Appendix G

Groundwater impact assessment (Bland Creek Palaeochannel Borefield and Eastern Saline Borefield groundwater assessment)

EMM creating opportunities

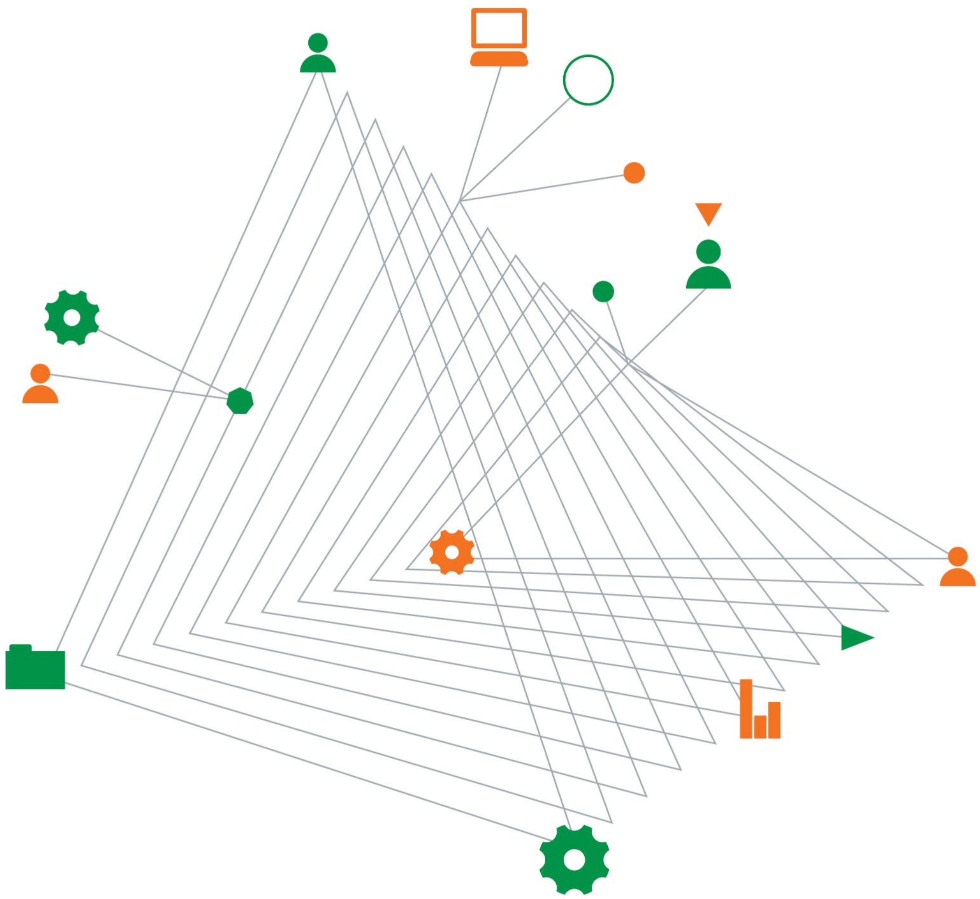
Evolution MINING

EMM Consulting Pty Ltd

Cowal Gold Operations Underground EIS

Bland Creek Palaeochannel Borefield and Eastern Saline Borefield Groundwater Assessment

27 August 2020



Cowal Gold Operations Underground EIS

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Executive Summary

A groundwater assessment was undertaken to assess potential impacts due to groundwater extraction from the Bland Creek Palaeochannel Borefield (BCPB) and Eastern Saline Borefield (ESB) under the proposed Cowal Gold Operations (CGO) Underground Development Environmental Impact Statement (UG EIS). The assessment employed predictive numerical simulation using an existing numerical groundwater flow model. An assessment of potential impacts on the groundwater system at the mine site has been undertaken using a separate numerical groundwater flow model and is reported separately.

The NSW government monitors groundwater levels in the Lachlan Formation at the BCPB and ESB (at the request of the Bland Palaeochannel Groundwater Users Group) using the following monitoring piezometer (with respective trigger level):

- GW036553 (Investigation Trigger Level 137.5 metres Australian Height Datum (m AHD) and Mitigation Trigger Level 134 m AHD).

If the trigger level at GW036553 is breached, this would trigger actions at the BCPB to protect the groundwater resource from overuse. Groundwater from this palaeochannel is used for mine process water by CGO.

In addition to extraction for process water (from the BCPB), irrigators at the Billabong and Maslin farms also extract significant groundwater volumes from the palaeochannel. The NSW government monitors groundwater levels in the Lachlan Formation at the Billabong and Maslin Farms (at the request of the Bland Palaeochannel Groundwater Users Group) using the following monitoring piezometers (with respective trigger levels):

- Billabong Area: GW036597 (Trigger Level 143.7 m AHD).
- Maslin Area: GW036611 (Trigger Level 145.8 m AHD).

Over the period 1 July 2004 to 31 December 2019, the average total pumping rates at the largest groundwater extraction bores (4.1 Megalitres per day [ML/day] at the borefield supplying CGO, 2.8 ML/day at the Billabong bores, and 2.7 ML/day at the Maslin bore) resulted in groundwater levels above the trigger levels at each of the NSW government monitoring bores. Pumping rates for the Billabong and Maslin bores, as used in verification analysis, involve significant assumptions. The lowest observed groundwater levels over the period 1 July 2004 to 31 December 2019 were as follows:

- BCPB Area - GW036553: 7.5 m above trigger (141.5 m AHD on 15 January 2010).
- Billabong Area - GW036597: 1.5 m above trigger (145.2 m AHD on 21-23 November 2019).
- Maslin Area - GW036611: 1.6 m above trigger (147.4 m AHD on 16 December 2019).

Modelling results indicate that the BCPB can pump at a maximum rate of 4.0 ML/day, from 1 January 2020 to 30 June 2040 (with the ESB pumping at 1.5 ML/day), without causing the water level in monitoring piezometer GW036553 to fall below the mitigation trigger level of 134 m AHD. The effects of pumping at this rate were also assessed at the locations of monitoring piezometers GW036597 and GW036611 located 15 kilometres (km) south of the mine borefield. At these locations the incremental effects of pumping from the mine bores at 4.0 ML/d from 1 January 2020 to 30 June 2040 were added to a measure of low recorded groundwater levels at these locations (based on the average of the lowest five events on record). The predicted groundwater levels for the impact of mine water use remained above the trigger levels for these monitoring piezometers. Note that

groundwater levels at piezometers GW036597 and GW036611 do not govern the operation of the BCPB or ESB.

The trigger level for GW036553 (located near the mine borefield) is not predicted to be breached under the adopted model conditions, based on extraction at a uniform rate with time.

Considering the worst case scenario for model parameter uncertainty, the water level at trigger piezometer GW036553 would be predicted to reach the effective trigger level in late 2033. On the other hand, considering the best case scenario for model parameter uncertainty, the water level at GW036553 is predicted to be approximately 4 m higher than the effective trigger level in 2040.

The effects of the uncertainty in the rate of irrigator pumping from Billabong 3/6, Billabong 4 and Maslin are clearly evident. A 50% increase in the future pumping rate from these bores results in the predicted water level at GW036553 reaching the effective trigger level in 2026. This also shows the importance of climate on future groundwater availability. During periods of high irrigator pumping and drought, groundwater trigger levels for both the mine and irrigators will require management.

Maximum drawdowns at the end of mine life (2040) are predicted to be 40 m or less in the Lower Cowra Formation and 61 m or less in the Lachlan Formation within the BCPB. A maximum drawdown of about 32 m (in the Lower Cowra Formation) is modelled for GW029574 (a private bore listed on the NSW Government bore register), the only known water bore installed to a depth within the Lower Cowra Formation and within 15 km of the BCPB. However, the bore is 88 m deep and may be able to continue operation if the screen is sufficiently deep. Overall, maximum modelled drawdown in the Lower Cowra Formation (including drawdown at GW029574) due to the UG EIS is less than the drawdown in the Lower Cowra Formation predicted for Modification 13 (Coffey, 2016).

Previous simple numerical transport simulation indicates total dissolved solids (TDS) at BLPR1 will increase by about 20 percent (%) or less, by 31 December 2032, from pre-mining concentrations. Modelling of pumping ceasing at 31 December 2032 indicates TDS at BLPR1 will increase by about 40% or less, by 30 June 2040, from pre-mining concentrations.

At cessation of BCPB and ESB pumping, groundwater levels at GW036553 are predicted to recover to around 166 m AHD in 10 years (about 30 m below 1998 water levels), and would continue to gradually recover over time, to a level that is dependent on the volume historically pumped, private bore usage following mine closure, and climatic conditions.

1. Introduction

This report presents the results of a groundwater assessment of the Bland Creek Palaeochannel Borefield (BCPB) and Eastern Saline Borefield (ESB), both operated by Evolution Mining (Cowal) Pty Limited (Evolution) as water supplies for its Cowal Gold Operations (CGO). The CGO site is located approximately 350 kilometres (km) west of Sydney and 38 km north east of West Wyalong in New South Wales (NSW). The BCPB and the ESB are located approximately 20 km and 30 km north east of the CGO, respectively, within the Bland Creek Palaeochannel. Figure 1-1 shows the location of the CGO. Figure 1-2 shows the location of the BCPB and ESB in relation to the CGO.

Evolution is the owner and operator of the CGO, an existing open cut mine which has been operational since 2005 and has current approvals in place to continue processing ore at a rate of 9.8 million tonnes per annum (Mtpa) until 2032.

Evolution recently obtained approval for development of an exploration decline (GRE46 exploration decline) to explore further an identified underground orebody immediately adjacent to the current open pit. Based on drilling results obtained to date Evolution is now considering options to further develop CGO over the Life of Mine, including additional open pit development and an underground mining operation. Evolution are firstly seeking to obtain an approval for the Underground Development Environmental Impact Statement (UG EIS), followed by obtaining subsequent approval for an open cut expansion development.

Large groundwater extraction rates from the Bland Creek Paleochannel, near the CGO, are concentrated in three main areas. One of the areas encompasses the BCPB and ESB, both operated by Evolution as water supplies for the CGO. The other two areas encompass private bores. These areas are identified on the map in Figure 1-2. Each of the three areas has a monitoring piezometer used by the NSW government to monitor groundwater levels in the Lachlan Formation (at the request of the Bland Palaeochannel Groundwater Users Group) for groundwater management purposes. These piezometers have associated triggers defined by water levels at the piezometer. Operation of the BCPB and ESB is governed by water levels at monitoring piezometer GW036553. Should the bore water level at GW036553 fall to the trigger, various management actions for the BCPB and ESB would be initiated. The other two monitoring piezometers relate to groundwater usage at the Billabong and Maslin farm areas which are Figure 1-2. Breach of their trigger levels would initiate various management actions in those areas.

The objective of the modelling study presented in this report is to assess future water security of the mine by carrying out an assessment of drawdown impacts compared to set trigger levels, within the Bland Creek Palaeochannel. This comprises a study of potential impacts on groundwater levels and quality caused by future groundwater extraction from the BCPB and ESB for the underground development.

An assessment of impacts on the groundwater system at the area immediately surrounding the CGO was undertaken using a separate numerical groundwater flow model and is reported separately.

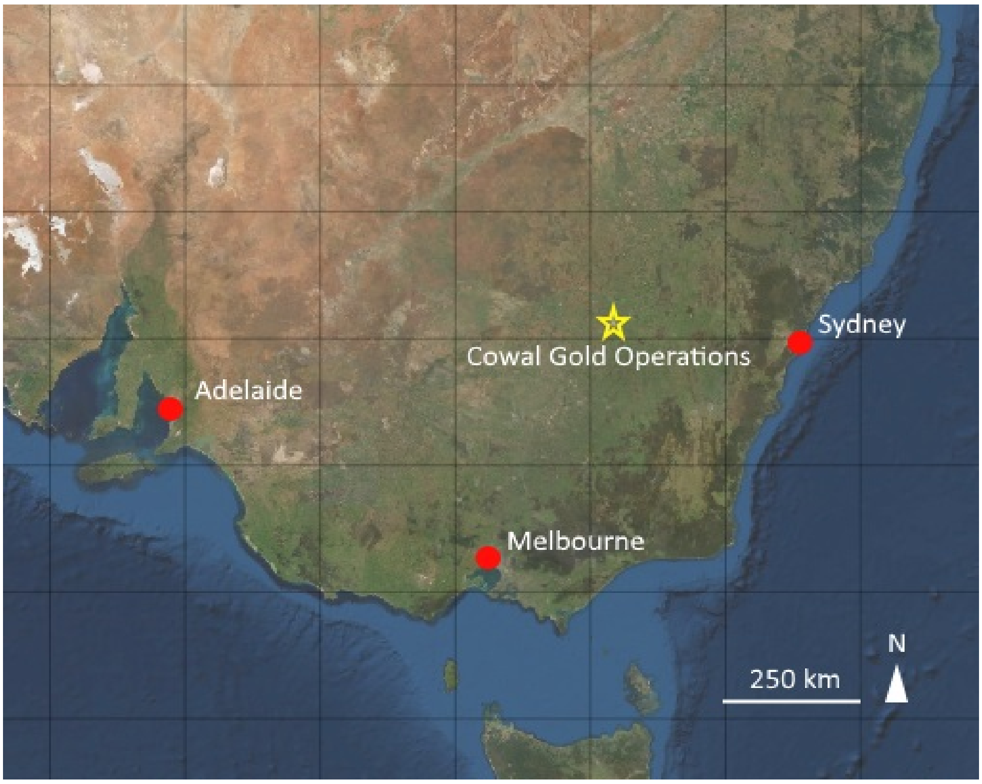


Figure 1-1: Cowal Gold Operations Location

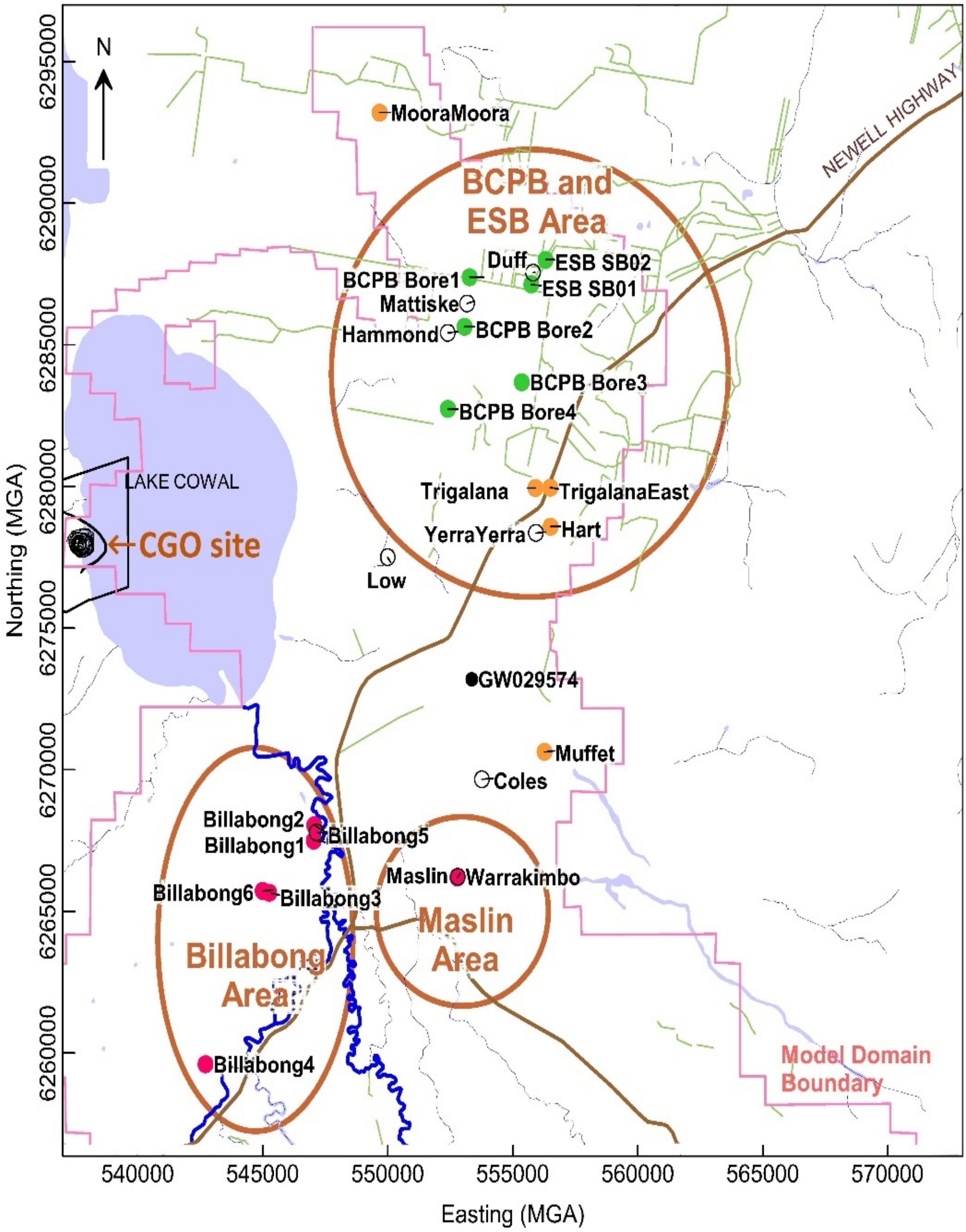


Figure 1-2: BCPB and ESB location in relation to the CGO

1.1. CGO Underground Development

The area of land to which the CGO Development Consent (DA 14/98) is relevant includes ML 1535, ML 1791, the CGO water supply pipeline and Bland Creek Palaeochannel Borefield. Open pit mining operations are currently undertaken within ML 1535, which encompasses approximately 2,636 hectares (ha). Evolution seeks to extend mining operations at the CGO by an underground development, which would be wholly contained within ML 1535.

The underground development proposal seeks for construction and operation of an underground mine at the CGO using stope mining practices, in addition to continuing operation of the existing open cut mine, to exploit an identified ore deposit in proximity (refer to Figure 1-3). Key features of the CGO Underground Development include:

- Extension of mine life from 2032 to 2040.
- A box-cut entry to the underground workings.
- A decline from the box-cut to provide access for personnel and maintenance.
- Six access points to the decline for access, ore haulage, ventilation circuit, underground services and emergency egress.
- A network of underground tunnels to provide access to the ore, transportation to the surface and ventilation.
- Use of sub-level open stoping to extract the ore.
- Production of up to 27 Mt of ore at a rate of 1.8 Mtpa.
- Production of approximately 5.74 Mt of waste rock.
- Stopes to be fully backfilled with paste material made from dewatered tailings and cement.
- A height increase from 245 m AHD to 246 m AHD to the final rehabilitated height of the integrated waste landform.
- Delivery of extracted ore and waste rock to the surface by truck.
- Development of a paste fill plant, and the delivery of paste fill via a borehole and then backfilling underground stopes with the paste.
- Development of ancillary underground infrastructure to support the underground operation, including dewatering infrastructure, ventilation system, electrical reticulation.

1.2. Approvals Strategy

To facilitate the underground development environmental impact assessment process, Evolution proposes to seek approval under the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) for two separate but inter-related applications:

- Underground workings EIS (UG EIS) – a State Significant Development (SSD) application under section 4.38 of the EP&A Act for the new underground component of the Underground Development.
- Surface changes modification – a request for modification (Modification 16) to the existing CGO development consent (DA 14/98) under section 4.55 of the EP&A Act for the ancillary surface changes associated with the Underground Development.

1.3. Secretary's Environmental Assessment Requirements

The Secretary's Environmental Assessment Requirements (SEARs) for the UG EIS (provided on 27 September 2019) included the following requirements related to groundwater:

- An assessment of the likely impacts of the development on the quantity and quality of regional surface water and groundwater resources.
- An assessment of the likely impacts of the development on aquifers, watercourses, riparian land, water-related infrastructure, and other water users.
- Water supply arrangements for the development.

