MOOLARBENCOAL

Moolarben Coal Complex
Open Cut Optimisation Modification

Environmental Assessment

APPENDIX I

Groundwater Assessment

YANCOAL
兖煤澳大利亚有限公司

Moolarben Coal

Open Cut Optimisation Modification Groundwater Assessment

FOR

Moolarben Coal Operations Pty Ltd

BY

NPM Technical Pty Ltd
trading as
HydroSimulations

Project number: YAN012
Report: HS2017/30

Date: October 2017

DOCUMENT REGISTER

Revision	Description	Date	Comments
A	Draft1	6-Oct-2017	
B	Draft2	17-Oct-2017	
C	Final	24-Oct-2017	

Role	Persons
Authors	Becky Rollins; Dr Noel Merrick

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ATTACHMENTS

1 INTRODUCTION

This Groundwater Assessment has been prepared to support an Environment Assessment for the Moolarben Coal Complex (MCC) Open Cut Optimisation Modification (the Modification).

1.1 APPROVED MINING OPERATIONS

The MCC is an existing open cut and underground mining operation located approximately 40 kilometres (km) north of Mudgee and 25 km east of Gulgong, New South Wales (NSW), in the Western Coalfield (**Figure 1**).

Mining operations at the MCC are approved until 31 December 2038 in accordance with the Stage 1 Project Approval (05_0117) and Stage 2 Project Approval (08_0135).

Stage 1 of the Moolarben Coal Project was approved in September 2007, and consists of three open cut mines (OC1, OC2, OC3) and one underground mine (UG4). Stage 2 of the MCC was approved in January 2015, and consists of one open cut mine (OC4) and two underground mines (UG1, UG2).

Approved components of the MCC are shown on **Figure 2**.

1.2 THE MODIFICATION

Relevant to potential groundwater impacts, the Modification involves the following changes to the approved open cut mining operations:

- Increases in the annual rate of run-of-mine (ROM) coal extraction and mine sequencing to achieve:
    - up to 10 million tonnes per annum (Mtpa) of ROM coal from Stage 1 open cuts (OC1, OC2 and OC3) (currently approved limit of 8 Mtpa);
    - up to 16 Mtpa of ROM coal from the Stage 2 open cut (OC4) (currently approved limit of 12 Mtpa); and
    - combined total (Stage 1 and Stage 2) of up to 16 Mtpa of ROM coal (currently approved limit of 13 Mtpa).
- Minor changes to the OC2 and OC3 pit limits to reflect the latest resource definition drilling results (**Figure 2**).

The Modification **does not** involve any changes to the approved MCC underground mining operations.

1.3 NEIGHBOURING MINING OPERATIONS

Historically there has been, and continues to be, coal mining in the area surrounding the MCC. Coal is currently extracted by underground (longwall) and/or open cut mining methods at two coal mines adjacent to the MCC (**Figure 2**):

- Ulan Coal Mine to the north-west of the MCC. Mining of coal at Ulan has been conducted since the early 1920s. Modern open cut and underground mining operations commenced in 1982 and 1986 respectively. Open cut mining ceased in 2014, and underground mining is ongoing.

- Wilpinjong Coal Mine to the south-west of the MCC. The Wilpinjong open cut coal mine has been operating since 2006.

1.4 GROUNDWATER MANAGEMENT

The MCC is located within or near the Water Sharing Plans (WSPs) listed in **Table 1** and shown in **Figure 3** as defined by Department of Primary Industries – Water (DPI Water).

Surface water and alluvial groundwater resources are managed under the 'Hunter Unregulated and Alluvial' WSP, which commenced in 2009. The MCC is located within the Wollar Creek and Upper Goulburn River water sources within the Goulburn Extraction Management Unit of this WSP.

Non-alluvial groundwater sources are managed under the 'North Coast Fractured and Porous Rock Groundwater Sources' WSP which commenced in 2016.

Table 1 Water Sharing Plans in Proximity to Moolarben Coal

Water Sharing Plan	Comments
North Coast Fractured and Porous Rock Groundwater Sources (commenced 2016)	The MCC is located within the extent of this WSP. MCC non-alluvial water sources are managed under this WSP.
Hunter Unregulated and Alluvial Water Sources (commenced 2009)	The MCC is located within the extent of this WSP. MCC surface water and alluvial groundwater sources are managed under the Wollar Creek and Upper Goulburn River water sources within the Goulburn Extraction Management Unit.
NSW Murray Darling Basin Porous Rock Groundwater Sources (commenced 2012)	The MCC is **not** located within the extent of this WSP. Located to the north-west of the MCC.
NSW Murray Darling Fractured Rock Groundwater Sources (commenced 2012)	The MCC is **not** located within the extent of this WSP. Located to the west of the MCC.
Macquarie-Bogan Unregulated and Alluvial Water Sources (commenced 2012)	The MCC is **not** located within the extent of this WSP. Located to the north-west of the MCC.

1.5 APPROACH TO GROUNDWATER ASSESSMENT

This report has assessed the potential impacts of the Modification to groundwater resources using the following approach:

1. Update and re-calibration of the groundwater model for the MCC:
    - Modelling software updated to MODFLOW-USG Beta (Panday *et al*., 2013).
    - Re-calibration of the model to account for groundwater monitoring data to March 2017.
    - Incorporation of proposed open cut mine plan for the Modification (for predictive modelling runs).
    - Incorporation of latest approved mine plans for other operations (e.g. Wilpinjong Extension Project).
2. Modelling of 'Approved' and 'Modification' scenarios to identify potential impacts of the Modification:
    - Approved scenario – approved MCC and other approved mining operations.
    - Modification scenario – modified MCC open cut mining operations, with all other operations as per the approved scenario.
3. Assessment of potential impacts to groundwater resources associated with the changes in open cut mining operations for the Modification.

The remainder of this report is structured as follows:

Section 2 Hydrogeological Setting

Section 3 Groundwater Modelling

Section 4 Scenario Analysis

Section 5 Potential Effects

Section 6 Conclusions

2 HYDROGEOLOGICAL SETTING

2.1 CLIMATE

Moolarben Coal Operations operates a weather station at the MCC with rainfall data available from 2007. Average monthly rainfall at the MCC is shown in **Table 2**. The highest average rainfall occurs during the summer months, with lower rainfall during the winter months.

Table 2 Average Monthly Rainfall (mm) at Moolarben Climate Station

Rainfall (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Moolarben	83.8	86.0	58.1	35.8	41.4	71.4	46.6	40.1	57.6	50.5	95.1	127.2

Note: mm = millimetres

Cumulative Rainfall Departure (CRD) from the monthly mean at the Moolarben Weather Station is shown in **Figure 4**. An increasing trend on the CRD plot shows above average long-term rainfall conditions, and a decreasing trend on the CRD plot shows below average rainfall conditions. Above average rainfall conditions were observed from 2007 to the end of 2008, late 2009 to the end of 2010, and from April to October 2016. Below average rainfall conditions were observed from the end of 2008 to late 2009, 2011 to early 2016, and from October to December 2016.

The actual evapotranspiration (ET) in the district is approximately 650 millimetres per annum (mm/a) according to the Bureau of Meteorology (BoM) (2017a)[1]. The definition for actual ET is: "... the ET that actually takes place, under the condition of existing water supply, from an area so large that the effects of any upwind boundary transitions are negligible and local variations are integrated to an areal average. For example, this represents the ET which would occur over a large area of land under existing (mean) rainfall conditions."

2.2 TOPOGRAPHY AND DRAINAGE

An overview map of the regional topography is shown in **Figure 5**. Elevations in the vicinity of the MCC range from approximately 400 metres Australian Height Datum (mAHD) at the Goulburn River to 750 mAHD to the south of Moolarben. Ridges of higher topography are capped by Triassic sandstone, and the broader river valleys of the Goulburn River are eroded into the Permian Coal Measures.

The MCC OC1 is situated adjacent to the Goulburn River diversion (**Figure 2**). Moolarben Creek runs adjacent to OC2 and OC3. Wilpinjong Creek is situated to the north-east and east of OC4. Bora Creek and Saddlers Creek are ephemeral and are situated to the west and north-east of the MCC infrastructure handling area respectively.

[1] Site-specific values for evapotranspiration were not used in this assessment due to the scale of the area modelled. This regional actual evapotranspiration value is suitable for the purposes of this assessment by setting a maximum rate in the numerical model.

2.3 GEOLOGY

The MCC is located in the Western Coalfield on the north-western edge of the Sydney-Gunnedah Basin, which primarily contains sedimentary rocks of Triassic and Permian age, including coal measures.

The dominant outcropping lithologies over the MCC are the Triassic Narrabeen Group (Wollar Sandstone) and the Permian Illawarra Coal Measures (**Figure 6**). The siltstones and sandstones of the Triassic Narrabeen Group form elevated, mesa-like and incised plateaus associated with the Goulburn River National Park and the Munghorn Gap Nature Reserve. The Illawarra Coal Measures include the Ulan Seam, which is the target coal seam at the MCC.

2.3.1 QUATERNARY ALLUVIUM

Quaternary alluvial deposits are associated with the Goulburn River, Lagoon Creek, Moolarben Creek and Wilpinjong Creek (**Figure 6**). DPI Water has identified a portion of the alluvial aquifer associated with Wilpinjong Creek (approximately 9 km downstream of the MCC) and downstream of the Wilpinjong Coal Mine as "highly productive". There is no highly-productive alluvium adjacent to the MCC.

2.3.2 PALAEOCHANNEL

Tertiary palaeochannel deposits have been recognised in the Goulburn River (at Ulan) and along portions of Murragamba and Wilpinjong Creeks, with a maximum thickness of 40-50 metres (m). The infill sediments consist of poorly-sorted semi-consolidated quartzose sands and gravels in a clayey matrix.

It is noted that these palaeochannel deposits do not align with current surface drainage. That is, the palaeochannel dips to the south-east, whereas surface drainage flows in the opposite direction (i.e. to the west and north) in the vicinity of Bora Creek and the Goulburn River Diversion.

Isolated Tertiary palaeochannel deposits have also been recognised on the western side of Moolarben Creek (i.e. along the eastern edge of OC3).

2.3.3 LIVERPOOL RANGE VOLCANICS

Small areas of Liverpool Range Volcanics of Tertiary age outcrop within the MCC (UG1 and UG2 areas) and to the north of UG4, including within the Ulan Coal Mine underground mining area. The Liverpool Range Volcanics typically include basalt, dolerite, sandstone and siltstone.

2.3.4 JURASSIC GROUP

The Jurassic Purlawaugh Formation and Jurassic Pilliga Sandstone overlie the Triassic Narabeen Group and outcrop in the north of the study area, including over the northern end of the Ulan underground mine. The Jurassic group increases in thickness to over 200 m to the north of the MCC.

2.3.5 TRIASSIC NARRABEEN GROUP

The Triassic Narrabeen Group forms ridges and high plateaus where it is at outcrop within the study area. Typical lithologies include pebbly to medium-grained quartz sandstone, red-brown and green mudstone and lenses of quartz conglomerate. The Triassic Narrabeen group increases in thickness to the north of the study area, where the thickest deposits are approximately 150 m.

2.3.6 PERMIAN COAL MEASURES

The Permian Illawarra Coal Measures comprise a well-bedded sequence of claystone, mudstone, siltstone, sandstone and coal. The Ulan coal seam lies within the Illawarra Coal Measures and is the primary economic coal resource in the area, being mined at Moolarben, Ulan and Wilpinjong. The Ulan coal seam is approximately 10 to 13 m thick and contains several plies.

The Illawarra coal measures dip to the north north-east, and are at outcrop at the MCC and Wilpinjong mines where open cut mining occurs. The Illawarra coal measures underlie the Triassic Narrabeen Group at the MCC and Ulan underground mining areas.

The Ulan seam is underlain by the Marrangaroo Formation, which is a conglomerate or sandstone in this area. Beneath the Marangaroo Formation lies the Shoalhaven Group which comprises fine-grained silty marine sandstone.

2.3.7 CARBONIFEROUS

The basement underlying the Shoalhaven Group consists of Carboniferous monazite and granite. These plutonic intrusions outcrop extensively to the west of the MCC (**Figure 6**).

2.4 GROUNDWATER USAGE

There is limited private groundwater use in the MCC area.

A bore census was conducted that investigated groundwater use on private property holdings within and close to the MCC. This census identified bores, wells and farm dams in the vicinity of the MCC (RPS Aquaterra, 2011). The DPI Water groundwater bore database identifies approximately 130 registered bores, wells and DPI Water monitoring bores within approximately 10 km of the MCC area, the majority of which are coal exploration bores (Moolarben Coal, 2016).

There were two bores identified during the census survey that are located on private property (**Table 3** and **Figure 7**). This does not include bores located on private properties to the west of the MCC that are developed in the outcropping basement rocks or associated regolith that underlie the Permian Coal Measures, and that are hydraulically disconnected from the hydrogeological regimes of the Permian sedimentary strata and associated alluvial sediments (Moolarben Coal, 2016).

Table 3 Privately Owned Bores in the Vicinity of Moolarben Coal Complex

Work ID	Licence No.	Bore Type	Hydro-geological Unit
GW800279	80BL236762	Domestic	Triassic Narrabeen Group
GW064580	20BL137225	Stock & Domestic	Triassic Narrabeen Group

2.5 GROUNDWATER MONITORING

Groundwater monitoring at the MCC is conducted in accordance with the approved Groundwater Management Plan (GWMP) (Moolarben Coal, 2016). The objectives of the GWMP are to establish baseline groundwater level and quality data and to implement a program of data collection that provides a basis for assessing potential impacts of mining activities on the groundwater resources of the area.

The details of the MCC monitoring bores used in this assessment (current and previous monitoring networks) are provided in **Table 4**. The locations of the monitoring bores are shown in **Figure 7.**

Table 4 Moolarben Coal Complex Monitoring Bores Used in this Assessment

Bore ID	Easting	Northing	Ground Level (mAHD)	Total Depth (mbgl)	Bore Type	Screened Geology
PZ3	762714	6417964	475	21	Standpipe	Ulan Seam
PZ4	762251	6416655	517	32	Standpipe	Ulan Seam
PZ18	760088	6422136	15	15	Standpipe	Ulan Seam and sediments below
PZ39	763832	6424259	428	90	Standpipe	Lower Permian
PZ40B	763928	6423743	428	16	Standpipe	Lower Permian
PZ43A	760458	6417102	510	30	Standpipe	Marrangaroo Conglomerate (below Ulan Seam)
PZ43B	760456	6417102	510	19	Standpipe	Shoalhaven Group
PZ44	759906	6417069	491	24	Standpipe	Ulan Granite
PZ50A	762532	6422848	449	70	Standpipe	Ulan Seam
PZ50B	762531	6422848	450	45	Standpipe	Lower Permian
PZ50C	762530	6422848	449	12	Standpipe	Alluvium
PZ55	758773	6423995	429	15	Standpipe	Quaternary / Tertiary alluvium
PZ58	761616	6418360	478	12	Standpipe	Tertiary palaeochannel
PZ72A	764661	6415236	510	36	Standpipe	Upper / Middle Permian
PZ50C	762530	6422848	449	12	Standpipe	Alluvium
PZ72C	764664	6415235	510	14	Standpipe	Quaternary / Tertiary alluvium
PZ74	762689	6415586	531	35	Standpipe	Upper / Middle Permian
PZ101B	762646	6431445	403	60	Standpipe	Lower Permian
PZ101C	762646	6431446	402	30	Standpipe	Lower Triassic
PZ102A	761118	6429150	408	128	Standpipe	Marrangaroo Formation
PZ102B	761117	6429147	408	86	Standpipe	Ulan Seam
PZ103A	762410	6429261	425	128	Standpipe	Ulan Seam
PZ103B	762397	6429264	425	87	Standpipe	Lower Permian
PZ103C	762397	6429264	424	30	Standpipe	Lower Triassic
PZ104	766832	6426451	439	160	Standpipe	Ulan Seam
PZ105A	763988	6431610	388	115	Standpipe	Lower Permian

Bore ID	Easting	Northing	Ground Level (mAHD)	Total Depth (mbgl)	Bore Type	Screened Geology
PZ105B	763987	6431607	389	64	Standpipe	Upper / Middle Permian
PZ105C	763986	6431606	388	28	Standpipe	Lower Triassic
PZ106A	765128	6418275	510	132	Standpipe	Lower Permian
PZ106B	765124	6418279	511	41	Standpipe	Upper / Middle Permian
PZ107	762813	6419869	499	125	Standpipe	Ulan Seam
PZ108	763134	6434793	419	227	Standpipe	Ulan Seam
PZ109	766123	6435558	437	254	Standpipe	Lower Permian
PZ111	767082	6423096	405	83	Standpipe	Ulan Seam
PZ112B	766139	6419517	485	12	Standpipe	Quaternary / Tertiary Alluvium
PZ127	762799	6424948	494	154	VWP @ 43,68,112,141m	Triassic/Upper Permian/Lower Permian/Ulan Seam
PZ128	763227	6432120	409	61	VWP @ 20,36,55m	Upper Triassic /Lower Triassic /Upper Permian
PZ129	763624	6432251	418	74	VWP @ 35,53,74m	Upper Triassic /Lower Triassic /Upper Permian
PZ130	760940	6422438	535	111	VWP @ 39,64,97m	Upper Permian/Lower Permian/Ulan Seam
PZ131	763668	6422406	454	27	Standpipe	Upper / Middle Permian
PZ133	763468	6422445	447	74	VWP @ 32,43,59m	Permian / Ulan Seam
PZ134	763468	6422445	447	26	Standpipe	Upper / Middle Permian
PZ137	763286	6422481	479	30	Standpipe	Upper / Middle Permian
PZ141	762783	6420385	467	9	Standpipe	Lower Permian
PZ149	763994	6420281	478	11	Standpipe	Upper / Middle Permian
PZ150	765785	6421570	452	89	Standpipe	Ulan Seam
PZ151	764825	6421712	444	72	Standpipe	Ulan Seam
PZ152	765789	6421563	452	13	Standpipe	Upper / Middle Permian
PZ155	763474	6422443	448	10	Standpipe	Upper / Middle Permian
PZ156	763289	6426194	456	136	Standpipe	Ulan Seam
PZ157	763825	6425391	446	122	Standpipe	Ulan Seam
PZ164	762990	6422548	441	27	Standpipe	Upper / Middle Permian
PZ165	762993	6422547	441	6	Standpipe	Regolith / Surficial
PZ168	763431	6424356	451	31	Standpipe	Upper / Middle Permian
PZ170	763591	6424306	437	31	Standpipe	Upper / Middle Permian
PZ172	763779	6424266	429	24	Standpipe	Upper / Middle Permian
PZ173	763782	6424266	429	9	Standpipe	Regolith / Surficial
PZ174	763927	6424235	425	32	Standpipe	Upper / Middle Permian
PZ175	763932	6424234	425	12	Standpipe	Regolith / Surficial
PZ176	764065	6424208	419	28	Standpipe	Upper / Middle Permian

Bore ID	Easting	Northing	Ground Level (mAHD)	Total Depth (mbgl)	Bore Type	Screened Geology
PZ177	764067	6424212	419	7	Standpipe	Regolith / Surficial
PZ179	764688	6426591	442	145	VWP @ 33,82,145m	Triassic / Permian / Ulan Seam
PZ181	763915	6423447	435	30	Standpipe	Quaternary / Tertiary alluvium (backfilled to 25m)
PZ184	765411	6423142	419	12	Standpipe	Quaternary / Tertiary alluvium /Palaeochannel
PZ186	764788	6425865	419	114	Standpipe	Permian
PZ187	764784	6425871	419	22	Standpipe	Alluvium
PZ188	764478	6426084	424	60	Standpipe	Alluvium
PZ189	764503	6426089	424	65	Standpipe	Permian
PZ191	761776	6426772	418	72	Standpipe	Ulan Seam
PZ192	763787	6429831	454	178	VWP @ 68,166,178m	Lower Triassic/Lower Permian/Ulan Seam
PZ193	763733	6429326	461	184	VWP @ 80,162,184m	Lower Triassic/Lower Permian/Ulan Seam
PZ194	763712	6428517	487	196	VWP @ 78,173,196m	Lower Triassic/Lower Permian/Ulan Seam
PZ195	763724	6427832	471	175	VWP @ 72,162,175m	Lower Triassic/Lower Permian/Ulan Seam
TB103	762415	6429261	425	100	Production	Lower Permian
TB105	763981	6431611	389	132	Production	Lower Permian / Ulan Seam
TB179	764703	6426598	444	150	Production	Lower Permian

Note: mgbl = metres below ground level, VWP = Vibrating Wire Piezometer.

2.6 BASELINE GROUNDWATER LEVEL DATA

2.6.1 SPATIAL GROUNDWATER LEVEL DATA

Natural groundwater levels are influenced by rainfall recharge, topography, geology and surface water elevations. Typically, groundwater tends to mound beneath hills and then discharge to alluvium associated with creeks and rivers at lower elevation. During short events of high surface flow, streams tend to lose surface water to the underlying groundwater system but, during recession, the groundwater system tends to discharge groundwater slowly back into the stream from alluvial storage. Regional groundwater flows from elevated to lower-lying terrain.

A spatial contour plot of groundwater levels in the Ulan Seam at January 2016 in the vicinity of the MCC open cuts is shown in **Figure 8**. The groundwater gradient in the Ulan Seam is from south-west to north-east.

2.6.2 TEMPORAL GROUNDWATER LEVEL DATA

All available groundwater level data within the MCC have been examined to check for cause-and-effect responses in temporal water level changes which could result from rainfall recharge or mining effects. The locations of all monitoring bores are shown in **Figure 7**.

Monitoring bores have been grouped spatially and by response type as shown in **Table 5**. Detailed groundwater hydrographs for all the MCC monitoring bores are shown in **Attachment A**.

Table 5 Groundwater Monitoring Bores Cause-and-Effect Responses

<table>
<tr><th>Location</th><th>Cause-and-Effect Response</th><th>Key Bores</th><th>Comments</th></tr>
<tr><td>Within OC4 area</td><td>Rainfall response</td><td>PZ165, PZ165, PZ133, PZ040B, PZ181, PZ151, PZ152, PZ184, PZ111, PZ149, PZ141, PZ107, PZ106B, OZ112B, PZ43A</td><td>Groundwater levels follow rainfall trends</td></tr>
<tr><td>Above / adjacent to UG1 and OC4</td><td>Rainfall response</td><td>PZ168, PZ170, PZ172, PZ173, PZ176, PZ177</td><td>Permian and regolith monitoring follows rainfall trends, no response to UG1 or OC4 mining</td></tr>
<tr><td rowspan="3">Above / east of UG1</td><td>Mining effect</td><td>PZ156, PZ157, PZ179, PZ127, PZ186, PZ189</td><td>Permian monitoring shows drawdown response to UG1</td></tr>
<tr><td>Rainfall response</td><td>PZ187, PZ188</td><td>Alluvial monitoring at nested sites (with Permian monitoring) does not show drawdown response to UG1</td></tr>
<tr><td>Rainfall response</td><td>PZ104</td><td>Permian monitoring does not show response to UG1, outside the limit of drawdown extent</td></tr>
<tr><td rowspan="2">Above UG4 / close to Ulan</td><td>Rainfall response</td><td>PZ102A, PZ102B, PZ101B, PZ129, PZ191</td><td>Permian monitoring follows rainfall trends</td></tr>
<tr><td>Rainfall response</td><td>PZ103, PZ105, PZ128, PZ192</td><td>Permian monitoring follows rainfall trends, limited rainfall response at Triassic monitoring</td></tr>
</table>

2.7 GROUNDWATER CHEMISTRY

A spatial plot showing the median (50^{th} percentile) of electrical conductivity (EC) data collected at the MCC monitoring bores is shown in **Figure 9**. The spatial plot shows that there is generally lower EC measured over the northern area of the MCC at UG1 and UG4, and generally higher EC measured over the southern area of the MCC at OC3 and OC4.

2.8 GROUNDWATER DEPENDENT ECOSYSTEMS

Figure 10 shows terrestrial and riparian ecosystems with potential for groundwater interaction as listed by the BoM GDE Atlas (2017b). High priority Groundwater Dependent Ecosystems (GDEs) listed in the WSPs are also shown.

The closest high priority GDE listed in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2006* is approximately 140 km away, and would not be affected by groundwater drawdown from the MCC. There are several springs listed in the *Water Sharing Plan for the North Coast Fractured and Porous Rock Groundwater Sources 2016,* as shown in **Figure 10**. These springs are included inside the numerical groundwater model boundary to ensure that any potential groundwater impacts could be quantitatively assessed. The BoM GDE Atlas identifies the Goulburn River as a GDE with low to moderate potential (**Figure 10**).

A spring known as The Drip is a local dripping sandstone feature located on the northern side of the Goulburn River to the north of UG4 (**Figure 10**) and is also classified as a GDE for this assessment. The groundwater discharges are derived from perched groundwater in zones that are exposed in the cliff face at a height of approximately 10 m above the river water level. The perched aquifers are in the Triassic Narrabeen Group sediments, and are formed by accumulations of groundwater above less permeable horizons in the Triassic sequence. The groundwater seepages are only observed on the northern side of the Goulburn River.

2.9 CONCEPTUAL MODEL

The hydrogeological regime of the MCC area comprises two main groundwater systems:

- Alluvial groundwater system.
- Porous rock groundwater system.

2.9.1 ALLUVIAL GROUNDWATER SYSTEM

Groundwater in the alluvial system is associated with the Goulburn River (i.e. upstream of the Goulburn River Diversion), Lagoon Creek, Moolarben Creek and Wilpinjong Creek (including the portion of the alluvial aquifer associated with Wilpinjong Creek 9 km downstream of the MCC and downstream of the Wilpinjong Coal Mine identified by DPI Water as "highly productive"). There are no registered users of the alluvium in the vicinity of the MCC (i.e. within the extent of measurable predicted impacts of the MCC).

Tertiary palaeochannel deposits have been recognised in the Goulburn River Diversion (at Ulan) and along portions of Murragamba and Wilpinjong Creeks, with a maximum thickness of 40-50 m. There is some spatial overlap of the Quaternary alluvium and Tertiary sediments near OC1 as shown in **Figure 11** and in the conceptual cross-sections in **Figure 12a** and **Figure 12b**. Much of the palaeochannel along the Goulburn River Diversion and Ulan Creek has been mined out.

Tertiary palaeochannel deposits are also present along the eastern edge of OC3.

2.9.2 POROUS ROCK GROUNDWATER SYSTEM

The porous rock groundwater system includes the sandstones, mudstones and conglomerates of the Triassic Narrabeen Group, and the Permian Coal Measures consisting of coal seams, conglomerate, mudstones and siltstones.

None of the identified porous rock groundwater systems is a significant aquifer.

The sandstones of the Narrabeen Group are of low permeability and are elevated above the the MCC. The Permian Coal Measures also include low permeability mudstones and siltstones. In places, the coal measures are more permeable, and some high-yielding bores are recorded. Large extents of Triassic strata are dry, either naturally or from depressurisation caused by mining at Ulan Coal Mine.

2.9.3 RECHARGE AND DISCHARGE MECHANISMS

Recharge occurs by infiltration of rainfall through the outcropping strata. Analysis of groundwater hydrographs indicates that there is limited vertical recharge and flow through the Triassic, and that there is strong lateral recharge and flow in the Permian. Rainfall recharge also occurs to the Quaternary alluvium and Tertiary palaeochannel sediments.

It is likely that the Ulan East Pit provides a lateral recharge source to the downgradient Permian coal measures to the north-east, such as at UG4**.**

In some areas, creeks may 'lose' to the groundwater system and provide a recharge source, depending on the relative level of the groundwater in the alluvium compared with the creeks. In the vicinity of Moolarben, most of the streams are 'gaining' and act as discharges for both alluvial and porous rock groundwater.

Groundwater discharge occurs through ET, baseflow, seepage and spring flow where the groundwater levels intersect the ground surface. Groundwater discharge also occurs as groundwater inflow to the Moolarben, Ulan and Wilpinjong coal mines.

3 GROUNDWATER MODELLING

3.1 PREVIOUS MODELS

Several groundwater models have been constructed in the area to simulate the stresses on the groundwater environment from mining activities. A summary of the extent and use of the previous models is provided below.

3.1.1 MOOLARBEN COAL COMPLEX MODEL

A groundwater impact assessment was prepared for Moolarben Coal by Peter Dundon and Associates Pty Ltd in 2006. A groundwater model was developed using MODFLOW (Harbaugh & McDonald, 2000) to assess potential groundwater impacts from open cut and longwall mines at Moolarben, Ulan and Wilpinjong.

Potential impacts on water sources were assessed by groundwater modelling conducted by RPS Aquaterra (2011) for the Preferred Project (including Stages 1 and 2 of the MCC) and by RPS Aquaterra (2012) for Stage 2 in isolation. The extent of the RPS Aquaterra groundwater model is shown in **Figure 13.** This groundwater model was developed using MODFLOW-SURFACT v4 (HydroGeoLogic) which allows for both saturated and unsaturated flow conditions, using the Groundwater Vistas user interface (ESI, 2011).

The Moolarben UG1 Optimisation Modification (HydroSimulations, 2015a) was conducted using the RPS Aquaterra groundwater model.

3.1.2 ULAN MODEL

Mining of coal at Ulan has been conducted since the early 1920s. Modern open cut and underground mining operations commenced in 1982 and 1986 respectively. Open cut mining ceased in 2014, and underground mining is ongoing (Mackie Environmental Research Pty Ltd [Mackie], 2009a). Following the commissioning of Mackie in 2009 to consolidate the existing groundwater studies, an updated numerical groundwater model was developed using MODFLOW-SURFACT (HydroGeoLogic). The extent of the Ulan groundwater model is shown in **Figure 13** (Mackie, 2009a).

There have been several updates to the Ulan groundwater model to assess different modifications to the mine plan. The most recent modification and groundwater model update was conducted in 2015 (Mackie, 2015).

3.1.3 WILPINJONG MODEL

The Wilpinjong Coal Mine has been operating since 2006. A groundwater model was developed for the original project approval by Australasian Groundwater and Environmental Consultants Pty Ltd (AGE)(2005). Several modifications to the mine plan have been modelled, including the Wilpinjong Mine Modification 5 (HydroSimulations, 2013).

In 2015 a groundwater assessment was conducted for the Wilpinjong Extension Project (WEP) (HydroSimulations, 2015b). An updated groundwater model was developed for the WEP groundwater assessment using MODFLOW-USG (Panday *et al*., 2013) and the AlgoMesh user interface (HydroAlgorithmics, 2017). The groundwater model for the WEP included Wilpinjong Mine and the MCC. The 2015 Wilpinjong model extent is shown in **Figure 13.**

3.2 SOFTWARE

For this study, a new groundwater model has been built making use of the previous groundwater models for the MCC and Moolarben Coal Operations' latest geological model.

Numerical modelling has been conducted using MODFLOW-USG Beta (Panday et al., 2013) with the AlgoMesh v1.2 user interface (HydroAlgorithmics, 2017). AlgoMesh was used to generate a 3D mesh of Voronoi cells and to produce the input files for MODFLOW-USG simulation.

Post-processing was conducted using the PEST Groundwater Data Utilities for unstructured grids (Doherty *et al*., 2017).

3.3 MODEL EXTENT

The groundwater model boundary is shown in **Figure 13**. The model extends approximately 55 km from west to east and approximately 60 km from north to south, covering an area of approximately 3,000 km^2. The groundwater model extent was designed to be large enough to include the neighboring mines of Ulan and Wilpinjong to allow cumulative effects to be modelled, and to prevent boundary influence on modelled drawdown associated with these mines.

The extents of the existing Ulan and Wilpinjong groundwater models are shown in **Figure 13**. The MCCmodel boundary is based on the Ulan model boundary to the north and west, and the Wilpinjong model boundary to the south and east. The model extent includes the high priority GDEs as listed in the WSPs to allow quantitative assessment of predicted drawdown at these locations, and any potential receptors such as surface water bodies that could be adversely affected by mining.

3.4 MODEL LAYERS

The groundwater model layers are listed in **Table 6**. Model layer 1 is present across the whole model extent, and includes the Quaternary Alluvium, Tertiary Palaeochannel and base of weathering. The Tertiary Palaeochannel and base of weathering has been split across layers 1 and 2 where present. The Triassic has been split into two layers, and the Permian has been split into three layers (not including the Ulan Seam) to allow vertical gradients through the stratigraphic column to be represented.

The main working section of the Ulan Seam is represented in layer 9. The Ulan Seam is also represented in layer 8.

Model layers 2 to 10 are not present across the whole model domain, as the layers have been pinched out where the geology has been eroded at outcrop.

Table 6 Groundwater Model Layers

Layer	Geology
1	Quaternary Alluvium / Tertiary Palaeochannel / Base of Weathering
2	Tertiary Palaeochannel / Base of Weathering (below alluvium) / Jurassic
3	Upper Triassic
4	Lower Triassic
5	Upper Permian
6	Middle Permian
7	Lower Permian
8	Ulan Seam (A1 to C lower)
9	Ulan Seam (Working Section 2)
10	Marrangaroo Formation
11	Basement

3.5 MESH DESIGN

The large spatial area of the model extent resulted in the need for an unstructured grid with varying cell sizes, and refinement in the areas of interest. The mesh over the whole model extent is shown in **Figure 14a** and the mesh at the MCC is shown with more detail in **Figure 14b**. The following features have been included in the mesh design:

- Rivers in the immediate vicinity of the MCC have a 50 m Voronoi cell size constraint. Rivers in the vicinity of Ulan and Wilpinjong Mines have a 100 m Voronoi cell size constraint. Rivers towards the edge of the model domain have a 250 m Voronoi cell size constraint.
- Open cut mine areas have a 100 m Voronoi cell size constraint.
- The cell count for one layer is 101,394. Over the 11 model layers, with pinch-out areas (where a layer is not present) in layers 2 to 10, the total cell count for the model is 848,753.

3.6 HYDRAULIC PROPERTIES

The geology has been split into 11 layers, as shown in **Table 6**, for the purpose of numerical modelling. The thicker stratigraphic units, have been split into multiple layers to allow vertical gradients to be represented.

Previous studies and investigations in the region (RPS Aquaterra, 2011; HydroSimulations, 2015b; Mackie, 2009b) have provided the basis for the initial hydraulic properties used in the MCC groundwater model.

3.7 MODEL STRESSES AND BOUNDARY CONDITIONS

The model domain covers all potentially sensitive receptors. All significant creeks and rivers that could be affected by mining activities are fully contained within the model domain and have been represented in the model, as shown in **Figure 13**.

3.7.1 MODEL BOUNDARY

The model boundary as shown in **Figure 13** is represented using the MODFLOW General Head Boundary (GHB) package. The general head elevation is set at 10 m below the topography. The GHB conductance is calculated based on the area of the model cell, and varies between 30 and 2,000 square metres per day (m^2/d).

3.7.2 WATERCOURSES

All major watercourses as shown in **Figure 13** are represented using the MODFLOW River (RIV) package, with the time-invariant stage higher than the riverbed.

Bora Creek and Saddlers Creek are ephemeral drainage lines and are represented as 'river' boundary cells in the model with the stage equal to the base of the riverbed.

Watercourses towards the edge of the model domain are also represented as 'river' boundary cells in the model with the stage equal to the base of the riverbed. Groundwater is able to discharge to these drainage lines as baseflow. Time-variant stages are applied to the Ulan East Pit and the OC1 North Void during the model calibration period.

3.7.3 MOOLARBEN, ULAN AND WILPINJONG MINE WORKINGS

The open cut mining at the MCC and Wilpinjong is represented as drain cells in model layer 9 (Ulan Seam) with the drain elevation set 0.1 m above the seam floor. Drain cells are also applied to model layers 1 to 8 with the drain elevations set at the bottom of the model layers across the open cut areas. Drain cells are applied in accordance with the mine schedules at the MCC and Wilpinjong, and are kept active for 1 year. The drain conductance is calculated based on the area of the model cell, and is approximately 50 m^2/d across the the MCC and Wilpinjong open cut areas.

The approved longwall extraction at the MCC and Ulan is represented as drain cells in model layer 9 (Ulan Seam) with the drain elevation set 0.1 m above the seam floor. The drain cells were applied in accordance with the mine schedules at the MCC and Ulan, and the development headings were activated in advance of the active longwall mining.

Spoil Emplacement and Final Void

Completed open cut mining areas will be backfilled with waste overburden as the extraction proceeds, except for the existing void at the OC1 Boxcut and approved final voids at OC3 and OC4. The Modification would not change the number or location of approved final voids at the MCC.

Backfill was given uniform hydraulic conductivity of 1 metres per day (m/day) and specific yield of 0.2. Rainfall recharge at 5% of average rainfall was applied to the backfilled areas with a delay of 5 years to allow for the time required to travel through the unsaturated zone.

The OC3 and OC4 final voids were given a higher hydraulic conductivity of 1,000 m/day, specific yield of 1.0 and a specific storage of 4.6×10^{-6} m^{-1} (specific storage calculation for pure water).

The rainfall recharge and ET rates were set to zero over the OC3 and OC4 final voids. This approach assumes zero net recharge other than groundwater inflow.

The hydraulic properties were varied with time using the TVM package of MODFLOW-USG Beta.

3.7.4 RECHARGE AND EVAPOTRANSPIRATION

Rainfall recharge was applied to the model using the MODFLOW Recharge (RCH) package. Rainfall was specified as a percentage of historical rainfall at the MCC site rainfall gauge for transient calibration, and specified as the same percentage of long-term average rainfall for the prediction scenarios. The rainfall recharge percentages for each outcropping geology type are shown in **Table 7**. A regional geology map of areas that this recharge is applied to is shown in **Figure 6**. An additional zone was used to simulate the areas of backfill during mining and post-mining as shown in **Table 7**.

Table 7 Rainfall Recharge

Geology	Recharge %
Alluvium / Palaeochannel	5
Triassic / Carboniferous	3
Jurassic	1
Permian	1.5
Backfilled areas (spoil emplacement)	5

The MODFLOW ET package was used with a maximum ET rate of 650 mm/a and an extinction depth of 3.0 m. In the model, ET occurs only in low-lying areas where the water table is close to the surface (along rivers/creeks).

3.8 MODEL SIMULATIONS

Six different model simulations were conducted as follows:

1. **Model Initial Conditions (2005).** A 10,000-day transient run was conducted to allow groundwater levels in the model area to reach equilibrium and provide initial heads for the transient calibration simulation. This was done instead of using steady-state simulation because the strong hydraulic conductivity contrasts and historical mining in the region resulted in numerical instability. Historical mining at Ulan to 2005 was included in the model initial conditions. Mining at the MCC and Wilpinjong had not commenced as at 2005.

2. **Transient Calibration (January 2005 – March 2017)**. Calibration of recharge and hydraulic properties over time (for more than 12 years) was conducted based on historical groundwater levels and mine inflows. Transient calibration was based on annual stress periods from 2005 to 2015. Monthly stress periods were used from January 2016 to March 2017 to allow calibration to monthly inflow data to the UG1 development headings.

3. **Baseline Prediction Scenario (April 2017 to 2038)**. The Baseline Scenario included mining at Ulan and Wilpinjong, but not mining at the MCC. Transient predictions included simulation of the progression of open cut and underground mining for more than 21 years (less than double the calibration period). Average rainfall recharge was assumed so that impacts due to mining were isolated from seasonal effects.

4. **Moolarben Open Cut Approved Scenario (April 2017 to 2038) (Approved Scenario)**. Progression of approved mining at the MCC, and the Ulan and Wilpinjong coal mines were included in the Approved Scenario simulation.

5. **Moolarben Open Cut Modification Scenario (April 2017 to 2038) (Modification Scenario).** Progression of the modified higher open cut mining rate and progress at the MCC was simulated, along with approved MCC underground mining and approved mining at the Ulan and Wilpinjong coal mines.

6. **Transient Recovery Simulation**. Groundwater level recovery towards equilibrium for the Modification Scenario was simulated.

3.9 MODEL CALIBRATION

Transient model calibration was conducted from January 2005 to March 2017. Initial heads were provided from the Model Initial Conditions 10,000-day model run. Calibration of hydraulic conductivity and storage was conducted based on historical groundwater levels and mine inflows.

3.9.1 CALIBRATED HYDRAULIC PROPERTIES

The calibrated hydraulic properties are shown in **Table 8**. Both manual and automatic calibration (PEST) were carried out. The hydraulic conductivity of the Ulan Seam in layers 8 and 9 was a particular focus of the model calibration. PEST was used to identify the most suitable horizontal hydraulic conductivity, specific yield and specific storage in zones within the MCC and Ulan mining areas in layers 8 and 9.

Table 8 Calibrated Hydraulic Properties

Layer	Zone	Geology	Kx (m/d)	Kz (m/d)	Kx/Kz	Sy	Ss (m^{-1})
1	12	Quaternary Alluvium	1	0.01	100	1.00E-01	n/a
	13	Tertiary Palaeochannel	1	0.015	66.7	1.00E-01	n/a
	1	Base of Weathering	0.5	0.001	500	1.00E-02	n/a
	17	TEM Clay (middle Palaeochannel)	0.1	0.015	6.7	1.00E-01	n/a
	24	Lower Triassic (L1 K zone)	0.2	0.0003	666.7	2.00E-03	n/a
	25	Lower Triassic (L1 K zone PZ128 PZ129)	0.02	5.0E-06	4000	2.00E-03	n/a
2	14	Tertiary Palaeochannel	5	1	5	1.00E-01	1.00E-05
	15	Base of Weathering	0.5	0.001	500	1.00E-02	1.00E-05
	18	TEM Clay (middle Palaeochannel)	0.1	0.015	6.7	1.00E-01	1.00E-05
	2	Jurassic	0.5	0.0001	5000	0.01	7.00E-06
3	3	Upper Triassic	0.5	0.0001	5000	0.028	3.00E-05
4	4	Lower Triassic	0.2	0.00005	4000	2.00E-03	9.00E-06
5	5	Upper Permian	0.01	0.000025	400	8.00E-03	2.00E-06
6	6	Middle Permian	0.01	0.000025	400	3.00E-03	1.00E-06
7	7	Lower Permian	0.01	0.000025	400	3.00E-03	1.00E-06
8	8	Ulan Seam (A1 to C lower)	3	0.0005	6000	0.0055	4.28E-05
	16	Ulan UG	1	0.0005	2000	0.0055	4.28E-05
	19	UG1 Footprint	16	0.0005	32000	0.0055	4.28E-05
	20	UG4 Footprint	12	0.0005	24000	0.0055	4.28E-05
9	9	Ulan Seam (working section)	3	0.5	6	0.0055	4.28E-05
	16	Ulan UG	1	0.5	2	0.0055	4.28E-05
	19	UG1 Footprint	16	0.5	32	0.0055	4.28E-05
	20	UG4 Footprint	12	0.5	24	0.0055	4.28E-05
10	10	Marrangaroo Formation	0.1	0.0001	1000	0.01	6.00E-06
11	11	Basement	0.0005	0.00001	50	0.01	6.00E-06
1 - 9	21	West and East pit spoil	1	1	1	0.1	5.00E-03

Layer	Zone	Geology	Kx (m/d)	Kz (m/d)	Kx/Kz	Sy	Ss (m^{-1})
1 - 10	22	Diatreme (Halo)	0.0001	0.0001	1	1.00E-03	1.00E-06
1 - 10	23	Diatreme (Core)	0.001	0.001	1	1.00E-03	1.00E-06
5	26	Upper Permian UG4 Footprint	0.01	0.00025	40	8.00E-03	2.00E-06
6		Middle Permian UG4 Footprint	0.01	0.00025	40	3.00E-03	1.00E-06
7		Lower Permian UG4 Footprint	0.01	0.00025	40	3.00E-03	1.00E-06

Kx = Horizontal Hydraulic Conductivity.

