
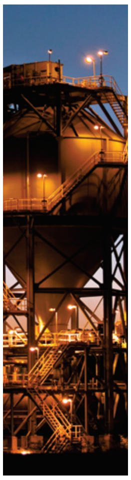
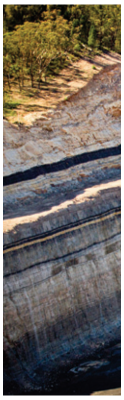

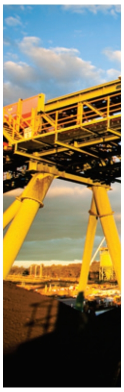

MOOLARBENCOAL

Moolarben Coal Complex
UG1 Optimisation Modification

Environmental Assessment

APPENDIX B

GROUNDWATER ASSESSMENT

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21 May 2015

Yancoal Australia Ltd
Level 26, 363 George Street
Sydney NSW 2000

Attention: Mark Jacobs

Dear Mark,

Re: Moolarben Coal Complex – UG1 Optimisation Modification – Groundwater Assessment

1. Background

The Moolarben Coal Complex (MCC) includes four open cut mines and three underground mines. The locations of open cuts and underground mines are shown on **Figure 1**.

In September 2006, Moolarben Coal Mines Pty Limited (MCM) lodged an Environmental Assessment (EA) (MCM, 2006) for the proposed development of the Stage 1 of the MCC, incorporating three open cut mines (OC1, OC2 and OC3) and an underground mine (UG4) together with a coal preparation plant, coal handling and storage facilities, rail loop, train loading system, and associated mine infrastructure and services. Stage 1 of the MCC was granted approval by the Minister for Planning on 6 September 2007, and mining commenced in OC1 in 2010.

In 2008, a Major Project Application was lodged for Stage 2 of the project, comprising one open cut mine (OC4), two underground mines (UG1 and UG2) and associated additional infrastructure. At the same time, an application was lodged for a Section 75W Modification under the *Environmental Planning and Assessment Act, 1979* to Stage 1, to allow concurrent and integrated mining of both Stage 1 and Stage 2 of the project. An EA for these approvals was prepared (Wells and Coffey, 2009) and put on public exhibition during March-April 2009.

MCM subsequently made a number of changes to the proposed layout and design for Stage 2, and at the request of the Director-General, a Preferred Project Report (PPR) was prepared (Hansen Bailey, 2012a) and placed on public exhibition in January and February 2012. Stage 2 was approved by the Planning Assessment Commission (as delegate to the Minister for Planning) on 30 January 2015.

MCM is currently proposing the UG1 Optimisation Modification (the Modification) as part of the Stage 2 project, which involves lengthening of UG1 to the north-east and south-west, as well as changes to panel width and extraction height, relocation of main headings within the mine plan and increasing the underground mining rate from 4 million tonnes per annum (Mtpa) to 8 Mtpa.

This letter report details the incremental changes to groundwater-related impacts as a result of the proposed Modification. Full details of the Modification are provided in Section 3 below.

2. Previous Groundwater Impact Assessments

A comprehensive groundwater assessment report was prepared by Peter Dundon and Associates Pty Ltd (PDA) for inclusion in the Stage 1 EA (PDA, 2006). This included assessment of the impacts from open cuts OC1, OC2 and OC3, and underground mine UG4.

The Major Project Application for the Stage 2 EA of the MCC, incorporating one open cut mine (OC4) and two underground mines (UG1 and UG2), which was lodged with the Minister for Planning in May 2008, was supported by a groundwater impact assessment completed by Aquaterra Consulting Pty Ltd (2008).

A revised groundwater impact assessment for the Stage 2 PPR was completed by RPS Aquaterra (2011). After the PPR was placed on public exhibition in January 2012, a number of written submissions were received in response to the PPR (Hansen Bailey, 2012b). A further groundwater impact assessment report addressing issues raised in the submissions was prepared by RPS Aquaterra (2012).

3. UG1 Optimisation Modification

Following a review of mine planning, Moolarben Coal Operations Pty Limited (MCO) the operator of the MCC mining operations, has identified opportunities to extract additional economically viable coal and improve underground mining and processing efficiencies associated with its underground operations, namely UG1. In particular, the Modification comprises the following:

- Recovery of approximately 3.7 million tonnes of additional run-of-mine (ROM) coal over the life of the mine;
- An extension of UG1 longwall panels in the north-east by approximately 150 to 500 metres (m);
- An extension of two UG1 longwall panels in the south-west by approximately 75m;
- Relocation of underground access to UG2 and UG4;
- Longwall extraction of the portion of coal that forms the approved (central) main headings;
- An increase in the coal seam extraction height by approximately 300 millimetres to a maximum extraction thickness of 3.5 m;
- An increase to longwall panel void width from approximately 305 to 311 m;
- Construction of a ROM coal conveyor and associated transfer points between the UG1 pit top facilities in OC1 and the coal handling and preparation plant (CHPP) to transport underground ROM coal;
- Extension to the underground product coal stockpile in the CHPP area and relocation and expansion of the underground ROM coal stockpile at the UG1 pit top facilities;
- An increase in the maximum underground ROM coal extraction rate up to 8Mtpa from UG1, UG2 and UG4 (combined);
- An increase in the maximum total site ROM coal rate to 21Mtpa (i.e. 13Mtpa from open cut operations and 8Mtpa from underground operations);
- An increase in average daily rail departures from five to seven and increase in peak daily rail departures to nine;
- Construction of Remote Services Facilities and rear intake shaft and associated fans above the extended UG1 longwall panels; and
- Relocation of the underground Mine Infrastructure Area and site administration offices.

The changes in the mine layout of headings and longwall panels involved in the Modification are shown on **Figure 2**.

The main components of the Modification that may influence the groundwater impact assessment are:

- Lengthening of the longwall panels to the north-east, thus approaching closer to the alluvium associated with Wilpinjong Creek and Murragamba Creek, and the deeper Tertiary palaeochannel in that area.
- Increasing the extraction height by approximately 0.3m to a maximum of 3.5m.
- Increasing the panel width by approximately 6m from 305m to 311m.

- Relocation of the approved UG1 central mains to the north-east end of the panels.
- Providing for access to UG4 from UG1.
- Changes to the timing of OC1, OC2 and OC4.

All other elements of the Modification are considered to have no significant impact on the groundwater impact assessment.

4. Additional Work Undertaken for Groundwater Impact Assessment

Additional work that has been undertaken since the previous groundwater impact assessments were completed includes the following:

- A Transient Electro-Magnetic (TEM) and Direct Current (DC) electrical resistivity survey program has been conducted by Groundwater Imaging Pty Ltd, to help better define the depth of regolith and the extent of the palaeochannel at the north-eastern end of UG1 (Groundwater Imaging, 2014).
- A groundwater modelling study to inform this groundwater assessment. The objective of the modelling is to quantify the incremental impacts of the Modification on groundwater levels, the baseflows of Murragamba Creek and Wilpinjong Creek, and induced leakage from alluvium associated with Murragamba Creek and Wilpinjong Creek, and the Tertiary palaeochannel (HydroSimulations, 2015).

5. Groundwater Impact Assessment Requirements

This letter report has been requested by MCO to support the Modification EA. I have been asked to report on the incremental changes to previously reported impacts due to the Modification.

I have based this report largely on the results obtained from the HydroSimulations modelling study referred to above (HydroSimulations, 2015). The modelling carried out by HydroSimulations and results are discussed in detail in **Section 7** below. The groundwater modelling report is included as Attachment A.

6. Description of Existing Hydrogeological Environment

The existing hydrogeological environment has been extensively described in previous groundwater impact assessment reports. The groundwater assessment report prepared for the PPR (RPS Aquaterra, 2011) provides the most comprehensive description.

UG1 is located beneath an elevated north-east / south-west orientated ridgeline of outcropping Triassic Narrabeen Group sediments. Underlying the Triassic sediments there is approximately 90-100m of Permian coal measures between the base of the Triassic and the target Ulan Seam.

The Triassic sediments are essentially dry, based on the results of limited drilling, and extrapolation from other areas of outcropping Triassic to the north and south. The underlying Permian is partly saturated.

The UG1 longwall panel area is flanked to the west by open cut OC1 and to the east by the proposed open cut OC4. In the open cut areas, the Ulan Seam is overlain by varying thickness of Permian coal measures, which is partially saturated. Both open cuts as well as UG1 target the Ulan Seam.

The upper surface comprises a weathered zone which has been assigned a nominal thickness of 10m based on drilling results. In elevated areas, where the Triassic has not been eroded away, this regolith layer is essentially dry. In lower-lying areas, where the Triassic is absent as a result of erosion, the regolith layer may contain surficial groundwater resulting from local rainfall and rainfall recharge.

7. Modelling Undertaken by HydroSimulations

The HydroSimulations (2015) report states that the same groundwater model that had been used for the most recent impact assessment of the MCC (RPS Aquaterra, 2012) was used for this current assessment of impacts due to the Modification. This was done as the RPS Aquaterra model has been extensively calibrated against observed impacts from the neighbouring Ulan and Wilpinjong coal mines, both of which have been operating for a longer period of time than the MCC. This model also has been through a rigorous independent review process through previous project applications, and has been accepted by the regulators.

The most recent RPS Aquaterra modelling, carried out in 2012, involved a series of model runs that aimed to assess the impacts of the Stage 2 project, isolated from the effects of other nearby existing and approved mining operations, namely the Ulan coal operation immediately to the west of the MCC, and Wilpinjong coal project immediately east of the MCC, as well as the approved MCC Stage 1 project, all three of which are expected to continue concurrently with the proposed MCC Stage 2 project.

7.1 The Groundwater Model

The main features of the groundwater model, as described in the Hydro Simulations report, are as follows:

- The model uses the following software:
    - MODFLOW SURFACT v4 (by HydroGeoLogic) modelling software, which allows for both saturated and unsaturated flow conditions.
    - Groundwater Vistas (Version 6.68) visualisation software (ESI, 2011).
- The model geometry comprises:
    - A model domain discretised into 1,166,592 cells comprising 434 rows, 336 columns and 8 layers.
    - An extent of 49.8 kilometres (km) from west to east (Eastings 740000 to 789800) and 54.7km from south to north (Northings 6405300 to 6460000), covering an area of approximately 2,725 square kilometres (km^2).
    - Cell dimensions ranging from 100 m x 100 m in the mining areas to 500 m x 500 m near the model domain boundaries.
- The model has 8 active layers:
    - Layer 1: Quaternary alluvium (nominal 10m thickness where present), Tertiary palaeochannel alluvium (varying thickness from 10m to 50m) and weathered bedrock/ regolith (assigned nominal 10m thickness wherever alluvium is not present).
    - Layer 2: Triassic (upper), and overlying Jurassic in down dip areas to the north – thickness ranges from zero to maximum of more than 400m at the down dip extremity to the north.
    - Layer 3: Triassic (lower) – thickness ranges from zero to maximum 30m (nominal 30m, but less if partly or fully eroded).
    - Layer 4: Permian (upper) – maximum 25m thickness (nominal 25m, but less if partly or fully eroded).
    - Layer 5: Permian (middle) – maximum 25m thickness (nominal 25m, but less if partly or fully eroded).
    - Layer 6: Permian (lower) – maximum 50m thickness (nominal 50m, but less if partly or fully eroded).
    - Layer 7: Ulan Seam – nominal 10m thickness.
    - Layer 8: Basement layer – Marrangaroo Formation, Ulan Granite and Volcanics – uniform thickness of 100m.

7.2 Fractured Zone Implementation

The groundwater models used to simulate the mining operations at Moolarben all include time-varying property changes for the strata overlying the longwall panels, so that the effects of subsidence on rock properties and consequently on groundwater properties can be adequately represented in the model. The results of subsidence predictions have been used to inform the groundwater model, both in terms of defining the height of the zone of fracturing above the extracted seam, and also in terms of the extent of change in hydraulic properties within that zone due to the subsidence fracturing. The properties ultimately adopted for the subsidence-affected strata have been determined from model calibration as discussed below.

In previous modelling by RPS Aquaterra using this model, the fractured zone immediately overlying extracted longwall panels was simulated with vertical hydraulic conductivity enhanced according to a log-linear monotonic ramp function. Vertical hydraulic conductivity post-subsidence was increased by a factor of 400 times for the 50m zone immediately above the goaf (ie Layer 6 in the model, representing the lower part of the Permian coal measures) and by 40 times for the next layer up (Layer 5, thickness 25m, representing the middle section of the Permian coal measures). No increase in vertical hydraulic conductivity was adopted for the uppermost part of the Permian coal measures, ie Layer 4 in the model, also 25m thick, on the basis that monitoring at the neighbouring Ulan mine had shown that direct hydraulic connection between the goaf and the base of the Triassic Narrabeen Group sediments (ie Layer 3 in the model) was unlikely to have occurred as a result of mining from longwall panels with a width of around 260m, slightly less but similar to the 305m then proposed by Moolarben Coal for UG1. Hydraulic connection through into the Triassic was shown to have occurred at Ulan after 2007 when they switched to 400m wide longwall panels.

No changes to hydraulic properties have been made in areas outside of the longwall panel footprints.

The height adopted for the fractured zone (ie Layers 5 and 6 totalling 75m) was based on calibration of the model against the monitoring results from the neighbouring Ulan mine where prior to 2007[1], panel widths of 260m and similar extraction heights to those proposed for UG1 had been used.

Sensitivity modelling was used to assess the potential impacts of higher fractured zones and different multipliers for vertical hydraulic conductivity. Uncertainty analysis modelling was also undertaken for several scenarios with higher extent of direct connected fracturing and higher conductivity ratios.

HydroSimulations checked these fracture height parameters against a more recent model developed by Ditton and Merrick (2014). They checked the previously assumed heights of direct-connected fracturing above the Ulan seam after longwall extraction against predictions using the new fracture height model, and then used the new model to check what difference the proposed Modification would make to the predicted heights of direct-connected fracturing.

HydroSimulations found that the new model predictions were broadly consistent with the previous assumptions of fracture heights that had been used to assign altered hydraulic conductivity values to the fracture-affected zones. Their assessment of the proposed Modification suggested that the height of direct-connected fracturing may be up to 6-8m higher with the Modification relative to the mine plan and design detailed in the PPR. The higher extent of direct-connected fracturing arises from the increase in extraction thickness by approximately 0.3m and the change in panel width.

HydroSimulations concluded that the previously adopted changes to hydraulic conductivities within the fracture-affected zone above extracted longwall panels was consistent with the predictions based on the new Ditton model, and that the changes in fracture heights associated with the proposed Modification were insufficient to require any change to the adopted parameters.

Accordingly, in order to allow direct comparison of the model predictions with and without the Modification, no change was made to the representation of subsidence fracturing in the model. As the previously adopted parameters were well calibrated against observed impacts at the adjoining Ulan mine, and were also consistent with the output from the new Ditton model, this is considered acceptable.

[1] Since 2007, mining at Ulan has been with wider (400m) longwall panels.

7.3 Model Calibration

As no changes were made to the model prior to running the two simulations listed above, the calibration modelling carried out for the most recent modelling by RPS Aquaterra (2012) was relied upon. The RPS Aquaterra calibration was carried out in transient mode, to achieve a match with measured groundwater levels from the period 1987 to 2008 (RPS Aquaterra, 2011).

As reported by RPS Aquaterra, the model calibration was satisfactory, with a Scaled Root Mean Square (SRMS) of approximately 8%, which is within the target range (0-10%) suggested in the old groundwater modelling guideline which was current at that time (MDBC, 2001). A mass balance error of less than 0.1% was achieved, which is the criterion of acceptability in the new Australian Groundwater Modelling Guidelines (Barnett et al, 2012).

7.4 Model Simulation Scenarios

HydroSimulations reported that two model scenarios were run, viz:

- Scenario 1 (the "without Modification" case) – Ulan + Wilpinjong + MCC Stage 1 + MCC Stage 2 (UG1 layout as per PPR)
- Scenario 2 (the "with Modification" case) – Ulan + Wilpinjong + MCC Stage 1 + MCC Stage 2 (UG1 layout as per Modification).

Scenario 1 is almost identical with one of three scenarios that were run with this model and reported in the November 2011 and June 2012 RPS Aquaterra reports (RPS Aquaterra, 2011; RPS Aquaterra, 2012). Scenario 2 is a new model run devised for this assessment to determine the impacts from the proposed Modification.

The same mine plans and scheduling were assumed for both simulations, apart from differences in the longwall panel lengths in UG1 – in Scenario 1 the same panel lengths that were proposed in the PPR were used, while in Scenario 2, the longer panels proposed in the Modification as described in **Section 3** above were assumed. Only the panel lengths were different, as the other changes embodied in the Modification, notably panel widths and extraction height, were considered to be too small relative to the model cell size to be able to be represented differently in the model.

In the mine plan proposed in the PPR, UG1 had mains located centrally within the panel, and it was proposed to mine the northern part of each panel from north to south, and the southern part of each panel from south to north. In the Modification, the mains are located at the northern end of the panels, and it is proposed to mine all panels from south to north. For the current study, the same mine schedule was assumed for UG1 in Scenarios 1 and 2, with mining assumed to be from south to north, and ignoring the presence of the central mains in Scenario 1. This was done to ensure that the only difference between the two Scenarios was the lengths of the panels.

The decision to assume the same mining direction in both Scenarios would result in a different pattern of groundwater inflows for the "without Modification" scenario than for the PPR modelling of that mine plan, as the timing of mining in particular locations would be different. However to have retained the same mine schedule for UG1 in the Scenario 1 model as had been proposed in the PPR would have made comparison of the Scenario 1 and Scenario 2 inflows difficult. Hence it was decided to limit the differences between Scenario 1 and Scenario 2 to only the lengths of the longwall panels.

The results from these two simulations were subtracted one from the other to quantify the differences in impact between the two, and these differences were assumed to be solely the incremental impacts of the proposed Modification. This approach is the accepted way to assess incremental impacts due to changes to a mine plan.

7.5 Results of Modelling

The modelling results are detailed in the HydroSimulations report (Attachment A).

As stated earlier, the incremental impacts of the changes embodied in the Modification were determined by subtracting the impacts from the "without Modification" model from the impacts from the "with Modification" model.

7.5.1 Water Balance

The two model scenarios were first compared in terms of water balance. Across the model domain, total water balances are almost identical between the “without Modification” model and the “with Modification” model, as shown in Table 6 of the HydroSimulations (2015) report. This table is reproduced below as **Table 1**.

Across the entire model, the Modification is predicted to result in a slightly greater net groundwater outflow (an extra 0.05 megalitres per day (ML/d), which is a 0.01% increase), comprising a 0.08 ML/d increase in mine inflow, partly offset by very slight reductions in evapotranspiration (0.01 ML/d), baseflow (0.01 ML/d) and reduction in pumping from water supply wells (0.2 ML/d), and a slightly greater change in groundwater storage.

These additional groundwater losses are close to negligible, and are readily accountable by licensing.

Table 1: Average Simulated Water Balance for the Moolarben Prediction Model - as per Table 6 of HydroSimulations (2015)

COMPONENT	SCENARIO 1 “without Modification”		SCENARIO 2 “with Modification”	
	Inflow (ML/d)	Outflow (ML/d)	Inflow (ML/d)	Outflow (ML/d)
Drains (mine inflow)	-	12.06	-	12.14
Recharge (direct rainfall)	81.79	-	81.79	-
Recharge (seepage faces)	-	2.12	-	2.13
Evapotranspiration	-	96.72	-	96.71
River (leakage/baseflow)	48.71	117.31	48.71	117.30
Wells (pumping)	-	2.67	-	2.65
Regional GW flow (GHB* cells)	122.59	55.18	122.59	55.18
Total	**253.09**	**286.06**	**253.09**	**286.11**
Change in storage	32.97 loss		33.02 loss	

* GHB = General Head Boundary

7.5.2 Mine Inflows

HydroSimulations have calculated the average mine inflow rates to UG1 for each year of the 9 years of mining UG1. These are plotted graphically for both modelling scenarios in Figure 22 of their report (Attachment A).

The modelling has shown that UG1 inflow rates are consistently higher for the Modification than for the original PPR mine plan, as shown in **Table 2** below. Inflow rates to UG1 are predicted to peak at 1.45 ML/d (529 megalitres per year [ML/y]) and average about 0.92 ML/d (335 ML/y) (Scenario 2), compared with a peak inflow rate of 1.26 ML/d (460 ML/y) and average of 0.77 ML/d (281 ML/y) (Scenario 1) for the mine plan proposed in the PPR. The inflow rate to UG1 is 18% higher for the Modification over the duration of mining UG1. This is believed to be due to the extension of all five longwall panels further to the north, which is downdip and therefore requires a greater lowering of groundwater levels in the Ulan Seam and the overlying coal measures.

Table 2: Predicted Average Groundwater Inflow Rates to UG1 - as per Table 8 of HydroSimulations (2015)

Mine Year	Average Inflow Rate (ML/d)		Increase (ML/d)
	Scenario 1 ("without Modification")	Scenario 2 ("with Modification")	
1	0.03	0.03	0
2	0.61	0.73	0.08
3	0.60	0.74	0.14
4	0.94	1.14	0.20
5	0.87	1.05	0.18
6	1.26	1.45	0.19
7	0.86	1.03	0.17
8	0.94	1.11	0.17
9	0.83	0.98	0.15
Average	**0.77**	**0.92**	**0.14**

7.5.3 Groundwater Levels

HydroSimulations then considered the groundwater levels predicted by the two model scenarios. They have presented groundwater level predictions for the Ulan Seam (Model Layer 7), and drawdowns for the Ulan Seam (Model Layer 7), the lower Triassic (Model Layer 3) and the alluvium / regolith (Model Layer 1).

Groundwater contours in the Ulan Seam (Layer 7) at the completion of mining of UG1 are presented on Figures 8 and 9 of the HydroSimulations report for the "without Modification" and "with Modification" mine plans respectively.

There is slightly greater drawdown in the Ulan Seam as a result of the Modification, as demonstrated on Figures 25a and 25b of the HydroSimulations report, which show contours of total drawdown in the Ulan Seam from the start of UG1 to the end of mining at UG1, for the two model scenarios. There are slightly greater drawdowns near the northern end of UG1 with the Modification than without it. Elsewhere, drawdowns in the Ulan Seam by the completion of UG1 are essentially unchanged from those reported previously in RPS Aquaterra (2012).

It should be noted that the drawdowns plotted on Figures 25a and 25b in the HydroSimulations report represent the total drawdowns between the start and end of mining of UG1. Thus they ignore any drawdowns associated with prior open cut mining in OC1 and OC2 at the MCC, as well as the ongoing mining at Ulan and Wilpinjong. These drawdown contour plots also do not present the impacts from UG1 alone, as the total drawdowns plotted include the impacts of all other concurrent mining while UG1 is being mined. These drawdowns should therefore only be used for the purpose of comparing the impacts from the "with Modification" and "without Modification" scenarios.

Contours of the incremental drawdown impacts in the Ulan Seam due to the Modification, relative to the PPR mine plan, are shown on **Figure 3**. These contours show the difference in drawdown prediction between Scenario 1 and Scenario 2. **Figure 3** shows that additional drawdowns of up to 6.5m are predicted to occur around the lengthened north-eastern extents of longwalls 101 to 105, but elsewhere there is negligible change to the drawdowns predicted for the Ulan Seam in the PPR reports (RPS Aquaterra, 2011 and 2012).

Total drawdown contours for the alluvium and regolith (Model Layer 1) from the start to the end of mining of UG1 are presented in Figure 23a and 23b of the HydroSimulations report, for the "without Modification" and "with Modification" cases. Again, visually, any difference between the two plots is not easily seen.

Contours of the incremental drawdown impacts in the alluvium and regolith from the Modification, relative to the PPR mine plan, are not presented, as the maximum incremental impact is only 0.3m additional drawdown relative to the drawdowns predicted to occur from the PPR mine plan, as reported in RPS Aquaterra (2011 and 2012). The incremental effect of the Modification on alluvium groundwater levels is therefore immaterial, since all additional drawdowns predicted are much less than 2m, the minimal harm criterion value listed in the Aquifer Interference Policy.

Drawdown impacts of the Modification on the Triassic are negligible. Drilling in the vicinity of UG1 showed that the Triassic above UG1 is essentially dry. The calibrated groundwater model shows only limited saturation in the Triassic in this area, and in both scenarios, the Triassic is fully dewatered. Total drawdown plots for the lower Triassic are shown for the two modelling scenarios on Figures 24a and 24b of the HydroSimulations (2015) report. These contour plots show no discernible additional impact from the Modification.

7.5.4 Baseflows

The baseflow impacts due to mining for Moolarben Coal Project Stage 2 and the cumulative impacts from all mining in the area (ie Ulan, Wilpinjong and Moolarben Stage 1, as well as Stage 2) were reported in previous groundwater assessment reports (RPS Aquaterra, 2011 and 2012).

HydroSimulations have assessed baseflow impacts for the two model scenarios in Section 3.6 of their report (HydroSimulations, 2015). The results are summarised in their Table 7, from which relevant details have been reproduced in modified format in **Table 3**, and with the fluxes presented as ML/y.

