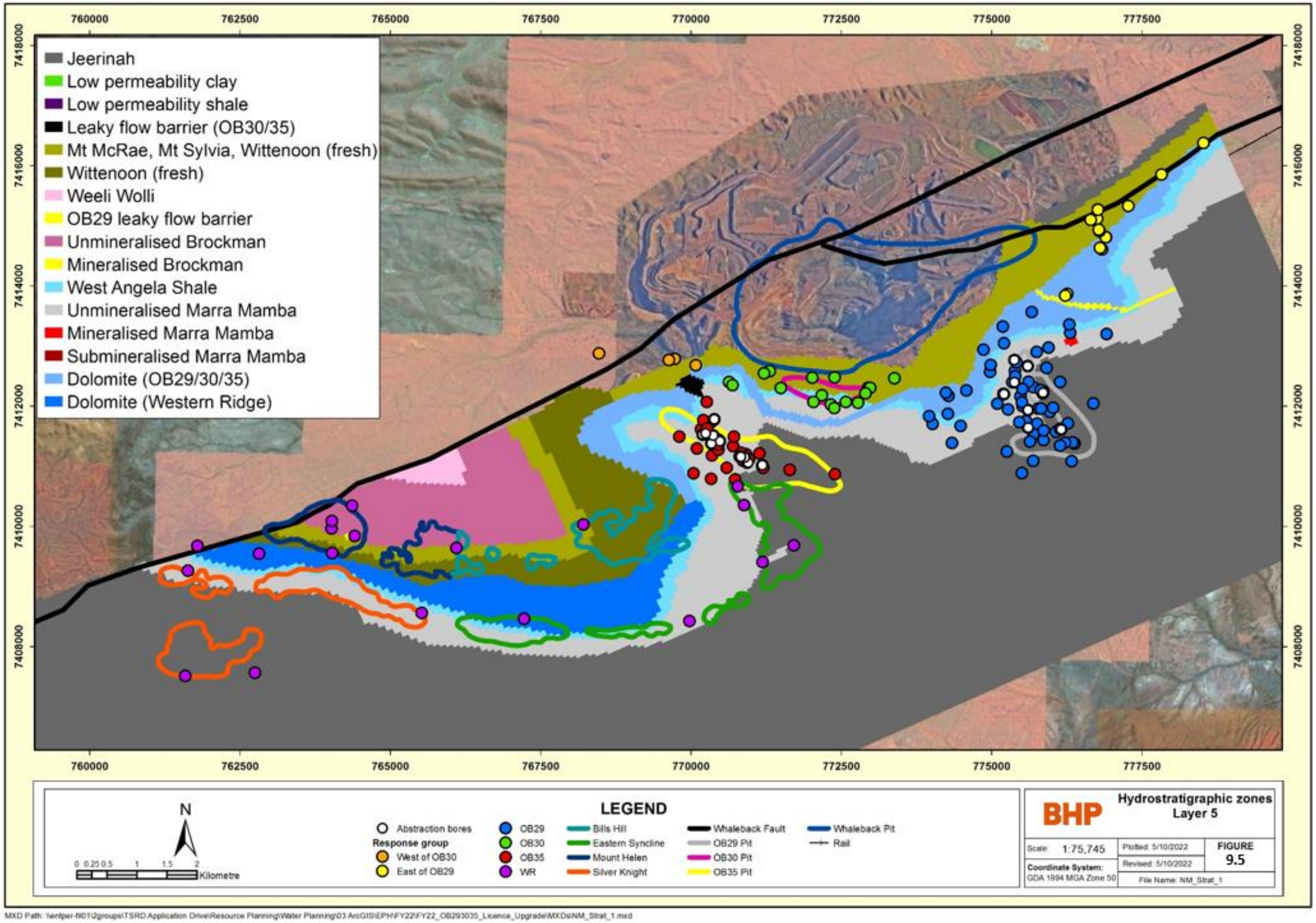

Figure 9.5: Hydrostratigraphic zones, Layer 5

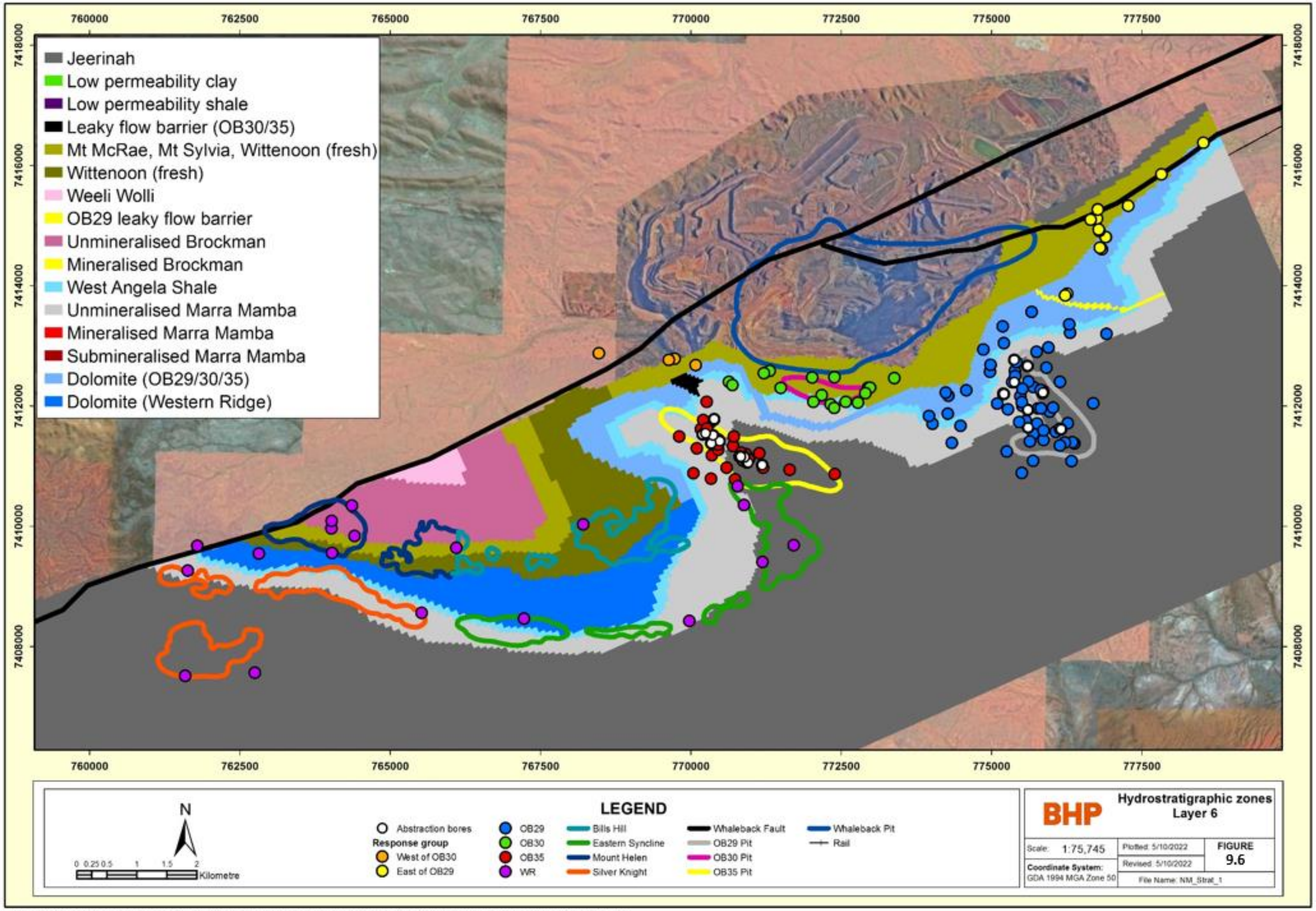

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Figure 9.6: Hydrostratigraphic zones, Layer 6

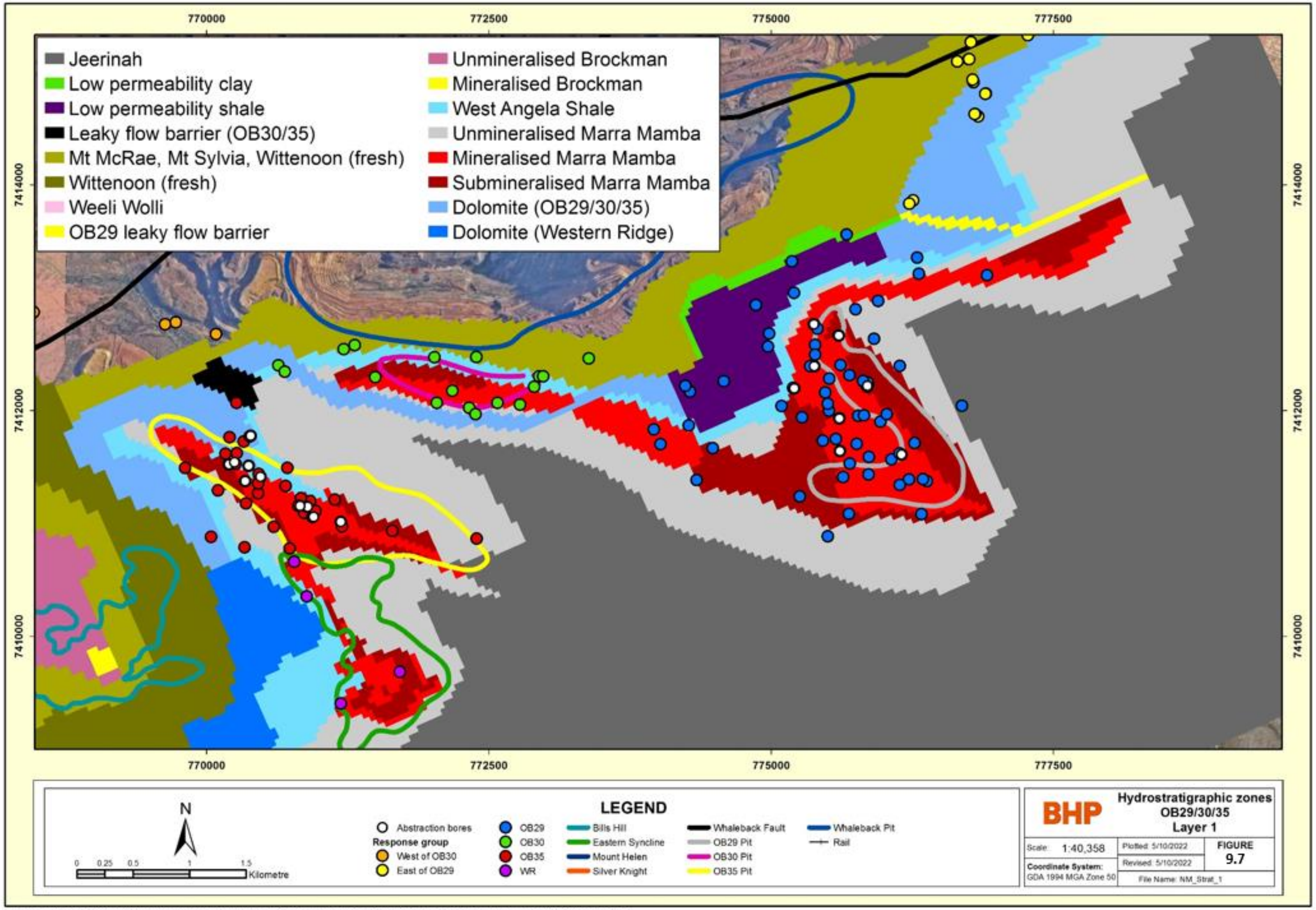

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Figure 9.7: Hydrostratigraphic zones, Layer 1, OB29/30/35 area

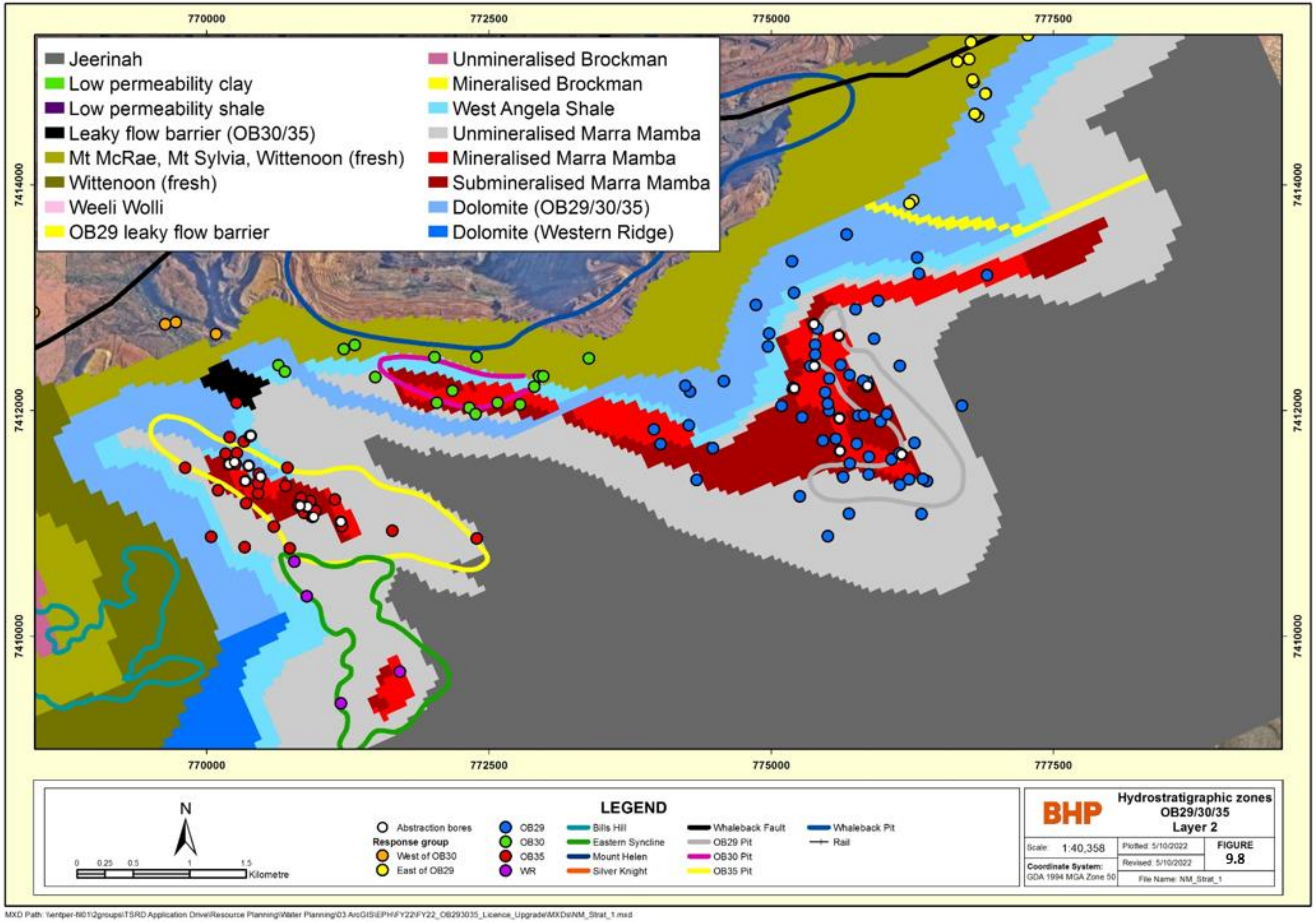

Figure 9.8: Hydrostratigraphic zones, Layer 2, OB29/30/35 area

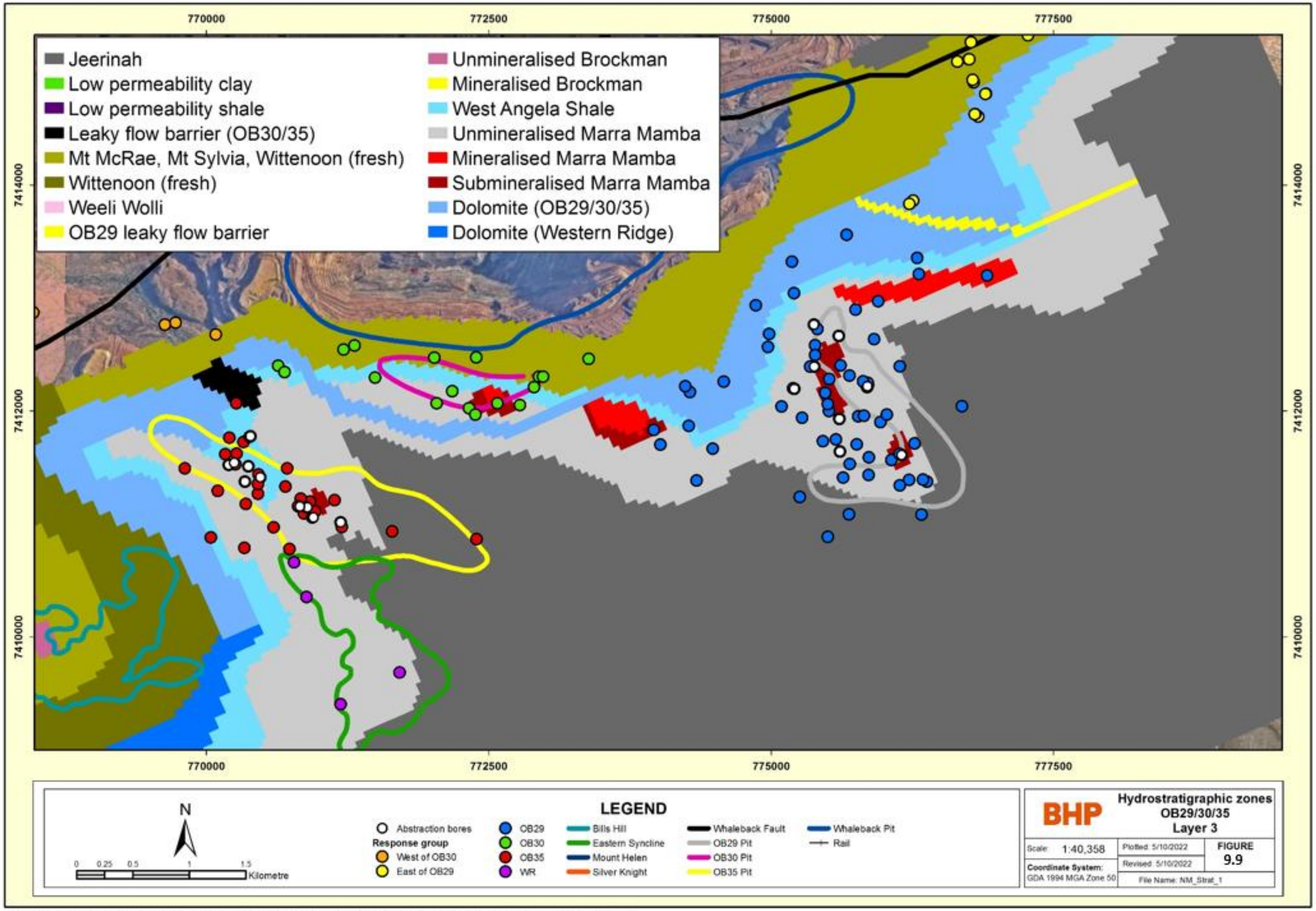

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Figure 9.9: Hydrostratigraphic zones, Layer 3, OB29/30/35 area

9.2.2. Boundary conditions

The model boundary conditions are:

- A General Head Boundary (GHB) along the eastern model boundary, set to equal the initial heads (522 mAHD). The conductance was set at a low value of 1 m^2/d.
- Well boundary conditions were used to simulate dewatering. In the Post-2015 model these were assigned observed abstraction rates. Well boundary conditions were also used in the Predictive Dewatering model. The abstraction rates applied to them were manually varied to achieve the target water levels.
- All other model boundaries were designated no flow. These were aligned with the Whaleback Fault to the north and west and well within the Jeerinah Formation to the south.
- Initial heads were:
    - Set at 522 mAHD at the start of the Post-2015 model.
    - Taken from the end of the Post-2015 model for the Predictive Dewatering model.
    - Taken from the Predictive Dewatering model for the Predictive Closure model.
- The recharge zones are based on the Hydrostratigraphic units defined in model Layer 1 with recharge applied to the highest active layer (recharge was only applied in the closure models).

9.2.3. History match

Introduction

The model was history matched using PEST (Doherty, 2015). All monitoring data was used in this process. For qualitative assessment in this report, the results are shown at several key monitoring bores, the locations of which are shown in Figure 9.10.

History match

The following changes were made to the model to improve the fit between observed and simulated groundwater levels between 2015 and 2022:

- The hydrostratigraphy was updated to reflect the findings from the OB29 PFAS modelling (BHP, in preparation) – this required the addition of a low permeability clay and shale zone in Layer 1 in place of the dolomite and some of the Mt McRae, Mt Sylvia north of OB29.
- A zone of low permeability through the dolomite between OB30 and OB35. This was applied to all model layers as a vertical feature.
- The hydraulic parameters of all units were varied (with PEST). The range of hydraulic conductivity used is shown in Table 9.2. The method utilised the existing model parameter zones.

Table 9.2. PEST hydraulic conductivity value ranges

Zone	Minimum (m/d)	Maximum (m/d)
1	1.00E-01	200
2	1.00E-01	1.00E+02
3	1.00E-03	5.00E-01
4	1.00E-01	100
5	1.00E-01	1.00E+01
6	1.00E-06	5
7	1.00E-03	1
8	1.00E-02	5.00E+01
9	1.00E-05	1.00E-02
10	1.00E-04	1.00E-01
11	1.00E-01	300
12	5.00E-03	5.00E-01
13	1.00E-04	1.00E-01
14	1.00E-06	5
15	1.00E-01	100
16	1.00E-01	10
17	1.00E-04	1.00E-01
18	1.00E-05	1.00E-02
19	1.00E-04	1
20	1.00E-01	200

The parameter values used in the final calibrated model (the base case) are shown in Table 9.3. Observed and simulated hydrographs at the key monitoring bores are shown in Figures 9.11 and 9.12 and the history match statistics are shown in Table 9.4. These show that:

- Western Ridge:
  - At WSR0296RM and WSR1270RM the observed drawdown is replicated accurately. These bores are far in the west of the model domain.
  - At WSR1029RM (Eastern Syncline) the model replicates the observed drawdown accurately until the end of 2018. From then onwards the model overpredicts drawdown.
- OB35:
  - The model accurately replicates the observed water level changes at HEK0111M.
- OB30:
  - The model simulates drawdown very well until January 2020 in EL0006DM.

  - From this point on the drawdown gradient in the observed water levels reduces significantly whereas the simulated gradient reduces only slightly. This results in overprediction of drawdown from January 2020.
- OB29:
  - Orebody bores: The model replicates the observed data, including stabilisation of water levels once OB29 abstraction ceased.
  - Regional bores: The model replicates the observed data until OB29 abstraction ceased. Observations show a leveling off of drawdown whereas in the model drawdown continues, although at a greatly reduced rate.
- East of the OB29 leaky flow barrier:
  - The model significantly overpredicts drawdown (approximately 16 m rather than the 5 m observed).