The SEARs also include policies, plans and guidelines, which have been considered during the preparation of this report (refer to Section 2).

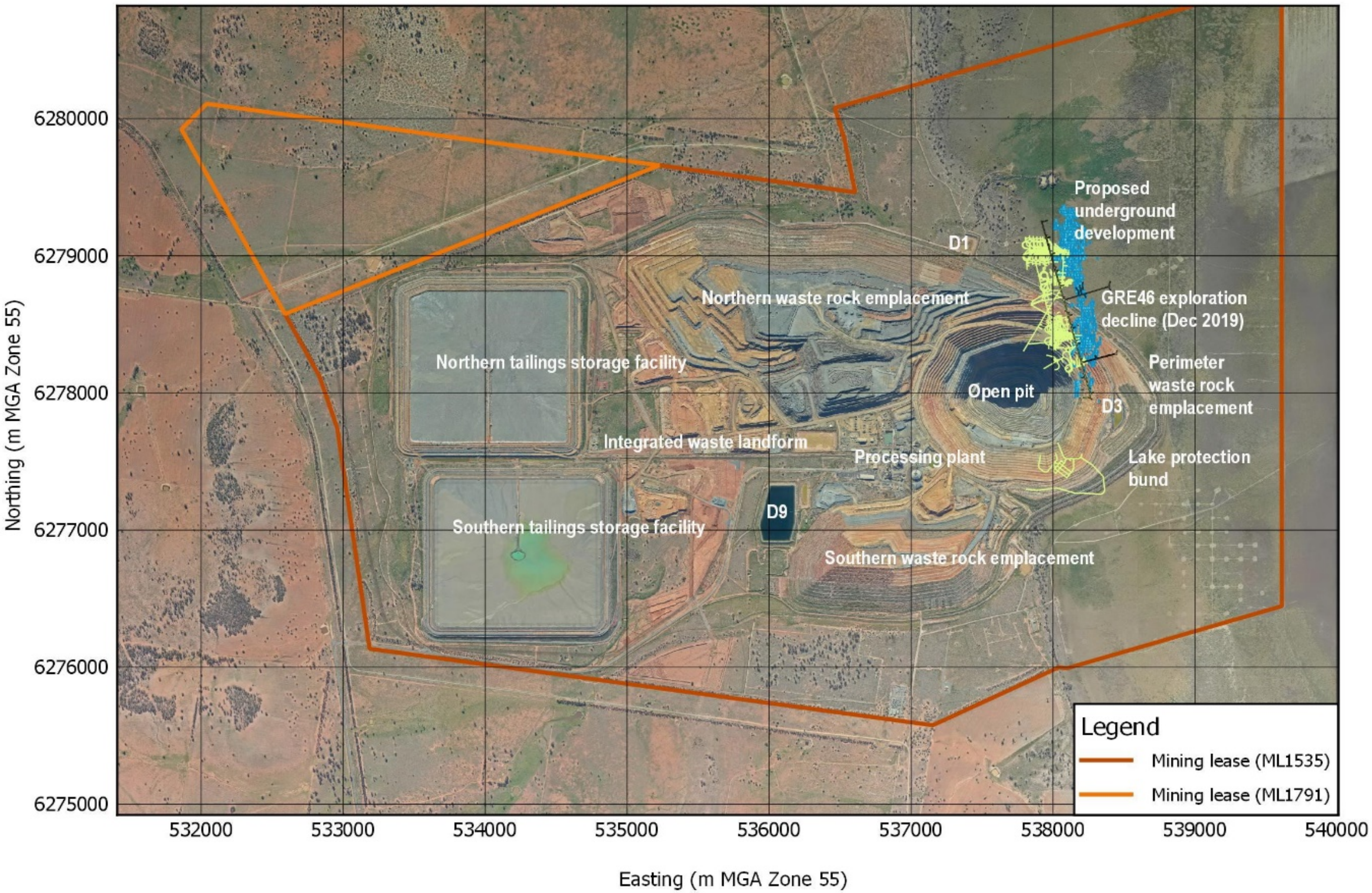


Figure 1-3: Proposed Underground Development

2. Legislation, Policy and Guidelines

This assessment has been prepared with consideration of the following policies, guidelines and plans:

- National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia (Australian and New Zealand Environment and Conservation Council, 1995).
- NSW Protection of the Environment Operations Act 1997.
- NSW State Groundwater Policy Framework Document (NSW Department of Land and Water Conservation [DLWC], 1997).
- NSW State Groundwater Quality Protection Policy (DLWC, 1998).
- NSW Groundwater Dependent Ecosystem Policy (DLWC, 2002).
- NSW Aquifer Interference Policy (NSW Department of Primary Industries Office of Water, 2012).
- Water Sharing Plan for the Lachlan Unregulated and Alluvial Water Sources – Background document for amended plan 2016 (NSW Department of Primary Industries Water, 2016).
- Australian Groundwater Modelling Guidelines (Barnett et al., 2012).
- Guidelines for the Assessment and Management of Groundwater Contamination (Department of Environment and Conservation NSW, 2007).

3. Previous Studies

In 2006 Coffey developed a three-dimensional numerical groundwater flow model for assessing the impacts of pumping from the BCPB on the surrounding environment and other groundwater users (Coffey, 2006). This was calibrated and used for predictive analysis. In 2010, due to changes in the mine plan and the introduction of the ESB, the model was upgraded and used to assess the impacts from proposed future changes in pumping from the BCPB and ESB. The 2010 upgrade comprised the following:

- Division of the Cowra formation into two model layers (the Upper and Lower Cowra Formations), forming a 3-layer model (with the bottom layer representing the Lachlan Formation as before), so pumping from the Cowra Formation could be simulated in more detail.
- Inclusion of the ESB (production bores SB01 and SB02).

Due to the inclusion of an additional layer in the model and to ensure that the model is continually updated, the model was recalibrated at the time of the upgrade. This task included the addition of new pumping and monitoring records collected since 2006.

Predictive simulations were undertaken in 2013, 2016 and 2017/2018 (Coffey 2013, 2016, 2018). The current assessment builds upon the previous work which assessed the impacts of the mining operations in relation to changes to the CGO associated with the approved Mine Life Extension modification.

The work undertaken in the current study uses the existing recalibrated model to simulate potential impacts on the groundwater system from operation of the BCPB and ESB due to the Underground development. It incorporates additional BCPB pumping measurements, and additional monitoring piezometer measurements, collected between 2017 and 2019. Refer to Coffey (2013) for a detailed description of the numerical model and the recalibration undertaken in 2010.

4. Site Characteristics

4.1. Topography

The region is characterised by a flat landscape with low undulating hills and occasional rocky outcrops. The majority of vegetation in the area has been cleared, with most of the cleared areas used for agriculture. Remnant and secondary vegetation is restricted to elevated rocky areas (SNC Lavalin Australia, 2003).

Figure 4-1 shows the topography and drainage of the area. Ground slopes fall from the north east (Lachlan Floodplain) and south east (upper Bland Creek Palaeochannel) towards Lake Cowal. Lake Cowal forms a local depression and fills with flood water every few years. It drains north west towards Nerang Cowal, and eventually to the Lachlan River. Breakout flows from the Lachlan River at Jemalong Gap drain towards Lake Cowal.

Ground elevations at the CGO range from around 225 metres Australian Height Datum (m AHD) on the western lease boundary to about 200 m AHD at the eastern lease boundary within Lake Cowal. The BCPB area has an elevation of just under 210 m AHD, with minimal variation. Hills formed by rock outcrops on the fringes of the Bland Creek floodplain reach to in excess of 300 m AHD.

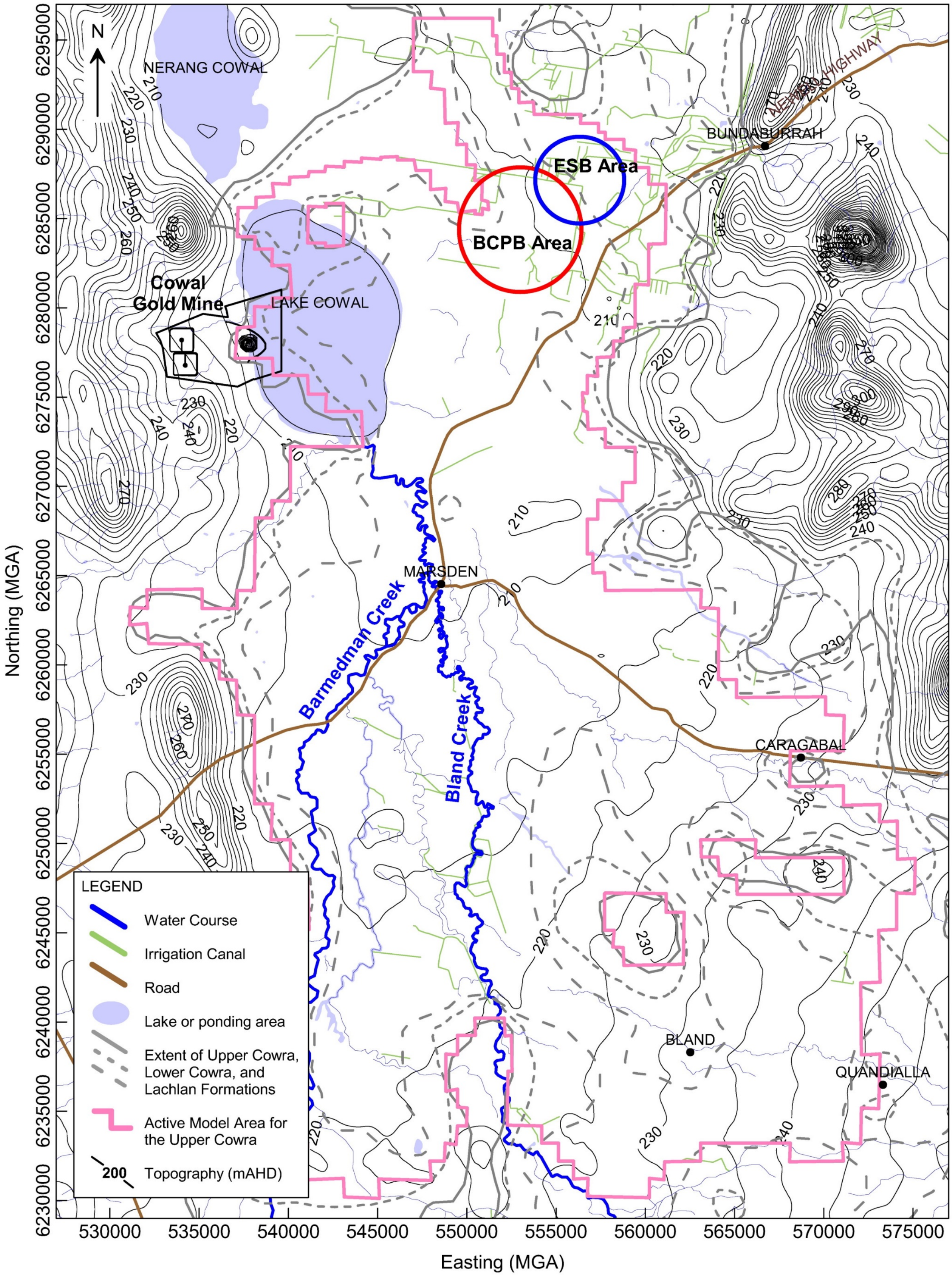


Figure 4-1: Regional topography

4.2. Climate

4.2.1. Regional Averages

The closest rainfall station to the study area with long-term records is Bureau of Meteorology (BoM) Station 73054 (Wyalong Post Office), located south of ML 1535, in the western part of the Bland Creek Palaeochannel. The closest climate station within 100 km of the site with reasonable amounts of pan evaporation data (from 1973 to 2019) is BoM Station 050052 (Condobolin Agricultural Research Station), located about 65 km to the north west of the BCPB. Table 1 lists average rainfall at station 73054 (1895 to 2019) and average monthly pan evaporation at station 050052. For average conditions, a rainfall deficit occurs for all months of the year.

Table 1: Average rainfall and pan evaporation in the regional area

Month	Mean rainfall (millimetres [mm]) at Wyalong Post Office (73054)	Mean pan evaporation (mm) at Condobolin Agricultural Research Station (050052)
January	41.2	313.1
February	38.2	246.4
March	38.1	210.8
April	34.0	129.0
May	39.0	74.4
June	43.0	48.0
July	41.6	49.6
August	38.4	77.5
September	36.8	117.0
October	44.3	182.9
November	36.7	234.0
December	43.9	297.6
Annual	475.2	1972.4

4.2.2. Mine Site Rainfall

Daily rainfall data is available for the period 2004 to 2019 inclusive from the CGO site weather station. The monthly site rainfall has been correlated with annual rainfall from Bureau of Meteorology (BoM) stations 73054 (Wyalong Post Office) and 50017 (West Wyalong Airport). A study was carried out for the period 2004 to 2015 to check the correlation between rainfall at these locations. More recent data is generally consistent with the correlation indicated. Figure 4-2 illustrates the correlations.

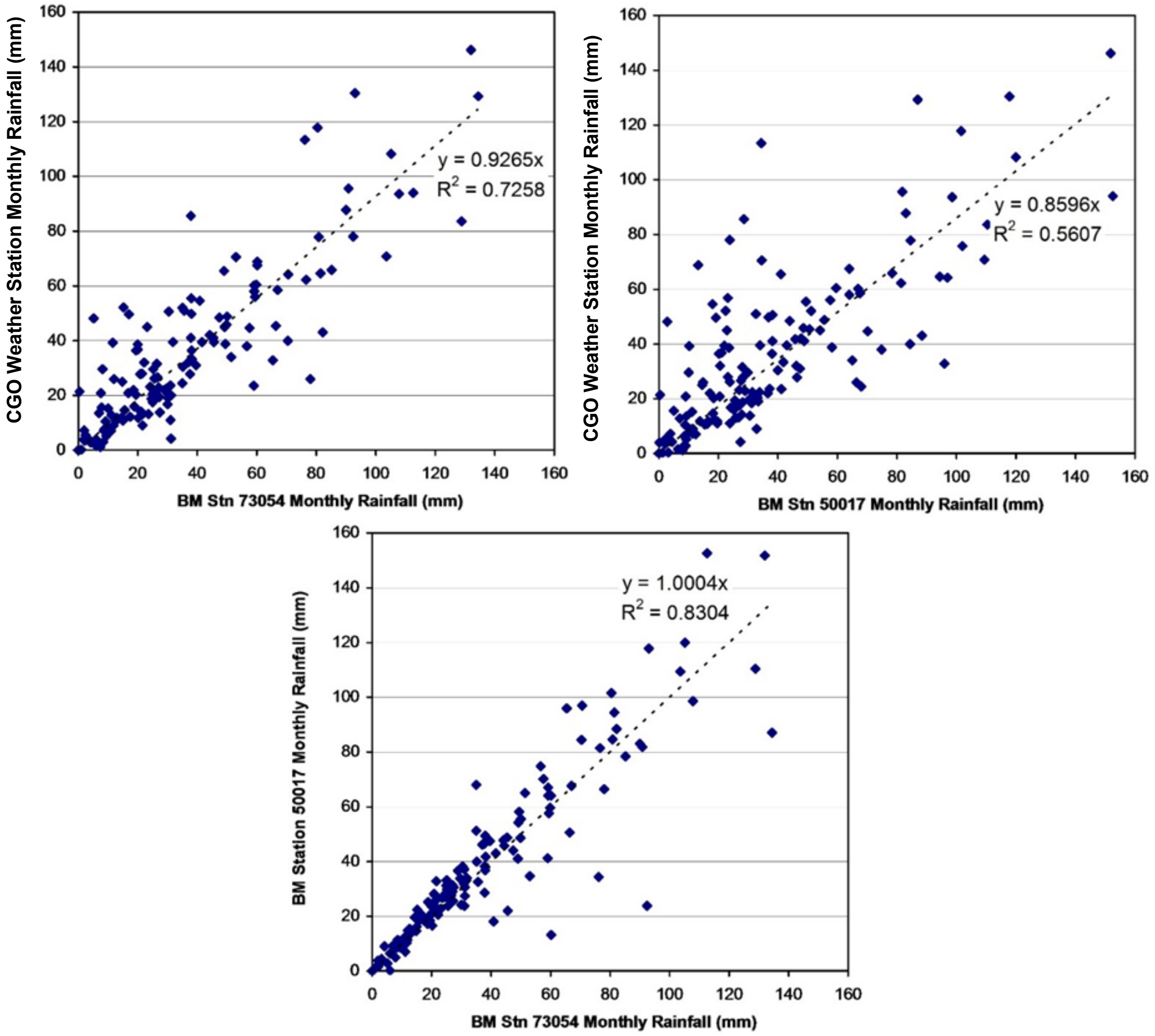


Figure 4-2: Correlation of monthly rainfall from the CGO site weather station with two BoM stations for 2004 to 2015 inclusive

CGO site rainfall correlates reasonably with station 73054 but less so with station 50017. The residuals normality for station 50017 with the CGO site and station 73054 is poor. CGO site monthly rainfall is an average of 93% of station 73054 rainfall. By corollary, the long-term average annual rainfall at the CGO site is estimated to be 444 mm.

4.3. Surface Drainage

The main water courses in the BCPB area are Bland and Barmedman Creeks (Figure 4-1). These are ephemeral and drain into Lake Cowal (also ephemeral), from the south. An extensive irrigation canal system is also present at the BCPB area and to the north. These canals deliver water to irrigators to sustain the local agricultural industry.

Flow gauging data from government flow gauge 412103 (Bland Creek at Morangarell) was available for the period 1976 to 2003. This gauge has a catchment area of 3,110 km^2 and is located in the Burragorang Palaeochannel, about 10 km south of the southern boundary of the modelled area. A review of the flow data for this period indicate the following:

- No flow for 61% of the period (the minimum measurable flow is 0.1 ML/day).
- An average flow over all days of 117 ML/day.
- An average flow over all days of measurable flow (39% of the period) of 298 ML/day.
- A maximum recorded flow of 17,854 ML/day (on 27 July 1993).

A baseflow analysis was undertaken for flow data from gauge 412103 using the local minimum method, implemented using the program BFI and the procedure of Wahl and Wahl (1995). This implementation is based on the deterministic procedure proposed by the British Institute of Hydrology (1980a, 1980b). Using this method, baseflow is estimated by analysing the minima in streamflow time series when partitioned into N-day periods. Unlike filtering methods, the local minimum method cannot calculate baseflows that are greater than streamflow and makes no assumptions about recession character. Based on experience, and the preferred use of the method by overseas agencies, this method is considered superior to filtering for extraction of baseflow magnitudes. Results of the analysis indicate that baseflow was an average of 0.3% of rainfall between 1977 and 2000.

Lake Cowal is an ephemeral shallow freshwater lake that is filled by runoff from the Bland Creek catchment to the south and flood breakout from the Lachlan River to the north east. The pit envelope impedes on the lake area, and a lake protection bund and dewatering programme form an integral part of the mine plan. At the overflow (full storage) level of about 205.7 m AHD the lake overflows into Nerang Cowal, another ephemeral lake to the north, and then into Bogandillon Swamp before returning to the Lachlan River. The base of the lake is at about 201.5 m AHD. Figure 4-3 shows available lake water level observations compared to flow at gauge 412103. When the lake is draining, water levels show a quasi-logarithmic fall. Below the full storage level, the rate of water level fall is approximately linear with time. An analysis of eight recession events was undertaken. For each event, the time period was selected such that other data suggest negligible inflows to the lake from creeks and surface runoff were occurring. For each event, pan evaporation and direct rainfall to the lake water body were taken into account. The average fall in lake water level (accounting for rainfall) from the events was equal to 80% of pan evaporation. This is similar to recorded rates of water level fall for large shallow lakes that contain suspended and dissolved solids in a semi-arid climate. Results indicate that transfer of groundwater to or from Lake Cowal is low, with the precision of the results being less than that required to quantify the transfer.