Table 3: Average Simulated Baseflow / Leakage for the Moolarben Prediction Model - as per Table 7 of HydroSimulations (2015)

Reach No	Reach Name	Predicted Increase in Average Total Baseflow/Leakage[2] (ML/y) due to the Modification[3]	% Increase in Impact Due to Modification	Comment
R101	Lagoon Creek	**0.03**	**0.00%**	Increased leakage
R102	Moolarben Creek Upper	**0.03**	**0.01%**	Reduced baseflow
R103	Moolarben Creek Middle	**0.05**	**0.00%**	Increased leakage
R105	Goulburn River West	**0.13***	**0.03%**	Increased leakage
R107	Murragamba Creek	**0.02**	**0.97%**	Reduced baseflow
R108	Wilpinjong Creek North	**0.66**	**14.4%**	Reduced baseflow
R109	Wilpinjong Creek (upstream of Wilpinjong)	**–0.01**	**–0.08%**	Increased baseflow

* This baseflow/leakage change is unlikely to be a real effect of the Modification and is likely a result of model imperfection.

As discussed in RPS Aquaterra (2012), the model-predicted changes in baseflows in the reaches in the eastern part of the model, reaches R110 and R111, are consequences of model limitations, due to the absence of calibration points east of Wilpinjong mine in the Wollar/Cumbo Creek catchment and downstream of MCC UG4 in the case of Goulburn River, as well as possible model drift due to the unavailability of true pre-mining (ie pre-Ulan) groundwater level data, and therefore the difficulty of doing a pre-mining steady state model calibration. These reaches have been omitted from **Table 3**.

The modelling also predicts an increase of 0.13 ML/y (0.36 kilolitres per day [kL/d]) for the Goulburn River catchment downstream of the Ulan mine diversion (reach R105). This is considered unlikely to be a real effect of the Modification, as this reach is too remote from UG1, and in any case is much closer to the Ulan mine operations than to the MCC operations at the time that UG1 is proposed to be mined. The difference in baseflows in Reach 105 between the two modelling scenarios suggested by the figures in **Table 3** is greater than the predicted change in impacts in Reach R103, which is closer

[2] Negative values indicate baseflow, ie loss of groundwater to the stream system. Positive numbers indicate leakage from the stream system to the groundwater. Therefore, either an increase in leakage or decrease in baseflow is considered an adverse impact, shown in **Table 3** as a positive percentage change.
[3] From start of UG1 tio end of model simulation.

to UG1. Hence the change in baseflow/leakage predicted by the model for reach R105 is likely a result of model imperfection, and should be excluded.

The comparison of baseflows and leakage rates for the two model scenarios shown in **Table 3** indicates that the Modification will result in a slight to very slight increase in adverse impact on surface water flows in some parts of the stream system. The baseflow impacts would be due almost exclusively to the open cut operations (Attachment A).

The Moolarben Coal Complex incorporating the Modification would result in an average baseflow reduction of 1.43 kL/d (3.93 ML/y) to the Wilpinjong Creek north catchment (sub-catchment R108). The peak baseflow reduction predicted for the Wilpinjong North catchment with the PPR mine plan (ie "without Modification") was 4.8 ML/y in Mining Year 20 (RPS Aquaterra, 2012).

Annual incremental baseflow impacts have not been reported by HydroSimulations (2015), however in Figures 11 to 21 they have plotted the total baseflows or leakage rates for each of the sub-catchments. The start and end of mining from UG1 are shown on each plot. The only catchment that visually shows a difference between the "with Modification" and "without Modification" impacts is Reach 108, Wilpinjong Creek North. This shows a slight decrease in baseflows starting at about the third year of UG1, and the divergence between the two baseflow curves steadily increases thereafter through the rest of UG1 and continuing post-mining. The incremental baseflow impact of the Modification is about 1.9 kL/d (0.69 ML/y) at the end of UG1 mining, but the incremental impact continues after UG1 extraction has been completed, and increases to a value of about 2.65 kL/d (0.97 ML/y) 5 years after the end of mining from UG1. This additional impact continues through to the end of the model simulation 19 years after completion of UG1.

The changes to impacts in all other sub-catchments are very minor, at 0.05 ML/y or less individually, and 0.13 ML/y in total.

The total additional average baseflow/leakage impact due to the Modification for all affected sub-catchments is therefore 1.10 ML/y (ie 0.97 + 0.13 ML/y). This represents a 2.7% increase in the 40.4 ML/y average total baseflow impact from the approved Moolarben Stage 2, as reported in the PPR groundwater impact assessment report RPS Aquaterra (2012).

8. Potential Impacts of the Modification

The additional impacts from the proposed Modification overall are quite small, and all would be able to be accounted through licensing. The additional impacts are discussed in the following sections.

8.1 Mine Water Inflows

The mine inflows were predicted for the whole of Moolarben Stage 2 in the PPR groundwater assessment reports (RPS Aquaterra, 2011 and 2012). The recent modelling by HydroSimulations did not re-assess the total mine inflows, but was focussed on the incremental impacts of the proposed Modification to UG1.

The mine inflows to UG1 are predicted to be up to 0.20 ML/d (73 ML/y) higher with the Modification than with the PPR mine plan. However, the increase in inflow rate is predicted to be only 0.19 ML/d (69 ML/y) in the year of peak inflows to UG1, year 6 (see **Table 2** in **Section 7.5.2**). Inflow rates to the other open cuts and underground mines were predicted to be unaffected by the Modification.

8.2 Groundwater Levels

Additional drawdowns in the Quaternary alluvium and Tertiary palaeochannel alluvium with the proposed Modification are predicted by the HydroSimulations modelling to be 0.3m or less in magnitude, and limited to the immediate proximity of the north-eastern end of UG1. This is believed to be less than the limit of accuracy in the model predictions of absolute groundwater levels.

This small additional drawdown is reflected in slightly increased leakage rates from the alluvium to the underlying Permian during the mining of UG1. An additional leakage rate of up to 7.5 kL/d (2.7 ML/y) is predicted to occur, with the peak increase occurring during the last year of mining from UG1. A long-term increased rate of leakage of 3.3 kL/d (1.2 ML/y) is predicted to result from the Modification.

Additional drawdowns of 0.3m or less are considered to be acceptable in terms of the Aquifer Interference Policy, which lists 2m as the minimum harm criterion value for connected alluvium.

Drawdown impacts from the Modification are predicted to be greatest in the Ulan Seam. Additional drawdowns in the Ulan Seam of up to 6.5m are predicted to occur with the Modification, relative to the PPR mine plan. Contours of the additional drawdown in the Ulan Seam are shown in **Figure 3**. All of the incremental impact of the Modification is located around the north-eastern end of UG1, and is due to the proposed lengthening of the longwall panels to the north-east, which takes them further downdip, and further below the pre-mining potentiometric water pressure levels. The additional impacts associated with the Modification extend about 1.5 km from the north-eastern end of UG1.

Smaller and less extensive additional drawdowns are expected to occur in the overlying Permian coal measures.

The Modification will have no impact on groundwater within the Triassic Narrabeen Group sediments, which overlie UG1, but are dry in that area.

8.3 Baseflow/Leakage Impacts

An average baseflow increase of 1.81 kL/d (0.66 ML/y) was predicted to occur in the Wilpinjong Creek North catchment over the duration of the model simulation (ie to 2043). The increase in baseflow/leakage impact, relative to the PPR mine plan, is predicted to peak at 2.65 kL/d (0.97 ML/y) about 5 years after completion of extraction from UG1, and will continue at a similar magnitude thereafter into the long-term.

Smaller impacts are predicted to occur in other sub-catchments, Lagoon Creek, Moolarben Creek and Murragamba Creek – ranging up to 0.05 ML/y in individual catchments and 0.13 ML/y in total. Adding this to the peak impact predicted for the Wilpinjong North catchment, gives a total of 1.10 ML/y which will need to be accounted for by way of increased licence allocation.

8.4 Groundwater Licensing Requirements

The Modification results in a negligible increase in total maximum water take from the water sources in the Hunter Unregulated and Alluvial Water Sources Water Sharing Plan 2009.

Using a conservative approach, the additional licensing requirement for the Porous Rock groundwater source is up to 69 ML/y, which would increase total licensing requirement to 903 ML/y, compared with the PPR mine plan requirement of 834 ML/y. It is expected that the amount of groundwater taken from the porous rock aquifer system will reduce in later stages of the mine, as the additional dewatering associated with the lengthening of UG1 to the north will have a flow-on effect on longer term dewatering requirements at UG4 to the north.

The total predicted take would remain within MCO’s existing licensed allocation.

9. Conclusions

This letter report details the expected incremental impacts of the proposed UG1 Optimisation Modification, as described in **Section 3**.

This report has drawn on the results of previous studies undertaken for Stage 1 and Stage 2 of the MCC, including the Stage 2 PPR. The previous groundwater impact assessments carried out in support of the EAs for Stages 1 and 2 and the PPR have assessed the potential impacts of Stage 1 and Stage 2 separately, the combined MCC operations (ie Stage 1 and Stage 2), and the cumulative impacts of Moolarben Stages 1 and 2 with Ulan and Wilpinjong. The combined and cumulative impacts have not been re-assessed.

Additional modelling has been undertaken by HydroSimulations (2015) that focussed on assessing the incremental changes resulting from the proposed Modification. This was done by means of two model scenarios, both of which include MCC Stages 1 and 2, plus Ulan and Wilpinjong, but Scenario 1 used the UG1 mine plan proposed in the PPR, while Scenario 2 used the UG1 mine plan proposed in this optimisation Modification. By subtracting the “without Modification” results from the “with Modification” results, the incremental impacts of the Modification have been determined.

The key findings of this assessment are:

- The Modification would have no material additional impact on stream baseflows or natural leakage for any of the nearby streams. The baseflow for the upstream section of Wilpinjong

Creek (which is nearest to the north-east longwall extensions) is predicted to be reduced by 0.66 ML/y (0.002 ML/d) due to the Modification.

- Negligible additional drawdowns of 0.3m or less are predicted to occur within alluvium near the north-eastern end of UG1 with the Modification (classified as less productive alluvium in accordance with the Aquifer Interference Policy).
- Additional drawdowns of up to 6.5m are predicted to occur within the Ulan Seam around the north-eastern end of UG1, as the longwall panel extensions proposed in the Modification will take mining further downdip than previously proposed. This drawdown is minor from a regional perspective.
- This will be associated with an additional mine inflow of 69 ML/y in the peak inflow year as a result of the Modification.
- No adverse additional impacts would occur to any third-party groundwater user, in terms of the minimal harm considerations of the Aquifer Interference Policy.
- The MCC would continue to comply with the water performance measure in the Project Approvals for nil impact on the water supply to the Drip.

In summary, the Modification is predicted to not have a significant additional impact above the impacts associated with the approved mining at the MCC.

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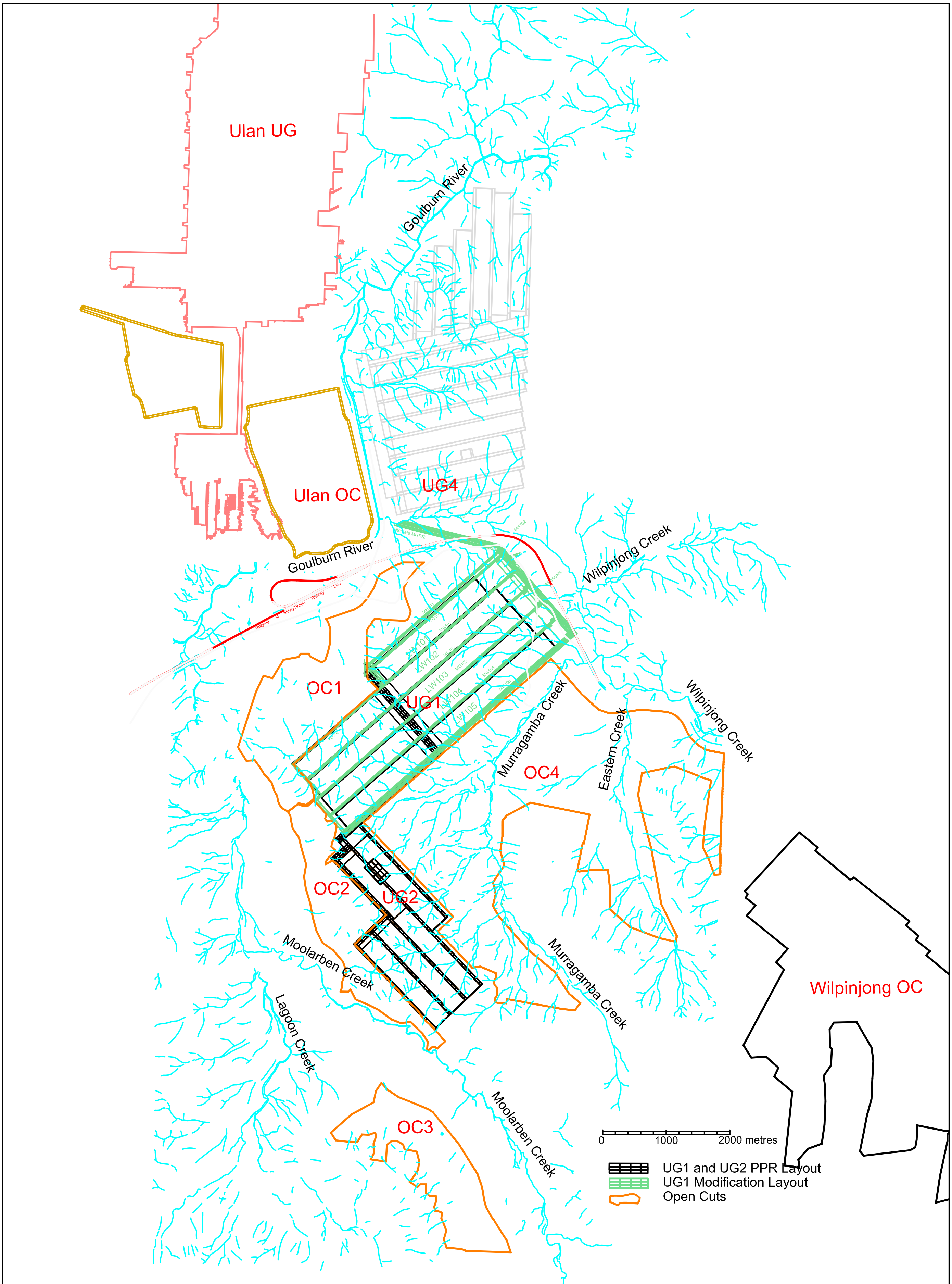
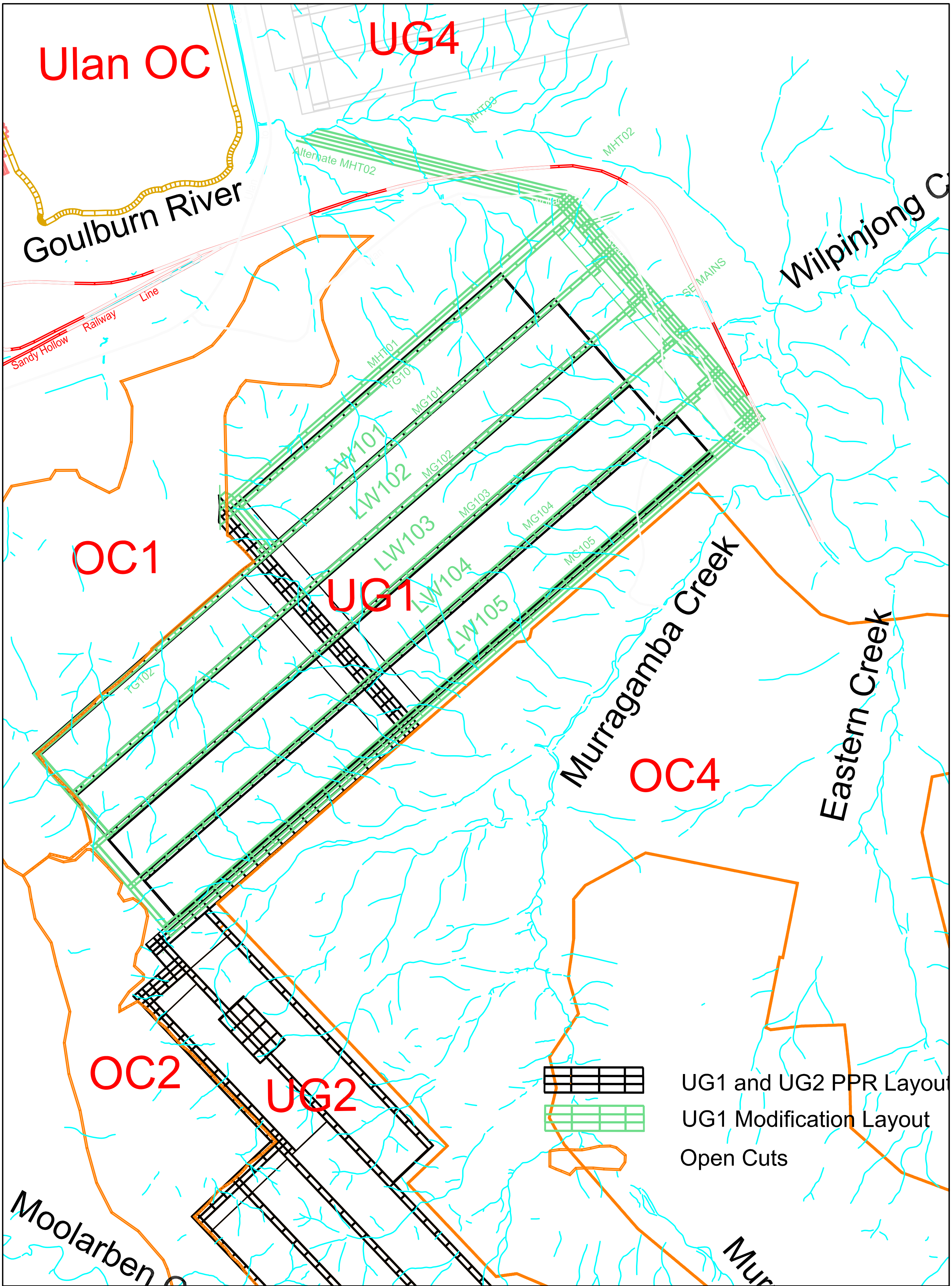
Yours faithfully.

Peter Dundon

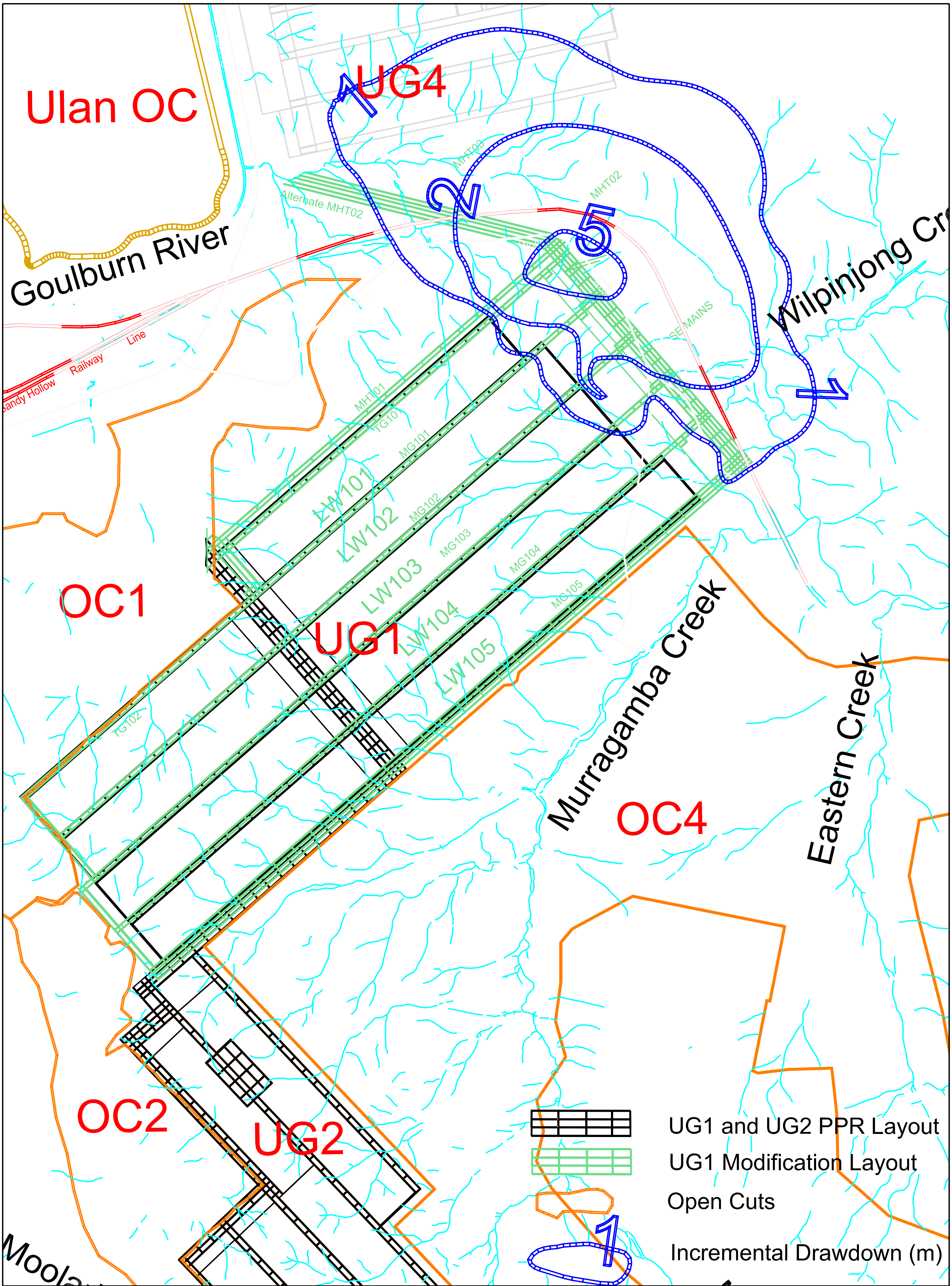
Attachment A: *Moolarben Underground Mine UG1 Optimisation Modification – Groundwater Modelling Assessment.* HydroSimulations, 2015.



DATE: 8 February 2015	SCALE: As shown	**Moolarben Coal Operations Limited**
AUTHOR: PJD CHECKED: PJD	PROJECT NO: 14-0279	**Moolarben Coal Complex**
DRAWING NO: 0279-08a	REVISION: A	**OC1, OC2, OC3, OC4, UG1, UG2, UG4 Locations**
Dundon Consulting Pty Ltd		**Figure 1**



DATE: 8 February 2015	SCALE: As shown	**Moolarben Coal Operations Limited**
AUTHOR: PJD CHECKED: PJD	PROJECT NO: 14-0279	**UG1 Mine Layout - Modification vs PPR Mine Plan**
DRAWING NO: 0279-07a	REVISION: A	
Dundon Consulting Pty Ltd		**Figure 2**



DATE: 8 February 2015	SCALE: As shown	**Moolarben Coal Operations Limited**
AUTHOR: PJD CHECKED: PJD	PROJECT NO: 14-0279	**UG1 Modification Incremental Drawdown in Ulan Seam - Modification vs PPR Mine Plan**
DRAWING NO: 0279-09a	REVISION: A	
Dundon Consulting Pty Ltd		**Figure 3**

ATTACHMENT A

MOOLARBEN UNDERGROUND MINE UG1 OPTIMISATION MODIFICATION

GROUNDWATER MODELLING ASSESSMENT

HYDROSIMULATIONS, 2015

Moolarben Coal Complex UG1 Optimisation Modification

Groundwater Modelling Assessment

FOR

Moolarben Coal Operations Pty Ltd

BY

Dr N.P. Merrick and Dr M. Alkhatib

Heritage Computing Pty Ltd

trading as

HydroSimulations

Project number: YAN002

Report: HC2014/034

Date: May 2015

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A	First Draft	4 Nov 2014	
B	Second Draft	10 Nov 2014	
C	Final Draft	7 Dec 2014	
D	Final	29 May 2015	

File:
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1 INTRODUCTION

The Moolarben Coal Mine is an existing open cut mining operation situated approximately 40 kilometres (km) north of Mudgee and 25 km east of Gulgong, New South Wales (NSW), in the Western Coalfield (**Figure 1**). Stages 1 and 2 of the Moolarben Coal Complex comprise four open cut mines (OC1, OC2, OC3, OC4) and three underground mines (UG1, UG2, UG4). Open cut OC1 commenced in May 2010 and OC2 commenced in 2014.

Exploration and mining activity is limited to Exploration Licences (EL) 6288, 7073 and 7074 (**Figure 2**), and Mining Leases 1605, 1606, 1628 and 1691. EL6288 is bordered by Ulan Mine Complex and Wilpinjong Coal Mine to the west and east, respectively.

Stage 1 of the Moolarben Coal Project was approved in September 2007. This consists of three open cut mines (OC1, OC2, OC3) and one underground mine (UG4). Approval was sought for Stage 2 in May 2008. This consists of one open cut mine (OC4) and two underground mines (UG1, UG2). A Preferred Project Report (PPR) for Stage 2 was issued in January 2012 with a Response to Submissions in June 2012. The approved Moolarben Coal Complex general arrangement, as specified in the PPR, is shown in **Figure 3**. Stage 2 of the Moolarben Coal Complex was approved in January 2015. Moolarben Coal Operations Pty Ltd (MCO) is seeking approval for a Modification of its proposed UG1 underground mine (herein referred to as the Modification).

This report focuses on groundwater modelling application and outcomes to inform a groundwater assessment prepared by Dundon Consulting Pty Ltd. The focus of the modelling is on quantifying the incremental impacts to the baseflows of Murragamba Creek and Wilpinjong Creek, induced leakage from associated alluvium and the Tertiary palaeochannel beneath Wilpinjong Creek, and mine inflows.