Table 9.3. Base case parameter values

Hydrostratigraphy	K (m/d)	Sy (%)
Weathered dolomite	36-40	12 (OB29/30/35 area) 1 (Western Ridge area)
Mineralised Brockman	0.39	10
Unmineralised Brockman	0.16	3
Mineralised Marra Mamba	4.4	9 (OB29/30/35) 10 (Western Ridge)
Submineralised Marra Mamba	4.4	1
Unmineralised Marra Mamba	0.82	0.5
Mt Sylvia Formation, Mt McRae Shale and Wittenoom (fresh)	0.035	0.1
West Angela Shale	0.57	0.1
Wittenoom (fresh) – Western Ridge	0.037	1
Jeerinah	$5x10^{-5}$	0.2
Weeli Wolli Formation	0.05	0.5
Leaky Flow Barrier (east of OB29)	0.1	1
Leaky Flow Barrier (between OB30 and OB35)	0.0125	0.3
Low permeability clay	$2x10^{-4}$	0.2
Low permeability shale	0.001	1

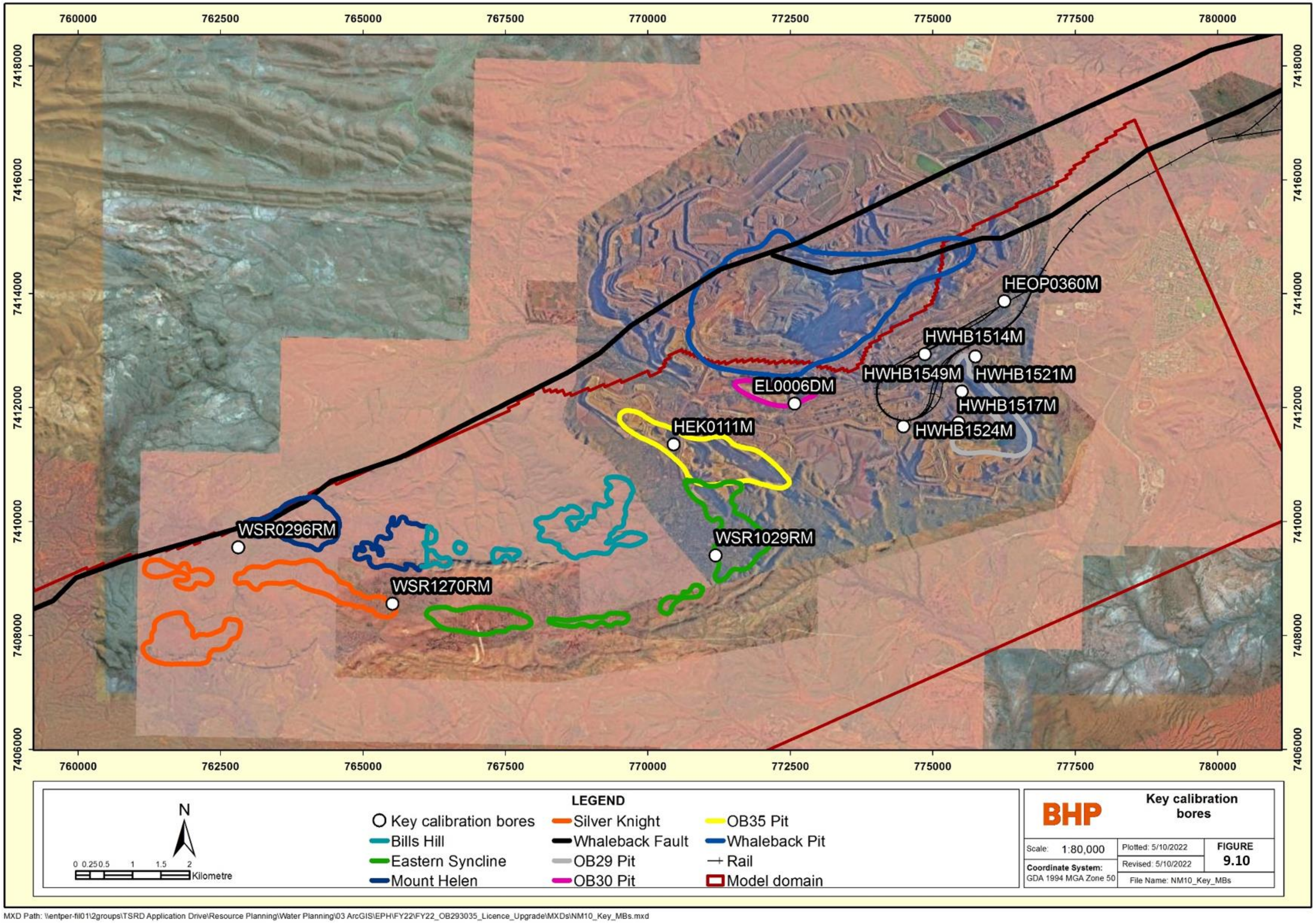

Figure 9.10: Key calibration bores

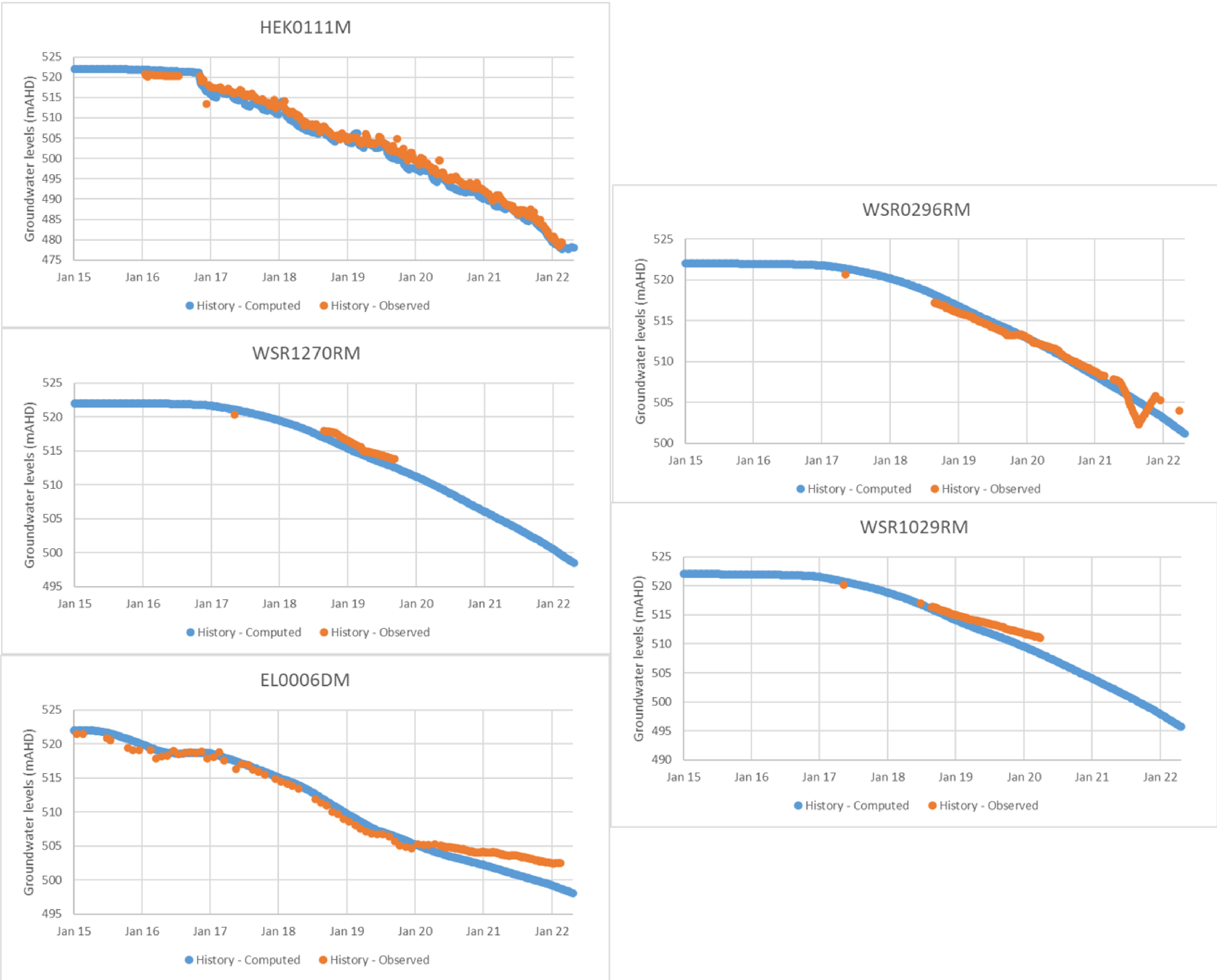

Figure 9.11: Base case model: Observed and simulated hydrographs – Western Ridge / OB35 / OB30

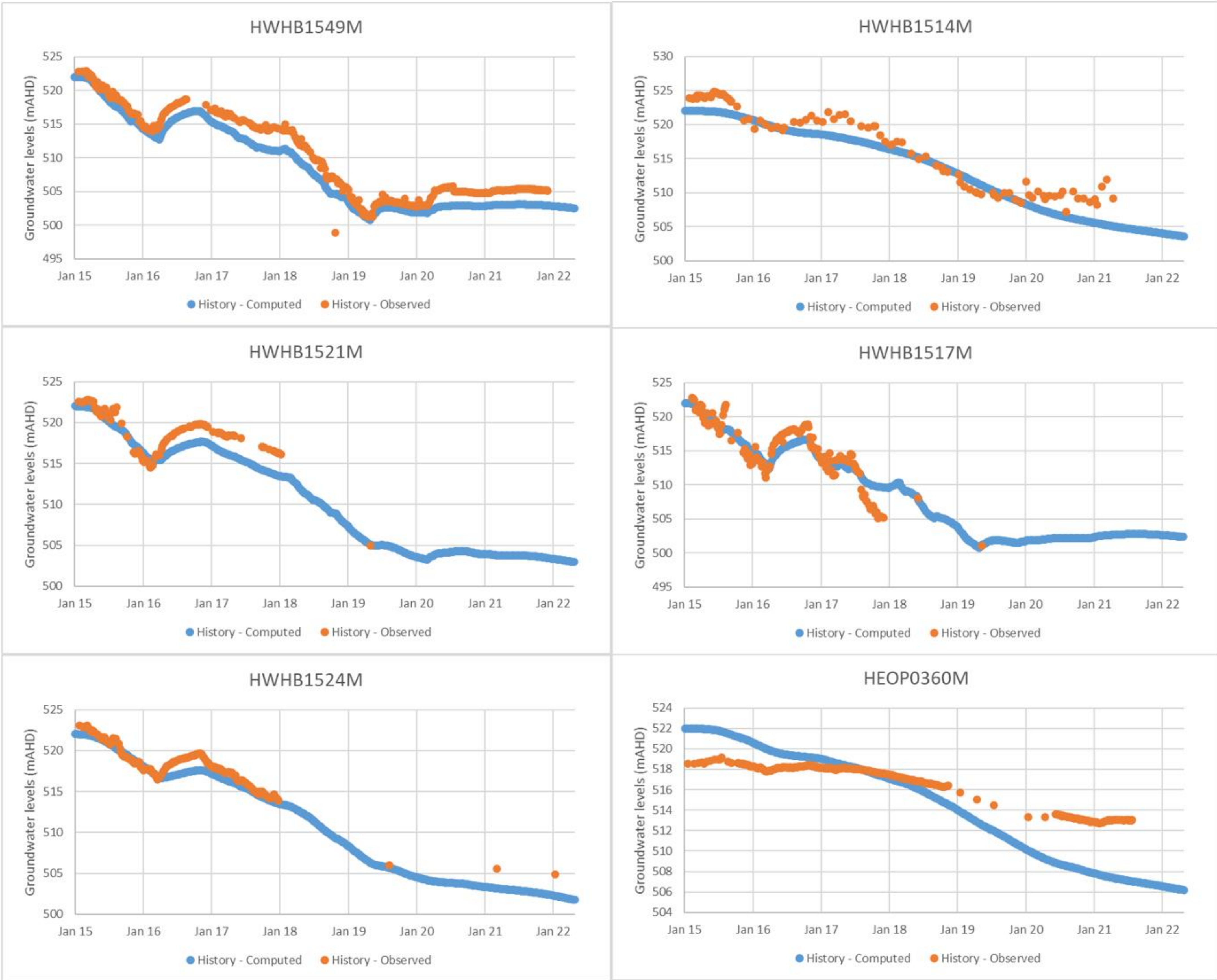

Figure 9.12: Base case model: Observed and simulated hydrographs – OB29

Conceptual uncertainty

The base case model was used to assess the uncertainty in the history match by testing several conceptual uncertainties between OB30 and OB29. Based on the main remaining data gaps, these were:

1. The presence of weathered Wittenoom Formation (aquifer) to the north of OB30 (rather than the south).
2. The presence of a high hydraulic conductivity structure from the south of OB29 to the south of OB30.

To investigate the importance of these uncertainties, the model was configured with both of the conceptual variations described above (Figure 9.13 and run through the history match period. The impact of these changes on the match between observed and simulated at the key monitoring bores was then assessed.

The results of these runs (Figures 9.14 and 9.15 and Table 9.4) show that:

- The changes result in very little difference to the history match in the OB29 area.
- Improves the history match in the area of OB30. Overall drawdown is underpredicted, but the response to cessation of OB29 dewatering is more accurately simulated.
- Reduces the drawdown predicted in the OB35 / Western Ridge area. This improves the fit between observed and simulated water levels in some locations but worsens it in others.

History match uncertainty

The base case was used to investigate two main shortcomings of the PEST history matched model. These were:

1. The two leaky flow barriers, one to the east of OB29 and the other between OB30 and OB35, allow too much flow across them. This results in the model overpredicting drawdown to the east of the eastern barrier (and therefore towards the Ethel Gorge TEC) and overpredicting drawdown migrating from OB35 into the OB30 / OB29 aquifer compartment.
2. There is too little recovery predicted in the OB29 orebody and regional aquifer north of OB29 in response to ceasing abstraction at OB29.

To investigate these factors, the following models were run:

I. Hydraulic conductivity of the eastern leaky flow barrier reduced from 0.1 m/d to 0.01 m/d. This resulted in a significant improvement of the history match to the east of the barrier, but a worsening to the west (i.e. around OB29).

II. Hydraulic conductivity of the leaky flow barrier between OB30 and OB35 reduced from 0.0125 to 0.00125. This resulted in no change compared to the base case. This suggests that the material to the south (unmineralised Marra Mamba), which has a slightly higher K than the flow barrier (which is only represented in the dolomite), is responsible for the majority of flow between OB35 and OB30. The barrier in its current state is therefore having a very limited effect on flow between OB35 and OB30.

III. The leaky flow barrier between OB30 and OB35 (with the lower K value of 0.00125) extended to the south east (Figure 9.16) and into the unmineralised Marra Mamba to cut off the flow through this unit. This resulted in a significant change in predicted water levels on both sides of the barrier. This did not represent an improvement but showed that the drawdown was indeed bypassing the barrier and travelling through the unmineralised Marra Mamba.

IV. The settings in runs I and III combined, but with the K of the flow barrier between OB35 and OB30 increased to the point where it improved the history match (0.06 m/d). The net result of this was a lower hydraulic connectivity both to the east and west of the OB29 / OB30 aquifer compartment. This resulted in only a marginal change around OB35 and improvement east of the OB29 flow barrier, but some significant degradation of the history match within the OB30 / OB29 aquifer compartment (i.e. overpredicting drawdown).

V. With the changes in IV, a higher hydraulic conductivity in the dolomite aquifer (throughout the model). This is to investigate whether this can provide more rapid recovery once abstraction at OB29 stops. The results show that the history match is not sensitive to this parameter. In other words, the history match data does not provide much information pertaining to the hydraulic conductivity in the dolomite aquifer. For this reason, this change was incorporated to test the uncertainty on predicted future dewatering rates.

VI. Combined with the changes in V, the orebody aquifer to the east of OB29 was expanded laterally in layers 1, 2 and 3 (Figure 9.16). This area was chosen because there are no other areas that could provide significant recharge into the OB29 orebody (as observed once dewatering stops) and geological information in this area is relatively scarce. The results show that this has a marked impact on the history match, resulting in less drawdown and a more significant rebound once OB29 dewatering ceases. There is still too much predicted drawdown in this run, however.

VII. As the changes above still do not supply the recharge needed for water levels to recover as observed, combined with the changes in VI, the specific yield of the unmineralised Marra Mamba (which surrounds the OB29 orebody aquifer) was increased to 15%. Whilst this is unlikely to be a realistic value for that material, this test will assess if the modelled water levels respond to this change. The results show that this change has a significant impact on the recovery once OB29 dewatering stops and improves the fit between observed and simulated water levels significantly.

The history match of the final run (VII) is shown in Figures 9.17 and 9.18 and the statistics in Table 9.4. This "history match uncertainty" model therefore presents a valid alternative to the base case model, even though some of the parameters are potentially proxies for other hydrogeological phenomena that are yet to be fully recognised / understood.

Table 9.4. History match statistics

	Base case	Conceptual Uncertainty	History match uncertainty
Residual Mean (m)	0.75	0.25	-1.42
Absolute Residual Mean (m)	2.06	1.93	2.54
Residual Std. Deviation (m)	2.92	2.88	3.24
RMS Error (m)	3.0	2.9	3.5
Min. Residual (m)	-32.0	-33.4	-34.5
Max. Residual (m)	42.7	41.6	37.6
Number of Observations	9915	9915	9915
Range in Observations (m)	59.1	59.1	59.1
Scaled Residual Std. Deviation (%)	4.9%	4.9%	5.5%
Scaled Absolute Residual Mean (%)	3.5%	3.3%	4.3%
Scaled RMS Error (%)	5.1%	4.9%	6.0%
Scaled Residual Mean (%)	1.3%	0.4%	-2.4%

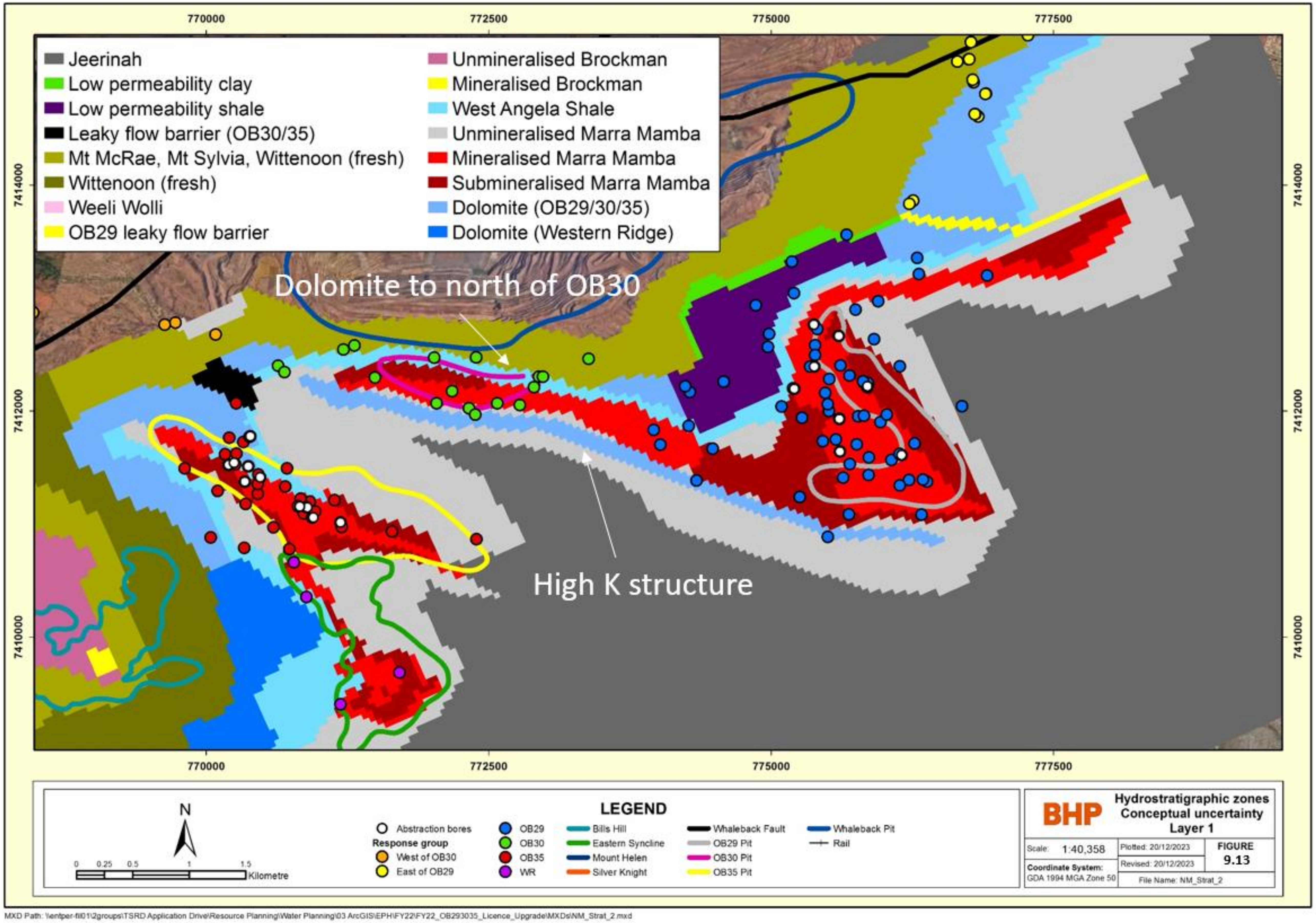

Figure 9.13: Hydrostratigraphic zones: Conceptual uncertainty – Layer 1

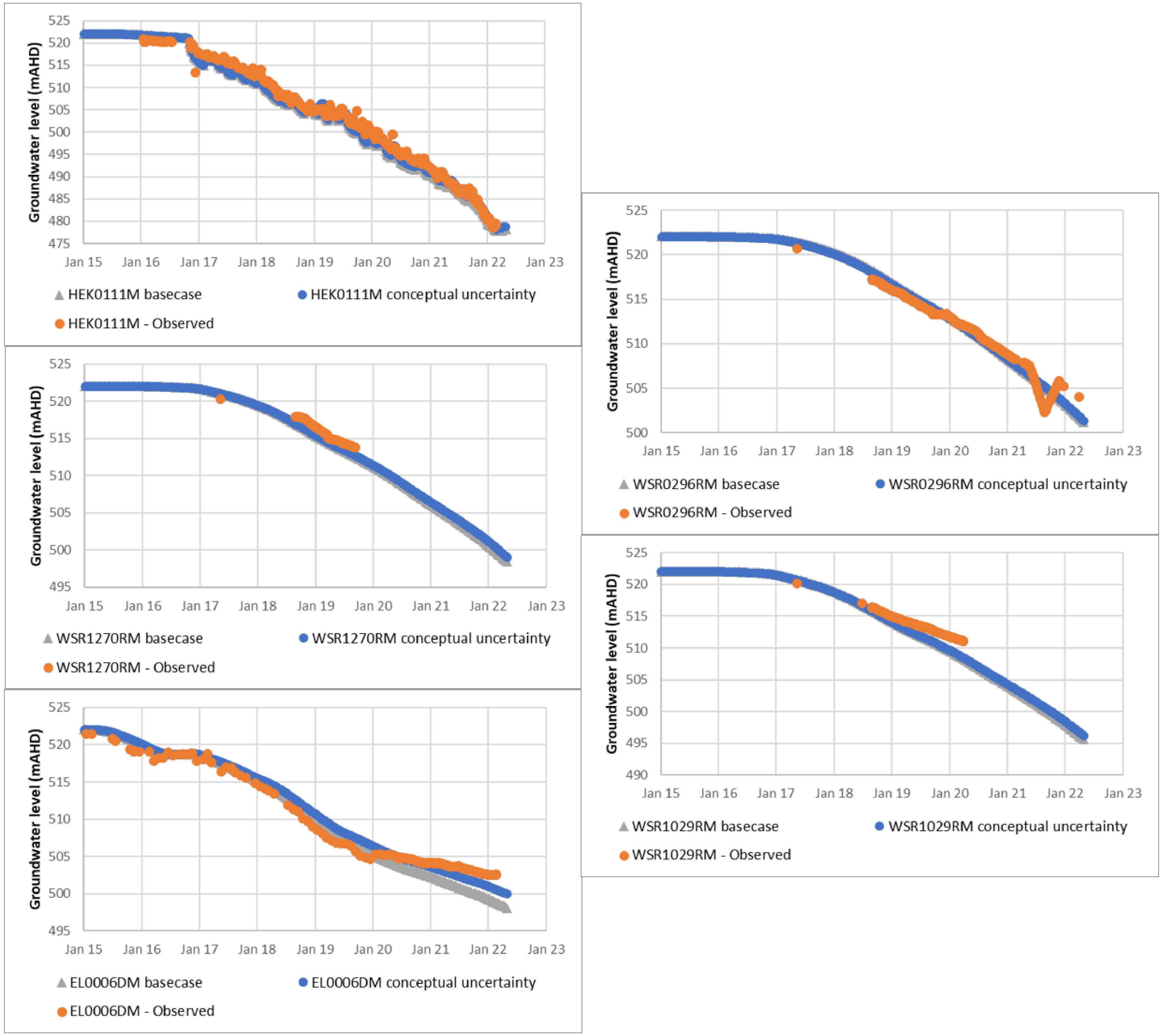

Figure 9.14: Conceptual uncertainty model: Observed and simulated hydrographs – Western Ridge/OB35/OB30