Irrigation canals are extensive and most of their combined reach appears to be unlined. These channels serve as artificial water courses to deliver water for local agriculture but are ephemeral (they are mainly use during the growing season). One of the main channels in the area (the Warroo channel) has been reported as suffering losses through seepage from the channel base (Van der Lely, 1993), estimated at around 2,000 ML/year but potentially ranging between 500 and 6000 ML/year.

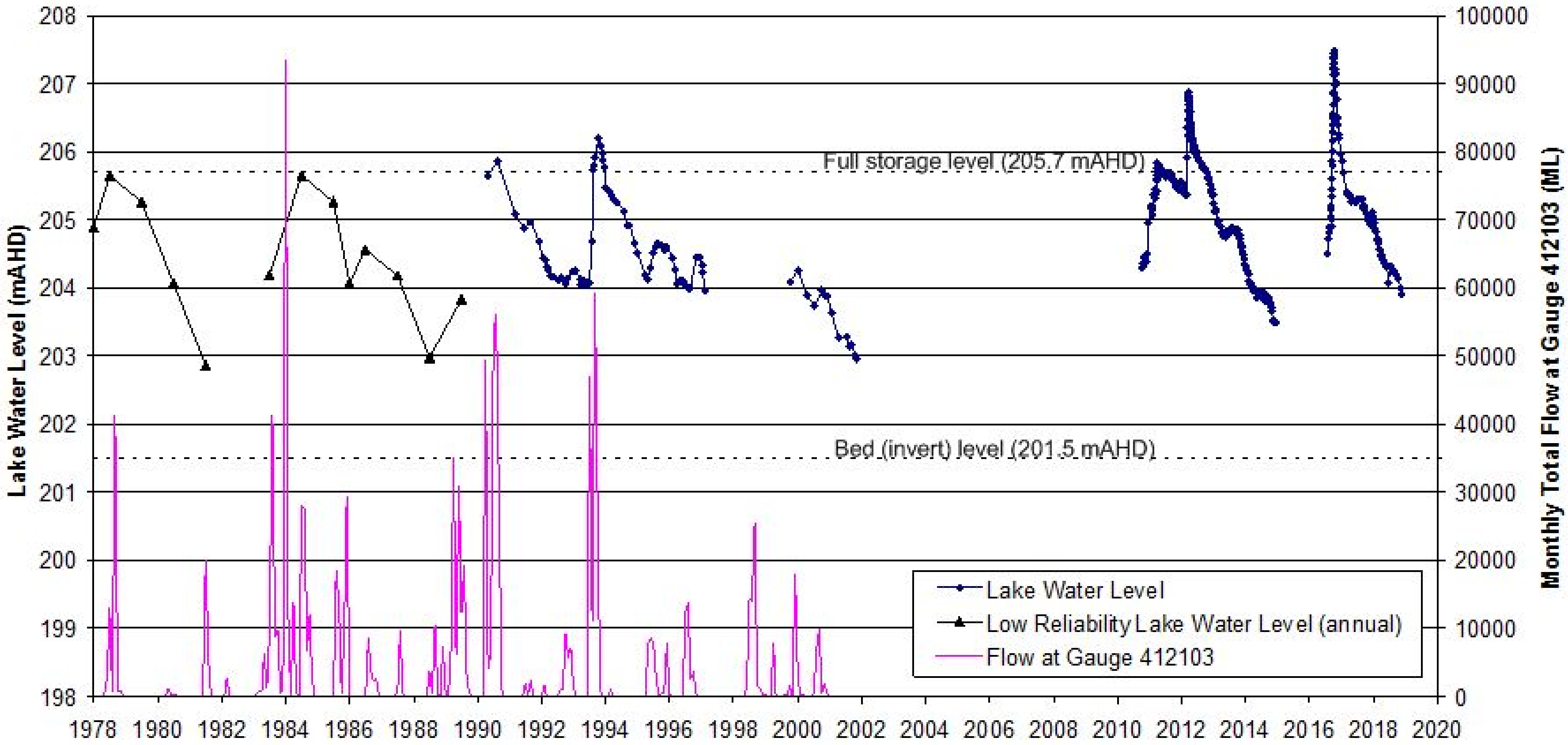


Figure 4-3: Observed water levels in Lake Cowal and flow at gauge 412103

4.3.1. Recharge to the Water Table

Studies of groundwater chemistry in the Bland Creek Palaeochannel (Carrara et al., 2004) indicate that the Thuddungra region is a recharge area for the Lachlan and Cowra Formations. Results also suggest that the Lachlan Formation shows a generalised preferential lateral groundwater flow system, without significant vertical recharge except in the Thuddungra region. In contrast, results suggest that the shallow part of the Cowra Formation comprises a system where recharge to the groundwater system is dominated by vertical infiltration at the surface, and lateral groundwater flow is limited and local.

Anderson et al. (1993) estimated that recharge through the base of stream channels and over-bank flooding are the dominant recharge processes in the Lachlan Valley. The amount of recharge provided by this process in the Bland Creek Palaeochannel is difficult to assess due to the impact of pumping on groundwater monitoring hydrographs. Minor flooding occurs intermittently in the palaeochannel area, however surface sediments in this area are less permeable than further north in the Jemalong / Wyldes Plains Irrigation District and the main Lachlan Valley, likely resulting in lower recharge from this source compared to the Lachlan Valley.

Coffey (1994) estimated a total accession rate (irrigation deep drainage and rainfall infiltration) to the groundwater system, from numerical model calibration, of between nil and 18 millimetres per year (mm/year) for the Upper Cowra Formation in the Jemalong / Wyldes Plains Irrigation District. The higher infiltration rates were restricted to a 10 km-wide zone south of the Lachlan River. The overall average calibrated recharge to the Upper Cowra Formation between Lake Cowal and the Lachlan River was around 10 mm/year or around 2% of average rainfall.

Ross (1982) estimated that 1.25% of rainfall accedes to the groundwater system in the low salinity groundwater areas of the Upper Lachlan Valley.

Williams (1993) estimated that long-term increases in groundwater storage in the Upper Cowra Formation in the Jemalong / Wyldes Plain Irrigation District were a minimum of about 5.2 mm/year (about 1% of incident rainfall, assuming a refillable void space of 5% at the water table). Results did not allow separate identification of contributions made by flooding, rainfall, and irrigation.

Cook et al (2001) estimated rainfall recharge over agricultural land of the Mallee region near the Murray River (average rainfall 300 to 400 mm/year). Results indicated deep drainage rates varying between 3 mm/year (0.9% of annual rainfall) and 30 mm/year (9% of annual rainfall) at crop rotation sites with average clay contents in the upper 2 m of the surface soil profile varying between 30% and 2% respectively.

Numerical modelling by Williams (1993) for the upper 20 m of the Cowra Formation indicated that evaporation from surface ponding caused by groundwater seeps was occurring in several locations in the more topographically depressed area in the vicinity of the Corinella Constriction.

Hydrograph Analysis for the BCPB Area

With the area characterised by high rates of irrigation, an assessment was undertaken for the area east of Lake Cowal to estimate zones where recharge to the water table is likely to be controlled mainly by rainfall or irrigation. This was the only area in the model domain where significant amounts of water table hydrographs were available (from monitoring piezometers maintained by Jemalong Irrigation Limited, for the period 1994 to 2006).

The assessment compared piezometer hydrographs to the cumulative monthly rainfall residual. Hydrographs showing a significant correlation with the rainfall residual were classified as being influenced mainly by rainfall. Irrigation may still have been active in these areas however its influence was interpreted as secondary. Hydrographs showing a characteristic trend of rise during dry conditions were classified as irrigation dominated.

Figure 4-4 shows the results of the assessment. Piezometer names are a single number. The pattern identifies the area where irrigation is affecting the water table. Recharge will thus vary across the area. Areas with irrigation-dominant recharge may have larger groundwater recharge. The numerical model adopts a single average rate which takes into account the irrigation process, however further south there are fewer tracts of land that are irrigated. Irrigation practices add a degree of approximation to the recharge rate used in the model.

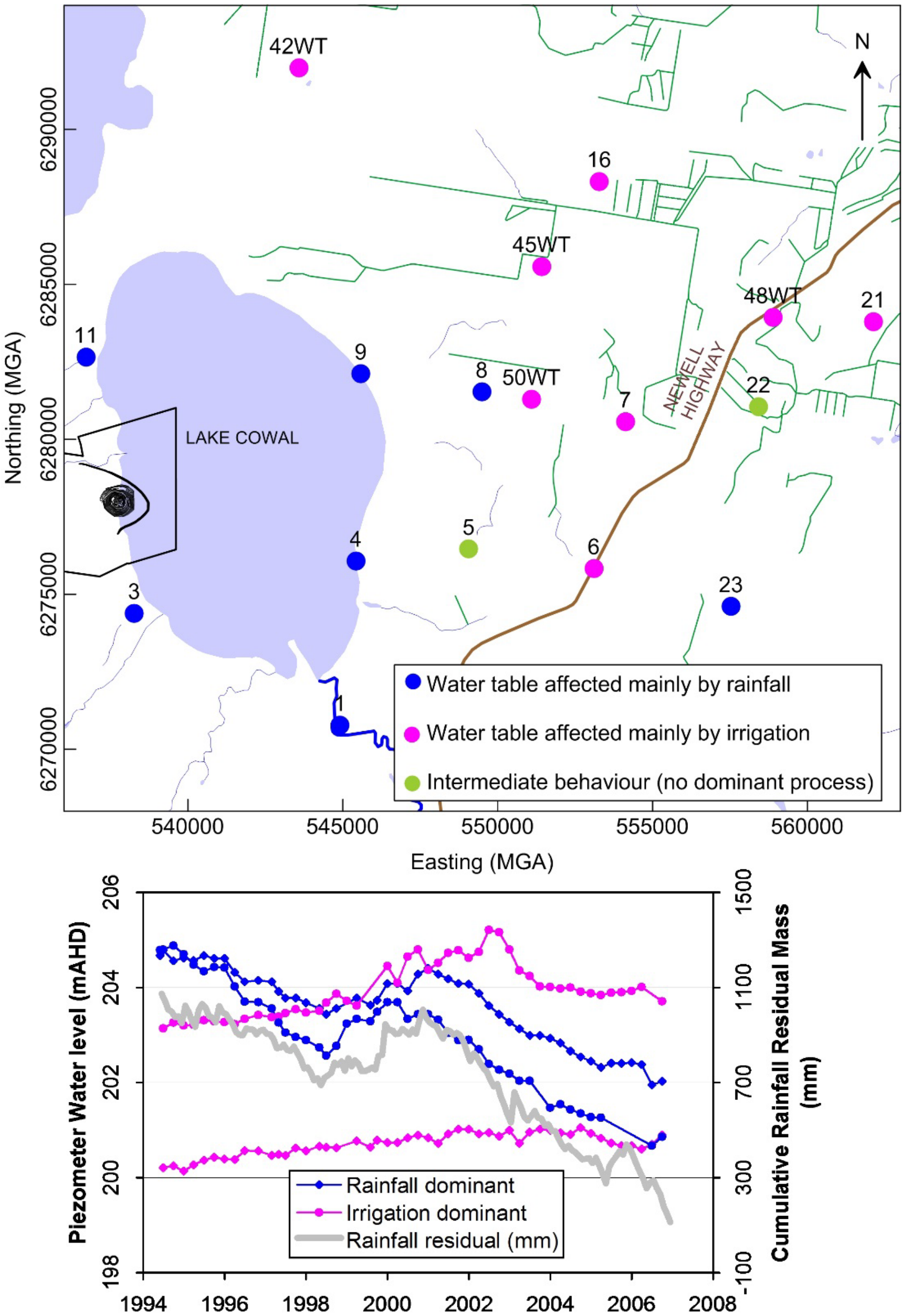


Figure 4-4: Spatial relationship of water table piezometers (maintained by Jemalong Irrigation Limited) classified according to the dominant influence on their hydrographs. Numbers at piezometer locations are their names

4.4. Geology

A detailed discussion of the geology of the area is made in Coffey (2013). A summary is provided below.

The alluvial sequence in the study area consists of the Cowra Formation and the underlying Lachlan Formation. The Lachlan Formation is the main aquifer in the study area. The Cowra Formation has lower hydraulic conductivity and higher groundwater salinity.

The Cowra Formation comprises predominantly stiff red/yellow/brown high plasticity clay (grading to grey at depth) with intermittent sand and silt horizons. The base of the Cowra formation is generally marked by a conspicuous multi-coloured clay layer. Geophysical (gamma) logs and hydraulic test data for bores in the vicinity of the BCPB suggest that the Cowra Formation can be divided into upper and lower sequences. The base of the Upper Cowra sequence is assessed to be at about 47 m below ground level at the BCPB.

The Lachlan Formation consists of light grey fine to coarse-grained sand and fine to medium gravel, mostly composed of smoky quartz, chert, and wood fragments. The Lachlan Formation is underlain by bedrock. Between 2 m and 5 m of clay lies between the base of high hydraulic conductivity sediments in the Lachlan Formation and the top of bedrock, however in some places the clay is absent. The clay is interpreted to consist mostly of residual weathered product of underlying rocks. The modelled extent of the Lachlan Formation includes lower hydraulic conductivity sediments surrounding the high permeability sands and minor gravels in the deeper parts of the palaeochannel. The high hydraulic conductivity sands and minor gravels appear to be located adjacent to steep bedrock surface gradients within the deeper parts of the palaeochannel. The spatial variation in high and low conductivity sediments in the Lachlan Formation indicates that the high conductivity part of the Lachlan Formation bifurcates just north of Marsden.

A constriction in the bedrock surface occurs to the north of the BCPB at Corinella and is referred to as the Corinella Constriction.

4.5. Subsurface Hydraulic Properties

4.5.1. Hydraulic Conductivity

For previous studies, a large database was compiled of hydraulic conductivity measurements from in-situ hydraulic testing. The database consists of the following:

- 26 single rate pump tests conducted at the CGO.
- Three packer tests in volcanic rocks conducted at the CGO.
- Two long-term single rate pump tests conducted at the two saline borefields (at other sites).
- Six long-term single rate tests conducted at the BCPB.
- 102 estimates of hydraulic conductivity from specific capacity data in government records for private water bores. 45 estimates are for the Lachlan Floodplain (north of the Corinella Constriction). Appendix A shows the method used to obtain hydraulic conductivity from specific capacity.

Figure 4-5 shows the hydraulic conductivity database developed from these measurements.

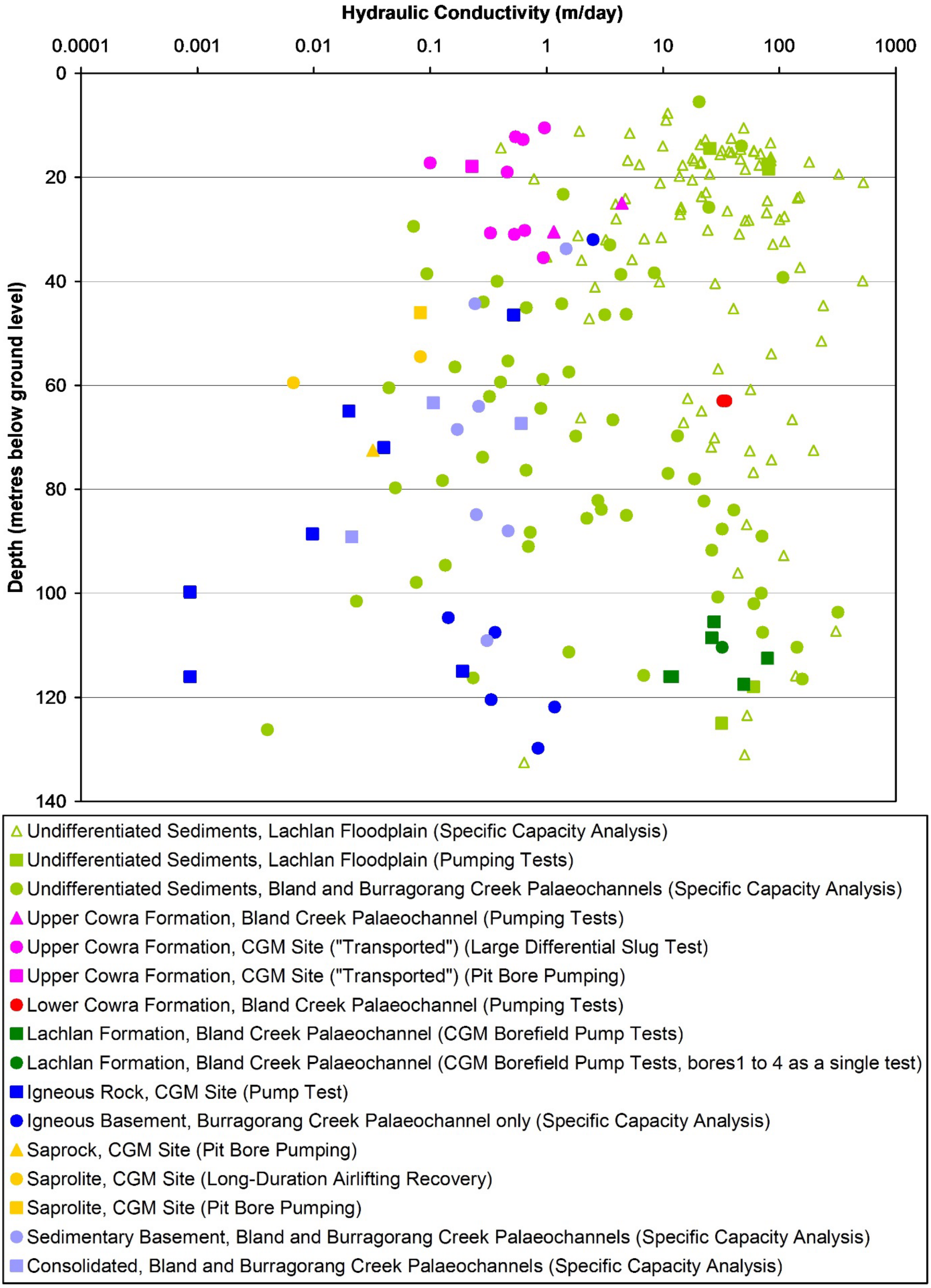


Figure 4-5: Hydraulic conductivity database for the Bland Creek Palaeochannel area

Three distinct alluvial sequences are interpreted to be present. These are as follows:

- Upper Cowra Formation. This sequence generally occurs from ground surface to an average depth of around 45 m to 50 m. The average depth to groundwater is around 7 m, giving an average saturated thickness of just over 40 m. This sequence generally shows decreasing hydraulic conductivity with depth.
- Lower Cowra Formation. This sequence generally occurs over an average depth interval of around 50 m to 90 m over most of the study area. This layer appears to have different hydraulic properties to the Upper Cowra formation.
- Lachlan Formation. This sequence generally occurs over an average depth interval of around 90 m to 120 m in the Bland Creek Palaeochannel and between 75 m and 110 m in the Burragorang Palaeochannel. Within this formation, two distinct sequences are interpreted as follows:
    - High hydraulic conductivity sands and minor gravels close to and within the deeper parts of the palaeochannel. This sequence has a geometric mean hydraulic conductivity of about 30 metres per day (m/day).
    - Lower hydraulic conductivity sediments generally occurring further away from the deeper parts of the palaeochannel and surrounding the high hydraulic conductivity sands and minor gravels. The hydraulic properties of this sequence appear similar to the Lower Cowra Formation.