1.1 MODIFICATION DESCRIPTION

Following a review of mine planning, MCO has determined that it can improve the efficiency of coal resource recovery by making a number of alterations to the Stage 2 mine plans, including:

- An extension of UG1 longwall panels in the north-east by approximately 150 to 500 metres (m).
- An extension of two UG1 longwall panels in the south-west by approximately 75 m.
- Relocation of the approved central main headings to the north-east.
- Relocation of underground access to UG2 and UG4.
- Longwall extraction of the portion of coal that forms the approved (central) main headings.
- An increase in the total coal seam extraction height by approximately 300 millimetres to a maximum extraction height of 3.5 m.
- An increase to longwall panel void width from approximately 305 to 311 m.
- Construction of a ROM coal conveyor and associated transfer points between the UG1 pit top facilities in OC1 and the coal handling and preparation plant (CHPP) to transport underground ROM coal.
- Extension to the underground product coal stockpile in the CHPP area and relocation and expansion of the underground ROM coal stockpile at the UG1 pit top facilities.

- An increase in the maximum underground ROM coal production rate up to 8 million tonnes per annum (Mtpa) from UG1, UG2 and UG4 (combined).
- An increase in the maximum total site ROM coal rate to 21 Mtpa (i.e. 13 Mtpa from open cut operations and 8 Mtpa from underground operations).
- An increase in average daily rail departures from five to seven with an associated increase in peak daily rail departures to nine.
- Construction of remote services facilities and rear air intake shaft and associated fan above the extended UG1 longwall panels.
- Relocation of the underground Mine Infrastructure Area and site administration offices.

This report also considers modified timing for the commencement of OC1, OC2 and OC4 to reflect the current and the proposed extraction time for these open cuts.

The Modification includes lengthening of the five longwalls (LW101 to LW105) by 150-500 m in the north-east, lengthening of two longwalls (LW104 and LW105) in the south-west and relocation of the central mains to the north-east, as shown in **Figure 4**. The direction of mining would be from south to north for the Modification, whereas the Stage 2 plan had a north to south mining direction for the panels north of the central mains.

There would be no extension to the existing Stage 2 mine life.

A consideration for the extension of the longwall panels to the north-east has been the proximity to the Tertiary palaeochannel in that area. Extensive Transient ElectroMagnetic (TEM) and Direct Current (DC) electrical resistivity surveys have been conducted by Groundwater Imaging Pty Ltd (2014) to define the palaeochannel at the north-eastern end of UG1. The interpreted palaeochannel thicknesses and the outline of higher-permeability sediments are shown in **Figure 5**.

The findings of the geophysical surveys are:

- good definition of the palaeochannel location;
- good definition of sediment thickness in the palaeochannel;
- good definition of relative sand and clay content in the palaeochannel;
- detection of more recent clayey sediments cutting across the path of the palaeochannel and disrupting lateral continuity;
- detection of pockets of thick sediments now isolated from the main channel; and
- generally good agreement with the previous interpretations of the location of the palaeochannel based on drilling alone.

One of the isolated pockets of sediments occurs at the north-eastern end of LW101-102 (**Figure 5**). However, the palaeochannel sediments are generally dry at this location. No palaeochannel has been detected at the north-eastern end of LW103, but the palaeochannel has been detected above the proposed mains at the north-eastern end of LW104-105 (**Figure 5**). Here, the proposed longwall takeoff lines are terminated short of the palaeochannel.

In summary, the extended longwall panels would not pass beneath any water-bearing palaeochannel sediments.

1.2 GROUNDWATER RESOURCE

The Moolarben Coal Complex is located in the Western Coalfield on the north-western edge of the Sydney-Gunnedah Basin, which contains sedimentary rocks, including coal measures, of Permian and Triassic age. The dominant outcropping lithologies over the Moolarben Coal Complex are the Triassic Narrabeen Group (Wollar Sandstone) and the Permian Illawarra Coal Measures (**Figure 2**). 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 Moolarben Coal Complex.

In this area, surface water and alluvial groundwater resources are managed under the "Hunter Unregulated and Alluvial Water Sources" WSP[1,] which commenced in 2009. The "North Coast Fractured and Porous Rock Groundwater Sources" WSP is currently under development[2] by the NSW Office of Water (NOW) and would be relevant to the Moolarben Coal Complex once commenced.

Until the *North Coast Fractured and Porous Rock Groundwater Sources* plan is introduced, the *Water Act 1912* continues to apply to non-alluvial groundwater sources. MCO currently holds 15 water licences under the *Water Act* for 2,950 megalitres per annum (ML/a). The Moolarben Coal Complex resides within the Wollar Creek and Upper Goulburn River water sources within the Goulburn Extraction Management Unit of the Hunter Unregulated and Alluvial Water Sources (**Figure 6**).

Consistent with the relevant water sharing plans, the data supports two distinct groundwater systems in this area:

- Alluvial groundwater system; and
- Porous rock groundwater system.

All groundwater in the vicinity of the Moolarben Coal Complex is "less productive" in terms of the meaning in the Aquifer Interference Policy.

1.2.1 ALLUVIAL AQUIFERS

Quaternary alluvial deposits are associated with Lagoon Creek, Goulburn River, Moolarben Creek and Wilpinjong Creek (**Figure 2**). The NOW has identified a portion of the alluvial aquifer associated with Wilpinjong Creek downstream of the Wilpinjong Coal Mine as "highly productive".

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. The infill sediments consist of poorly-sorted semi-consolidated quartzose sands and gravels in a clayey matrix.

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[1] http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/Plans-commenced/Water-source/Hunter-Unregulated-and-Alluvial/default.aspx

[2] http://www.water.nsw.gov.au/Water-management/Water-sharing-plans/plans-under-development/default.aspx

1.2.2 POROUS ROCK AQUIFERS

The porous rock aquifers consist of the Narrabeen Group sandstones and the Illawarra Coal Measures, consisting of coal seams, conglomerate, mudstones and siltstones.

None of the identified groundwater systems is a significant aquifer. The most permeable units are the Ulan Seam and the underlying Marrangaroo Conglomerate, in general, while the sandstones of the Narrabeen Group are of lower permeability and are elevated above the Moolarben Coal Complex. The Illawarra Coal Measures also include low permeability mudstones and siltstones. In places, the Coal Measures are more permeable (due to fracturing) and some high-yielding bores are recorded. The Triassic strata are often dry, either naturally or from depressurisation caused by mining at the Ulan Mine Complex.

1.2.3 GROUNDWATER USERS

The closest high priority groundwater dependent ecosystem listed in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009* is approximately 140 km away and would not be affected by groundwater drawdown from Moolarben Coal Complex operations. However, the National Atlas of Groundwater Dependent Ecosystems (GDEs) identifies the watercourse of the Goulburn River as a potential GDE.

There are no high priority culturally significant sites listed in the *Water Sharing Plan for the Hunter Unregulated and Alluvial Water Sources 2009*. However, a spring known as *The Drip* has local cultural significance and is also a GDE. It is located on the northern bank of the Goulburn River to the north of ML 1605 and EL7074 on **Figure 2**. This feature is likely to be serviced by perched water in the Wollar Sandstone.

The Moolarben Coal Exploration Groundwater Monitoring and Modelling Plan (GMMP) notes 70 registered groundwater bores within 5 km of the Moolarben Coal Complex that are not on MCO-owned land or are not NOW monitoring bores (Moolarben Coal, 2014). The majority are to the west of Lagoon Creek outside EL6288 in granitic terrain (**Figure 2**).

2 GROUNDWATER SIMULATION MODEL

2.1 EXISTING GROUNDWATER MODELS

Potential impacts on water sources have been estimated by groundwater modelling conducted by RPS Aquaterra (2011) for the Preferred Project (Stage 1 and Stage 2) and by RPS Aquaterra (2012) for Stage 2 isolated from Stage 1 impacts.

A number of groundwater models has been constructed to simulate the stresses on the groundwater environment from mining activities within this area. Different versions of models have been developed by Aquaterra (2006 – 2009) and RPS Aquaterra (2011 – 2012).

The latest version of the RPS Aquaterra model (2012) was used in this project to ensure the consistency of predictions. This model version is called MC2.2[3]. There are various model versions that activate some or all of the mines. It is understood that there are three distinct versions:

1. Ulan + Wilpinjong + MCC[4] Stage 1 + MCC Stage 2;
2. Ulan + Wilpinjong (no MCC);
3. Ulan + Wilpinjong + MCC Stage 1.

Differencing of results from the various runs allows separation of the effects of Moolarben Coal Complex or Stage 2 alone.

A fourth version has been built for the Modification, based on Model 1:

4. Ulan + Wilpinjong + MCC Stage 1 + MCC Stage 2 + UG1 Modification.

For this Modification, Model 1 and Model 4 are run separately for the same conditions for the full simulation period of 34 years. The differences between the two runs allow isolation of the impacts due to the Modification.

The relevant cells associated with the minor UG1 longwall extensions in the south-west are almost entirely dry prior to the commencement of UG1, due to the effects of the encompassing open cut mining (i.e. OC1, OC2 and OC4) in the model. The extension of the UG1 longwalls in the south-west would have a negligible impact on groundwater in the model and therefore has not been considered further in this assessment.

2.1.1 PREVIOUSLY PREDICTED IMPACTS

The Stage 2 PPR Responses to Submissions model recalibration included groundwater information from Ulan Mine Complex that was not previously available (RPS Aquaterra, 2012). The Stage 2 PPR Responses to Submissions report focused impact assessment on 10 stream reaches and drawdown in each model layer at the end of Stage 2.

[3] While this version of the model excludes the Stage 1 open cut pit extensions associated with the Moolarben Coal Project Stage 1 Modification 9, its inclusion would only further dampen any effects of the Modification, because the adjacent cells would be dry.

[4] When referring to Models, MCC means Moolarben Coal Complex.

A summary of the predicted UG1 mine inflows and the potential baseflow reductions for the closest watercourses, due to Stage 2 alone, is given in **Table 1** (RPS Aquaterra, 2012) for the duration of UG1 mining.

Table 1. Predicted Stage 2 Mine Inflows and Baseflow Impacts (Prior to the Modification).

STATISTIC	UG1 Inflow [ML/a]	Murragamba Creek [ML/a]	Wilpinjong Creek North of confluence with Murragamba Creek [ML/a]	Wilpinjong Creek [ML/a]
Year 2	0	3.1	0.0	0.0
Year 4	218	6.0	0.0	0.1
Year 6	301	6.6	0.0	0.1
Year 8	264	6.7	0.0	0.1
Year 10	228	7.1	0.3	27.2
Year 12	324	13.5	1.4	42.8
Year 14	287	13.0	2.7	48.3

The progressive increase in the impact on Wilpinjong Creek is due to OC4 and not UG1. The report by RPS Aquaterra (2012) includes drawdown maps for each layer at the end of Stage 2. As the maps show negligible drawdown due to UG1 in the Upper Permian, Triassic and regolith/alluvial strata, the baseflow impacts would be due almost exclusively to the open cut operations.

2.2 SOFTWARE AND GEOMETRY

The software packages used to run the model for the current project are:

- MODFLOW SURFACT v4 (by HydroGeoLogic), which allows for both saturated and unsaturated flow conditions.
- Groundwater Vistas (Version 6.68) software package (ESI, 2011).

2.3 MODEL LAYERS AND GEOMETRY

No change has been made to the model layering or model geometry, other than better definition of the Tertiary palaeochannel resulting from geophysical surveying (**Figure 5**). Similarly, no changes have been made to physical properties or boundary conditions, other than stresses due to mining in accord with the Modification.

The model domain is discretised into 1,166,592 cells comprising 434 rows, 336 columns and 8 layers. The dimensions of the model cells are varied from 100 m in the mining areas to 500 m near the boundaries. The model extent is 49.8 km from west to east (Eastings 740000-789800) and 54.7 km from south to north (Northings 6405300-6460000), covering an area of approximately 2,725 km^2 (**Figure 6**).

Based on the conceptual hydrogeology described in the PPR report (RPS Aquaterra, 2011), the following layers were defined for the model:

- Layer 1: Quaternary alluvium, Tertiary palaeochannel and Weathered bedrock/ regolith.
- Layer 2: Triassic (upper) or Permian where Triassic is eroded.
- Layer 3: Triassic (lower) or Permian where Triassic is eroded.
- Layer 4: Permian (upper).
- Layer 5: Permian (middle).

- Layer 6: Permian (lower).
- Layer 7: Ulan Seam.
- Layer 8: Marrangaroo Formation, Ulan Granite and Volcanics.

2.4 FRACTURED ZONE IMPLEMENTATION

2.4.1 BACKGROUND

Conceptually, there are a number of physical hydrogeological effects that are expected to occur throughout the life of the underground mining which need to be represented in a numerical model. This includes the simulation of changes to the hydraulic properties of overburden material caused by caving and subsidence above longwall panels.

It is generally accepted that there will be a sequence of deformational zones consisting of the caved zone, the fractured zone (consisting of a lower zone of connective-cracking and an upper zone of disconnected-cracking), the constrained zone and the surface zone.

High permeability is expected in the caved zone where there is direct connectivity with the mined goaf. In the lower part of the fractured zone, the collapsed rocks will have a substantially higher vertical permeability than the undisturbed host rocks. In the disconnected-cracking fractured zone, the vertical permeability should not be significantly greater than under natural conditions. Depending on the width of the longwall panels and the depth of mining, and the presence of low permeability lithologies, increased horizontal permeability can be expected in the constrained zone. Near-surface fracturing can occur due to horizontal tension at the edges of a subsidence trough in the surface zone.

2.4.2 MODEL SIMULATION

In the RPS Aquaterra numerical model, the fractured zone was simulated with vertical hydraulic conductivity enhanced by varying vertical hydraulic conductivity field within the deformation zone overlying coal extraction areas. For UG1, multipliers of 400 and 40 were applied to Layer 6 (lower-Permian) and Layer 5 (mid-Permian) respectively. Sensitivity analysis was conducted for higher fractured zones and different multipliers.

Limits for enhanced permeability were governed by predicted fracture height and assigned upper and lower bounds on hydraulic conductivity. RPS Aquaterra (2011) state that ratios (A/W) of 0.40-0.45 at Moolarben Coal Complex and 0.67 at Ulan Mine Complex for fractured zone height (A) to panel width (W) were applied as the basis for determining the maximum height of subsidence fracturing which allows direct connection with the goaf. In this case, as the Moolarben UG1 Mine longwall panels are approximately 311 m wide, the fractured zone height would be about 124-140 m. Layers 5-7 for the mid-Permian, lower-Permian and the Ulan Seam were taken to be fractured in the model.

2.4.3 DITTON MODEL ESTIMATES

Better methods have become available recently for estimating the height of the fractured zone. However, for consistency with previous impact assessments, no change has been made to the implementation of the fractured zone in the model for this Modification, as only incremental effects are relevant.

Ditton and Merrick (2014) have released a new subsurface fracture height prediction model for longwall mines in NSW Coalfields. The new model includes the key fracture height driving parameters of panel width (W), cover depth (H), mining height (T) and local geology factors to estimate the A and B zone horizons above a given longwall panel. The A zone corresponds with the connective-cracking part of the fractured zone, while the B Zone corresponds with the disconnected-cracking part of the fractured zone which is equivalent to the lower dilated part of the constrained zone. Formulas are offered for two models:

- Geometry Model, which depends on W, H and T; and
- Geology Model, which depends on W, H, T and t' (where t' is the effective thickness[5] of the strata where the A Zone height occurs).

The formulas for fractured zone height (A) for single-seam mining are:

- Geometry Model: $A = 2.215\ W'^{0.357}\ H^{0.271}\ T^{0.372}$ +/- (0.1 - 0.16) W'
- Geology Model: $A = 1.52\ W'^{0.4}\ H^{0.535}\ T^{0.464}\ t'^{-0.4}$ +/- (0.1 - 0.15) W'

  where W' is the minimum of the panel width (W) and the critical panel width (1.4H).

The 95th percentile (maximum) A-heights (A95) are estimated by adding aW' to A, where *a* varies from 0.1 for supercritical panels to 0.16 (geometry model) or 0.15 (geology model) for subcritical panels. The models have been validated to measured Australian case-studies (including West Wallsend, Mandalong, Springvale, Able, Ashton, Austar, Berrima, Metropolitan and Wollemi/North Wambo Underground Mines) with a broad range of mining geometries and geological conditions included. The database also includes three cases in which connective cracking reached the surface (South Bulga, Homestead and Invincible Collieries).

A summary of the key fracture height driving parameters of panel width (W), cover depth (H) and mining height (T) is provided in **Table 2**. The effective beam thickness for the overburden (t') is taken as 20 m, the minimum of the calibrated range in the Western Coalfield.

Table 2. Geometric Factors for Moolarben UG1 Coal Mine

LONGWALL	Modification Panel Width [W (m)]	Cover Depth [H (m)]	Modification Mining Height [T (m)]	PPR Mining Height [T (m)]
101	310.8	70-160	3.3-3.5	2.8-3.0
102	310.8	50-160	3.3-3.4	2.8-2.9
103	310.8	70-140	3.2-3.4	2.7-2.9
104	310.8	50-140	2.7-3.4	2.2-2.9
105	310.8	60-130	2.9-3.3	2.4-2.8

The mean A-Zone (A) and 95th percentile A-Zone (A95) heights according to the Ditton Geology Model are listed in **Table 3** for the mining height planned for the Modification. They range from 32 m to 108 m for A and from 39 m to 130 m for A95. The A95/W ratio varies from 0.13 to 0.42.

5 Typically 20-30 m in the Western Coalfield.

Table 3. Ditton Geology Model A-Zone Heights (m) for Modification Parameters

LONGWALL	Panel Width [W (m)]	Cover Depth [H (m)]	Modification Mining Height [T (m)]	Fracture Zone Height [A (m)]	95th Percentile Fracture Zone Height [A95 (m)]
101	310.8	70-160	3.3-3.5	48-108	58-130
102	310.8	50-160	3.3-3.4	35-106	42-129
103	310.8	70-140	3.2-3.4	48-94	58-114
104	310.8	50-140	2.7-3.4	32-94	39-114
105	310.8	60-130	2.9-3.3	40-86	48-105

The A and A95 heights according to the Ditton Geology Model are listed in **Table 4** for the mining height in the PPR proposal. They range from 29 m to 100 m for A and from 36 m to 123 m for A95. The differential between the maximum heights for the PPR and Modification plans is 6-8 m. The A95/W ratio varies from 0.12 to 0.40.

Table 4. Ditton Geology Model A-Zone Heights (m) for PPR Parameters

LONGWALL	Panel Width [W (m)]	Cover Depth [H (m)]	PPR Mining Height [T (m)]	Fracture Zone Height [A (m)]	95th Percentile Fracture Zone Height [A95 (m)]
101	305	70-160	2.8-3.0	45-100	55-123
102	305	50-160	2.8-2.9	33-99	40-121
103	305	70-140	2.7-2.9	44-87	54-107
104	305	50-140	2.2-2.9	29-87	36-107
105	305	60-130	2.4-2.8	36-80	45-98

The new subsurface fracture height prediction model confirms that the stated A/W ratio of 0.40-0.45 in the groundwater model is representative of likely fracturing, as the maximum calculated A95/W ratio is 0.42 and the maximum calculated A/W ratio is 0.35 for the Modification. For the PPR plan, the maximum ratio would range from 0.32 to 0.40.

Calculations using the Geology Model (**Table 5**) indicate that mining as proposed for the Modification for the 95th percentile fractured zone height would cause a fractured zone to reach within 8-31 m of ground surface,. As some depths would be within the range of depth for shallow tensile cracking (say 10-15 m), connective fracturing could be essentially to the surface in places where the Ulan Seam is at shallow depths. For the PPR proposal, the fractured zone is expected to reach within 10-39 m of ground surface, for the 95th percentile fractured zone height. Again, some instances of effective fracturing to land surface could be expected, but only where cover depth is low.

Table 5. Ditton Geology Model Depths (m) to Top of Fracturing

LONGWALL	95th Percentile Modification Fracture Zone Height [A95 (m)]	Depth to Modification Fracture Zone (m)	95th Percentile PPR Fracture Zone Height [A95 (m)]	Depth to PPR Fracture Zone (m)
101	58-130	12-30	58-130	15-37
102	42-129	8-31	42-129	10-39
103	58-114	12-26	58-114	16-33
104	39-114	11-26	39-114	14-33
105	48-105	12-25	48-105	15-32

2.5 MODEL VARIANTS

Two variants of the prediction models are used to assess the impact of the Modification UG1 mine plan:

A. Basecase Prediction model which includes:
   Ulan + Wilpinjong + MCC Stage 1 + MCC Stage 2;

B. Modification Prediction model which includes:
   Ulan + Wilpinjong + MCC Stage 1 + MCC Stage 2 + UG1 Modification.

Model A was run for the full simulation period of 34 years, and then Model B was run for the same conditions. The differences between the two runs isolate the impacts due to the Modification.

2.6 MODEL CALIBRATION

The aim of this project is to assess the differential impacts due to the Modification UG1 mine plan using the same model that was used to quantify Stage 2 impacts. Therefore the prediction models are based on the latest calibration model reported by RPS Aquaterra (2012).

Calibration was carried out in a transient mode to achieve a history match to the reported observed groundwater levels during the period 1987 to 2008 (RPS Aquaterra, 2011). The calibration was done against 1,227 target water levels, using a combination of auto-sensitivity analysis and manual modification of zones and model parameters. These targets were distributed throughout the model layers in the form of 145 groundwater hydrographs.

Calibration achieved a Scaled Root Mean Square (SRMS) performance measure of about 8%, which is below the target 10% SRMS suggested in the MDBC flow model guideline (MDBC, 2001). The mass balance error was less than 0.1%, which is acceptable under the Australian Groundwater Modelling Guidelines (Barnett *et al.*, 2012).

3 SCENARIO ANALYSIS

3.1 MINING SCHEDULE

A summary of the mining schedule that has been used for UG1 in the groundwater model is provided in **Figure 7**. This table outlines stress period setup for transient simulation for historical (calibration), prediction and recovery model runs. The prediction period runs from stress period 12 (July 2008) to stress period 46 (June 2042) which covers the full duration of Moolarben Coal Complex's approved Stage 1 mines and the Basecase and Modification scenarios for Stage 2 mines. The timing of the UG1 mining is from stress period 19 to stress period 27 to cover all longwall operations. UG1 is proposed to start extraction from Longwall 101 in approximately 2016 and finish extraction at Longwall 105 in approximately 2023.

3.2 MODELLING APPROACH

3.2.1 MODIFICATION-SPECIFIC IMPACTS

The potential impacts of the Modification have been assessed by making comparisons of model outputs to allow assessment of the incremental changes due to lengthening of Longwalls 101-105.

This comparison allows the subsequent assessment to be concentrated on the incremental changes of the proposed Modification to the Basecase UG1 Mine. The use of the same simulation (prediction) period allows the isolation of effects from the lengthening of UG1 Longwall panels, due to all other influences being kept constant, such as the effects of neighbouring mines and recharge.

Two model scenarios have been run to analyse the effects and impacts of the increased length of UG1 Longwall panels:

Scenario A	The Basecase Mine layout, i.e. the Stage 2 proposed UG1 Longwall panel configuration.
Scenario B	Scenario A plus the modified lengths of UG1 Longwall panels.

3.2.2 CUMULATIVE IMPACTS

Figure 7 specifies the mining periods for the neighbouring Ulan Mine Complex and Wilpinjong Coal Mine open cut and underground mines that have been included in the model. As all external mines have remained active for Scenarios A and B, cumulative impacts are embedded in the results presented for Scenarios A and B. The differential impacts between this pair of scenarios are, therefore, inclusive of cumulative effects.

As the existing Moolarben Coal Complex and Ulan Mine Complex have contributed to extensive depressurisation of the Permian coal measures in the vicinity of UG1, a theoretical simulation with all external mines deactivated would be inappropriate. The drawdown impacts associated with the UG1, under cumulative mining conditions, would be expected to be less than under isolated conditions as the initial groundwater heads would be lower than pre-mining conditions.

Ulan Coal Mines Limited is currently seeking to modify the Ulan West underground operation (which forms part of the Ulan Mine Complex) to extend six longwall panels. Mackie Environmental Research (2015) concluded that the longwall extensions at the Ulan West underground operation would result in no difference to cumulative impacts compared to the approved Ulan Mine Complex. On this basis the Moolarben Coal Complex model scenarios have not been revised to include the proposed longwall extensions at Ulan West.

3.3 MODEL IMPLEMENTATION

The underground mining and dewatering activity is simulated in the model using MODFLOW Drain (DRN) cells, with Drain heads set to 1 m above the floor of the coal seams. These DRN cells were applied wherever workings occur, and were progressed through time increments coincident with the stress period durations (**Figure 7**).

For the Moolarben UG1 mine and the neighbouring Ulan underground mine, the model setup involved activating MODFLOW DRN cells along development headings in advance of the active mining. Active mining and the consequent subsidence were simulated by activating Drains throughout the relevant longwall panels whilst simultaneously changing the parameters with time in the goaf and overlying fractured zones.

For all open cut mines (i.e. Moolarben, Wilpinjong and Ulan pits), drain elevations are set to 1 m above the Ulan Seam. Drain cells were kept active for differing periods, representing the historical and proposed pit progression. After an area has been fully mined (i.e. extraction down to the Ulan Seam), in the next stress period the DRN cells were deactivated. In that following stress period the aquifer hydraulic parameters were changed to represent the emplaced spoil. The exception to that is in the areas that are to remain as the final void. In those areas the DRN cells are deactivated at the end of mining, and the layers are assigned high permeability and high storage properties to represent the final void.