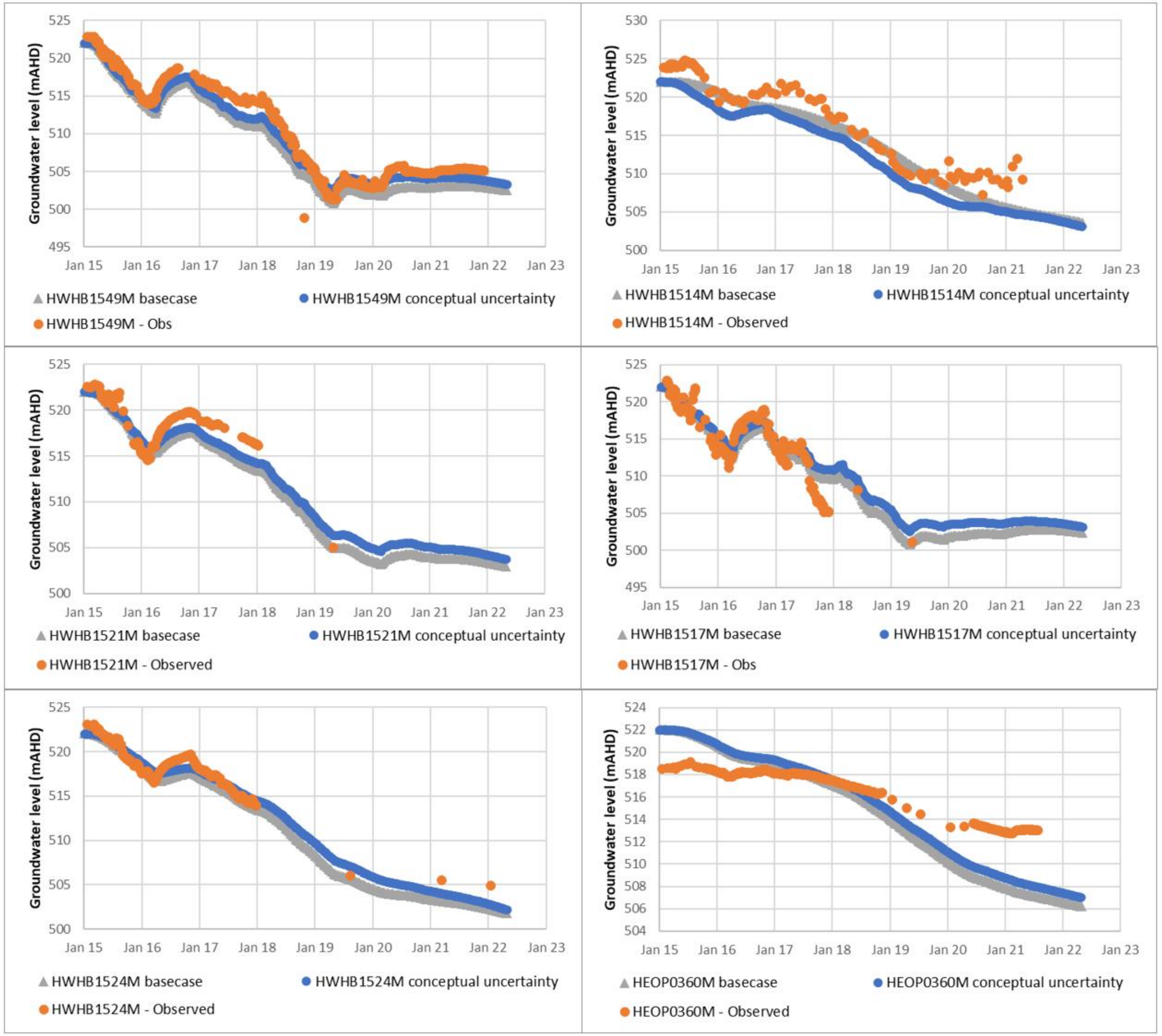

Figure 9.15: Conceptual uncertainty model: Observed and simulated hydrographs – OB29

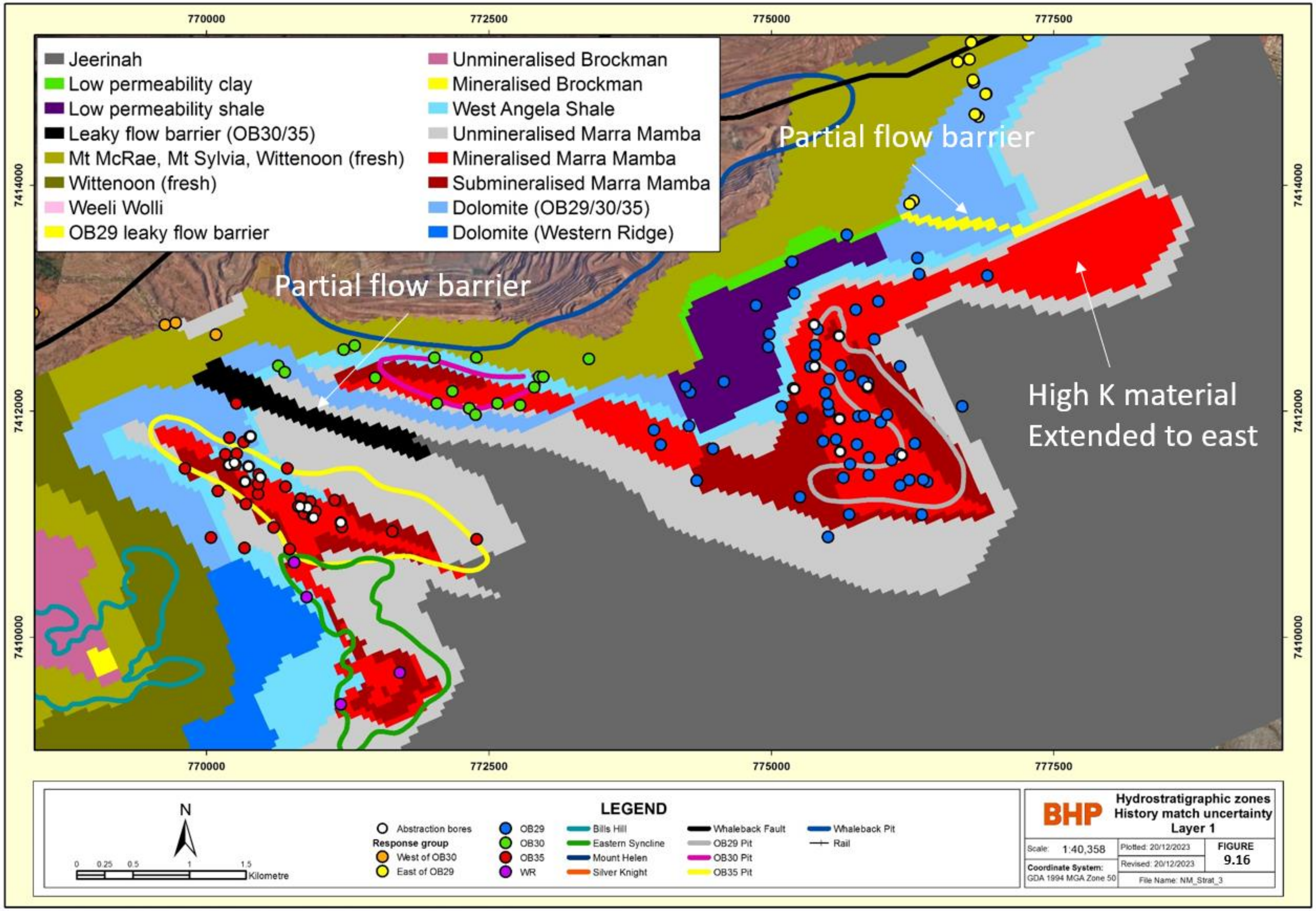

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Figure 9.16: Hydrostratigraphic zones: History match uncertainty - Layer 1

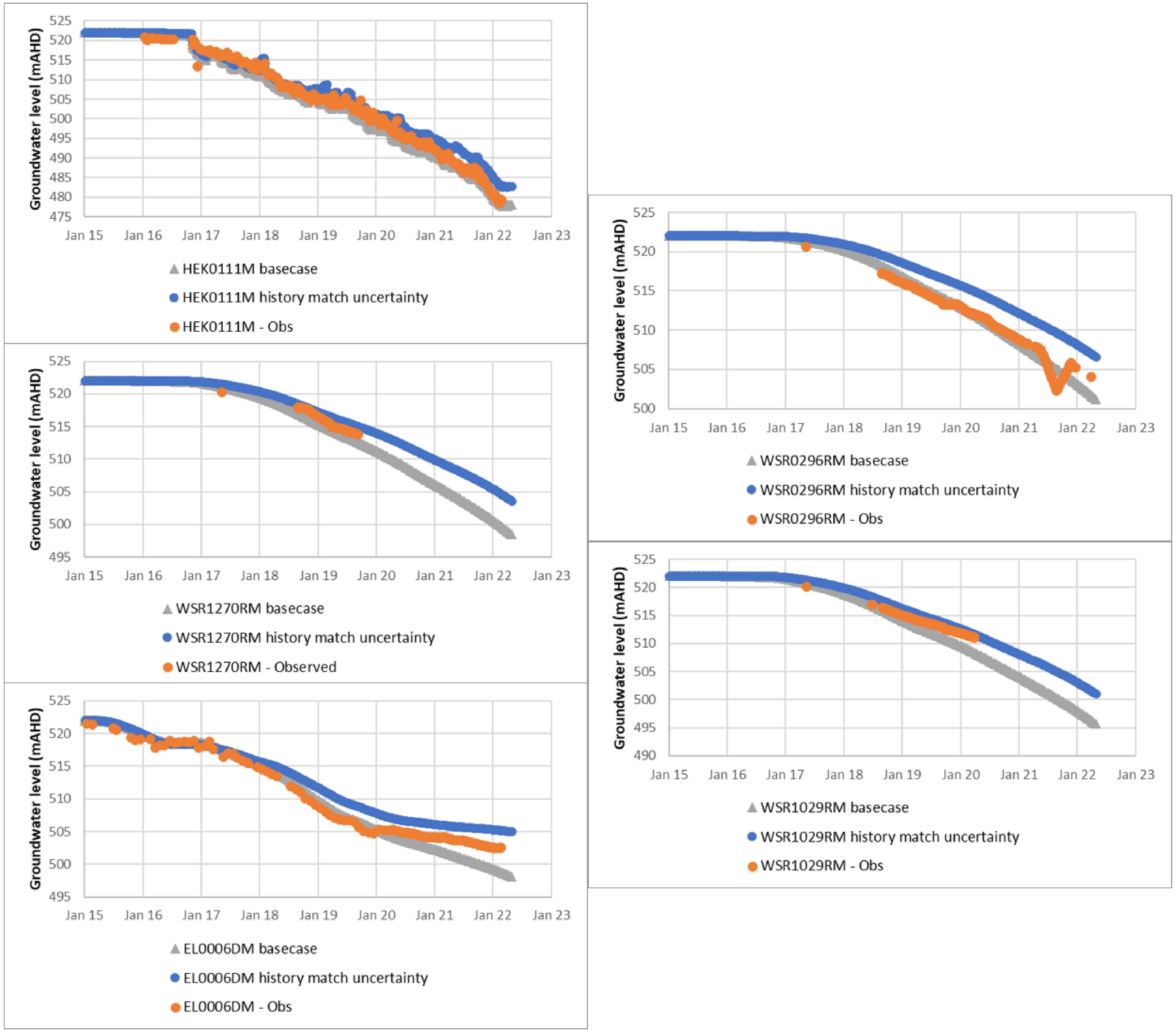

Figure 9.17: History match uncertainty model: Observed and simulated hydrographs – Western Ridge/OB35/OB30

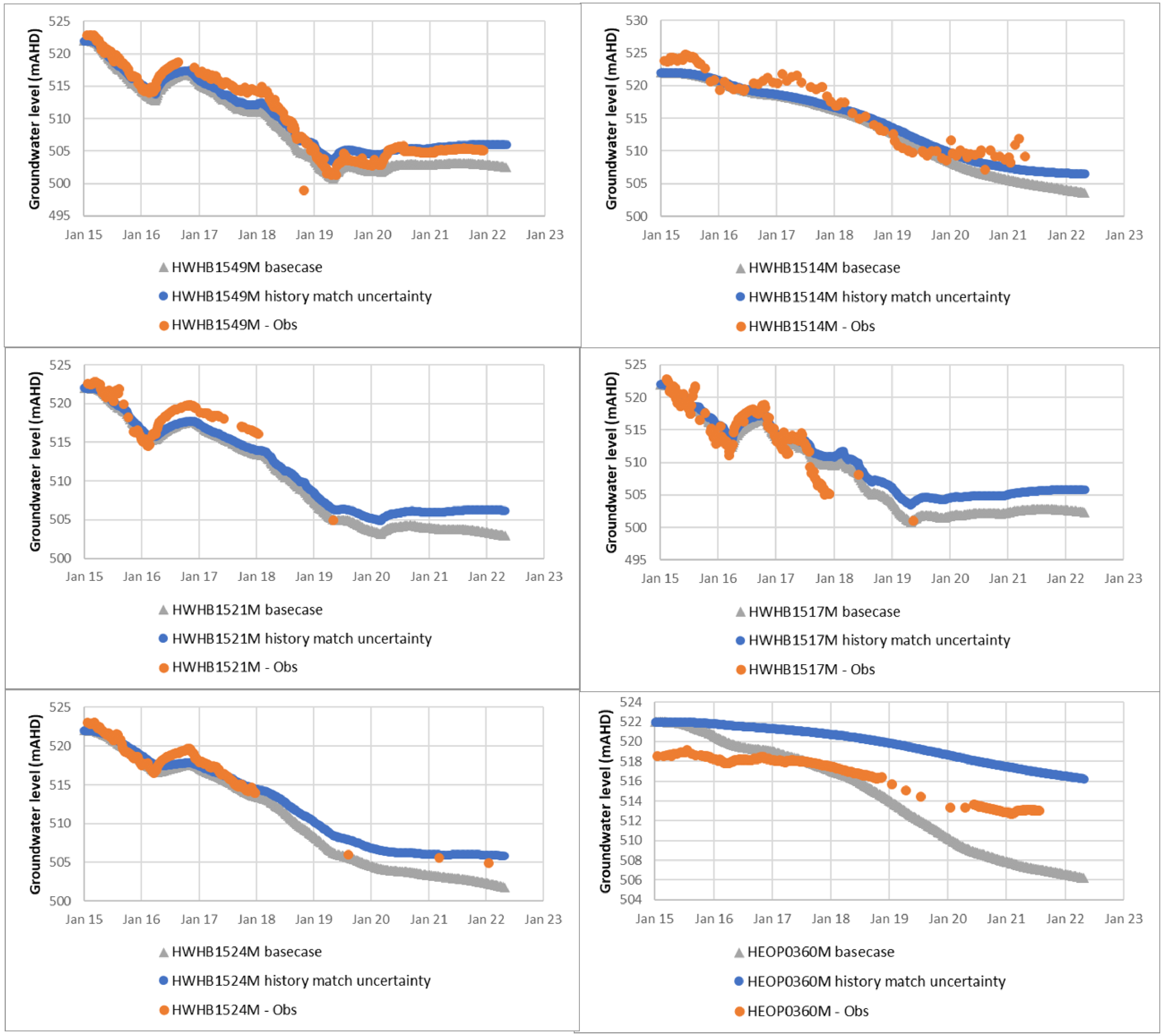

Figure 9.18: History match uncertainty model: Observed and simulated hydrographs – OB29

9.3. Dewatering Predictions

9.3.1. Mine plan

The simulated target dewatering water levels are shown in Figure 3.35. These are based on a water level drawdown rate of 24 m/yr.

These runs do not include Western Ridge dewatering.

9.3.2. Predictive uncertainty

The base case model was run with the target water levels. This provides the “best estimate predictions” and the standard against which the uncertainties can be compared.

The base case model abstraction was simulated using wells with specified abstraction rates. These rates were iteratively adjusted to achieve the desired target water levels. The reason for using wells was associated with the post processing of the model outputs for PFAS analysis (BHP, in preparation). As this method was not optimal for the uncertainty analysis undertaken as part of this scope, the subsequent runs use the Modflow Drain package in their place. In this case the conductance of the drains was set to a very high value and their elevation was set to the target water levels. They were placed in the deepest portions of the respective orebodies. Therefore, the first uncertainty analysis is the base case run using Modflow Drains instead of Modflow Wells.

Climate variability is unlikely to affect the predictions of either dewatering or drawdown during the operational phase of mining (i.e. up to 2050). Dewatering rates are expected to be many times more that recharge from rainfall and runoff, and consequently, variation in rainfall is unlikely to affect drawdown rates. The results from a number of Global Climate Models (CSIRO, 2013) show that the largest median predicted change in rainfall by 2050 is a less than 5% reduction in the December / January / February season.

The conceptual and history match sensitivity / uncertainty analysis described in Section 9.2.3 showed that:

1. the application to the model of several major conceptual uncertainties had very little impact on the history match results. The combined model run (with both dolomite to the north of OB30 and a high hydraulic conductivity structure connecting OB30 and OB29) was therefore considered in the predictive dewatering scenario.
2. the settings applied to the two leaky flow barriers and the general aquifer storage surrounding OB29 and OB30 could be optimised to some effect after the PEST history match. The final run with these changes combined provides a good match between observed and simulated water levels and should therefore be considered in the predictive dewatering scenario.

In addition to this, dewatering rate uncertainty should also be considered, although, as the 24 m/yr presents the aggressive case, the uncertainty lies in lower rates and therefore lower predicted dewatering.

Therefore, the following four variations of the predictive model were used to provide a range of possible dewatering and impact outcomes for OB29/30/35:

1. The base case model (history matched with PEST) – one version with Modflow Wells and one with Drains.
2. The conceptual uncertainty model (dolomite north of OB30 and structure connecting OB30 to south of OB29) (Figure 9.13)
3. The history match uncertainty model (lower hydraulic connection across the two leaky flow barriers and higher storage close to the OB29 orebody) (Figure 9.16)
4. The mine plan uncertainty model (12 m/yr dewatering rather than the 24 m/yr used in the main scenarios).

9.3.3. Base case results

The results are displayed as:

- Hydrographs at the key monitoring bores (Figures 9.19 and 9.20)
- Groundwater level (Figures 9.21 to 9.24) and drawdown (Figures 9.25 to 9.28) contours at key times from the base case model (2022, 2030, 2040 and 2056)

- Dewatering rates (Figure 9.29)
- Change in flow across the eastern model boundary (Figure 9.30)

The results show that:

- The total dewatering rate peaks at approximately 62 ML/d in FY25.
- Drawdown is expected to occur throughout the regional and local (orebody) aquifers in the area.
- Drawdown extent (as defined by the 2 m drawdown contour) doesn't change much from 2022 to the end of dewatering in 2056. This is because:
    - By 2022 drawdown in excess of 2 m has already reached the north western, northern and north eastern model boundaries.
    - By 2022 the 2 m drawdown contour has reached the Jeerinah Formation to the south of all the orebodies. Due to the low permeability of this material, by 2056 the 2 m drawdown contour has only moved about 500 m further south.
- In the regional aquifer north of OB29 (HWHB1514M) drawdown is predicted to reach about 90 m by 2035 and 95 m by 2050.
- East of the leaky flow barrier east of OB29, drawdown is predicted to reach a maximum of about 80 m (at HEOP0360M) by 2035.
- At the western end of the regional aquifer (at the Whaleback Fault – WSR0296RM), drawdown is predicted to reach a maximum of about 90 m by 2056.
- In terms of flow across the eastern model boundary, the results show that flow into the model from the east increases from 0 ML/d to almost 7 ML/d by 2056. There is no constraint set on how much flow can enter the model across this boundary.