Kz = Vertical Hydraulic Conductivity.

Kx/Kz = Anisotropy

Ss = Specific Storage

Sy = Specific Yield

3.9.2 WATER BALANCE

The water balance at the end of the transient calibration period across the entire model area is summarised in **Table 9**. The average inflow (recharge) to the groundwater system is approximately 203 ML/d, comprising rainfall recharge (59%), boundary inflow (28%) and leakage from streams to the groundwater system (13%).

The largest proportion of model outflows is baseflow to rivers and streams (51%), followed by boundary outflow (19%), ET (17%) and mine inflows (13%). There was a net gain in storage of approximately 17 megalitres per day (ML/d) over the calibration period.

Table 9 Simulated Average Water Balance during the Transient Calibration Period

Component	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	120.4	-
Evapotranspiration	-	30.3
Rivers/Creeks	25.9	96.8
Mines	-	23.4
Boundary Flow	57.1	36.2
TOTAL	**203.4**	**186.7**
Storage	**16.7 GAIN**	
Discrepancy (%)	**0.00**	

3.9.3 CALIBRATION PERFORMANCE

Calibration Statistics

A scattergram of modelled versus observed heads (**Figure 15**) demonstrates good agreement across the whole range of measurements. There is no bias towards overestimation or underestimation.

The key calibration statistics are shown in **Table 10**. The key statistic is 4.6% Scaled Root Mean Square (SRMS), which is better than the groundwater modelling guideline value of 5-10% (Murray-Darling Basin Commission, 2001; Barnett *et al*., 2012) for acceptable model calibration.

Table 10 Calibration Statistics

Statistic	Value
Root Mean Square (RMS) (m)	11.9
Scaled Root Mean Square (SRMS) (%)	4.6
Average Residual (m)	8.6

Calibration Hydrographs

Transient calibration hydrographs showing modelled and observed heads over time for all monitoring locations are shown in **Attachment A**. The locations of all monitoring bores are shown in **Figure 7**.

Key calibration hydrographs at PZ156 and PZ157 at the MCC UG1 are shown in **Figure 16** and **Figure 17**, respectively. Modelled and observed groundwater levels in the Ulan Seam (model layer 9) at PZ156 and PZ157 show an increase in groundwater levels from 2008 to 2011 in response to above average rainfall conditions. From 2011 to 2016, groundwater levels at PZ156 and PZ157 decrease approximately 10 m in response to mining at OC1. From April 2016 to March 2017 modelled groundwater levels decrease by approximately 25 m at PZ156 and approximately 15 m at PZ157 in response to mining of the development heading at UG1, as seen in the observed data.

4 SCENARIO ANALYSIS

4.1 APPROVED AND MODIFICATION MINE SCHEDULES

The key changes of the Modification compared to Approved operations are changes in the rate of open cut mining and minor extensions to the pit limits of OC2 and OC3.

The proposed increases in mining rate have been incorporated into the modelling via changes in the mining sequence in OC3 and OC4, in particular mining in OC3 in 2018 to 2022 in the Modification Scenario, compared to 2032 to 2038 in the Approved Scenario.

The changes in OC3 pit limits have also been considered in the modelling. The changes in OC2 pit limits for the Modification scenario are minor, and are effectively indistinguishable in comparison to the Approval Scenario from a groundwater modelling perspective.

The timing of open cut mining at OC1 and OC2, and approved underground mining, is the same for both the Approved and Modification Scenarios.

4.2 MODELLING APPROACH

4.2.1 MODIFICATION SPECIFIC EFFECTS

The potential effects, in particular groundwater drawdown and depressurisation, of the changes in open cut mining operations for the Modification have been assessed by comparing model outputs for the Approved and Modification scenarios.

The effects of approved underground mining, neighbouring mines and other influences such as rainfall recharge are the same in both models, so by comparison of the Approved and Modification Scenarios, the incremental effects of the changes in open cut mining operations for the Modification can be identified uniquely.

4.2.2 CUMULATIVE EFFECTS

As the neighbouring mines are active for the Approved and Modification Scenarios, cumulative drawdown and depressurisation are embedded in the results presented for the scenarios. The differential drawdown and depressurisation between the scenarios are therefore inclusive of cumulative effects.

As the neighbouring mines have contributed to depressurisation of the Permian coal measures in the vicinity of the MCC, the modelling includes the neighbouring mines to account for existing mine perturbation of the potentiometric surfaces.

4.3 WATER BALANCE

The modelled duration of the Approved and Modification Open Cut Prediction Scenarios is from April 2017 to December 2038 (stress periods 27 to 56). The average water balance for the prediction period for the two scenarios across the entire model area (for all active mines) is summarised in **Table 11**.

Table 11 Simulated Average Water Balance During the Prediction Period

Component	Approved Scenario		Modification Scenario	
	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)	Groundwater Inflow (Recharge) (ML/day)	Groundwater Outflow (Discharge) (ML/day)
Rainfall Recharge	121.4	-	121.4	-
Evapotranspiration	-	29.9	-	29.9
Rivers/Creeks	28.5	96.9	28.5	96.9
Mines	-	25.2	-	25.1
Wells	-	0.6	-	0.6
Boundary Flow	57.0	36.4	57.0	36.4
TOTAL	**206.9**	**189.1**	**207.0**	**189.0**
Storage	**17.8 GAIN**		**18.0 GAIN**	
Discrepancy (%)	**0.5**		**0.5**	

The results for the two scenarios are almost identical for the components of the water balance.

The Modification Scenario has 0.1 ML/day (0.05%) less total mine inflow (for the MCC, Wilpinjong and Ulan mines) than the Approved Scenario due to the more rapid mining sequence at OC4. Discussion of predicted inflows is provided in **Section 4.4**.

The average inflow (recharge) to the groundwater system is approximately 207 ML/d for both scenarios, comprising rainfall recharge (59%), boundary inflow (28%) and leakage from streams to the groundwater system (14%). Groundwater discharge is dominated by baseflow to rivers and streams (51%), followed by boundary outflow (19%), ET (16%) and mine inflows (13%). Assumed pumping from the approved borefield accounts for 0.3% of the total groundwater outflow during the prediction period. There is a net gain in storage of approximately 18 ML/d over the prediction period.

4.4 PREDICTED MINE INFLOWS

Total inflows for both the Approved and Modification Scenarios are presented in **Figure 18a.** No change in peak inflows is predicted due to the Modification (when compared to the Approved scenario) only differences in the timing when peak inflows would occur (i.e. peak inflows to OC3 occur earlier in the mine life for the Modification).

Predicted changes in groundwater inflows to the MCC mining areas due to the Modification Scenario are presented in **Figure 18b**. The year-by-year predicted inflows for the Modification vary from 3.7 ML/d less inflow (in 2022) to 3.6 ML/d more inflow (in 2029), with an average of 0.1 ML/d less inflow. These changes are associated with changes in the open cut mining sequence for the Modification, in particular, mining of OC3 earlier in the mine life and accelerated mining in OC4.

It is noted total inflows for both the Modification and Approved scenarios are greater than those predicted by RPS Aquaterra (2011) and HydroSimulations (2015a) for a number of reasons, including:

- Model revision and recalibration.
- Changes related to the Modification:
    - increased mining rate in the open cuts;
    - minor extensions of the open cut pit limits; and
    - revised timing of mining for OC4 and OC3.
- Changes unrelated to the Modification:
    - changes to the sequencing of the approved underground mining areas (including the requirement to continue to dewater UG1 for the life of UG4 to maintain safe access to the UG4 workings);
    - approved underground mining rate of 8 Mtpa as a result of the UG1 Optimisation Modification;
    - differences in the timing of advanced dewatering of the UG4 area via the approved borefield; and
    - water stored in the Ulan East Pit providing potential recharge to down-dip workings in the Ulan Seam.

4.5 PREDICTED GROUNDWATER LEVELS

Predicted changes in groundwater levels at the end of mining at the MCC are presented in **Figures 19** to **20**.

Figures 19a and **19b** show the predicted water table (generally Model Layer 1) at the end of MCC mining for the Approved and Modified scenarios, respectively. There is no discernible difference in the water table between the two scenarios at the end of mining.

Figures 20a and **20b** show the predicted groundwater levels in the Ulan Seam (Model Layer 9) for the Approved and Modified scenarios, respectively. There is no discernible difference in the groundwater levels in the Ulan Seam between the two scenarios at the end of mining.

4.6 PREDICTED BASEFLOW

Predicted changes in baseflow and stream leakage due to the Modification have been assessed for Moolarben Creek, Lagoon Creek, Goulburn River, Murragamba and Eastern Creeks, Wilpinjong Creek, Bobadeen Creek, Bora Creek and Saddlers Creek from 2017 to the end of the predictive simulation in December 2038.

The locations of the watercourses/drainage lines for which changes in baseflow and stream leakage have been assessed are shown in **Figure 21**.

The predicted changes due to the Modification (i.e. changes in open cut mining operations) are shown in **Figure 22**.

It is predicted there would be a reduction in baseflow to Moolarben Creek (maximum of about 0.2 ML/d) due to the Modification scenario, as a result of the earlier mining of OC3 for the Modification scenario. At the end of MCC mining, there would be no change in baseflow to Moolarben Creek due to the Modification.

Similarly, it is predicted there would be an incremental reduction in baseflow to Lagoon Creek (maximum reduction to the stream of 0.05 ML/day) due to the Modification, as a result of the revised OC3 mining sequence. At the end of MCC mining, there would be no change in baseflow to Lagoon Creek due to the Modification.

Murragamba and Eastern Creeks behave as gaining streams (receiving baseflow) from 2017 to 2020, and as losing streams (river leakage) from 2021 to 2028 for the Approved Scenario. For the Modification scenario Murragamba and Eastern Creeks behave as gaining streams for a longer period from 2017 to 2024, and there is a reduction in river leakage (maximum 0.52 ML/d) from 2025 to 2038 compared to the Approved Scenario. This is due to the different mining sequence at OC4 in the two scenarios. As the creek reaches upstream of OC4 are modelled with a permanent water depth, the predicted leakage losses would be overestimated when the creeks do not flow.

It is predicted there would be a reduction in leakage from Wilpinjong Creek (maximum reduction in leakage to the groundwater system of 0.56 ML/day) due to the Modification, as a result of the revised OC4 mining sequence. At the end of MCC mining, there would be no change in river leakage from Wilpinjong Creek due to the Modification.

No discernible change in baseflow or stream leakage is predicted for other watercourses/drainage lines due to the Modification.

5 POTENTIAL EFFECTS

5.1 POTENTIAL EFFECTS ON GROUNDWATER

The potential effects of the Modification on groundwater resources have been evaluated as part of this impact assessment. The potential effects on groundwater related to the changes in open cut mining operations for the Modification include:

- drawdown of groundwater levels and depressurisation of groundwater during operational mining and associated potential effects to groundwater users, GDEs and baseflow/leakage to/from water courses and drainage lines; and
- groundwater recovery levels post-mining.

5.2 POTENTIAL EFFECTS ON GROUNDWATER LEVELS

The predicted change in drawdown of the water table (generally Model Layer 1) at the end of MCC mining as a result of the Modification is shown in **Figure 23.** Differences in drawdown of the water table are predicted to be minor (i.e. localised areas of +/- 2 m drawdown).

Figure 24 shows the predicted change in drawdown in the Ulan Seam (Model Layer 9) at the end of MCC mining due to the Modification. The most significant change is a predicted reduction in drawdown in the Ulan Seam at the end of the mine life for the Modification scenario in a localised section of OC3, as mining in OC3 occurs earlier in the mine life (allowing more time for recovery of groundwater levels).

5.3 GROUNDWATER DEPENDENT ECOSYSTEMS

As the changes in predicted water table levels due to the Modification are minor, it is inferred that the Modification would not result in additional impacts to GDEs.

5.4 POTENTIAL DRAWDOWN INTERFERENCE AT PRIVATELY OWNED BORES

There were two bores identified during the census survey that are located on private property relevant to potential impacts from the MCC (**Table 12**).

Table 12 shows that the Modification is predicted to result in negligible change in maximum drawdown at these two privately owned bores.

The NSW *Aquifer Interference Policy* minimal harm criterion refers to cumulative impact and therefore cumulative drawdown has been considered also. The two private bores in the vicinity of the MCC do not have a predicted drawdown in excess of 2 m due to the Approved or Modification Scenarios.

Table 12 Predicted Change in Maximum Predicted Drawdown (m) at Privately Owned Bores in the Vicinity of Moolarben Coal Complex due to the Modification

Work ID	Licence No.	Bore Type	Hydro-geological Unit	Predicted Change in Maximum Predicted Drawdown (m) due to the Modification
GW800279	80BL236762	Domestic	Triassic Narrabeen Group	<0.1
GW064580	20BL137225	Stock & Domestic	Triassic Narrabeen Group	<0.1

5.5 RECOVERY OF GROUNDWATER LEVELS

A recovery simulation has been run in transient mode for 100 years after the completion of all mining at the MCCfor the Modification Scenario. For the recovery simulation all mining at the MCC, Ulan and Wilpinjong (modelled as Drain cells) was deactivated. Backfill hydraulic properties and recharge were applied to all open cut areas at the MCC and Wilpinjong.

Figure 25 shows the predicted water table at the end of the 100-year recovery period (2138). There are no discernible signs of residual water table drawdown at the open cut mining areas.

Figure 26 shows the predicted groundwater levels in the Ulan Seam (model layer 9) at the end of the 100-year recovery period (2138). There are no discernible signs of residual groundwater drawdown in the Ulan Seam across the MCC at the end of the recovery period.

5.6 GROUNDWATER LICENSING

Moolarben Coal Operations currently holds the following groundwater licences in the Hunter Unregulated and Alluvial WSP (Water Access Licence [WAL] 37582 for the Upper Goulburn River Management Zone and WAL 36340 for the Wollar Creek Management Zone) and North Coast Fractured and Porous Rock Groundwater Sources (WAL 39799).

Additional licence requirements resulting from the proposed changes in open cut mining operations for the Modification have been estimated.

For each water source, the peak takes for the Modification are the same as or less than those calculated for the Approved Scenario.

Therefore, the Modification would not result in the requirement for Moolarben Coal Operations to obtain additional licences.

However, the peak licensing requirements are likely to occur earlier in the mine life under the Modification scenario. For example: the peak take from the Porous Rock of the North Coast Fractured and Porous Rock Groundwater Sources is likely to occur about one year earlier (around 2026); and the peak take from the Upper Goulburn River Groundwater Source of the Hunter Unregulated and Alluvial Water Sources is expected about 15 years earlier (2021 versus 2036).

Moolarben Coal Operations would need to hold groundwater licences to account for mining at the MCC incorporating the Modification, as required.

5.7 UNCERTAINTY

This Assessment has focused on quantification of differential effects due to the Modification by comparison between the Approved and Modification scenarios, rather than absolute magnitudes for either scenario. Uncertainty analysis was not considered necessary for this Assessment, as the alteration of parameters (e.g. hydraulic conductivities) would be applied equally to both the Approved and Modification scenarios, which would negate any changes to the differential effects between the two scenarios. This practice aligns with Guiding Principle 7.4 of the National Modelling Guidelines (Barnett *et al.*, 2012):

> *"Analysis of uncertainty should recognise that there is more uncertainty when reporting confidence intervals around an absolute model output, and less uncertainty when a prediction can be formulated as a subtraction of two model results."*

5.8 CLIMATE CHANGE AND GROUNDWATER

The NSW Climate Impact Profile – The Impacts of Climate Change on the Biophysical Environment of New South Wales (Department of Environment, Climate Change and Water, 2010) indicates changes to the climate may include:

- increase in maximum and minimum temperatures;
- increase in summer rainfall;
- increase in evaporation; and
- increase in the intensity of flood producing rainfall events.

Annual rainfall is expected to change by -10 to +5% by 2030 (Pittock, 2003) in parts of south-eastern Australia. In addition, annual average temperatures are projected to increase by 0.4 to 2.0 degrees Celsius (relative to 1990) at that time.

In consideration of the above, there are potential cumulative effects to the groundwater system associated with the Modification and climate change. However, as the Modification is not predicted to have significant effects beyond the effects of approved mining, no additional groundwater effects associated with the Modification would be expected when considered cumulatively with potential effects associated with climate change.

5.9 AQUIFER INTERFERENCE POLICY CONSIDERATIONS

There is no mapped highly productive groundwater in the vicinity of the MCC. It follows that the remaining alluvial and porous rock aquifers in the vicinity of the MCC are less productive.

The NSW *Aquifer Interference Policy* minimal harm criterion requires consideration of cumulative drawdown impacts at private bores. Cumulative drawdowns (incorporating the Modification) would remain less than 2 m at the two privately owned bores in the vicinity of the MCC. The closest high priority GDE is 140 km away and would not be impacted by the MCC.

Predicted changes in drawdown due to the Modification are within Level 1 minimal harm criterion for water table and water pressure attributes. The predicted impacts of the Modification are also within the Level 1 criterion for water quality.

The minor predicted changes in drawdown would lead to very minor changes in groundwater flow directions, and consequently no mechanism for changes in beneficial use of groundwater (noting also there is limited use of groundwater in the vicinity of the MCC).

6 CONCLUSIONS

The MCC is an existing coal mine comprising approved open cut and underground mining operations. Mining is approved to 2038. The MCC is located in close proximity to two other mining operations (the Wilpinjong and Ulan coal mines).

Modifications proposed at the MCC, which are relevant to potential impacts to groundwater resources, are related to changes in the rate (and sequencing) of open cut mining operations and minor changes in open cut pit limits.

This groundwater assessment has considered the potential effects of the Modification on groundwater resources using the following approach:

1. Update and re-calibration of the groundwater model for the MCC, including the use of updated modelling software (MODFLOW-USG Beta [Panday *et al*., 2013]) and re-calibration of the model to account for groundwater monitoring data to March 2017.

2. Modelling of 'Approved' and 'Modification' scenarios to identify potential impacts of the Modification.

3. Assessment of potential impacts to groundwater resources associated with the changes in open cut mining operations for the Modification.

In summary, it is predicted:

- While the Modification may result in changes to the timing of located drawdown effects (e.g. mining of OC3 earlier in the mine life in comparison to the Approved scenario), at the end of mining at the MCC the Modification is predicted to result in minimal changes in drawdown of the water table or drawdown in the Ulan Seam.

- As a consequence, potential impacts to private groundwater users, GDEs and watercourses and drainage lines due to the Modification are predicted to be negligible.

- Additional groundwater licences are not likely to be required due to the Modification. However, peak takes would occur earlier in the mine life under the Modification scenario. For example: the peak take from the Porous Rock of the North Coast Fractured and Porous Rock Groundwater Sources is likely to occur about one year earlier (around 2026); and the peak take from the Upper Goulburn River Groundwater Source of the Hunter Unregulated and Alluvial Water Sources is expected about 15 years earlier (2021 versus 2036).

- Moolarben Coal Operations would need to hold groundwater licences to account for mining at the MCC incorporating the Modification, as required.

7 REFERENCES

Australasian Groundwater and Environmental Consultants, 2005. *Wilpinjong Coal Project Groundwater Impact Assessment*. May 2005.

Barnett, B, Townley, L.R., Post, V., Evans, R.E., Hunt, R.J., Peeters, L., Richardson, S., Werner, A.D., Knapton, A. and Boronkay, A.,2012. *Australian Groundwater Modelling Guidelines.* Waterlines report 82, National Water Commission, Canberra.

Bureau of Meteorology, 2017a. *Climate Data Online*. Available at: http://www.bom.gov.au/climate/data/

Bureau of Meteorology, 2017b. *Groundwater Dependent Ecosystem (GDE) Atlas*. Available at: http://www.bom.gov.au/water/groundwater/gde/

Department of Environment, Climate Change and Water, 2010. *NSW Climate Impact Profile – The Impacts of Climate Change on the Biophysical Environment of New South Wales*.

Doherty, J., Muffels, C., Rumbaugh, J., Tonkin, M., 2017. *Model-Independent Parameter Estimation and Uncertainty Analysis*, http://www.pesthomepage.org/Home.php

ESI, 2011. *Groundwater Vistas Software Package*.

Harbaugh. A. W., Banta E. R., Hill M. C., and McDonald M. G., 2000. *MODFLOW-2000 - The USGS Modular Groundwater Flow Model – User Guide to Modulization Concepts and the Groundwater Flow Process*: U. S. Geological Survey Open-File Report 00-0092.

HydroAlgorithmics, 2017. *AlgoMesh for Mesh Generation*, http://www.hydroalgorithmics.com

HydroGeoLogic Inc., *MODFLOW SURFACT Software (Version 3.0)*, Herdon, VA, USA.

HydroSimulations, 2013. *Wilpinjong Coal Mine Modification (Mod 5) Groundwater Assessment*. Report for WCPL, document WIL004-HC2013-11, July 2013.

HydroSimulations, 2015a. *Moolarben Coal Complex UG1 Optimisation Modification*, Groundwater Modelling Assessment for Moolarben Coal Operations Pty Ltd. Report HC2014/34, May 2015.

HydroSimulations, 2015b. *Wilpinjong Extension Project Groundwater Assessment*, Wilpinjong Coal Pty Ltd, Report HC2015/42, November 2015.

Mackie Environmental Research, 2009a. *Continued Operations – Groundwater Assessment*, Ulan Coal Mines Ltd, July 2009.

Mackie Environmental Research, 2009b. *Hydrogeological Characterisation of Coal Measures and Overview of Impacts of Coal Mining on Groundwater Systems in the Upper Hunter Valley of NSW*. PhD Thesis submitted to Faculty of Science, University of Technology, Sydney N.S.W. Australia.

Mackie Environmental Research, 2015. *Assessment of Groundwater Related Impacts Arising from Modification to the Ulan West Mine Plan*, Ulan Coal Mines Ltd, Report 2747-14/Rev3, January 2015.

Moolarben Coal Operation Pty Ltd, 2016. *Groundwater Management Plan*, Moolarben Coal Operations, Report MCO_ENV_PLN_0038, October 2016.

Murray-Darling Basin Commission, 2001. *Groundwater Flow Modelling Guideline.* Canberra, August 2001, 125p. ISBN: 1876830166.

Panday, S., Langevin, C.D., Niswonger, R.G., Ibaraki, M., and Hughes, J.D., 2013. *MODFLOW–USG version 1: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation*. U.S. Geological Survey Techniques and Methods. Book 6.

Peter Dundon and Associates Pty Ltd, 2006. *Moolarben Coal Project Groundwater Assessment*, Moolarben Coal Mines Pty Ltd, September 2006.

Pittock, B, 2003. *Climate Change – An Australian Guide to the Science and Potential Impacts*. Australian Greenhouse Office.

RPS Aquaterra, 2011. *Moolarben Coal Complex Stage 2 - Preferred Project Report - Groundwater Impact Assessment*, November 2011

RPS Aquaterra, 2012. *Moolarben Coal Complex Stage 2 - Additional Groundwater Impact Assessment*. June 2012.

FIGURES

Figure 1 Regional Location

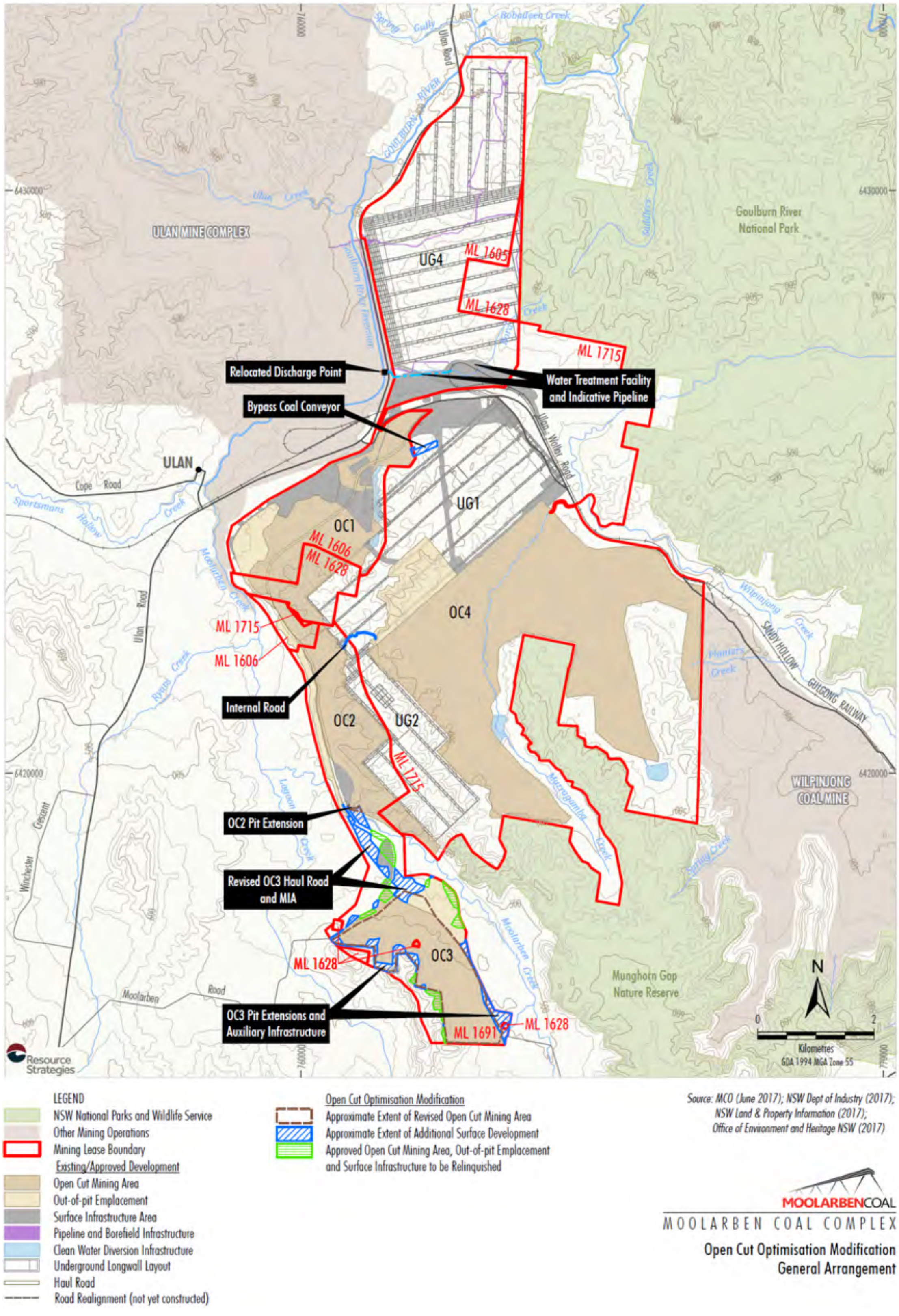
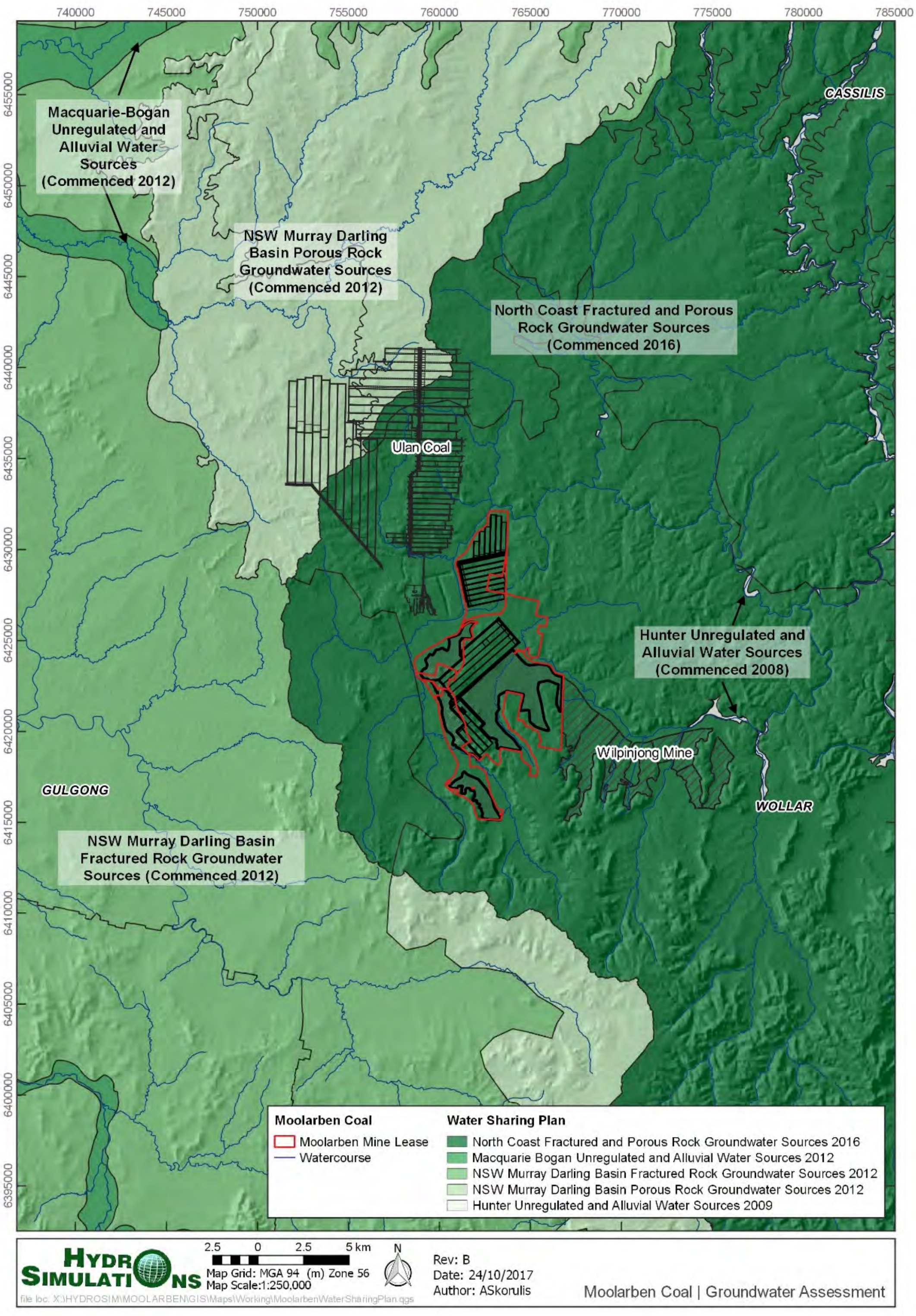


Figure 2 Modification General Arrangement



Note 1: Figure shows approved OC3

Figure 3 Water Sharing Plans and Groundwater Management Areas

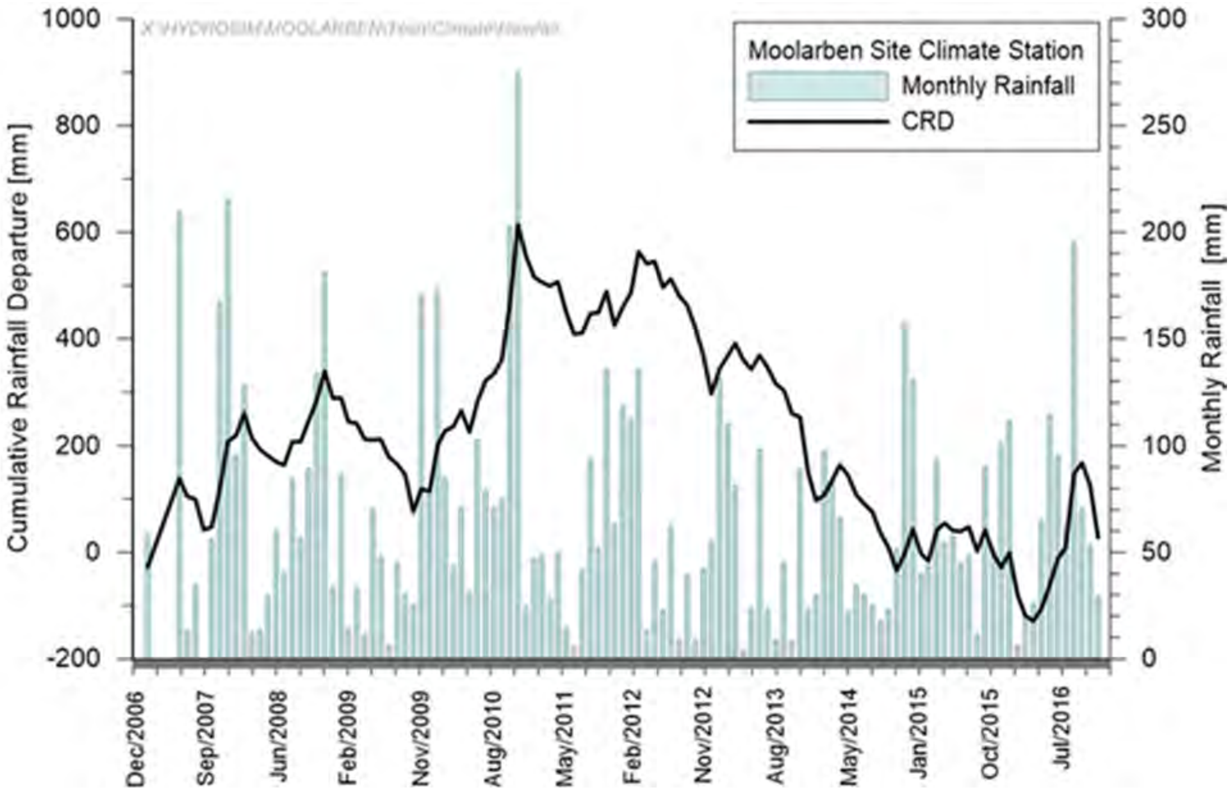
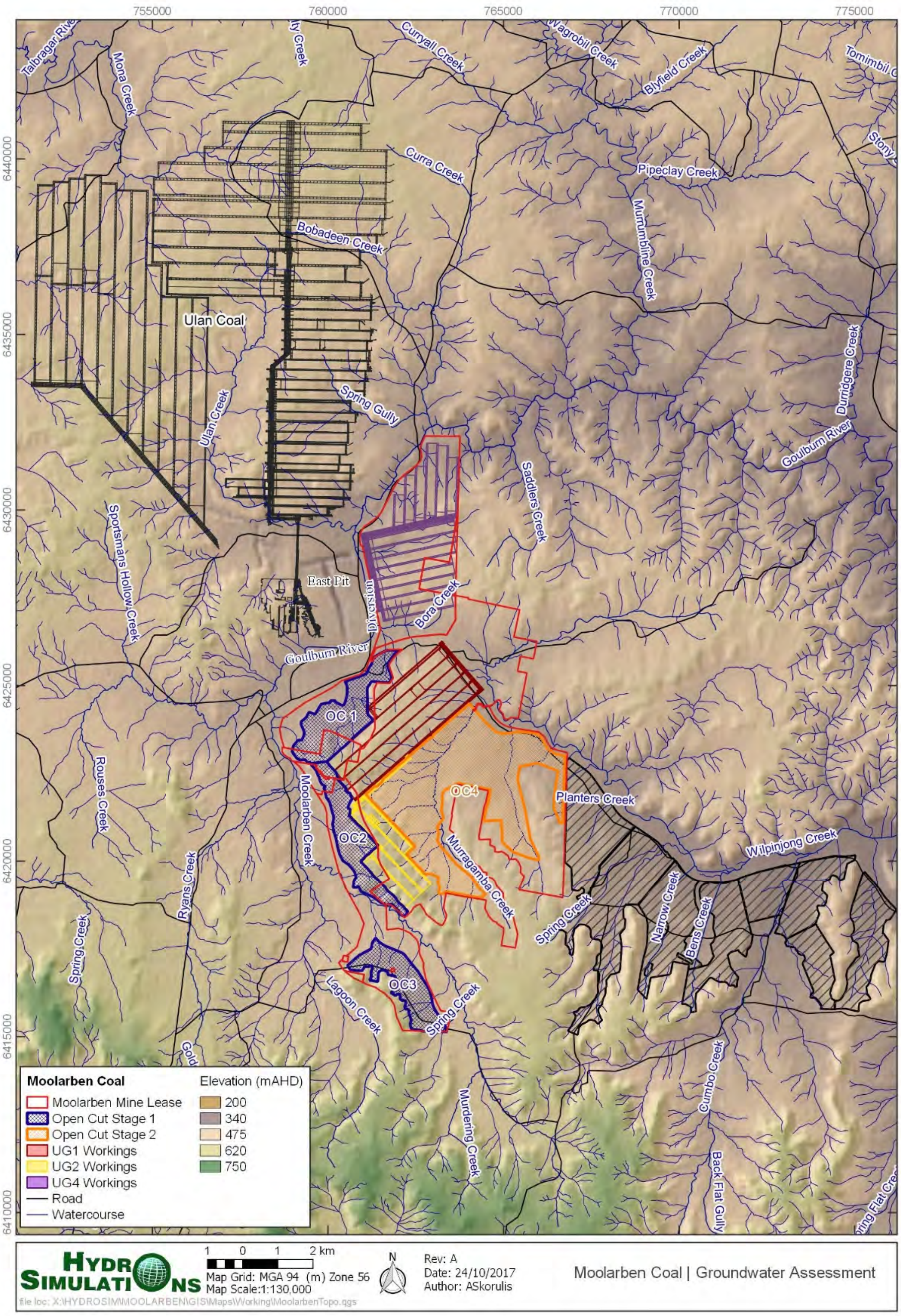
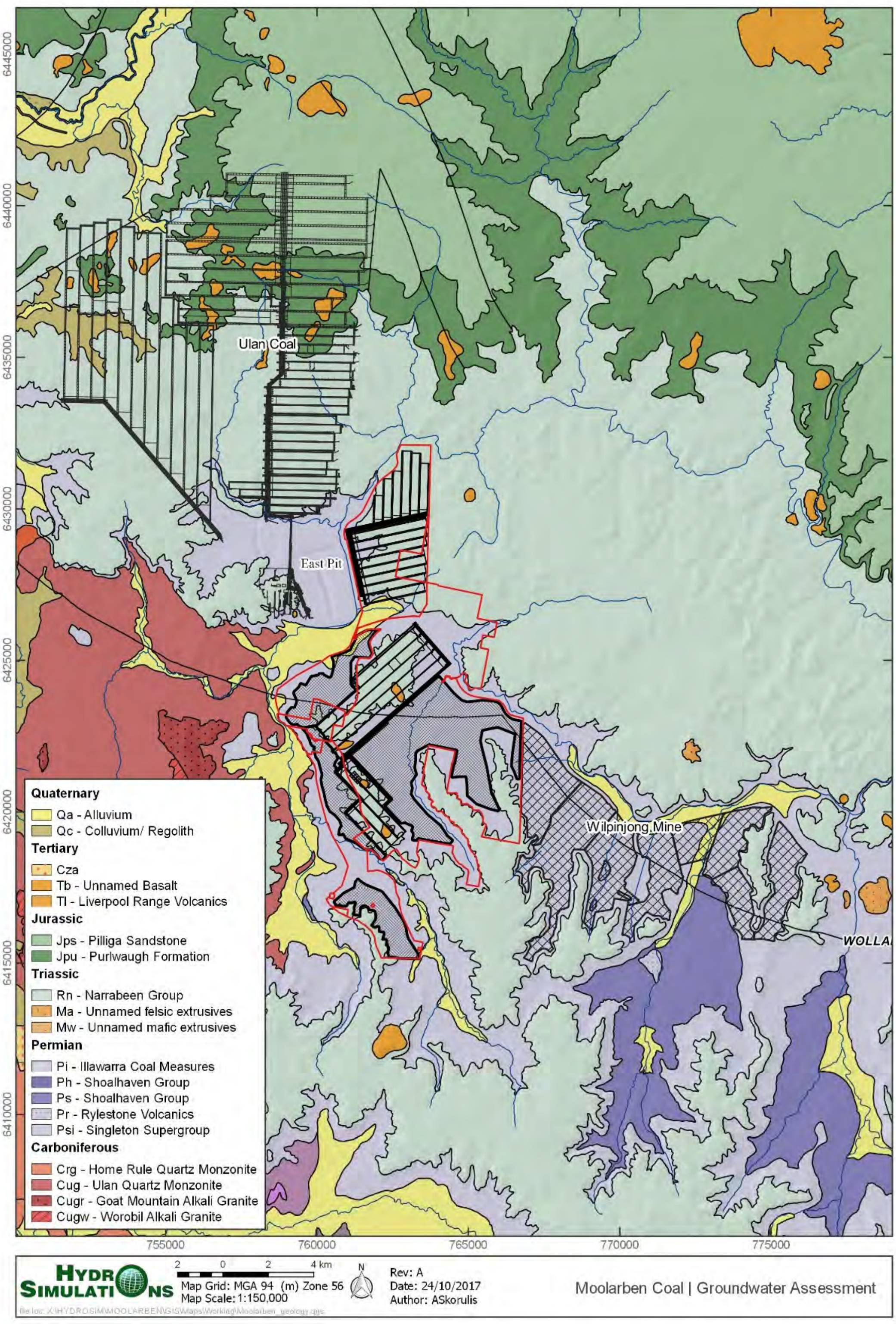


Figure 4 Cumulative Rainfall Departure from the Monthly Mean at Moolarben Climate Station