To accommodate time-varying physical properties for pit spoil and underground fractured zones, time-slice sub-models were designed that were generally two stress periods long (**Figure 7**). The final heads of one sub-model became the initial conditions for the next sub-model.

3.4 WATER BALANCE

Simulated water balances for the Scenarios A and B across the entire model extent have been averaged over the 34 years of the predictive period from July 2008 to June 2042 (stress periods 12 to 46) and are summarised in **Table 6**. The average water balance reports the inflows, outflows and change in storage over the entire model domain.

The results for the predictive scenarios are almost identical, with the only observable minor difference being to mine inflows; about 0.6% increase in inflow between Scenario A and Scenario B (12.06 to 12.14 megalitres per day [ML/d]). The scenarios show an almost equivalent decline in groundwater storage.

Therefore, the average mine inflow rate for UG1 is increased by 0.08 ML/d due to the lengthening of UG1 Longwall panels. Discussion of predicted inflows is provided in Section 3.7.

Table 6. Average Simulated Water Balance for the Prediction Model during the Moolarben Coal Complex Life

COMPONENT	SCENARIO A BASECASE MINE PLAN		SCENARIO B MODIFICATION MINE PLAN	
	Inflow (ML/d)	Outflow (ML/d)	Inflow (ML/d)	Outflow (ML/d)
Drains (Mine inflow)	-	12.06	-	12.14
Recharge (Direct Rainfall)	81.79	-	81.79	-
Recharge Seepage Face	-	2.12	-	2.13
Evapotranspiration (ET)	-	96.72	-	96.71
River (Leakage / Baseflow)	48.71	117.31	48.71	117.30
Wells (Pumping)	-	2.67	-	2.65
Regional GW flow (GHB)	122.59	55.18	122.59	55.18
Total	**253.09**	**286.06**	**253.09**	**286.11**
Storage	32.97 loss		33.02 loss	

For the Modification, the total inflow (recharge) to the aquifer system is approximately 253 ML/d, comprising rainfall recharge (33%), inflow from the general head boundary on the margins (48%), and leakage from streams into the groundwater system (19%). Groundwater discharge is dominated by stream baseflow (41%). The other significant discharge mechanisms are evapotranspiration (34%) and outflow from the general head boundary (19%) with lesser roles played by mine inflow (4%) and about 2% from the combined simulated production wells and seepage face discharge to cliffs.

3.5 PREDICTED GROUNDWATER LEVELS

Predicted groundwater levels at the end of UG1 mining operations (2023) for scenarios A and B are shown in **Figures 8** and **9**. These figures show groundwater levels in the Ulan Seam (where it exists) in model layer 7. The Ulan Seam is the target coal seam at Ulan, Wilpinjong and Moolarben mining operations.

The main difference in predicted groundwater levels between the two scenarios occurs on the north-eastern edge of the UG1 longwall panels. Comparing **Figure 8** with **Figure 9** shows that drawdown in the Ulan seam is predicted to be slightly greater after the lengthening of UG1 longwall panels.

Better resolution of predicted changes to groundwater conditions is afforded by differential water levels discussed in Section 4.2.

3.6 PREDICTED BASEFLOW CAPTURE

The river and creeks in the vicinity of the Moolarben Coal Complex have been divided into multiple reaches (segments) in order to assess whether any baseflow reduction or increase in leakage might occur due to the mining activity of the project. **Figure 10** shows the location map for 12 reaches, all simulated as river (RIV) boundaries in the model.

Predicted changes in baseflow and natural river leakage have been assessed for Goulburn River, Wilpinjong Creek, Moolarben Creek, Lagoon Creek, Murragamba Creek and Ulan Creek from the commencement of the prediction period in July 2008.

Table 7 summarises a comparison of the average simulated stream baseflow in kL/d units for the two scenarios (Basecase and Modification) and as a percentage of the average Basecase baseflow. The results show that the maximum average baseflow reduction would be expected to be about 14% (1.8 kL/d) in reach 108 which represents Wilpinjong Creek North that is located to the immediate north-east of UG1. The predicted streamflow reduction in all other creeks is not significant with a maximum reduction of about 1% in the Murragamba Creek (reach 107) which is located to the immediate south of UG1.

The predicted changes can be inferred from **Figures 11** to **21** where comparisons are made for the two scenarios. It can be seen clearly that only Wilpinjong Creek North (reach 108) shows a perceptible baseflow reduction due to the Modification UG1 mine plan (**Figure 18**). The model results show that under the Modification UG1 mine plan, Wilpinjong Creek North would receive a slight reduction in baseflow at about 0.02 kL/d at the beginning of LW101 mine to about 1.8 kL/d by the end of LW105 mining. The baseflow reduction in Wilpinjong Creek North will continue after the end of UG1 mining to reach a peak of 2.65 kL/d in approximately 2029-2030; the additional reduction in baseflow after UG1 ceases is predicted to occur as the result of the fracturing due to lengthening of Longwall panels in the Modification.

In summary, the model results indicate that the Modification has no discernible impact on stream baseflow or river leakage, beyond the effects of the Basecase mining, for Goulburn River, Wilpinjong Creek, Moolarben Creek, Lagoon Creek, Murragamba Creek and Ulan Creek. The Modification is predicted to cause minor reductions in the volume of baseflow discharged to Wilpinjong Creek North of up to 0.97 ML/a (in 2029) declining to about 0.68 ML/a in 2036, compared to a total modelled baseflow of 3.1-6.7 ML/a under the Basecase mine plan. Gaining conditions are predicted to persist on Wilpinjong Creek North.

Table 7. Simulated Average Streamflow and Percentage Reduction between the Two Model Scenarios during the Project Life

Reach No.	Name	Predicted Average Streamflow (kL/d) 2016-2042			%	Comment
		Basecase**	Modification**	Difference		
R101	Lagoon Creek	1403.05	1403.11	-0.07	0.00%	Increase in Leakage
R102	Moolarben Creek Upper	-638.39	-638.31	-0.08	0.01%	Reduction in Baseflow
R103	Moolarben Creek Middle	2919.24	2919.38	-0.14	0.00%	Increase in Leakage
R104	Ulan Creek	0.88	0.89	-0.01	-0.65%	Increase in Leakage
R105	Goulburn River West	1315.86	1316.21	-0.35	-0.03%	Increase in Leakage
R106	Goulburn River Tributary	0.00	0.00	0.00		Dry
R107	Murragamba Creek	-7.05	-6.98	-0.07	0.97%	Reduction in Baseflow
R108	Wilpinjong Creek North	-12.57	-10.76	-1.81	14.4%	Reduction in Baseflow
R109	Wilpinjong Creek	-27.12	-27.14	0.02	-0.08%	Increase in Baseflow
R110	Wollar / Cumbo Creek	-453.20	-453.39	0.19	-0.04%	Increase in Baseflow
R111	Goulburn River eastern extent	-10416.07	-10415.26	-0.80	0.01%	Reduction in Baseflow

** -ve: Outflow from the Aquifer into the River (Baseflow)
** +ve: Inflow into the Aquifer from the River (Leakage)
Note: Differences may have minor discrepancies due to rounding.

3.7 PREDICTED MINE INFLOW

The predicted groundwater inflows to UG1 are shown in **Figure 22** for the Basecase and Modification scenarios. The simulated inflows to UG1 for the Basecase mine plan are predicted to increase from 0.61 ML/d at the start of underground mining activities in year 2016 (approximately Year 2) to peak about 1.26 ML/d by the end of Longwall 104 (approximately Year 6). From that time the predicted inflows for the Basecase mine plan are predicted to decline to reach about 0.83 ML/d by the end of Longwall 105 at the end of year 2023 (approximately Year 9).

Under the Modification UG1 mine plan (this project), inflows to UG1 are predicted to follow the same pattern as for the Basecase mine plan but will be consistently higher due to the extended lengths of the longwall panels. The inflows are predicted to start from 0.73 ML/d in year 2016 (approximately Year 2), to peak about 1.45 ML/d by the end of Longwall 104 (approximately Year 6) and then declining to reach about 0.98 ML/d at the end of longwall 105 in year 2023 (approximately Year 9). The differential inflow is less than 0.2 ML/d.

The predicted mine inflow rates from the Basecase and Modification mine plans for all open cuts and underground mining including Ulan Mine Complex and Wilpinjong Coal Mine are summarised in **Table 8**.

Table 8. Predicted Mine Inflow Rates

Mine Year	Total Ulan Coal Mine Inflows (ML/d)		Wilpinjong Coal Mine Inflows (ML/d)		Moolarben Coal Complex Mine Inflows																Modelled Borefield Pumping (ML/d)	
					OC1 (ML/d)		OC2 (ML/d)		OC3 (ML/d)		OC4 (ML/d)		UG1 (ML/d)		UG2 (ML/d)		UG4 (ML/d)		Total Moolarben Coal Complex Inflows (ML/d)			
	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification
0	14.15	14.15	2.51	2.51	0.27	0.27	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.32	2.63	2.63
1	12.63	12.63	0.77	0.77	0.23	0.23	0.01	0.01	0.00	0.00	0.26	0.26	0.03	0.03	0.00	0.00	0.00	0.00	0.52	0.52	2.62	2.62
2	14.64	14.64	1.87	1.87	0.32	0.32	0.02	0.02	0.00	0.00	0.20	0.20	0.61	0.73	0.00	0.00	0.00	0.00	1.15	1.27	2.43	2.35
3	12.86	12.85	1.71	1.71	0.28	0.27	0.03	0.03	0.00	0.00	0.15	0.15	0.60	0.74	0.00	0.00	0.00	0.00	1.06	1.19	2.43	2.34
4	15.38	15.38	2.03	2.03	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.29	0.94	1.14	0.00	0.00	0.00	0.00	1.23	1.42	2.36	2.24
5	13.59	13.58	2.31	2.33	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.14	0.87	1.05	0.00	0.00	0.00	0.00	1.01	1.19	2.29	2.17
6	15.36	15.36	2.62	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	1.26	1.45	0.00	0.00	0.00	0.00	1.36	1.55	2.33	2.20
7	13.69	13.69	2.57	2.56	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.61	0.86	1.03	0.00	0.00	0.00	0.00	1.47	1.65	2.29	2.16
8	4.13	4.13	1.27	1.27	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.92	0.94	1.11	0.00	0.00	0.00	0.00	1.86	2.03	2.56	2.44
9	3.67	3.67	1.14	1.13	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.94	0.83	0.98	0.00	0.00	0.00	0.00	1.77	1.92	2.79	2.67
10	5.61	5.61	1.07	1.06	0.00	0.00	0.00	0.00	0.00	0.00	2.17	2.12	0.00	0.00	0.00	0.00	0.00	0.00	2.17	2.12	3.16	3.20
11	5.73	5.73	0.77	0.76	0.00	0.00	0.00	0.00	0.00	0.00	1.05	1.05	0.00	0.00	0.01	0.01	0.00	0.00	1.06	1.06	2.99	3.01
12	7.19	7.19	0.65	0.66	0.00	0.00	0.00	0.00	0.00	0.00	1.36	1.35	0.00	0.00	0.03	0.03	0.64	0.63	2.02	2.01	3.09	3.12
13	6.65	6.65	0.47	0.47	0.00	0.00	0.00	0.00	0.00	0.00	1.09	1.08	0.00	0.00	0.02	0.02	0.68	0.67	1.79	1.78	3.08	3.11
14	7.48	7.48	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	1.05	1.04	0.00	0.00	0.01	0.01	0.86	0.84	1.91	1.90	3.07	3.09
15	6.83	6.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.91	0.90	0.00	0.00	0.00	0.00	0.90	0.89	1.80	1.78	3.00	3.01
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.82	0.00	0.00	0.00	0.00	1.07	1.06	1.90	1.88	2.96	2.97
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.88	0.88	0.00	0.00	0.00	0.00	1.06	1.04	1.94	1.92	2.99	3.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.09	1.13	1.12	0.00	0.00	0.00	0.00	1.24	1.22	2.46	2.43	3.01	3.02
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.08	0.82	0.81	0.00	0.00	0.00	0.00	1.71	1.69	2.61	2.58	2.52	2.53
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.19	1.41	1.40	0.00	0.00	0.00	0.00	2.94	2.92	4.54	4.51	0.74	0.74
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.26	1.24	1.22	0.00	0.00	0.00	0.00	2.39	2.37	3.90	3.86	2.25	2.26
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.92	3.91	3.92	3.91	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.90	3.89	3.90	3.89	0.00	0.00

Mine Year	Total Ulan Coal Mine Inflows (ML/d)		Wilpinjong Coal Mine Inflows (ML/d)		Moolarben Coal Complex Mine Inflows																Modelled Borefield Pumping (ML/d)	
					OC1 (ML/d)		OC2 (ML/d)		OC3 (ML/d)		OC4 (ML/d)		UG1 (ML/d)		UG2 (ML/d)		UG4 (ML/d)		Total Moolarben Coal Complex Inflows (ML/d)			
	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification	Basecase	Modification
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.02	4.00	4.02	4.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.01	3.99	4.01	3.99	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.11	4.09	4.11	4.09	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.10	4.08	4.10	4.08	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.15	4.13	4.15	4.13	0.00	0.00

4 POTENTIAL IMPACTS

4.1 POTENTIAL IMPACTS ON GROUNDWATER

The main effect of the underground mining upon the groundwater regime comes from changes in bulk rock mass permeability caused by the fracturing associated with longwall subsidence, and the pumping out of groundwater that enters the mine as a consequence. This caving, and associated extraction of groundwater, have a number of effects on the hydrogeological system during mining operations that have been evaluated as part of the impact assessment. These can be summarised as follows:

- inflow of water to the underground mine and the management of that mine water;
- impacts on groundwater levels during operational mining, both within the Permian hard rock strata and the alluvium associated with Moolarben and Wilpinjong Creeks; and
- impacts on baseflow to Moolarben, Wilpinjong, Murragamba, Lagoon, Ulan and Wollar/Cumbo Creeks and Goulburn River during operational mining.

4.2 POTENTIAL IMPACTS ON GROUNDWATER LEVELS

The main impact on water levels due to the Modification is located at the north and north-east of UG1 as discussed in Section 3.5.

Groundwater levels in the Ulan Seam following completion of mining activities at UG1 for the Basecase mine plan and the Modification mine plan (this project) are shown in **Figures 8** and **9** respectively.

To assess the impacts of the Modification UG1 mine plan, two full model versions have been run in parallel to predict the impacts due to the approved Moolarben Coal Complex as well as the Moolarben Coal Complex incorporating the Modification. These model versions are classified as Scenario A and Scenario B:

A. Ulan + Wilpinjong + MCC Stage 1 + MCC Stage 2;

B. Ulan + Wilpinjong + MCC Stage 1 + MCC Stage 2 + UG1 Modification.

Figures 23 to **25** show the impacts of the approved Moolarben Coal Complex and the Moolarben Coal Complex incorporating the Modification for the Alluvium/Regolith (Layer 1), Upper Triassic / Shallow Permian Overburden (Layer 2), and Ulan Seam (Layer 7) at the end of UG1 mining (Year 9). The drawdowns shown in Figure 24 relate to shallow Permian sediments only. Reference to the Triassic geology in Figure 2 shows that no drawdown is anticipated in the Upper Triassic (or Lower Triassic) as these sediments are inherently dry.

With the exception of up to 6.5 m of drawdown at the level of the Ulan Seam in the north-eastern extents of UG1, there would be no discernible change in drawdown resulting from the Modification (**Figures 23** to **25**).

Given the drawdown minimal impact consideration of 2 m in the Aquifer Interference Policy, the incremental effect on water levels, due to this Modification, is expected to be negligible regionally in all strata other than the Ulan Seam (which is of low quality and has no productive water use, other than for mining purposes).

4.3 PREDICTED GROUNDWATER INFLOWS

Figure 22 shows a consistent differential mine inflow of less than or about 0.2 ML/d between the Basecase and Modification scenarios.

Near the completion of the UG1 underground mine, both the UG1 Basecase and Modification mine plans are predicted to experience a peak inflow rate of approximately 1.25 ML/d and 1.45 ML/d respectively at the end of Longwall 104 mining by the end of year 2020 (**Figure 22**).

4.4 PREDICTED IMPACTS ON WATER SOURCES

Potential impacts on water sources have been estimated by groundwater modelling conducted by RPS Aquaterra (2011) for the Preferred Project (Stage 1 and Stage 2) and by RPS Aquaterra (2012) for Stage 2 isolated from Stage 1 impacts.

UG1 is located within two water source catchments: Wollar Creek and Upper Goulburn River (**Figure 6**). The potential impacts from the proposed Modification UG1 mine plan on groundwater within the alluvium associated with Moolarben and Wilpinjong Creeks have been examined and compared with the UG1 Basecase mine plan. In addition to licensing considerations, the impact on the Tertiary palaeochannel is reported. This feature straddles the two water sources.

Water would not be lost directly from the alluvium, but there could be incidental loss through enhanced leakage from the bordering alluvium to the underlying hard rock strata.

The potential increase in leakage of groundwater from the alluvium to the underlying consolidated sediments as mining progresses has been examined for the four 'regions' where UG1 is closest to the Tertiary palaeochannel and the alluvium associated with Moolarben and Wilpinjong Creeks. These 'regions' are marked on **Figures 26** and **27** and named as:

1. Northern Palaeochannel;
2. Southern Palaeochannel;
3. Wollar Creek Alluvium; and
4. Upper Goulburn River Alluvium.

Figures 28 to **31** compare the flux from alluvium to the underlying hard rock for the four areas. It can be seen clearly that downward leakage for the UG1 Basecase and Modification UG1 mine plan are consistent for all areas at all model prediction times except for some deviation in the Northern Palaeochannel.

Table 9 summarises the average flux change in alluvium for the four areas from the start of the Modification up to the end of the model prediction period in June 2042. The largest average downward leakage due to the Modification UG1 mine plan is about 3.8 kL/d in the Northern Palaeochannel which represents only about 2% of the average downward flux in the Basecase UG1 mine plan.

In summary, the model results indicate that the Modification has no significant impact on the water sources alluvium, beyond the effects of the Basecase mining. The incremental losses from the two separate water sources are expected to be negligible (less than 1 ML/a).

Table 9: Average Flux Leakage and Flux Change in Alluvium/Palaeochannel Areas

Alluvium/Palaeochannel Area	Average Flux Leakage (kL/d)		Average Flux Change	
	Basecase	Modification	(kL/d)	%
Northern Palaeochannel	-163.1	-166.9	3.8	2.3
Southern Palaeochannel	-299.3	-299.7	0.4	0.15
Wollar Creek Catchment Alluvium**	-553.0	-553.0	0.0	0.00
Upper Goulburn River Catchment Alluvium**	-727.6	-728.6	1.0	0.13

** Includes alluvial sediments in outcropped areas.
Note: Differences may have minor discrepancies due to rounding.

4.5 POTENTIAL IMPACTS ON REGISTERED PRODUCTION BORES

Due to the very limited change in drawdown resulting from the Modification (**Figures 23** to **25**), there would be no impacts on third-party registered bores due to the Modification.

4.6 RECOVERY OF GROUNDWATER LEVELS

Due to the small magnitude of water level differences between Basecase and Modification stresses, there can be no material difference in the predicted recovery of groundwater levels. The findings in the RPS Aquaterra (2011) report remain relevant.

4.7 ASSESSMENT AGAINST THE MINIMAL IMPACT CONSIDERATIONS

The NSW *Aquifer Interference Policy* (NSW Government, 2012) establishes minimal impact considerations for highly productive and less productive groundwater. There is no mapped highly productive groundwater in the vicinity of the Moolarben Coal Complex. It follows that the remaining alluvial aquifers and porous rock aquifers in the vicinity of the Moolarben Coal Complex are less productive.

The drawdown results in Section 4.2 show that minimal harm considerations are within Level 1 for both water table and water pressure attributes.

The minor drawdown changes would lead to very minor changes in groundwater flow directions, and consequently no mechanism for changes in beneficial use of groundwater quality. As the effect on streams has been shown to be negligible in Section 3.6, no material effect on average stream salinity is feasible. Minimal harm considerations are within Level 1 for water quality attributes.

5 CONCLUSIONS

This report focuses on groundwater modelling application and outcomes to inform a groundwater assessment prepared by Dundon Consulting Pty Ltd. The focus of the modelling is on quantifying the incremental impacts to the baseflows of Murragamba Creek and Wilpinjong Creek, to induced leakage from associated alluvium and the nearby Tertiary palaeochannel, and to mine inflows. This assessment is for a modification that consists of lengthening five longwalls in the UG1 underground mine at Moolarben.

The groundwater modelling carried out for this Modification has relied on the previous groundwater model developed by RPS Aquaterra. In order to maintain consistency with previous model predictions, no changes have been made to model parameters or boundary conditions other than the additional stresses imposed by the Modification.

The incremental impacts of the UG1Modification have been considered as changes between the Stage 2 (Basecase) mine plan and this proposed Modification layout. Cumulative impacts of neighbouring Ulan Mine Complex and Wilpinjong Coal Mine have also been considered.

The key findings of this assessment are:

- The Modification would have no material impact on stream baseflow or natural river leakage for any nearby stream. The largest effect would be on the upgradient reach of Wilpinjong Creek, where baseflow is expected to be reduced by approximately 0.002 ML/day.
- The Modification mine plan is expected to generate about 15% extra mine inflow at peak, (approximately 69 ML/year).
- The Modification would cause negligible drawdown in the alluvium bordering the north-eastern end of UG1.
- With the exception of up to 6.5 metres of drawdown in the Ulan Seam in the north-eastern extents of UG1, there would be no discernible change in drawdown resulting from the Modification.
- No third-party groundwater users would be affected by the Modification, in terms of the minimal harm considerations of the Aquifer Interference Policy.
- The Modification is expected to result in a negligible increase in the net loss of groundwater from the alluvium to underlying rock strata of less than 1 ML/a.

In summary, the Modification would not materially affect (either by increasing or decreasing) the availability of water for human purposes, as the potential end of mining drawdown from the Moolarben Coal Complex, including the Modification, is not expected to exceed 2 m at any privately owned land (the minimal harm consideration in the Aquifer Interference Policy).

Therefore, it is unlikely that the Modification would result directly or indirectly in a substantial change in the hydrology of groundwater resources or surface water sources.

There is not expected to be a migration of groundwater away from the Moolarben Coal Complex areas in the Permian system either during mining or following completion of mining activities. On this basis, the Moolarben Coal Complex would not lower the beneficial use category of the groundwater within the Permian system.

Therefore, the Modification could not be considered to have a significant impact on groundwater quality, beyond the effects of approved mining.