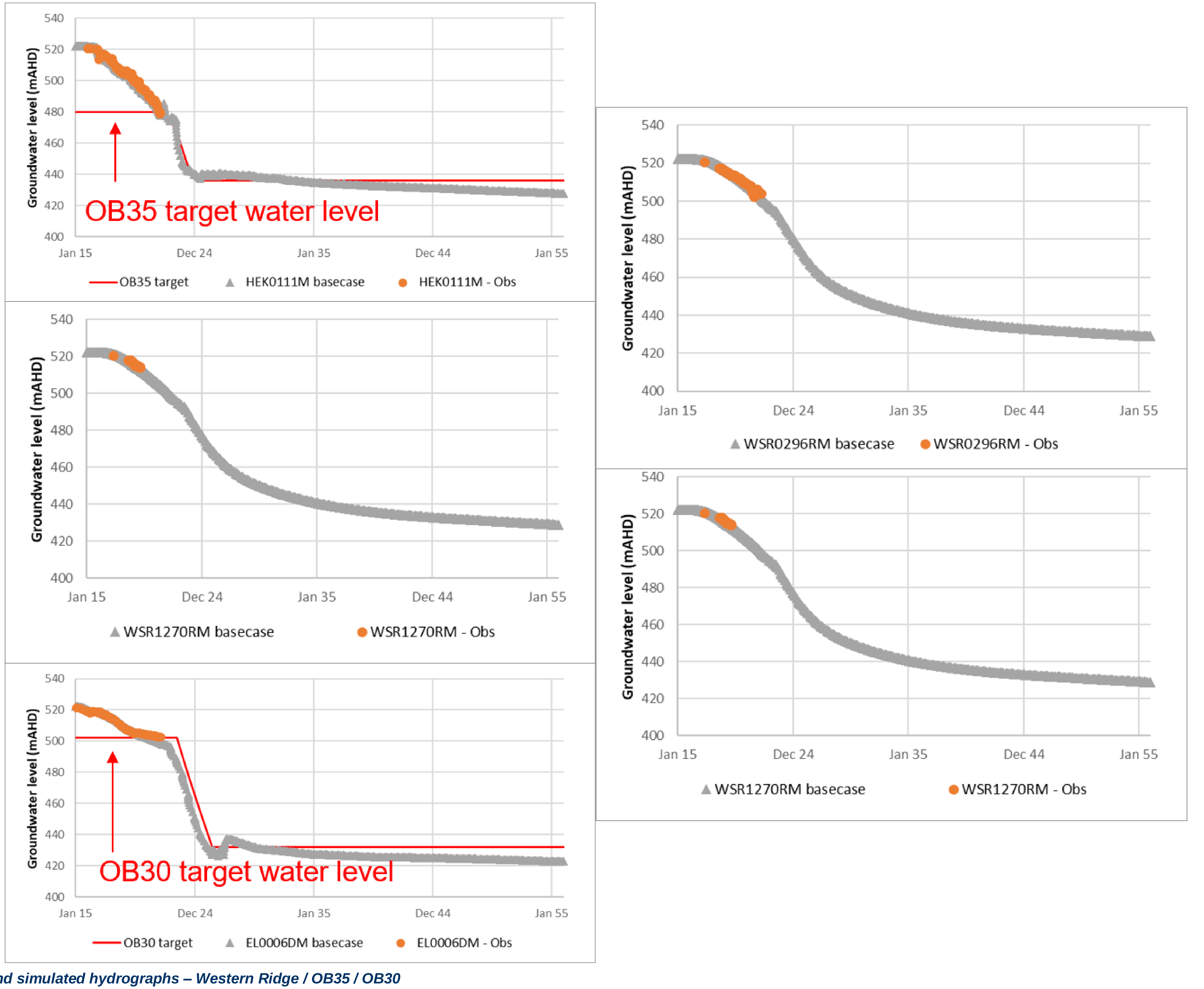

Figure 9.19: Observed and simulated hydrographs – Western Ridge / OB35 / OB30

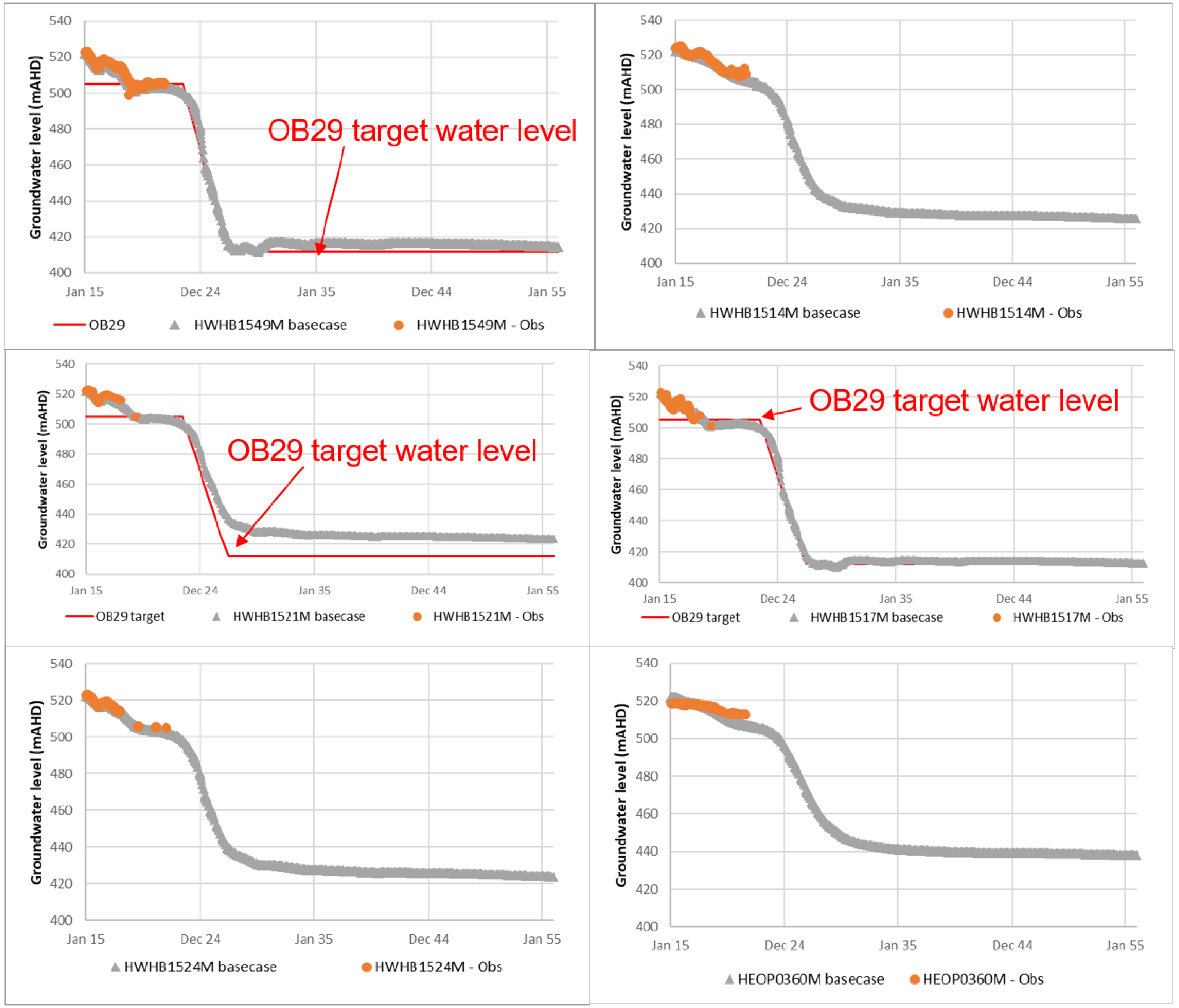

Figure 9.20: Observed and simulated hydrographs – OB29

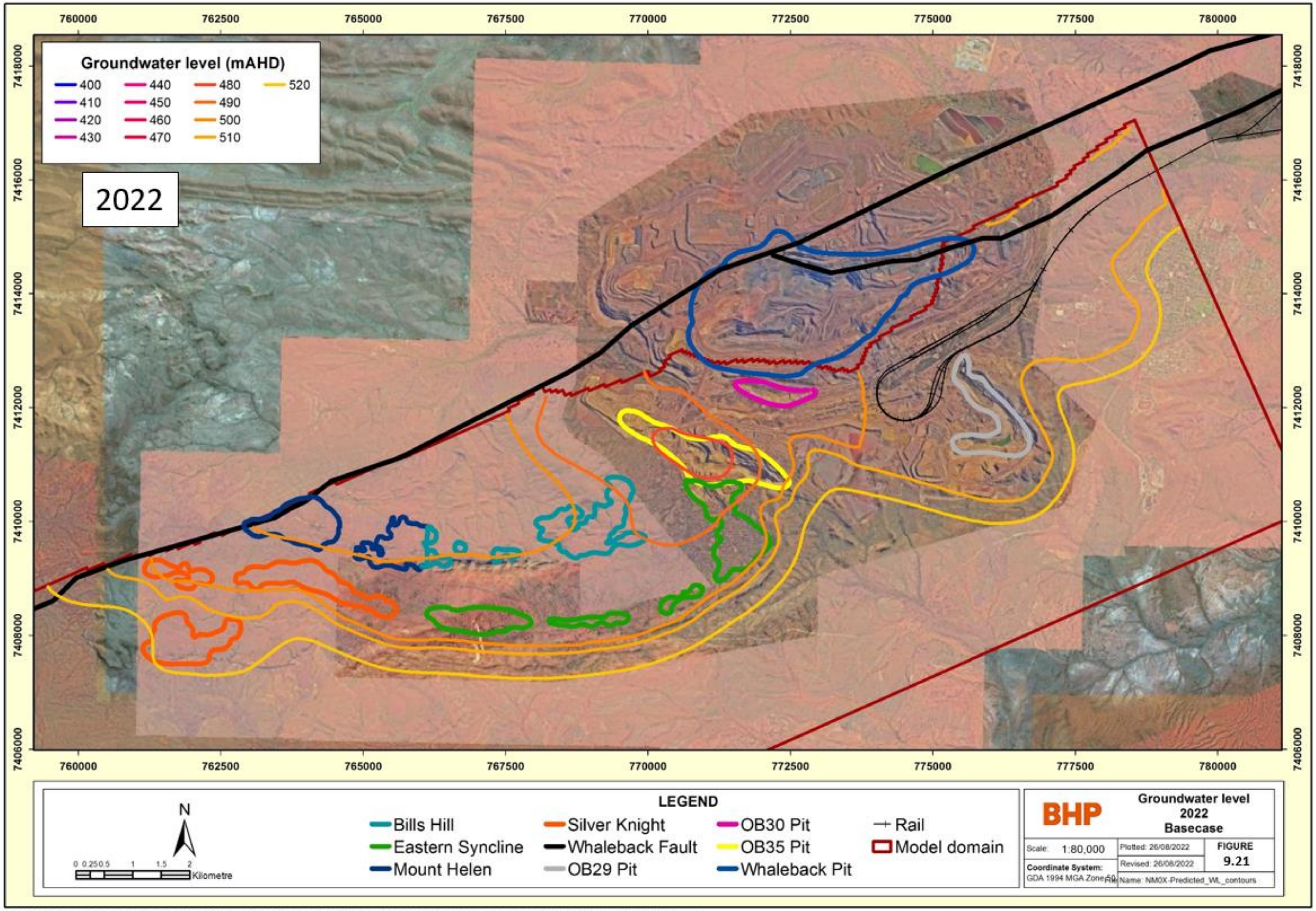

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Figure 9.21: Groundwater level – 2022 base case

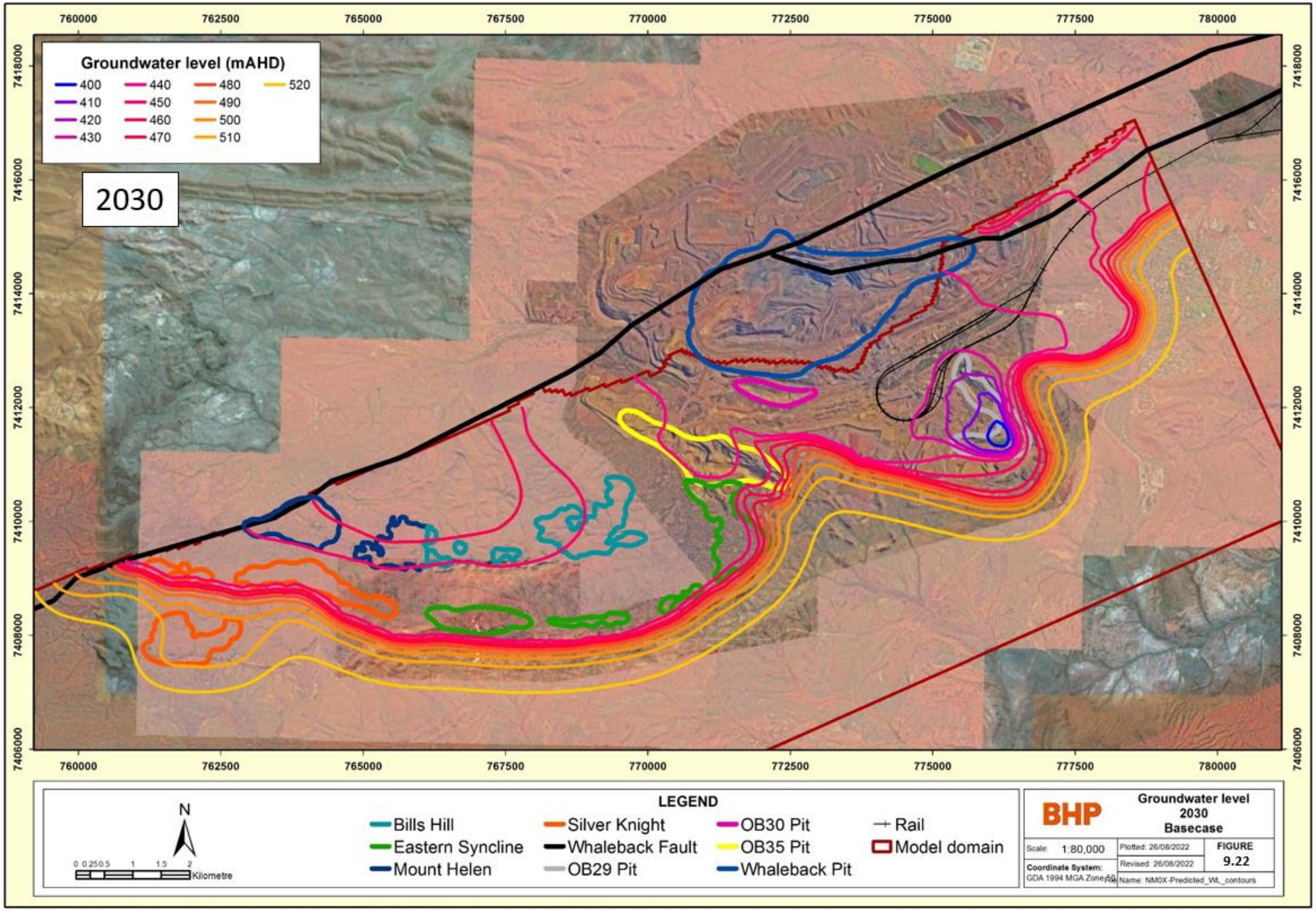

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Figure 9.22: Groundwater level – 2030 base case

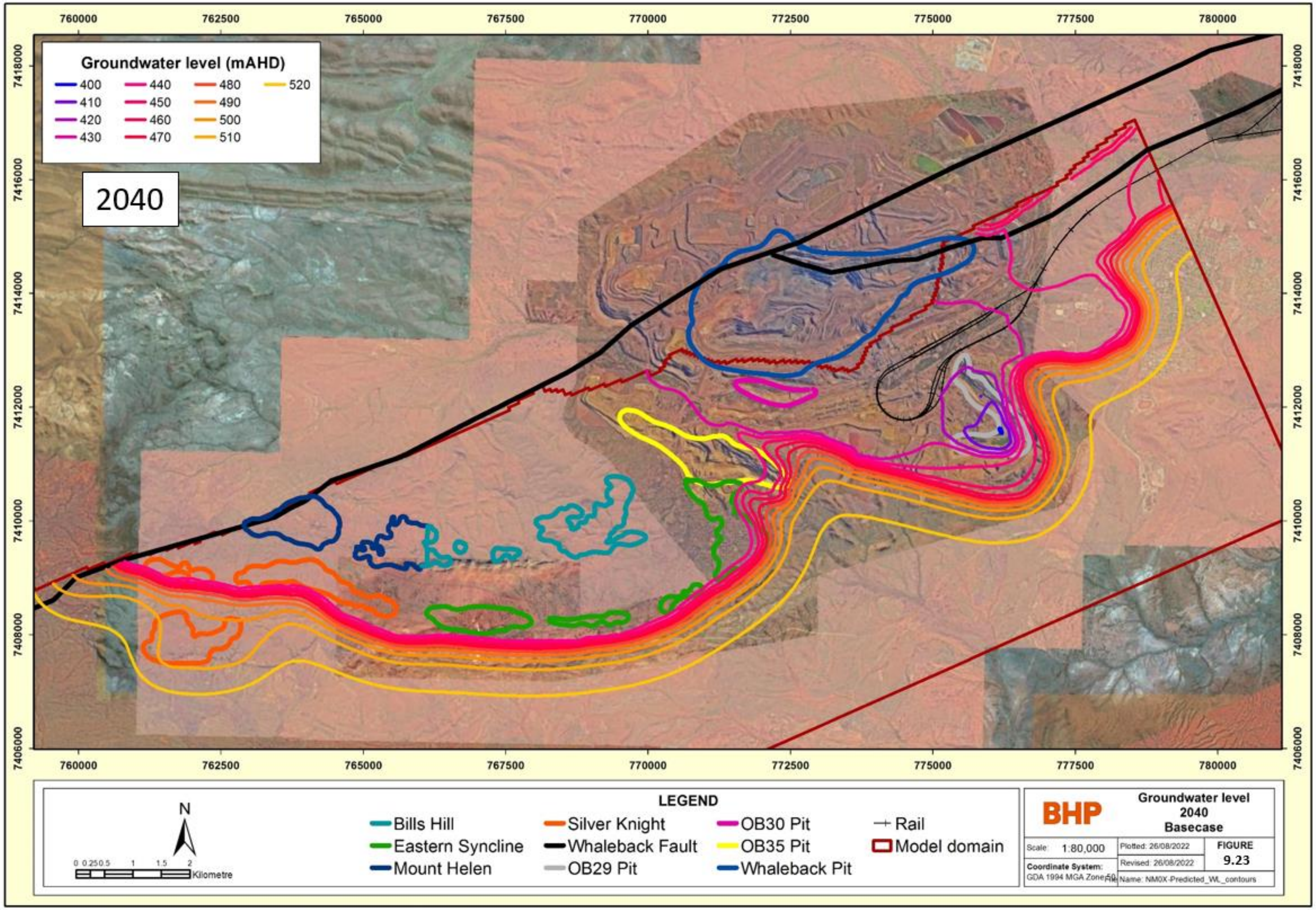

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Figure 9.23: Groundwater level - 2040 base case

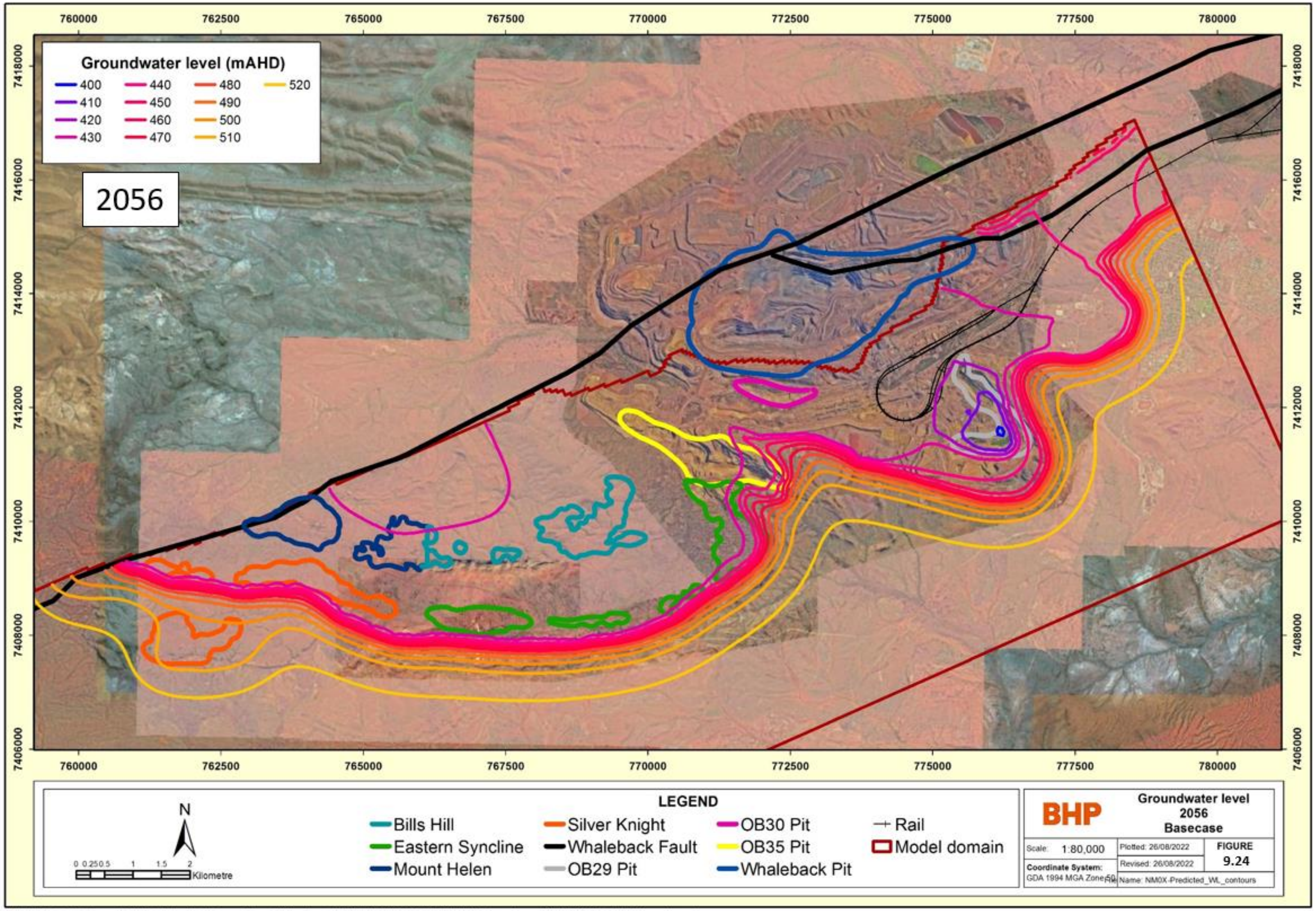

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Figure 9.24: Groundwater level – 2056 base case

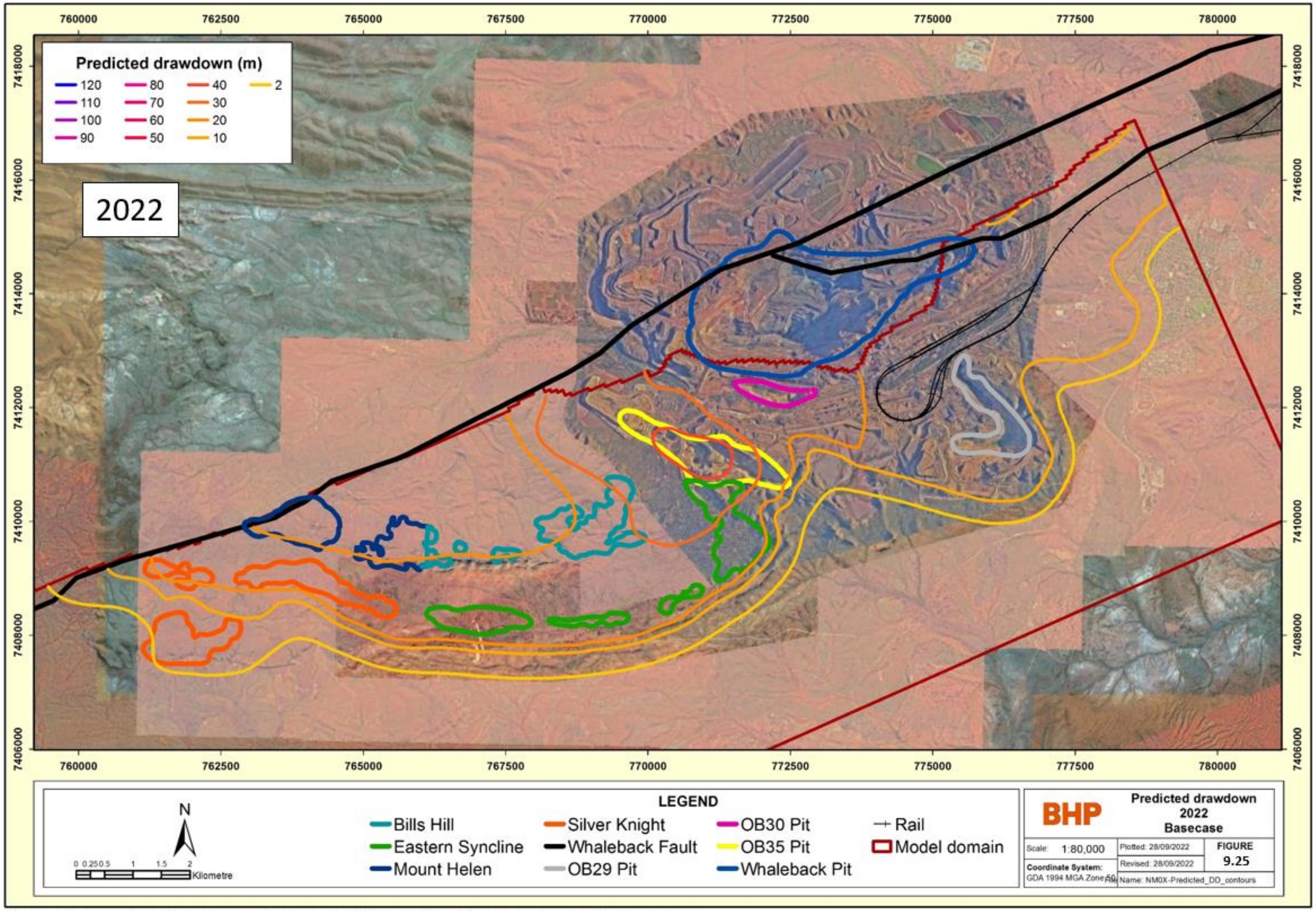

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Figure 9.25: Predicted drawdown – 2022 base case