The Bland Creek Palaeochannel basement consists mostly of sedimentary sequences (at burial depths exceeding 100 m). Igneous basement is present in the upper reaches of the Burragorang Palaeochannel. At the CGO, hydraulic conductivity of weathered and fresh rock follows a pattern of decreasing hydraulic conductivity with depth. Saprolite retains some of the original rock structure and can host open defects. The high hydraulic conductivity parts of the Lachlan Formation have a hydraulic conductivity approximately 100 to 1000 times larger than underlying bedrock. Bedrock at depth in the study area is considered to have significantly lower hydraulic conductivity than unconsolidated sediments except in structurally disturbed areas.

The bed of Lake Cowal is composed of a lacustrine clay layer of between 3 m and 8 m thickness. Hawkes (1998) reports an average vertical hydraulic conductivity of 5×10^{-7} m/day for the clay, from laboratory measurements on seven samples, and an average horizontal hydraulic conductivity of 6×10^{-5} m/day from three in situ hydraulic tests.

4.5.2. Storativity

No hydraulic test data were available from which an assessment of the specific yield of the Cowra Formation could be made. Williams (1993) estimated a value of 5% for the refillable void space at the water table in the Upper Cowra Formation in the Jemalong Plains Irrigation District. Surface sediments in that district are known to have a higher hydraulic conductivity than surface sediments in the Bland Creek Palaeochannel.

Results from hydraulic tests undertaken in 2004 in BCPB bores indicate an average storativity of 1.9×10^{-4} for the Lachlan Formation (Groundwater Consulting Services Pty Ltd (GCS), 2006). A pump test of seven days duration conducted at BLPR2 in 1995 (Coffey, 1995) indicated an average storativity of 1.7×10^{-4} for the Lachlan Formation. Assuming that confined processes provided the dominant influence on drawdowns during these tests (minimal drainage at the water table during the tests), the storativities are approximately equivalent to average specific storages of 9.5×10^{-6} m^{-1} and 8.5×10^{-6} m^{-1} respectively.

4.6. Groundwater Levels and Flow

4.6.1. Monitoring Network

Groundwater levels in the BCPB and ESB areas are monitored by Evolution using a network of standpipe piezometers as follows:

- BCPB: Piezometers BLPR1 to BLPR7.
- ESB: Piezometers PZ01 (decommissioned in 2012), PZ02, PZ05 to PZ11, and future pumping bores SB03 to SB05.

The NSW Department of Industry – Water (DIW) and Jemalong Irrigation Limited (JIL) also maintain extensive networks of standpipe monitoring piezometers in the area for various purposes.

Water level observations from the Evolution piezometers, and a selection of DIW and JIL piezometers, have been used in previous studies for assessment of the hydraulic head field, and numerical model calibration and verification. In selecting DIW piezometers, the following criteria were generally applied, to reduce the potential for unrepresentative measurements:

- Backfilling of 20 m or less from the base of the borehole to the bottom of the screen.
- Screens placed in separate boreholes.

Where multiple screens were installed in a single borehole, only the lowermost standpipe was selected, subject to the backfilling criterion and other factors.

The resulting network comprises 45 measurement points at 38 locations. Appendix B lists these piezometers and contains a map showing their locations. DIW monitors high-rate groundwater extraction in the area at piezometers GW036553, GW036597, and GW036611. These are fitted with automatic water level recorders.

For the current work, monitoring data from many DIW and JIL piezometers, and private water bores, was unavailable. Coffey sourced recorded water levels at DIW piezometers GW036553, GW036597, and GW036611, from the DIW internet-based data delivery system. The following sections summarise salient features of the hydraulic head field from before CGO operations commenced, using available information.

4.6.2. Hydrographs

Figure 4-6 shows hydrographs for the Upper Cowra, Lower Cowra, and Lachlan Formations in the BCPB area, using an approximately coincident set of monitoring piezometers throughout the vertical profile. They illustrate propagation of depressurisation at depth up through the profile. Increased groundwater extraction from the Lachlan Formation can be seen from the beginning of the drought in the 2000s. The vertical anisotropy of the sediments limits the upward propagation of depressurisation in the Lachlan Formation. The water table appears to remain unaffected over most of the record, however in this area, high volumes of irrigation are applied to the ground surface. The higher conductivity of the Lachlan Formation allows depressurisation from pumping to travel extensively in the lateral direction.

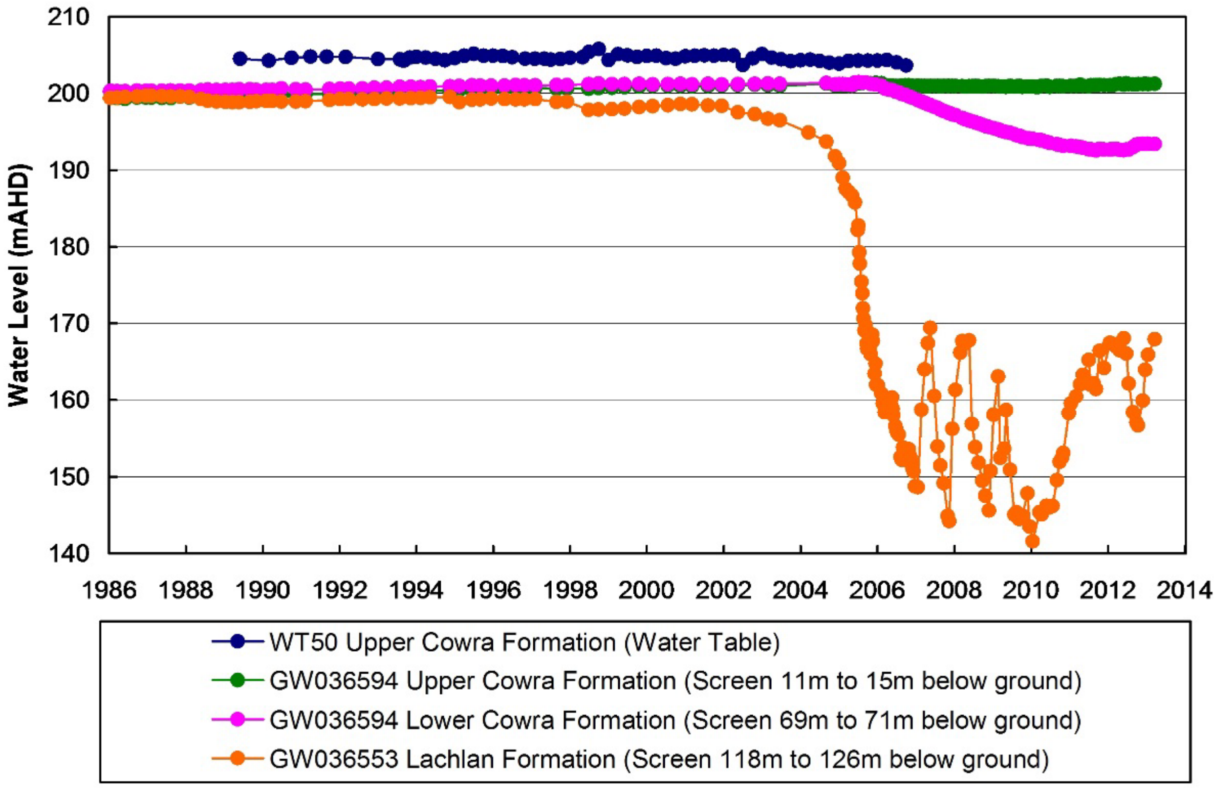


Figure 4-6: Hydrographs for approximately coincident piezometers in the BCPB area

Figure 4-7 and Figure 4-8 show water level observations for Evolution piezometers and GW036553 at the BCPB and ESB respectively, compared to total pumping, up to December 2019. The strong inverse correlation between piezometer water level and borefield pumping can be seen.

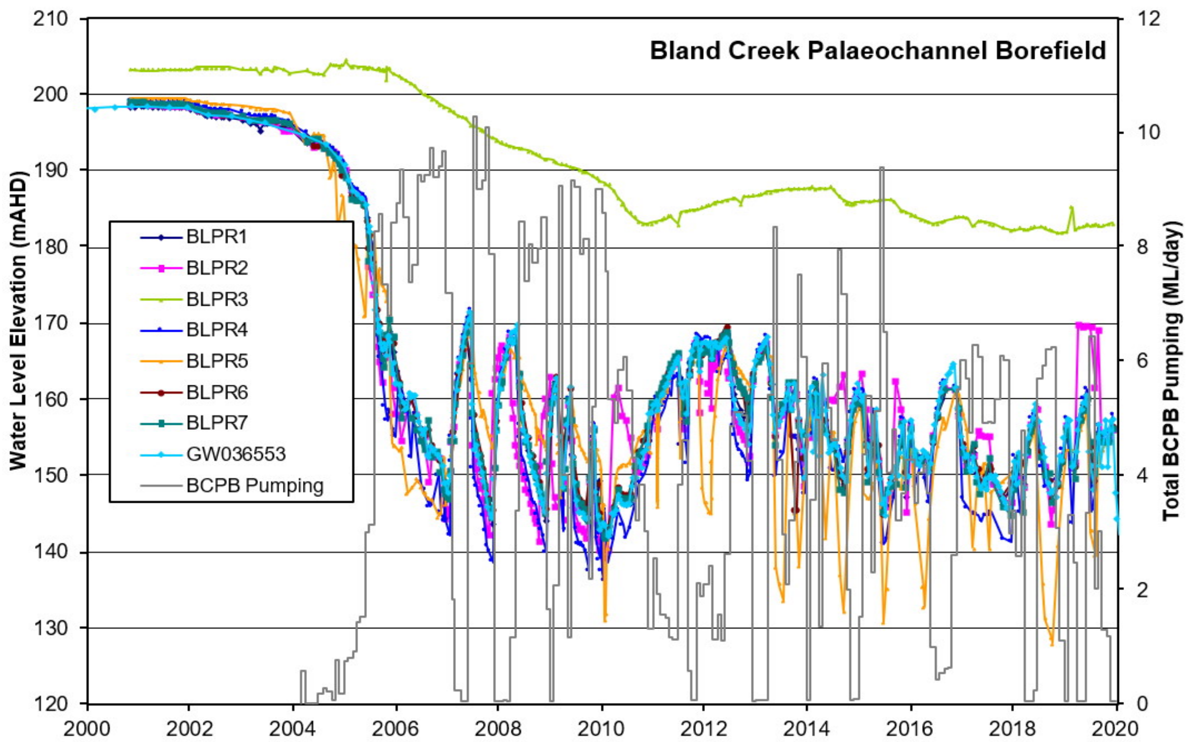


Figure 4-7: Monitoring piezometer hydrographs for the BCPB

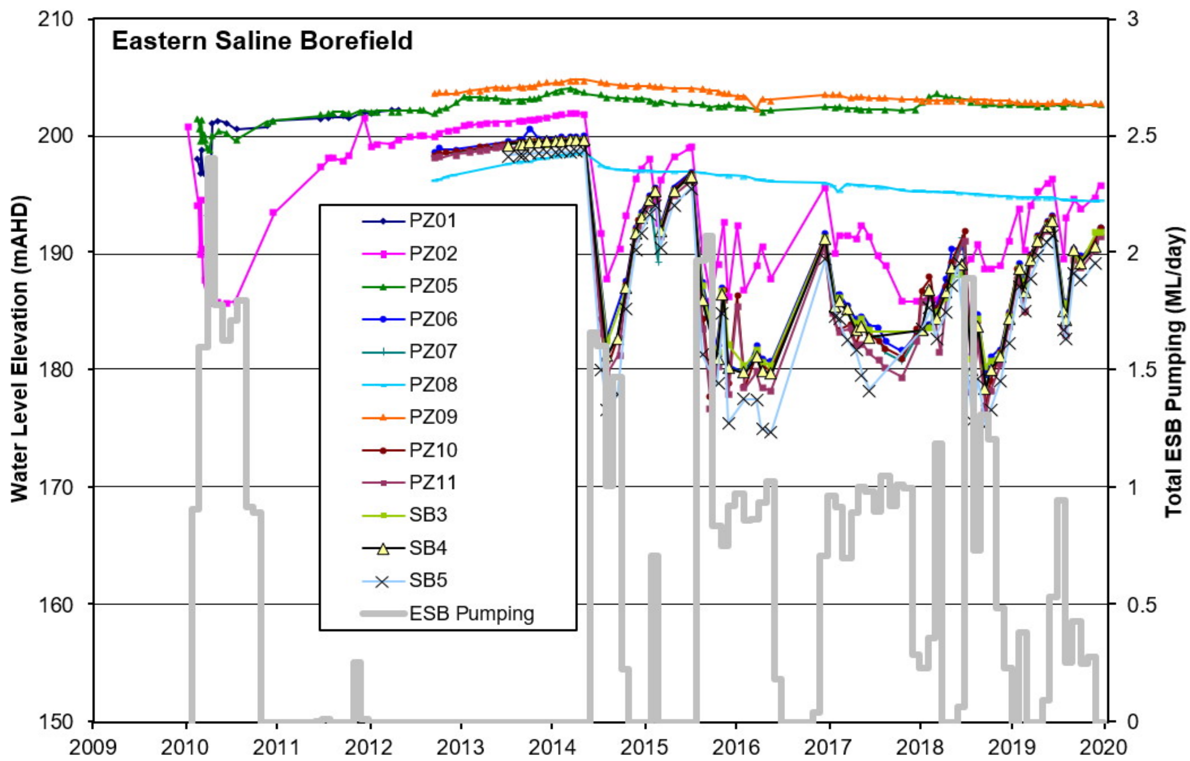


Figure 4-8: Monitoring piezometer hydrographs for the ESB

4.6.3. Hydraulic Head Surfaces

Available monitoring data has been used to interpolate hydraulic head surfaces for the Upper Cowra, Lower Cowra, and Lachlan Formations for December 1997 (prior to the commencement of significant pumping from the Lachlan Formation) and September 2006 (two years after commencement of the CGO). These surfaces are shown in Appendix C. The main changes in hydraulic head surfaces between these times are:

- The disappearance of the groundwater mound in the Upper Cowra Formation underneath Lake Cowal. The water level in Lake Cowal was probably at around 205 m AHD in mid-1998 (see Figure 4-3).
- The appearance of the drawdown cone around the BCPB.

The 1997 surfaces indicate overall westward groundwater flow. Trends in the Lower Cowra and Lachlan Formations suggest north-south structural features on the western side of the palaeochannel may play a part in groundwater drainage. The 2006 surfaces show the effects of significant pumping from the Lachlan Formation at the BCPB and in the Billabong Area. The time at which pumping started in the Billabong area is not known.

Water levels in the Upper Cowra Formation, where data are available, are an average of 5 m below ground level. Vegetation in the area is characterised by food crops and scrub plants, with root depths probably not deeper than 2 m below ground. Consumption of groundwater by evapotranspiration is therefore likely to be negligible, except at Lake Cowal, where water levels can rise to within the vicinity of the lake bottom during wet times.

Near the current mine pit, the Upper Cowra Formation shows some drawdown from drainage into the mine excavation, in conjunction with regional drawdown from drought conditions. This drawdown appears localised and is considered unlikely to significantly affect drawdown in the Upper Cowra, Lower Cowra, and Lachlan Formations further east (in the Bland Creek Palaeochannel).

4.6.4. Hydraulic Head Cross-Sections

Figure 4-9 and Figure 4-10 show interpreted hydraulic heads along a north-south cross-section running approximately through the middle of the model domain, for December 1997 and January 2010 respectively. Salinity corrections have not been applied to the water level measurements however the corrections are not considered necessary given the moderate salinity magnitude of the Upper Cowra, and the inverted salinity profile for the sediments (that is, salinity decreases with depth, which acts to slightly amplify the downward hydraulic head gradient in the Upper Cowra).

In December 1997, pumping from the Lachlan Formation was significantly lower than in subsequent years, since drought conditions had not yet developed. Hydraulic heads in the Lachlan Formation were similar to those in overlying strata, with gentle vertical gradients. The effect of drainage to the west is subtle but noticeable. Minor inflow from the Corinella Constriction appeared to be occurring. The BCPB and ESB were not active at this time.

The lowest hydraulic heads observed in the Lachlan Formation since monitoring began were observed in January 2010, when the BCPB and private bores were pumping at high levels from the Lachlan Formation. Several bore screens are more than 500 m from the cross-section, but their positions have been projected onto the cross-section. However, hydraulic head contours are for the cross-section itself, therefore the shape of the contours do not closely align with the bore screens. Significant vertical gradients are apparent in the Lower Cowra, in response to significant depressurisation in the Lachlan Formation. Hydraulic head gradients in the underlying rock are interpreted to be large, with minor upward leakage.