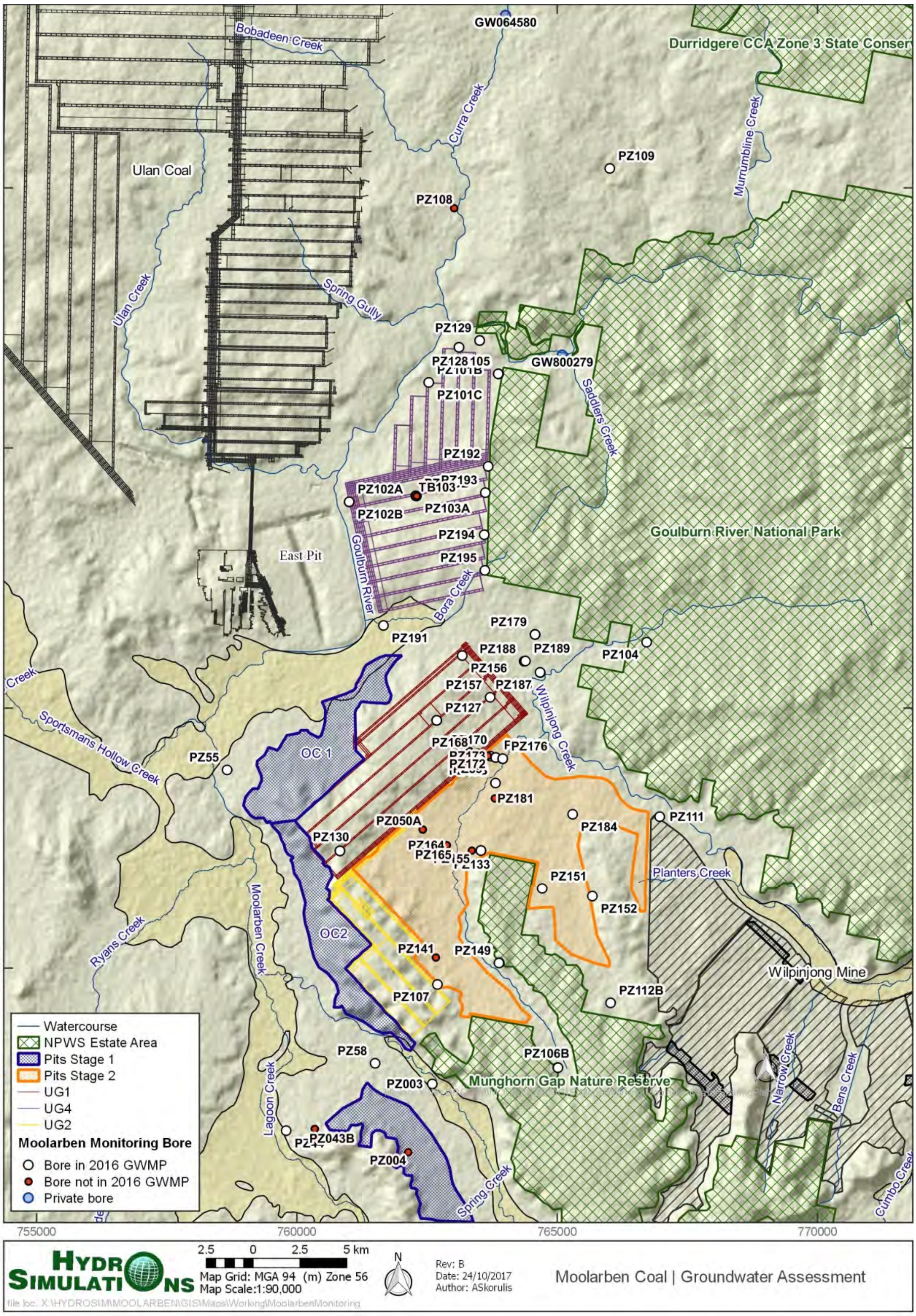
Note: Figure shows approved OC3

Figure 5 Regional Topography



Note: Figure shows approved OC3

Figure 6 Regional Geology



Note: Figure shows approved OC3

Figure 7 Moolarben Groundwater Monitoring Locations

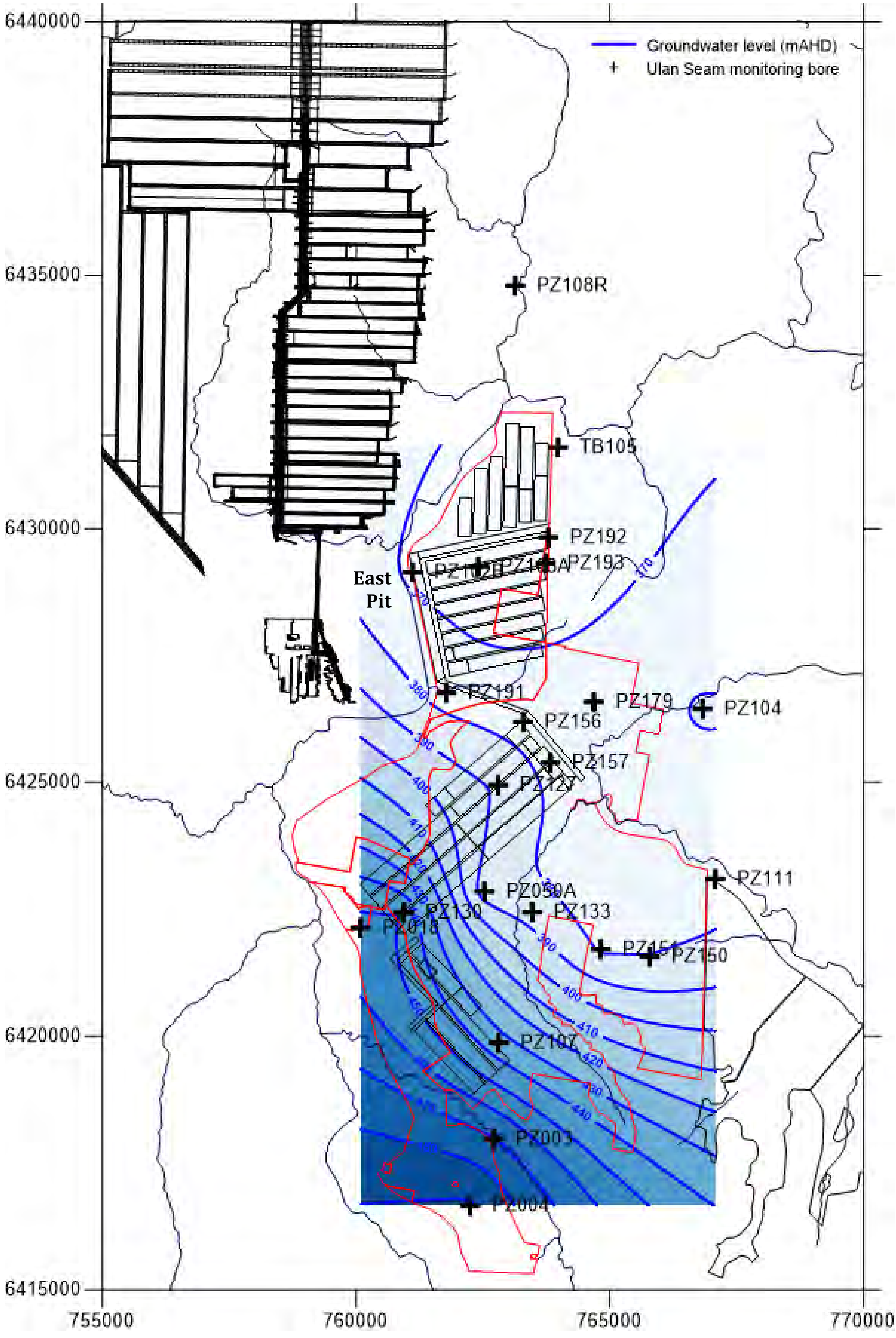
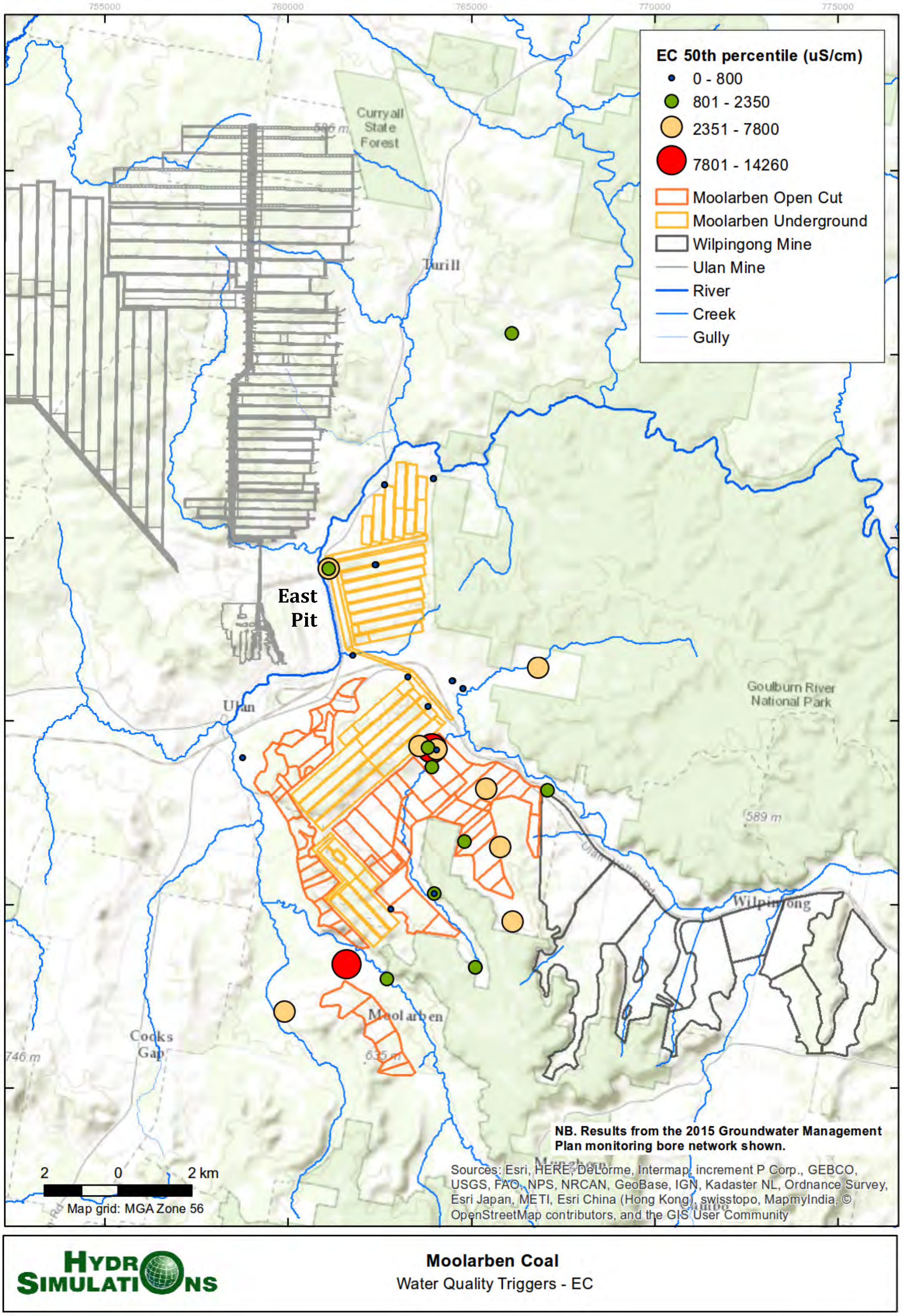
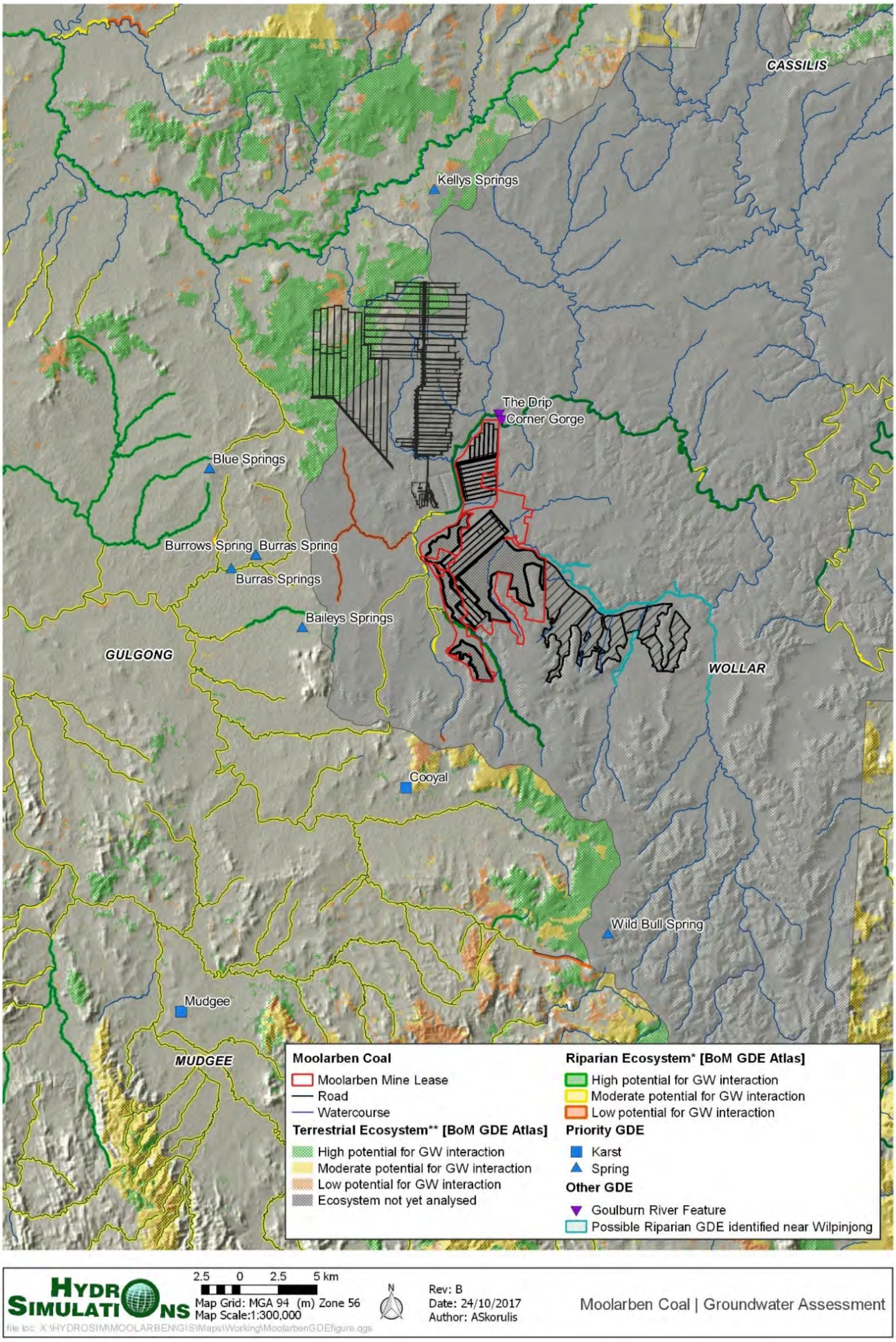


Figure 8 **Ulan Seam Groundwater Levels (mAHD) at January 2016**



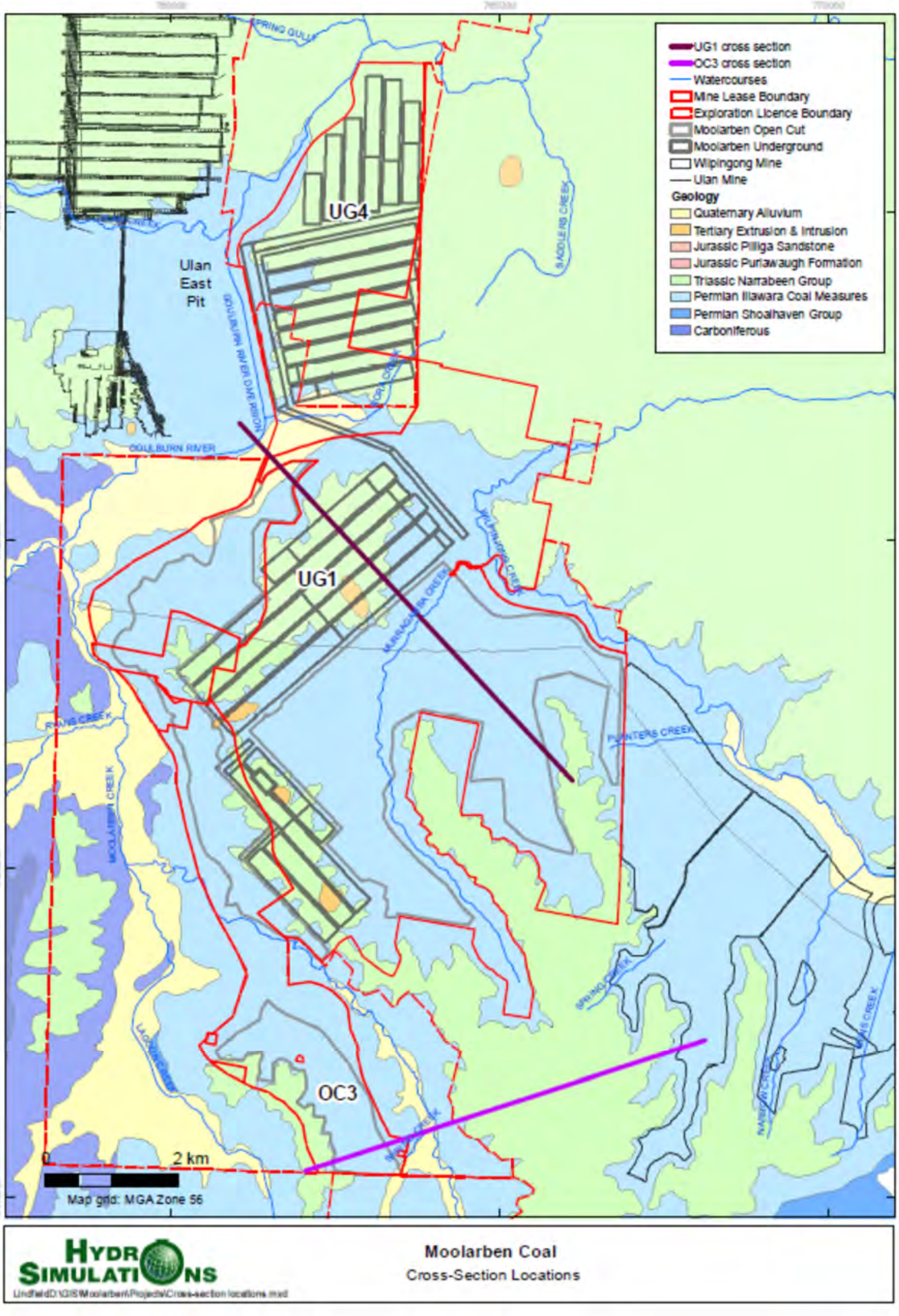
Note: Figure shows approved OC3

Figure 9 Median (50th Percentile) EC at Moolarben Monitoring Bores



Note: Figure shows approved OC3

Figure 10 Groundwater Dependent Ecosystems



Note: Figure shows approved OC3

Figure 11 Regional Geology and Locations of Conceptual Cross-Sections

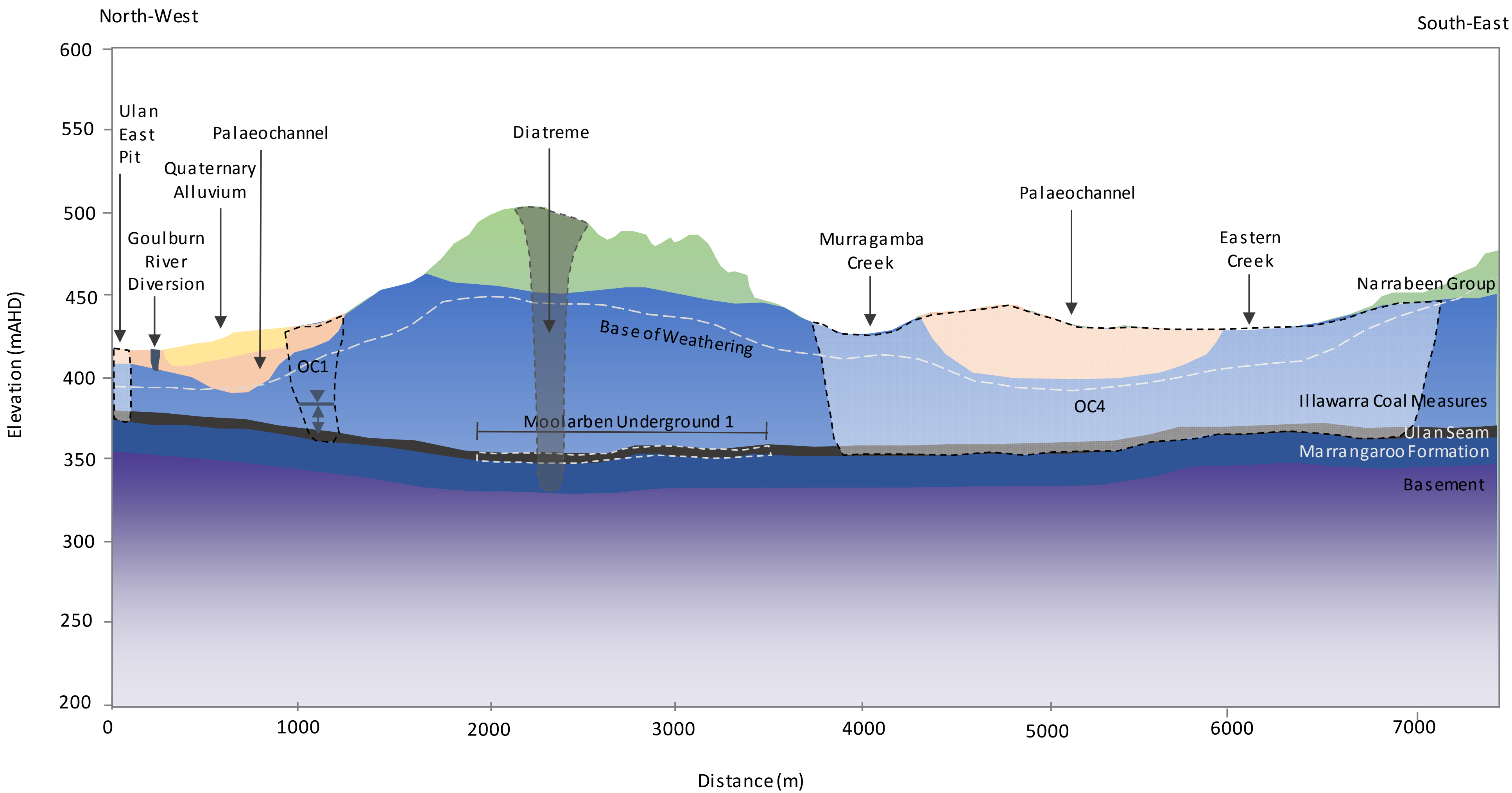


Figure 12a Conceptual Cross Section through OC1, UG1 and OC4

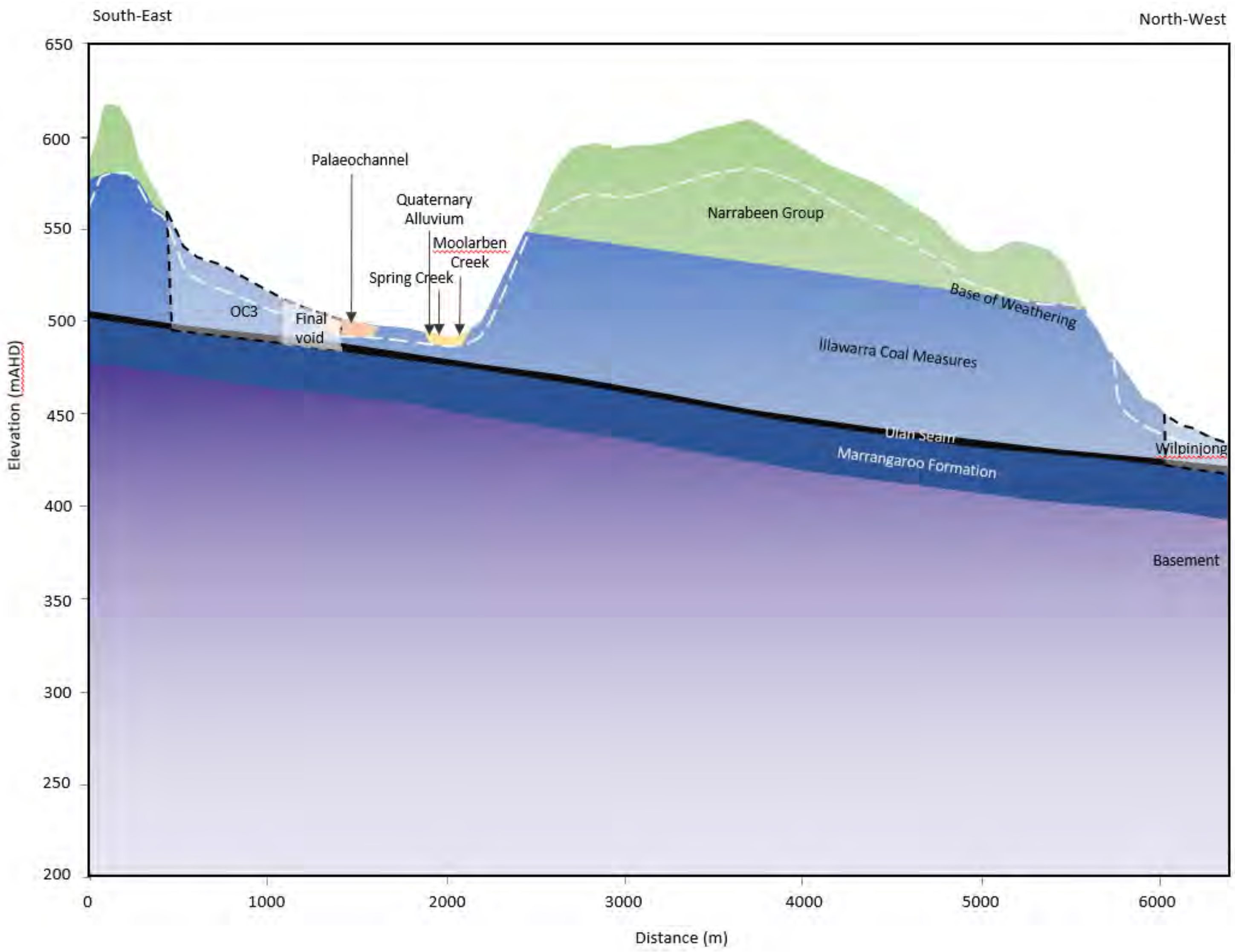
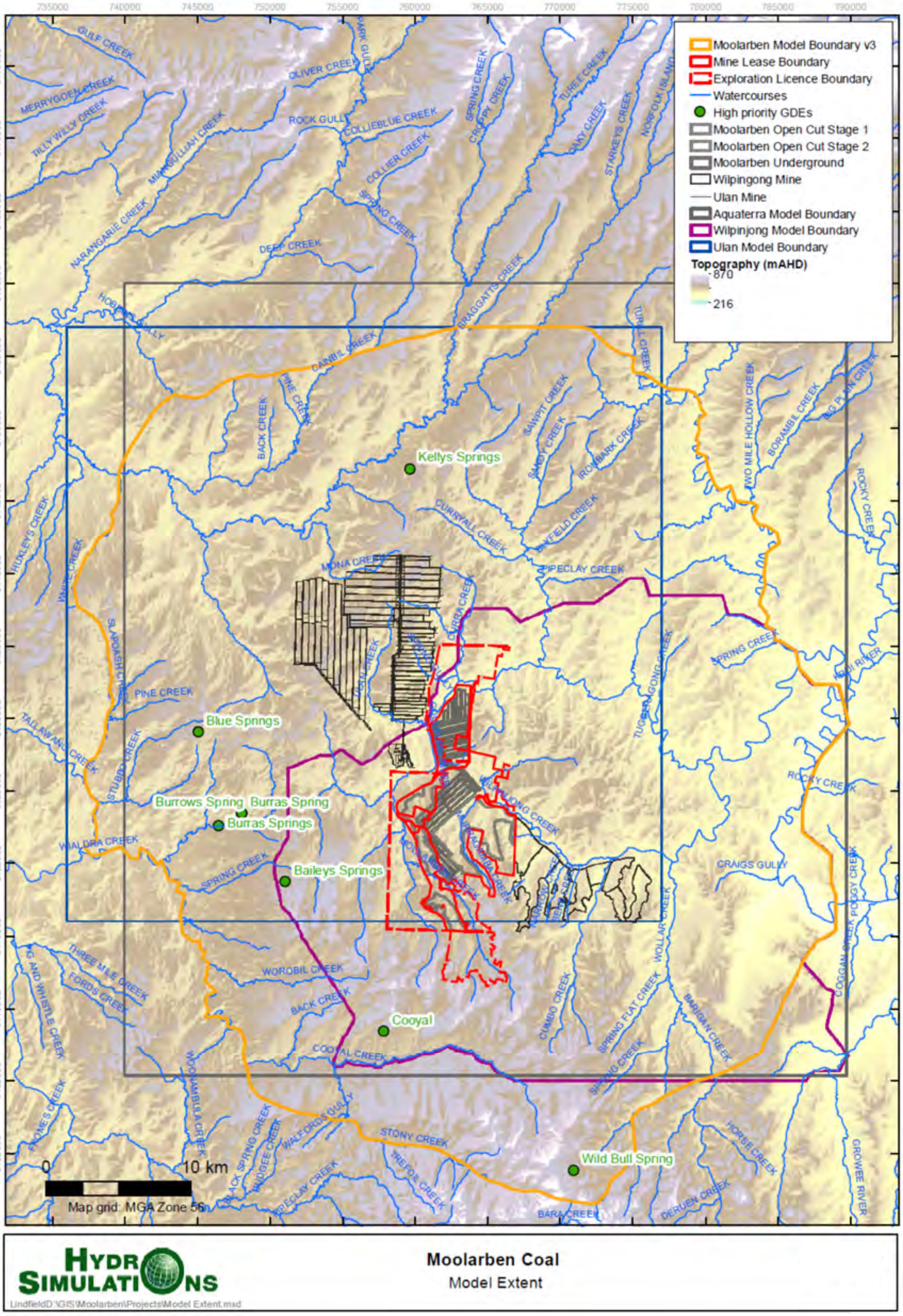
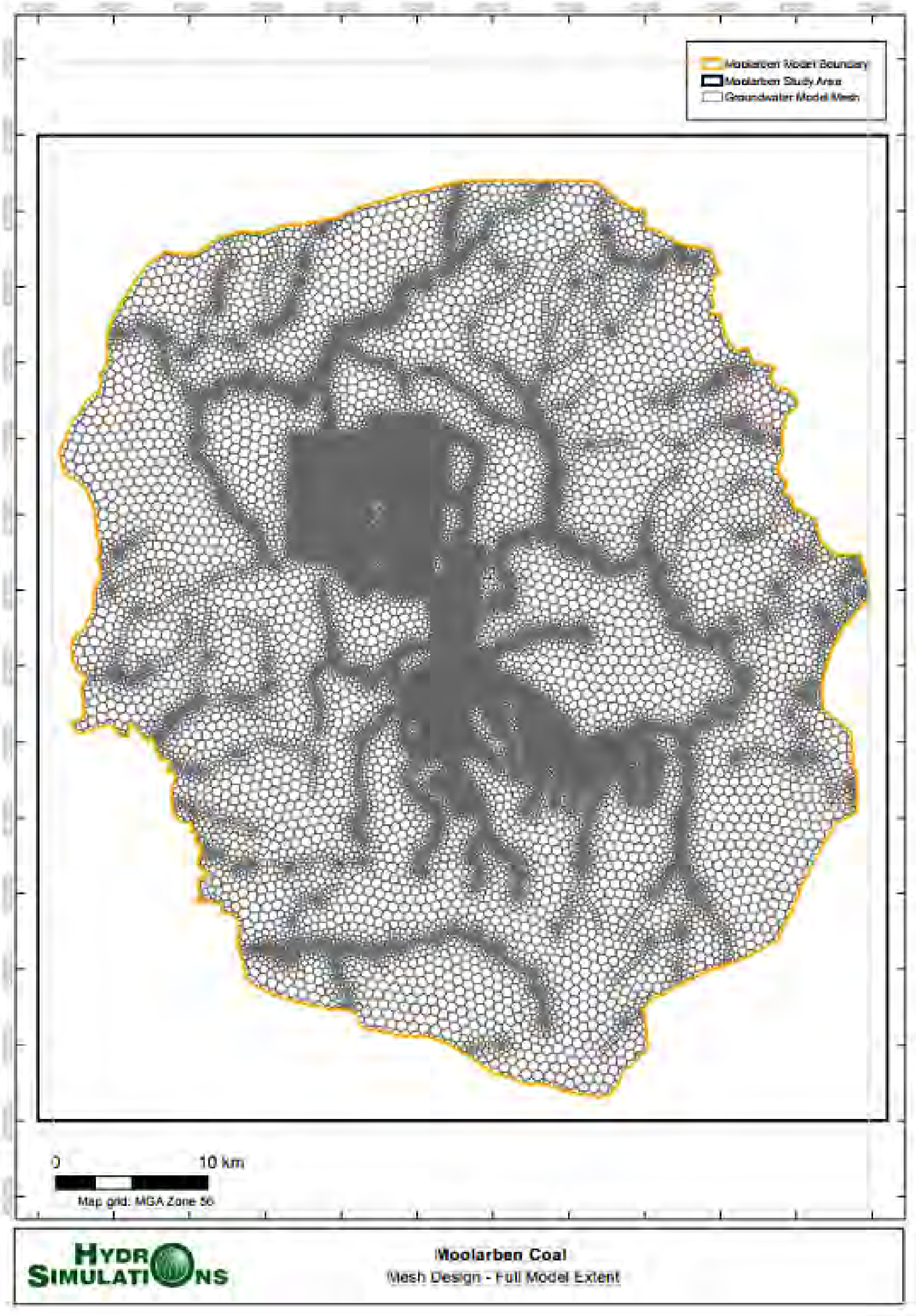


Figure 12b Conceptual Cross Section through OC3



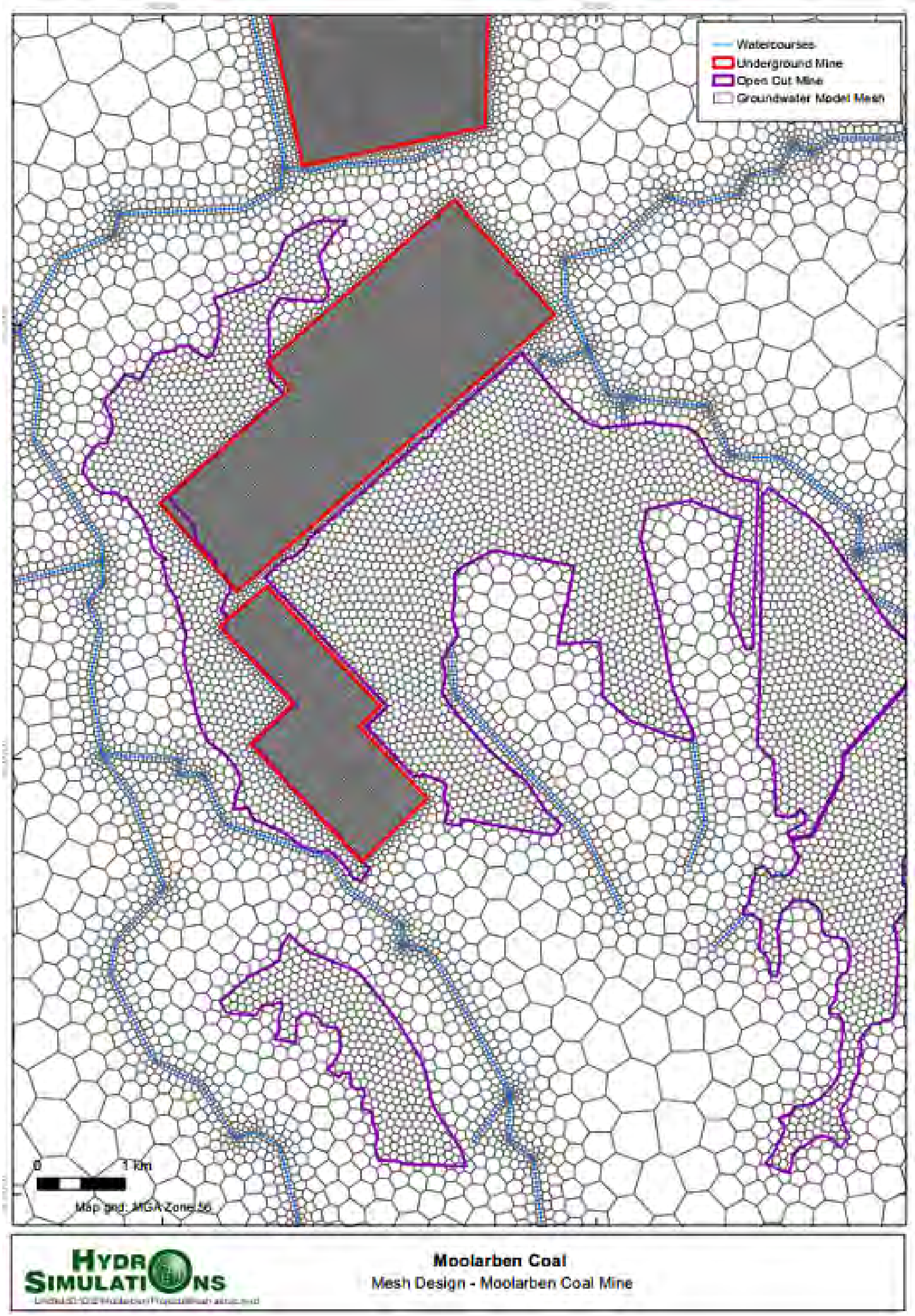
Note: Figure shows approved OC3

Figure 13 Groundwater Model Extents



Note: Figure shows approved OC3

Figure 14a Groundwater Model Mesh Design – Full Model Extent



Note: Figure shows approved OC3

Figure 14b Groundwater Model Mesh Design –Moolarben Coal Complex

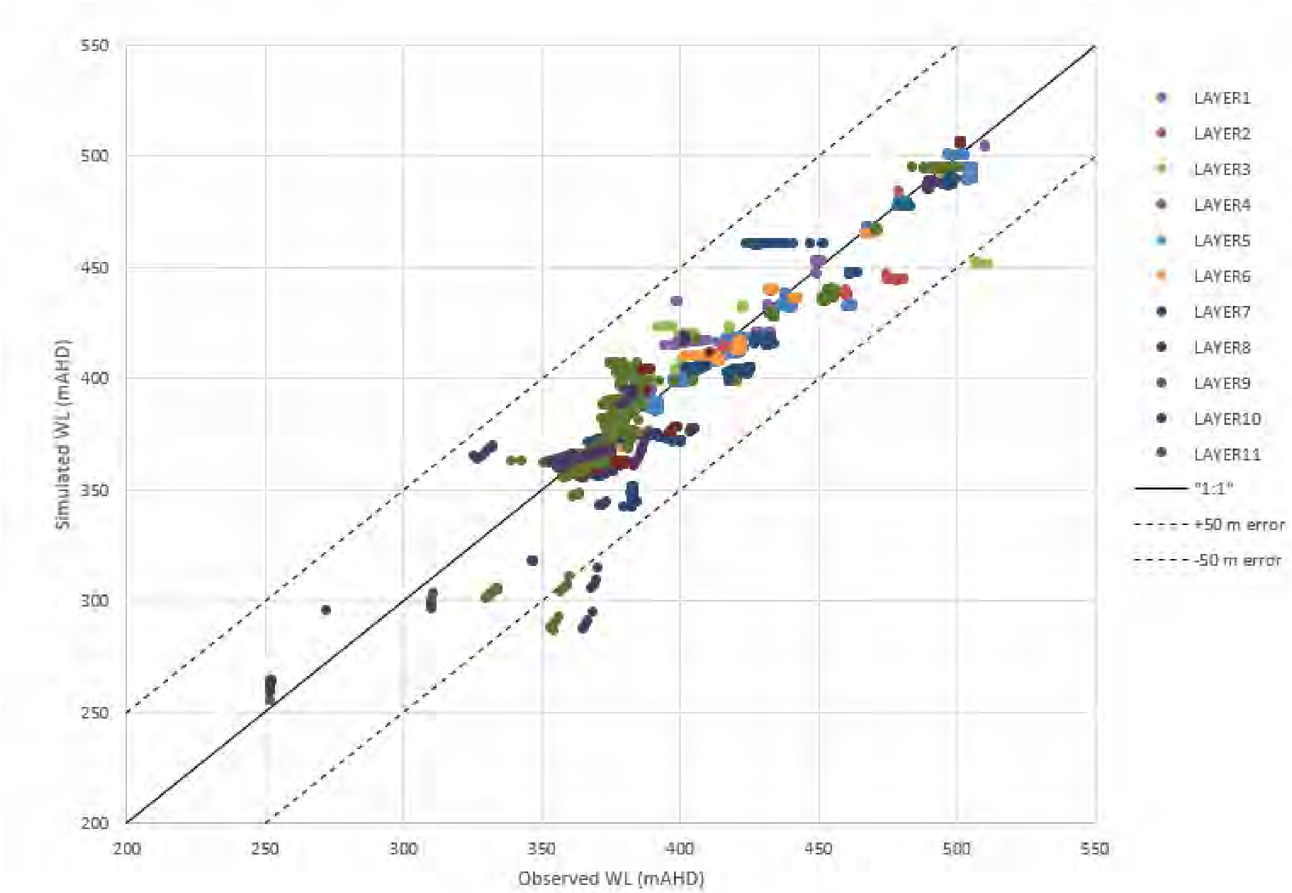


Figure 15 Scattergram of Observed and Simulated Heads

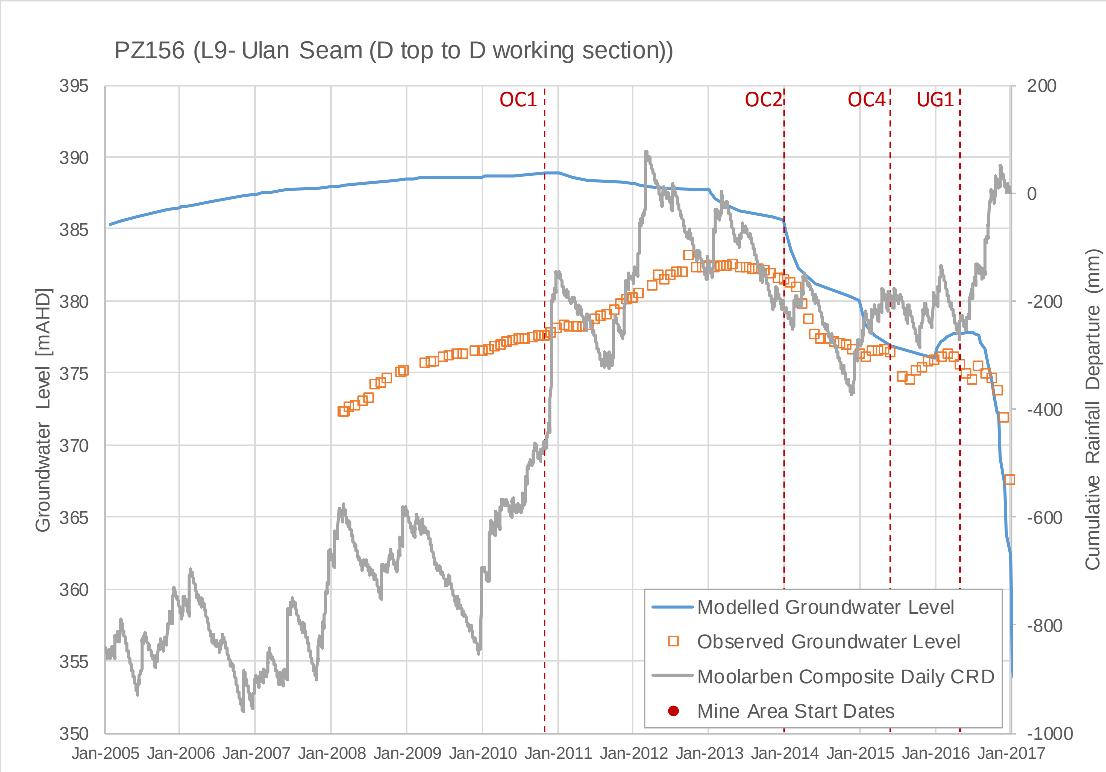


Figure 16 **Modelled and Observed Groundwater Levels at PZ156 (UG1)**

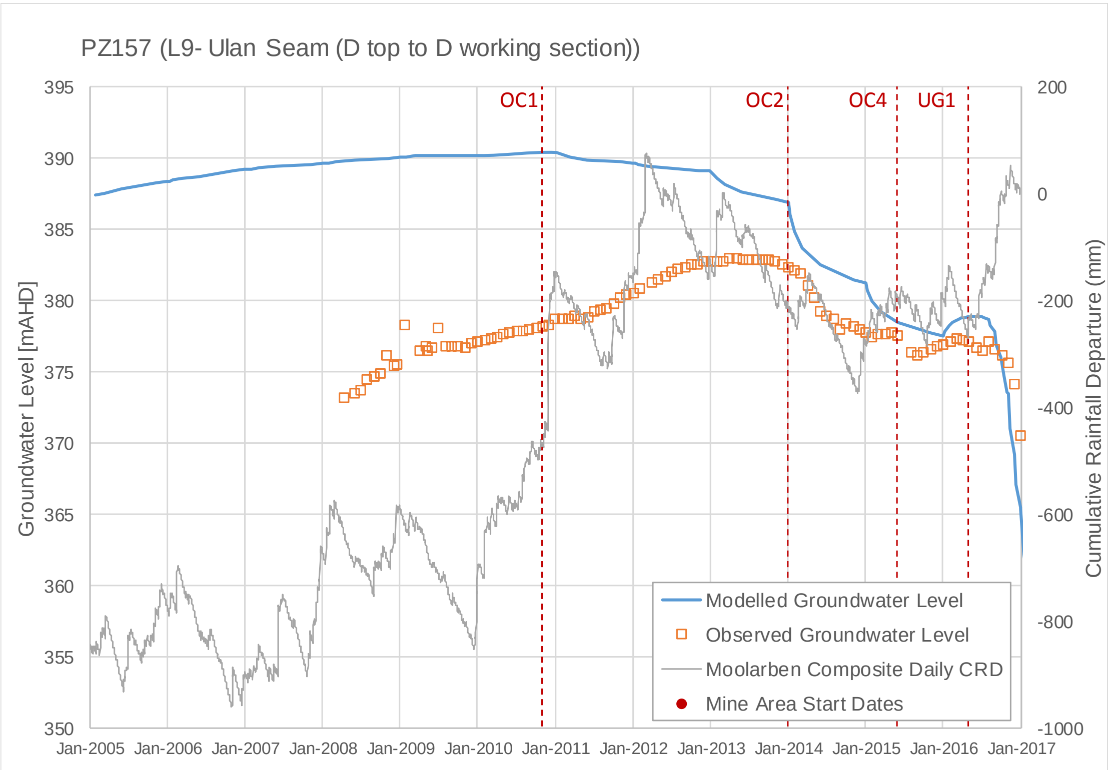


Figure 17 **Modelled and Observed Groundwater Levels at PZ157 (UG1)**

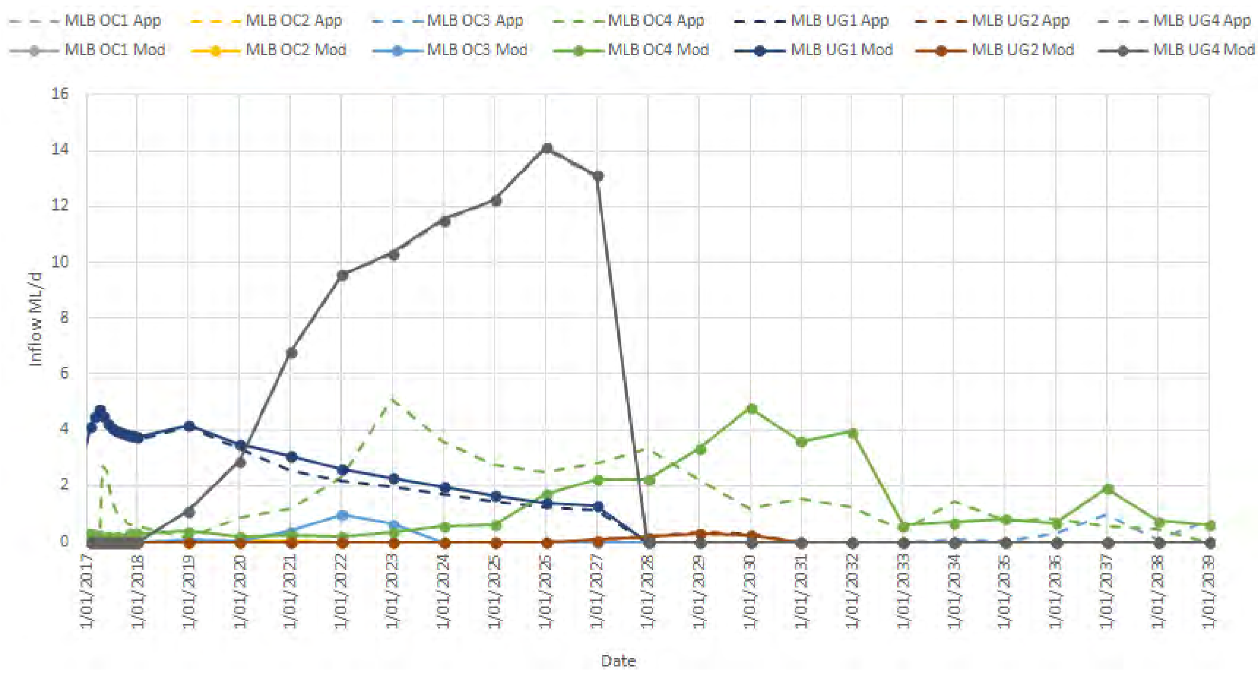


Figure 18a Predicted Moolarben Mine Inflows – Approved and Modification Scenarios