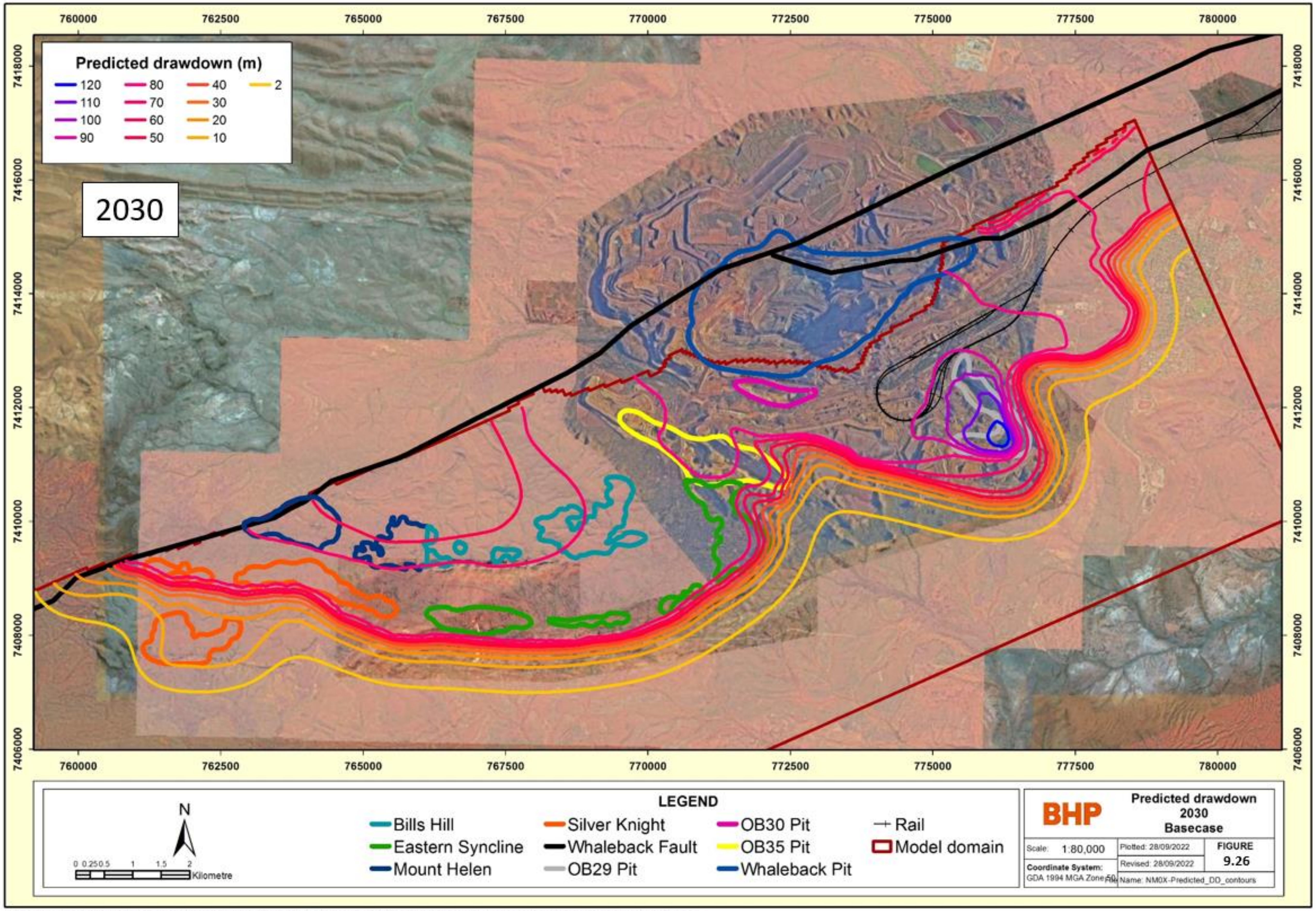

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Figure 9.26: Predicted drawdown – 2030 base case

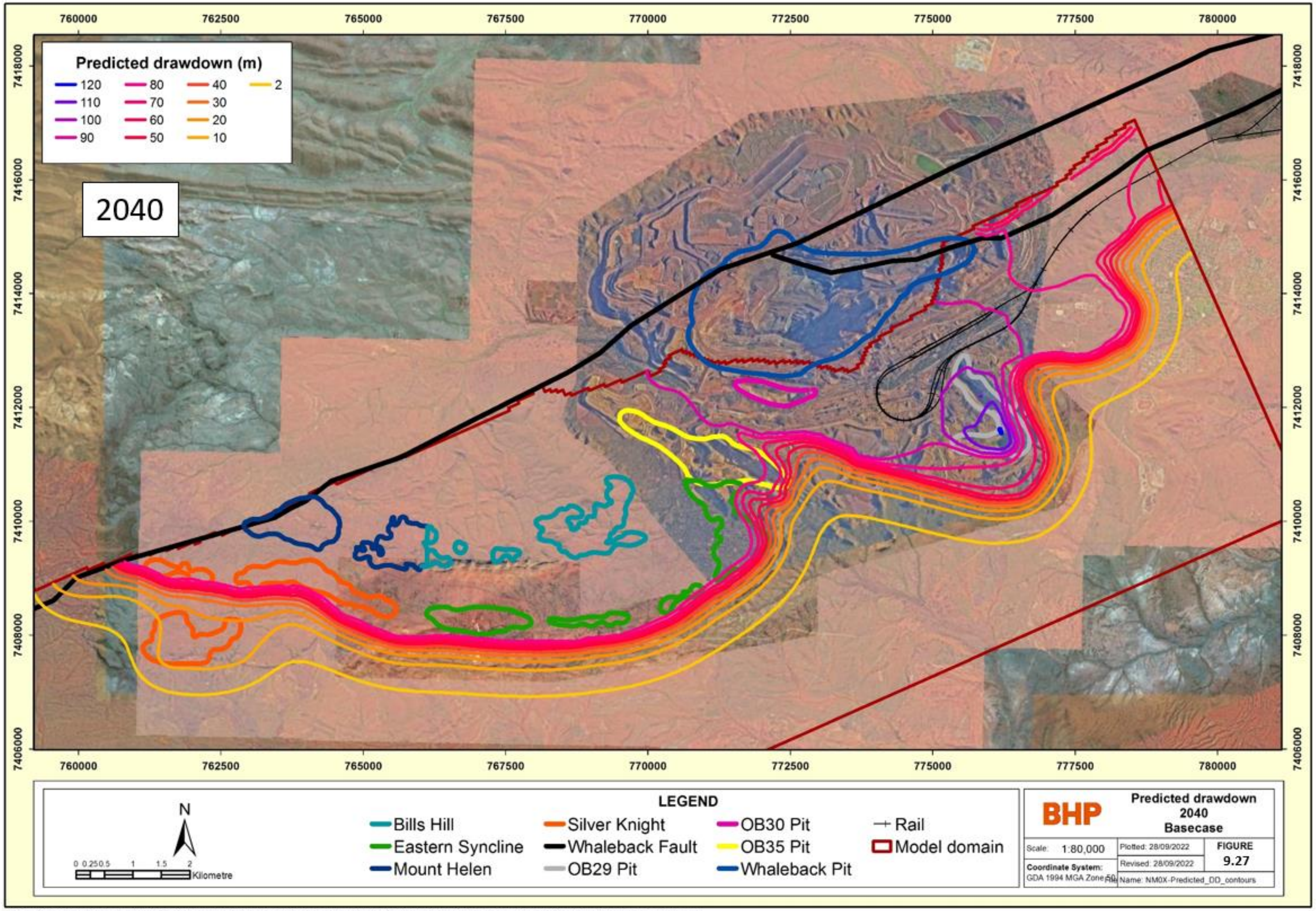

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Figure 9.27: Predicted drawdown – 2040 base case

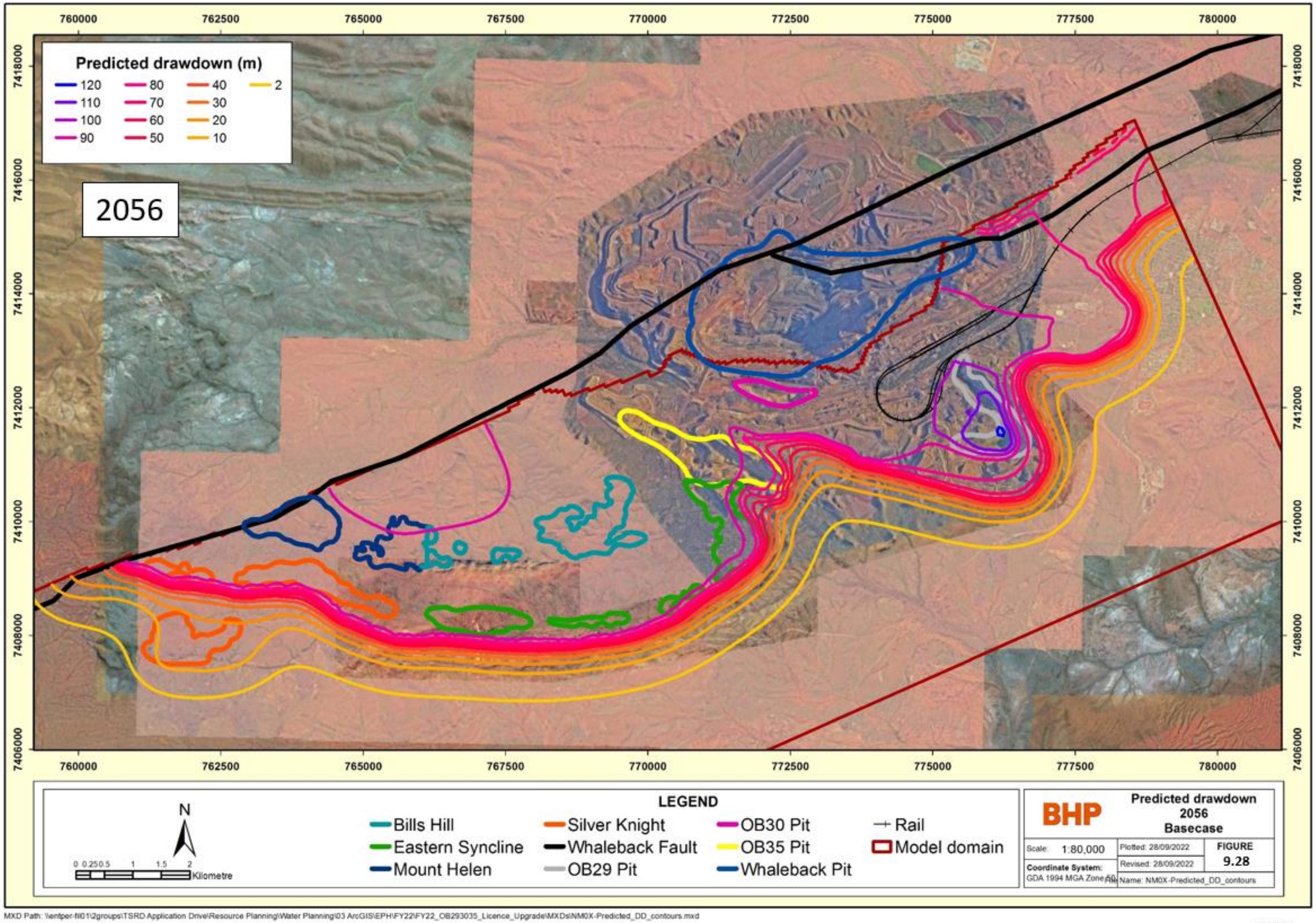

Figure 9.28: Predicted drawdown – 2056 base case

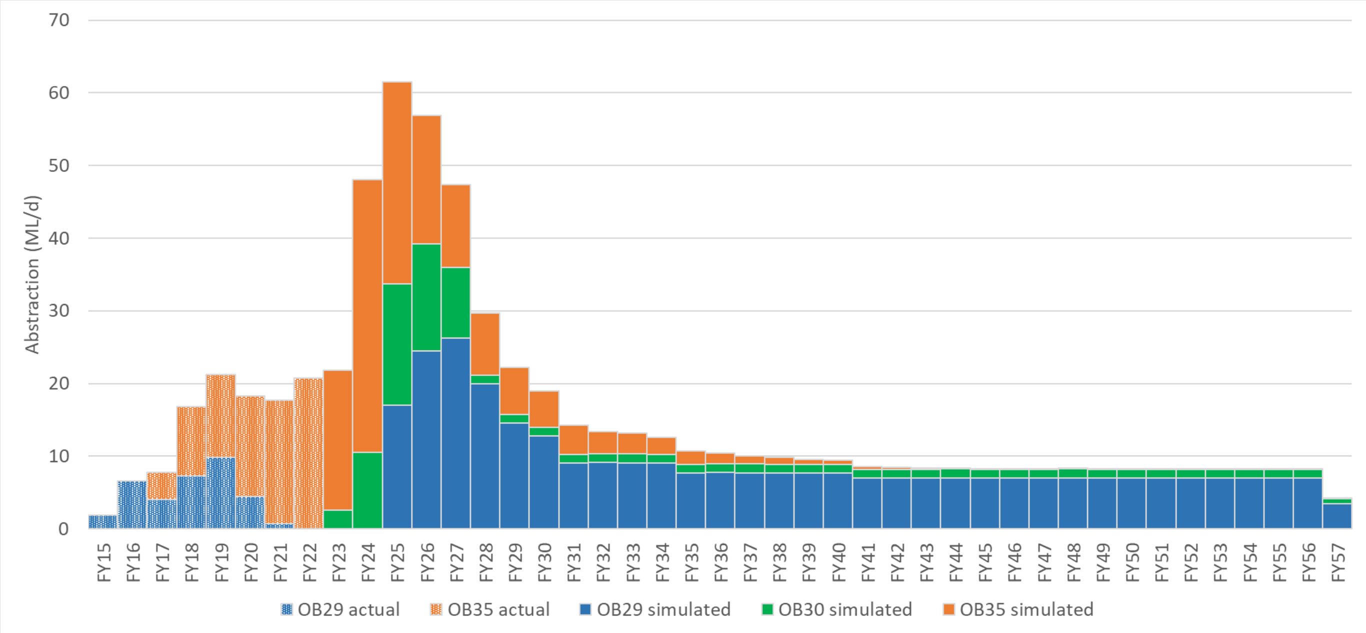

Figure 9.29: Base case predicted dewatering

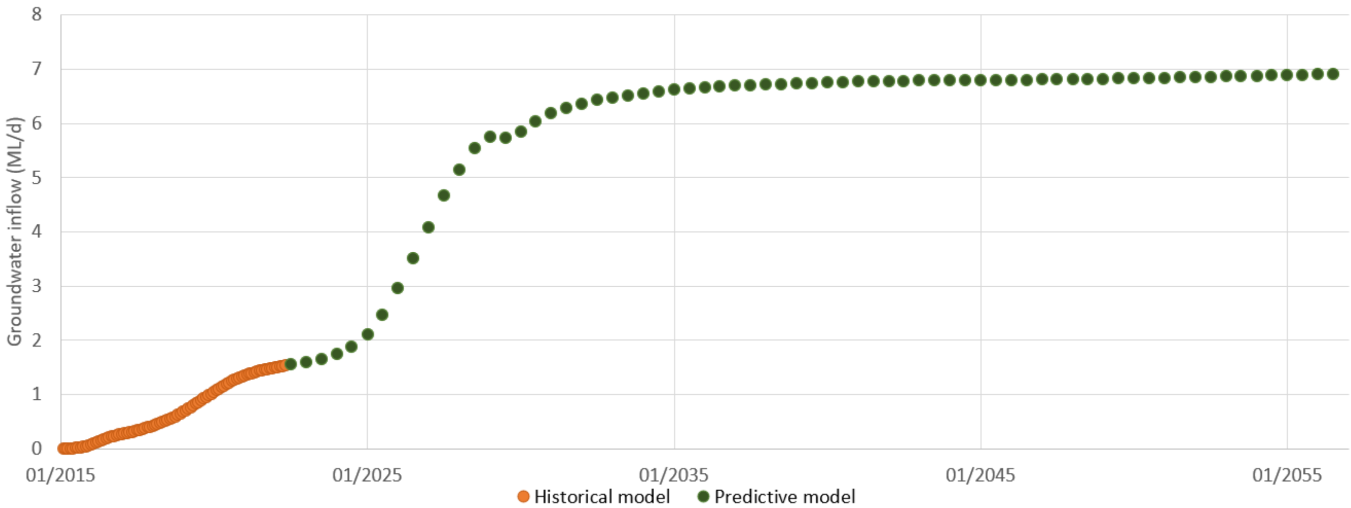

Figure 9.30: Predicted inflow through the eastern model boundary (base case)

9.3.4. Uncertainty analysis

The results from the four sets of uncertainty runs are described below.

Drains uncertainty model

The dewatering profile using Modflow Drains is significantly different to that using Wells (Figure 9.31). The peak is lower (51 ML/d rather than 62 ML/d) and the total volume abstracted is also significantly lower. This run shows the difference in predictions that can be generated from using these two numerical options to represent dewatering, which in this case amounts to approximately 20%.

The Drains represent a far more efficient dewatering system than is achievable in practice, however. And the Wells are most likely inefficient as they rely on the same wells throughout the over 30 years of dewatering. In reality new wells would be drilled over time and in more opportune locations as the dewatering requirements evolve. For this dewatering plan then, the "true" answer is probably somewhere between these two runs.

The difference in dewatering rates translates into less drawdown around OB29 for the Drains uncertainty run (a maximum of just over 100 m (Figure 9.33) rather than just over 120 m in the base case (with Wells) (Figure 9.32)). And slightly less drawdown at the model extents; between 80 and 90 m in the Western Ridge area (compared to between 90 and 100 m) and marginally less towards the eastern boundary.

Conceptual uncertainty model (dolomite north of OB30 and structure connecting OB30 to south of OB29).

Predicted dewatering from the conceptual uncertainty model was almost identical to the base case (Figure 9.31). The peak increased from 62 ML/d to 63 ML/d, but other than this, the two runs were essentially the same. Predicted drawdown extent and magnitude was also very similar to the base case (Figure 9.34).

As this scenario used Modflow Wells as per the base case, it shows that these uncertainties (dolomite to the north of OB30 and hydraulic connectivity between the south of OB30 and the south of OB29) are not material to the outcomes.

History match uncertainty model (lower hydraulic connection across the two leaky flow barriers and higher storage close to the OB29 orebody).

The changes made in this model were significant. This resulted in a higher maximum dewatering rate and a change to the magnitude of drawdown (although not the extent) (Figure 9.31 and Figure 9.35).

The maximum dewatering rate increased from 62 ML/d in the base case to 66 ML/d (Figure 9.31). However, as this run used Drains rather than Wells, the correct comparison is against the base case with Drains which had a peak of 51 ML/d. If this model had used Modflow Wells, the maximum dewatering rate may well have been even higher.

The predicted drawdown in 2022 is noticeably different compared to the base case (Figure 9.36 and 9.37). The history match uncertainty model produces much less drawdown than the base case and the drawdown is more compartmentalised between the two leaky flow barriers. However, by 2056, the differences are much less obvious, and the results are within 10 m of each other over most of the model domain. The only area where this is exceeded is within the OB29 pit, where the drawdown from the Wells in the base case exceed the drawdown from the Drains in the calibration uncertainty run. A good comparison to these predictions is the results from the base case with Drains scenario (Figure 9.33). These are very similar, showing that at the end of dewatering, the changes to these key parameters did not result in significant changes in drawdown predictions.

Mine plan uncertainty model (12 m/yr dewatering rather than the 24 m/yr used in the main scenarios)

The 12 m/yr dewatering target (using Modflow Wells) results in a peak dewatering rate of 44 ML/d (Figure 9.31), compared to 62 ML/d in the base case. The rate after the peak is higher than all the other scenarios however as even though the target level falls at half the rate of the base case, it does eventually reach the same final elevation.

The drawdown at the end of this run is very similar to the base case (Figure 9.38).

Summary

Even though the area has been extensively tested and has been subject to several years of dewatering and recovery, some uncertainty remains.

However, this uncertainty does not fundamentally change the predictive outcomes. The biggest uncertainty concerns the representation of dewatering in the model (and the target dewatering rate). Even though there remain some significant unknowns concerning the hydrogeology of the system, the models that incorporated this uncertainty produce roughly the same predicted dewatering requirements and drawdown extents and magnitude. For all models, drawdown of at least 80 m was predicted within the OB29/30/35 aquifer compartments and between 70 and 80 m immediately east of the OB29 leaky flow barrier.

For all models (excluding the 12 m/yr dewatering rate), the peak dewatering requirement was between 51 and 66 ML/d.