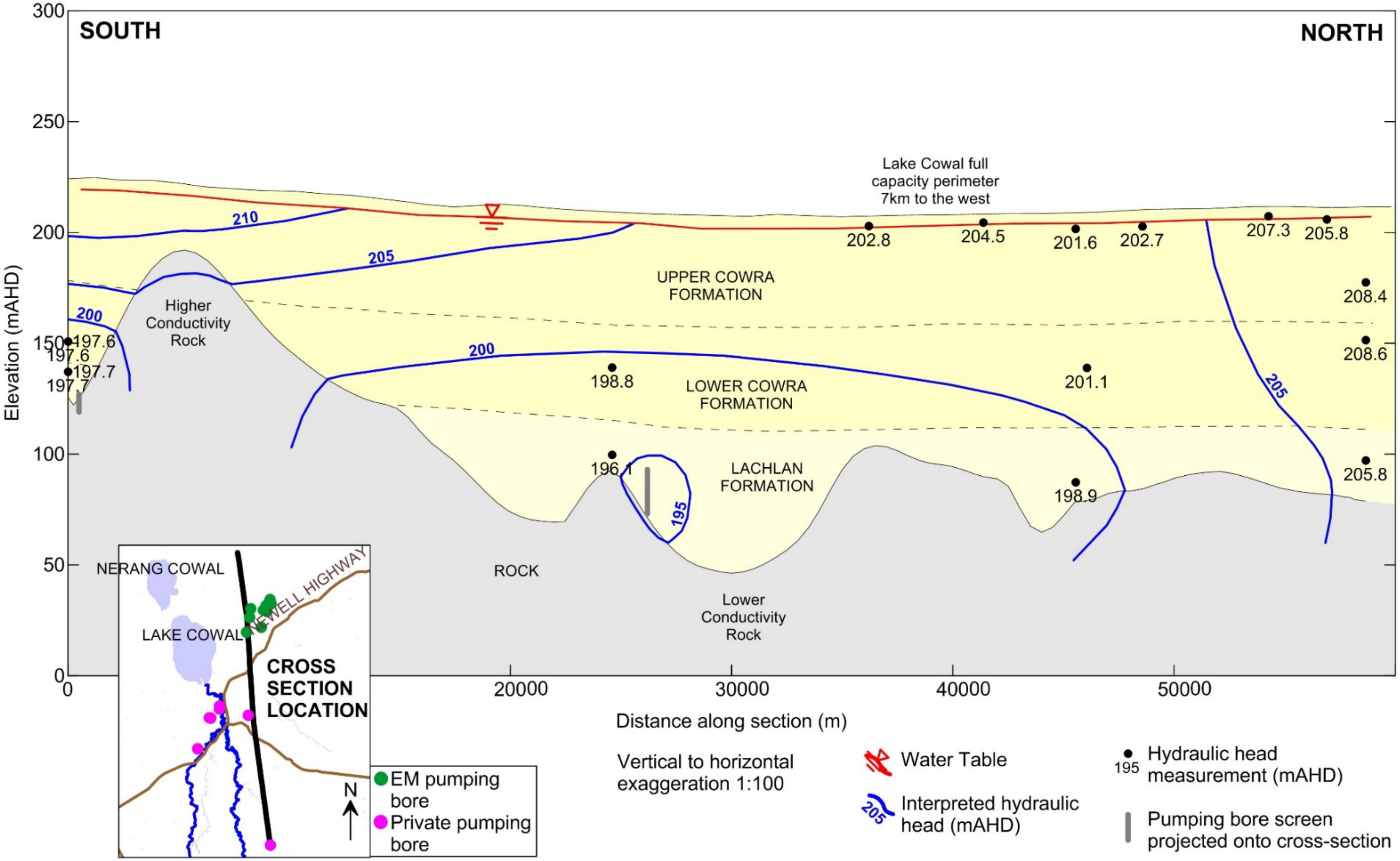


Figure 4-9: Interpreted hydraulic head cross-section for December 1997

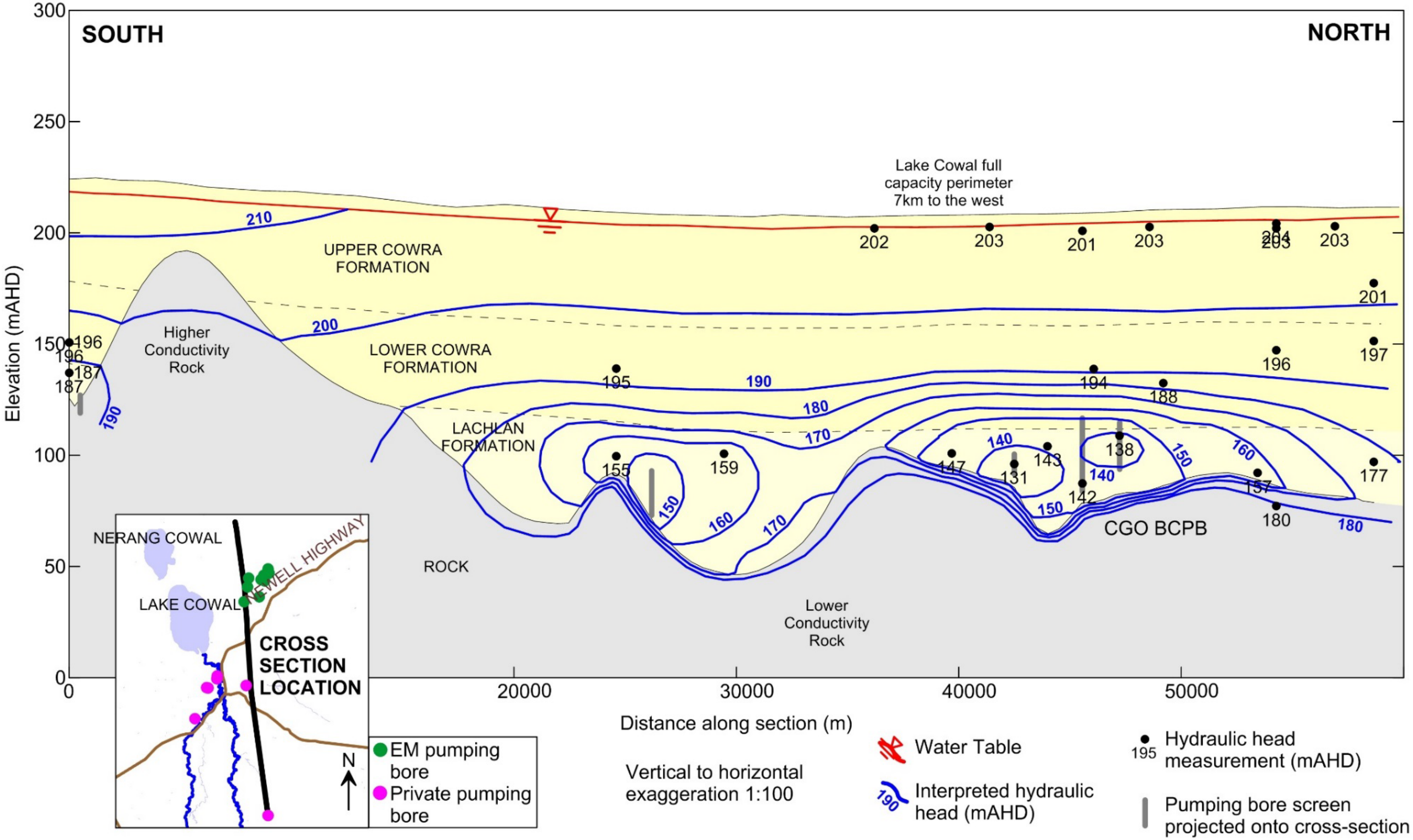


Figure 4-10: Interpreted hydraulic head cross-section for January 2010

4.7. Groundwater Salinity

Additional monitoring of groundwater electrical conductivity (EC) at the BCPB and ESB, obtained since 2013, has been combined with previously existing data. Figure 4-11 shows EC averages for piezometers in the database, versus depth. The database used in Figure 4-11 is listed in Appendix D.

Figure 4-11 indicates a strong trend of decreasing salinity with depth. The Cowra Formation is conspicuous above 80 m depth with greater salinities than the deeper Lachlan Formation. Near Lake Cowal, salinities in the Upper Cowra Formation are generally high (as are those in the Corinella and Lake Cowal cross-sections in Anderson et al., 1993).

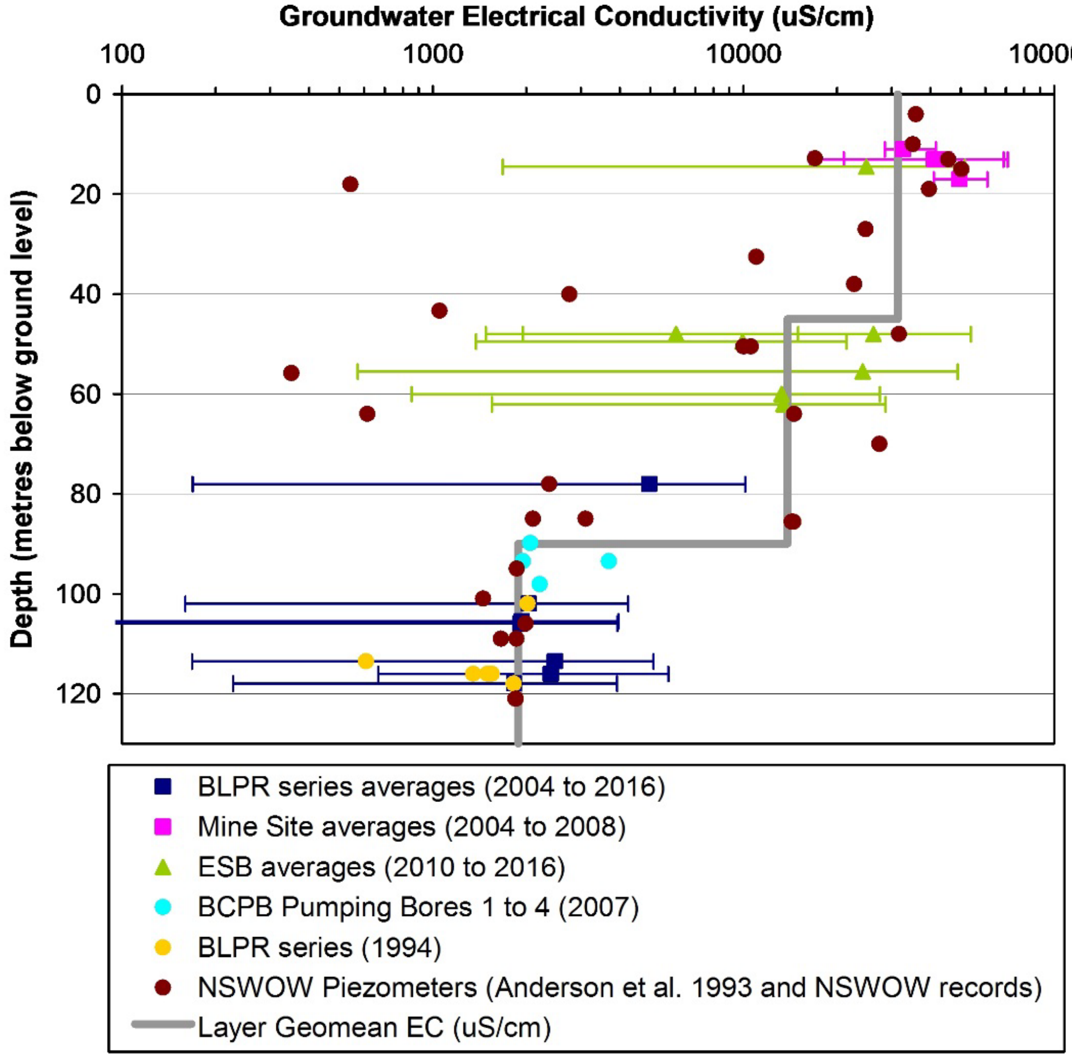
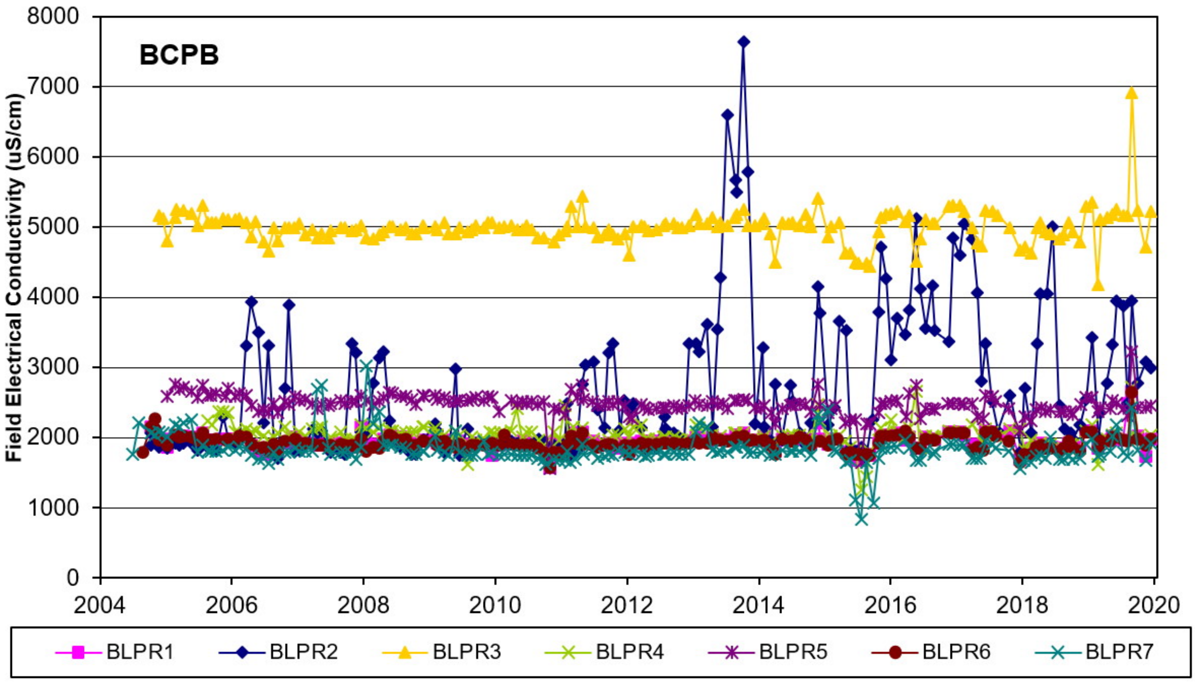


Figure 4-11: EC of groundwater in the regional area versus depth. Error bars indicate one standard deviation either side of the mean

Figure 4-12 shows field EC measurements from Evolution piezometers at the BCPB and ESB, up to December 2019, with instrumental measurement errors removed.



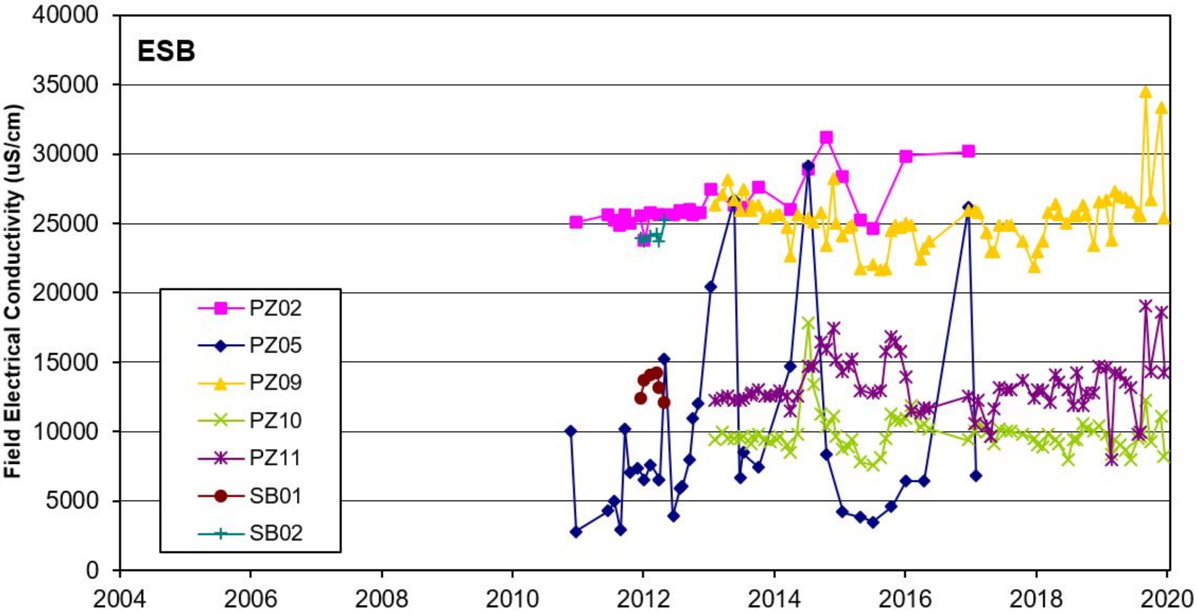


Figure 4-12: Groundwater EC versus time at Evolution monitoring piezometers

The data show an average salinity of around 2000 µS/cm for the Lachlan Formation, except for BLPR3 (about 5000 µS/cm, screened in the Lower Cowra Formation). BLPR2 shows fluctuating measurements for which the cause is uncertain. Groundwater EC at the ESB is variable within the profile, adhering to the trend of decreasing EC with depth (see Figure 4-11).

4.7.1. Trend Analysis

Trends in Lachlan Formation EC at the BCPB were investigated by comparing an average EC dataset to BCPB pumping and the cumulative annual rainfall residual. The average EC dataset was compiled using observations from BLPR1, 4, 5, 6, and 7. First, observations at these piezometers were averaged over the length of record. Second, observations at BLPR4 to 7 were offset by an amount equal to the difference between a piezometers average and the average at BLPR1. This produced a dataset with observations referenced to the BLPR1 mean. The process is reasonable given the similarity in absolute value and first derivative between the piezometers.

Figure 4-13a shows the average EC time series compared to BCPB pumping and the cumulative annual rainfall residual. A weak relationship with the rainfall residual may be present, however given the characteristics of the groundwater system and the extraction horizon, a relationship recognisable over a 10-year period would be considered unlikely.

A more perceptible, but inverse, relationship with pumping appears to be present. Figure 4-13b shows the correlation between the derivative in EC and the derivative in BCPB pumping and identifies a non-negligible inverse relationship. Since vertical flow velocities (from the Lower Cowra Formation into the Lachlan Formation) are likely to be significantly smaller than lateral flow velocities within the Lachlan Formation, the variation in pumping rate is thought to act by laterally attracting transient pulses of more distant lower EC Lachlan Formation groundwater (where downward vertical head gradients are smaller) into the immediate BCPB area, during pumping rate build-up, and thereby removing the slower build-up of higher EC groundwater seeping down from the Lower Cowra Formation. This supports the probable dominance of advective processes in solute transport in the system (Coffey, 2016). This process would imprint as a higher frequency variation in EC on a broader long-term build-up of EC through vertical drainage, but would not halt the longer-term vertical drainage of overlying groundwater of higher EC. The latter process will act over a broader time scale and will operate while downward vertical head gradients are present. Even should pumping stop completely, vertical drainage will continue afterwards, while these (dissipating) vertical gradients exist.

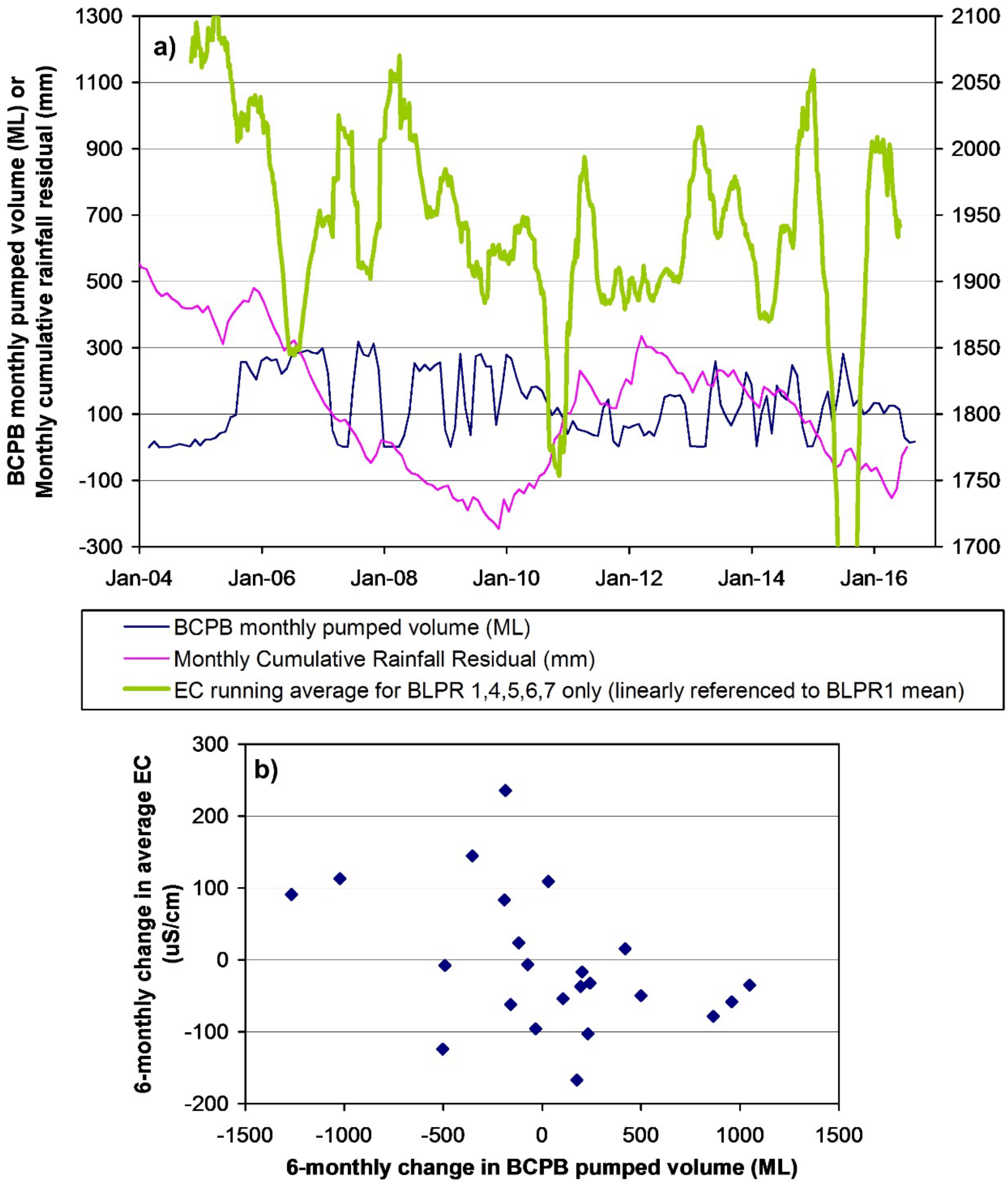


Figure 4-13: a) Comparison of average EC in the Lachlan Formation at the BCPB, and other trends; b) Correlation of EC and BCPB monthly derivatives

4.8. Groundwater Extraction

Groundwater extraction in the area covered by the model domain occurs from Evolution and private bores. Appendix E lists the pumping bores in the area, and contains a map showing their locations. The list excludes basic rights bores (registered for stock and domestic use) which have no associated entitlement. Basic rights bores are not active in the model. The following discussion excludes basic rights bores.