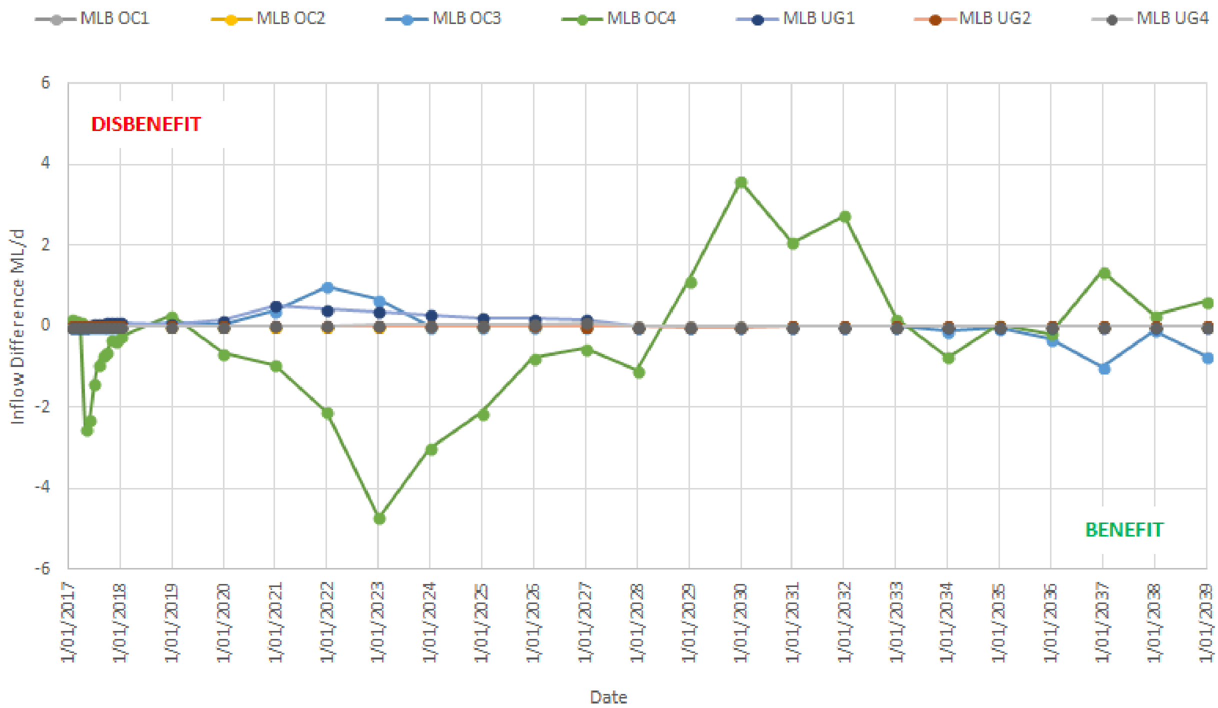


Figure 18b Predicted Changes in Moolarben Mine Inflows due to the Modification

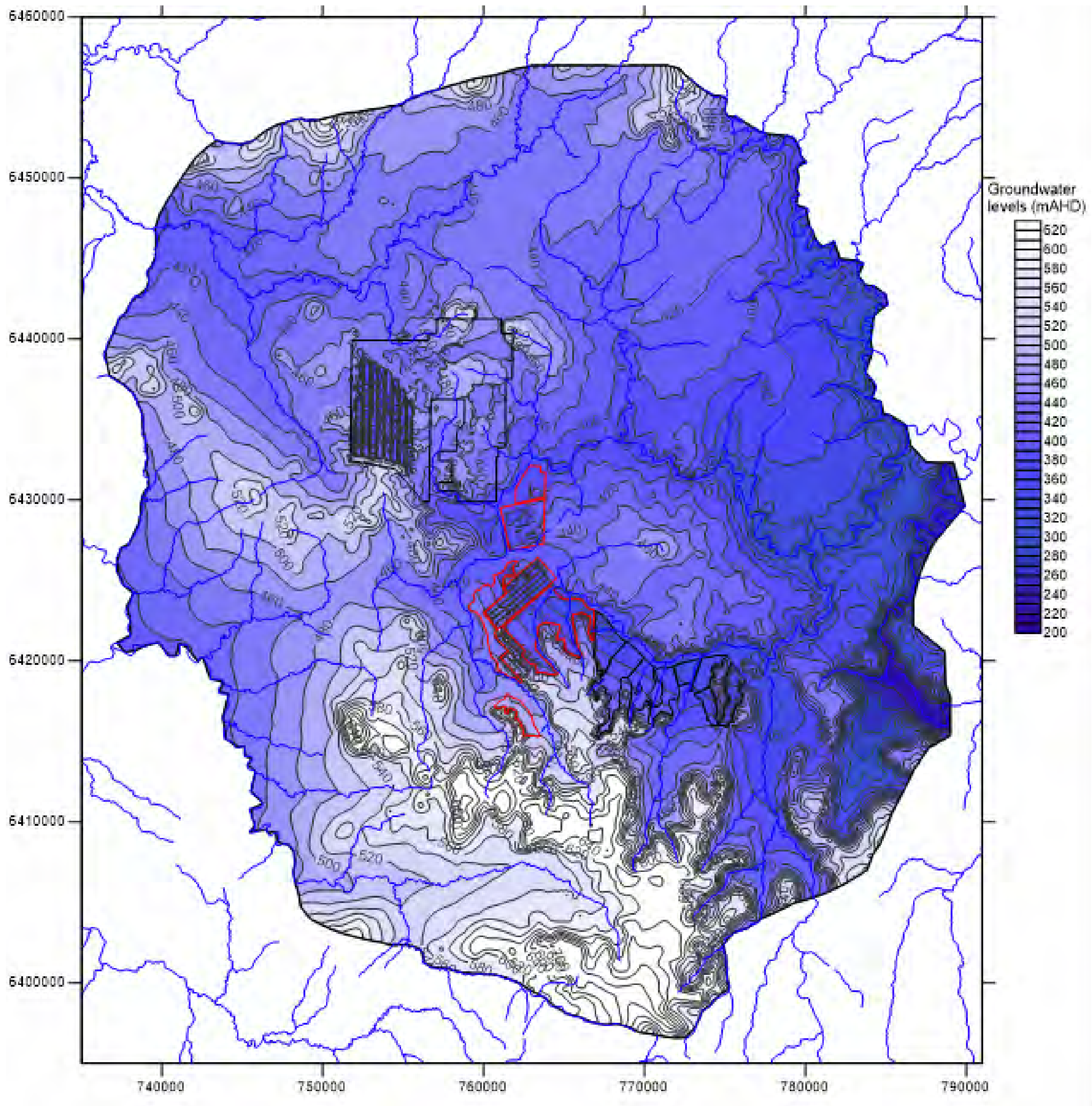
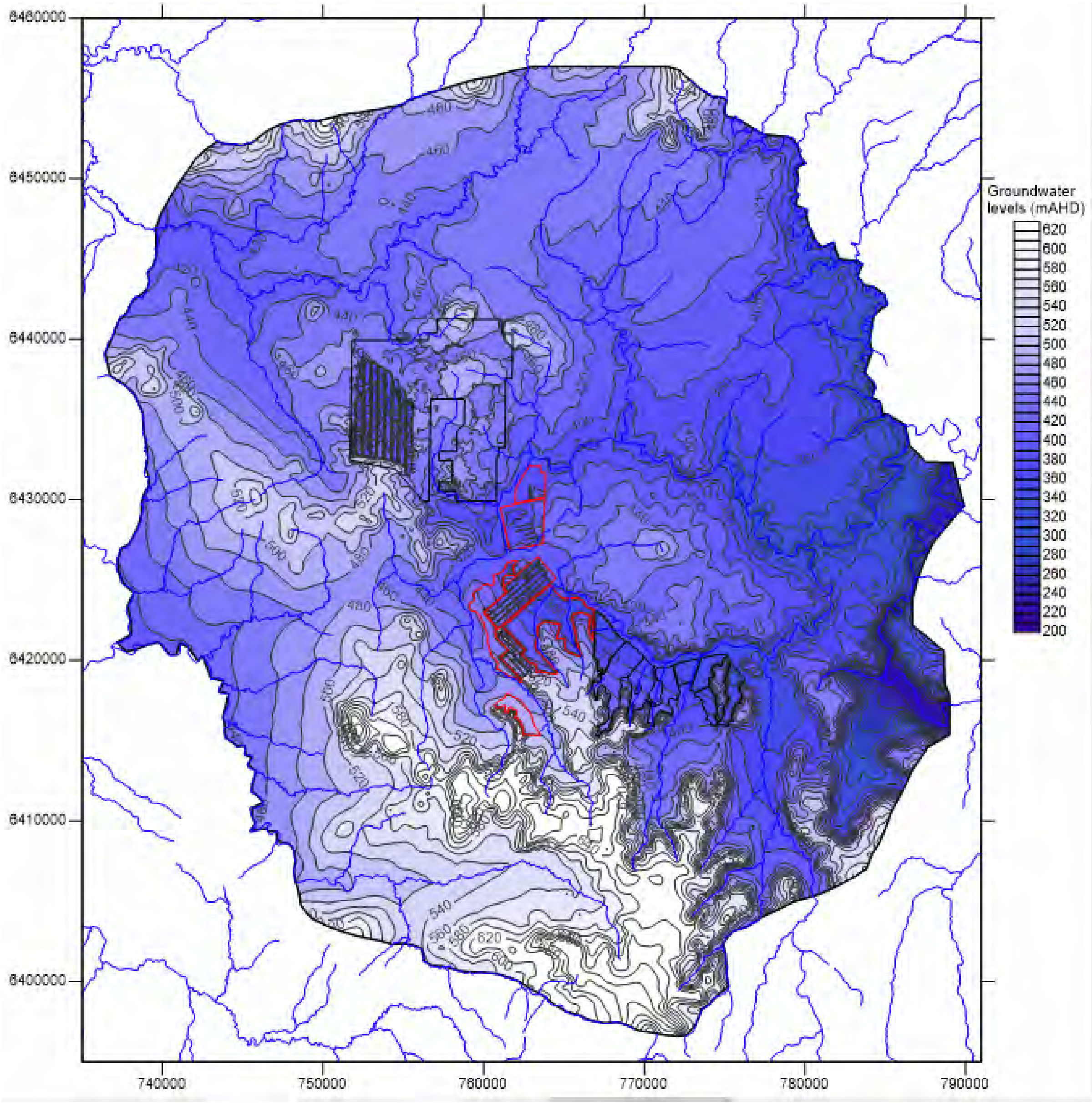
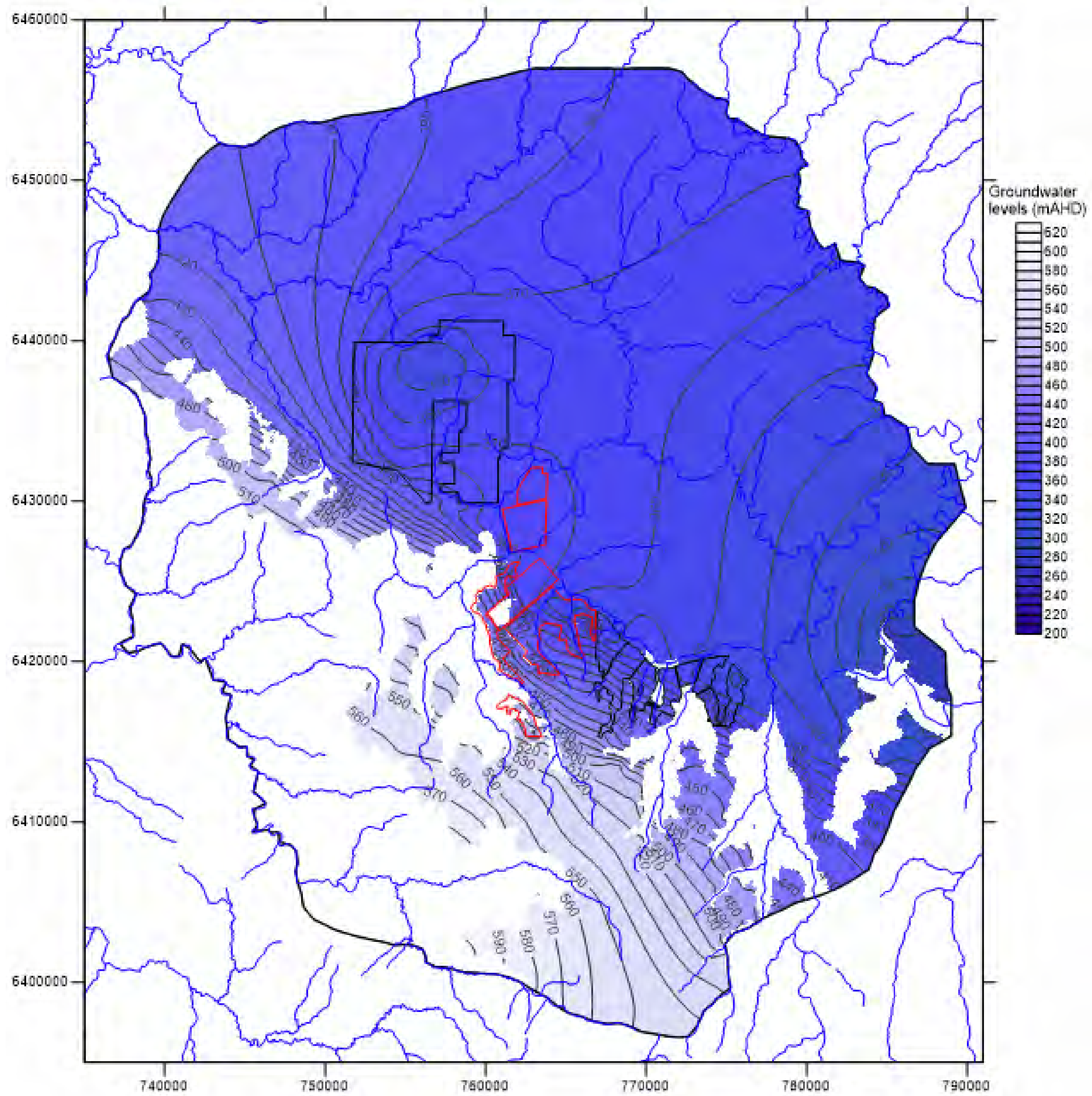


Figure 19a Predicted Water Table (mAHD) at the end of MCC Mining – Approved Scenario



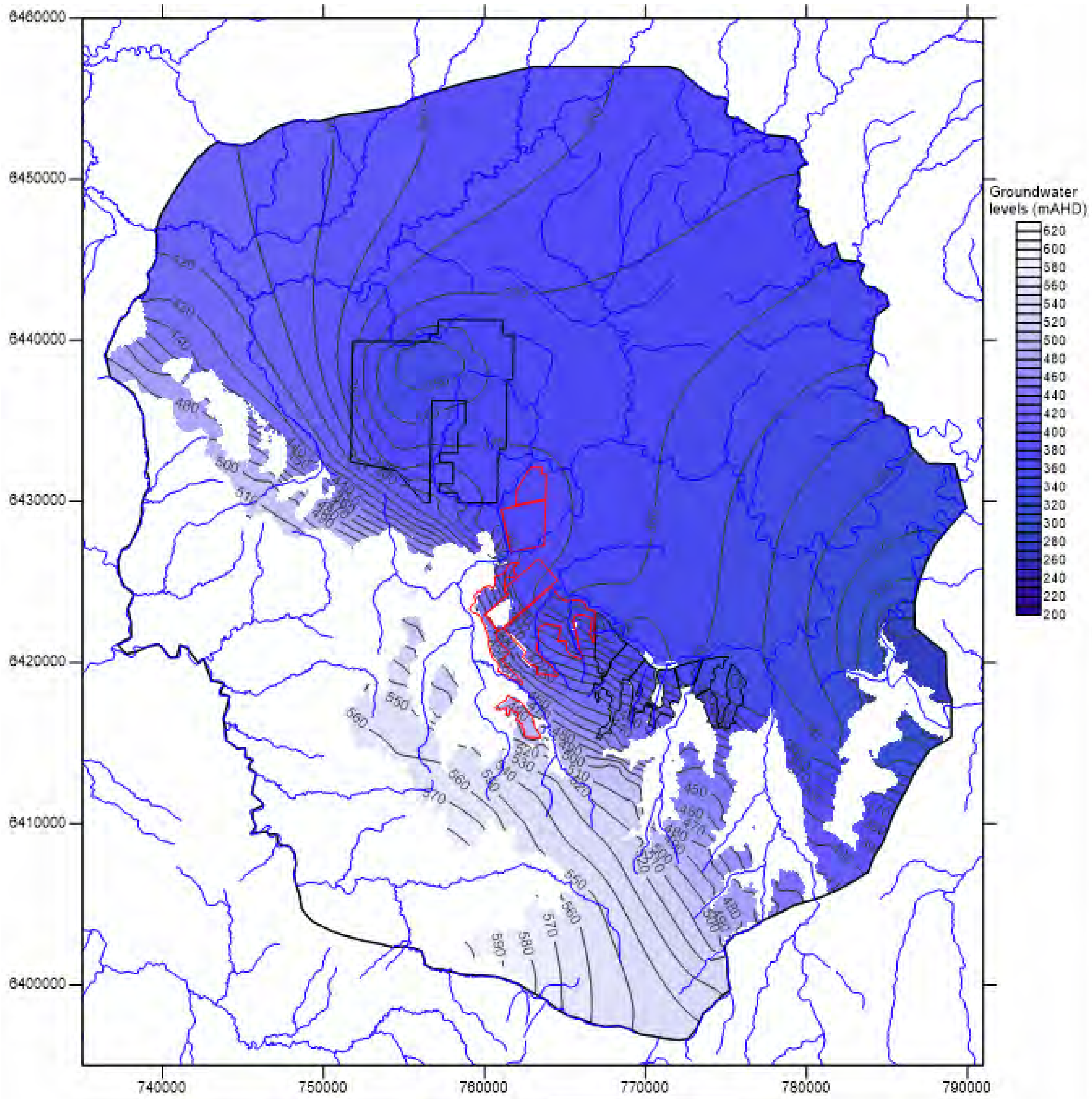
Note: Figure shows approved OC3

Figure 19b Predicted Water Table (mAHD) at the end of MCC Mining – Modification Scenario



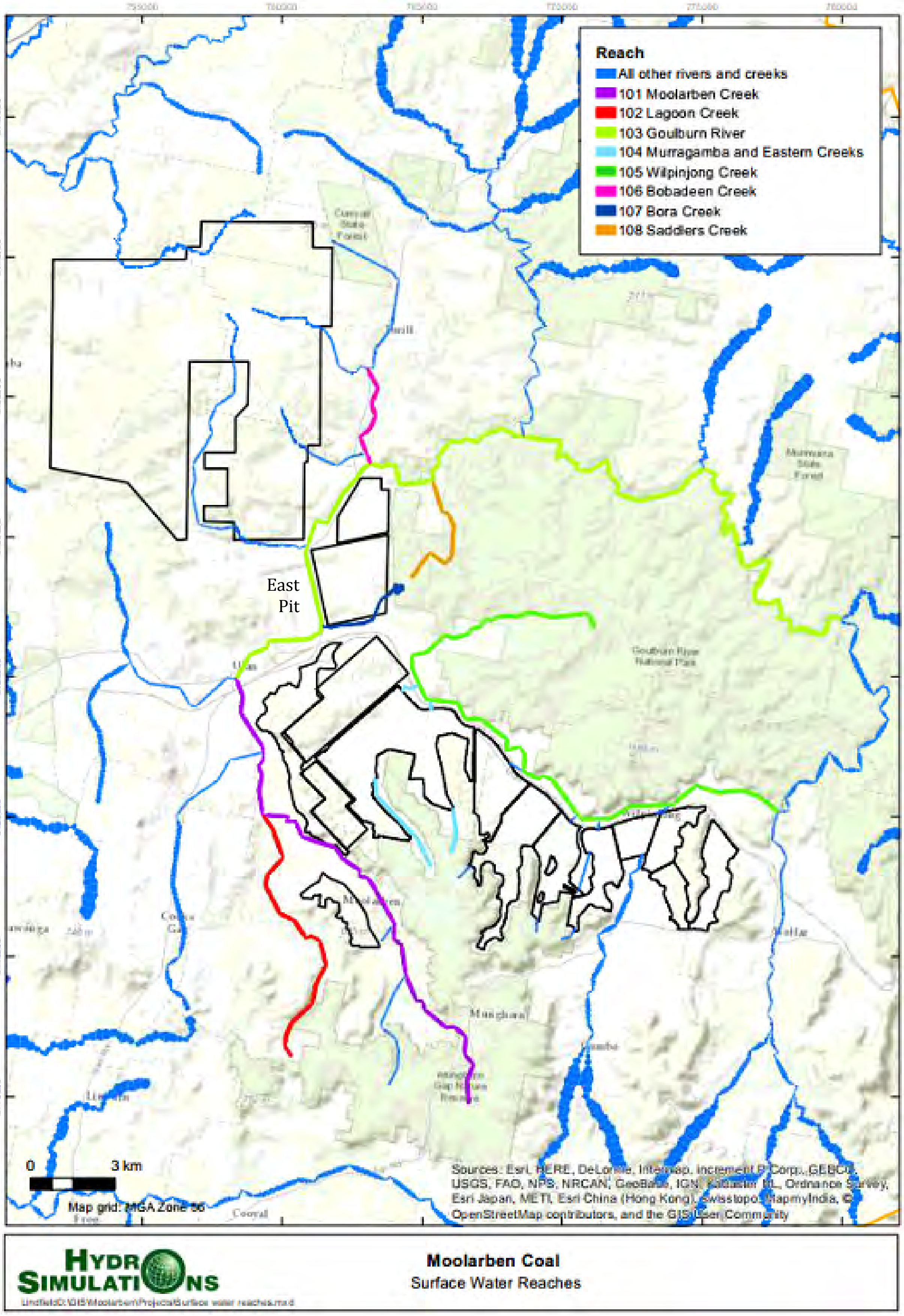
Note: Figure shows approved OC3

Figure 20a **Predicted Groundwater Level (mAHD) in the Ulan Seam (Model Layer 9) at the end of MCC Mining – Approved Scenario**



Note: Figure shows approved OC3

Figure 20b **Predicted Groundwater Level (mAHD) in the Ulan Seam (Model Layer 9) at the end of MCC Mining – Modification Scenario**



Note: Figure shows approved OC3

Figure 21 Surface Water Reaches

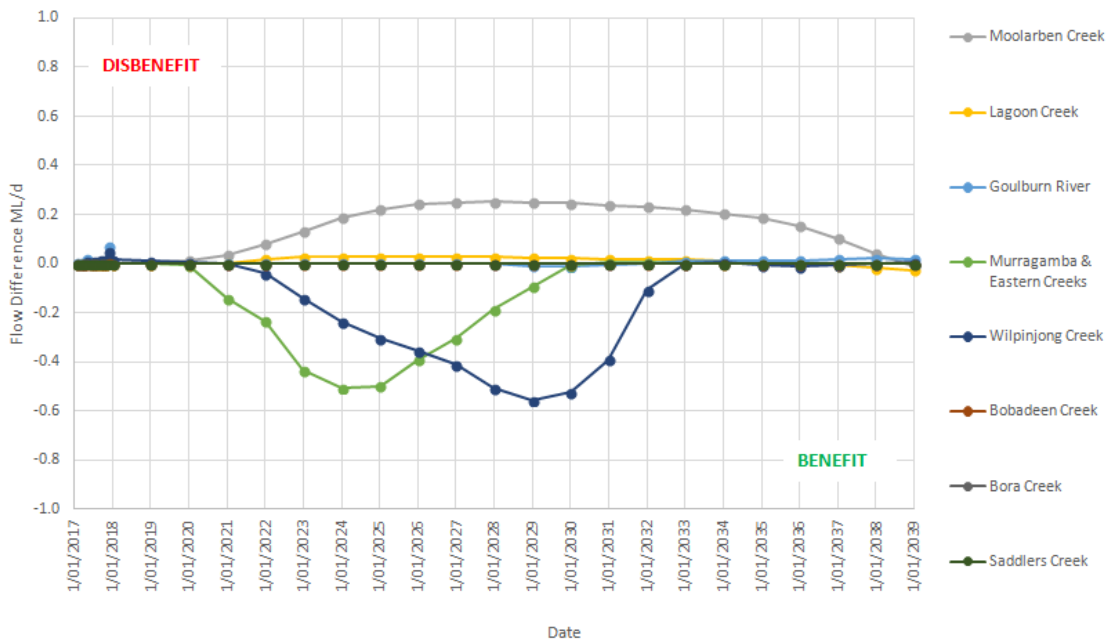
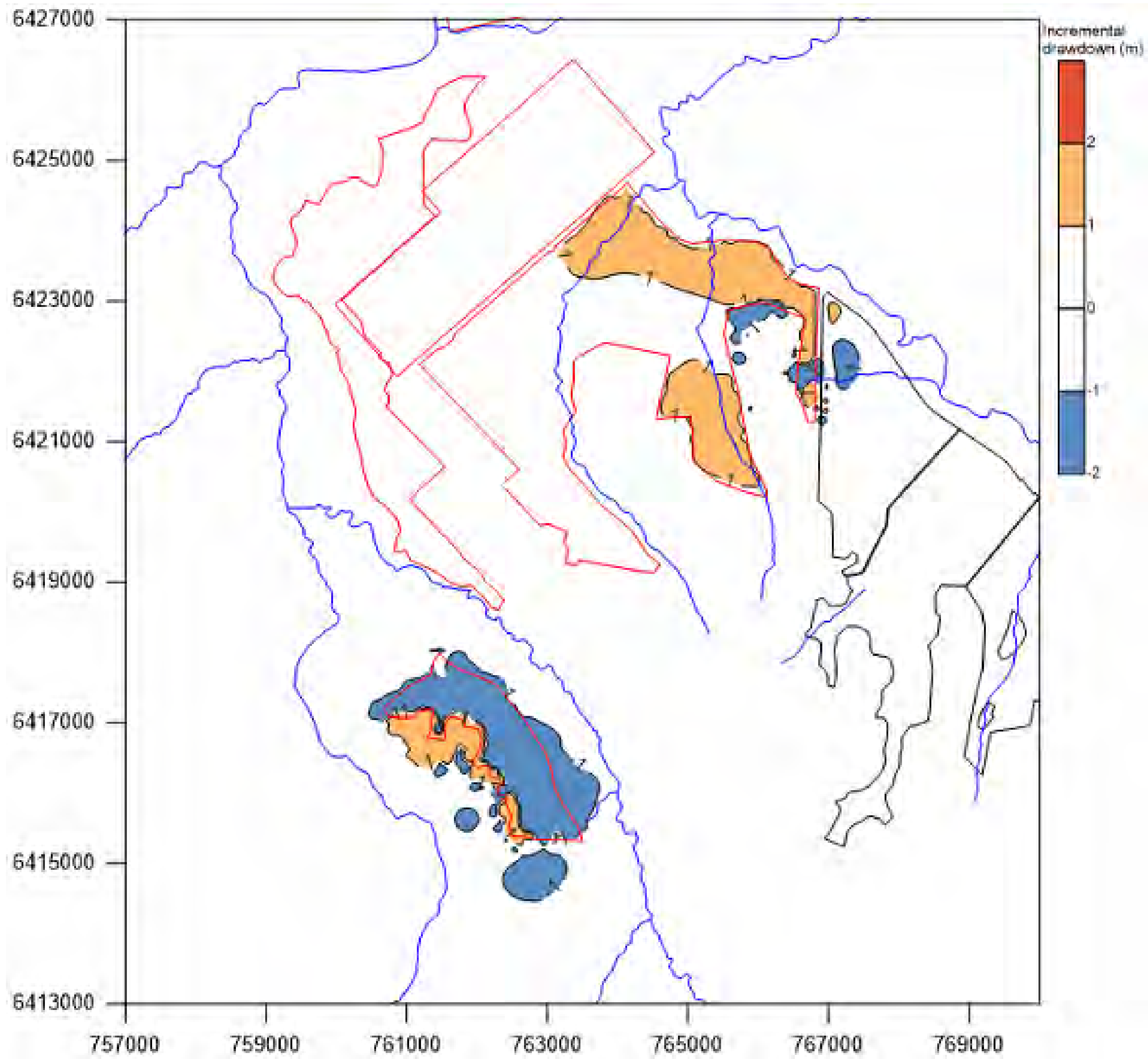
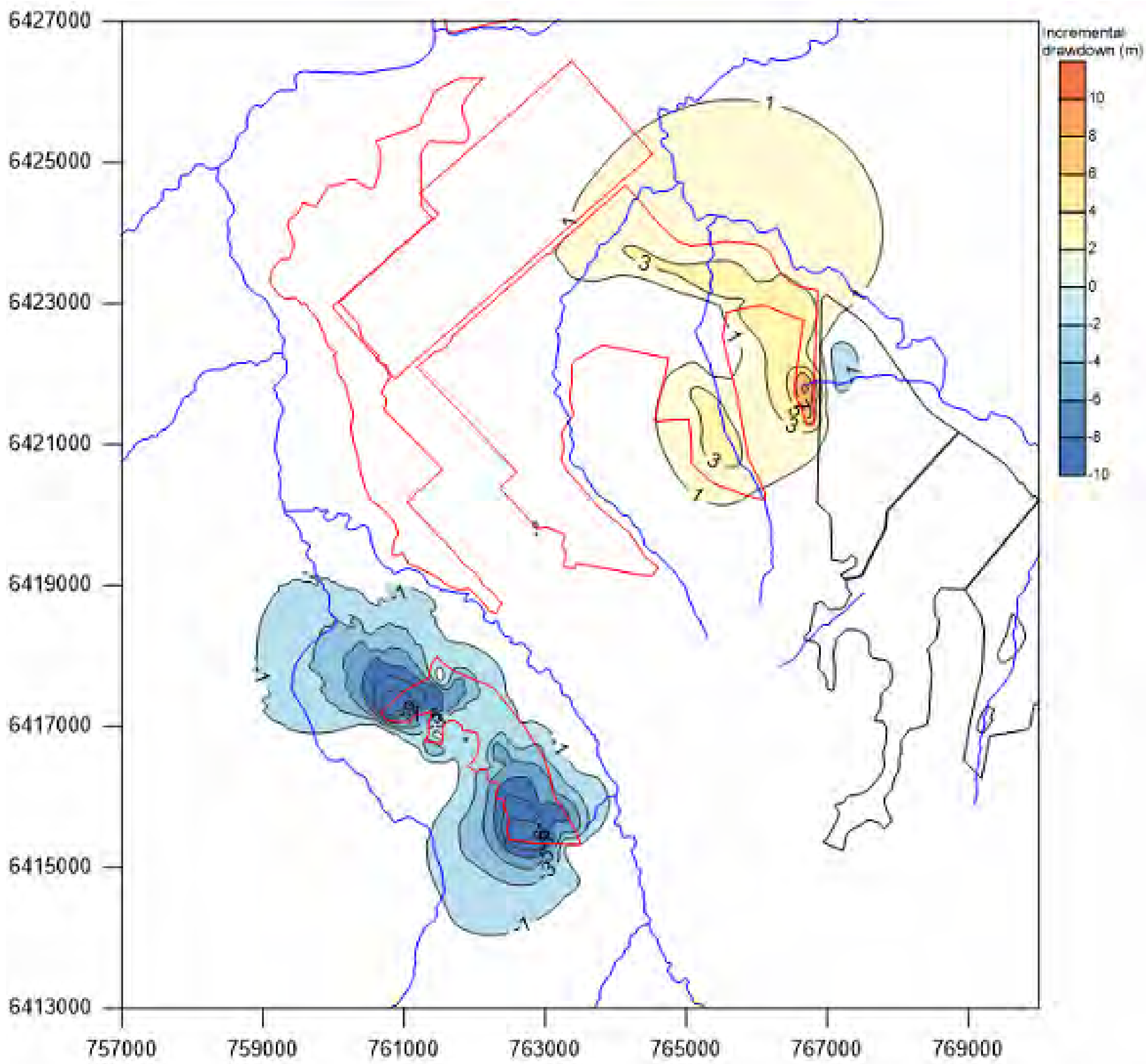


Figure 22 Predicted Changes in Baseflow/Leakage due to the Modification



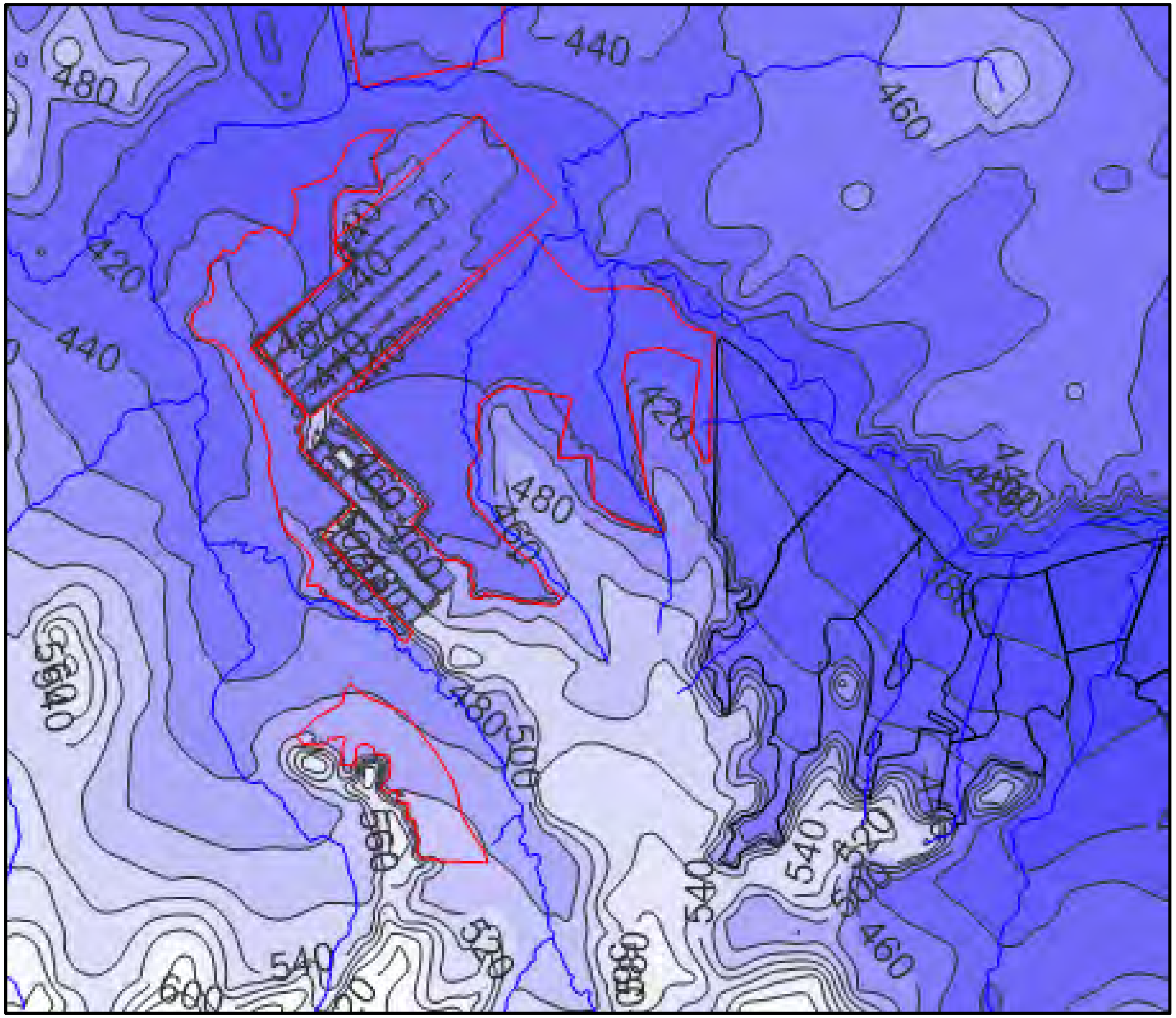
Note: Figure shows approved OC3

Figure 23 Incremental Water Table Drawdown (m) at the end of MCC Mining due to the Modification