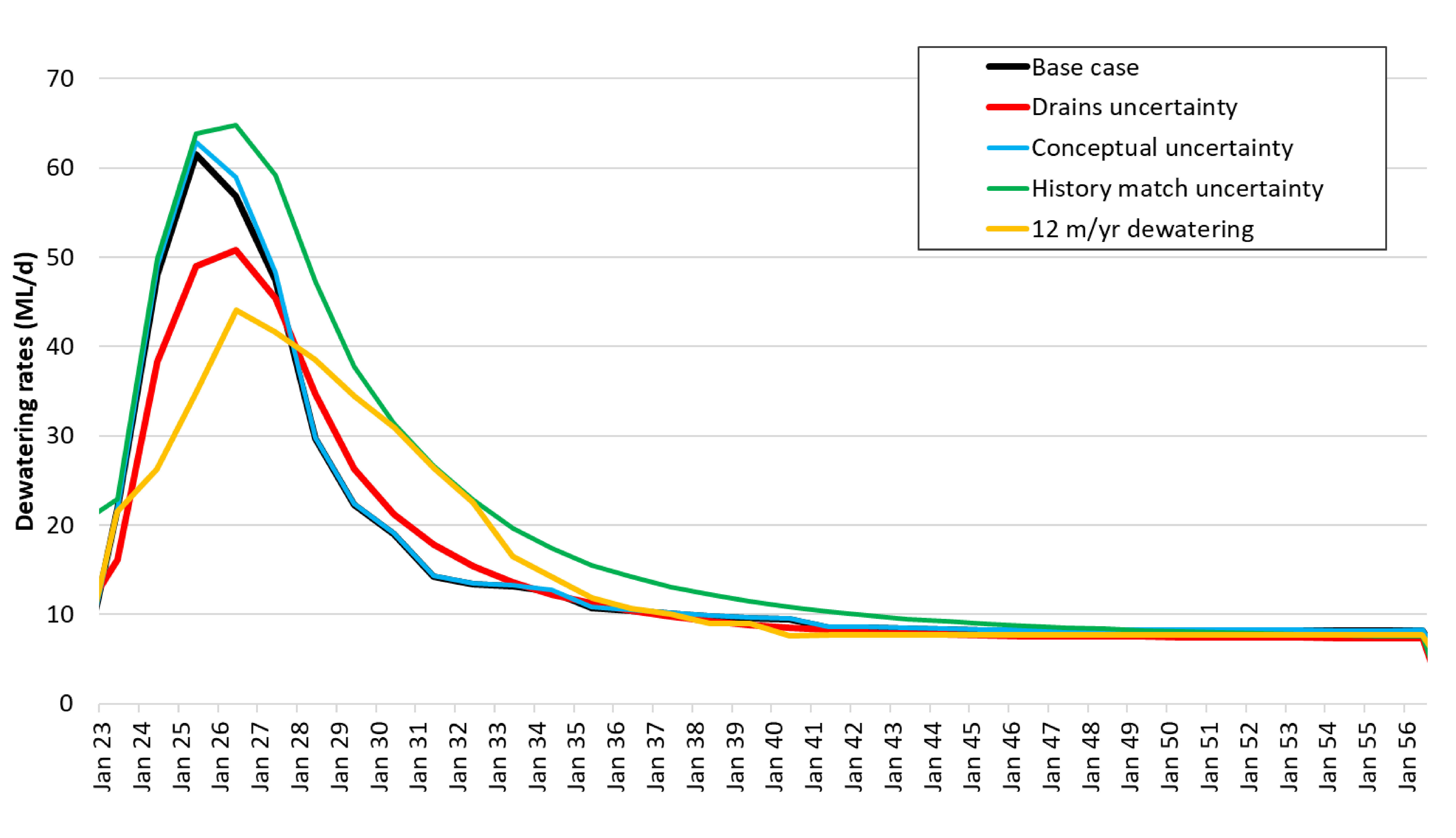

Figure 9.31: Predicted dewatering - uncertainty

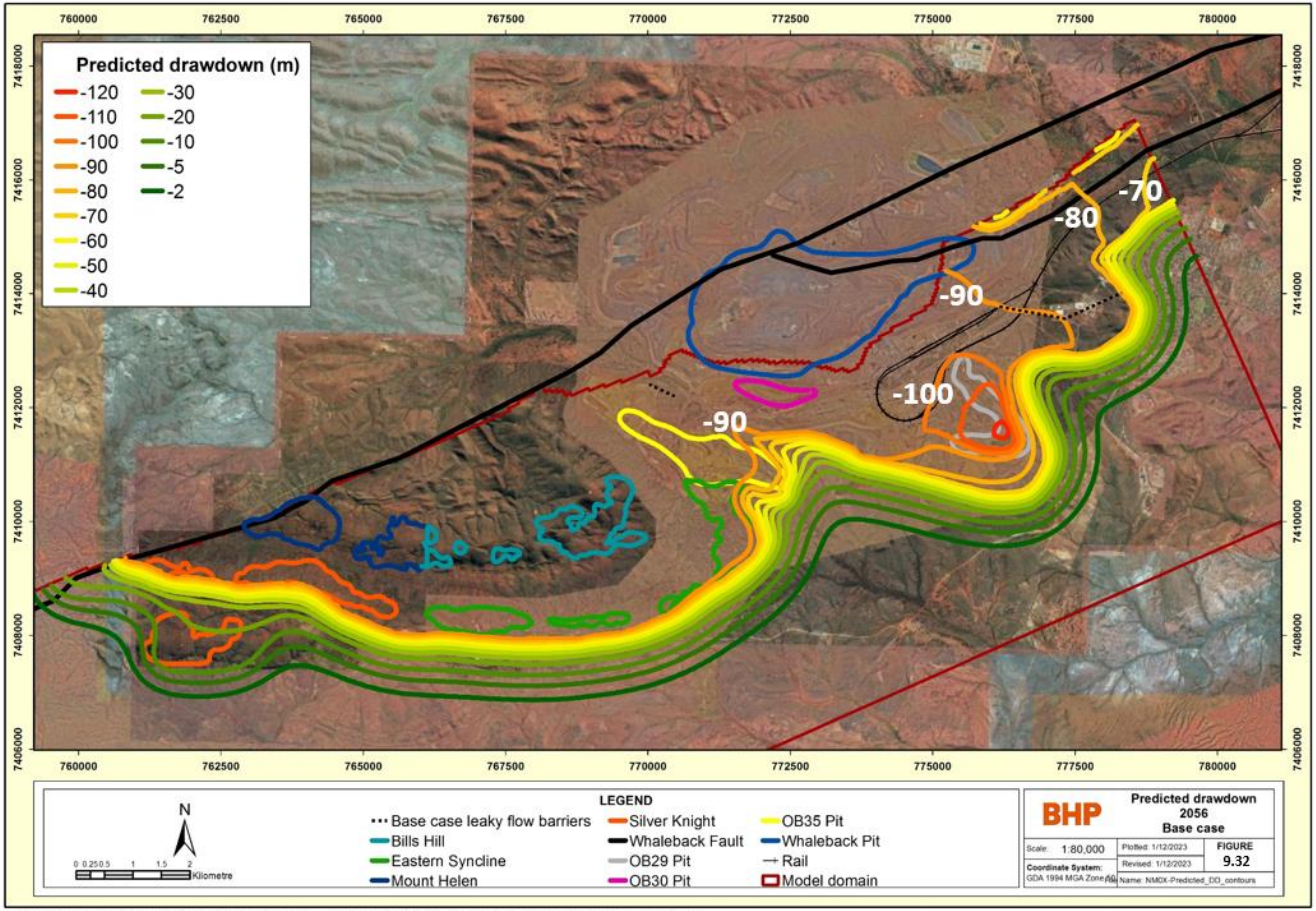

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Figure 9.32: Predicted drawdown – base case - 2056

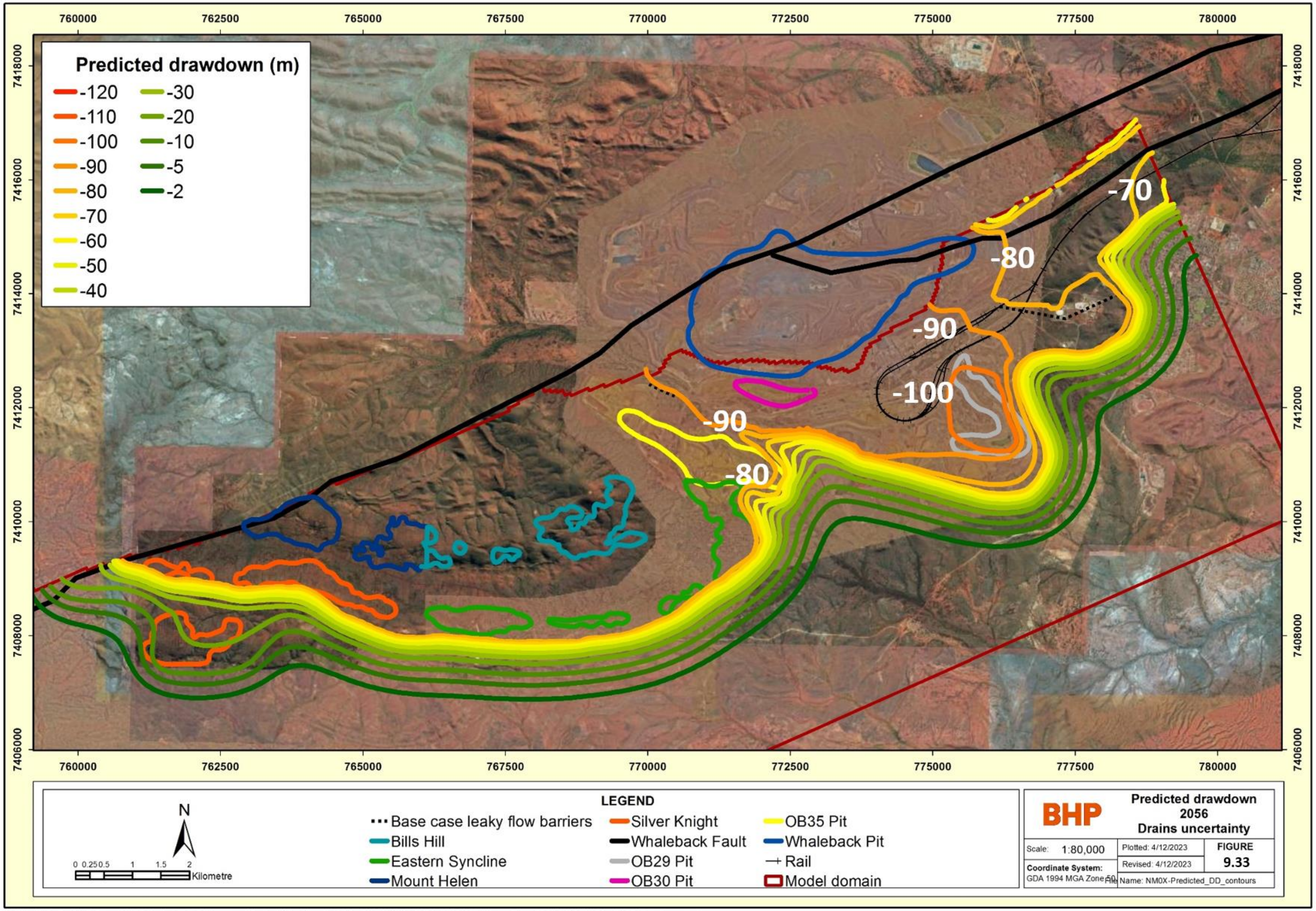

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Figure 9.33: Prediction drawdown – drains uncertainty – 2056

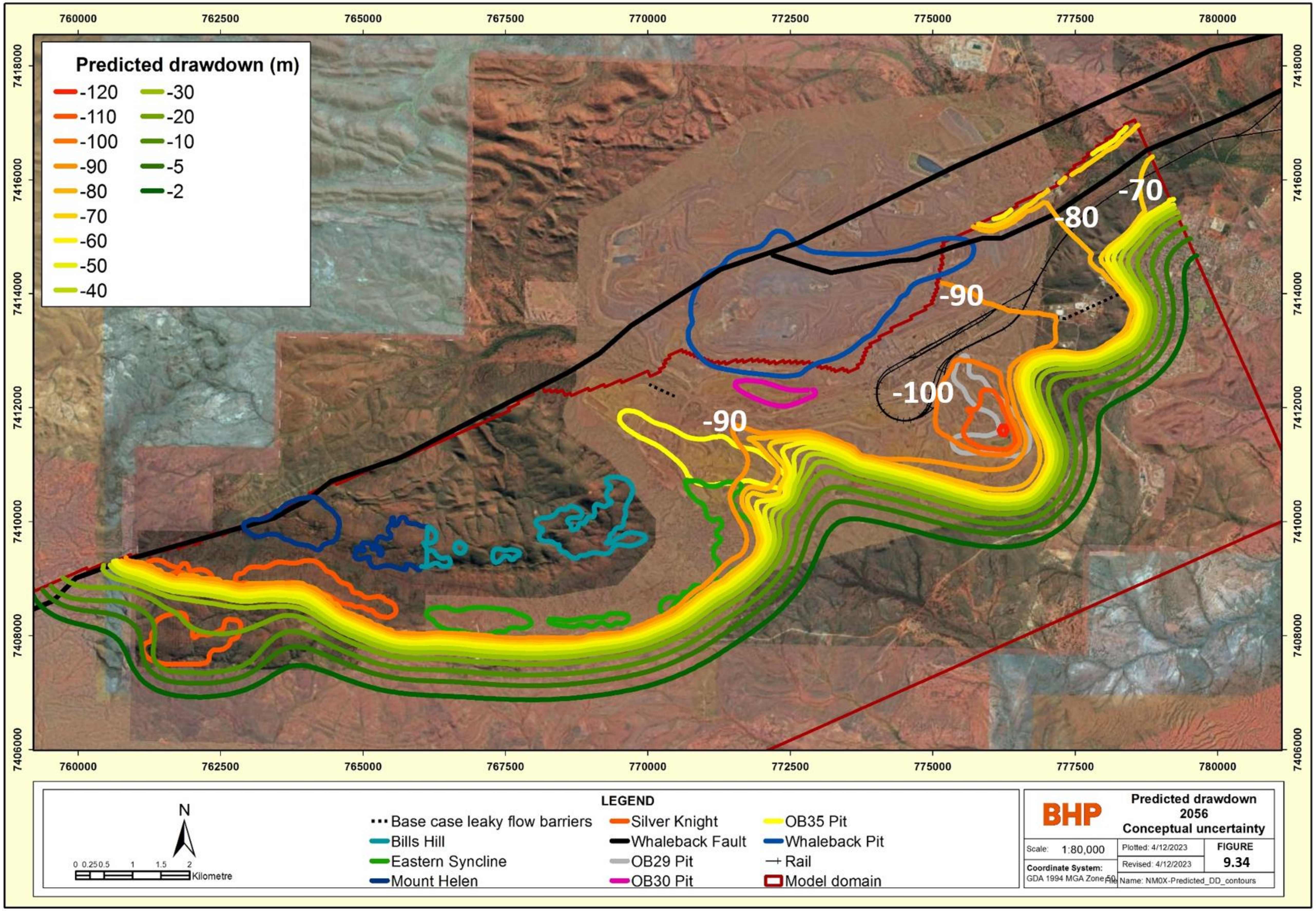

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Figure 9.34: Predicted drawdown – conceptual uncertainty - 2056

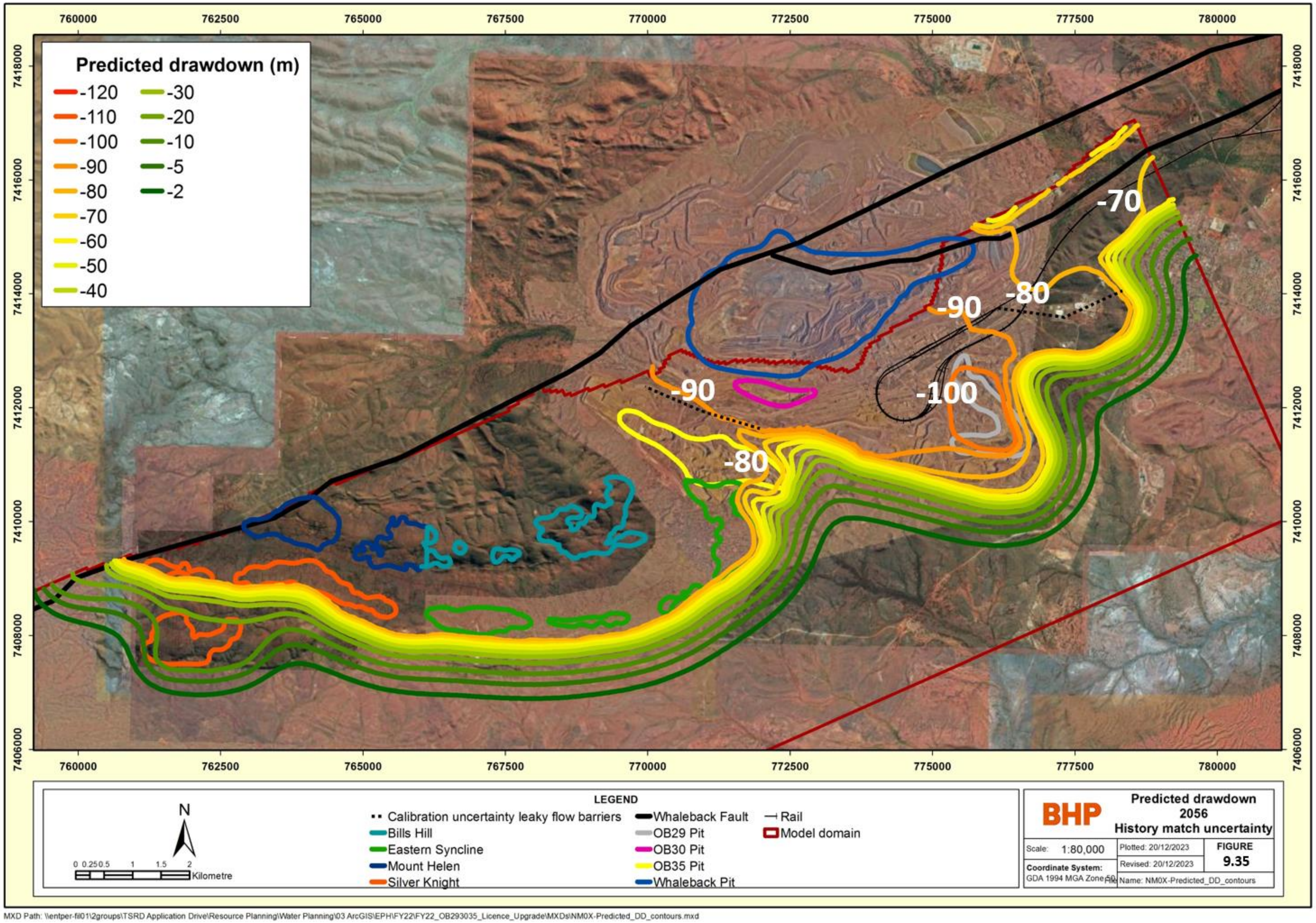

Figure 9.35: Predicted drawdown – history match uncertainty – 2056

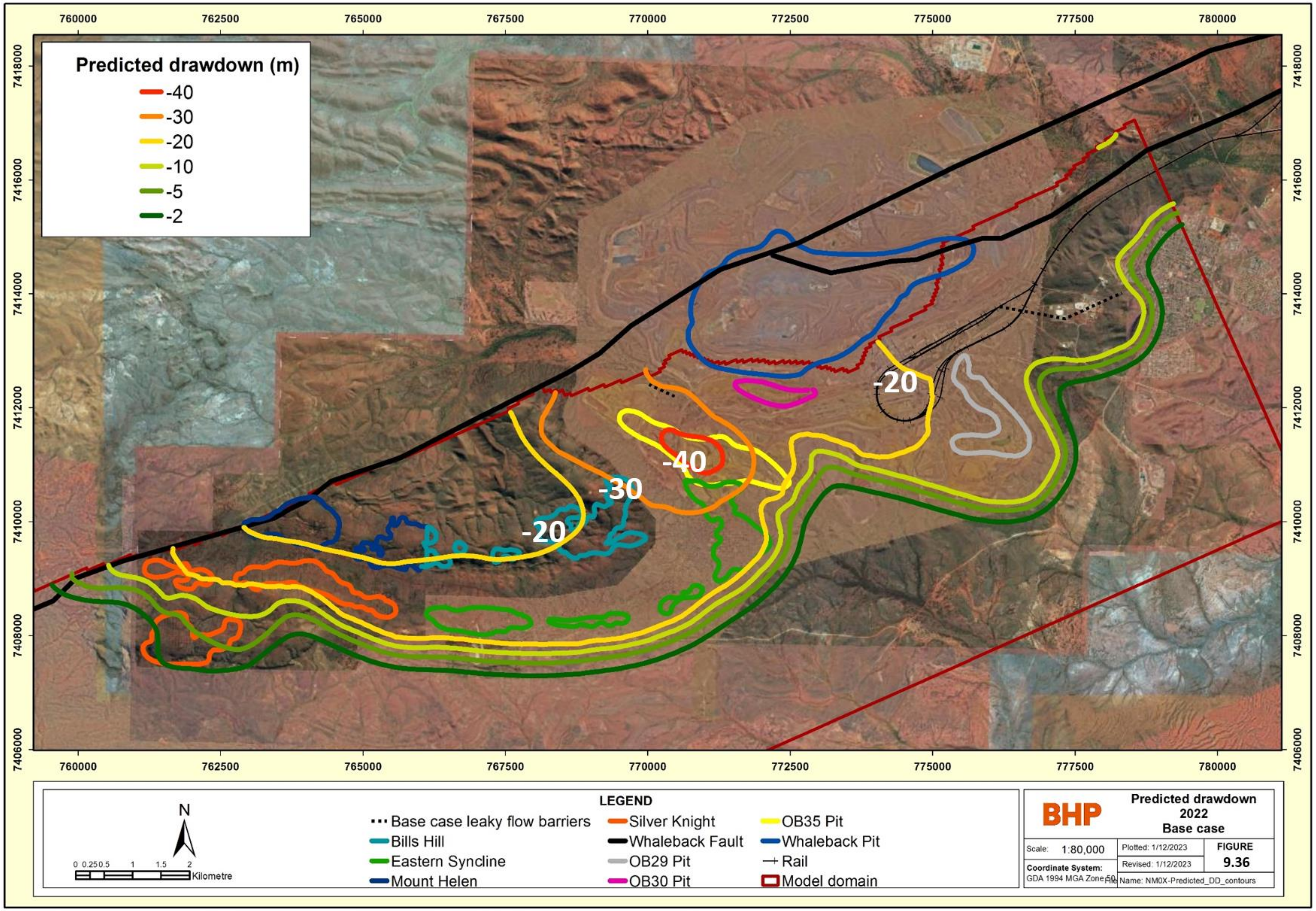

Figure 9.36: Predicted drawdown – base case – 2022

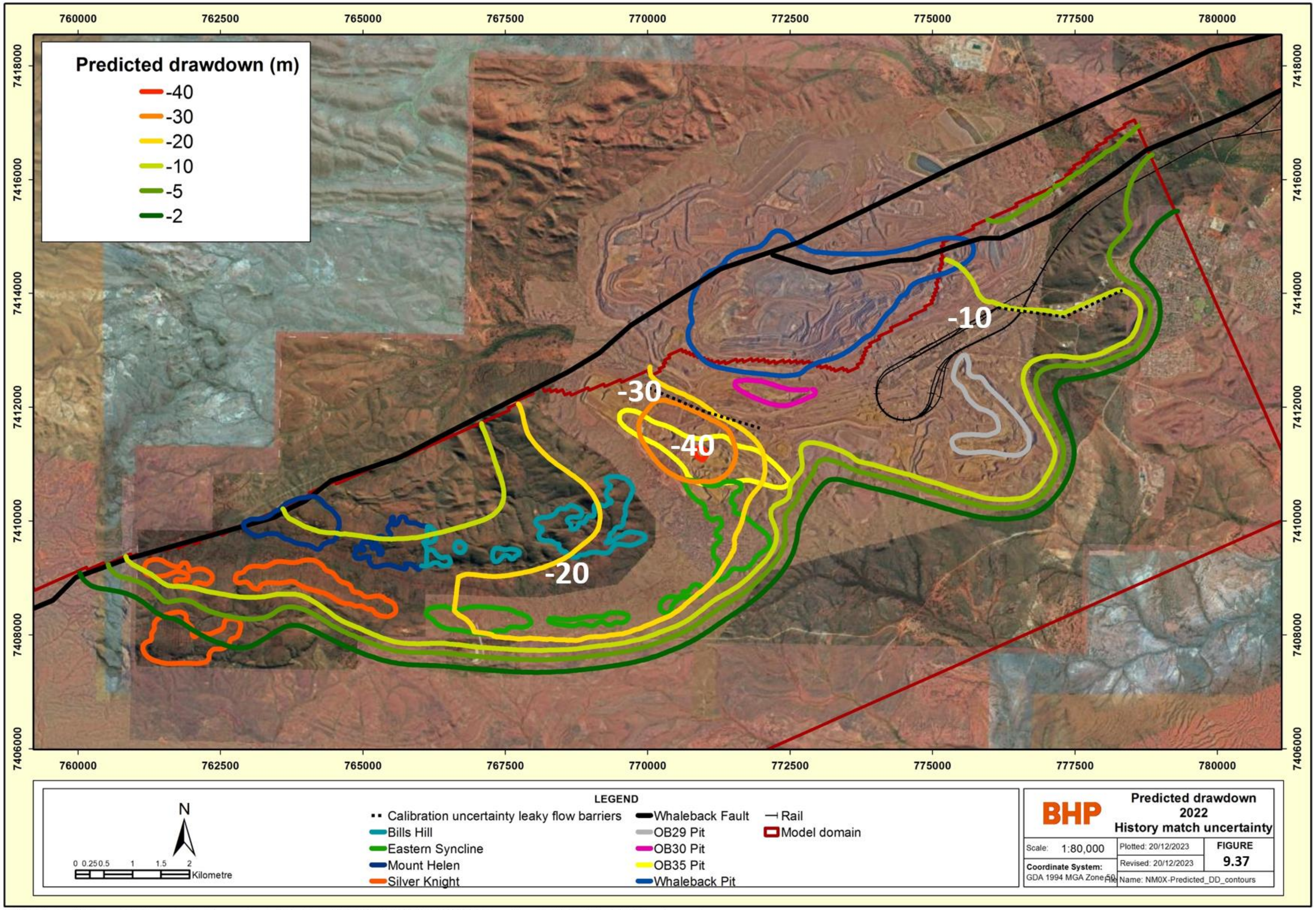

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Figure 9.37: Predicted drawdown – history match uncertainty – 2022