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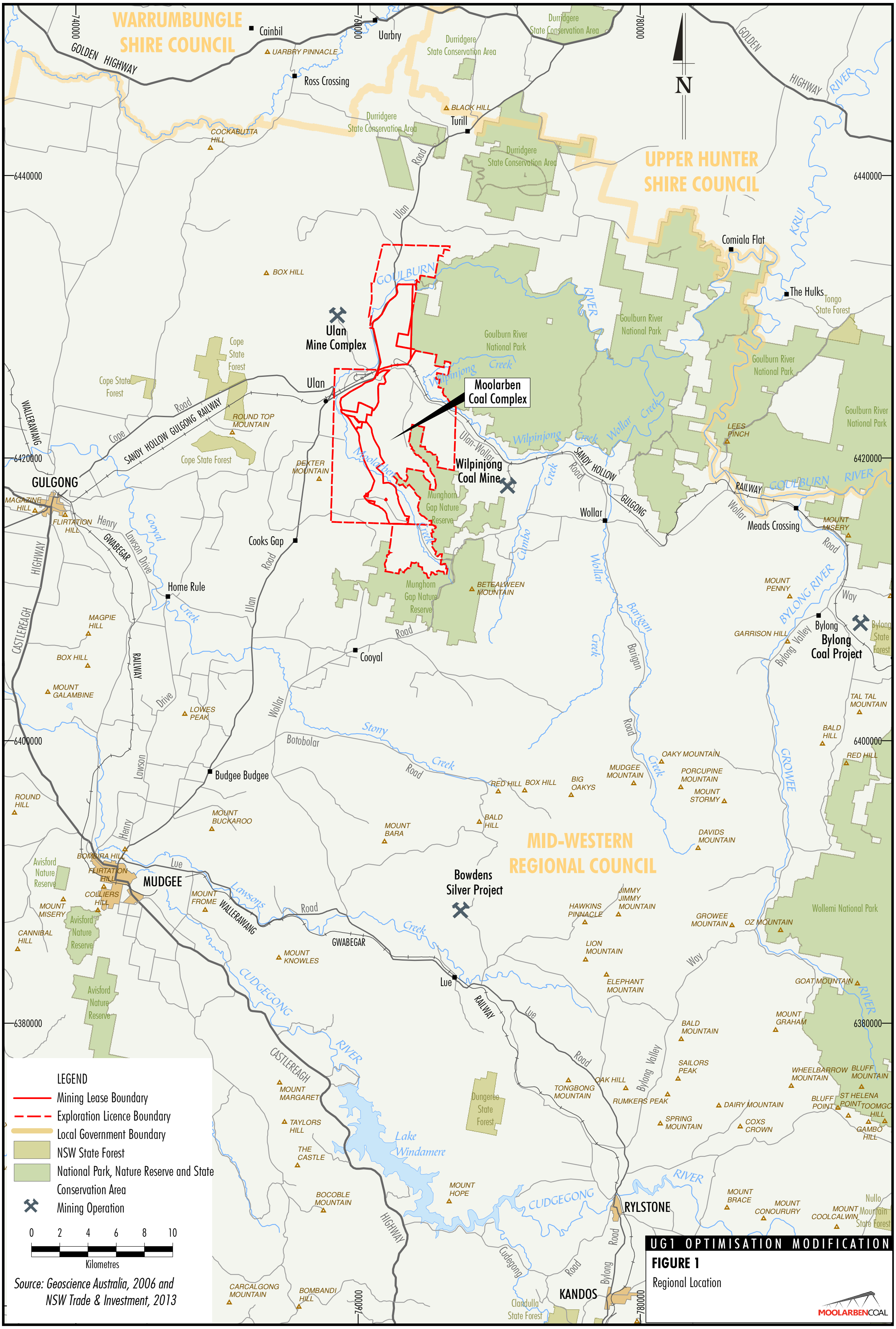
FIGURES

FIGURES 1 TO 31



UG1 OPTIMISATION MODIFICATION

FIGURE 1

Regional Location

MCM-14-05 UG1_OM_AppGWA_201B

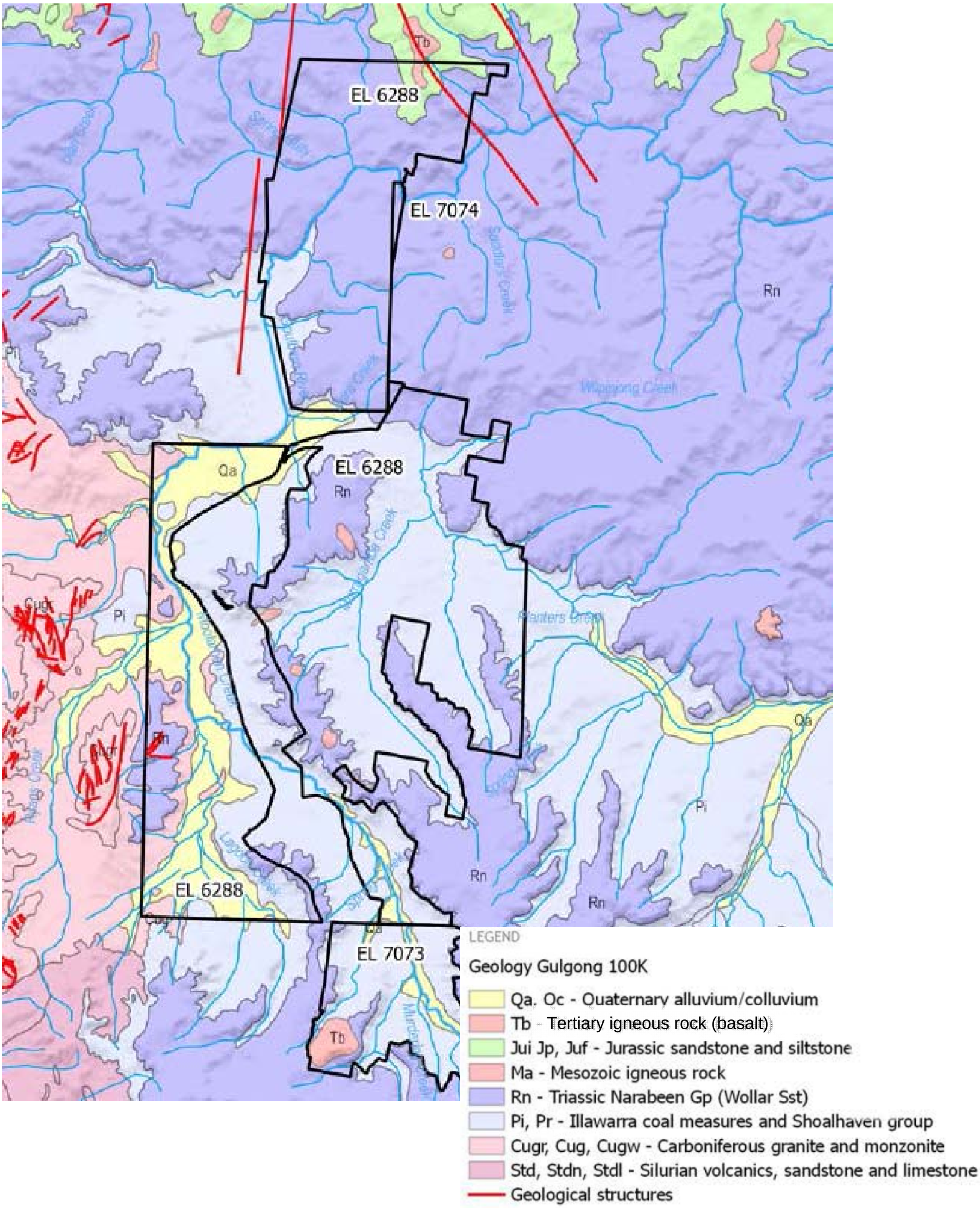
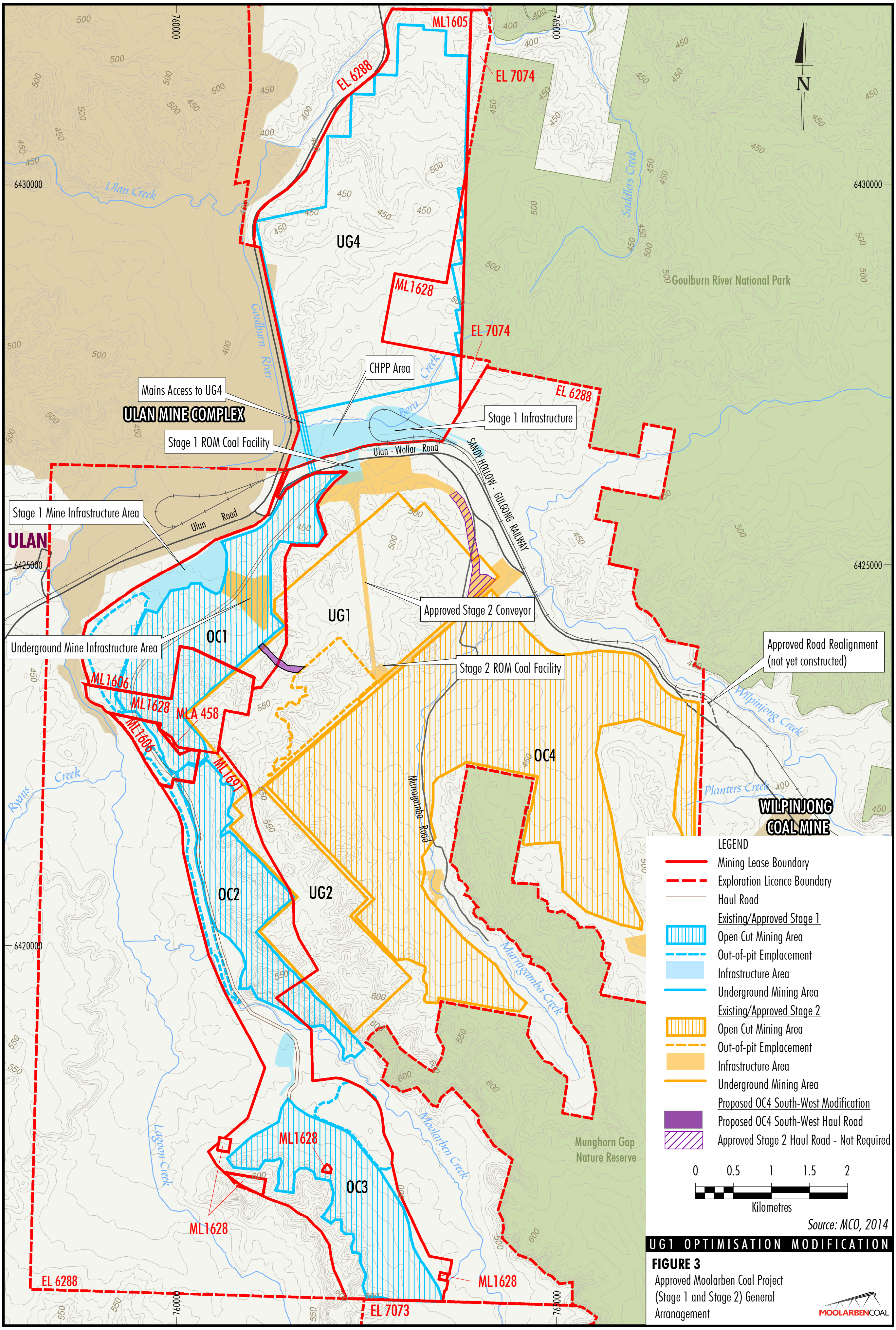


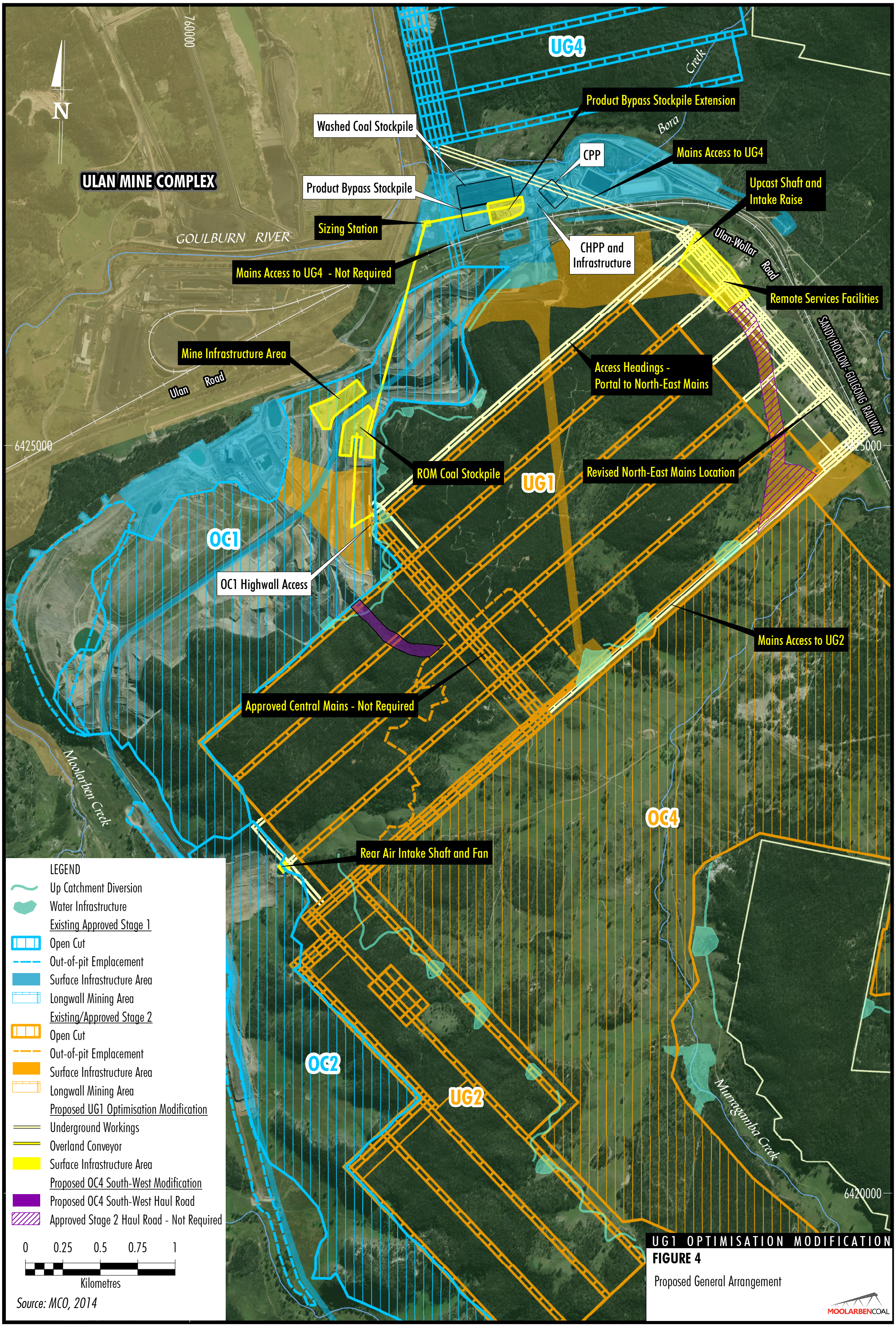
Figure 2. Regional Geology



UG1 OPTIMISATION MODIFICATION

FIGURE 3
Approved Moolarben Coal Project (Stage 1 and Stage 2) General Arrangement

MCM-14-05 UG1_OM_AppGWA_203B



UG1 OPTIMISATION MODIFICATION

FIGURE 4

Proposed General Arrangement

MOOLARBENCOAL

MCM-14-05 UG1_OM_AppGWA_202C

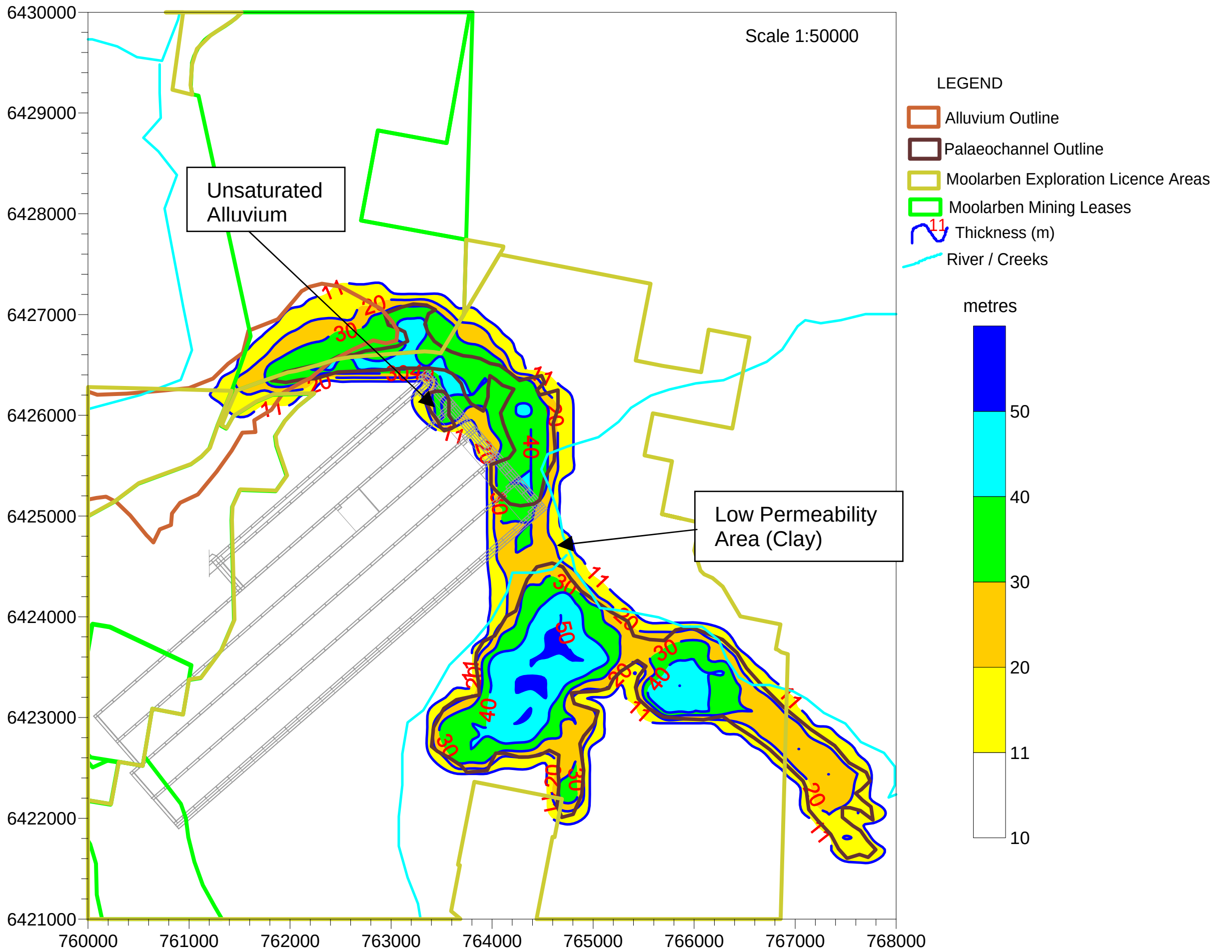


Figure 5: Palaeochannel Thickness (m)

(Higher permeability sediments in the palaeochannel, as inferred from TEM, are marked with the brown outline)

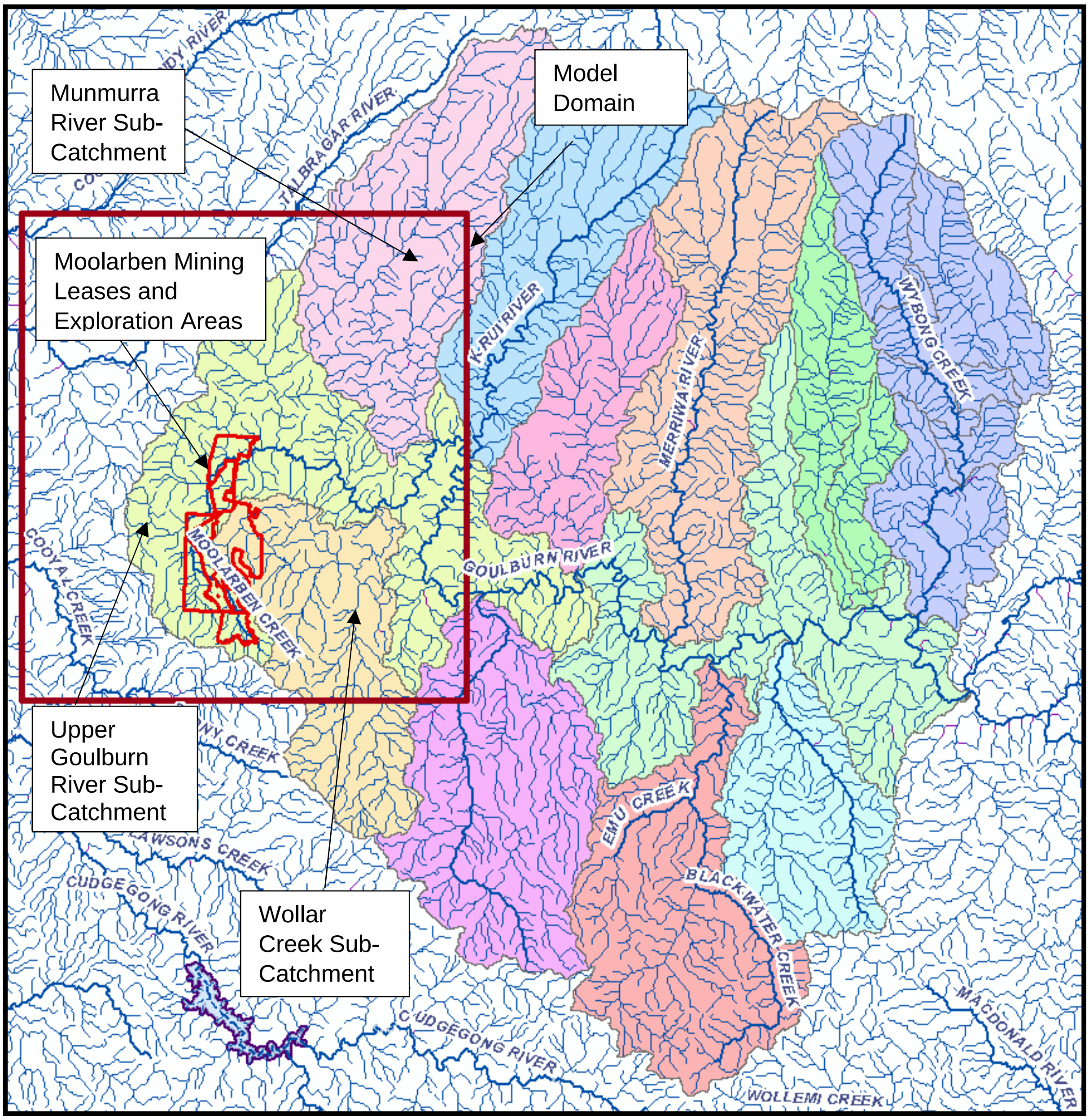


Figure 6. Water Sources inside the Model Domain: Upper Goulburn River; Wollar Creek; and Munmurra River Sub-Catchments

Phase	Stress Period-Time Slice	From	To	Days	Timing of Operations	Mine Year
CALIBRATION	**1-1**	1/07/1987	30/06/1990	1096		
	2-1	1/07/1990	29/06/1992	730		
	3-1	30/06/1992	30/06/1994	731		
	4-2	1/07/1994	29/06/1996	730		
	5-2	30/06/1996	30/06/1998	731		
	6-2	1/07/1998	29/06/2000	730		
	7-3	30/06/2000	30/06/2002	731		
	8-3	1/07/2002	29/06/2004	730		
	9-3	30/06/2004	30/06/2006	731		
	10-4	1/07/2006	30/06/2007	365		
	11-4	1/07/2007	30/06/2008	365		
PREDICTION	**12-5**	1/07/2008	30/06/2009	365.25		
	13-5	1/07/2009	31/12/2009	184		
	14-6	1/01/2010	31/12/2010	365.25		
	15-6	1/01/2011	31/12/2011	365.25		
	16-7	1/01/2012	31/12/2012	365.25		
	17-7	1/01/2013	31/12/2013	365.25	**Ulan Coal Mine Underground and Open Cut**	
	18-8	1/01/2014	31/12/2014	365.25	**MCC OC1**	**0**
	19-8	1/01/2015	31/12/2015	365.25	**MCC OC2**	**1**
	20-9	1/01/2016	31/12/2016	365.25		**2**
	21-9	1/01/2017	31/12/2017	365.25	**Wilpinjong Coal Mine Open Cuts**	**3**
	22-10	1/01/2018	31/12/2018	365.25		**4**
	23-10	1/01/2019	31/12/2019	365.25	**MCC UG1**	**5**
	24-11	1/01/2020	31/12/2020	365.25		**6**
	25-11	1/01/2021	31/12/2021	365.25		**7**
	26-12	1/01/2022	31/12/2022	365.25		**8**
	27-12	1/01/2023	31/12/2023	365.25		**9**
	28-13	1/01/2024	31/12/2024	365.25		**10**
	29-13	1/01/2025	31/12/2025	365.25	**MCC OC4**	**11**
	30-14	1/01/2026	31/12/2026	365.25	**MCC UG2**	**12**
	31-14	1/01/2027	31/12/2027	365.25		**13**
	32-15	1/01/2028	31/12/2028	365.25		**14**
	33-15	1/01/2029	31/12/2029	365.25		**15**
	34-16	1/01/2030	31/12/2030	365.25		**16**
	35-16	1/01/2031	31/12/2031	365.25		**17**
	36-17	1/01/2032	31/12/2032	365.25		**18**
	37-17	1/01/2033	31/12/2033	365.25	**MCC OC3**; **MCC UG4**	**19**
	38-18	1/01/2034	31/12/2034	365.25		**20**
	39-18	1/01/2035	31/12/2035	365.25		**21**
	40-19	1/01/2036	31/12/2036	365.25		**22**
	41-19	1/01/2037	31/12/2037	365.25		**23**
	42-20	1/01/2038	31/12/2038	365.25		**24**
	43-20	1/01/2039	31/12/2039	365.25		**25**
	44-21	1/01/2040	31/12/2041	365.25		**26**
	45-21	1/01/2041	31/12/2041	365.25		**27**
	46-22	1/01/2042	30/06/2042	182	Simulations include a lag time of up to 6 months	**28**
	47	1/07/2042	30/06/2143	36525	**Post-mining Recovery**	

Figure 7: MC2.2 Model Stress Period Setup (updated after RPS Aquaterra, 2011)