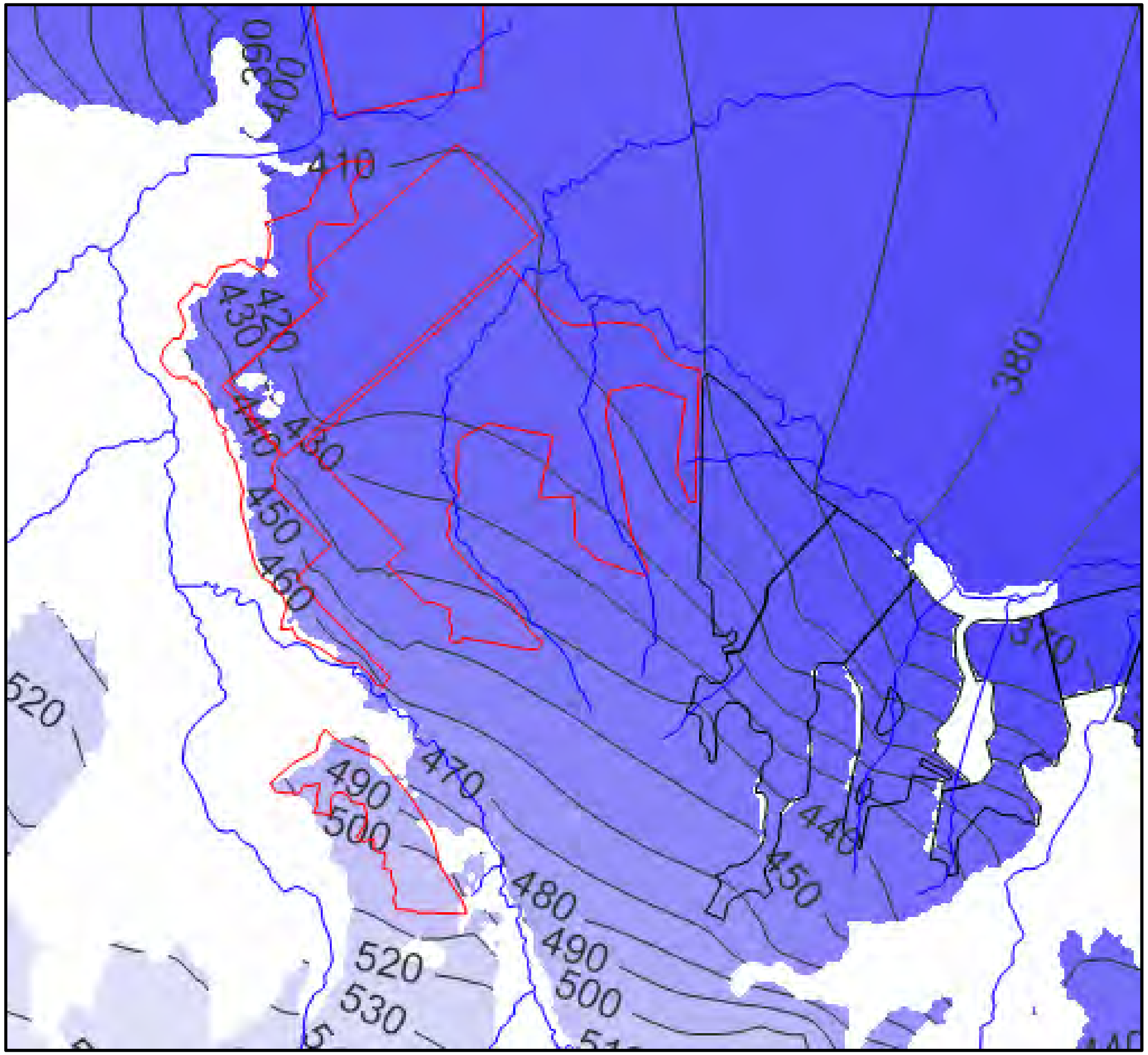
Note: Figure shows approved OC3

Figure 24 Incremental Drawdown (m) in the Ulan Seam at the end of MCC Mining due to the Modification



Note: Figure shows approved OC3

Figure 25 Predicted Water Table (mAHD) after 100 Years of Recovery



Note: Figure shows approved OC3

Figure 26 Predicted Groundwater Levels in the Ulan Seam (mAHD) after 100 years of Recovery