Table 1 in Appendix E lists the 18 active pumping bores in the model. The model simulates the groundwater system from 1998. Three bores (Billabong 1, 2, and 3) were decommissioned after 1998 and before 2016 and are not active during predictive simulations.

Large groundwater extraction rates are concentrated in three main areas. One of the areas encompasses the CGO, BCPB and ESB. The other two areas encompass private bores. These areas are identified on the map in Appendix E. Each area also has a monitoring piezometer used by the NSW government to monitor groundwater levels in the Lachlan Formation (at the request of the Bland Palaeochannel Groundwater Users Group) for groundwater management purposes. These piezometers have associated triggers defined by bore water levels where, should the bore water level fall to the trigger, various management actions are initiated.

If the investigation trigger level is breached, the effects on nearby users will be investigated and measures to mitigate impacts on water supply for existing stock and domestic use will be put in place for affected bores. If the mitigation trigger level is breached one or both of the following measures would be put in place in consultation with DIW:

- Alter the pumping regime to maintain the water level in the impacted stock and domestic bores;
- Maintain a water supply to the owner/s of impacted stock and domestic bores.

Table 2 lists the main pumping areas and associated pumping bores (see Appendix E for bore details) and trigger piezometers. The pumping bores listed in Table 2 account for about 96% of the known groundwater extraction from the Lachlan and Cowra Formations in the model area. All bores in Table 2 pump from the Lachlan Formation except the ESB which pumps from the Cowra Formation.

The operation of the BCPB and ESB is managed through the monitoring of water levels at GW036553. Water levels at GW036597 and GW036611 do not govern the operation of the BCPB and ESB.

Table 2: High-extraction pumping areas in the regional area

Area	Pumping Bores	DIW Trigger Piezometer	
		Registration No.	Trigger Level (m AHD)*
BCPB and ESB	BCPB: Evolution Bores 1 to 4. ESB: Evolution bores SB01 and SB02*	GW036553	137.5 (Investigation) 134.0 (Mitigation)
Billabong	Billabong 4 and Billabong 6	GW036597	143.7
Maslin	Maslin Bore	GW036611	145.8

* ESB pumping bores SB03 to SB05 (see Appendix E) are currently not used for pumping.

4.9. BCPB and ESB usage

Total usage for each of the BCPB and ESB, from commencement of the CGO (1 July 2004) to 31 December 2019, is shown graphically in Figure 4-7 and Figure 4-8. The regulatory constraints for BCPB pumping (from the four bores in total), under the licence conditions, are understood to be as follows:

- Daily maximum of 15 ML.
- Yearly maximum of 3,650 ML.

In addition, the operation of the BCPB and ESB is managed through the monitoring of water levels at GW036553. Should the bore water level at GW036553 fall to the trigger level at that bore, various management actions are initiated. Water levels at GW036597 and GW036611 do not govern the operation of the BCPB and ESB.

The water supply for the CGO includes a number of surface water and groundwater supplies. Surface water supplies, which are dependent on rainfall, comprise runoff from a series of dams and associated catchments within the Mining Lease, and use of water supplied via the Jemalong irrigation channel when available.

4.10. Groundwater Extraction to Date

Groundwater extraction at the bores in Table 2, over the period 1 July 2004 to 31 December 2019, resulted in groundwater levels above the trigger levels at the three DIW trigger piezometers. The lowest observed groundwater levels over the period 1 July 2004 to 31 December 2019 were as follows:

- BCPB Area bore GW036553: 7.5 m above trigger (141.5 m AHD on 15 January 2010);
- Billabong Area bore GW036597: 1.5 m above trigger (145.2 m AHD on 21-23 November 2019);
- Maslin Area bore GW036611: 1.6 m above trigger (147.4 m AHD on 16 December 2019).

These extraction rates (including extraction undertaken at Billabong 1, 2, and 3, and excluding pumping at the ESB) are listed in Table 3. The pumping rate for the BCPB was obtained from records. Estimates based on historical information and advice were made for the extraction for irrigation at the Billabong and Maslin properties.

Table 3: Pumping rates at the high extraction bores, averaged over the period
1 July 2004 to 31 December 2019

Area	Pumping Bores	Average Pumping Rate over the period 1 July 2004 to 31 December 2019 (ML/day)
BCPB	Evolution Bores 1 to 4.	4.1
Billabong *	Billabong 1, 2, 3, 4 and 6	2.8
Maslin *	Maslin Bore	2.7

* Significant assumptions have been made in estimating pumping for these bores.

5. Hydrogeological Conceptual Model

Monitoring data collected at the CGO since 2013, supplied to Coffey, supports the conceptual model used in Coffey (2013). There are no observations that suggest any alteration to the conceptual model. The conceptual model from 2013 is adopted in the current study and summarised below.

The climate in the model area is characterised by low rainfall and high evaporation. For average conditions, a rainfall deficit occurs over most months of the year. Surface drainage is intermittent.

Recharge to the groundwater system occurs by the following processes:

- Rainfall infiltration.
- Leakage from Bland Creek when flowing.
- Intermittent flooding.
- Deep drainage from irrigation practices (mostly in the northern areas).
- Groundwater inflow through the Corinella Constriction.

There will also be a minor component of recharge to the fringes of the alluvial sequence from shallow bedrock which will have higher conductivity due to lower overburden pressures.

The subsurface medium comprises unconsolidated sediments. Finer-grained, lower hydraulic conductivity sediments overlie a thin but significant sequence of coarser-grained, higher hydraulic conductivity sediments. Media properties, combined with the prevailing climate, creates a system of high groundwater salinity near the surface and lower salinity at depth. Observations collected at the ESB since 2012 have allowed a more detailed definition of the variation of EC with depth.

Discharge from the groundwater system occurs by the following processes:

- Extraction from water supply bores for stock/domestic, irrigation, and industrial uses.
- Intermittent evaporation from surface ponds (local groundwater flow systems only).
- Groundwater outflow through the Corinella Constriction.

Figure 5-1 shows a graphical representation of the hydrogeological conceptual model.

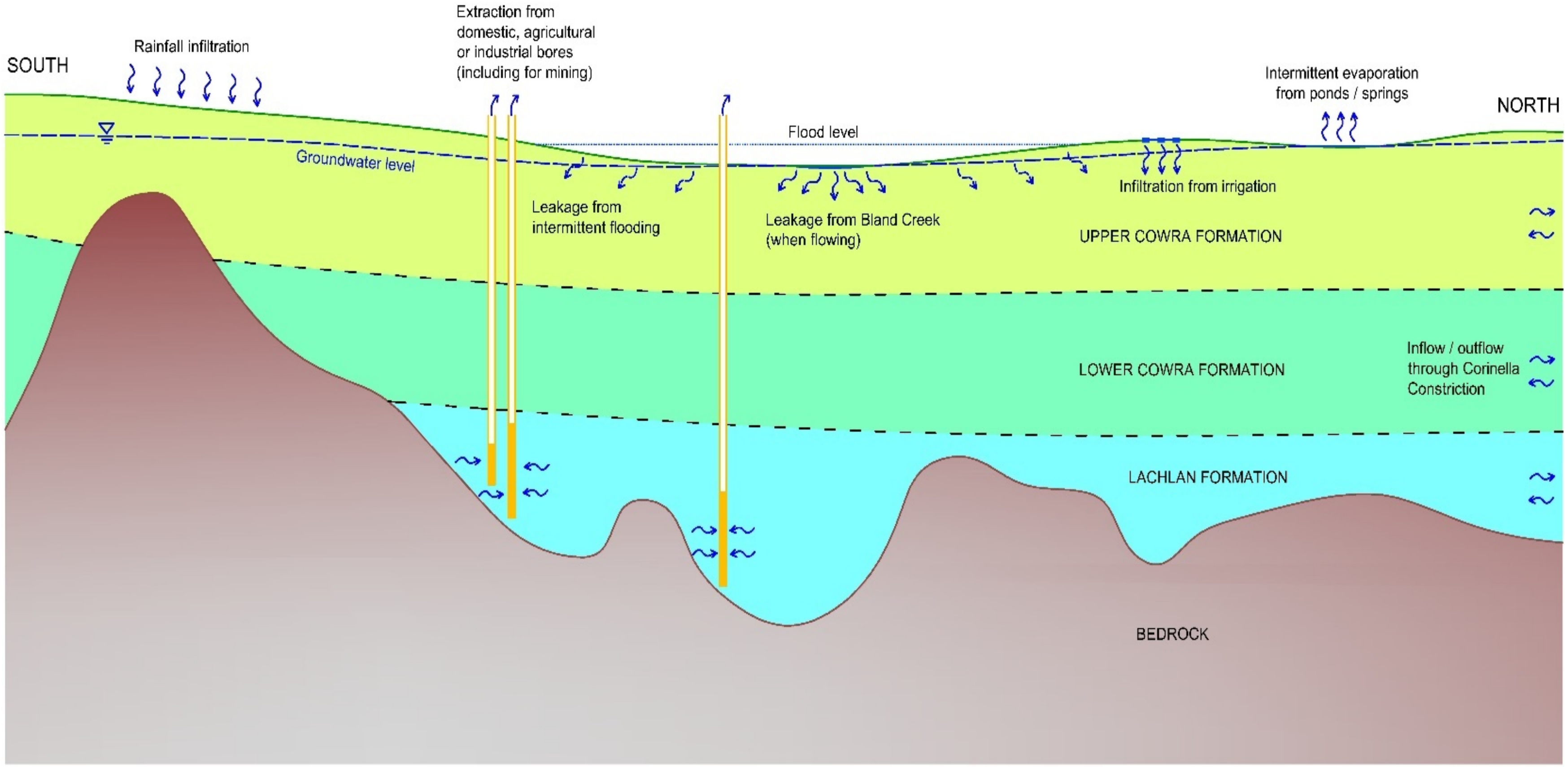


Figure 5-1: Hydrogeological conceptual model

6. Numerical Model Development and Verification

6.1. Model Structure

Numerical modelling was carried out using the 2000 version of the groundwater simulation algorithm MODFLOW, compiled by the United States Geological Survey (Harbaugh et al, 2000). MODFLOW is a three-dimensional, finite difference, block-centred flow algorithm. It is an internationally recognised groundwater simulation algorithm accepted by most water resource authorities in Australia and world-wide.

The model active area covers about 1,800 km^2. The model mesh consists of a uniform grid of 50 m by 50 m cells over the BCPB area (covering an area of about
36 km^2) gradually expanding to a maximum cell size of 1 km by 1 km at the edges of the model area. Cell dimensions increase by a factor of 1.2 between cells to maintain numerical stability and allow accurate calculation of heads. The model domain is shown in Figure 6-1 and the model mesh is shown in Figure 6-2.

The model is discretised in the time domain using a model time step size of 3 days between January 2011 and January 2046 and a model time step size of 9 days between January 1998 and December 2011 and between February 2046 and June 2050.

The groundwater system is represented in the model using three layers as follows:

- Layer 1: The Upper Cowra Formation (unconfined). The base of the Upper Cowra is set to 47 m below ground level based on hydraulic conductivity data and downhole gamma logs from bores in the vicinity of the BCPB (see Coffey, 2013).
- Layer 2: The Lower Cowra Formation (confined / unconfined).
- Layer 3: The Lachlan Formation (confined / unconfined).

The Upper Cowra Formation has one parameter zone. The Lower Cowra Formation has three parameter zones (northern, central, and southern) of approximately equal extent, broadly based on geology. The Lachlan Formation has two parameter zones representing:

- High hydraulic conductivity sands and gravels close to and within the deeper parts of the palaeochannel.
- Lower hydraulic conductivity, finer-grained sediments that generally occur further away from the deeper parts of the palaeochannel and surround the high hydraulic conductivity sands and gravels.

Bedrock in the Bland Creek Palaeochannel underlying the alluvial sequence has been assumed to be impermeable for the purpose of numerical simulation. This is considered reasonable since the high hydraulic conductivity parts of the Lachlan Formation have a hydraulic conductivity approximately 100 to 1000 times larger than underlying bedrock, as discussed in Section 4.5.1.

The model layer extents, parameter zones and boundary condition locations are shown in Figure 6-3.