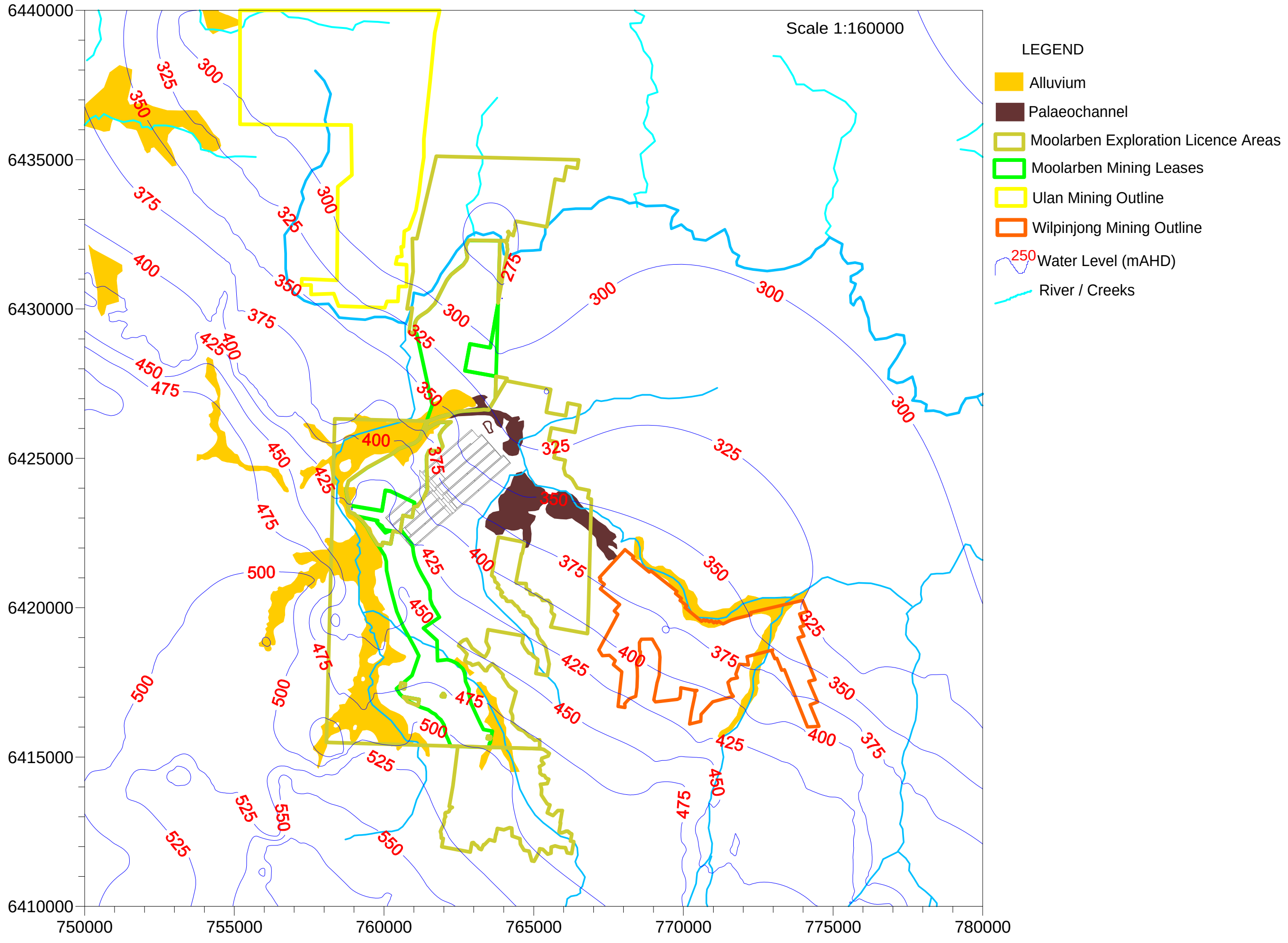


Figure 8. Predicted Water Levels (mAHD) in the Ulan Seam (Model Layer 7) at the End of Moolarben UG1 Mining (Year 9) - Basecase Mine Plan

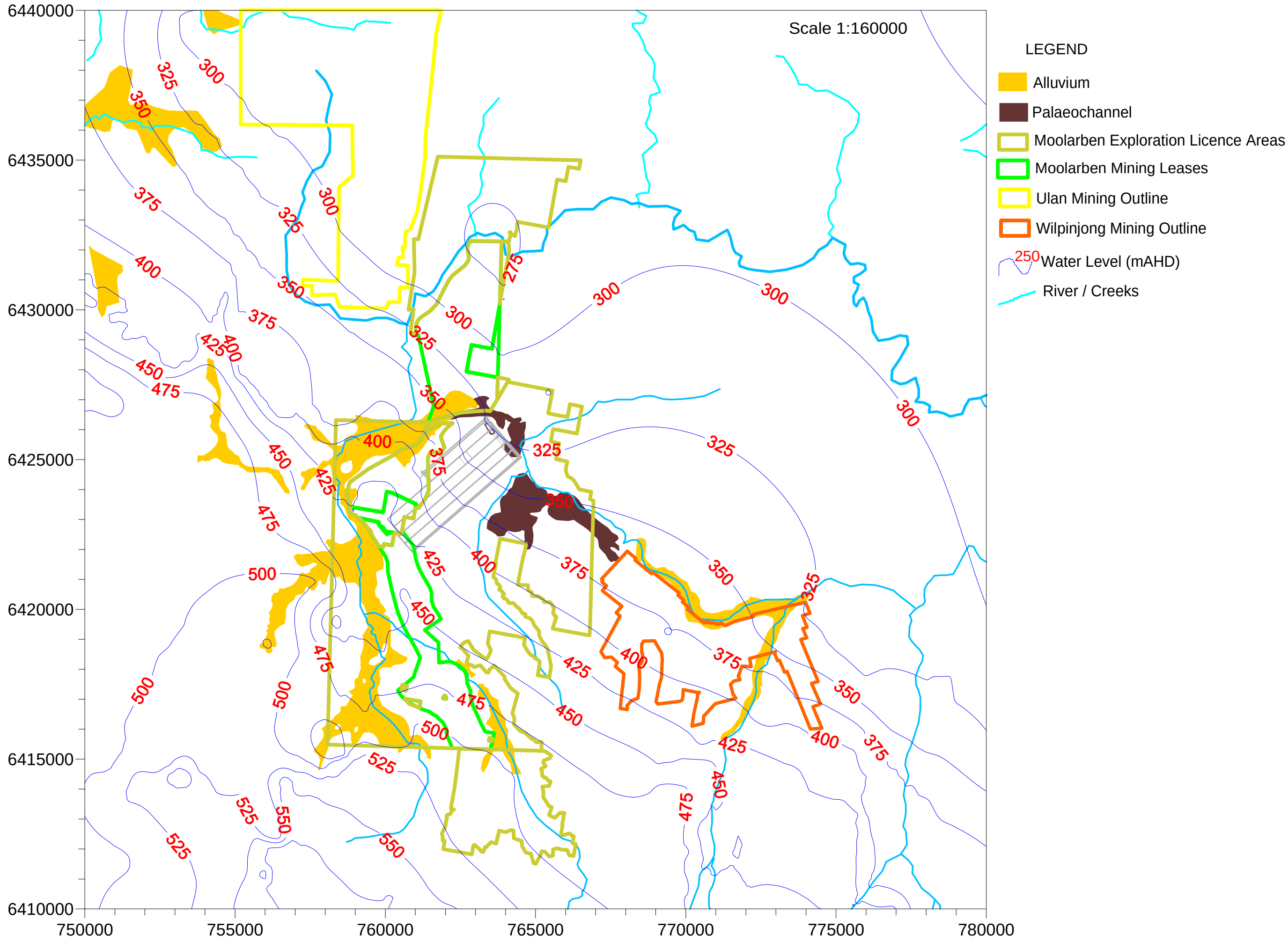


Figure 9. Predicted Water Levels (mAHD) in the Ulan Seam (Model Layer 7) at the End of Moolarben UG1 Mining (Year 9) - Modification Mine Plan

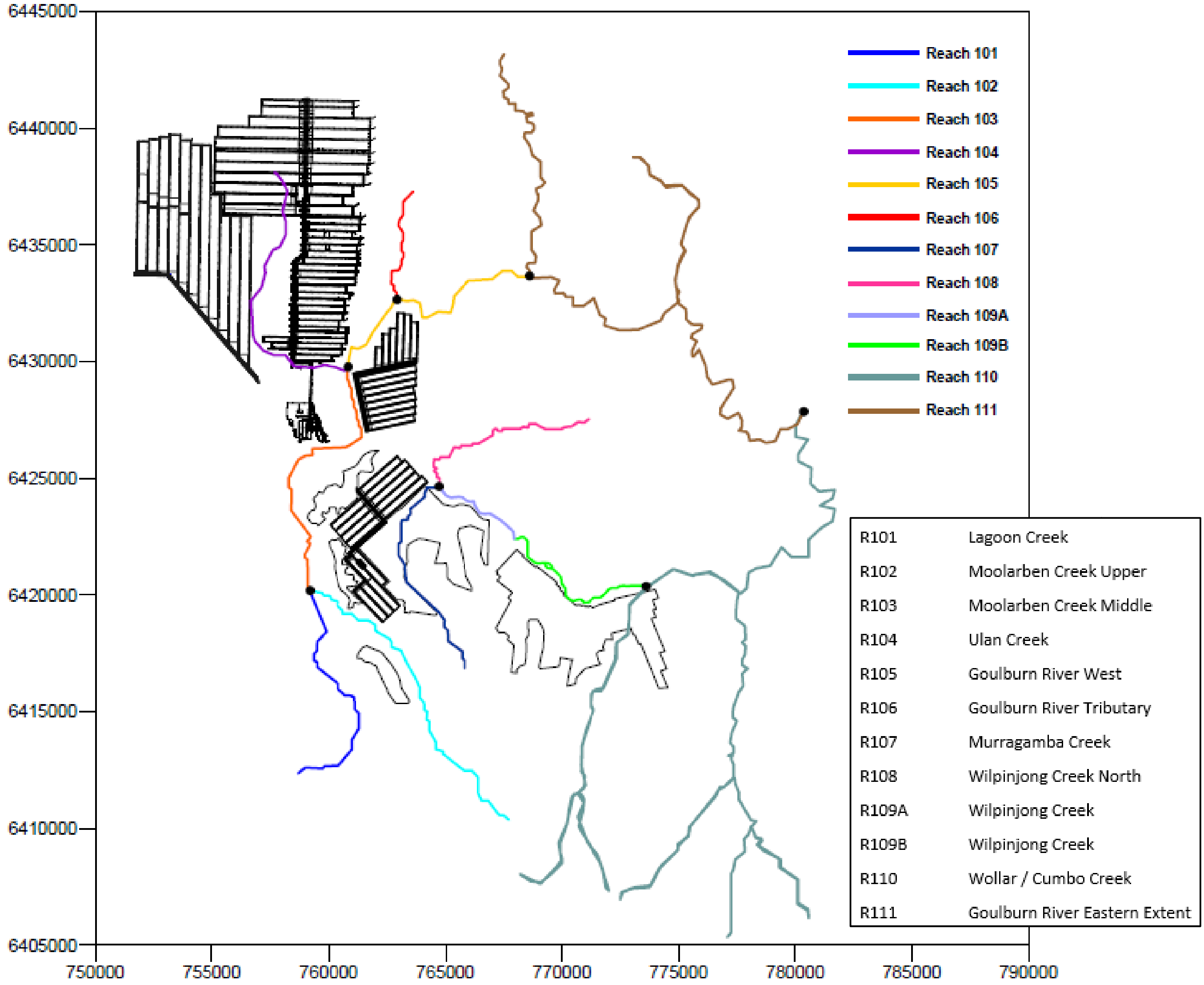


Figure 10. Surface Water Reach Location Map (RPS Aquaterra, 2011)

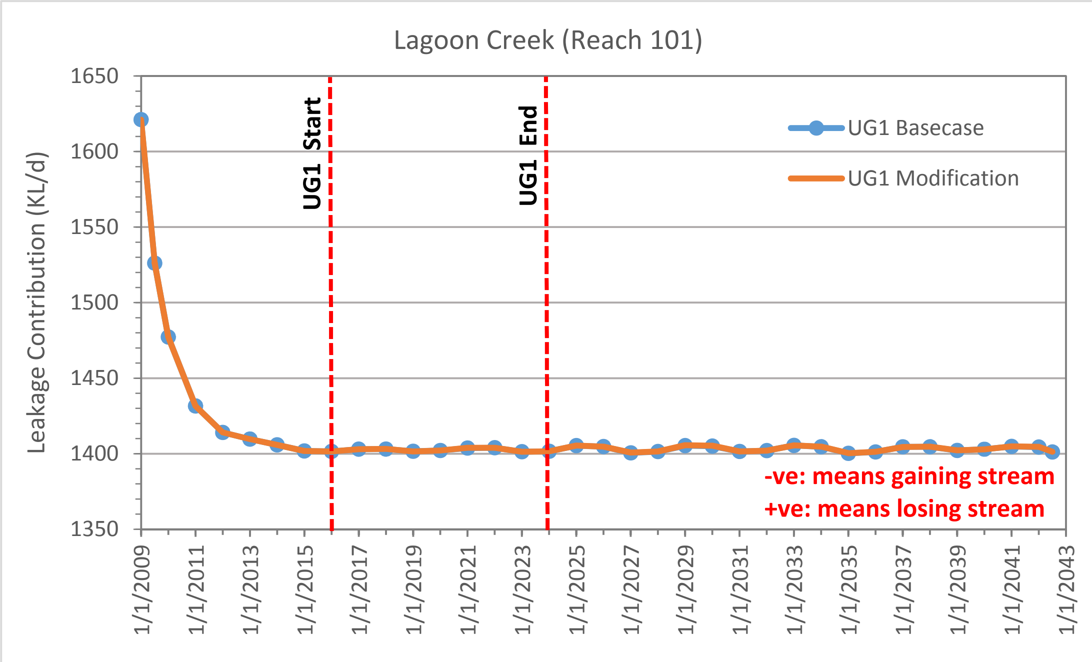


Figure 11. Predicted Groundwater-Surface Water Interaction on Lagoon Creek

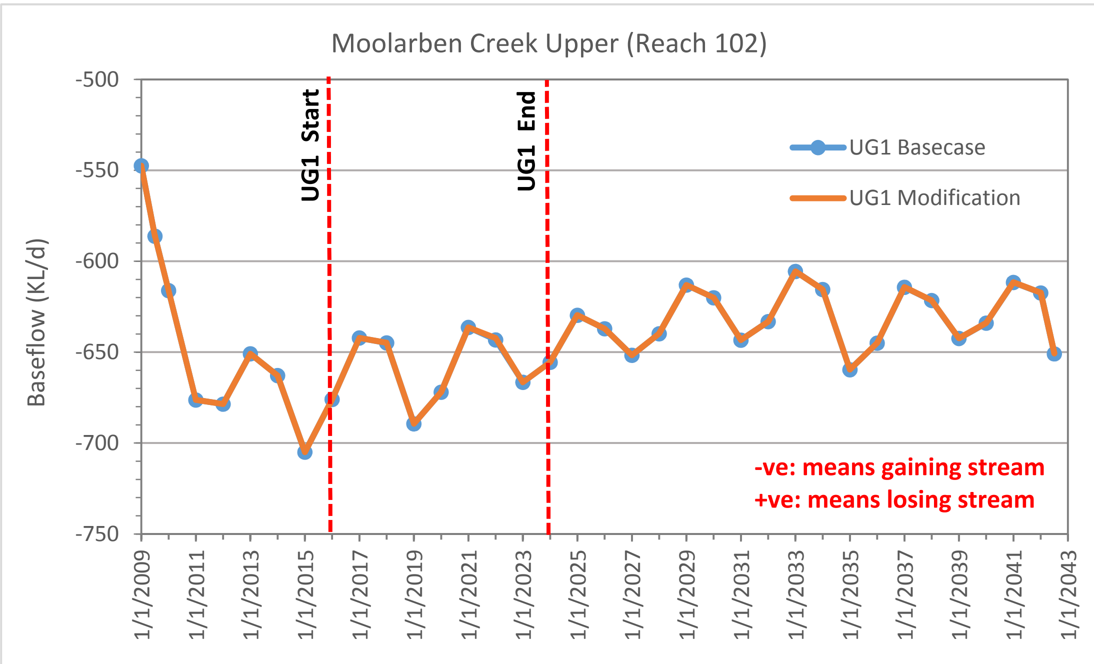


Figure 12. Predicted Groundwater-Surface Water Interaction on Moolarben Creek Upper

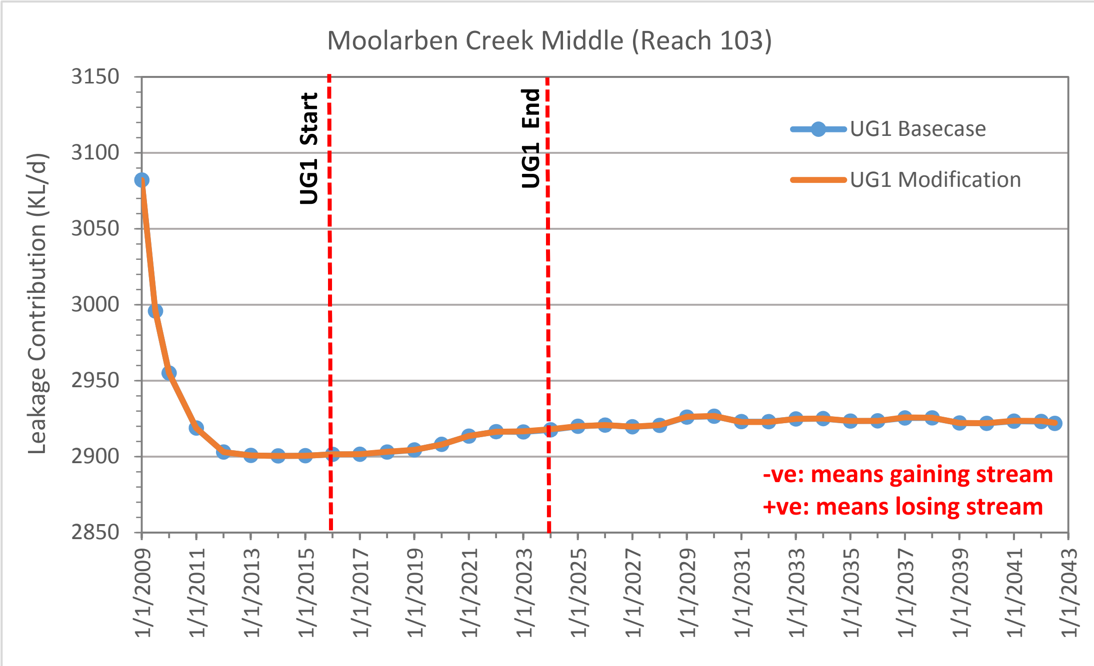


Figure 13. Predicted Groundwater-Surface Water Interaction on Moolarben Creek Middle

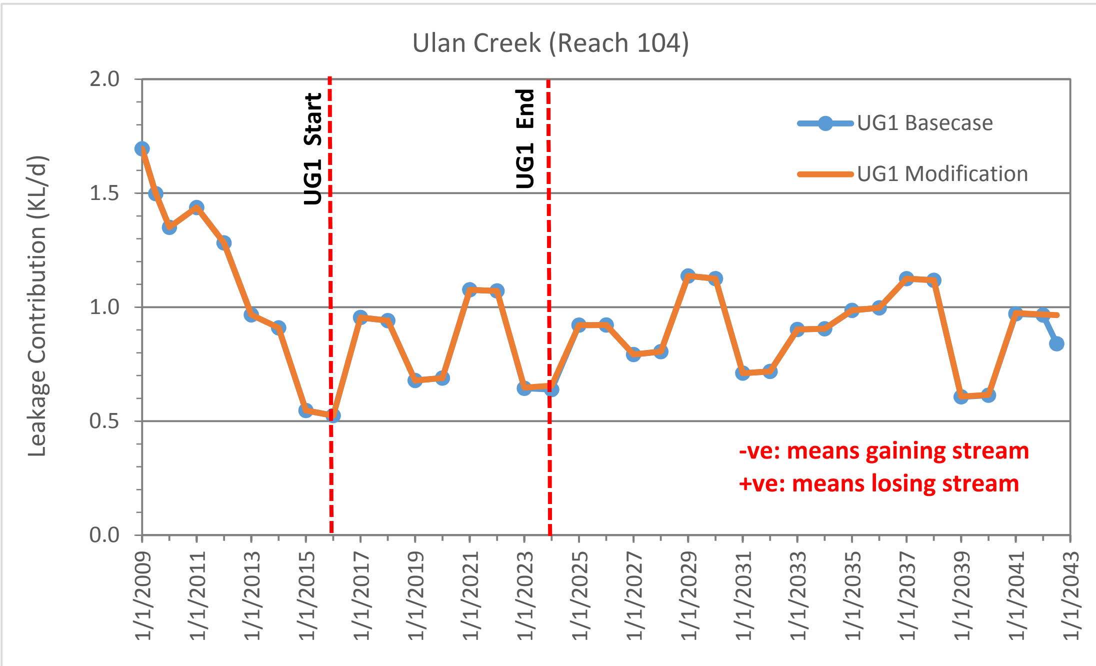


Figure 14. Predicted Groundwater-Surface Water Interaction on Ulan Creek

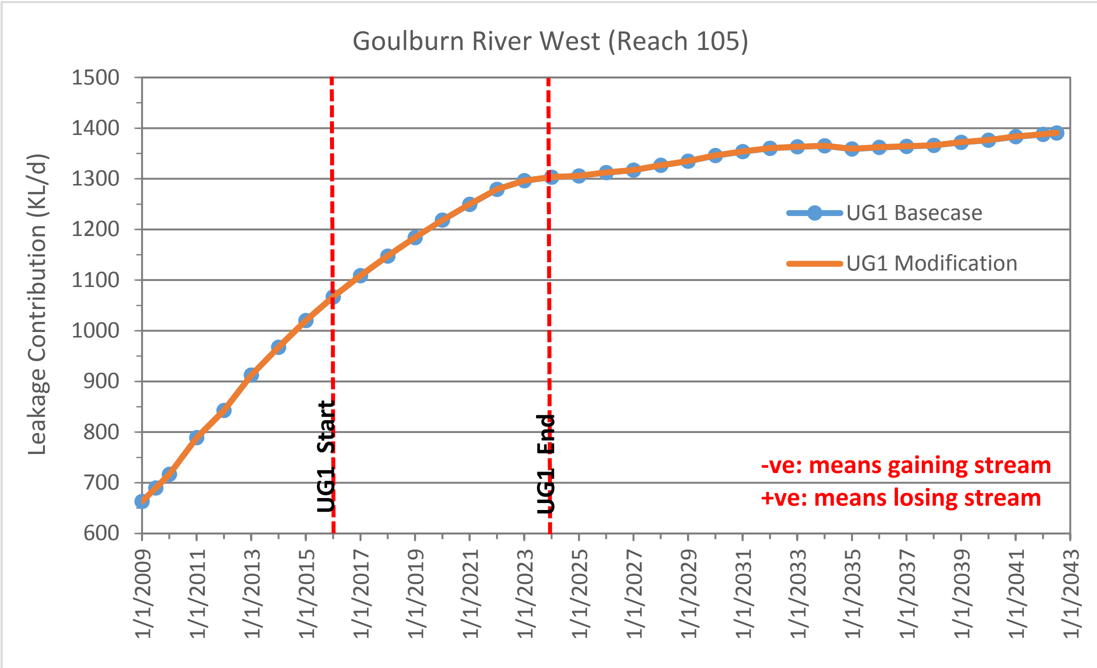


Figure 15. Predicted Groundwater-Surface Water Interaction on Goulburn River West

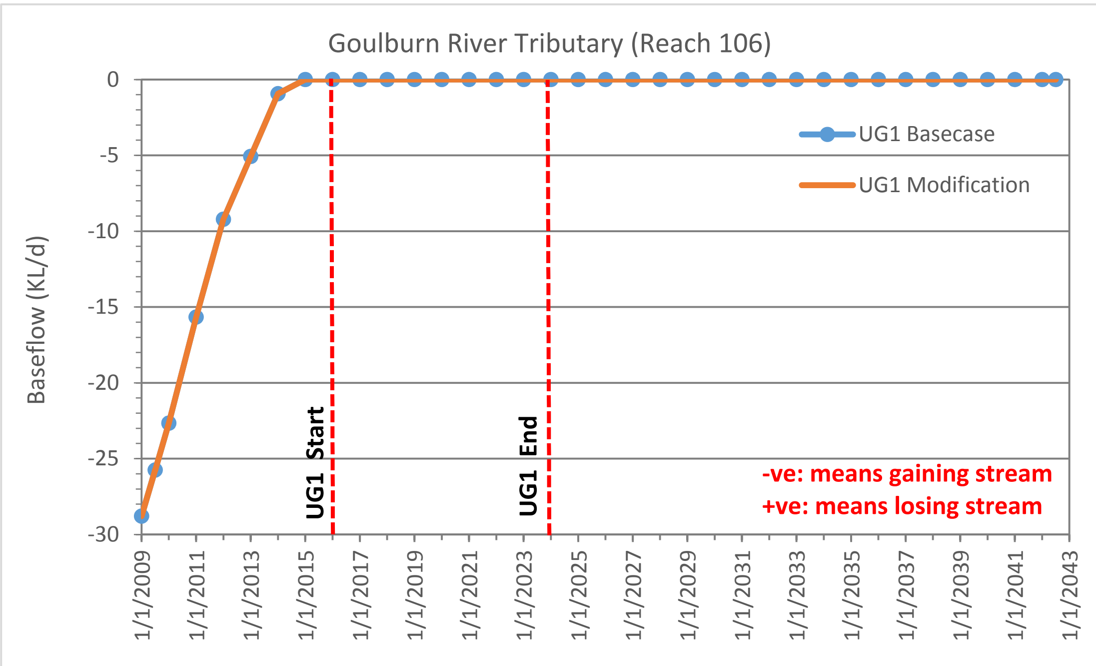


Figure 16. Predicted Groundwater-Surface Water Interaction on Goulburn River Tributary