ATTACHMENT A

Moolarben Groundwater Level Hydrographs

HYDRO SIMULATIONS

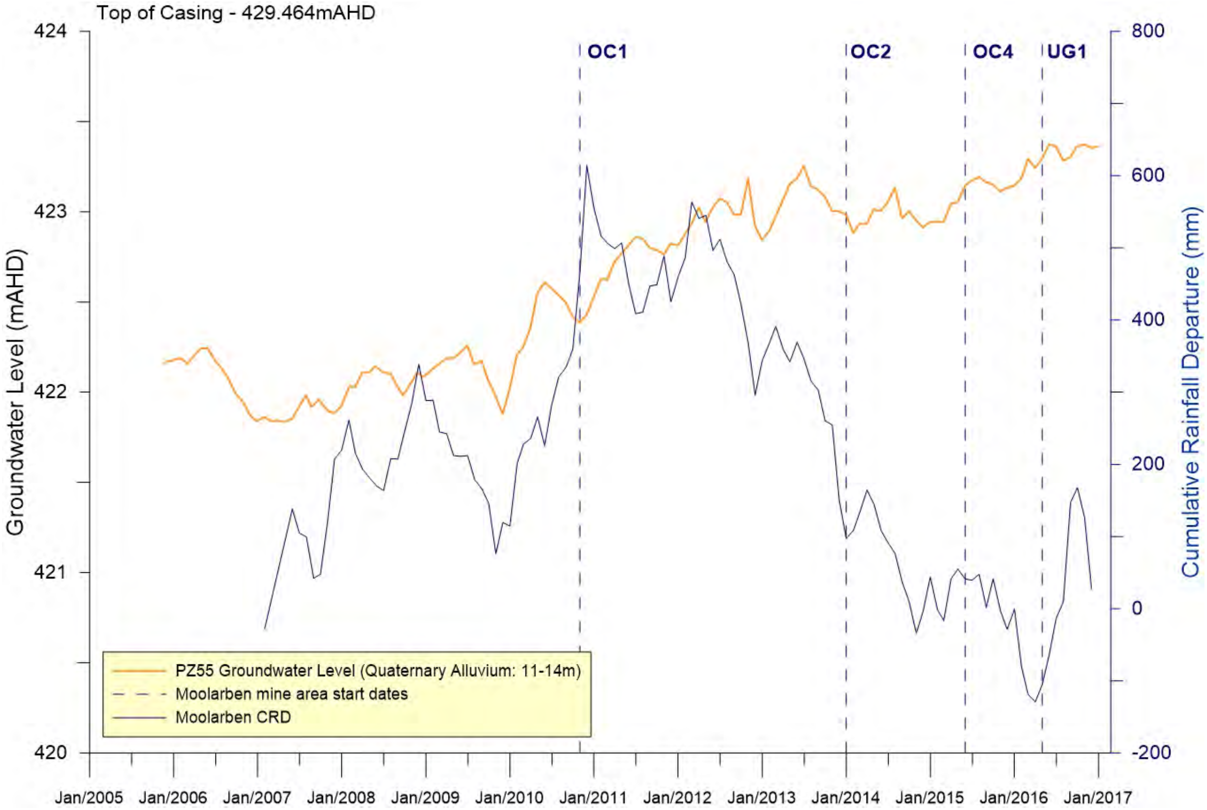


Figure A 1 - Alluvial Hydrographs PZ55

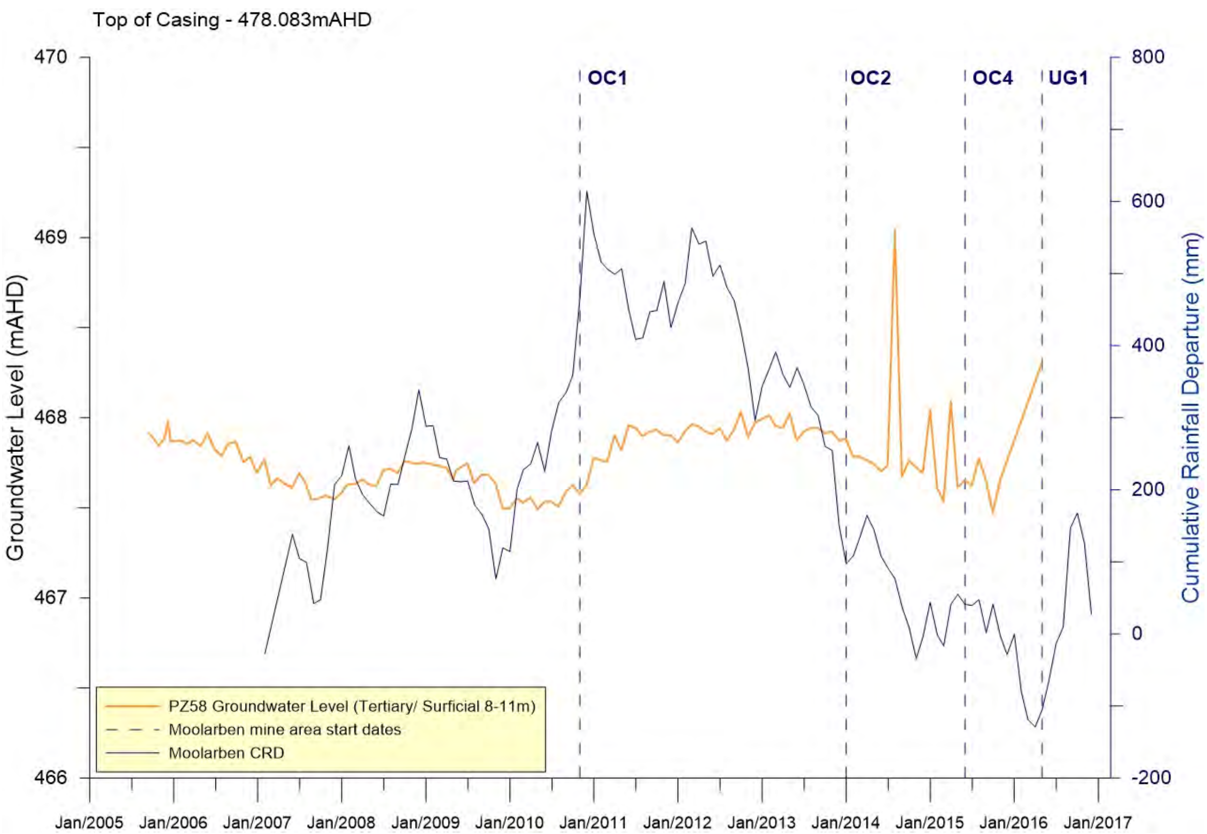


Figure A 2 - Alluvial Hydrographs PZ58

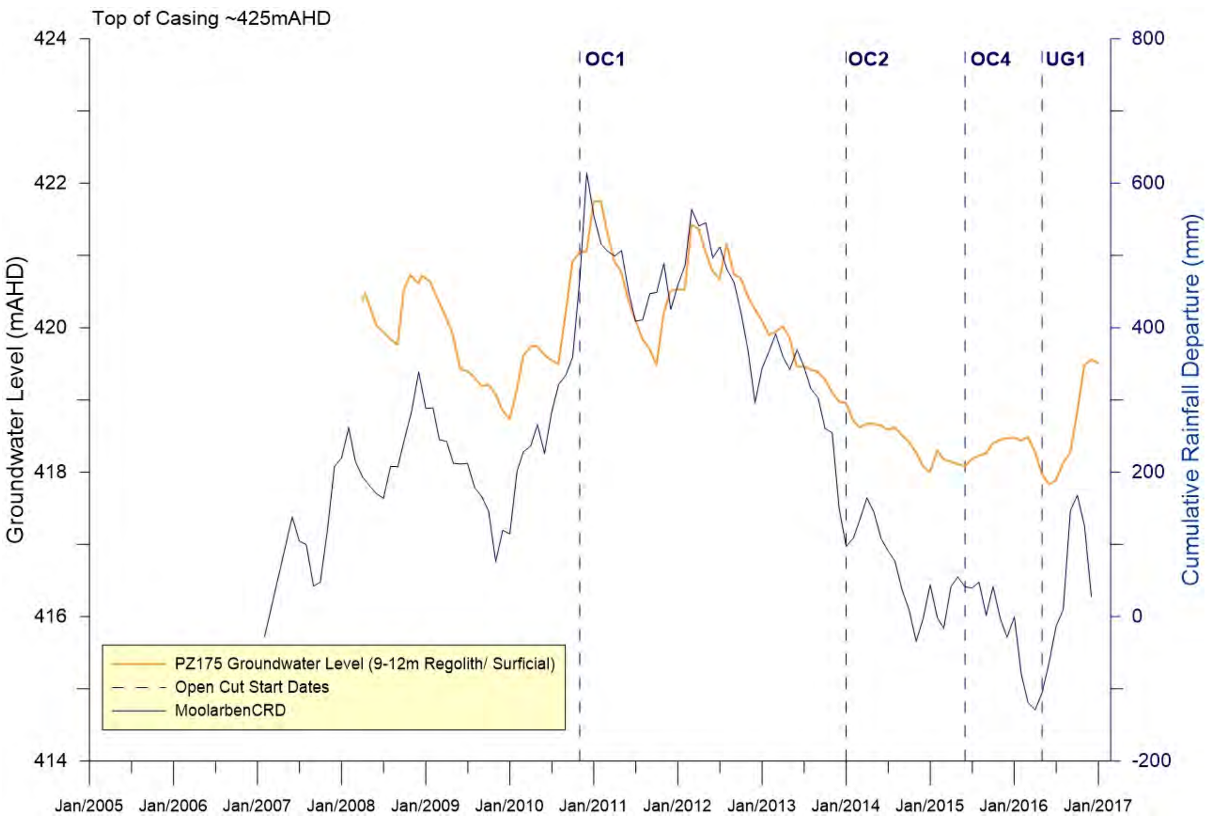


Figure A 3 Alluvial Hydrographs PZ175

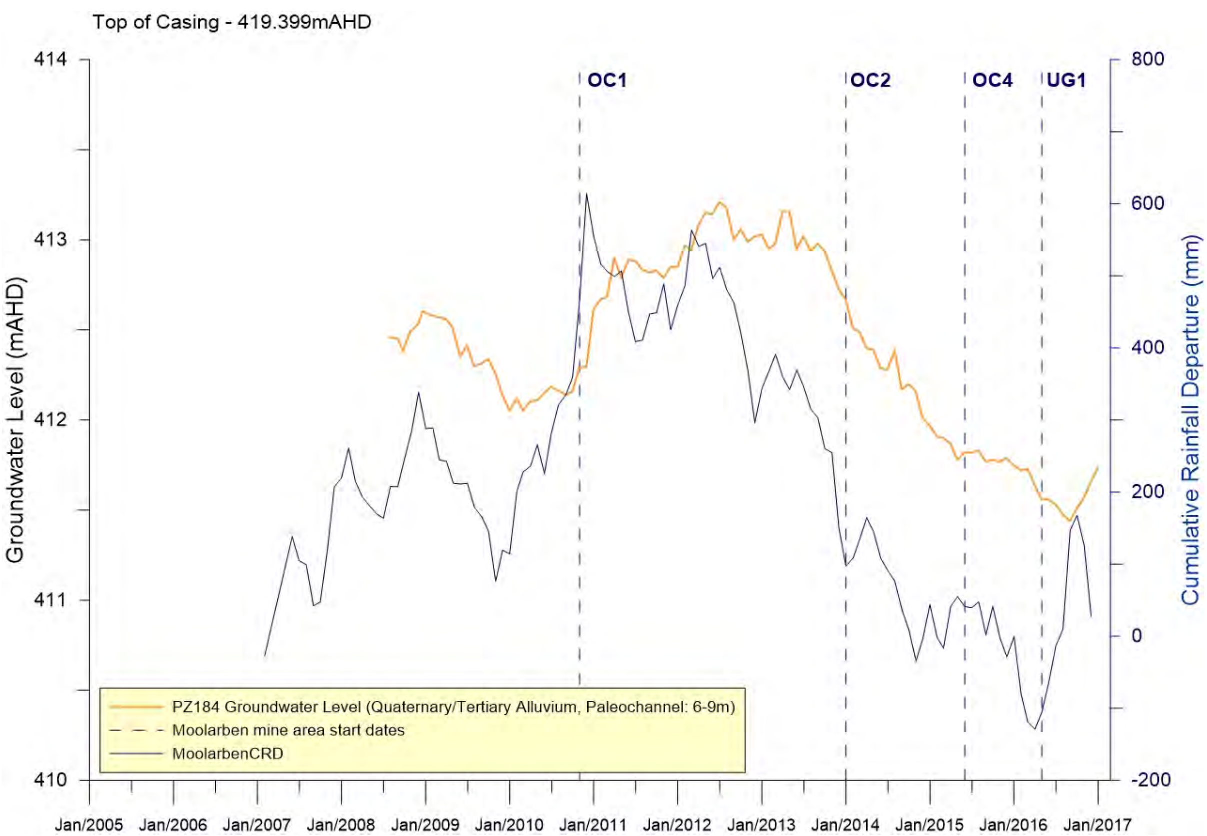


Figure A 4 - Alluvial Hydrographs PZ184

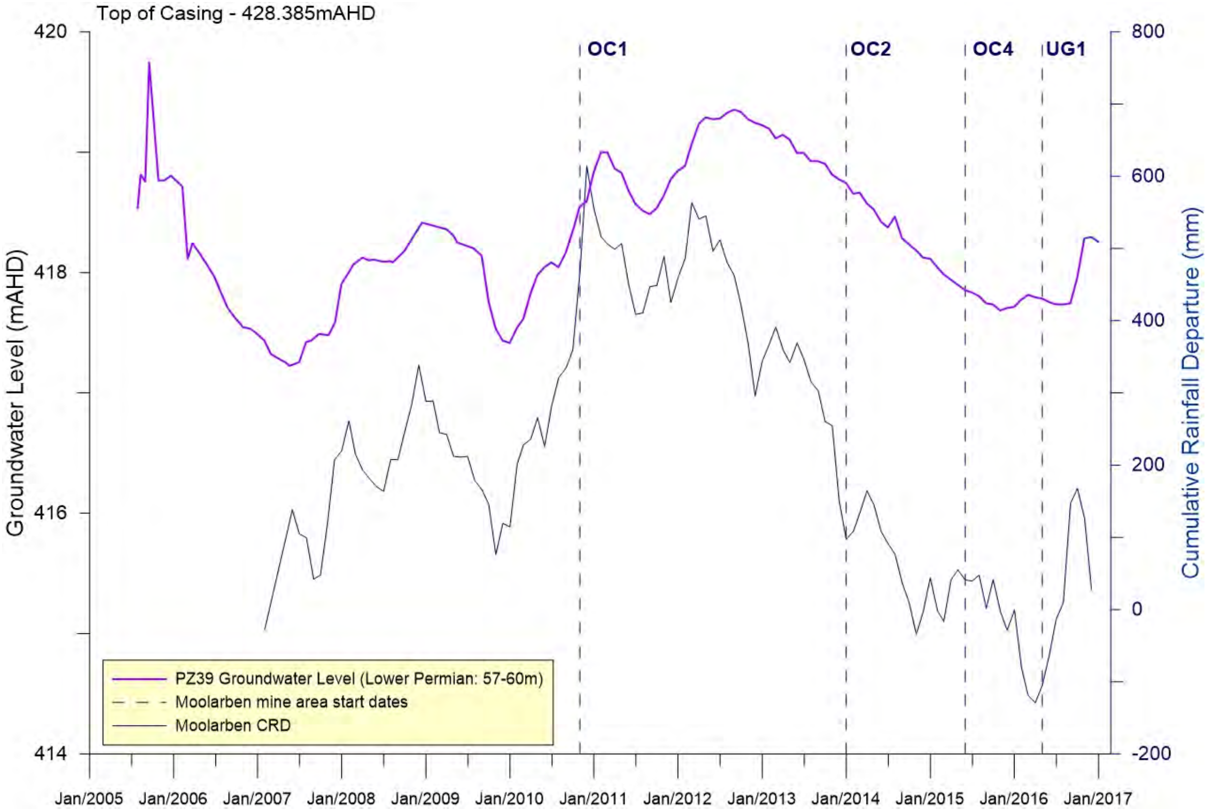


Figure A 5 - Permian Hydrographs PZ39

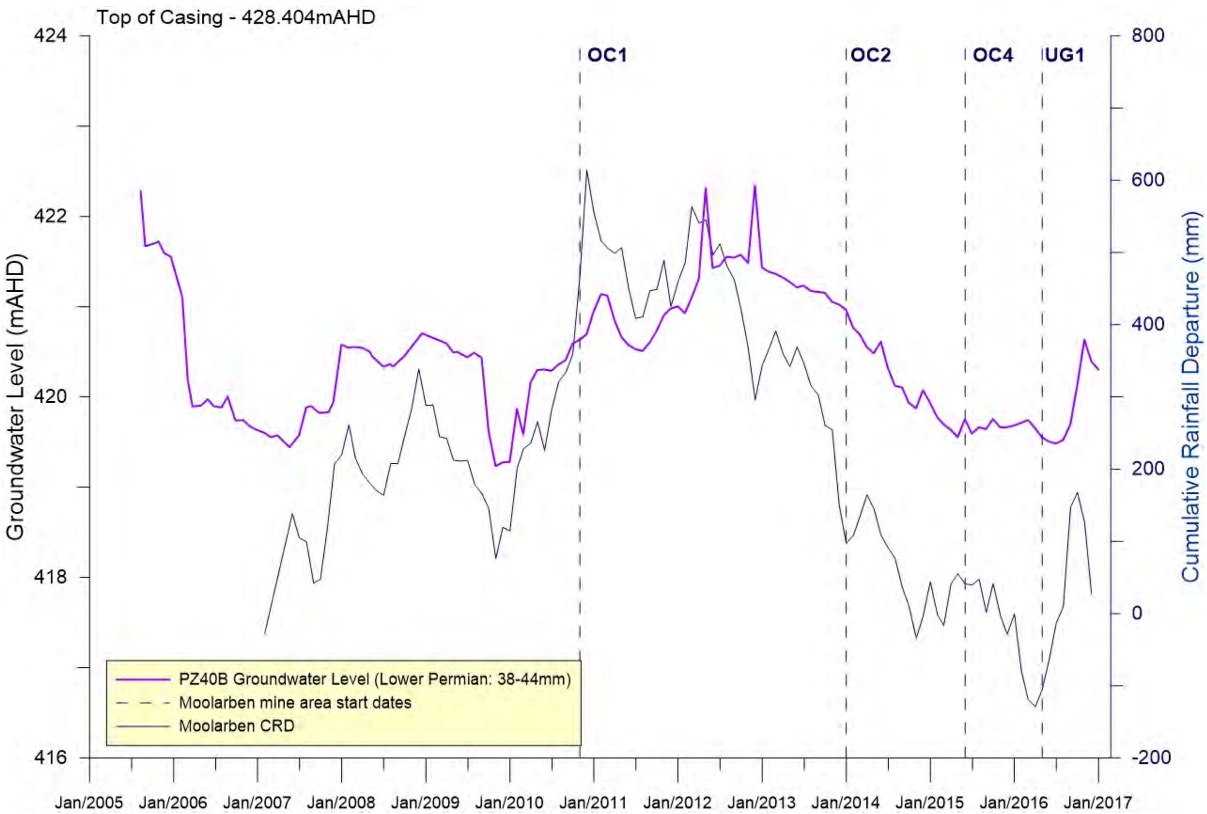


Figure A 6 - Permian Hydrographs PZ40B

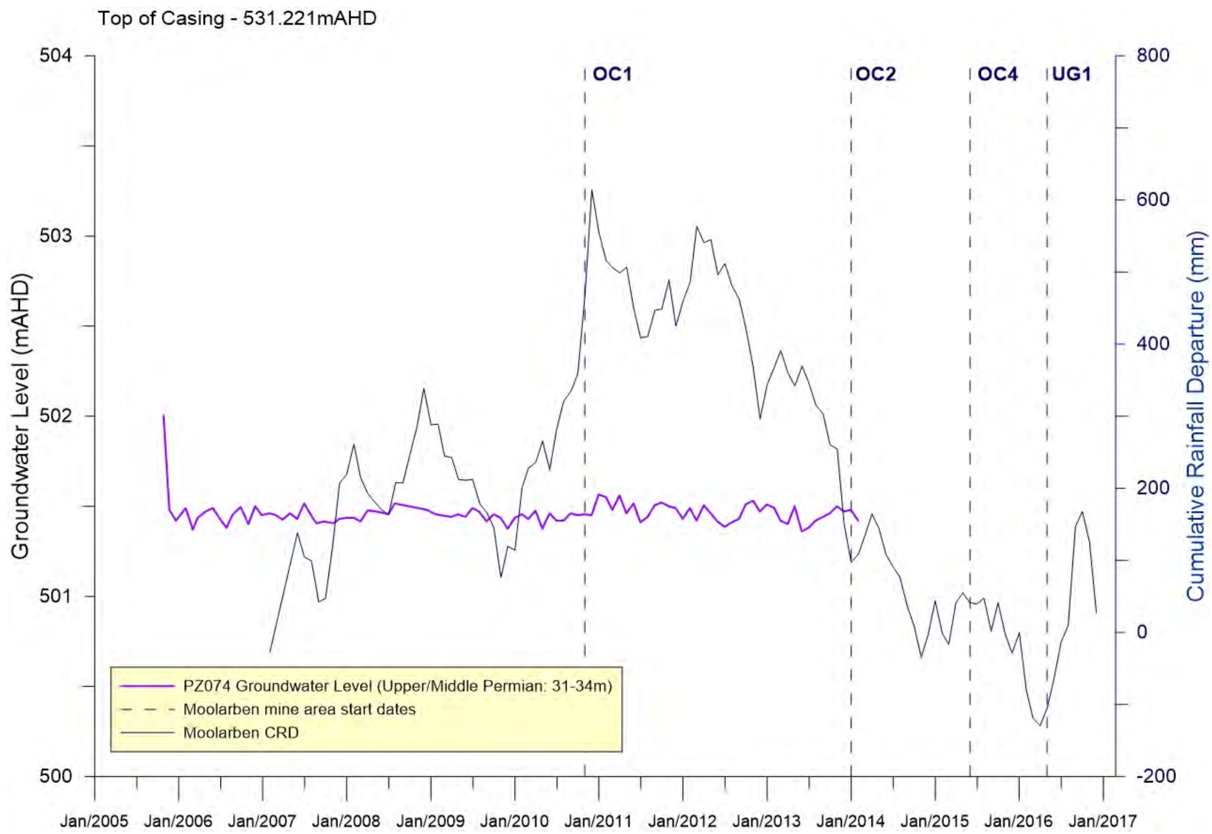


Figure A 7 - Permian Hydrographs PZ074

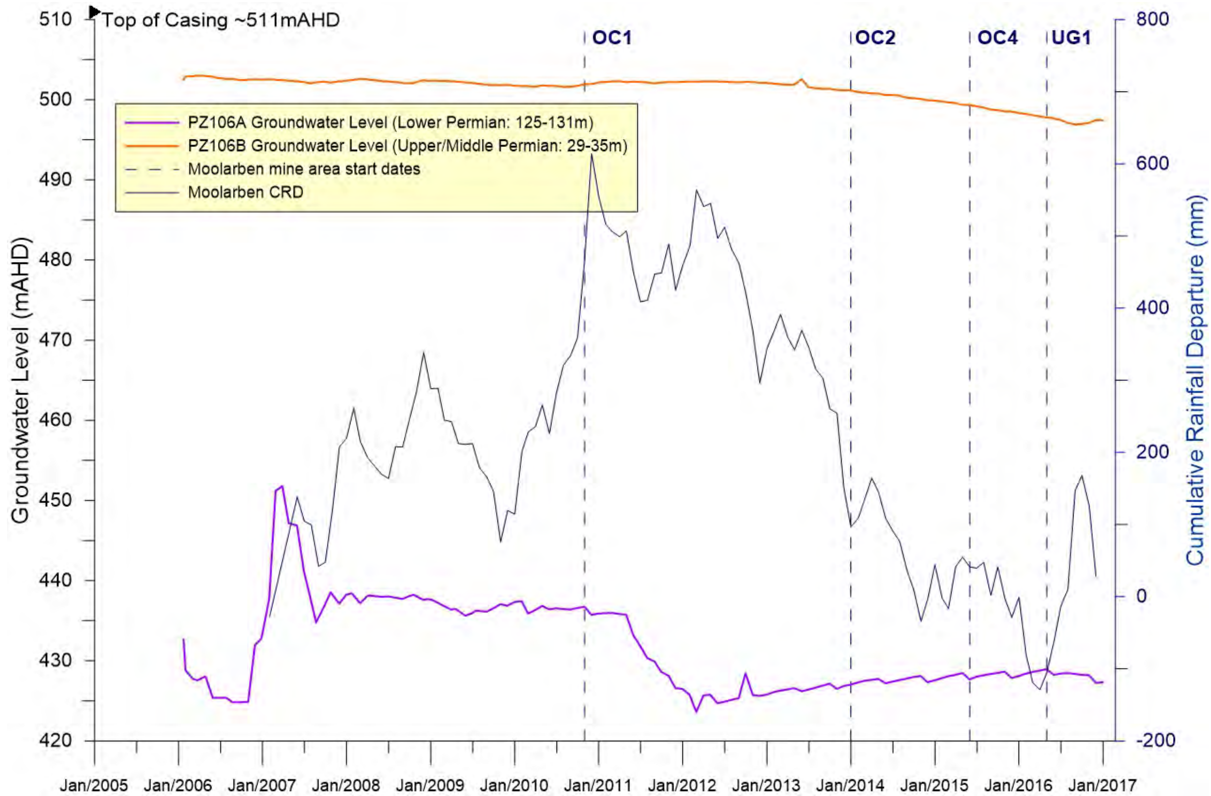


Figure A 8. - Permian Hydrographs PZ106A & PZ106B

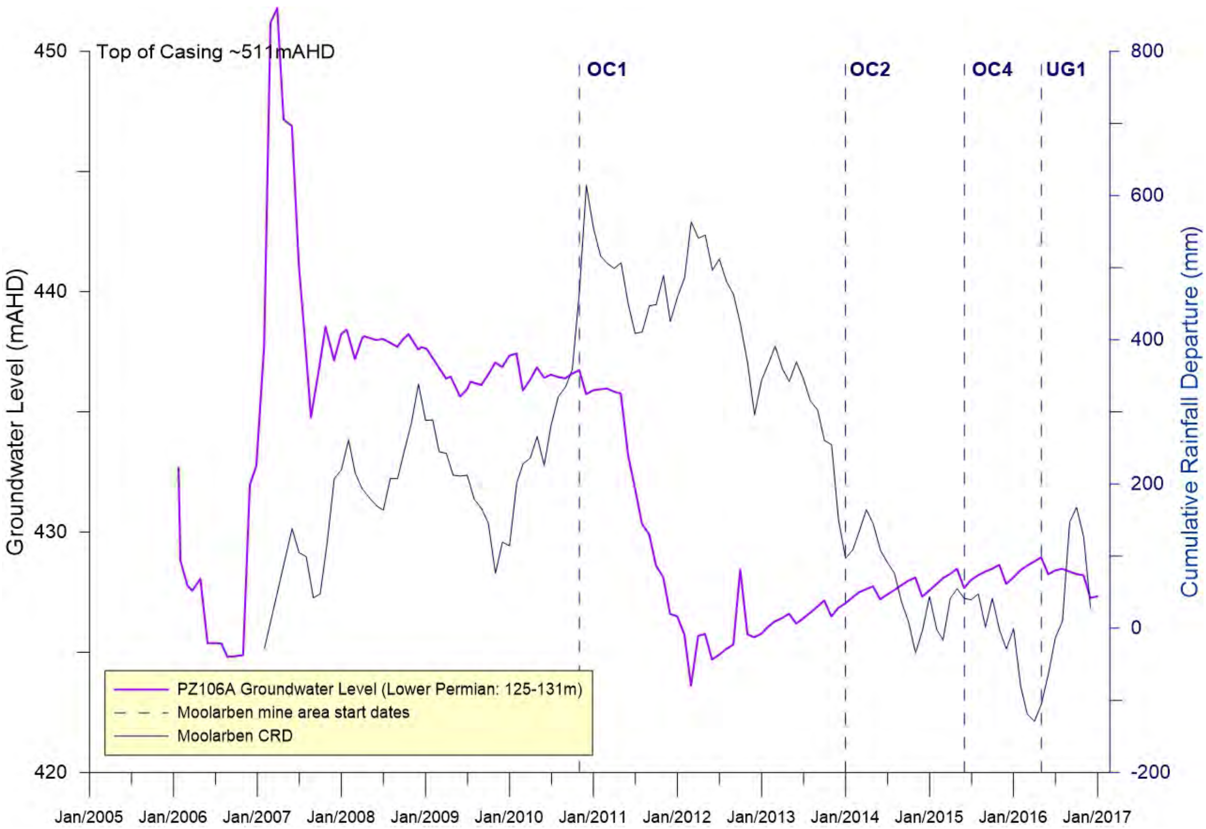


Figure A 9 - Permian Hydrographs PZ106A

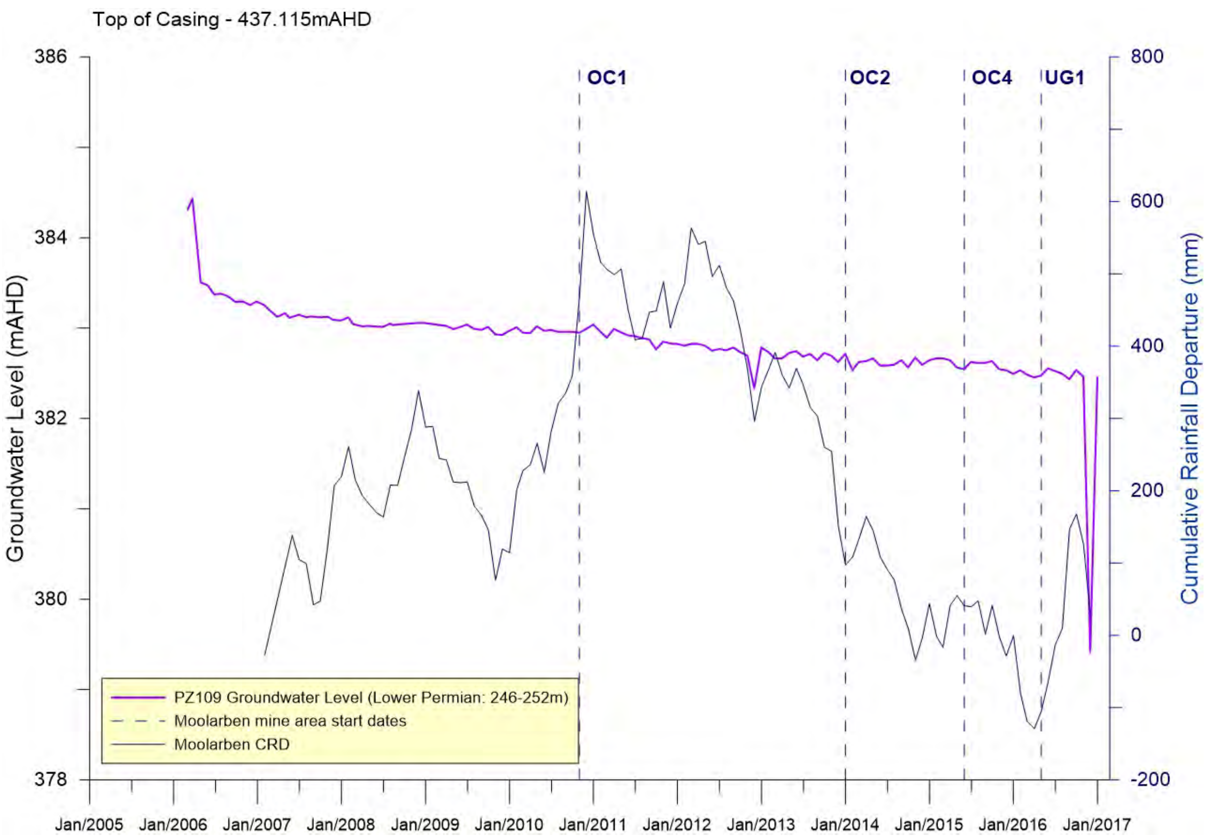


Figure A 10 - Permian Hydrographs PZ106B

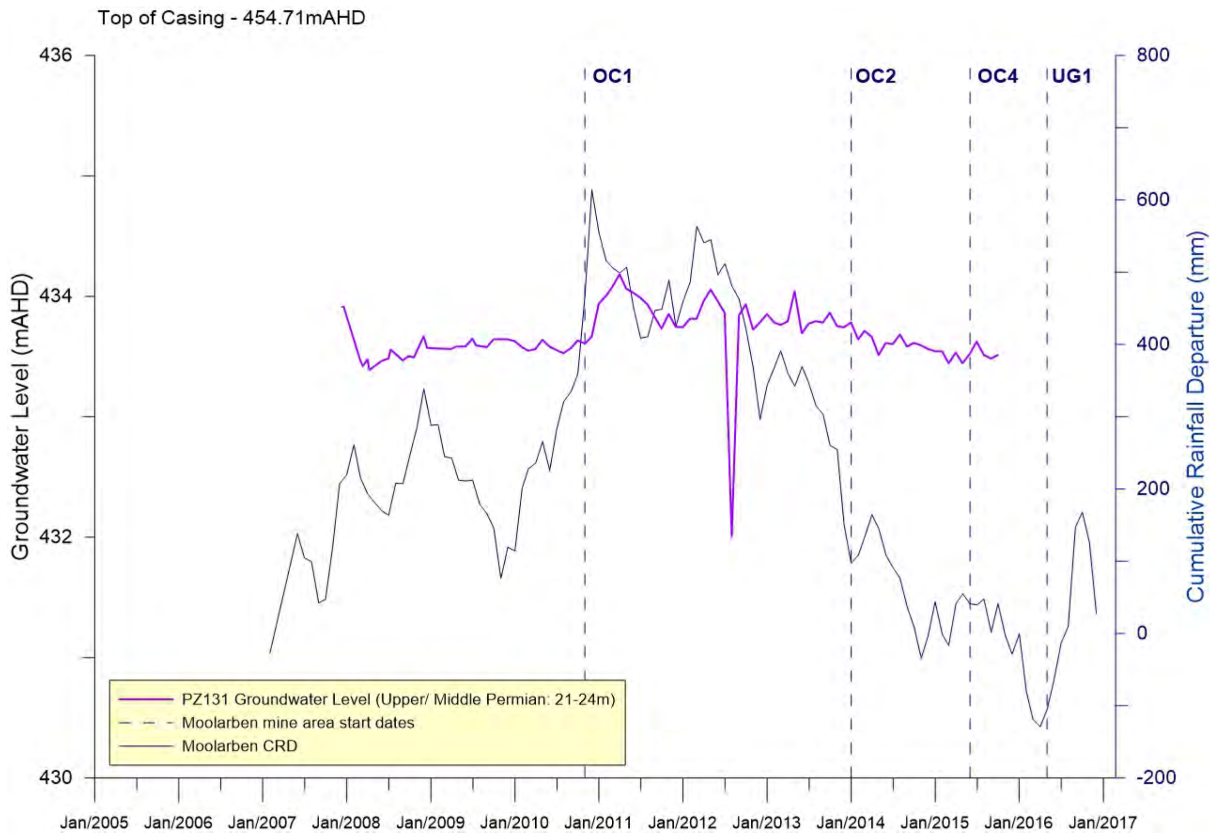


Figure A 11 - Permian Hydrographs PZ131

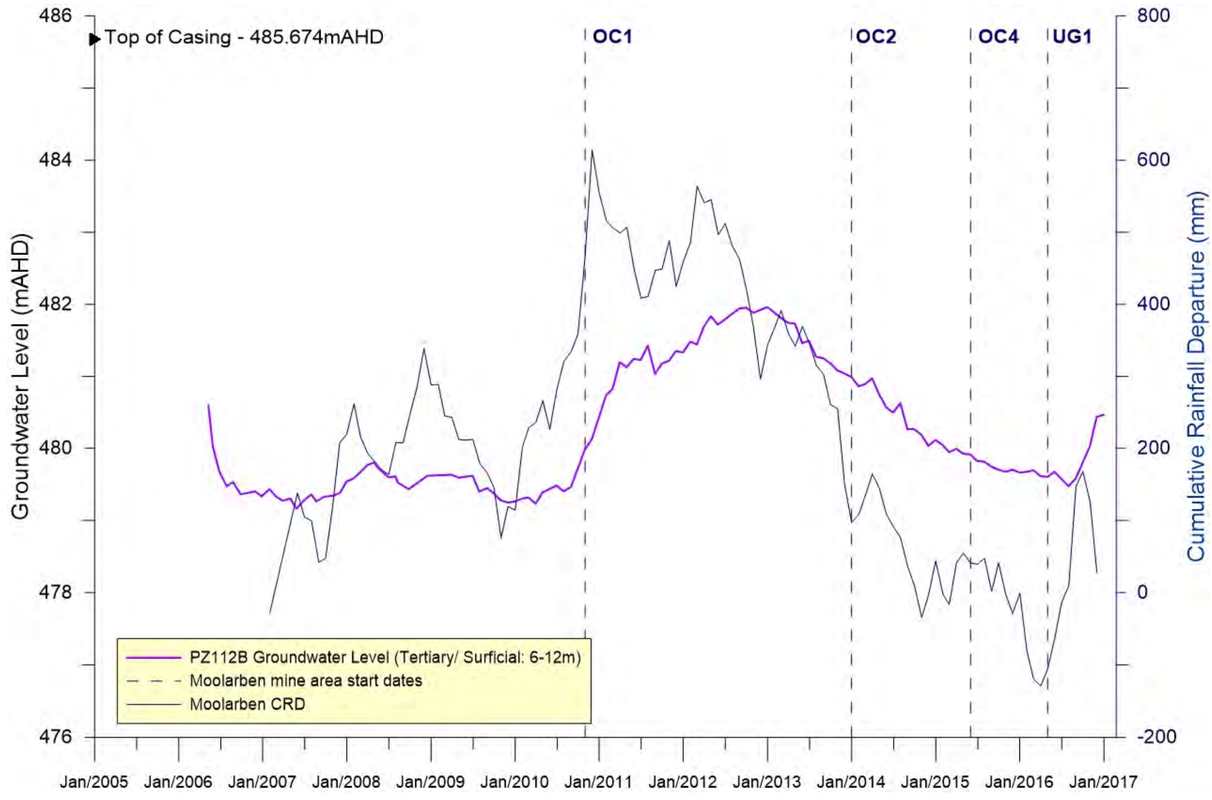


Figure A 12 Permian Hydrographs PZ112B

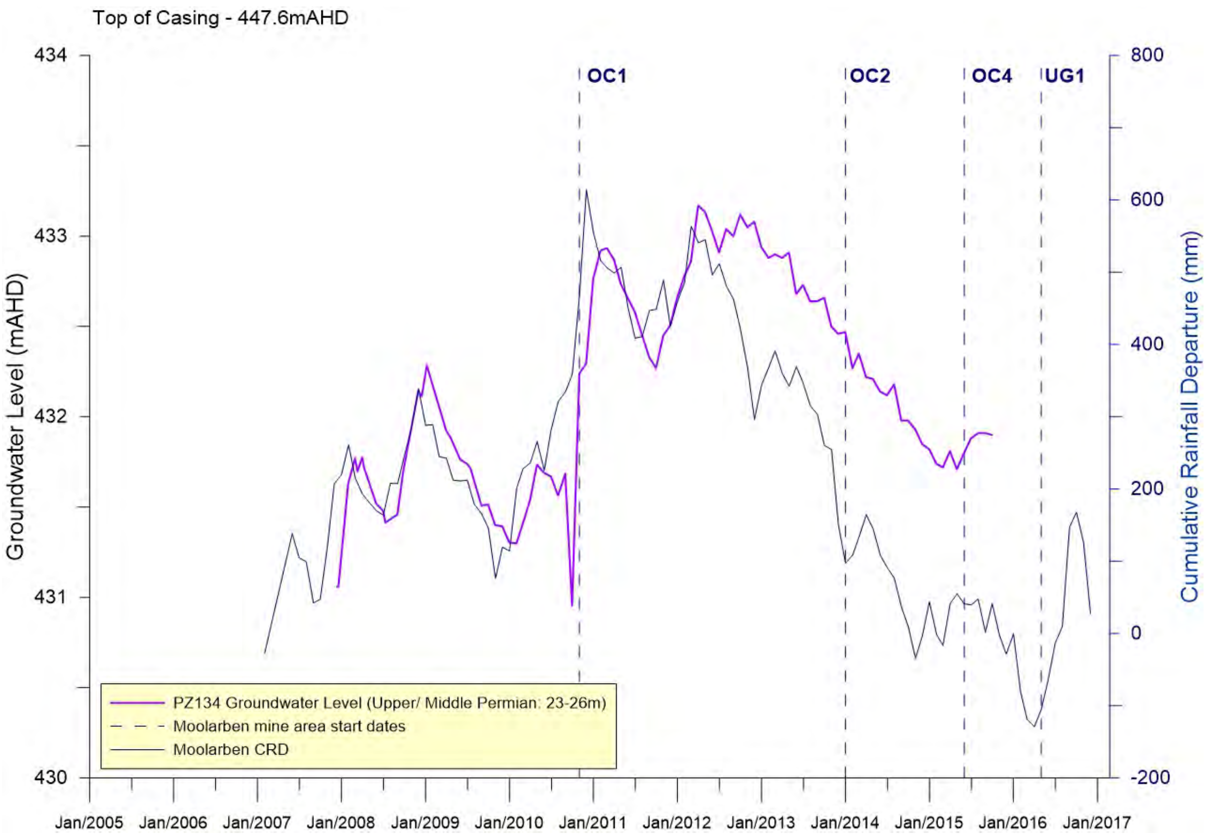


Figure A 13b Permian Hydrographs PZ134

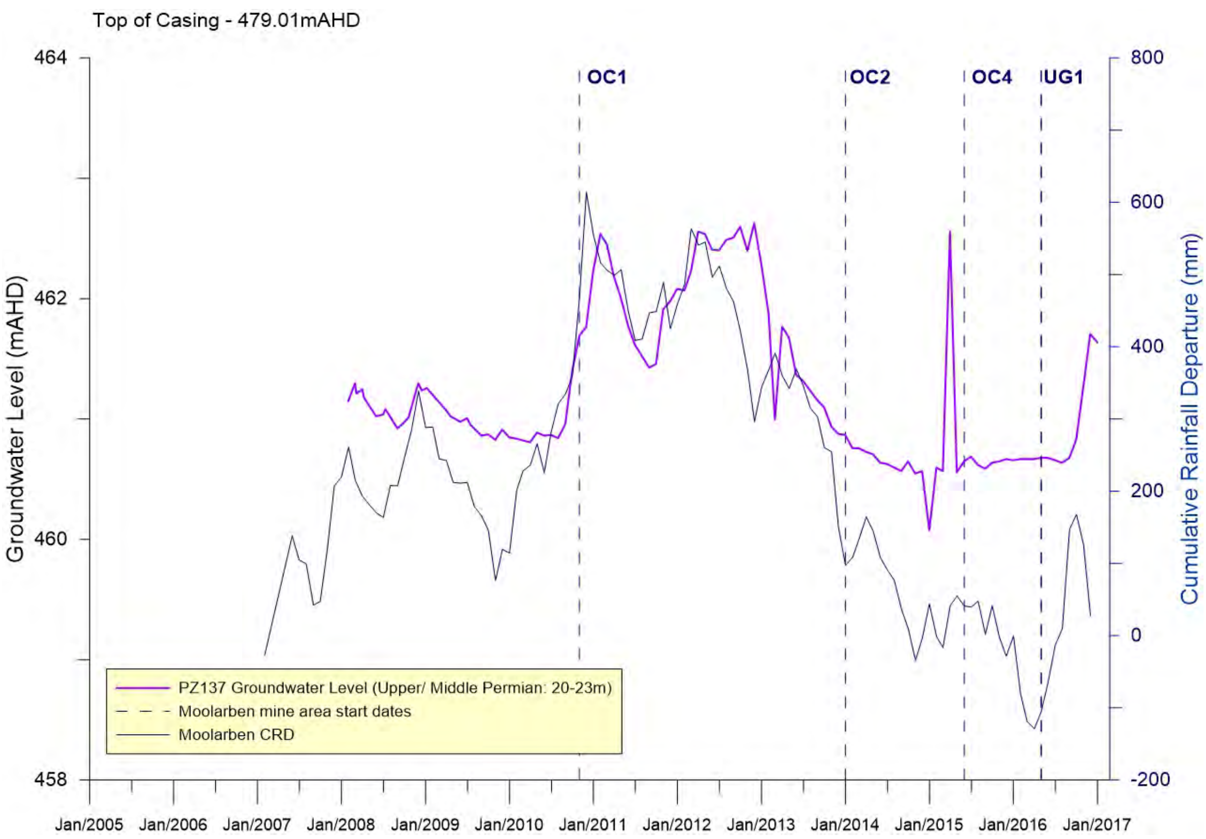


Figure A 13 - Permian Hydrographs PZ137

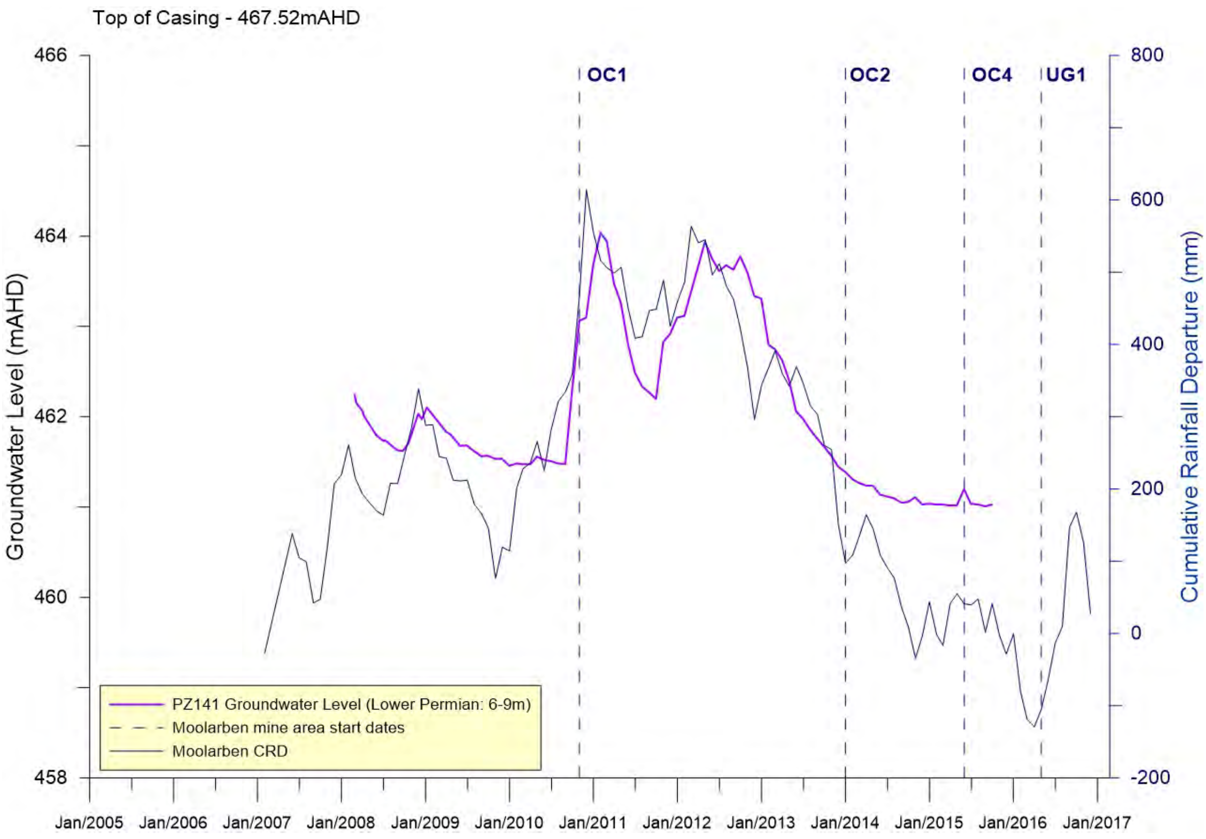


Figure A 14 - Permian Hydrographs PZ141

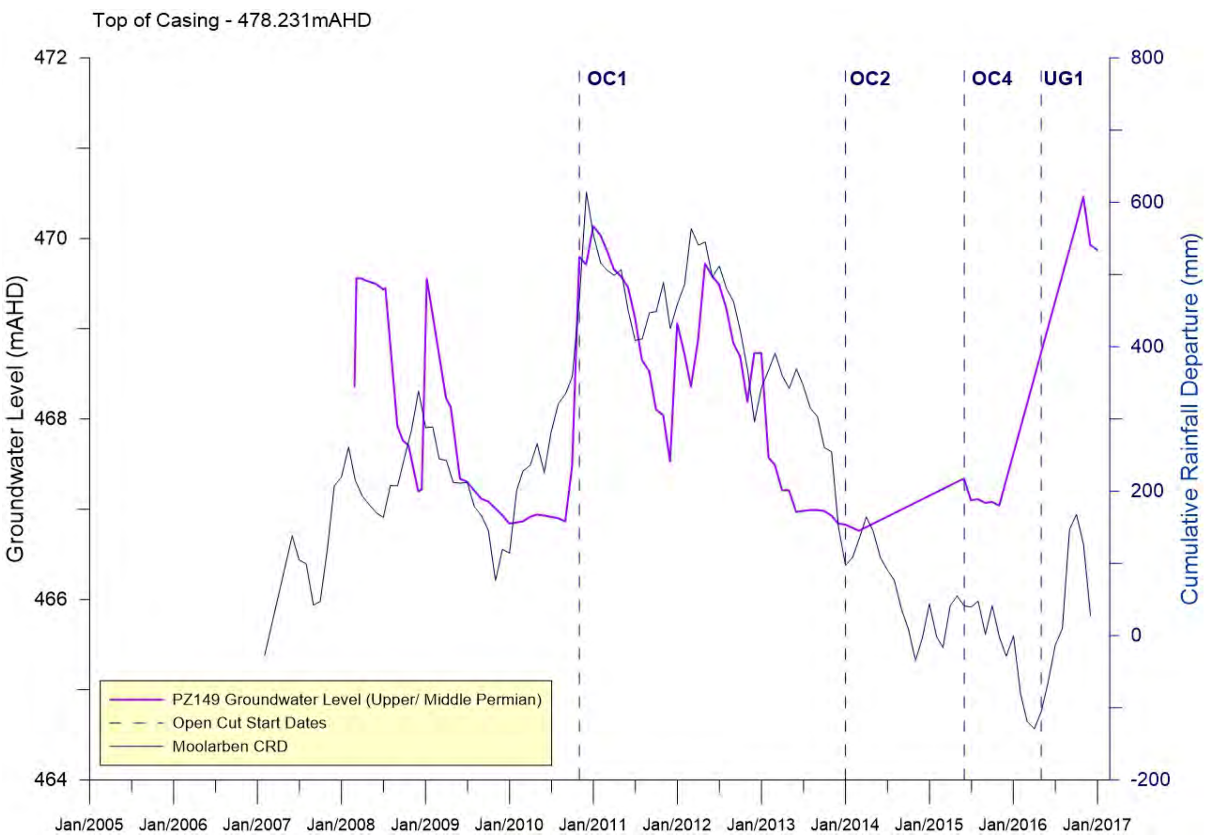


Figure A 15 - Permian Hydrographs PZ149

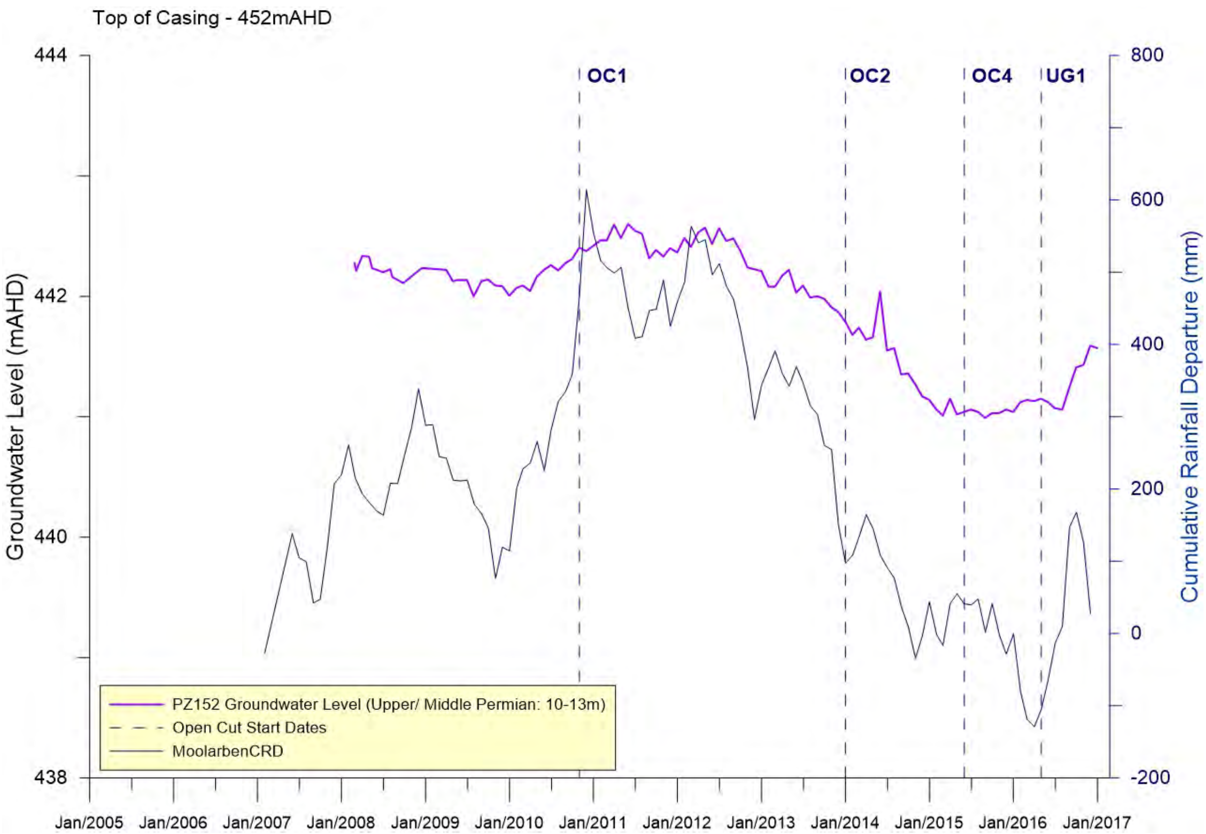


Figure A 16 - Permian Hydrographs PZ152