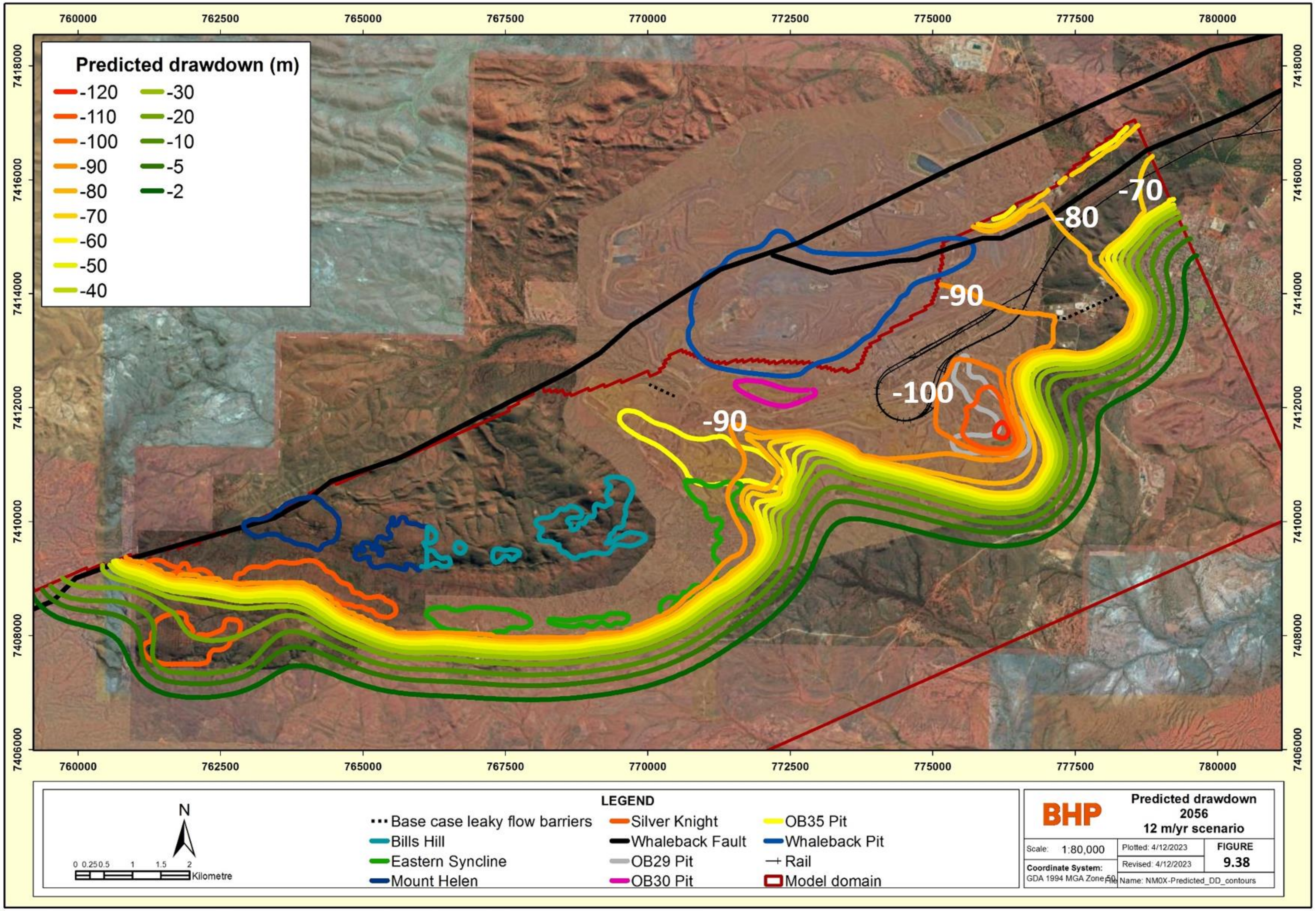

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Figure 9.38: Predicted drawdown – 12 m/yr - 2056

9.3.5. Extended dewatering case

The base case and history match uncertainty models were run with dewatering extended to the end of 2065 (an additional 9 years) and deeper target water levels (Figure 9.39). This was done to investigate mine plan variability on model results. The maximum dewatering depths were:

- OB29 - increased from 412 mAHD to 376 mAHD.
- OB30 - increased from 432 mAHD to 418 mAHD.
- OB35 - increased from 436 mAHD to 424 mAHD.

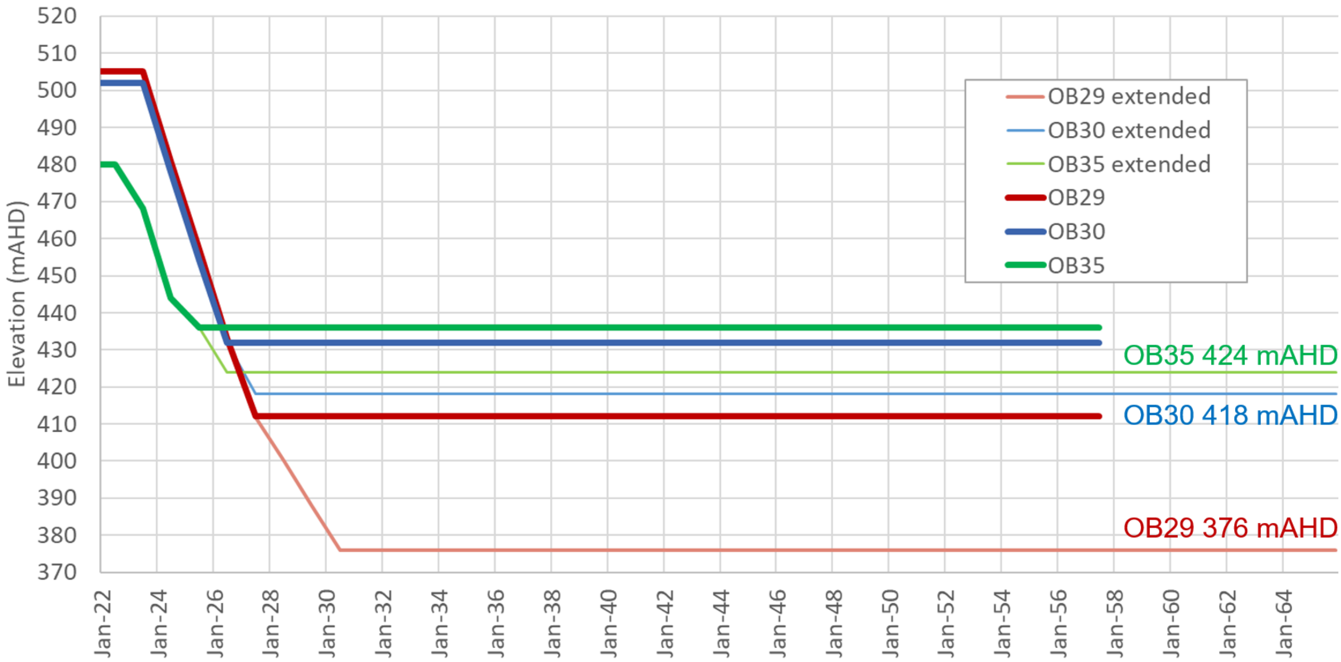

Figure 9.39: Extended target water levels

The predicted dewatering rates from both models are shown in Figure 9.40 and the drawdown in 2065 in Figures 9.41 and 9.42.

In both cases, the maximum dewatering rate increases; up to 66 ML/d in the base case and 67 ML/d in the history match uncertainty.

The additional years of dewatering, combined with extra dewatering, results in significantly more drawdown within the orebody and regional aquifers. In the regional aquifer towards the east (i.e. in the direction of the Ethel Gorge TEC) both models predict approximately 20 m more drawdown with the extended dewatering targets than the original. The base case model results in the most drawdown in this area (i.e. at the eastern model boundary), approximately 90 to 100 m compared to the 70 to 80 m in the original model.

These two models show therefore that the extension of the dewatering targets in this way results in only a small increase in maximum dewatering rate, but a significant increase in the regional drawdown by the end of dewatering.

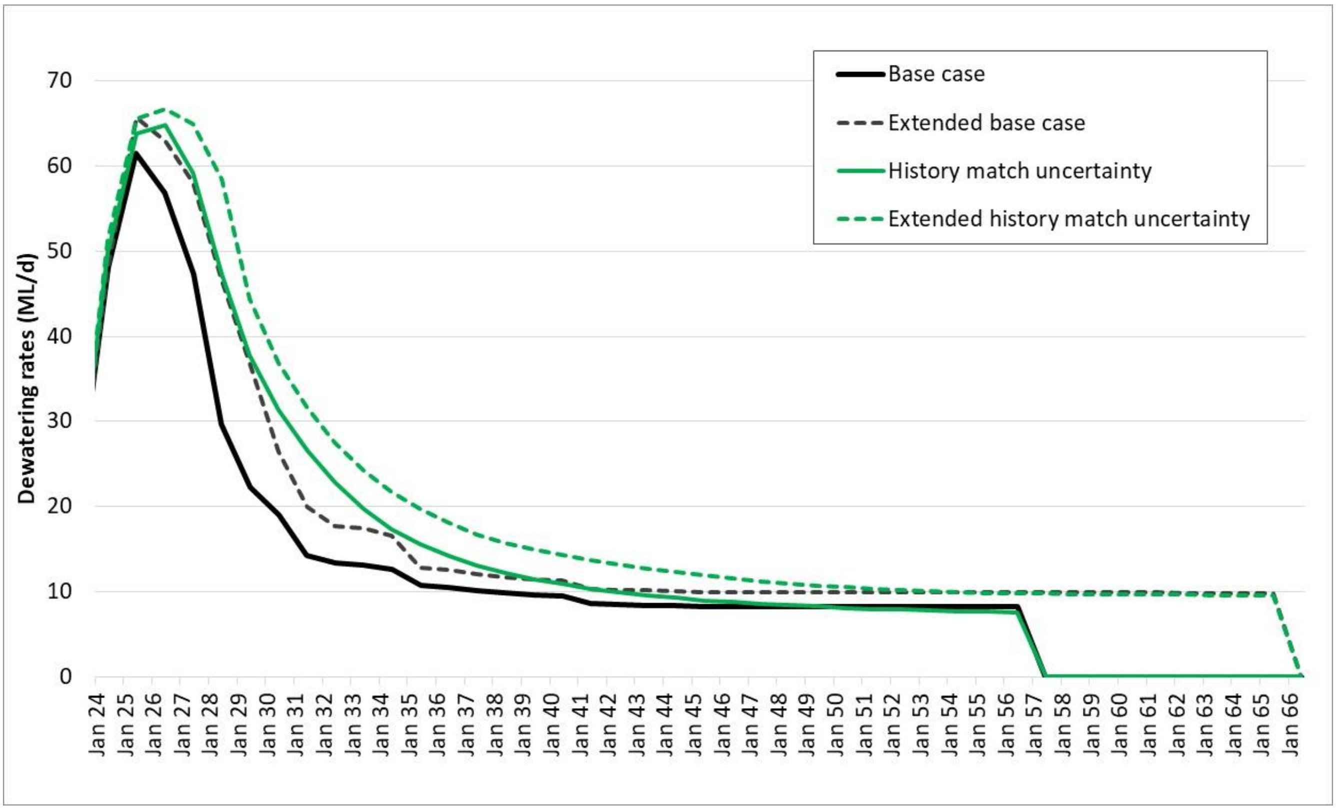

Figure 9.40: Predicted dewatering from extended models

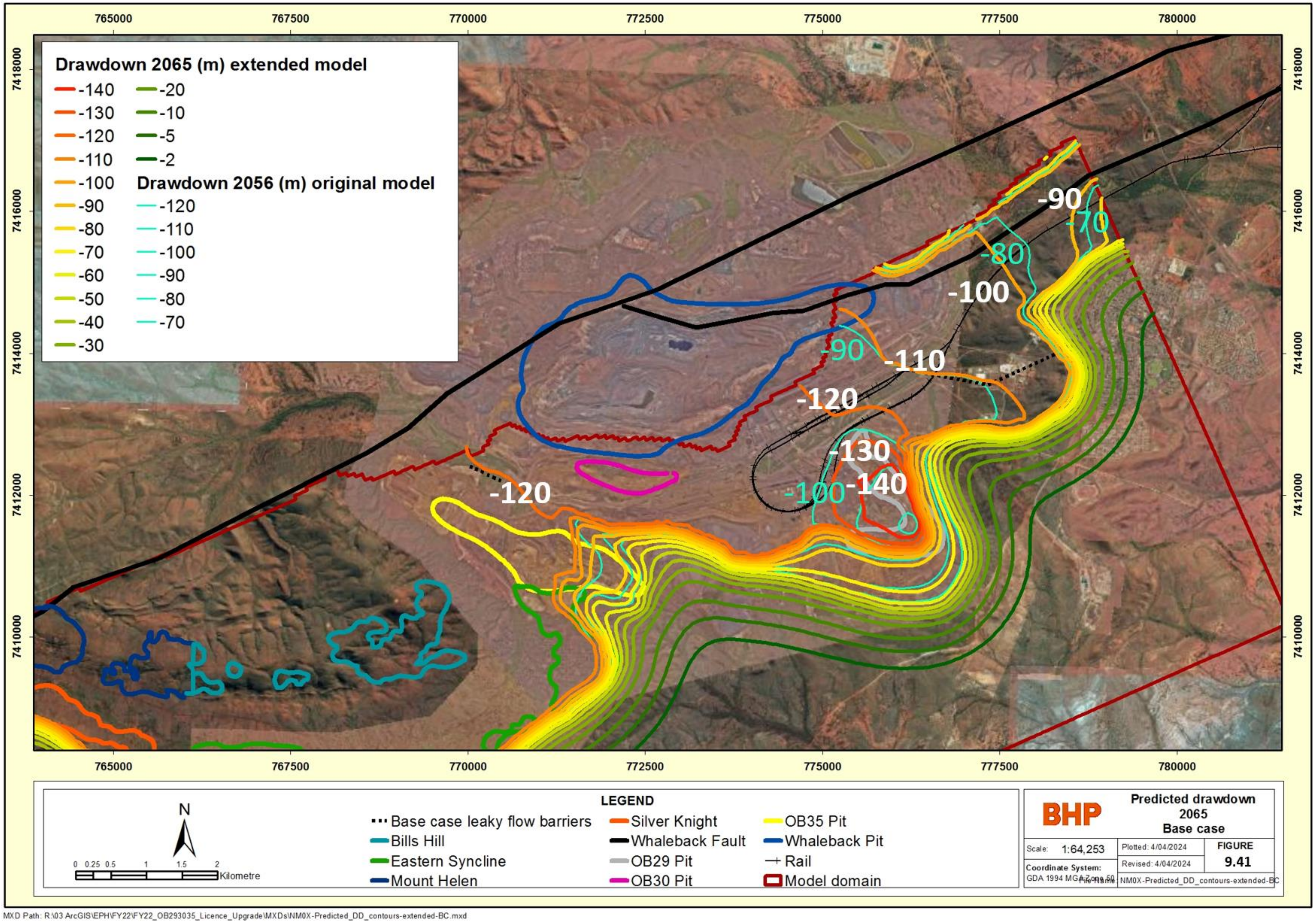

Figure 9.41: Predicted drawdown - base case extended - 2065

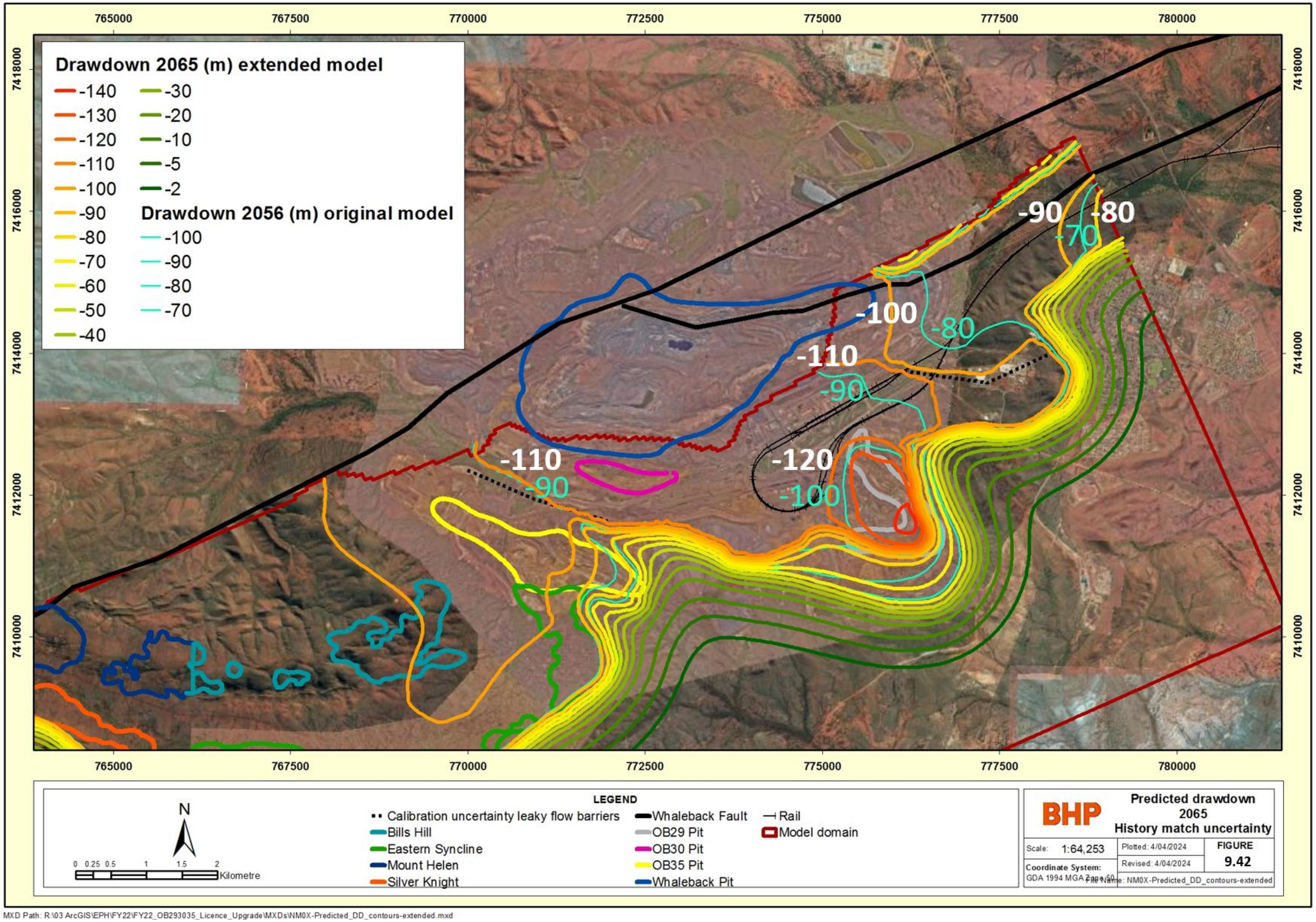

Figure 9.42: Predicted drawdown - history match uncertainty extended - 2065

9.3.6. Predicted drawdown to the east (towards the Ethel Gorge TEC)

The numerical model domain does not extend to the Ethel Gorge TEC. The regional aquifer is however continuous between the edge of the eastern model boundary to the TEC. The potential for dewatering to impact the TEC is therefore extrapolated from both the predicted impact of dewatering at the model boundary, and the data from monitoring and drilling the area between the boundary and the TEC.

The boundary condition assumes that approximately 7 ML/d will flow into the model from the east (Figure 9.30) by the end of the dewatering period. This increases to 8.5 ML/d in the extended dewatering target scenario. This is instead of what would have been a small flow (a few ML/d) in the other direction prior to dewatering. There is, however, significant uncertainty associated with this prediction.

The predicted flow across this boundary is controlled by the drawdown at the eastern boundary of the model (approximately 90 m by 2065) and the conductance term set at the boundary condition (1 m^2/d). The conductance term loosely represents the hydraulic quality of the aquifer directly to the east of the model domain, which, based on groundwater monitoring data in that area is expected to present a significantly lower transmissivity than the OB29/30 regional aquifer. The conductance term does not consider the fact that the transmissivity of the material just to the east of the boundary will continue to reduce as the drawdown increases and that that will therefore reduce the capacity of the material to transmit increasing amounts of water. Given this, it is likely that the 8.5 ML/d flow into the model predicted at the end of dewatering is an upper case.

By the end of dewatering then, it is possible that a significant amount of water will be flowing into the OB29/30/35 aquifer system from the east (i.e. from the direction of the Ethel Gorge TEC). The resulting migration of drawdown towards the Ethel Gorge TEC will be controlled by three main factors (discussed in detail in Section 3.3.3.4):

- The transmissivity of the aquifer between OB29 and the Ethel Gorge TEC, which monitoring strongly suggests is moderate to low.
- The presence of at least one partial flow barrier along the flow path (located to the south of OB25).
- The buffering effect of the Ophthalmia Dam MAR system, which will continue to capture surface water flows from the creeks that flow into it and the surplus water discharge from other BHP mines in the area.