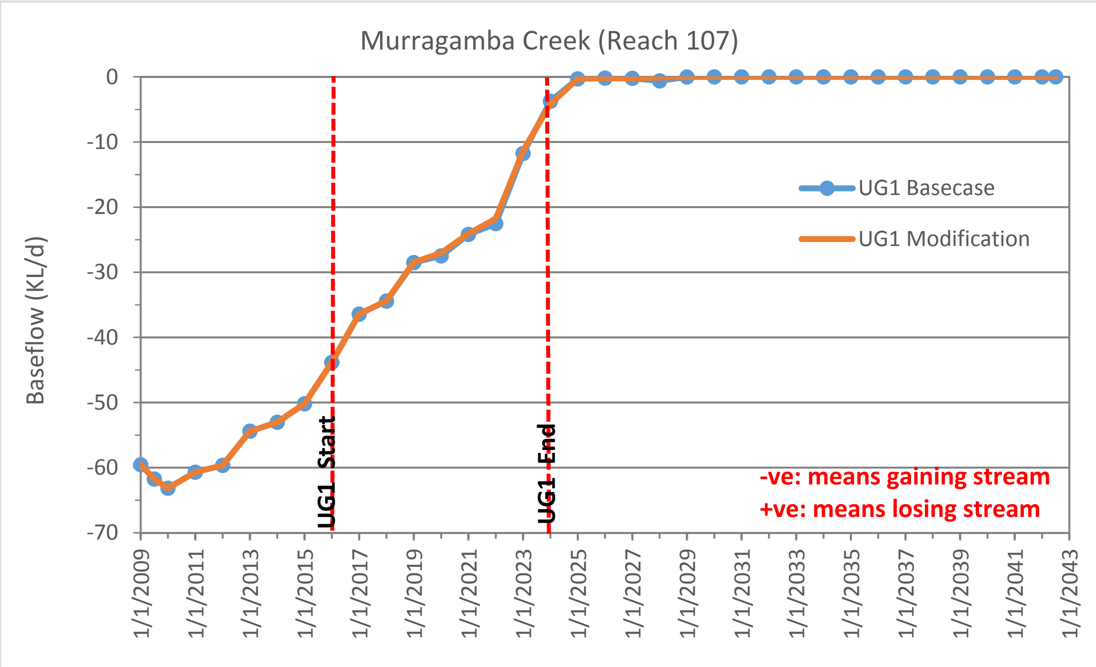


Figure 17. Predicted Groundwater-Surface Water Interaction on Murragamba Creek

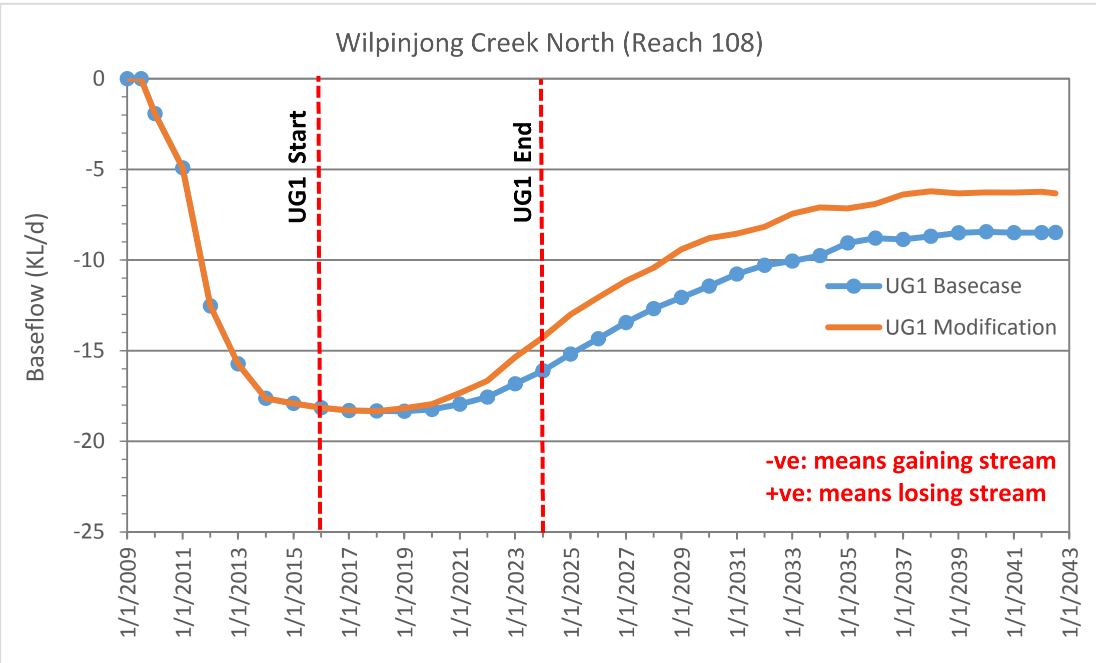
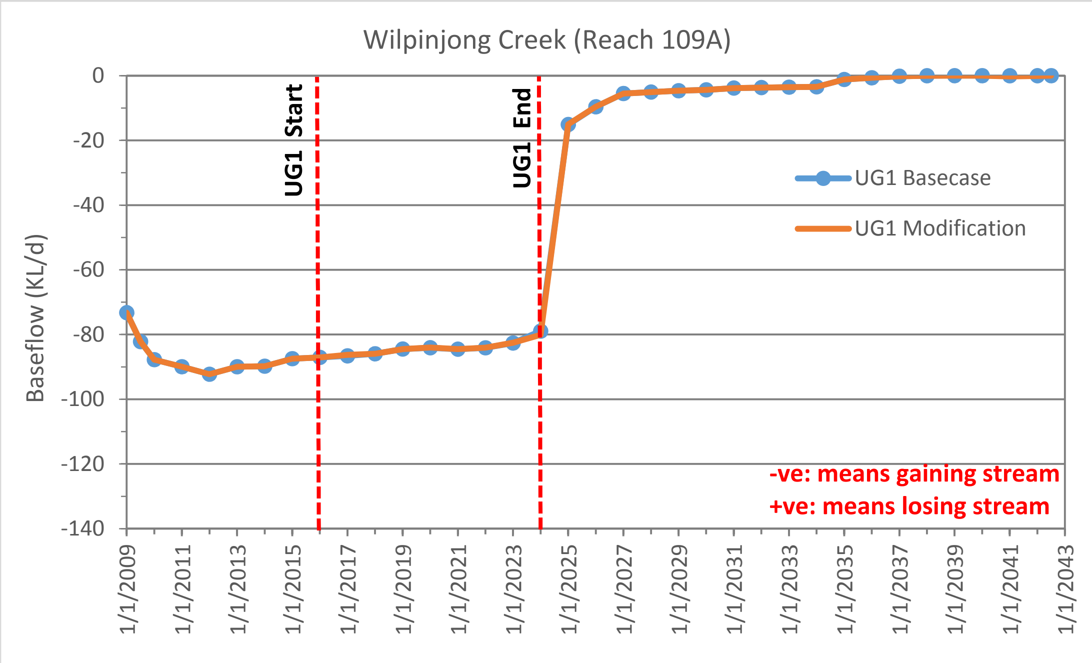


Figure 18. Predicted Groundwater-Surface Water Interaction on Wilpinjong Creek North



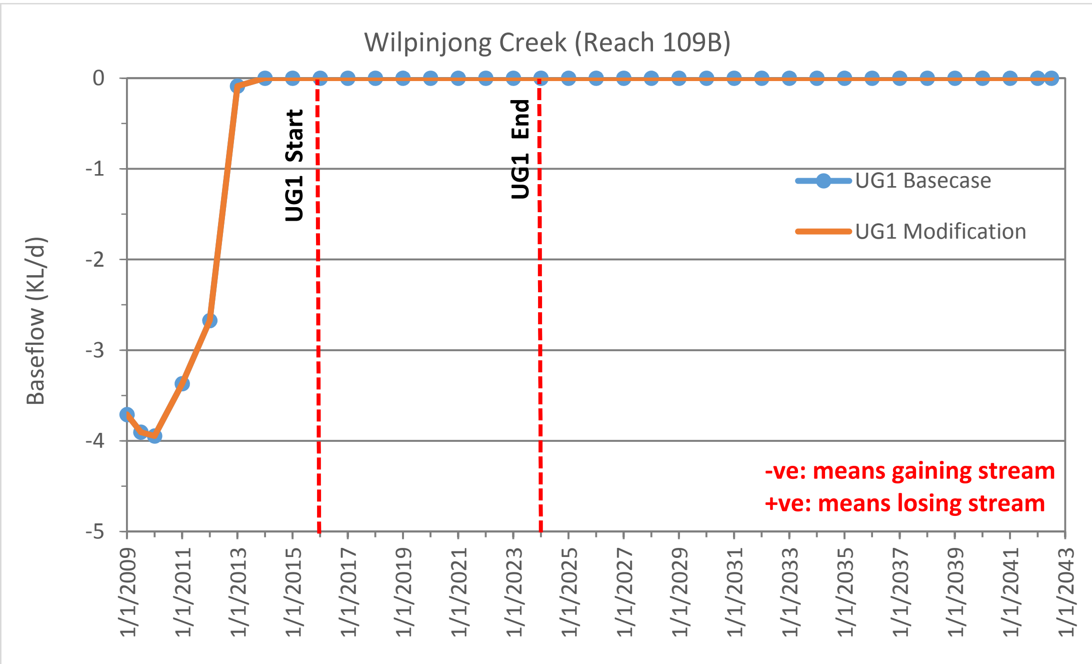


Figure 19. Predicted Groundwater-Surface Water Interaction on Wilpinjong Creek

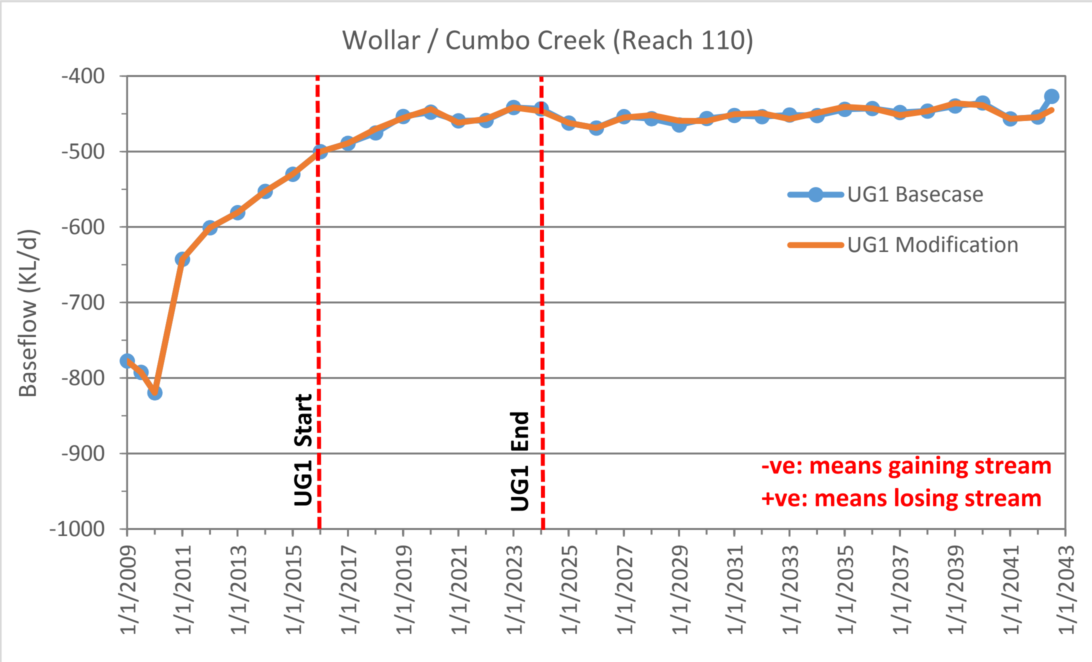


Figure 20. Predicted Groundwater-Surface Water Interaction on Wollar / Cumbo Creek

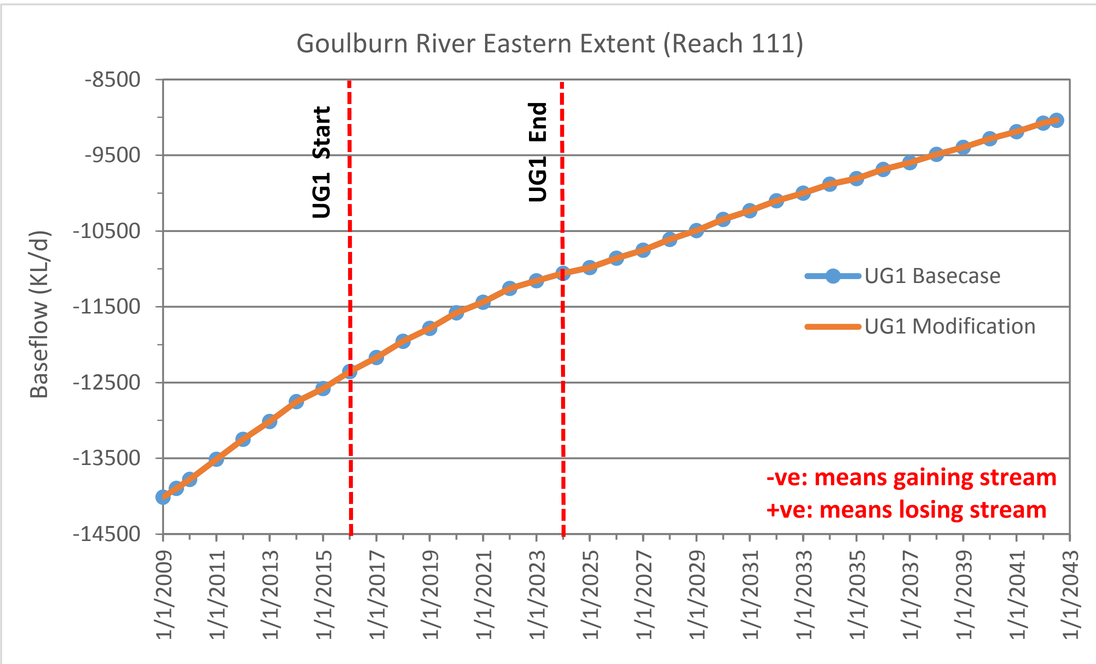


Figure 21. Predicted Groundwater-Surface Water Interaction on Goulburn River Eastern Extent

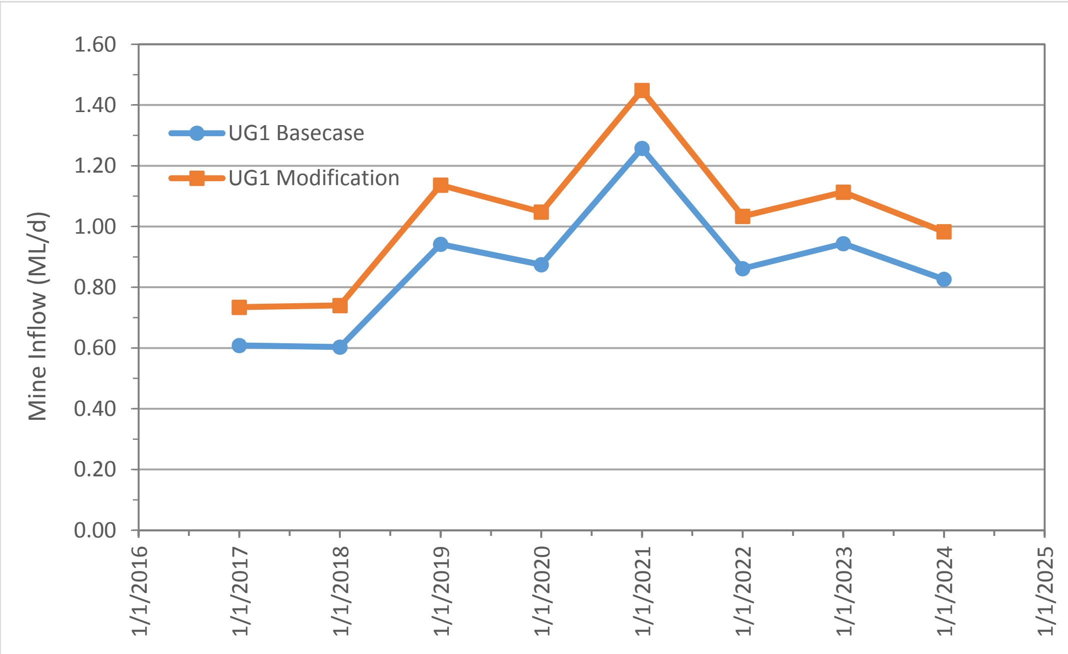
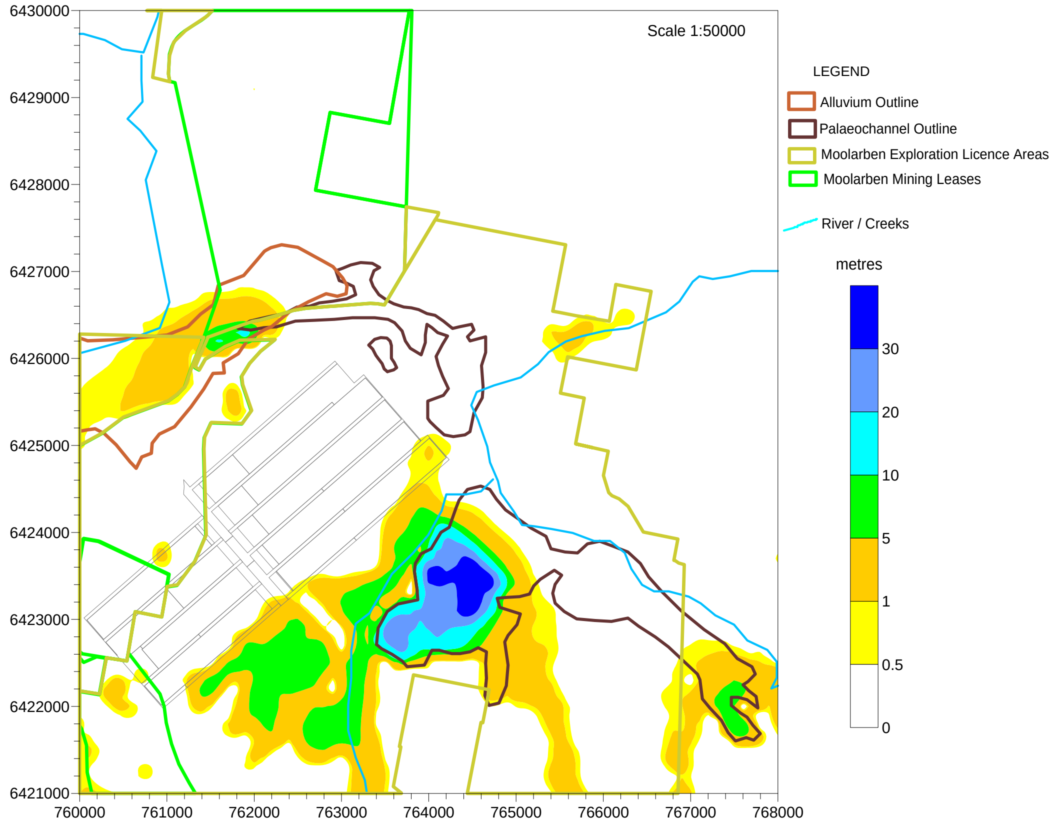


Figure 22. UG1 Mine inflow comparison between the Basecase and Modification mine plans

a)



b)

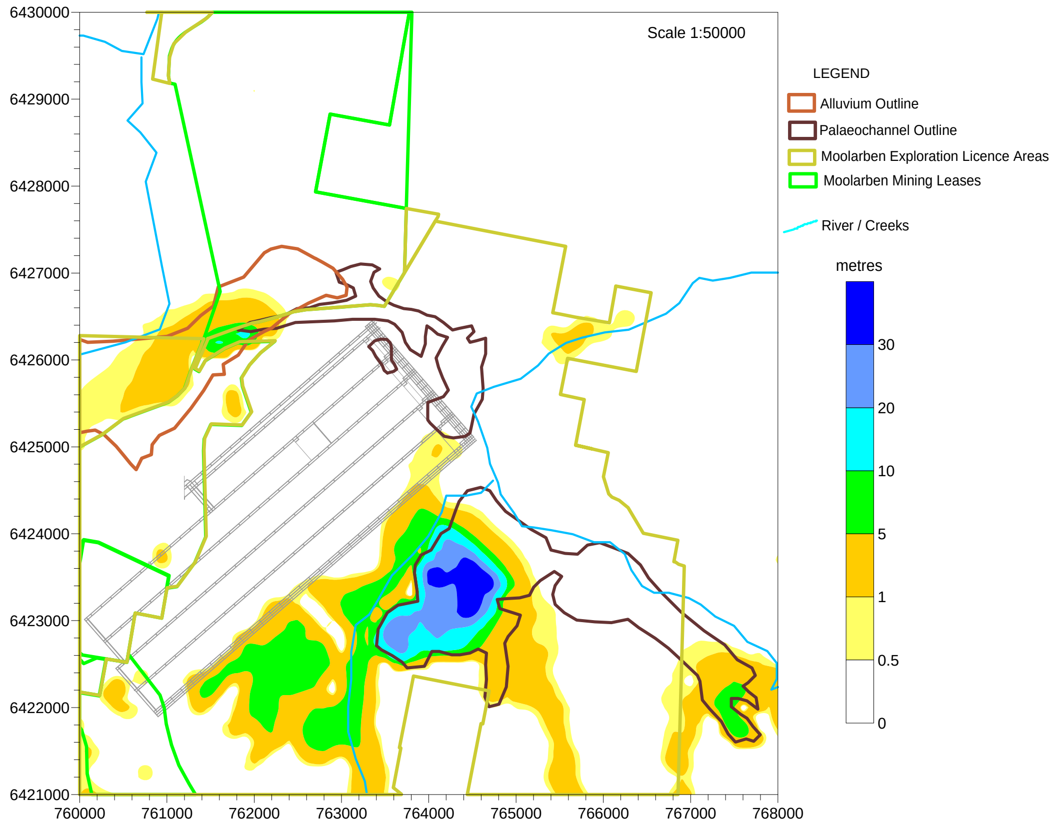
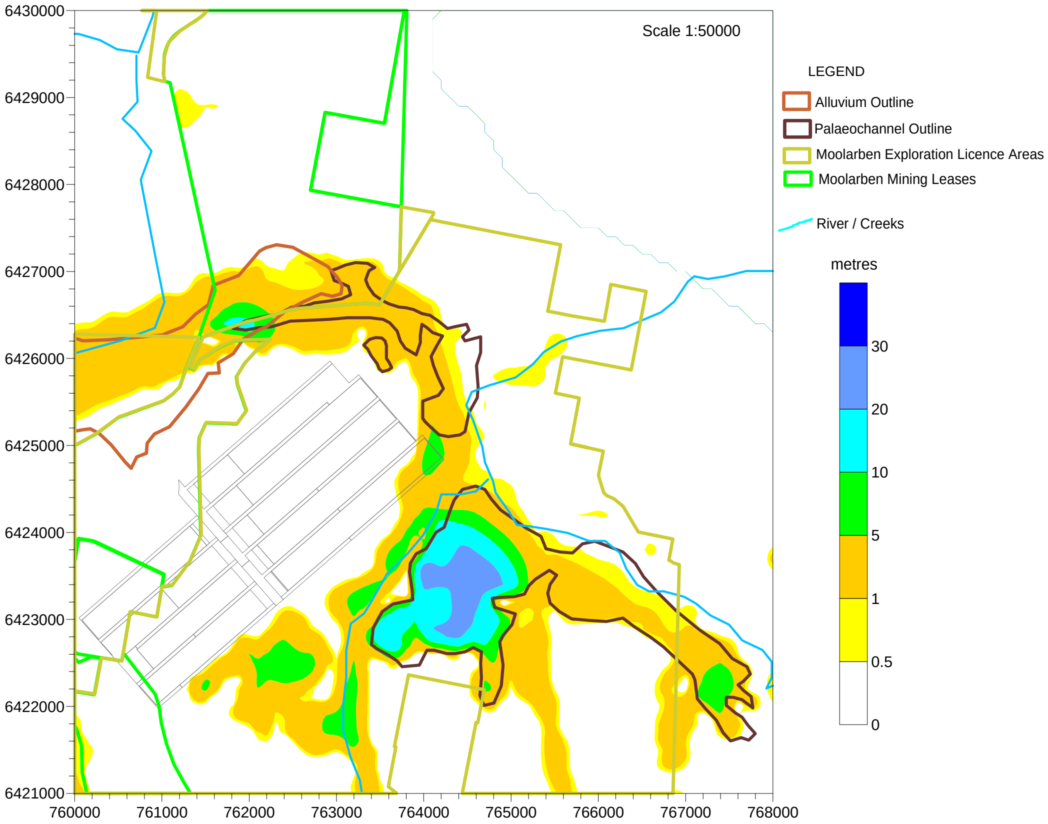


Figure 23. Total Drawdown (m) in Alluvium / Regolith (model layer 1) at the end of UG1 Mining in Stress Period 27 (mine year 9) a) UG1 Basecase mine plan; b) Modification UG1 mine plan

a)



b)