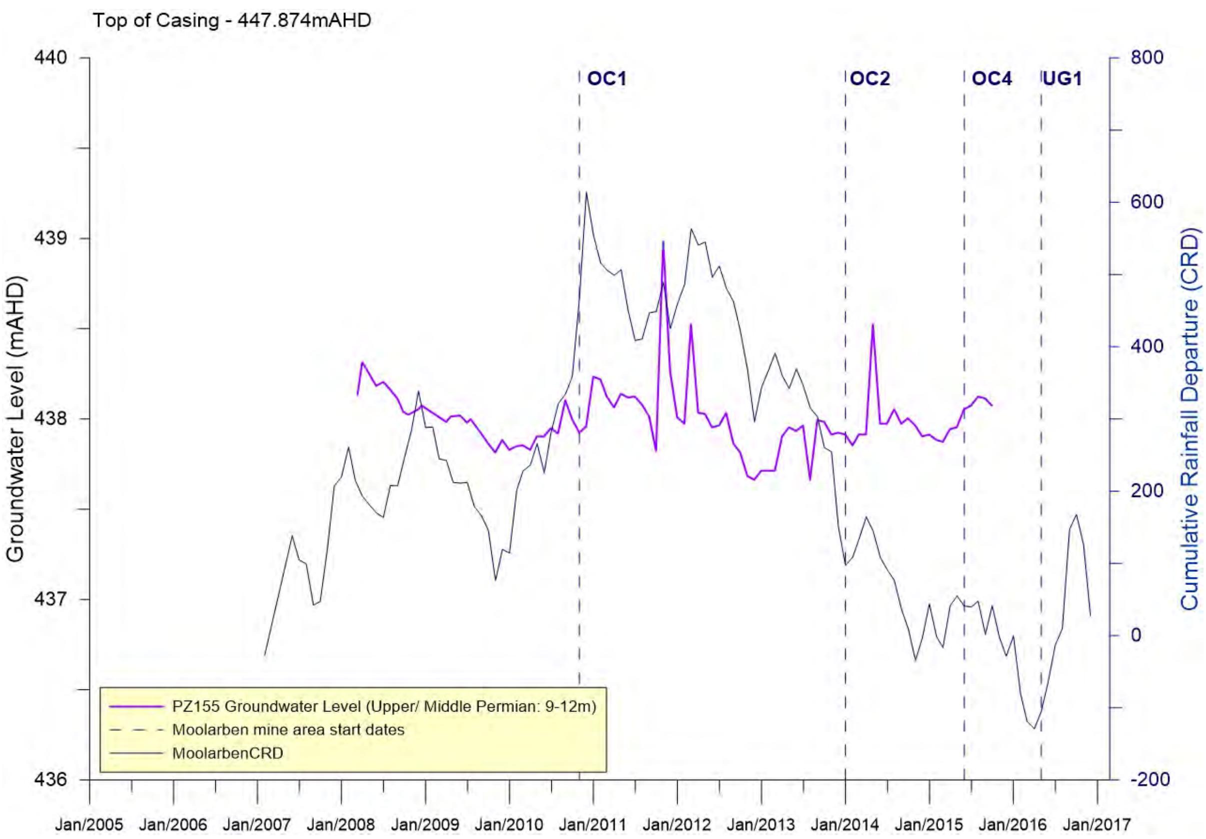


Figure A 17- Permian Hydrographs PZ155

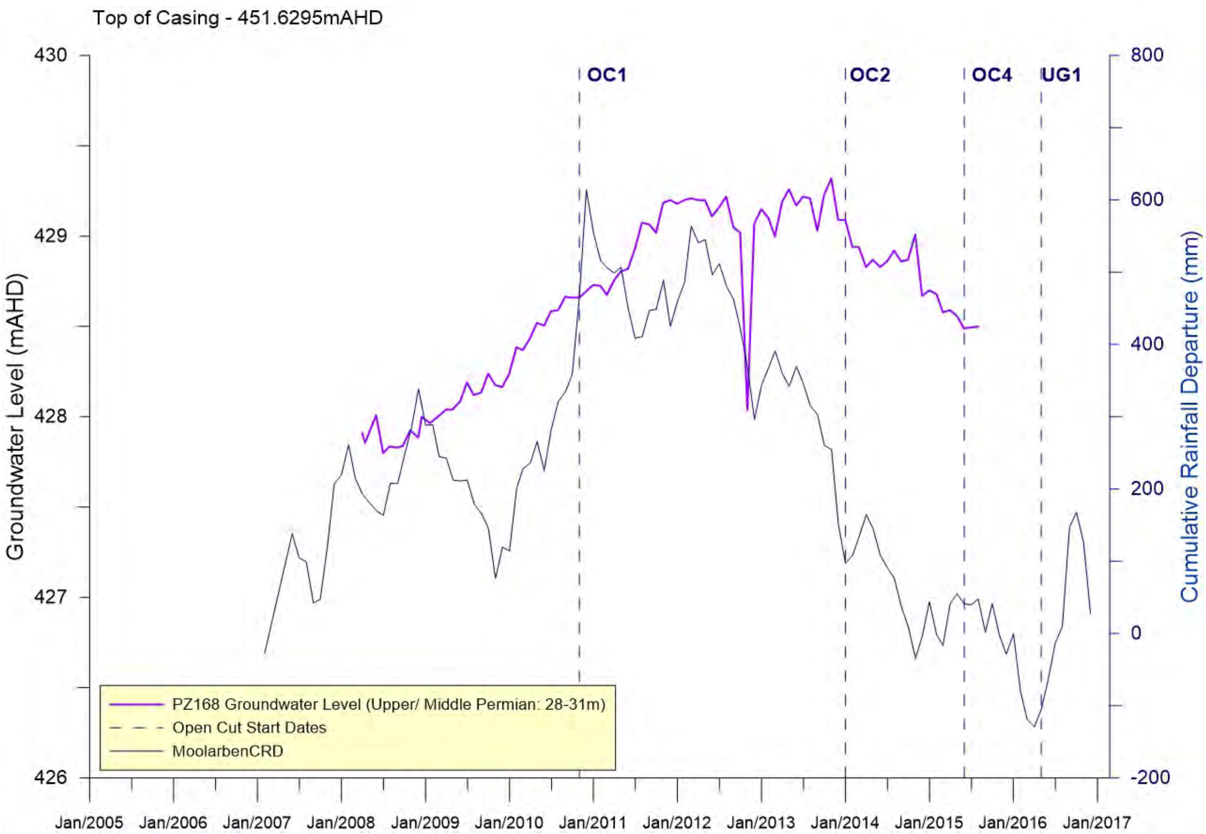


Figure A 18 - Permian Hydrographs PZ168

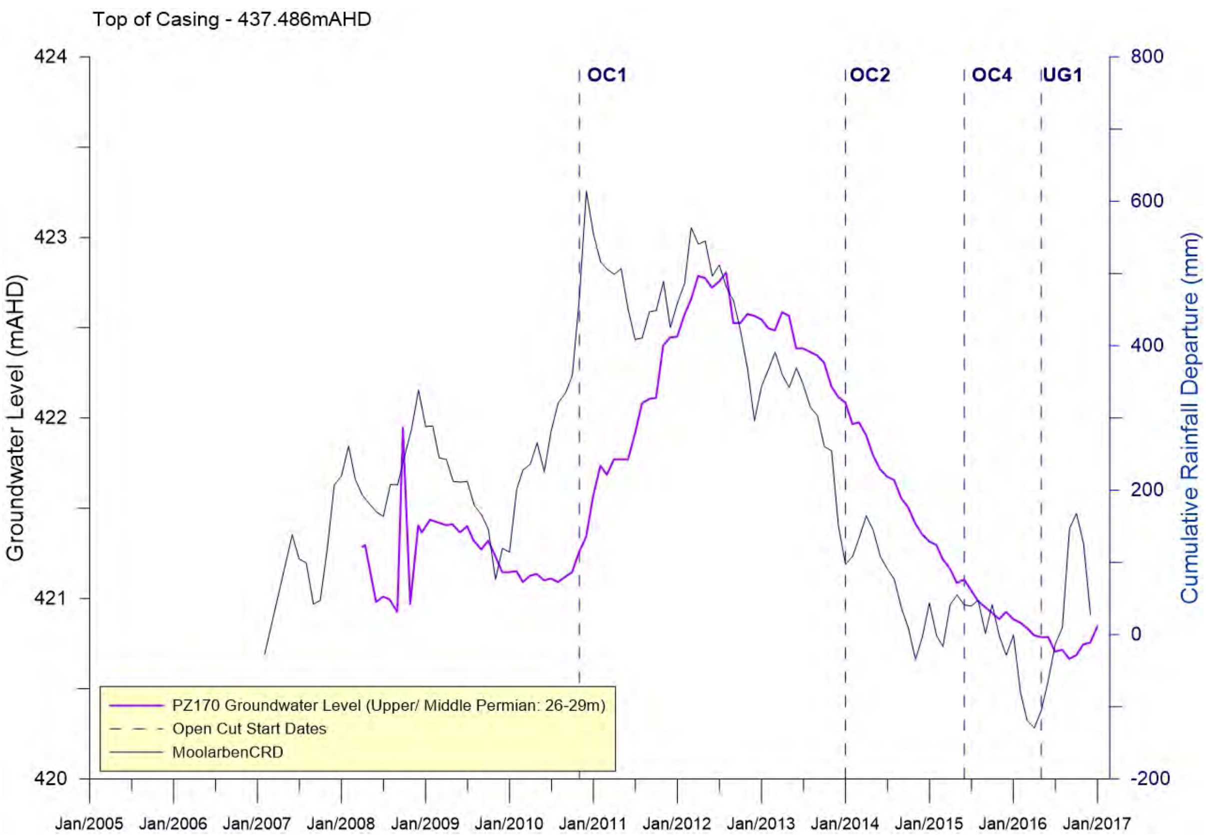


Figure A 19 - Permian Hydrographs PZ170

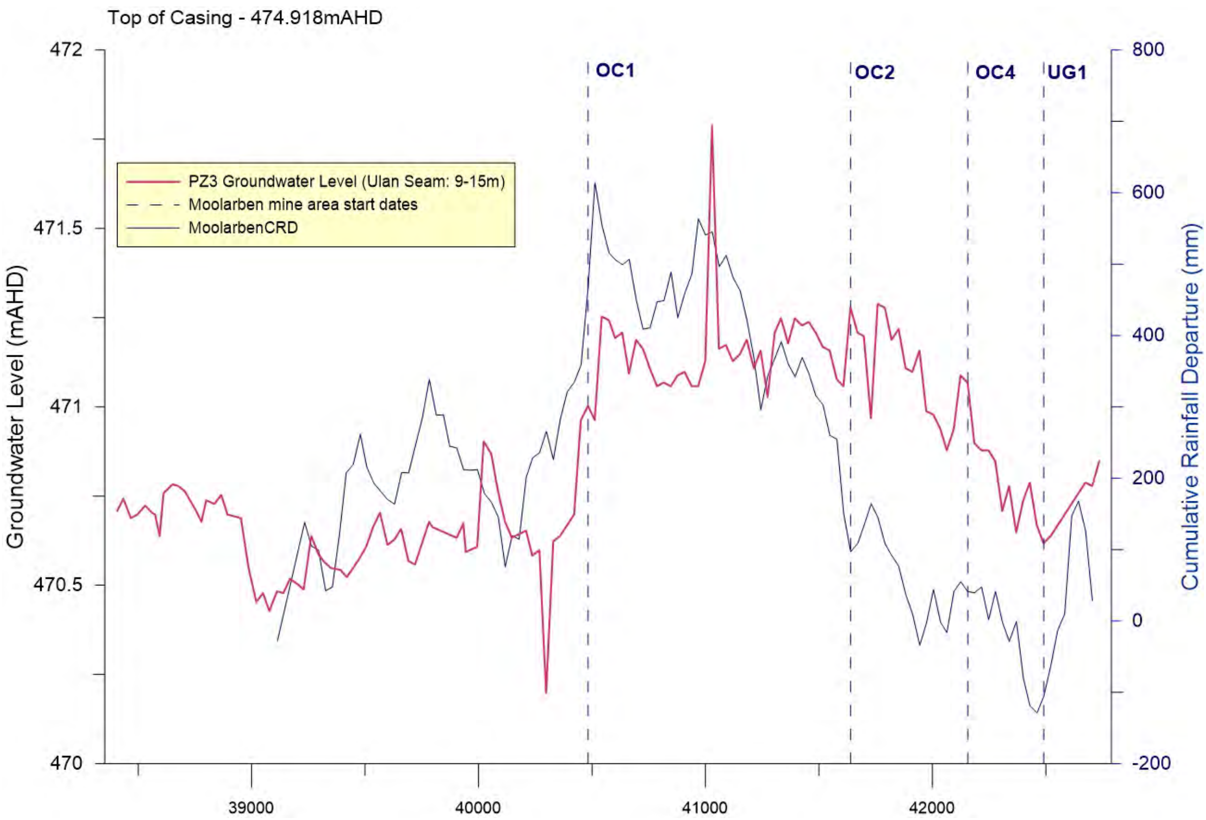


Figure A 20 - Ulan Seam Hydrographs PZ3

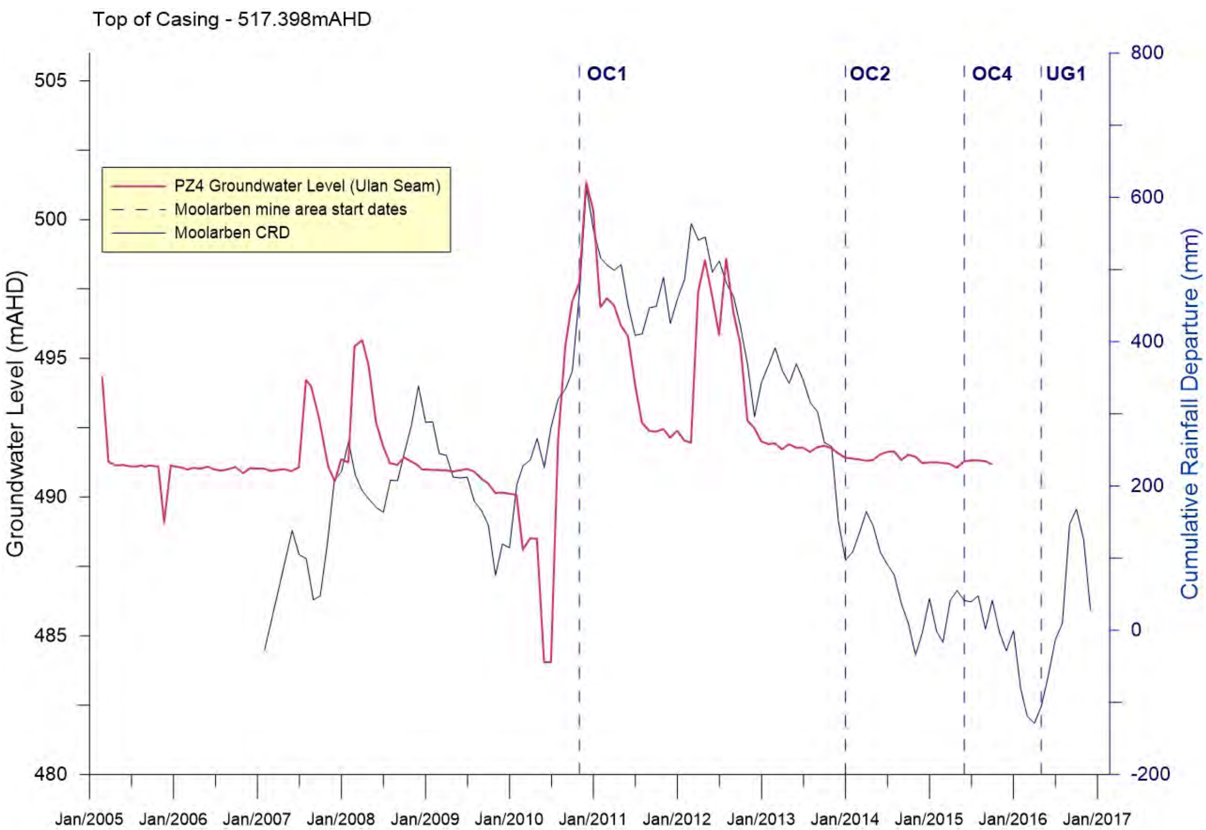


Figure A 21 - Ulan Seam Hydrographs PZ4

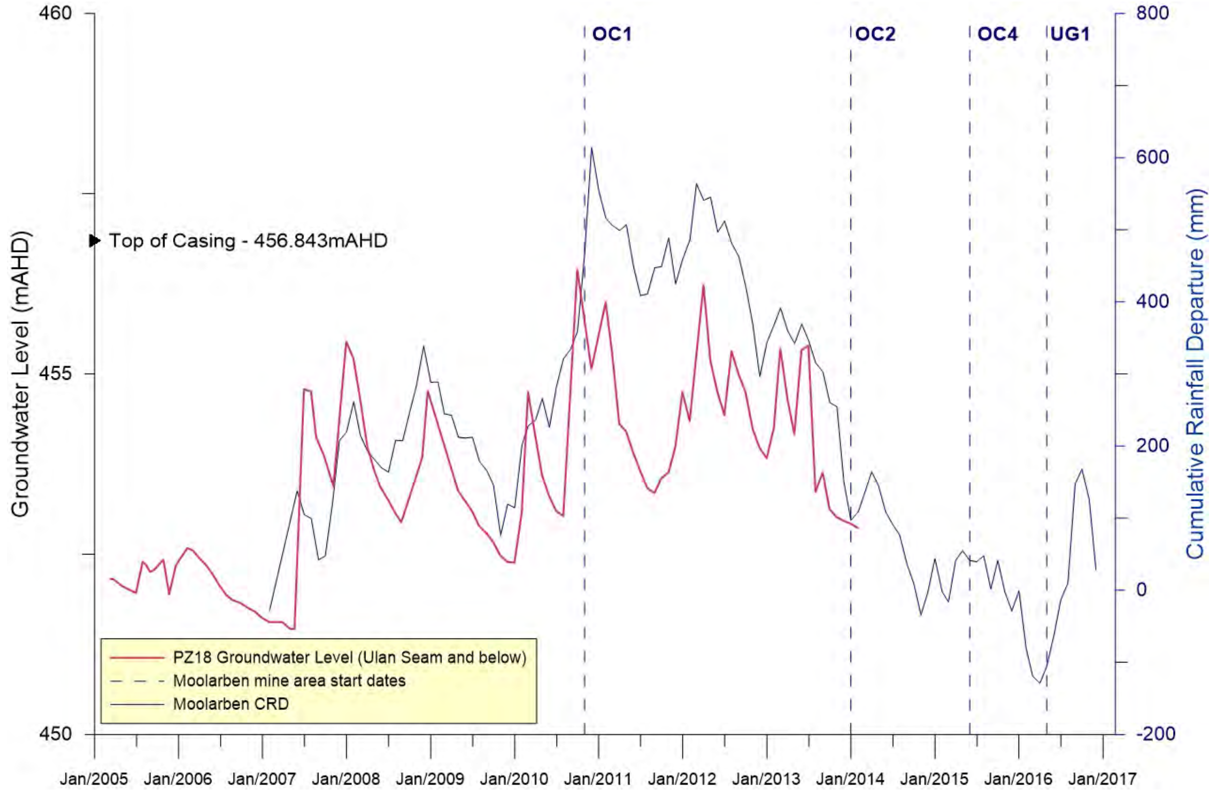


Figure A 22 - Ulan Seam Hydrographs PZ18

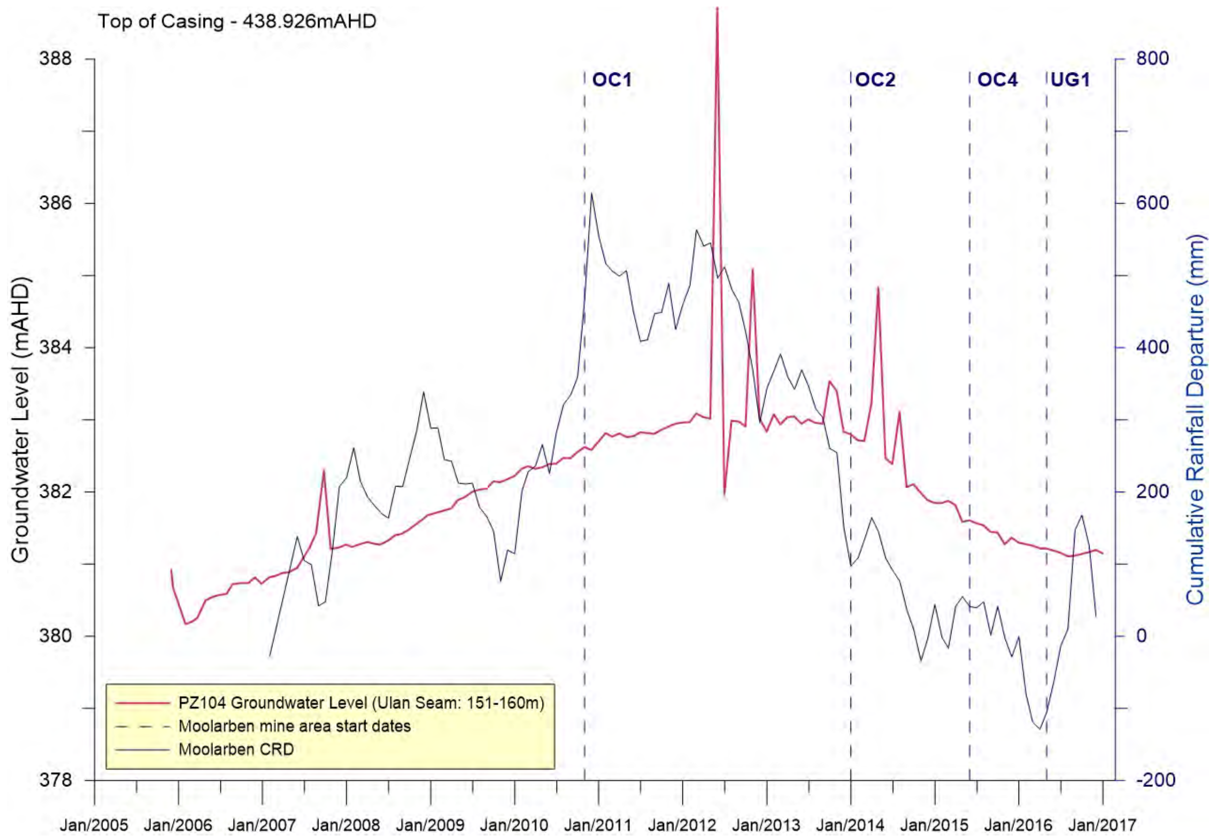


Figure A 23 - Ulan Seam Hydrographs PZ104

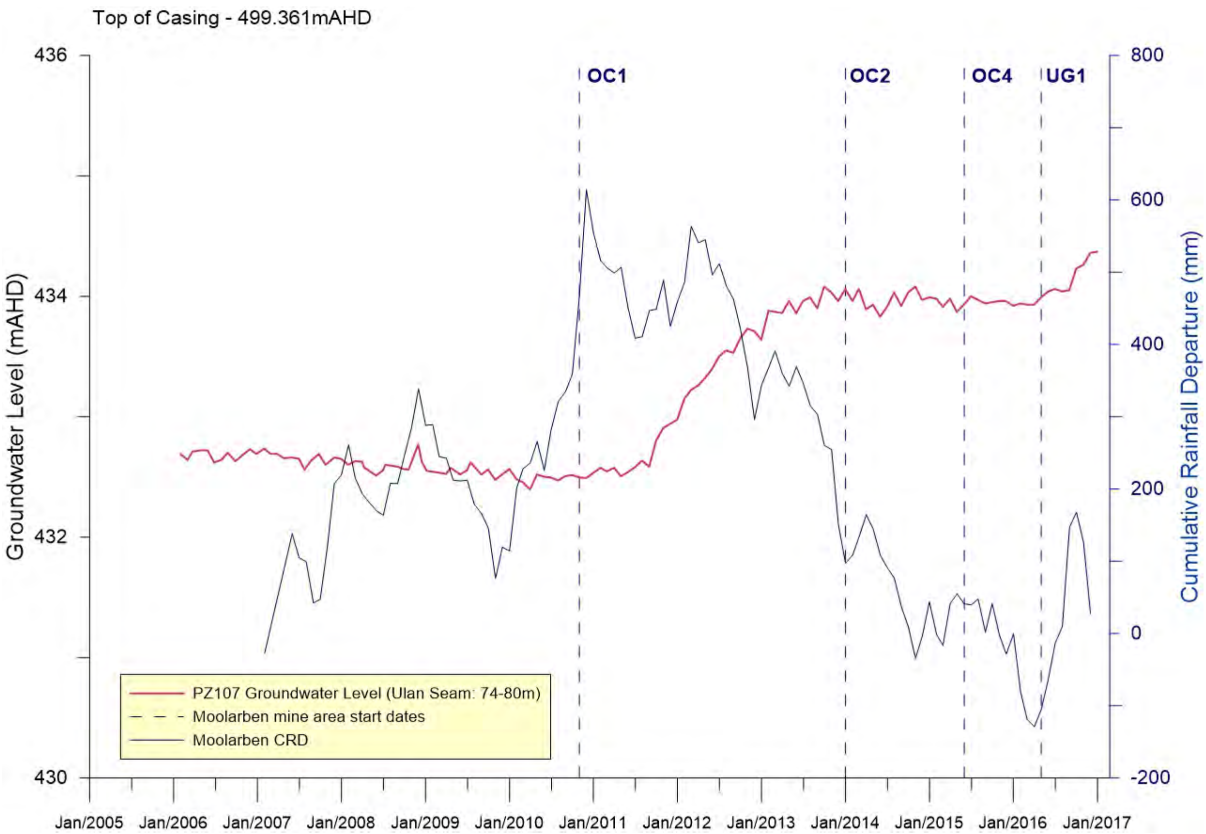


Figure A 24 - Ulan Seam Hydrographs PZ107

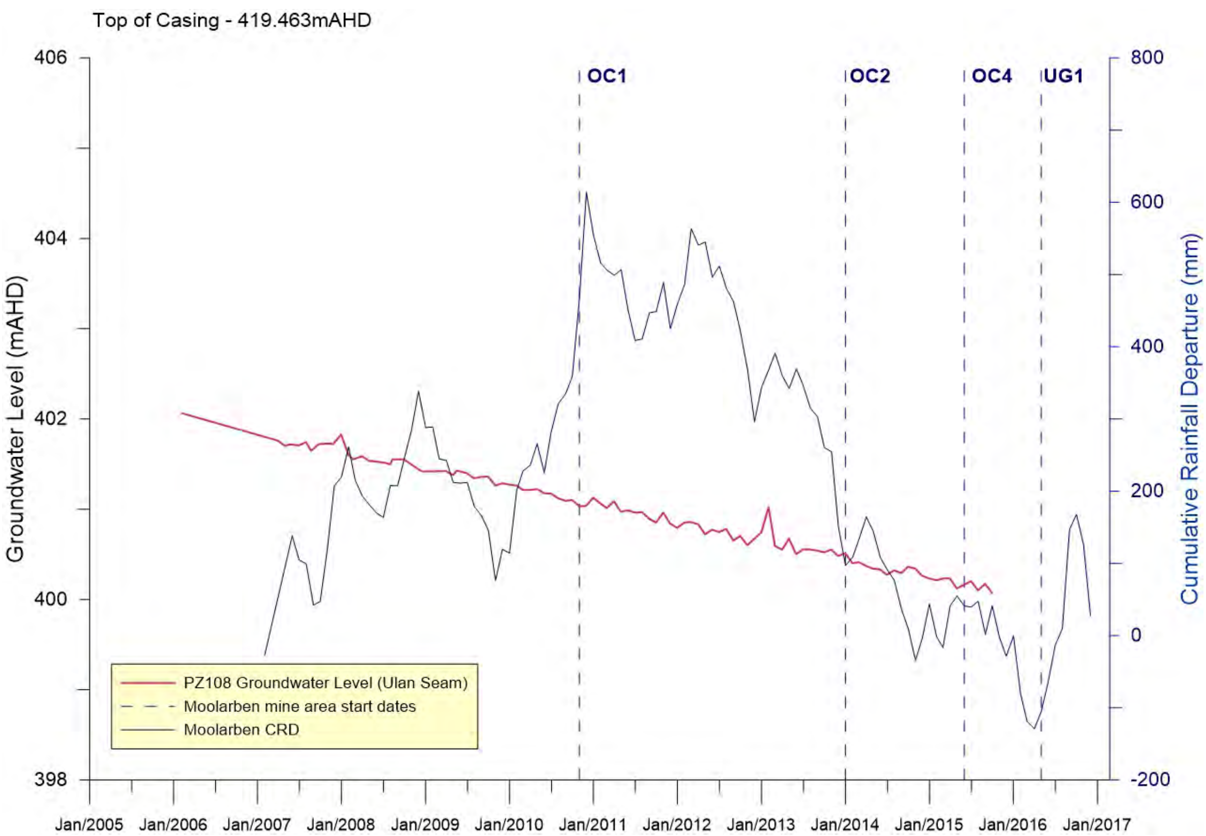


Figure A 25 - Ulan Seam Hydrographs PZ108

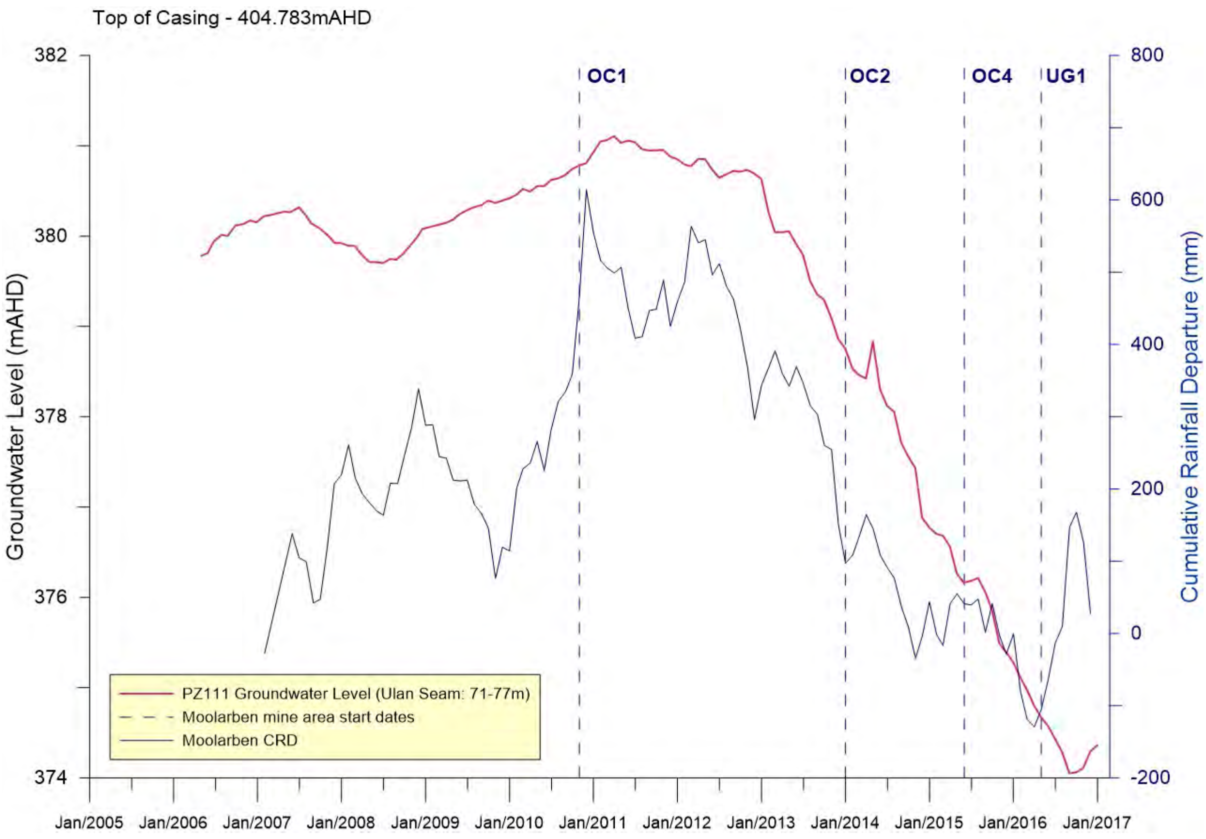


Figure A 26 - Ulan Seam Hydrographs PZ111

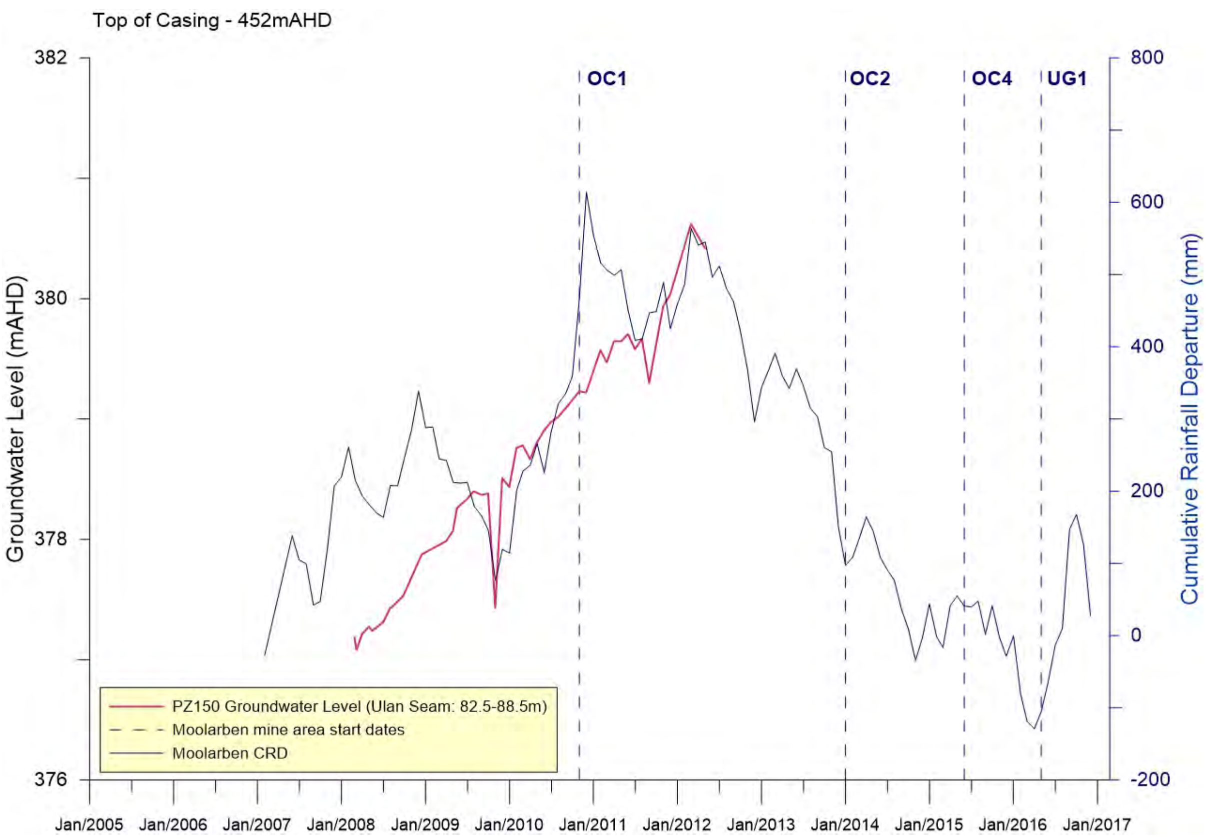


Figure A 27 - Ulan Seam Hydrographs PZ150

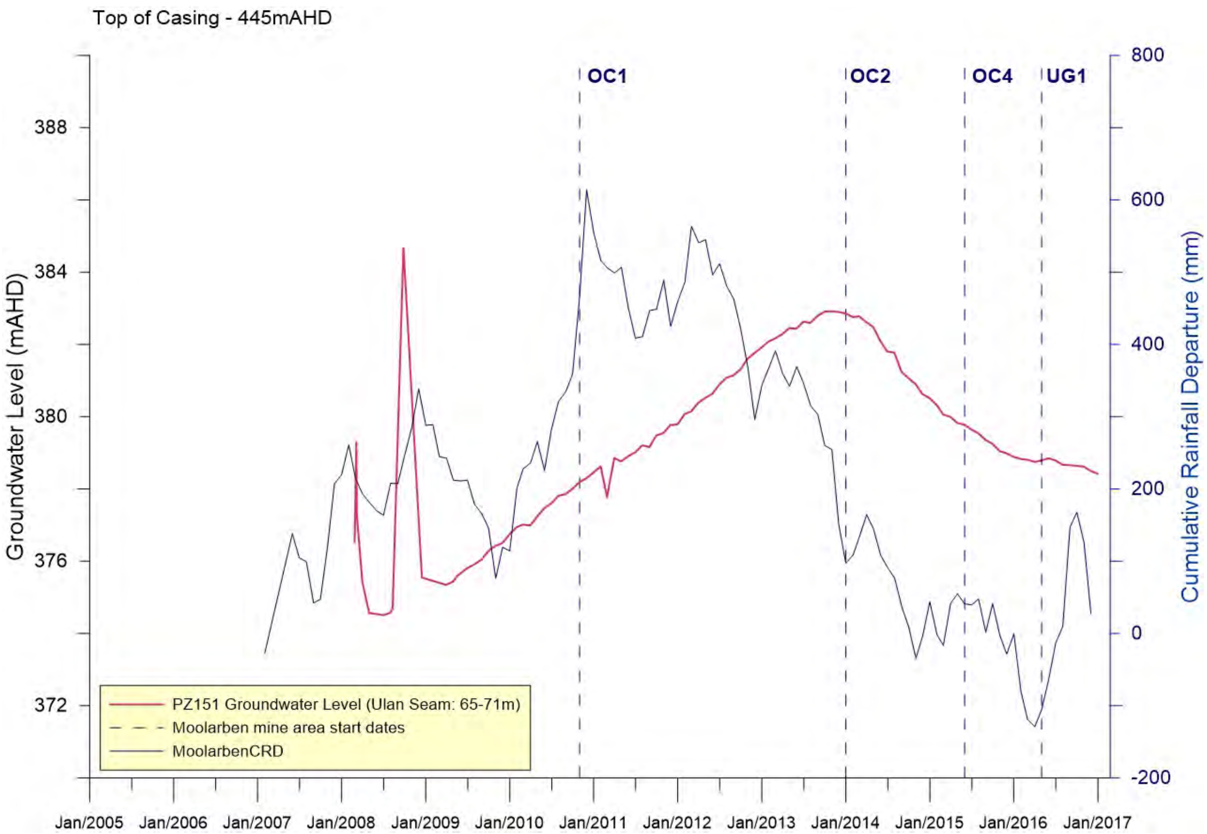


Figure A 28 - Ulan Seam Hydrographs PZ151

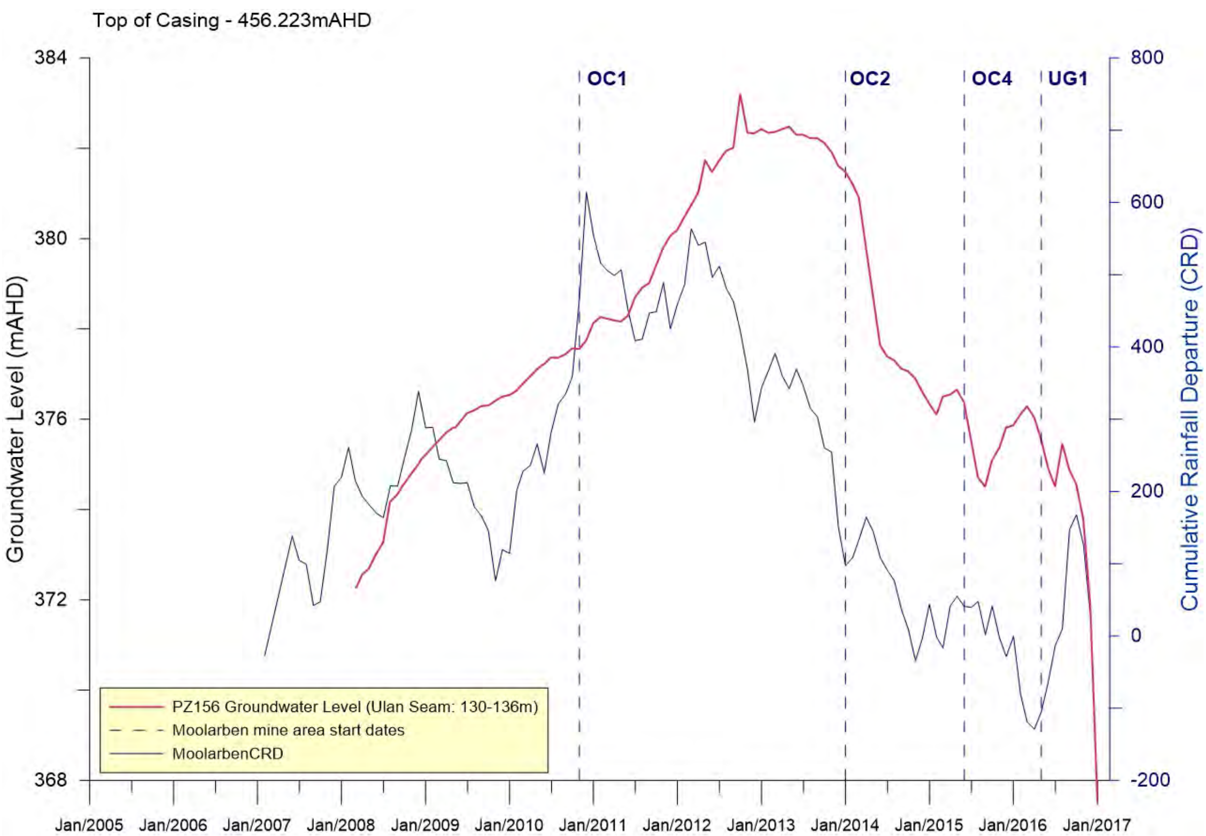


Figure A 29 - Ulan Seam Hydrographs PZ156

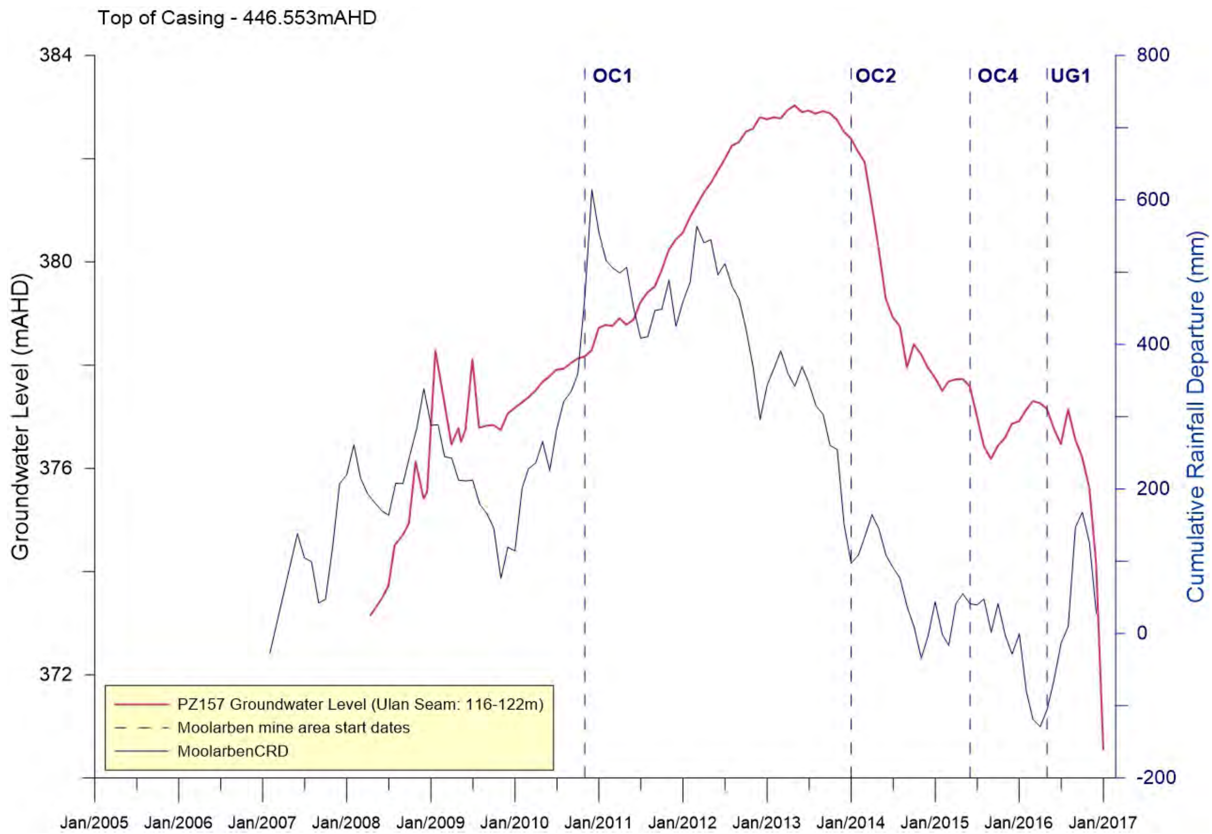


Figure A 30 - Ulan Seam Hydrographs PZ157

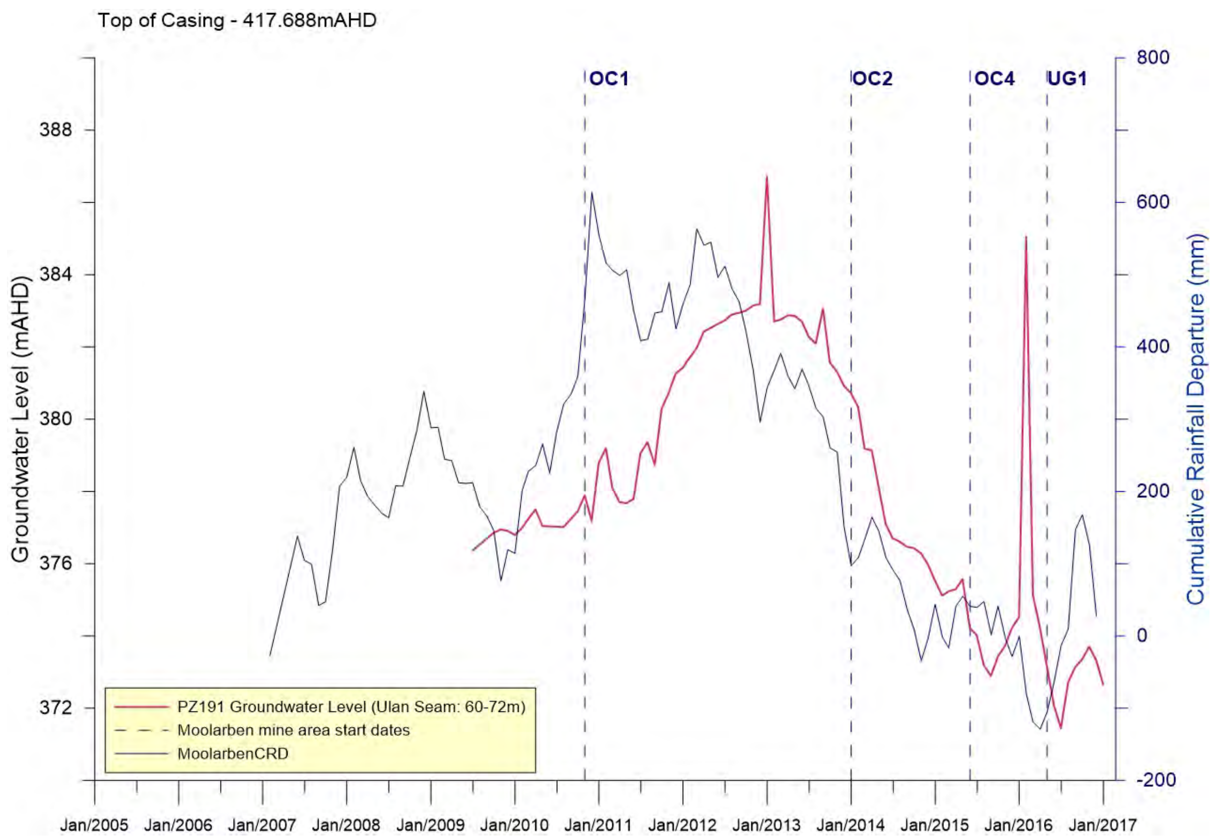


Figure A 31 - Ulan Seam Hydrographs PZ191

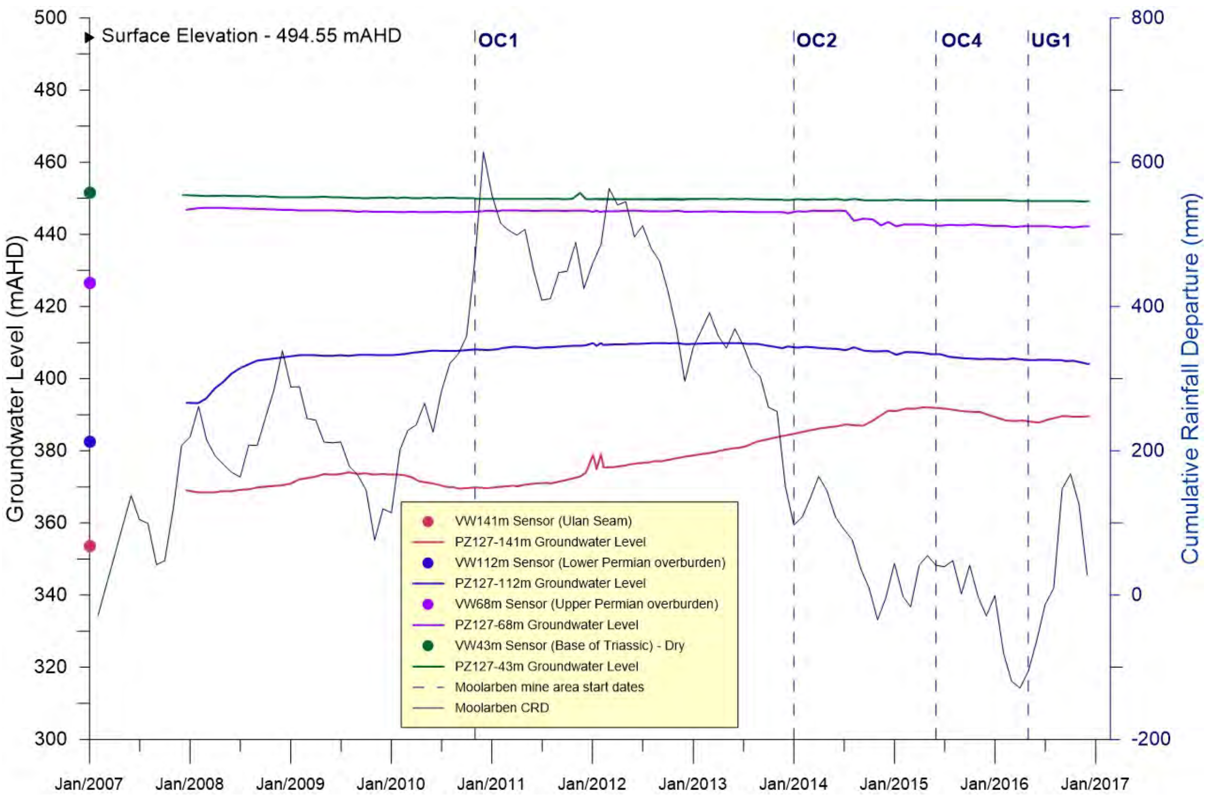


Figure A 32 – VWP Hydrographs

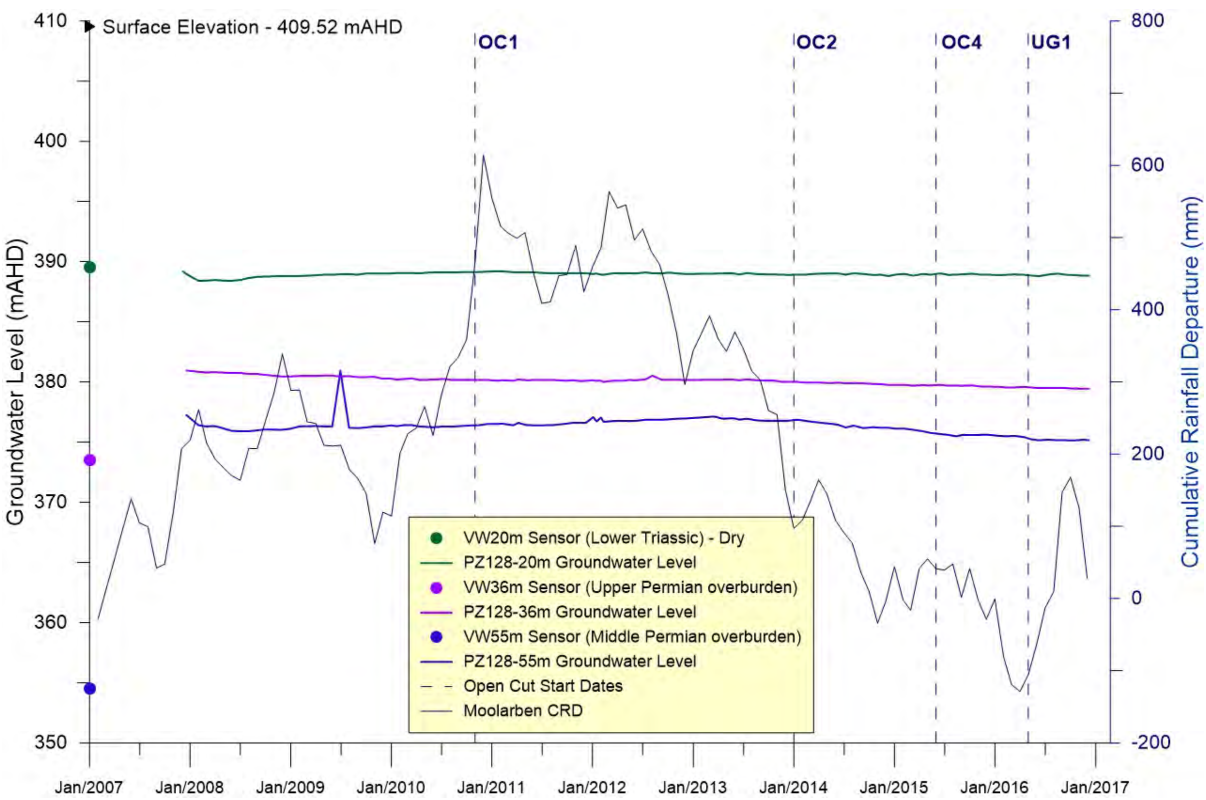


Figure A 33 - VWP Hydrographs

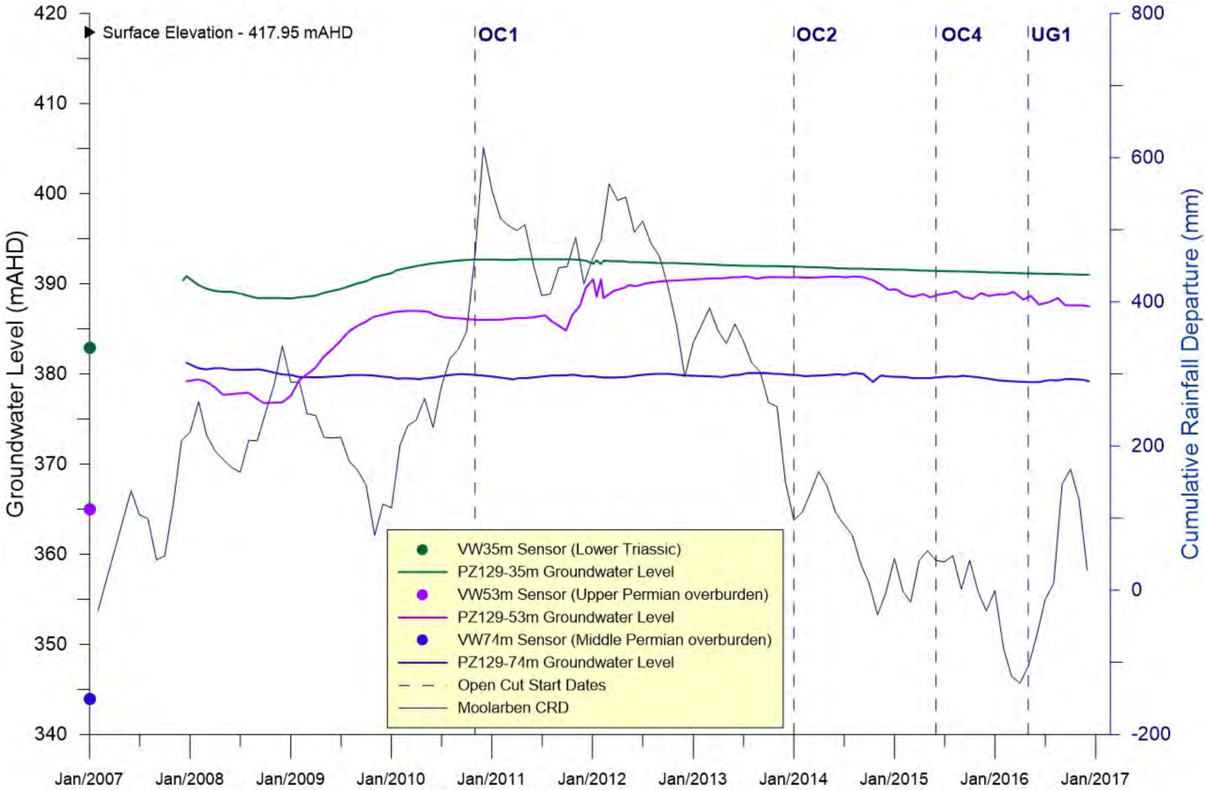


Figure A 34 - VWP Hydrographs