The results of the modelling, combined with the three elements described above, suggest therefore that the drawdown from dewatering OB29/30/35 will not extend further than the partial flow barrier located south of OB25 and will not reach the Ethel Gorge TEC. An estimate of the final lateral extent of drawdown, based on all of the above, is shown in Figure 9.43.

This predicted extent of drawdown (for OB29/30/35) is the same as the predicted drawdown extent for the Western Ridge hydrogeological assessment (BHP, 2022). This is because the drawdown at the eastern model boundary is roughly the same with, or without, Western Ridge dewatering as OB29 dewatering has the greatest control on the outcomes in that location.

9.4. Closure predictions

A post-mining closure model was run for a period of 600 years. The base case model was used for this purpose and the additional time simulated with half yearly stress periods. The base case was used as the uncertainties associated with closure predictions are significant, different to the uncertainties governing dewatering, and this model is sufficient to understand the rough time frames and magnitudes of change.

Recharge inputs were calculated based on CSIRO projections (CSIRO, 2015). These projections were available until 2059. From this point on, 10 year seasonal averages were used.

Two closure scenarios were simulated:

- Backfill – This scenario assumes all pit voids are backfilled with similar material that was mined out. That is, aquifer parameters were not changed from the base case model. For this scenario, the Evapotranspiration (ET) surface was applied to the final infilled pit surface.
- Partial Backfill – This scenario assumes that the OB29 and OB30 pit voids are not backfilled (but the OB35 void is). The ET surface was applied at the base of the mined-out areas. The base of the OB29 pit is assumed to be 376 mAHD and the OB30 pit is assumed to be 418 mAHD.

For both scenarios the Evapotranspiration (ET) Package was used to simulate evaporation from pit void lakes that formed above the level of the pit voids. To investigate the uncertainty associated with the evaporation rate from the pit voids, two maximum ET rates were used; 2000 mm/yr and 2500 mm/yr. An extinction depth of 0.3 m was used in both cases.

The final equilibrium groundwater level for the backfilled case is expected to be 522 mAHD (i.e. the same as the pre-development). This is predicted to occur roughly in the year 2275, 219 years after dewatering ceases.

The pit voids in the Partial Backfill case are predicted to form pit lakes (Figures 9.44 and 9.45). With the two ET cases, the base case model predicts that water levels in the pit lakes will reach an equilibrium at between approximately:

- 476 and 480 mAHD in OB29, and
- 480 and 483 mAHD in OB30

The system is predicted to reach this equilibrium by approximately the year 2200 (144 years after dewatering ceases). Therefore, the equilibrium pit lake and groundwater levels will remain lower than the 522 mAHD pre-development groundwater level.

As well as the evaporation rate for the void case, both scenarios will be very sensitive to the recharge rate, the final landform geometry and the ability for groundwater to flow back into the aquifer compartment from the east (represented by a boundary condition in the model). These settings are not known with any degree of confidence. These predictions are therefore highly uncertain.

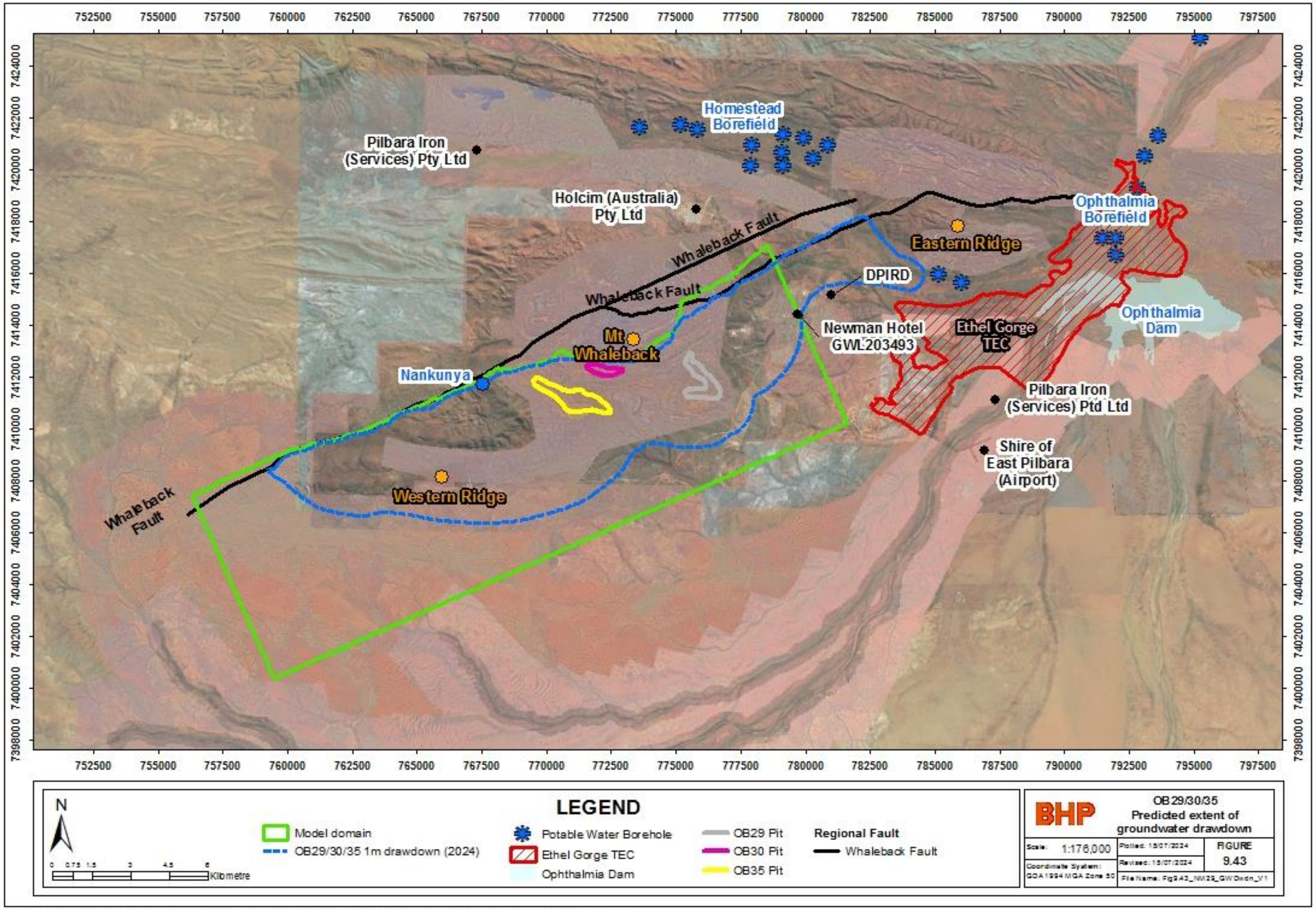

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Figure 9.43: Predicted lateral extent of groundwater drawdown (1 m extent) and key receptors

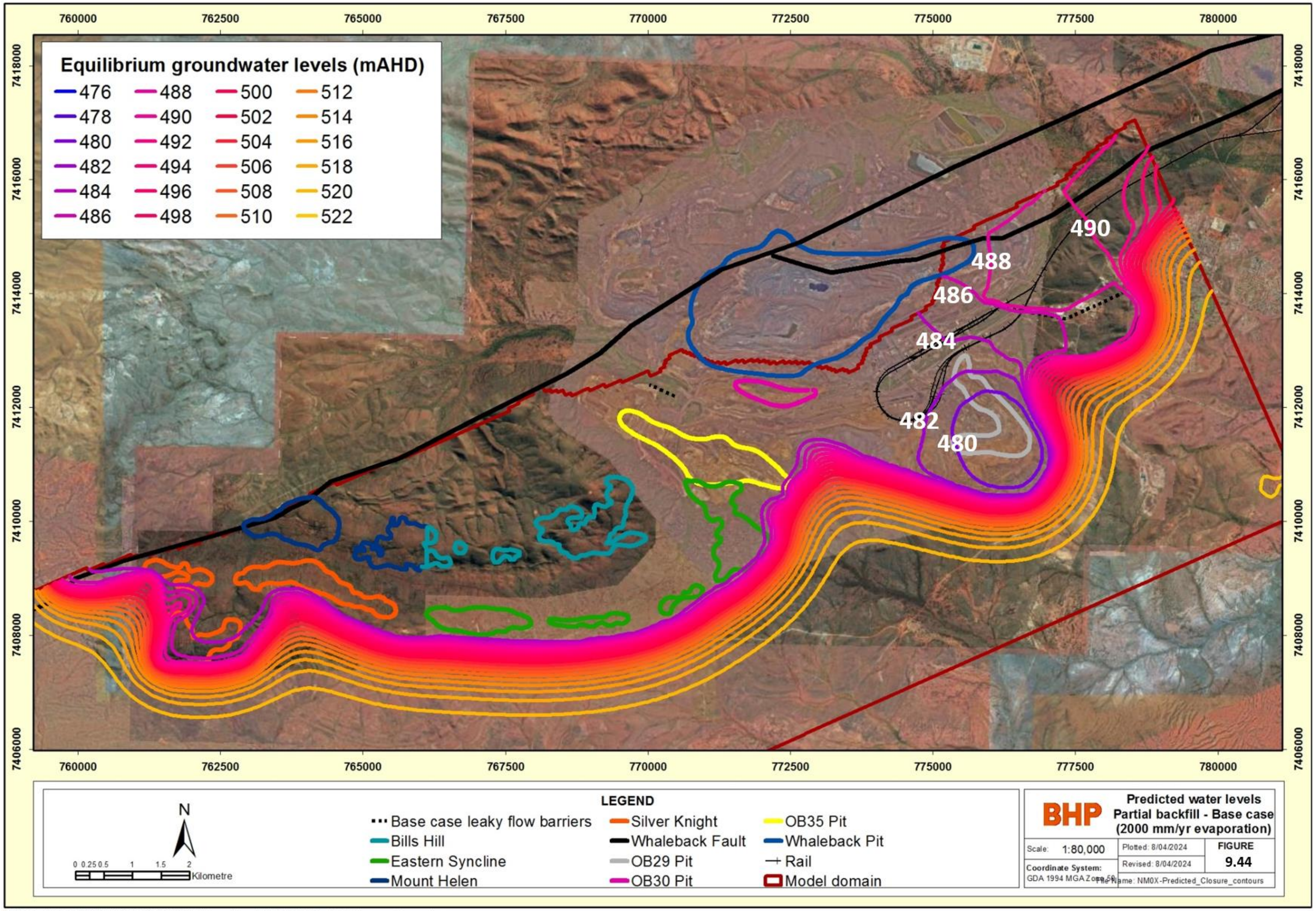

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Figure 9.44: Predicted water levels – Partial backfill (OB29/30 voids) – 2000 mm/yr evaporation

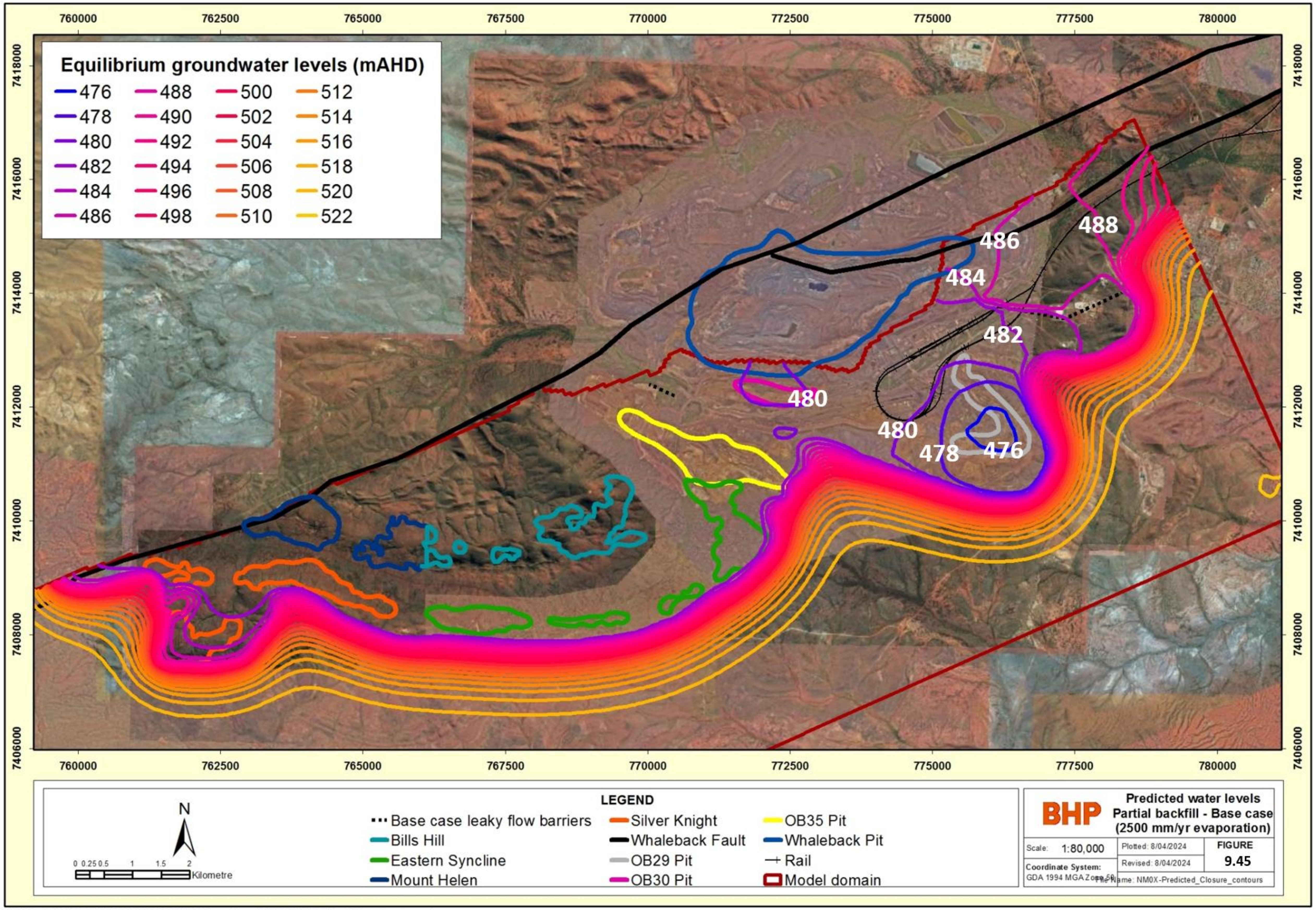

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Figure 9.45: Predicted water levels – Partial backfill (OB29/30 voids) – 2500 mm/yr evaporation

10. Assessment of Potential Impacts

10.1. Introduction

The groundwater model described in Section 9, has been used to estimate the peak dewatering volumes required to enable the mine plan and the lateral extent of associated drawdown. The results are described in Section 9.3.

As identified in Section 4, the key receptors that have the potential be impacted by groundwater abstraction from OB29/30/35 are:

1. Ecological receptors - Ethel Gorge TEC;
2. Homestead and Ophthalmia potable water supply borefields, operated by BHP; and
3. Third party groundwater users.

The predicted drawdown extent (Section 9.3) is used to determine the potential impacts to the identified receptors from planned dewatering activities.

10.2. Ecological assets

10.2.1. Ethel Gorge TEC

The groundwater drawdown from dewatering associated with OB29/30/35 peak abstraction of 67 ML/d (or 24,500,000 kL/a (rounded to nearest whole kL) is not expected to reach Ophthalmia Dam or the Ethel Gorge Aquifer Stygobiont TEC (Figure 9.43), located approximately 15 km north-east of the OB29/30/35 aquifer system. The flow from the orebody aquifers to the regional aquifers to the east is constrained by the leaky flow barrier north-east of OB29, the lower transmissivity section of the regional aquifer between OB29 and the Ethel Gorge TEC, the leaky flow barrier south of OB25 and the buffering effects of the Ophthalmia Dam MAR (Section 3.3.3.4 and 9.3.5).

The presence of a number of constraining elements to groundwater flow is supported by long-term groundwater monitoring data between OB29/30/35 and within and around the Ethel Gorge TEC aquifer (Figures 3.31 and 3.32). Any drawdown impact to the regional aquifer north-east of OB29 is anticipated to be mitigated by the current Eastern Pilbara mines surplus schemes and/or Ophthalmia dam.

10.3. Other BHP operations

There are two potable water supply borefields for the Newman town water supply, located north (Homestead potable borefield) and east (Ophthalmia potable borefield) of the model domain (Figure 4.1). Both are owned and managed by BHP.

The Homestead potable borefield is north/north-east of the Whaleback fault, which behaves as a significant flow barrier reducing any impact from dewatering drawdown. The conceptual model also suggests a limited connectivity between OB29/30/35 and the Ophthalmia water supply borefield.

Any detrimental impact to the Ophthalmia borefield is anticipated to be mitigated by the current Eastern Pilbara mines surplus schemes or Ophthalmia Dam itself (section 9.3).

10.4. Third party groundwater users

Five third party groundwater users have been identified within 10 km of the OB29/30/35 operations. Figure 9.43 shows third party groundwater users in the area.

Newman Hotel is located within the boundary of the groundwater model domain. Conceptually, this area is located east of the OB29 leaky flow barrier and any drawdown predicted to occur is expected to be minimal.

The Department of Primary Industries and Regional Development site, within the Newman township, is located outside the model domain and further east of the leaky flow barrier. Drawdown impacts at this location are also likely to be minimal.

There are two nearby groundwater users, Holcim (Australia) Pty Ltd (concrete batching) and Pilbara Iron Services located to the north of the Whaleback fault line, which is acts as a significant flow barrier. Drawdown impacts at this location are therefore unlikely.

The Shire of East Pilbara (Airport) and another site managed by Pilbara Iron Services are located 10-15km south east of OB29 and east of Fortescue River. They are therefore not expected to be impacted by dewatering of OB29/30/35.

BHP will ensure that if any significant impact on the available groundwater resource is observed at these locations, they will engage with the relevant affected users.

11. Groundwater monitoring

Monitoring of abstraction and the associated drawdown from OB29/30/35 will be carried out in accordance with the details outlined in the Groundwater Licence Operating Strategy (GWOS) for the Whaleback Hub, OB29/30/35 and Western Ridge. The current version (3.0, 2018) was approved by DWER in June 2018, with an Addendum 1 approved in December 2023 to include Western Ridge water supply bores and key Nankunya monitoring bores.

An updated GWOS will be submitted following this application. Design of the monitoring program will follow a source, pathway and receptor approach. It will focus around area of uncertainties identified by analysis of groundwater monitoring and the model, such as the area east of OB29 in the vicinity of the leaky flow barrier.

The GWOS will sit under the foundation of BHP's broader strategic water management plans, discussed further in the following section – Management Approach.

12. Management approach

The Annual Aquifer Review (AAR) and GWOS will be the primary tools for monitoring and understanding changes to local and regional groundwater levels and water quality in the Newman Hub.

In addition to local operating strategies, BHP has formulated and operates under a regional water management strategy that delivers sustainable, feasible and cost-effective measures to address our existing and future challenges.

The objective is to enable sustainable water resource management for below water table mining operations and operations which intercept surface water and groundwater flows by setting outcome-based conditions and adaptive management techniques to mitigate and offset our operational effects on water levels and quality through:

1. Preferentially returning surplus dewater to the aquifer; and
2. Maintaining baseline hydrological conditions at the key environmental receptors.

13. Conclusions

An H3 level detailed hydrogeological assessment was conducted to support the assessment of impacts associated with increasing the dewatering abstraction volumes from 8 GL/a to 24.5 GL/a (which equates to a peak abstraction of 67 ML/day) at OB29/30/35.

The assessment consists of a description of the conceptual hydrogeological model, which formed the basis for the development of a numerical groundwater model. The groundwater model was used to estimate the potential range in dewatering requirements and associated regional drawdown extent.

The study concluded the following:

- Analysis of post-2015 and long-term monitoring data provide evidence for the following:
    - The Western Ridge & OB29/30/35 orebody aquifers are well connected to the regional aquifer (Wittenoom Formation and Tertiary detritals).
    - There is either no connection between the Whaleback and the Western Ridge-OB29/30/35 aquifer systems, or, if there is, it is very limited.
    - A leaky flow barrier east of OB29, which constrains the flow from the Western Ridge-OB29/30/35 orebody aquifers to the Ethel Gorge aquifer system.
    - A flow barrier along the Whaleback Fault in the west of OB35 and Western Ridge deposits.
    - The presence of a leaky flow barrier between OB30 and OB35.
    - A lower transmissivity part of the regional aquifer between OB29 and the Ethel Gorge TEC.

  - A leaky flow barrier through the regional aquifer south of OB25.
- The main uncertainties in the study area are the:
  - Hydrostratigraphy around OB30 and potential for structural hydraulic connection to OB29.
  - Behaviour of the leaky flow barrier east of OB29 and between OB30 and OB35 as dewatering continues in the Newman hub and water levels fall.
  - Lower transmissivity aquifer to the east of OB29. Historic data suggest a limited and shallow connection through the Whaleback Creek valley however connection at depth may be possible. Adequate monitoring will be undertaken in this area and added to the proposed GWOS update.
  - Karstic dolomite, which is assumed to extend to depth, but this is unknown. This will influence the overall dewatering rate and drawdown migration.
  - Limited data available on the connectivity and hydraulic parameters of the Western Ridge orebody aquifers.
- Drawdown resulting from dewatering is likely to be contained within the aquifers by the low permeability Mt McRae and Mt Sylvia formations to the north, and by the low permeability Jeerinah Formation to the south. Drawdown is likely to be constrained by the Whaleback Fault west of Western Ridge. Drawdown will extend past the leaky flow barrier east of OB29. This drawdown is unlikely to go beyond the leaky flow barrier that cuts through the regional aquifer south of OB25.
- Impacts to groundwater are not expected at any other BHP operated assets in the area or groundwater dependent ecological assets (Ethel Gorge TEC). Minimal impact is predicted to occur at two known third party groundwater users in the area (Seasons Hotel, Department of Primary Industries and Regional Development and Newman Gun Club).

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15. Definitions

Abbreviation/Acronym	Full Title
5c	5c licence to take water
AAR	Annual Aquifer Review
BoM	Bureau of Meteorology
DBCA	Department of Biodiversity, Conservation and Attractions
DoW	Department of Water
DWER	Department of Water and Environmental Regulation
EPWRMP	Eastern Pilbara Water Resource Management Plan
GHB	General Head Boundary
GL	Gigalitres
GL/a	Gigalitres per annum
GWL	Groundwater Licence
GWOS	Groundwater Operating Strategy
H3	H3 Detailed Hydrogeological Assessment
HDT	Hydrodynamic trial
kL	Kilolitres
kL/a	Kilolitres per annum
km	Kilometres
mAHD	Meters elevation relative to the Australian Height Datum
MAR	Managed Aquifer Recharge
m/d	Meters per day
ML/d	Megalitres per day
mm	Millimetres
Mt	Mount
OB23	Orebody 23
OB24	Orebody 24
OB25	Orebody 25
OB29	Orebody 29
OB30	Orebody 30
OB35	Orebody 35
OB29/30/35	Orebody 29/30/35 below water table mine, approved under Part IV (Ministerial Statement 963)
Part IV	Part IV of *Environmental Protection Act 1986*
PEST	PEST refers to a software package and to a suite of utility programs for model independent parameter estimation and uncertainty analysis.
RiWI	*Rights in Water and Irrigation Act 1914*
TDS	Total Dissolved Solids
TEC	Threatened Ecological Community

Appendix A – Bore Logs