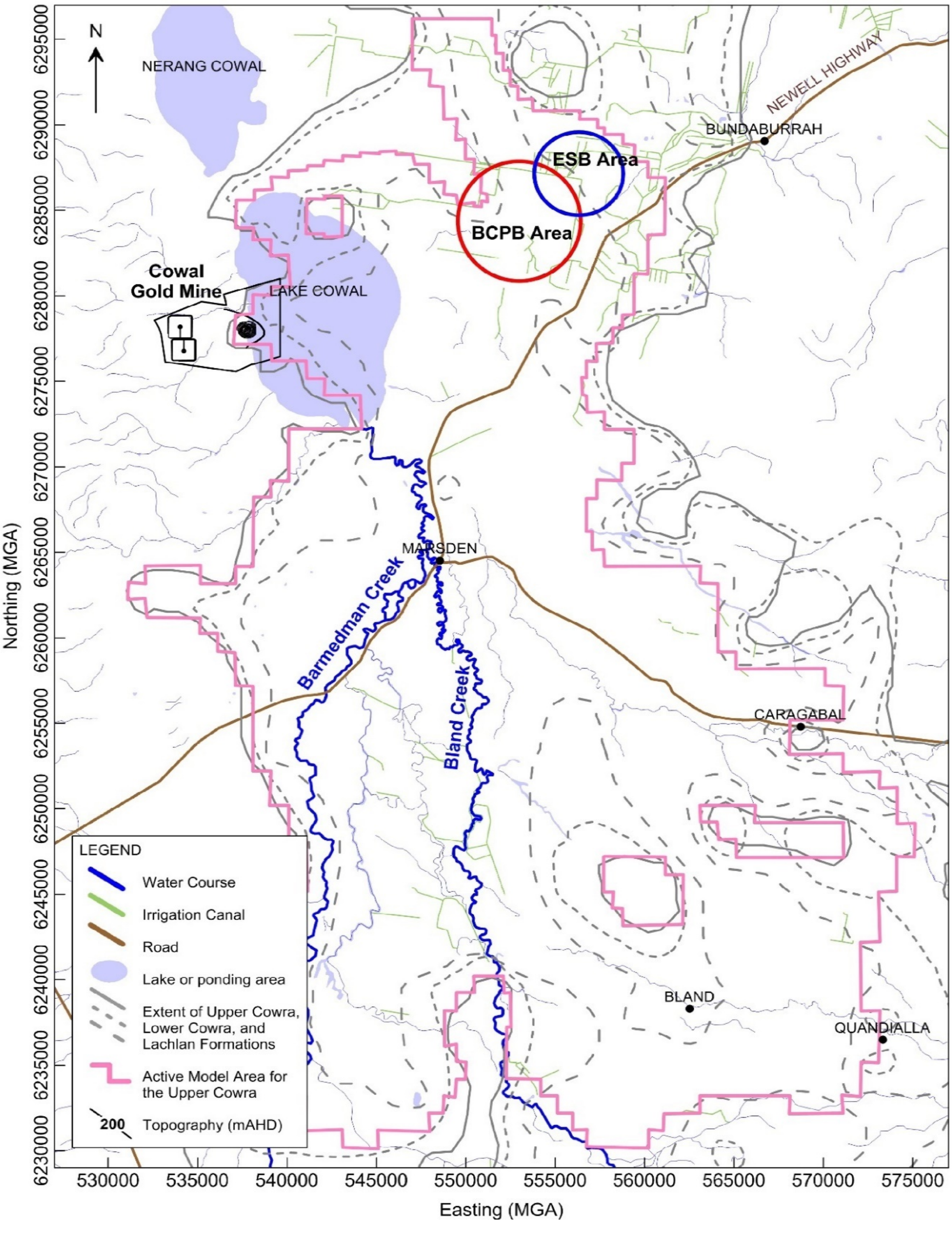


Figure 6-1: Model domain

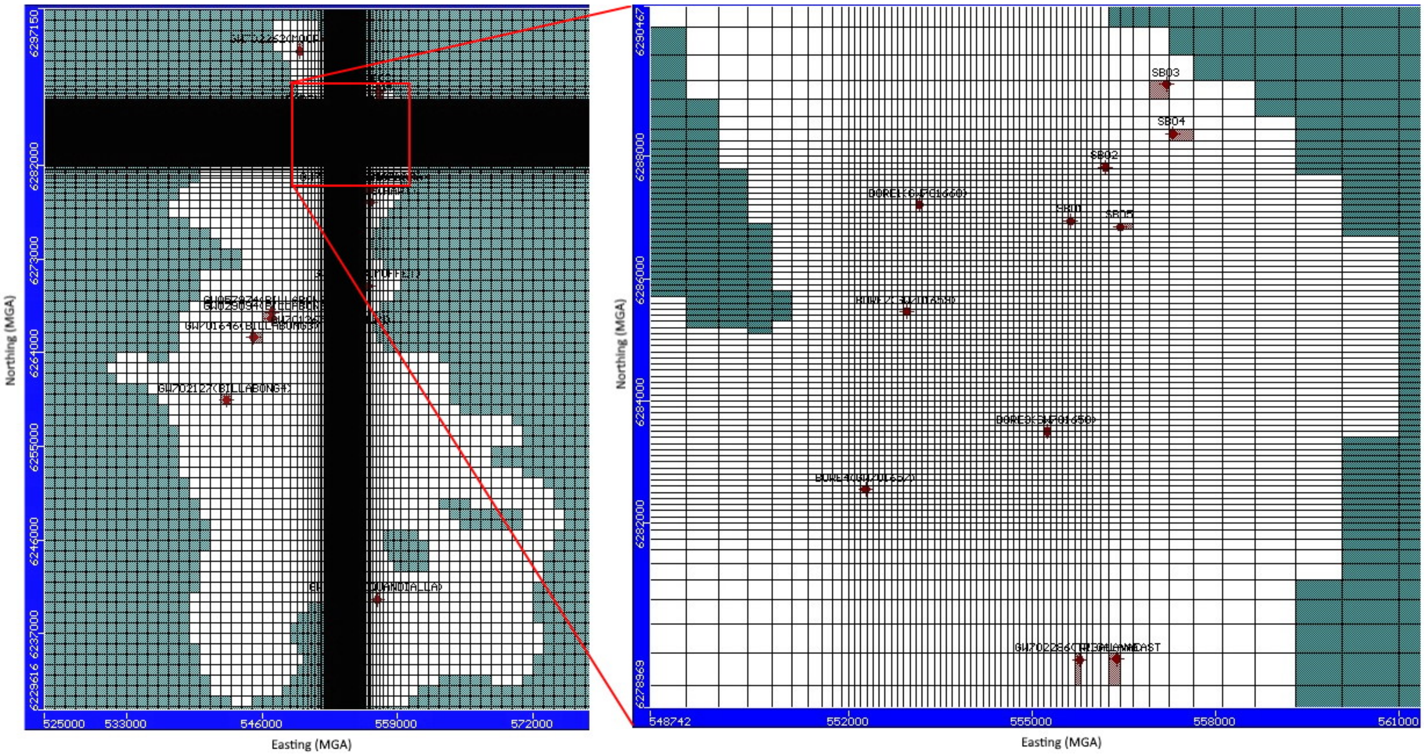


Figure 6-2: Model mesh

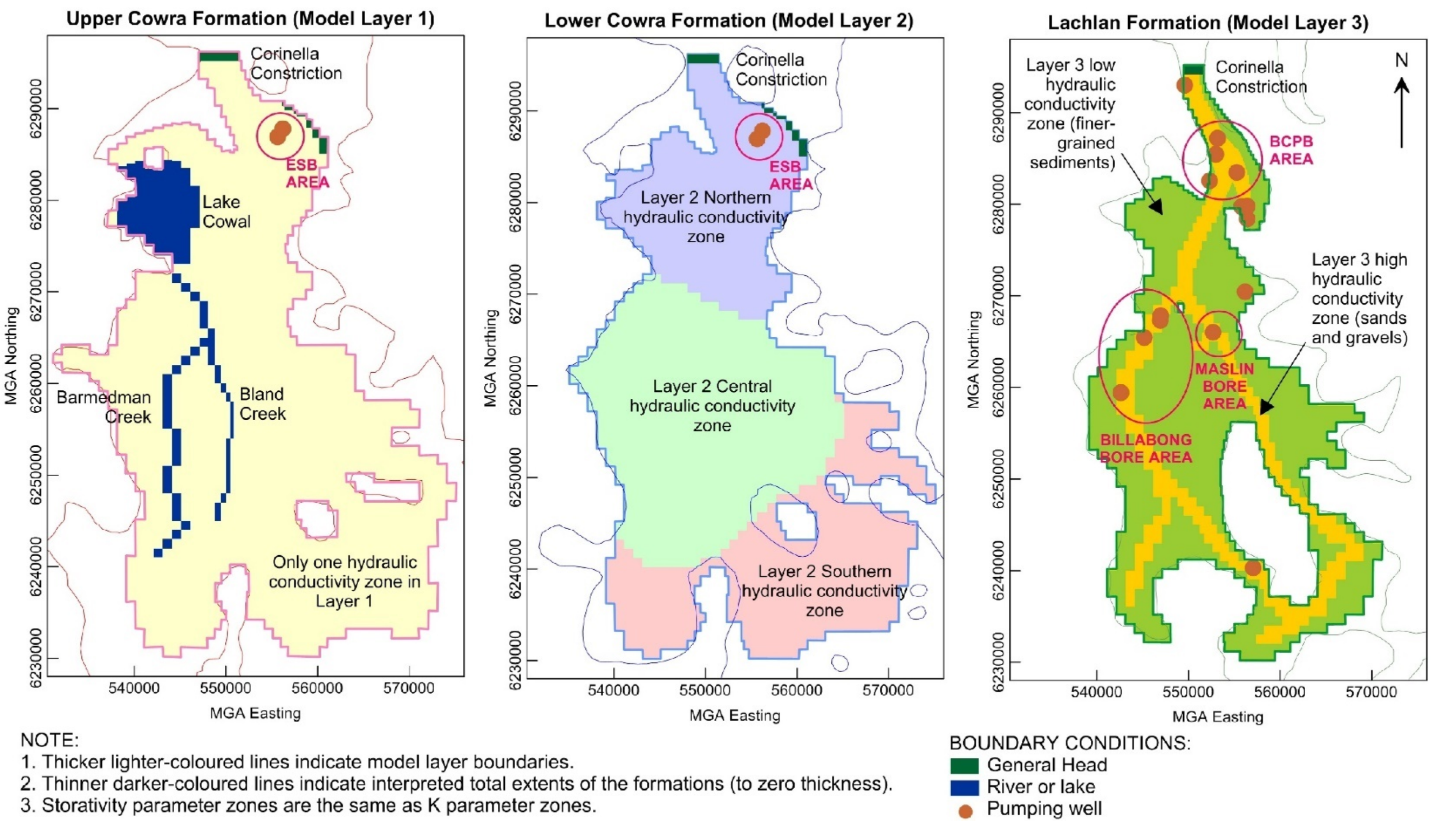


Figure 6-3: Model layers and boundary condition locations

The calibrated aquifer parameters and boundary conditions are provided in Table 4.

The southern boundary was modelled as a no flow boundary. This was considered appropriate for the purposes of the model. The southern boundary is located some 50 km south of the BCPB and 30 km south of the Billabong and Maslin areas. The influence of the southern model boundary condition on model results at the BCPB area is limited due to its distance from the borefield and the presence of lower hydraulic conductivity material in the Lachlan Formation away from the palaeochannel. Potential flow from the southern model boundary to the BCPB is likely to be an order of magnitude smaller than that from the Corinella Constriction, which is located at the northern model boundary, less than 10 km from the BCPB area, and is connected to the BCPB area via the higher hydraulic conductivity parts of the Lachlan Formation, as shown in Figure 6-3.

Appendix F provides further details of the model boundary conditions and aquifer parameters.

Table 4: Calibrated model media parameters

Parameter	Upper Cowra	Lower Cowra (North)	Lower Cowra (Central)	Lower Cowra (South)	Lachlan (Low conductivity)	Lachlan (High conductivity)
Horizontal hydraulic conductivity (m/day)	1	2	1	1	3	28
Average thickness over model area (m)	35	34	34	34	30	30
Average transmissivity over model area (m^2/day)	35	68	34	34	90	840
Vertical hydraulic conductivity (m/day)	6×10^{-5}	1×10^{-5}	6×10^{-6}	1×10^{-5}	3	28
Specific storage (m^{-1})	N/A	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}
Specific yield	0.04	N/A	N/A	N/A	N/A	N/A
General head boundaries						
External head (m AHD)	198	196	N/A	N/A	N/A	196
Conductance (m^2/day)	1	1	N/A	N/A	N/A	25
Riverbed conductance (m^2/day)						
Bland and Barmedman Creeks	10	N/A	N/A	N/A	N/A	N/A
Lake Cowal	5	N/A	N/A	N/A	N/A	N/A
Rainfall Recharge (% of average annual rainfall)	1.0	N/A	N/A	N/A	N/A	N/A

6.2. Numerical Model Verification

Coffey 2013 provides a detailed description of the numerical model and the recalibration undertaken in 2010. Numerical modelling has been conducted in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

In the current work, model verification of measured water levels was undertaken for the following piezometers:

- Evolution BLPR piezometer series (monitoring of the BCPB).
- Evolution PZ02. The screen for this piezometer straddles the model boundary between Layers 1 and 2 (the Upper and Lower Cowra Formations respectively). Verification is undertaken by extracting modelled water levels in both Layers 1 and 2 and comparing to observations.
- DIW trigger piezometers (GW036553, GW036597 and GW036611).

Apart from the bores in the BCPB, the bores with the three largest groundwater extraction rates in the model area are Billabong 4, Billabong 6, and Maslin. This extraction significantly affects water levels in DIW trigger piezometers GW036597 and GW036611. Prior to the 2017 work (Coffey, 2018), available usage data for these private pumping bores covered a period up to 1 July 2010 only. As part of the 2017 modelling, usage for the Billabong bores was supplied by the proponent for the period January 2014 to August 2017 inclusive. Usages for the Billabong bores from 2010 to 2014 and 2017 to 2019 have been estimated. Usage for the Maslin bore between 2010 and 2019 has been estimated assuming a pump capacity of 12 ML/day. Usage estimates are discussed further in Section 7.2.

6.3. Results

Verification hydrographs for the DIW mitigation trigger piezometers are shown in Figure 6-4. Verification hydrographs for the BLPR series, and PZ02, are shown in Appendix G.

The modelled hydrograph for GW036553 indicates over-prediction of water levels from about 2012. Modelled hydrographs for GW036597 and GW036611 are reasonable, however modelled recovery is slower than observed. To incorporate the over-prediction present in modelled hydrographs in predictive simulations, the disparity between modelled and observed water levels is taken for the two lowest water level troughs in the series between 2014 and the present, and the averages of these taken. This results in the following over-prediction of observed hydrographs, as listed in Table 5. Modelled and observed patterns show reasonable agreement.

Table 5: Model over-prediction of DIW trigger piezometer hydrographs

Piezometer	Date	Water Level (m AHD)		Difference (m)	Average Difference (m)	Effective Trigger Level (m AHD)
		Observed	Calculated			
GW036553 (BCPB Area)	15-Jul-15	144.6	150.7	+ 6.1	+ 6.0	134.0 + 6.0 = 140.0
	29-Nov-17	145.5	151.5	+ 6.0		
GW036597 (Billabong Area)	22-Mar-19	146.1	148.2	+ 2.1	+ 2.7	143.7 + 2.7 = 146.4
	23-Nov-19	145.2	148.5	+ 3.4		
GW036611 (Maslin Area)	5-Nov-19	151.9	154.6	+ 2.7	+ 3.5	145.8 + 3.5 = 149.3
	16-Dec-19	147.4	151.7	+ 4.3		

Note: Component values are rounded to one decimal place. Totals are calculated from unrounded component values, then rounded to 1 decimal place, therefore each total may differ slightly from the sum of corresponding rounded components.

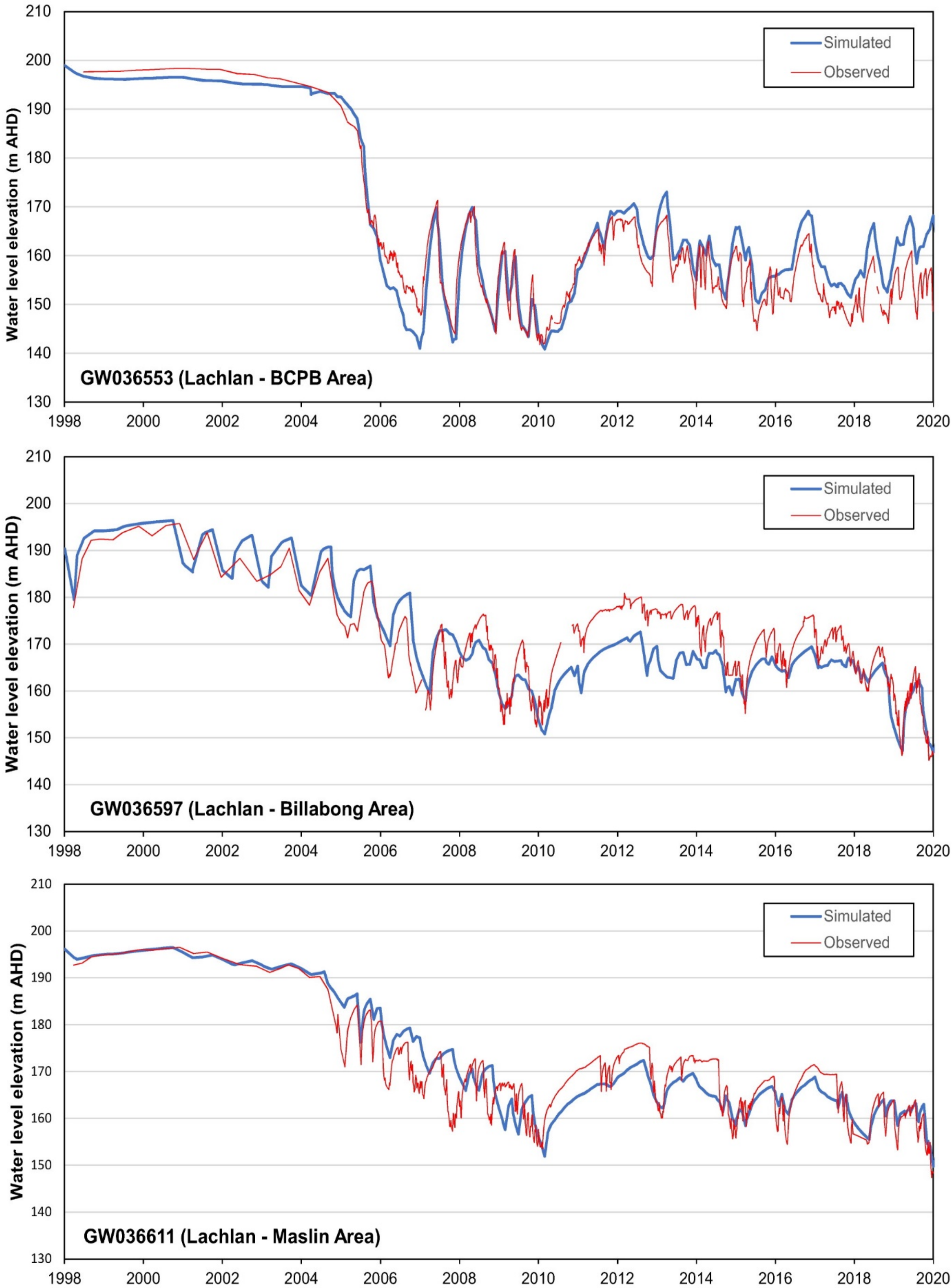


Figure 6-4: Verification hydrographs for DIW trigger piezometers

A comparison of the modelled versus observed results at the three DIW trigger piezometers and the seven BLPR series piezometers, as shown in Appendix G, results in a normalised root mean square error (NRMSE) of 9.2 % for the model calibration. This indicates a reasonable match between observations and model results.

Modelled versus observed groundwater levels are shown in Figure 6-5.

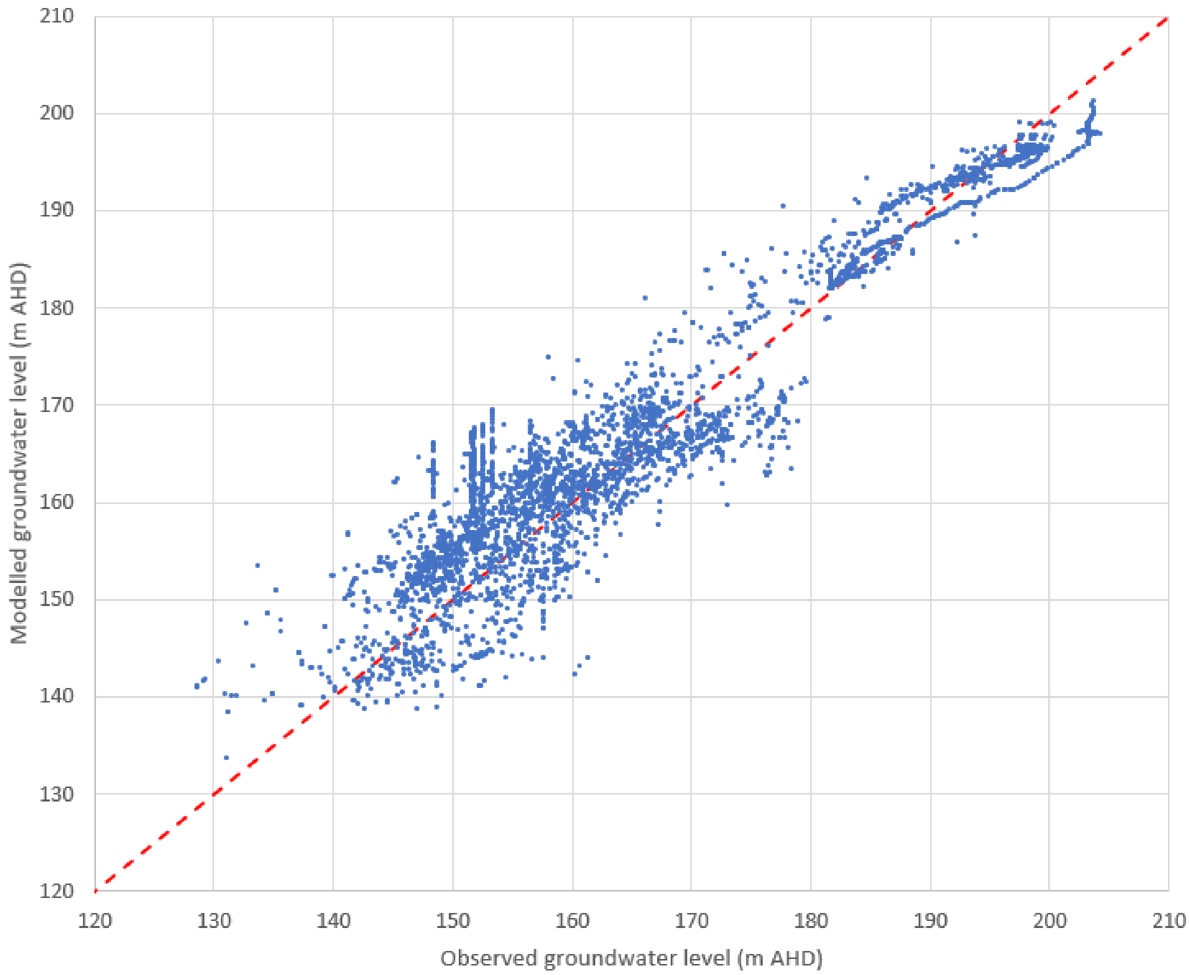


Figure 6-5: Modelled versus observed groundwater levels

The relative sensitivity of the NRMSE of the calibration to the hydraulic conductivity parameters, was assessed by varying each of these parameters by +50% and -50% and assessing the maximum percentage increase in the NRMSE for each parameter. The results are shown in Figure 6-6, normalised to provide relative sensitivities. It can be seen from Figure 6-6 that model calibration is most sensitive to the vertical hydraulic conductivity in the Lower Cowra Formation and the isotropic hydraulic conductivity in the Lachlan Formation.

The mass balance error in the numerical model is below 1% at all time steps. Figure 6-7 shows the mass balance error at selected times.