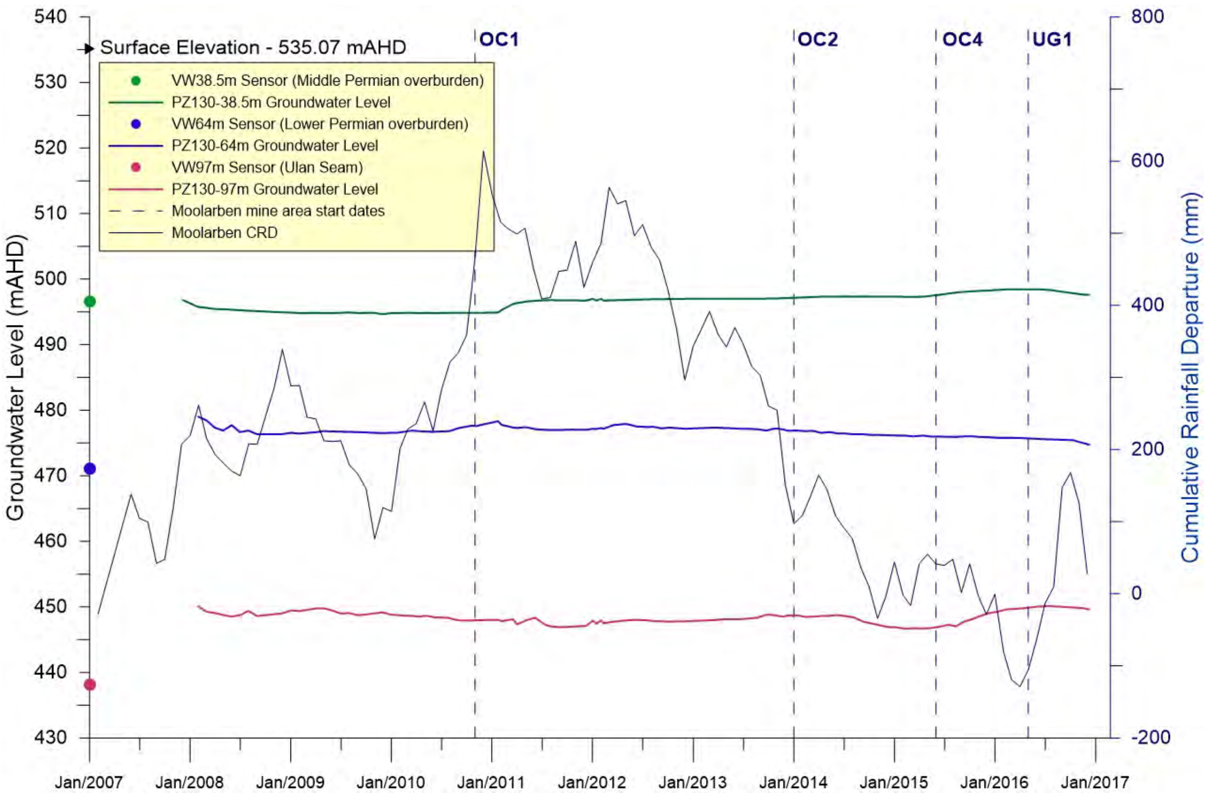


Figure A 35 - VWP Hydrographs

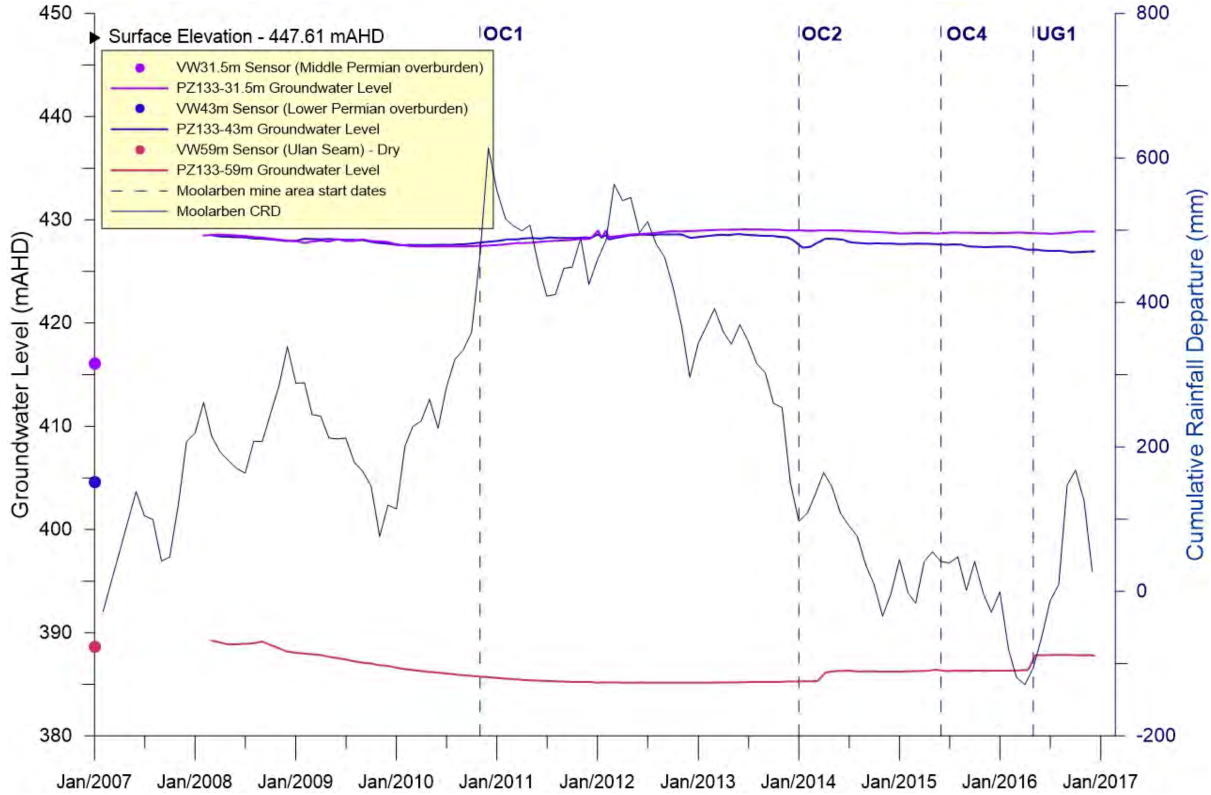


Figure A 36 - VWP Hydrographs

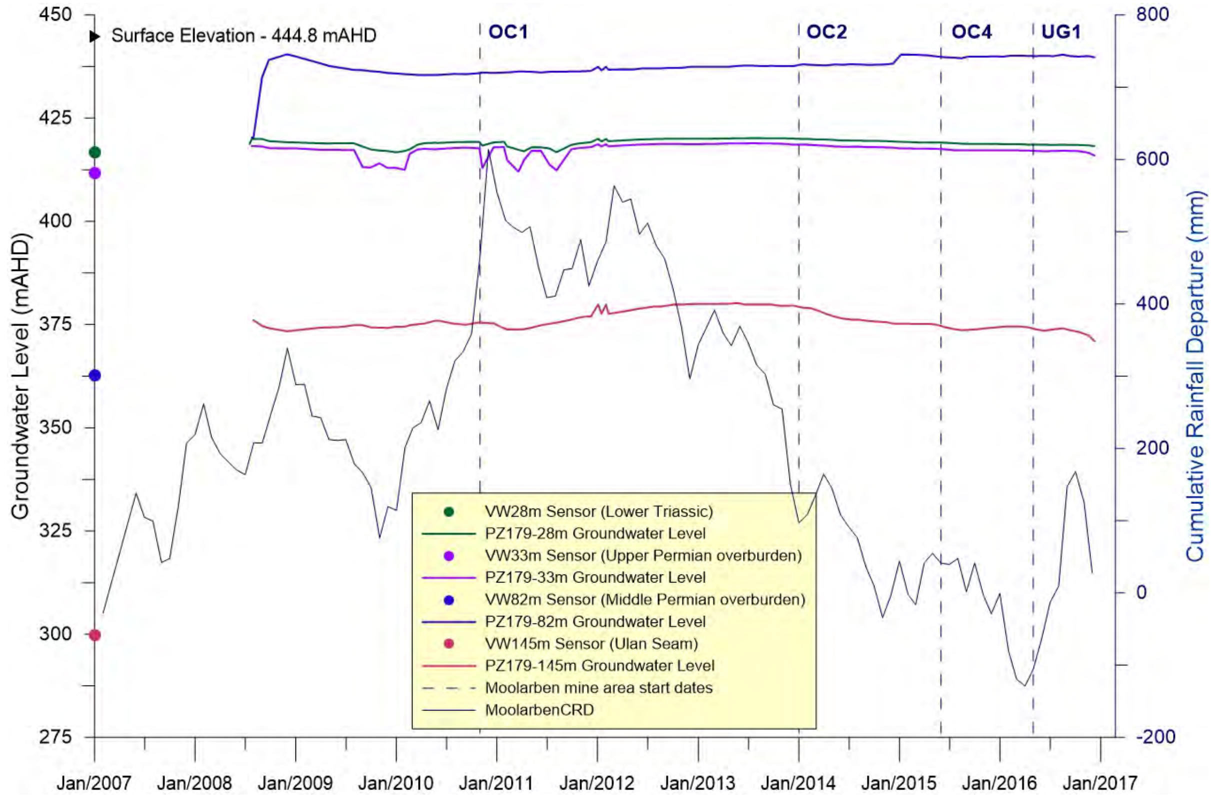


Figure A 37 - VWP Hydrographs

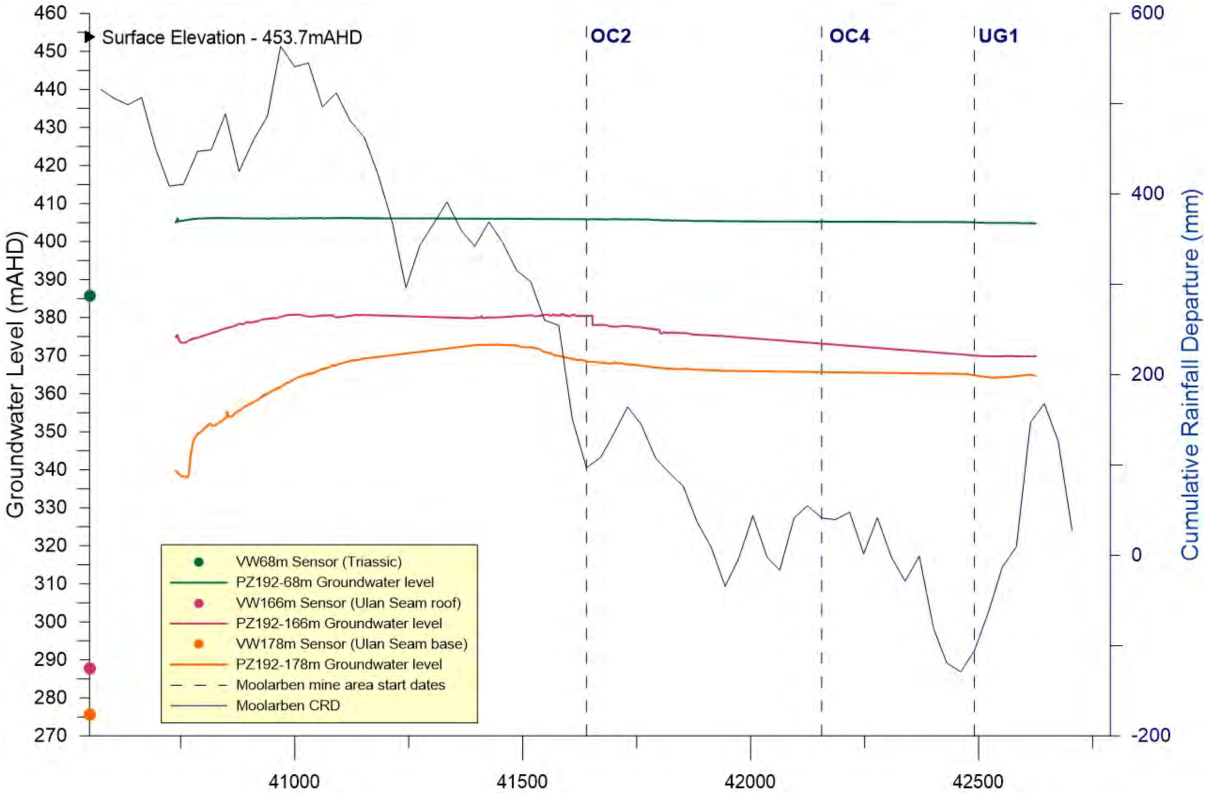


Figure A 38 - VWP Hydrographs

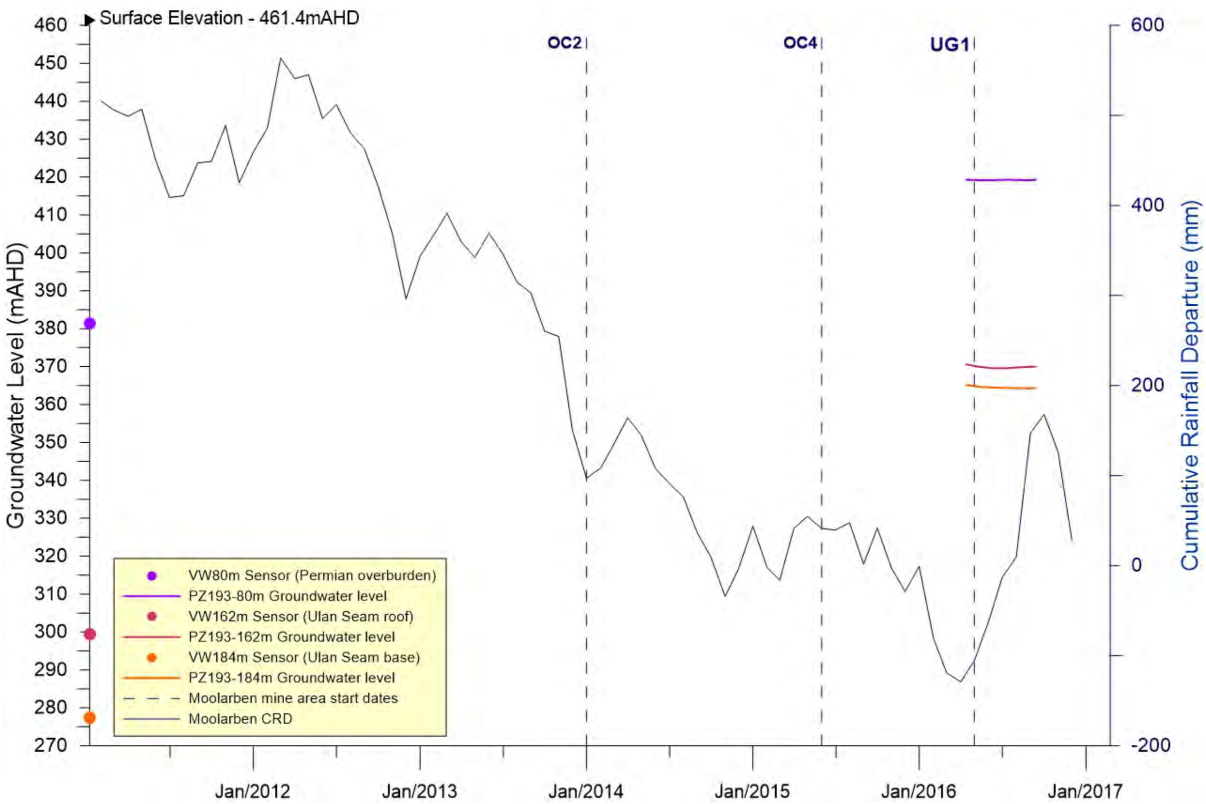


Figure A 39 - VWP Hydrographs

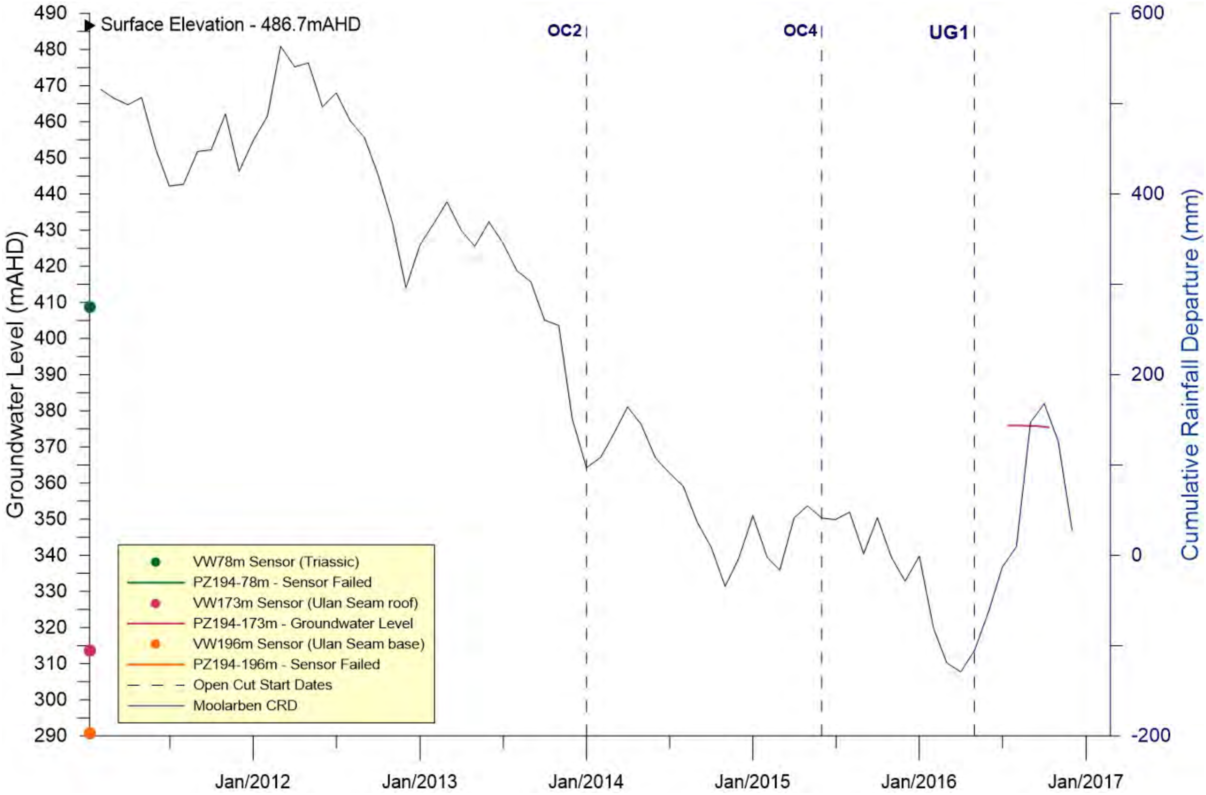


Figure A 40 - VWP Hydrographs

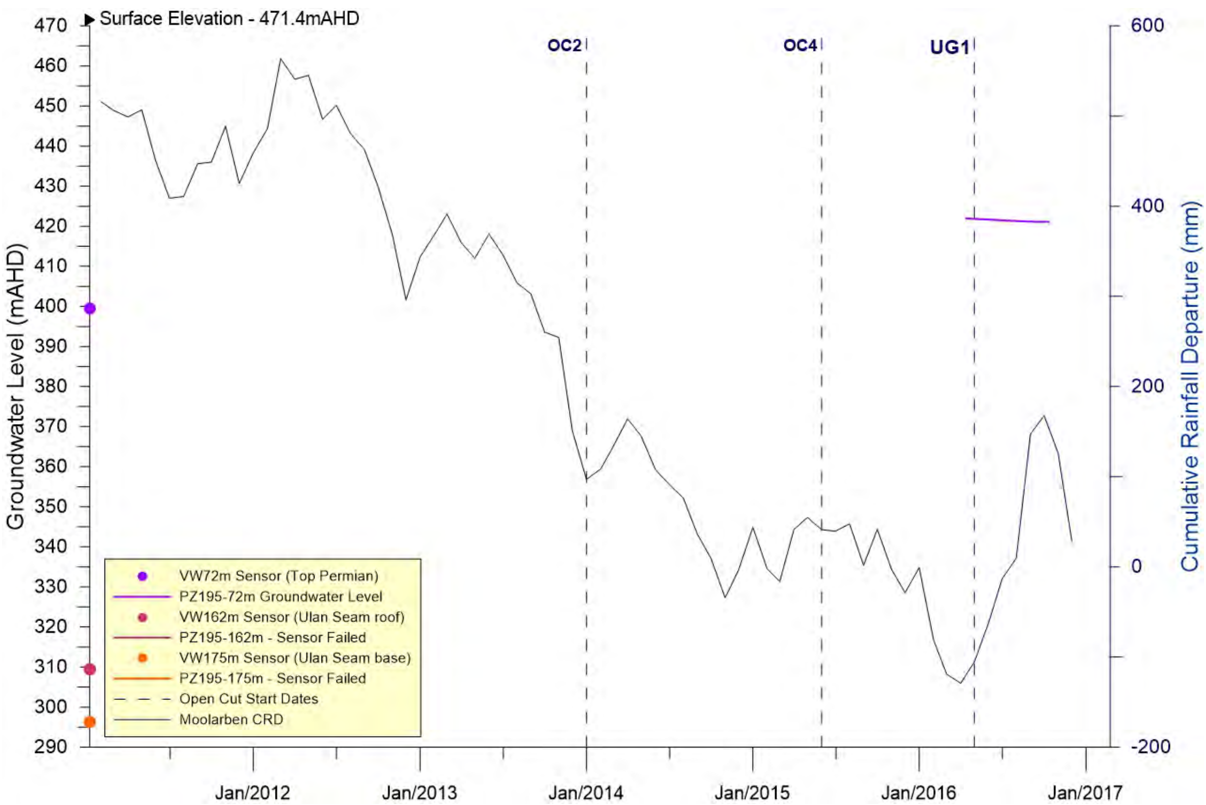


Figure A 41 - VWP Hydrographs

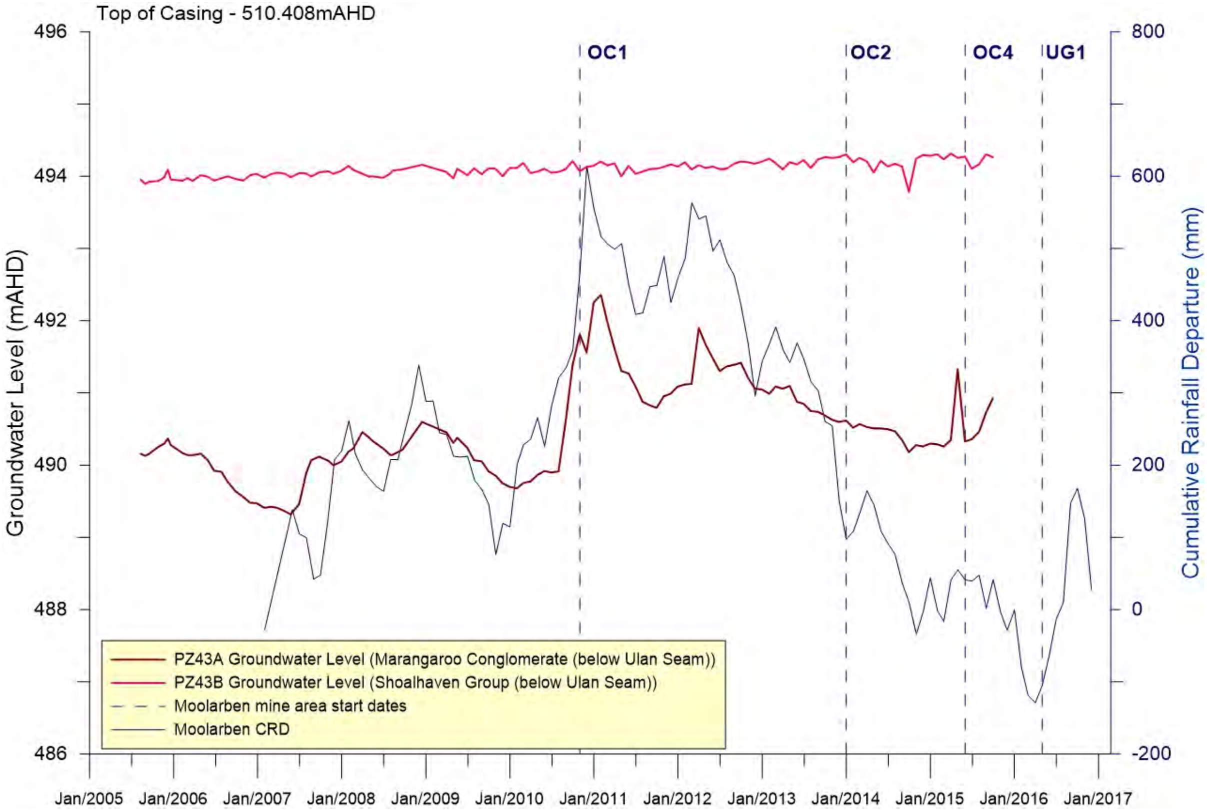


Figure A 42 – Multiple Standpipe Hydrographs

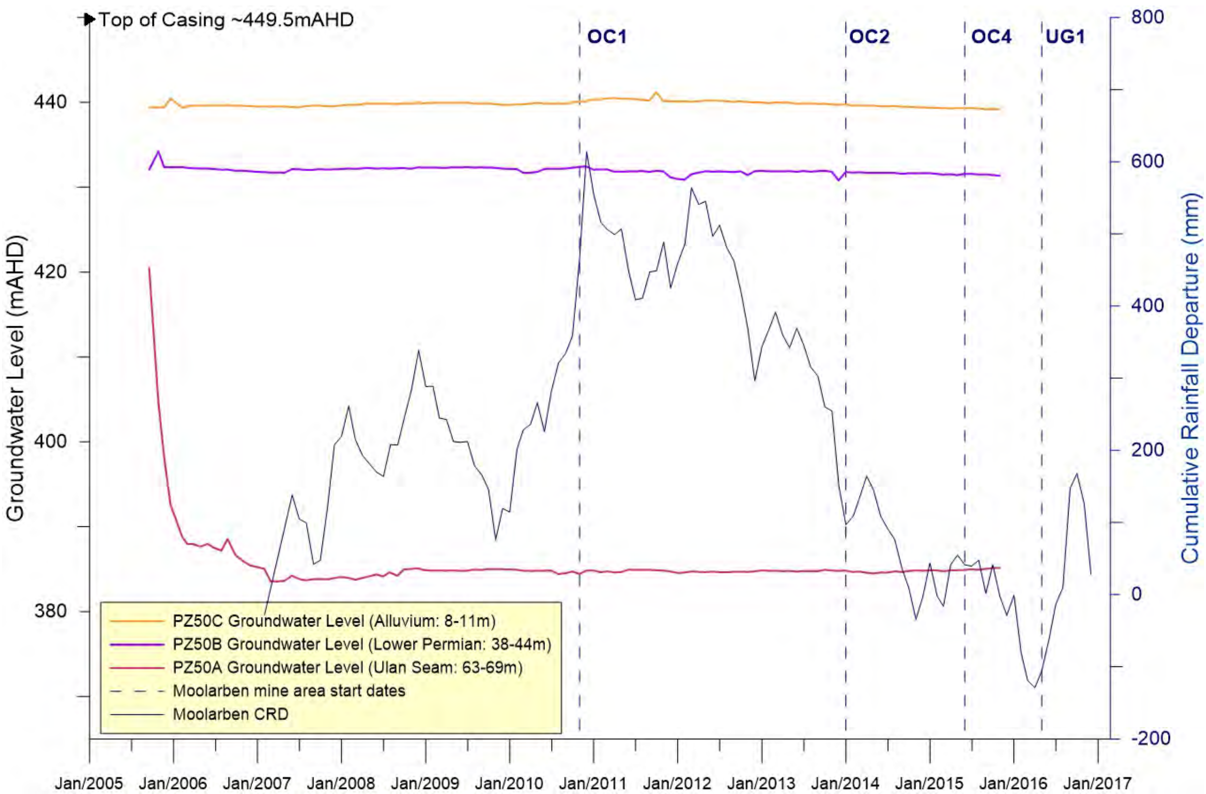


Figure A 43 – Multiple Standpipe Hydrographs

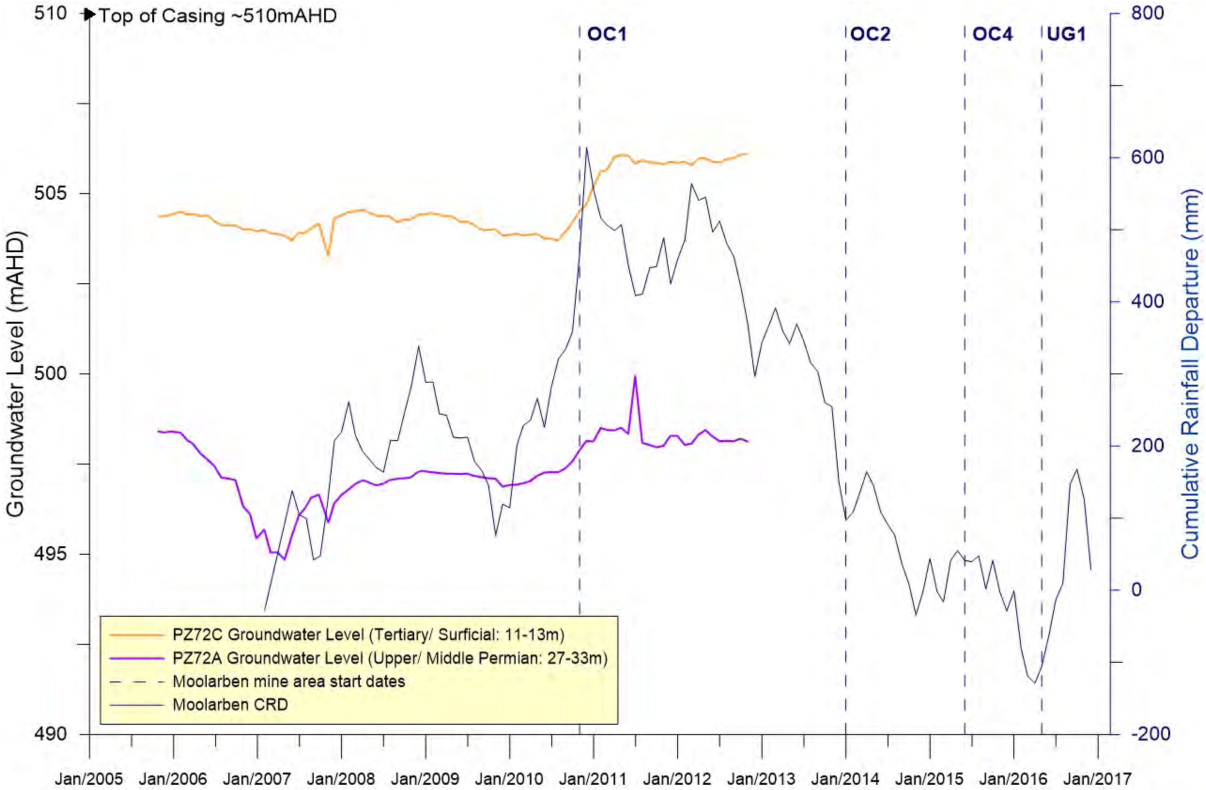


Figure A 44 – Multiple Standpipe Hydrographs

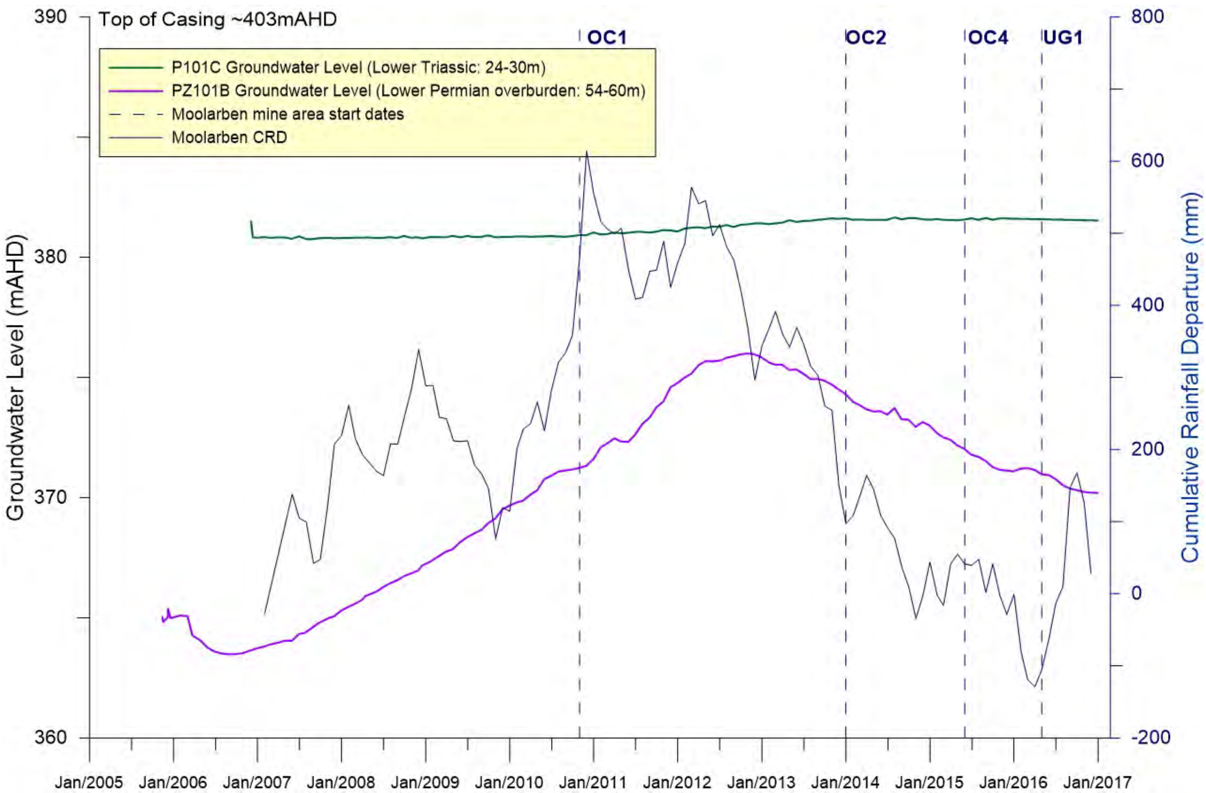


Figure A 45 – Multiple Standpipe Hydrographs

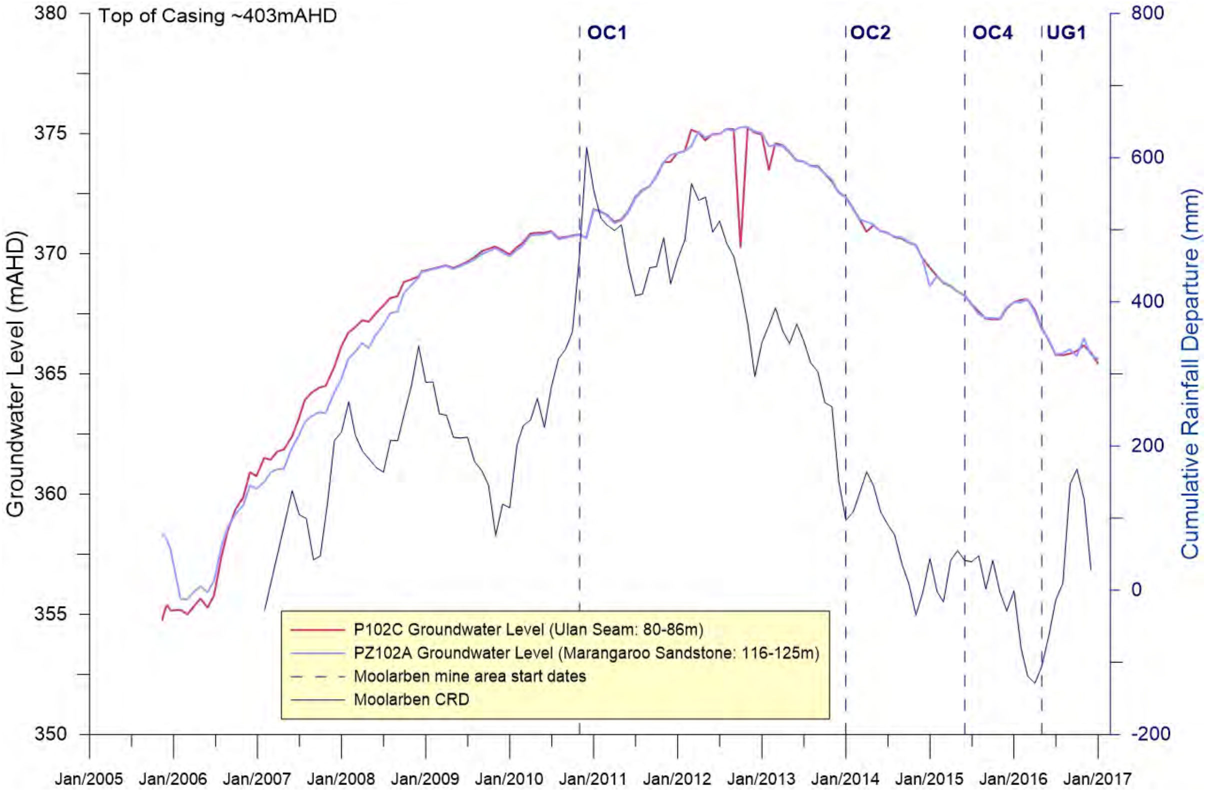


Figure A 46 – Multiple Standpipe Hydrographs

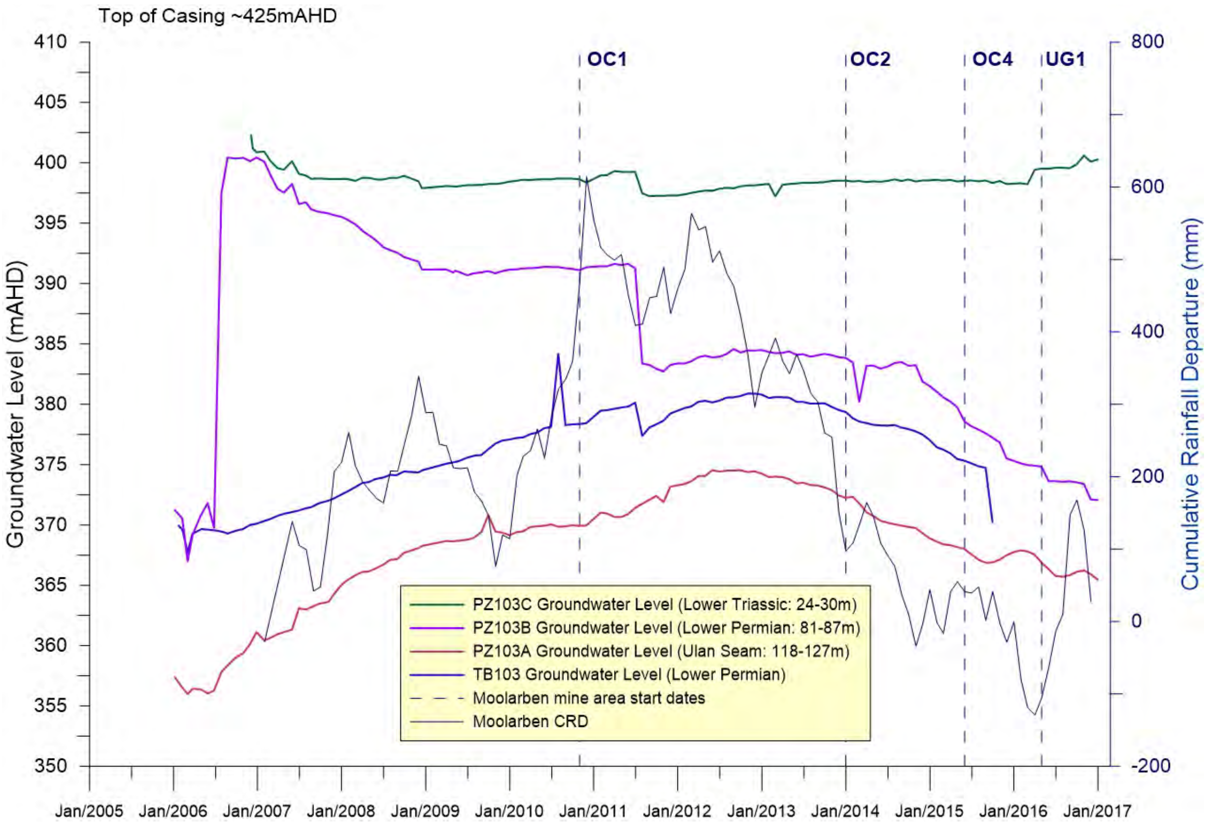


Figure A 47 – Multiple Standpipe Hydrographs

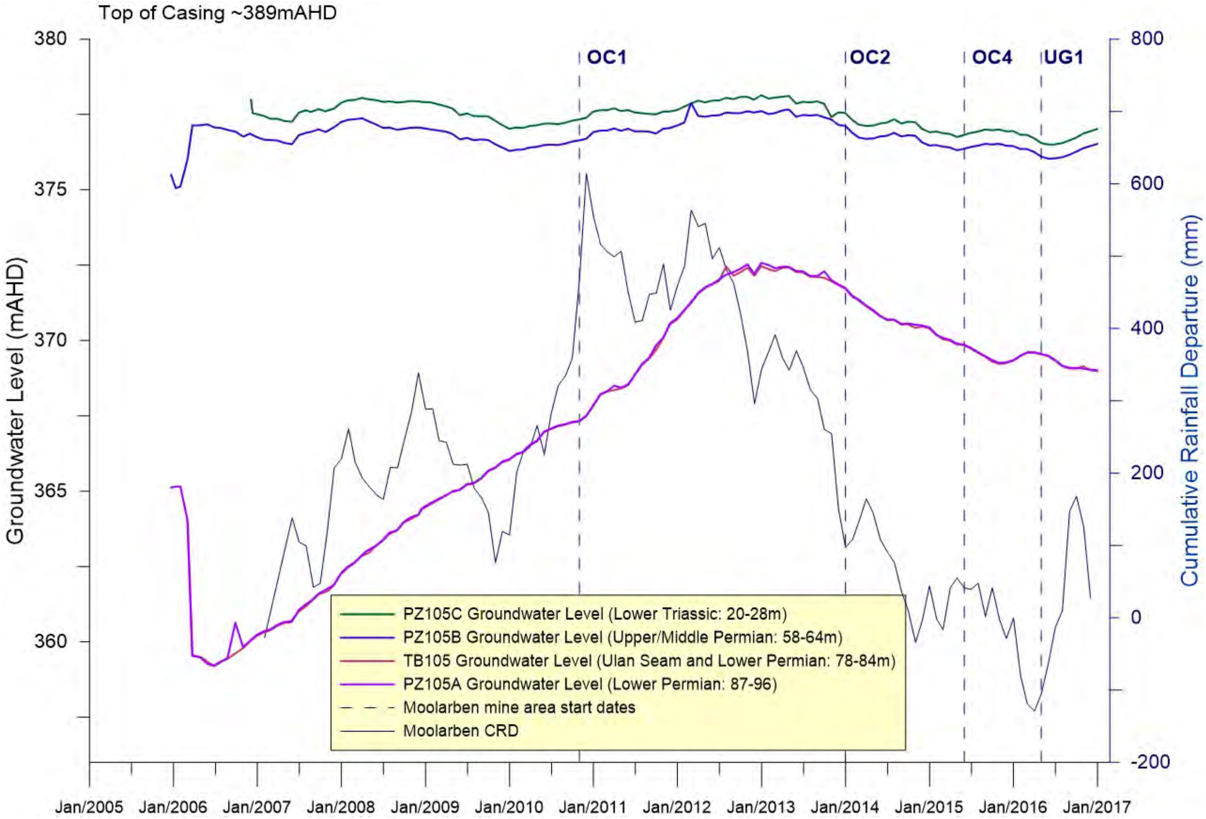


Figure A 48 – Multiple Standpipe Hydrographs

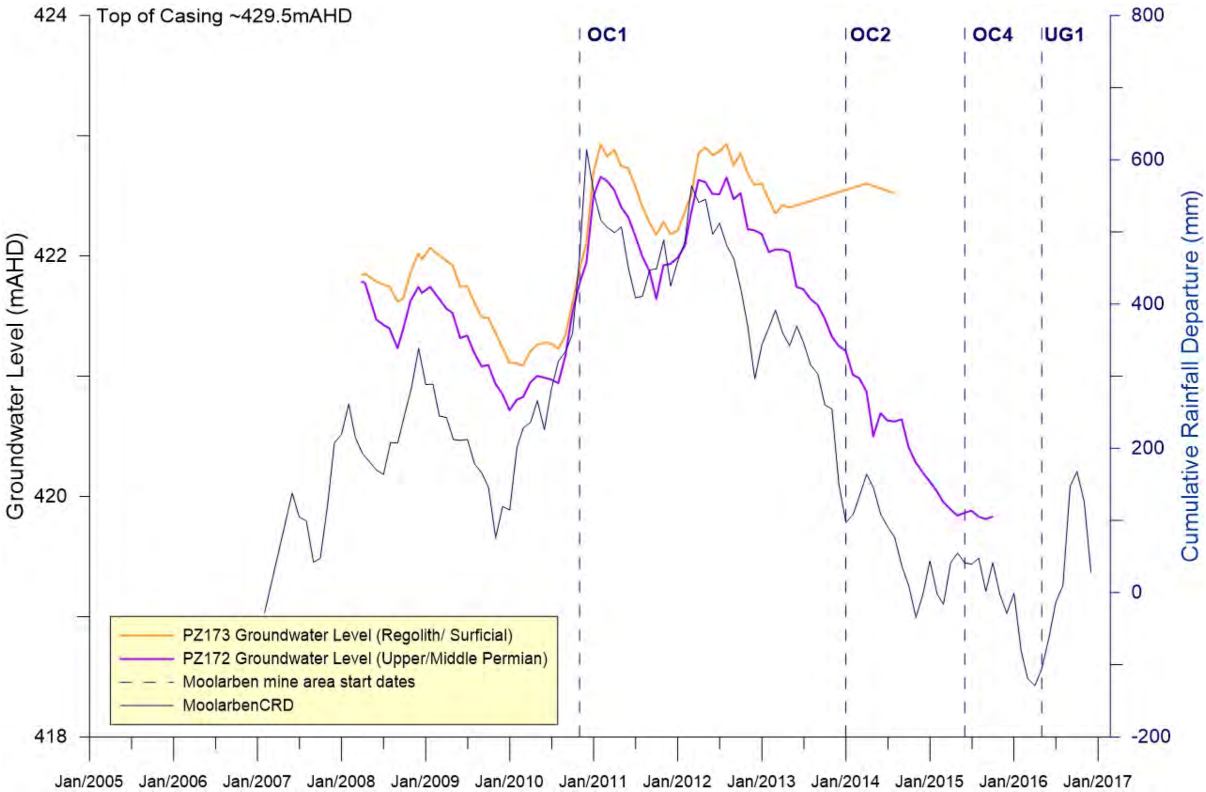


Figure A 49 – Multiple Standpipe Hydrographs

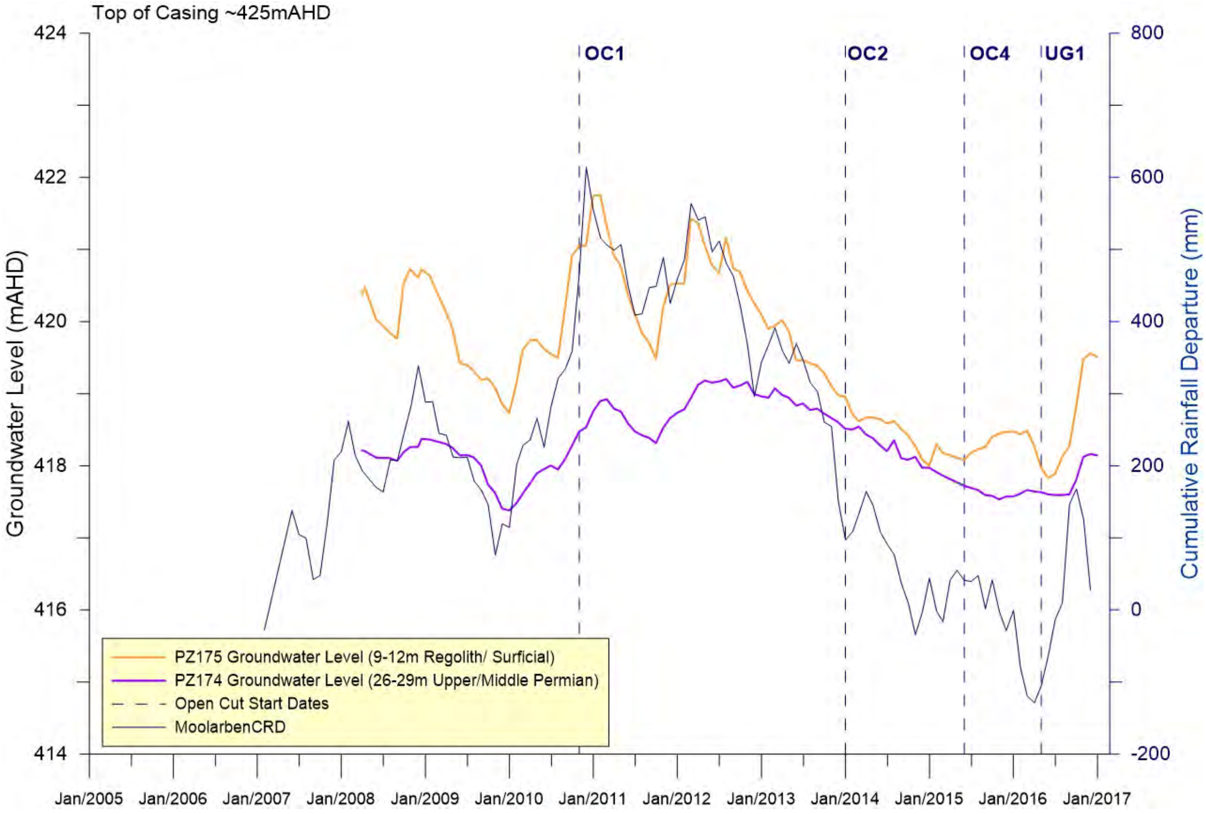


Figure A 50 – Multiple Standpipe Hydrographs

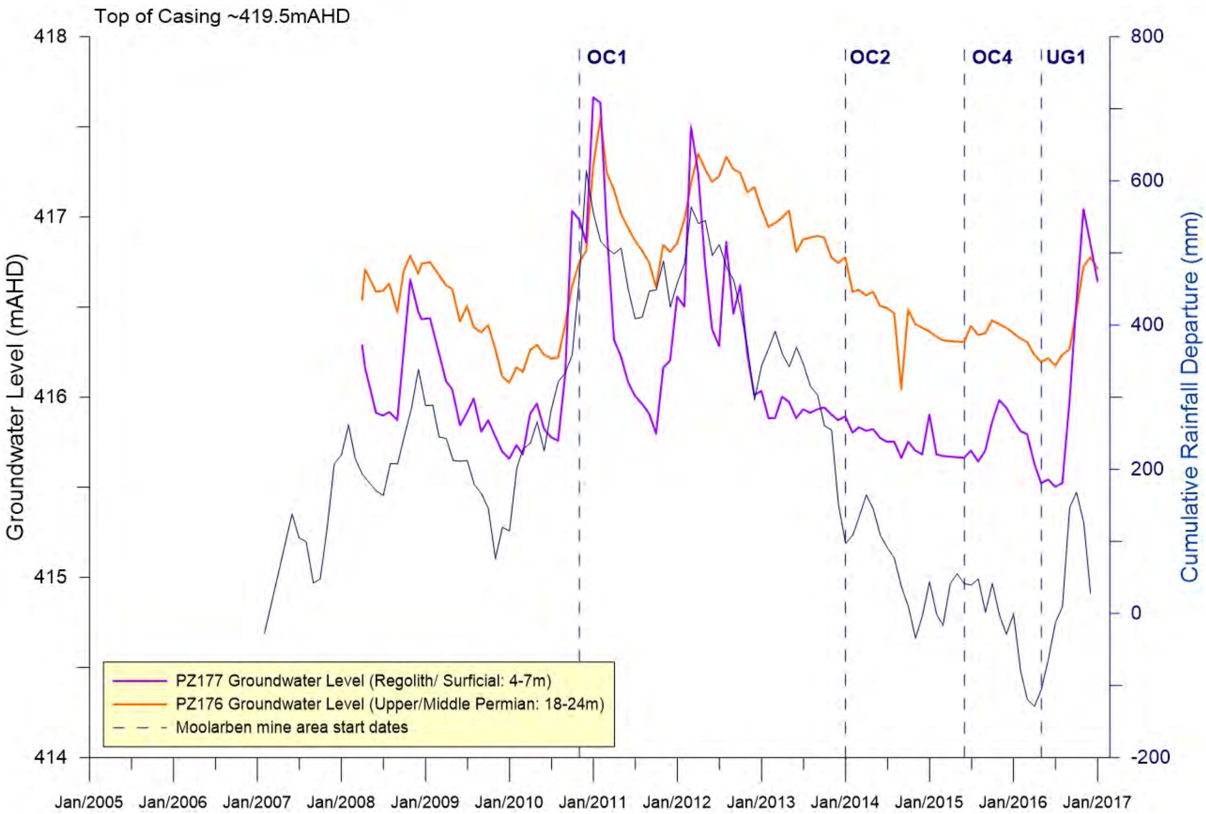


Figure A 51 – Multiple Standpipe Hydrographs

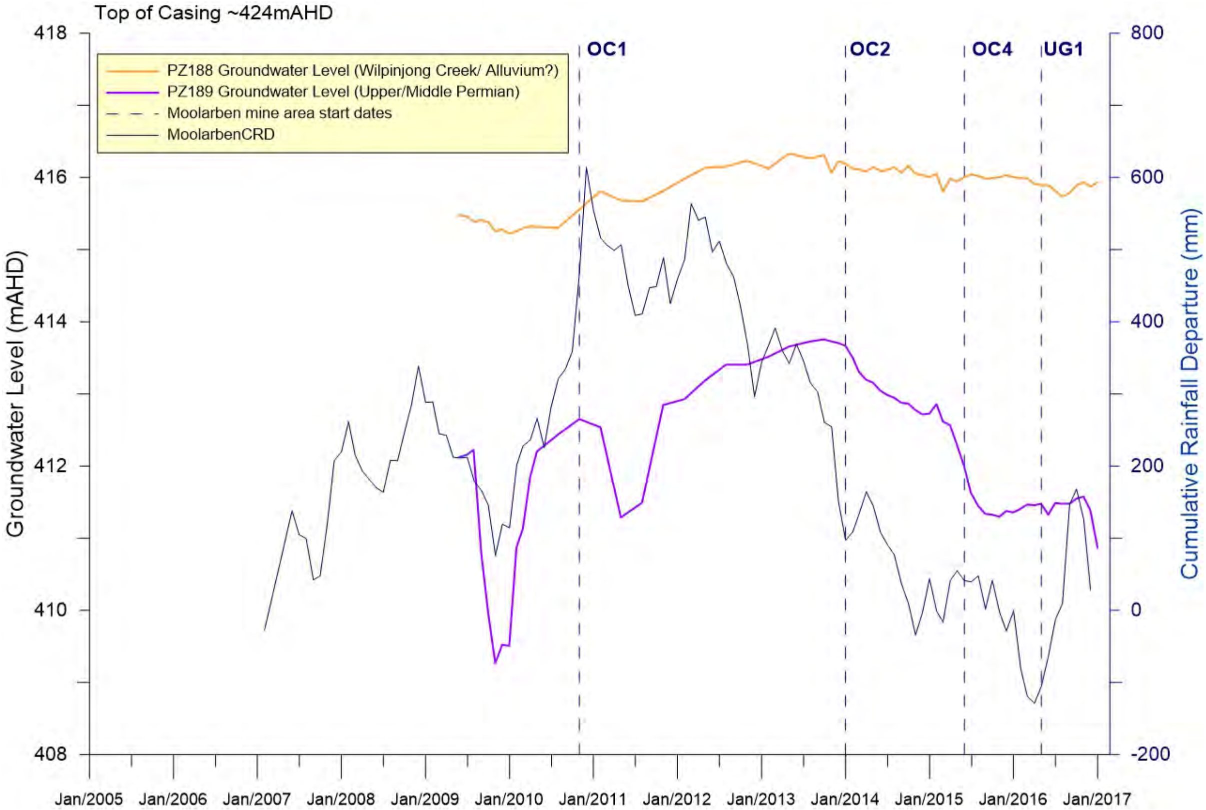


Figure A 52 – Multiple Standpipe Hydrographs