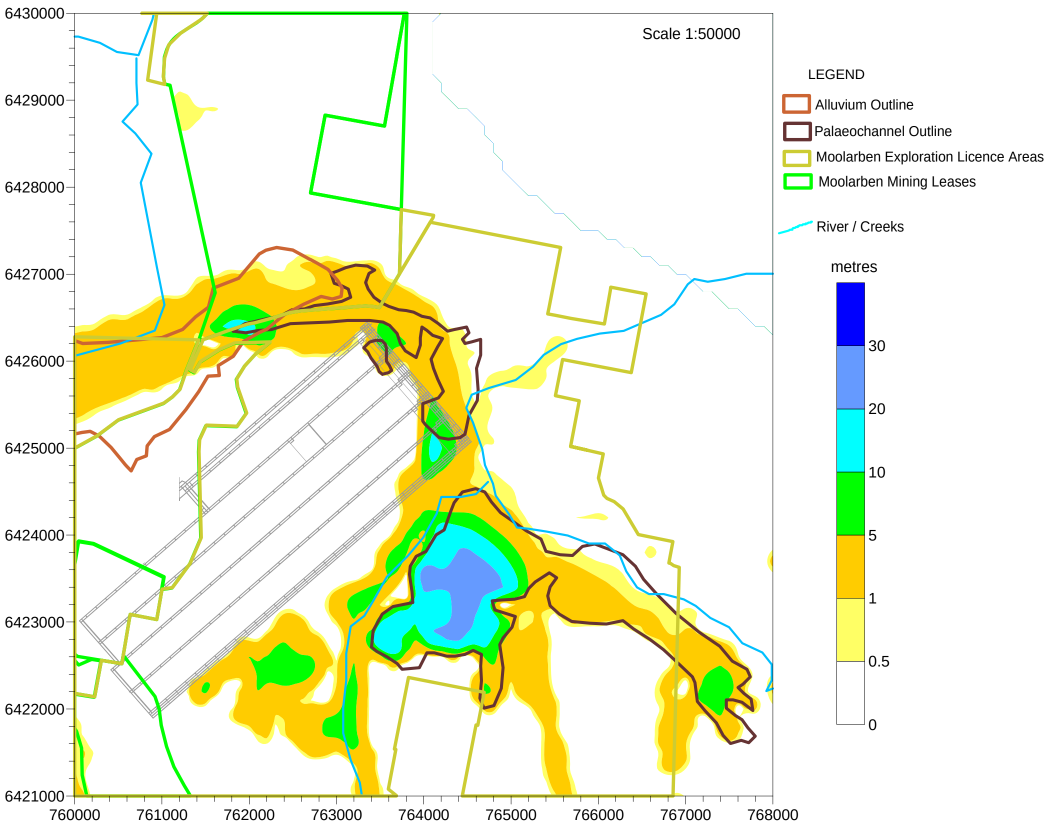
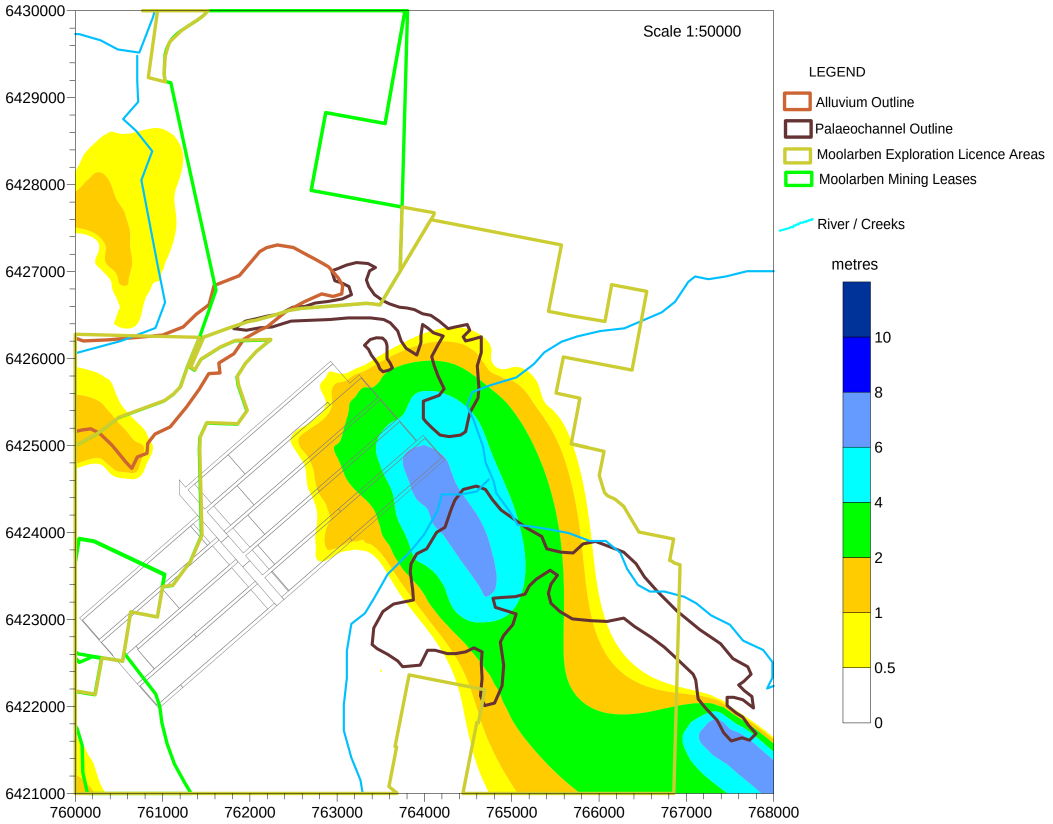


Figure 24. Total Drawdown (m) in Shallow Permian (model layer 2) at the end of UG1 Mining in Stress Period 27 (mine year 9) a) UG1 Basecase mine plan; b) Modification UG1 mine plan

a)



b)

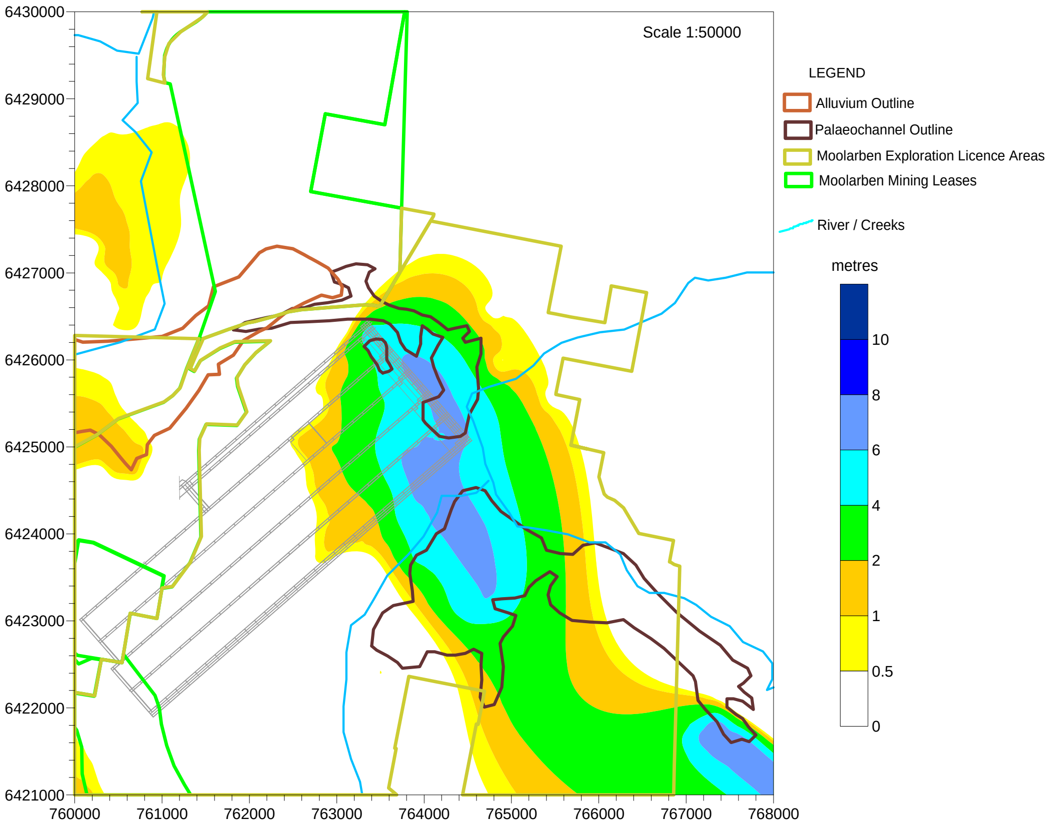
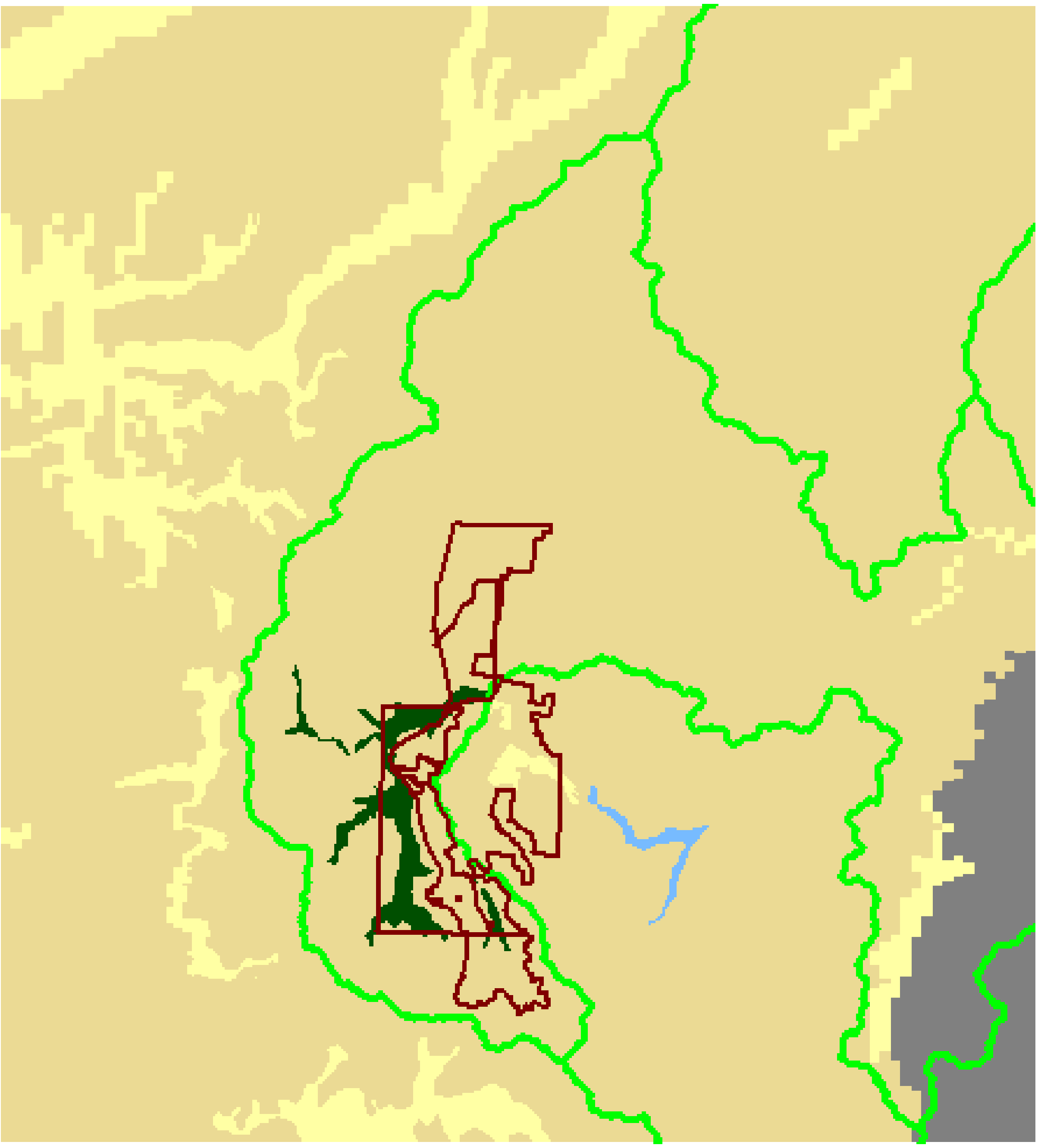


Figure 25. Total Drawdown (m) in Ulan Seam (model layer 7) at the end of UG1 Mining in Stress Period 27 (mine year 9) a) UG1 Basecase mine plan; b) Modification UG1 mine plan



Wollar Creek Alluvium

Upper Goulburn River Alluvium

Figure 26. Water Sources Alluvium Location Map

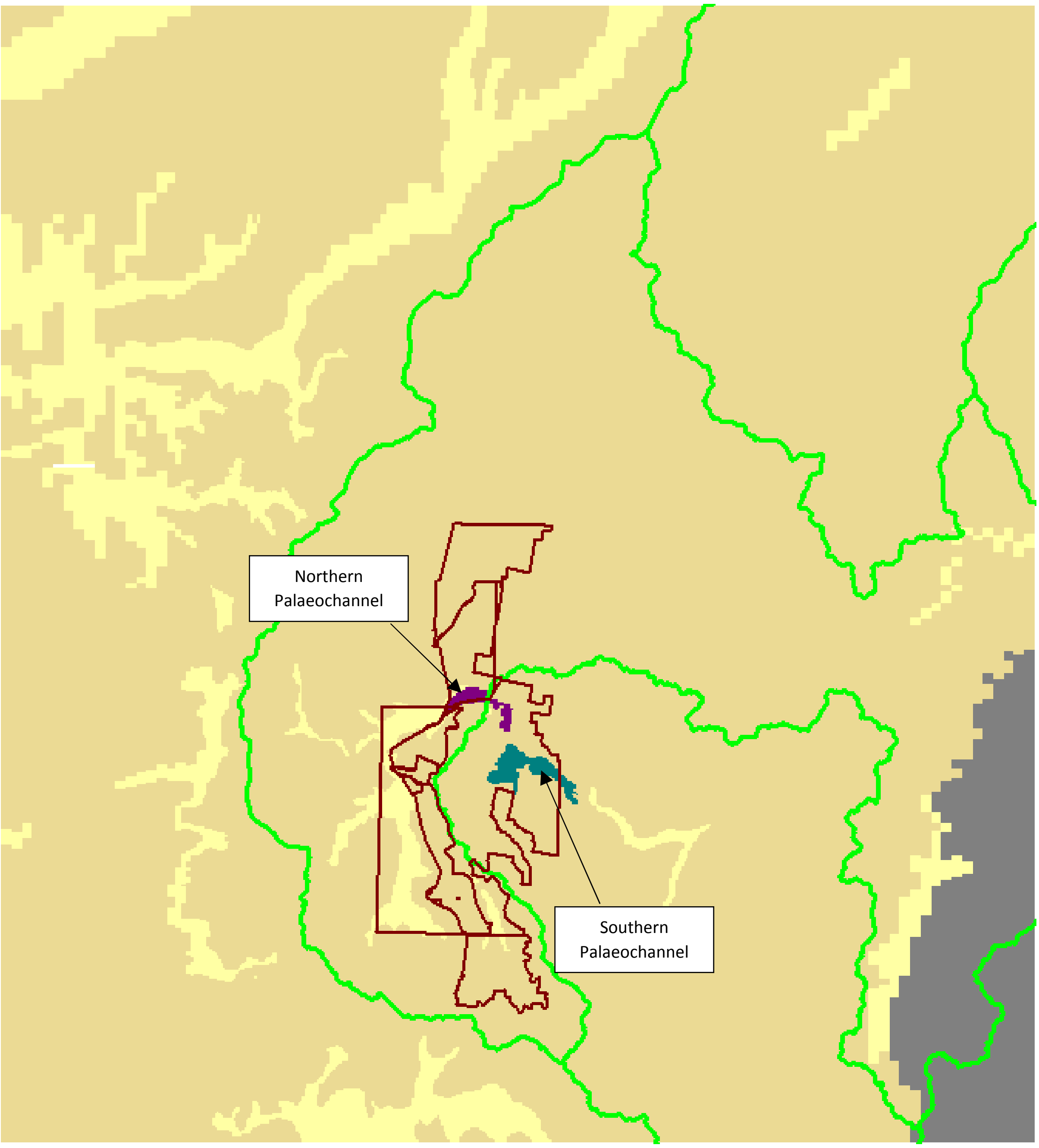


Figure 27. Tertiary Palaeochannel Location Map

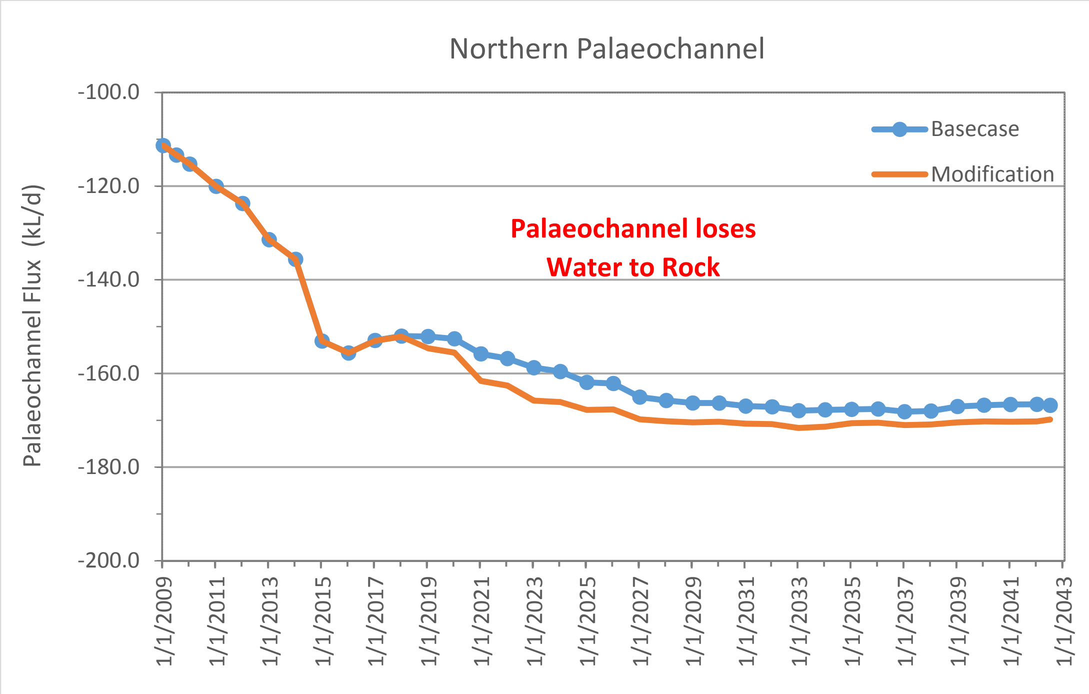


Figure 28. Time-Varying Downflow (negative) of Groundwater between Northern Palaeochannel and Hardrock for Basecase Mine Plan and Modified Mine Plan

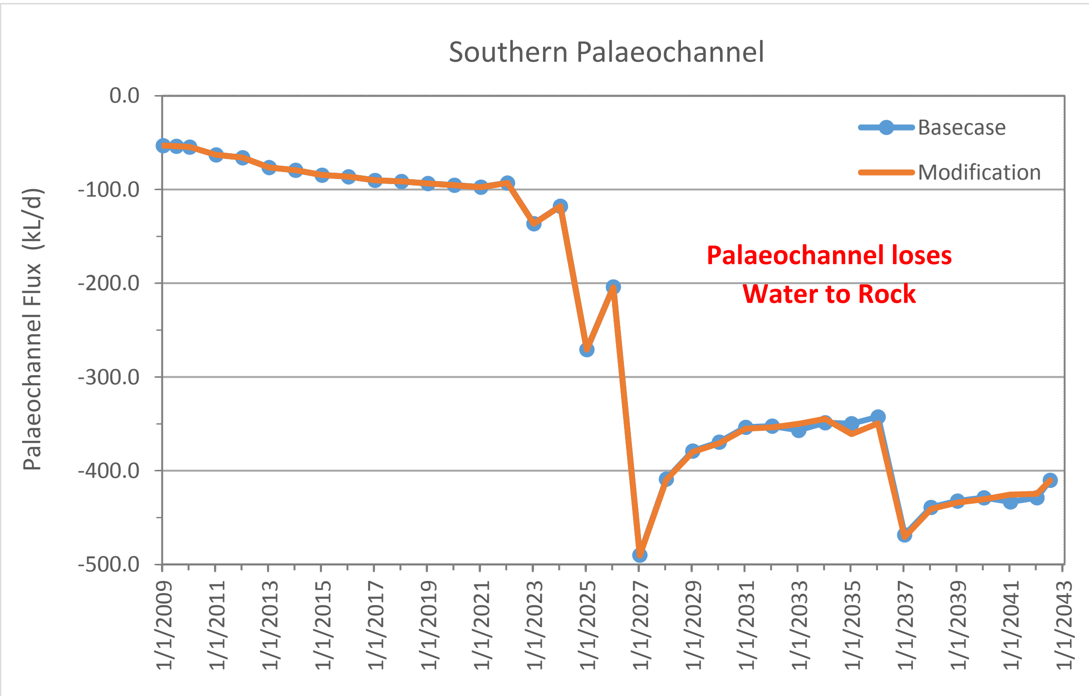


Figure 29. Time-Varying Downflow (negative) of Groundwater between Southern Palaeochannel and Hardrock for Basecase Mine Plan and Modified Mine Plan

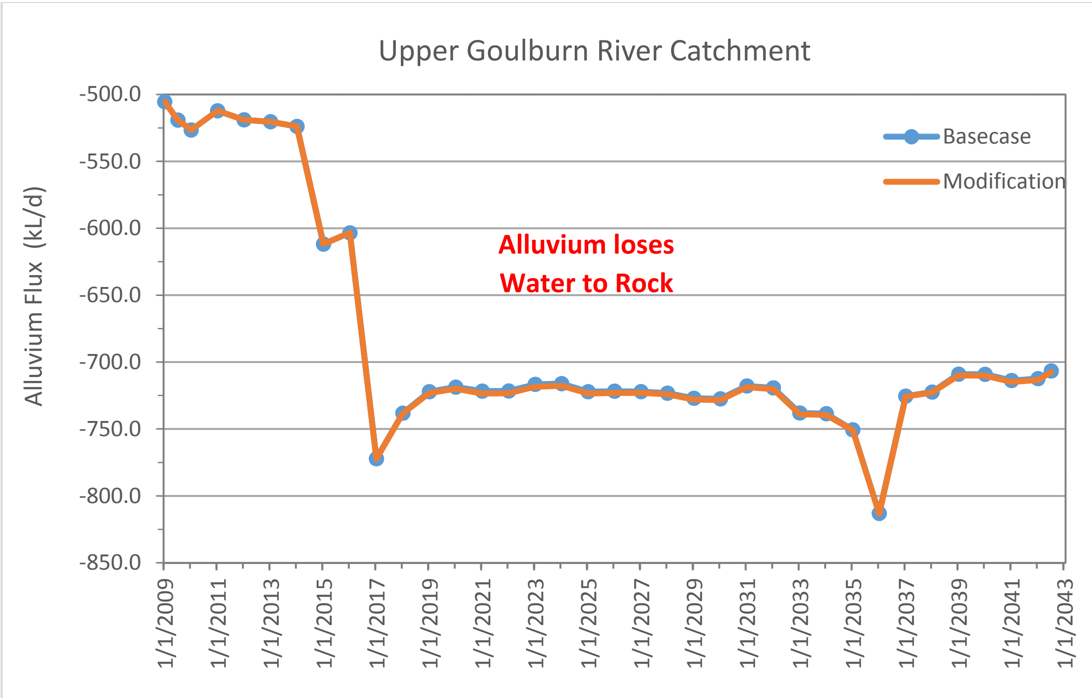


Figure 30. Time-Varying Downflow (negative) of Groundwater between Alluvium and Hardrock in Upper Goulburn River Catchment for Basecase Mine Plan and Modified Mine Plan

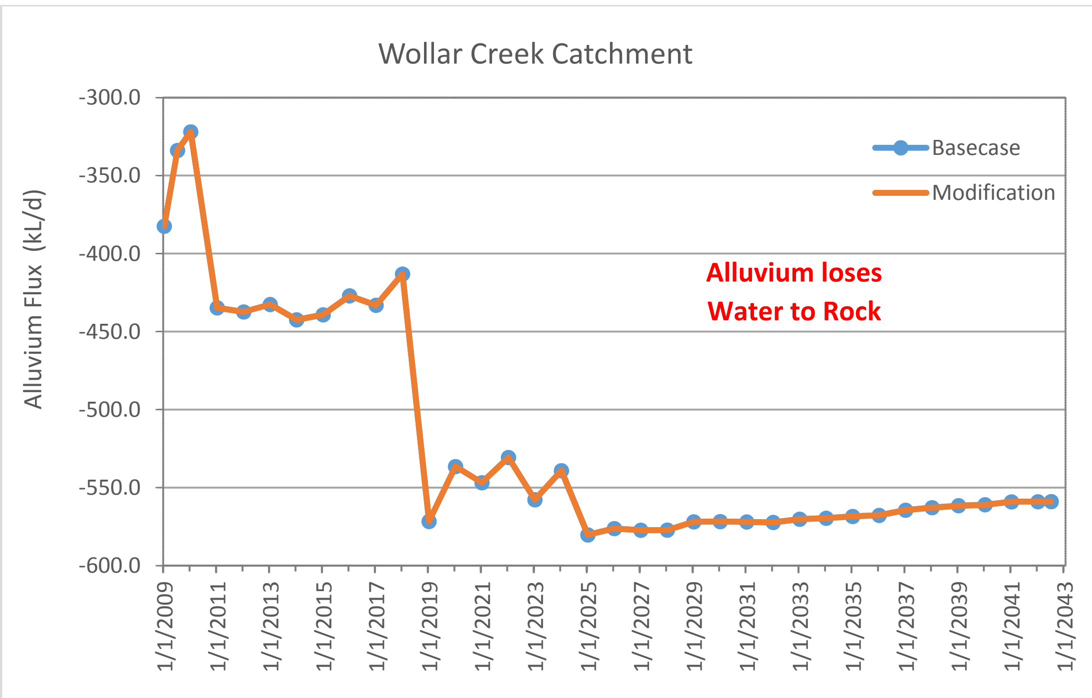


Figure 31. Time-Varying Downflow (negative) of Groundwater between Alluvium and Hardrock in Wollar Creek Catchment for Basecase Mine Plan and Modified Mine Plan