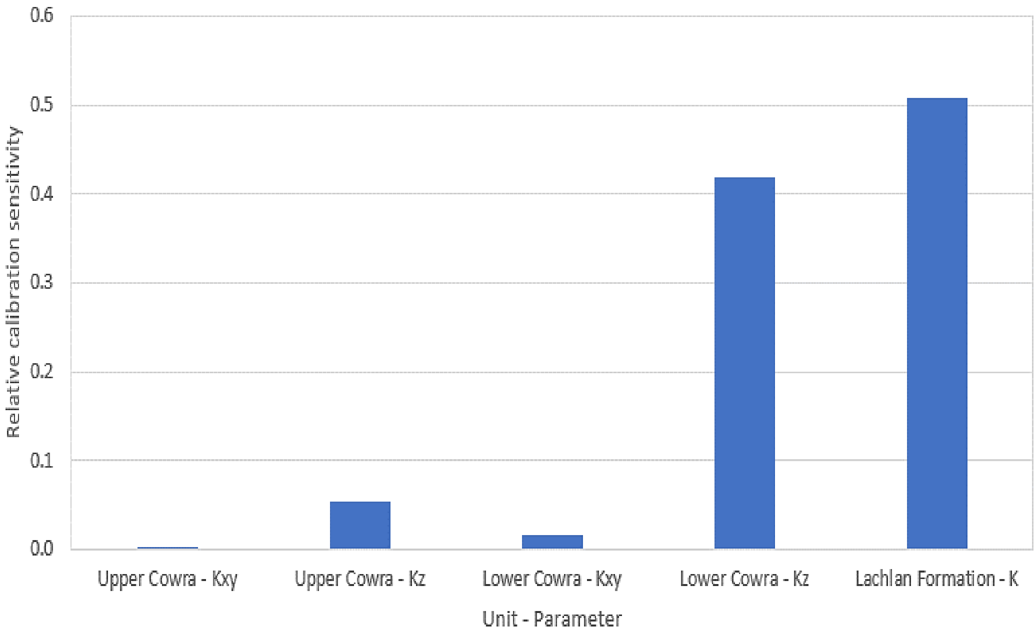


Figure 6-6: Calibration sensitivity to hydraulic conductivity parameters

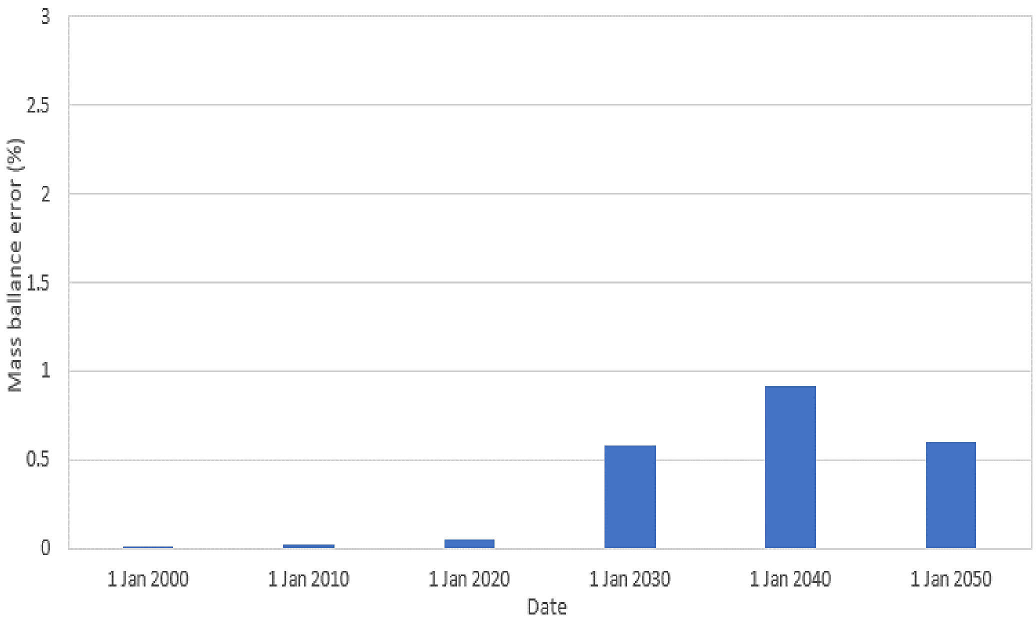


Figure 6-7: Mass balance error (%) at selected times

6.4. Model Classification

The Australian Groundwater Modelling Guidelines (Barnett et al, 2012) provide discussion on confidence level classifications for numerical groundwater models. The model described in this report is considered to meet the criteria for Class 2, with some aspects of Class 3. A summary of the key indicators is provided below:

- The model is based on groundwater level monitoring data and extraction records for piezometers and extraction bores in and around the model domain, in particular at the BCPB borefield.
- A conceptual model has been developed, incorporating the principal hydrogeological units and the main sources of groundwater recharge and discharge in the area covered by the model.
- Calibration has been carried out against three DIW trigger piezometers and seven observation piezometers (BLPR series piezometers) for a calibration/verification period of 21 years (1998 to 2019).
- The calibration statistics provide a NRMSE of 9.2% which indicates a reasonable match between observations and model results.
- The model is used to predict impacts to groundwater levels due to extraction from the BCPB borefield until 2040 and 10 years of recovery. The predictive timeframe of 30 years (2020 to 2050) is comparable to the timeframe used for calibration.
- The groundwater stresses for the predictive modelling period are similar to those for the calibration period. These principal stresses are groundwater extraction from the BCPB, ESB and private bores.
- The time discretisation for the predictive modelling period is the same as that for the calibration period, refer to Section 6.1.
- The mass balance error in the numerical model is below 1 % at all time steps.

7. Predictive Simulation

7.1. Simulations

Predictive simulations were modelled as follows:

- Case 1, the BCPB pumps at the maximum possible rate, beginning 1 January 2020, such that the water level in DIW trigger piezometer does not fall below the mitigation trigger level of 134 m AHD. ESB pumping is fixed at 1.5 ML/day (requested by Evolution in the same scenario undertaken in 2013 and adopted here). BCPB and ESB pumping terminates on 30 June 2040.
- A null case, where CGO pumping never occurs.

For the pumping case, the total pumping is distributed amongst the four bores of the BCPB and the two bores of the ESB according to the proportions pumped by each bore up to 31 December 2019. Pumping at the ESB is subject to the drawdown constraint where the groundwater level in PZ02 (the ESB monitoring piezometer historically showing the largest drawdown) is not to fall below the base of the bore screens. Based on supplied information, the elevation of the base of the PZ02 bore screen is 144.6 m AHD.

The simulations cover a future period of 30 years commencing on 1 January 2020 and ending on 30 June 2050. This allows for 10 years of recovery following termination of pumping at the BCPB and ESB. The following future conditions are applied:

- Average rainfall occurs from 1 January 2020 as an invariant annual rate equivalent to 1% of 475 mm/year (the average rainfall at Wyalong Post Office between 1895 and 2019).
- Water levels for Lake Cowal, and Bland and Barmedman Creeks, have been assigned by calculating their average water levels over the period of record and applying these averages over the entire simulation period. These averages are 0.35 m for Bland and Barmedman Creeks and 0.5 m for Lake Cowal.
- Private pumping as defined in the following section.

7.2. Private Bore Pumping

Nine private bores are active during the predictive simulations, as listed in Table 6. These bores all pump from the Lachlan Formation. Actual past usage is available for four of the bores up to June 2010. Usage is also available for the Billabong bores between 2014 and 2017.

For the purpose of verification of the hydrograph for GW036597, usage for the two Billabong bores was estimated from 2010 to 2013 and 2017 to 2019 using a pump capacity of 5 ML/day, and on/off times interpreted from the GW036597 hydrograph. To match the observed GW036597 hydrograph troughs in March and November 2019, both Billabong bores were estimated to be pumping at 5 ML/day, a total rate of 10 ML/day. Previous modelling assumed a pump capacity of 4 ML/day.

For the purpose of verification of the hydrograph for GW036611, usage for Maslin was estimated using a pump capacity of 12 ML/day, and on/off times interpreted from the GW036611 hydrograph. To match the observed GW036611 hydrograph troughs in November and December 2019, the Maslin bore was estimated to be pumping at 12 ML/day. Previous modelling assumed a pump capacity of 7 ML/day.

No usage information has ever been received for five of the bores. In 2007 the Lachlan Valley Water Group (LVWG) supplied future usage estimates for all nine bores, listed in Table 6, for use in predictive simulations.

The combined LVWG estimate for the Billabong bores is 4.62 ML/day, which compares with an estimated average actual pumping (from significant assumptions) of 2.8 ML/day used in the verification modelling (see Table 3). The LVWG estimate for the Maslin bore is 4.52 ML/day, which compares with an estimated average actual pumping (from significant assumptions) of 2.7 ML/day used in the verification modelling (see Table 3). The LVWG estimates were used in the current work for predictive simulations (applied from 1 January 2020).

Table 6: Private bore future average annual pumping rates for modelling

Bore	Estimated future average annual usage as at 2007 (Lachlan Valley Water Group)^ (ML/day)
Billabong 3/6*	2.22
Billabong 4	2.40
Maslin	4.52
Quandialla TWS	0.10
Hart	0.02
Moora Moora	0.13
Muffet	0.02
Trigalana	0.08
Trigalana East	0.13
Total:	9.62

* Billabong 3 was replaced by Billabong 6 in 2008 (see Appendix E).
^ Used for predictive simulations (applied from 1 January 2020).

7.2.1. Inactive Pumping Bores

Table 2 in Appendix E lists an additional 10 licensed private pumping bores in the model area that have the potential to pump large amounts, but for which no usage data have ever been received, and no usage estimates have ever been supplied. Their status is unknown, and as a result, they are designated inactive in the model. It is not known if any of these may be pumping groundwater, however their inactivity has allowed reasonable replication of water level observations up to the present. Their future usage was unable to be estimated and they are inactive in predictive simulations.

The Warrakimbo bore, located very close to the Maslin bore, is licensed for irrigation and has a large allocation. To match the observed GW036611 hydrograph troughs in November and December 2019, the Maslin bore was estimated to be pumping at 12 ML/day. Previous modelling assumed a pump capacity of 7 ML/day. The Warrakimbo bore may have been in use during these periods of low water levels and it is recommended that potential water usage from this bore is obtained.

Billabong 5 was completed on 23 December 2008 as a replacement for Billabong 1 and 2. The potential for this bore to have been used since 2008, or to be used in the future, is high. To match the observed GW036597 hydrograph troughs in March and November 2019, Billabong bores 4 and 6 were estimated to be pumping at 5 ML/day, a total rate of 10 ML/day. Previous modelling assumed a pump capacity of 4 ML/day. The Billabong 5 bore may have been in use during these periods of low water levels and it is recommended that potential water usage from this bore is obtained.

As at 2010, it was understood that the bore installed by Mr Mattiske in 2007 (not active in the model) approximately midway between Bores 1 and 2 of the BCPB, did not operate. Its operation after 2010 is unknown.

7.3. Results

7.3.1. Water Level Hydrographs

Table 5 shows that the numerical model under predicted drawdown at monitoring bore GW036553 by approximately 6.0 m during periods of high groundwater extraction in 2015 and 2017. While the form of modelled response follows observations a discrepancy between measurement and modelled groundwater level has gradually developed.

The separation between model result and measurement was taken into account by incorporation of an offset on the trigger level to compensate for the departure in the modelling result from observation.

The modelled pumping rate was as follows:

- Case 1 - Model over prediction incorporated (6.0 m added to the mitigation trigger value (134 m AHD) to account for model over prediction): 4.0 ML/day.

Figure 7-1 shows the predicted hydrographs for DIW trigger piezometers for Case 1, and for the null case. For the predictions in the irrigation area approximately 15 km to the south of the mine bores, the effects of groundwater extraction for CGO were assessed by adding the predicted drawdown associated with mining to the measure of historic low groundwater levels at each of two monitoring bores for which trigger levels are established. The representation of historic low groundwater levels was taken as the average of the five lowest level events on record. The low levels and the timing of these events are shown in Figure 7-1. In each case they are interpreted to correspond to the end of a period of pumping for irrigation. This approach is adopted to address the uncertainty in recent and future pumping rates from the irrigation bores. Results are discussed below.

Modelled future pumping rates are reported to the nearest 0.1 ML/day, rounded down. At a continual pumping rate of 4.0 ML/day, the model indicates that the water level at GW036553 does not fall below the effective mitigation trigger value of 140.0 m AHD (134 m AHD actual, plus 6.0 m to account for model over prediction of groundwater level).

Water levels at GW036597 and GW036611 would not fall below the respective effective trigger values based on predicted mining impacts upon the low historic levels at these locations. At both GW036597 and GW036611 there is minimal freeboard available at the end of pumping in June 2040 (about 2 m and 1 m respectively, taking into account the model over prediction listed in Table 5), to accommodate BCPB pumping.

Operation of the BCPB and ESB is governed by water levels at trigger piezometer GW036553. Water levels at trigger piezometers GW036597 and GW036611 do not govern the operation of the BCPB and ESB and are included in Figure 7-1 for information purposes only.

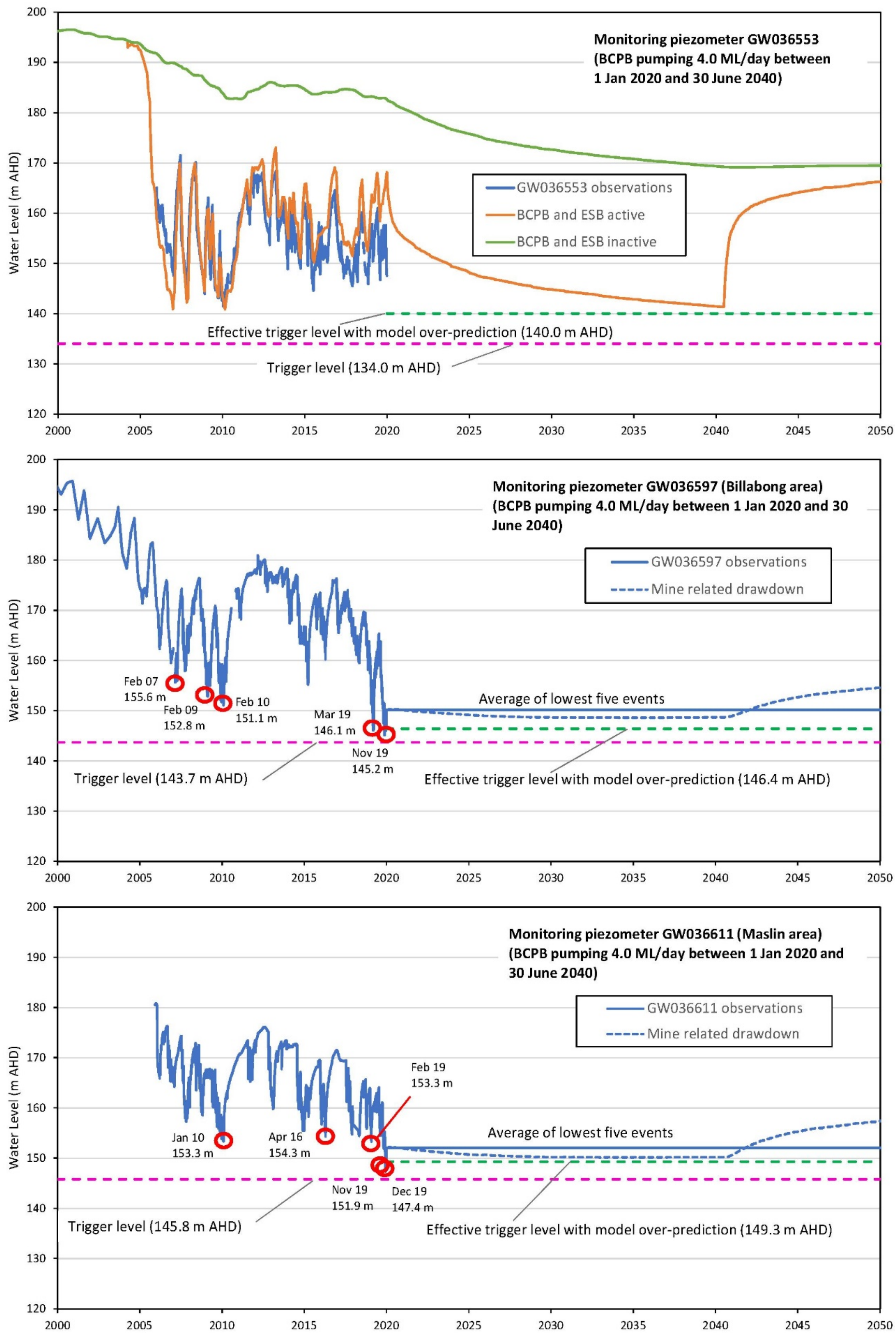


Figure 7-1: Predictive hydrographs for DIW trigger piezometers for Case 1 (mine impact)

7.3.2. Water Level Drawdown

Results are presented for Case 1.

Groundwater drawdown (compared with 1998 groundwater levels) achieves a maximum just before the end of BCPB and ESB operation, on 30 June 2040. At this time, the maximum modelled drawdown in the Upper Cowra Formation is 2.7 m, occurring in the central part of the ESB. This drawdown is not expected to create difficulty for the majority of private bores in the area.

Drawdown in the Lower Cowra and Lachlan Formations for 30 June 2040 are shown in Appendix H. Table 7 provides a summary of results.

Table 7: Drawdown in the Lower Cowra and Lachlan Formations for 30 June 2040 (cessation of BCPB and ESB pumping)

Formation and Location	Case 1
Maximum drawdown in Lower Cowra Formation	
Drawdown (m)	40.4
Location	ESB
Maximum drawdown in Lachlan Formation	
Drawdown (m)	68.2
Location	Maslin Area
Maximum drawdown in Lachlan Formation over the BCPB (m)	60.6

There are private registered bores screened in the Lachlan Formation in the area of the BCPB, however impacts on these bores are being monitored and mitigation measures have been developed to mitigate potential impacts (see below).

Based on a search of registered private water bore records in 2011, there are 34 private bores (excluding government piezometers and Evolution piezometers or pumping bores) within 15 km of the BCPB and ESB which appear to be screened in the Upper and/or Lower Cowra Formations (depths less than 90 m). 32 of these bores are located outside the model domain (29 are located to the east and north east, on the other side of rock ridges or interpreted shallow bedrock, and three are located to the north northeast, past the northern model boundary and within the northernmost parts of the Corinella Constriction). The remaining two bores are GW029574 and GW702230 (known as the Duff Bore). Their locations are shown on the map in Appendix E. Table 8 lists known completion details for these bores.

Table 8: Registered private bores screened in the Cowra formation within 15 km of the BCPB and ESB (excluding government and Evolution bores)

Bore	Easting (m MGA)	Northing (m MGA)	Depth (m bgl)	Water level (m bgl)	Licensed use
GW029574	553360	6273194	88	30	Stock
GW702230 (Duff Bore)	555812	6287547	66		Irrigation

GW702230 (Duff Bore) is located within the ESB. There is understood to be an agreement between Evolution and the bore owner that permits temporary transfer of water from this bore for use in the CGO water supply.

Government bore records indicate that GW029574 is privately owned and was installed in 1969. A maximum modelled drawdown of about 31.9 m (in the Lower Cowra Formation) is calculated for GW029574, however the bore is 88 m deep and may be able to continue operation if the screen length is sufficiently long and optimally located.

7.3.3. Flow Budgets

Table 9 lists the modelled groundwater flow budget for 30 June 2040, immediately prior to cessation of pumping at the BCPB and ESB, for Case 1, and the null case (BCPB and ESB inactive for the entire simulation period). This time is the time of greatest groundwater drawdown.

Table 9: Flow budgets at the end of BCPB and ESB pumping (30 June 2040)

Component	Case 1		Null (BCPB and ESB Inactive)	
	In (ML/day)	Out (ML/day)	In (ML/day)	Out (ML/day)
Recharge	17.74		17.74	
Media storage	2.08	8.22	1.90	10.30
River leakage	0.02	1.15	0.02	1.38
Flow across Corinella Constriction	4.82	0.25	1.95	0.31
Pumping		15.12		9.62
Total	24.66	24.75	21.61	21.61
Discrepancy	-0.09		0.01	

Note: Component values are rounded to two decimal places. Totals are calculated from unrounded component values, then rounded to 2 decimal places, therefore each total may differ slightly from the sum of corresponding rounded components.

Flow budgets indicate that groundwater pumping is being sourced almost entirely from media storage on 30 June 2040. Flow budget discrepancies are reasonable.

As noted in Section 6.3, the discrepancy (mass balance error) is less than 1% of the total flow at all model time steps.

7.3.4. Salinity

When a fresh water source is pumped and draws vertical leakage from an overlying source of higher salinity, the resulting distribution of total dissolved solids (TDS) concentration in the pumped source is not uniform. The concentration distribution will first be controlled significantly by the variation in the vertical hydraulic head difference between the sources (which is a maximum at the pumped bore). This distribution may change with time, during and after pumping, depending on the magnitude of lateral flow and other factors.

Based on numerical simulation of salinity concentrations undertaken in Coffey (2016) for Cowal Gold Operations Mine Life Modification (MOD13), it was estimated that total dissolved solids concentrations at BLPR1 will increase by 20% or less, by 31 December 2032, from pre-mining concentrations.

Figure 7-2 shows modelled and observed TDS concentrations at BLPR1 (using a conversion factor of 0.67 mg/L per µS/cm). Observed and calculated TDS concentrations show reasonable agreement excluding localised fluctuations at the pumping bore. Modelling of pumping ceasing at 31 December 2032 indicates TDS at BLPR1 will increase to around 1760 mg/L by 30 June 2040, an increase of about 40% from pre-mining concentrations.

EC trends are relatively stable after 15 years of mine water supply pumping, as illustrated in Figure 4-12 and reported in the latest annual groundwater review (Coffey, 2020). An increase in TDS of 40% or less by 30 June 2040 is therefore considered a reasonable estimate.

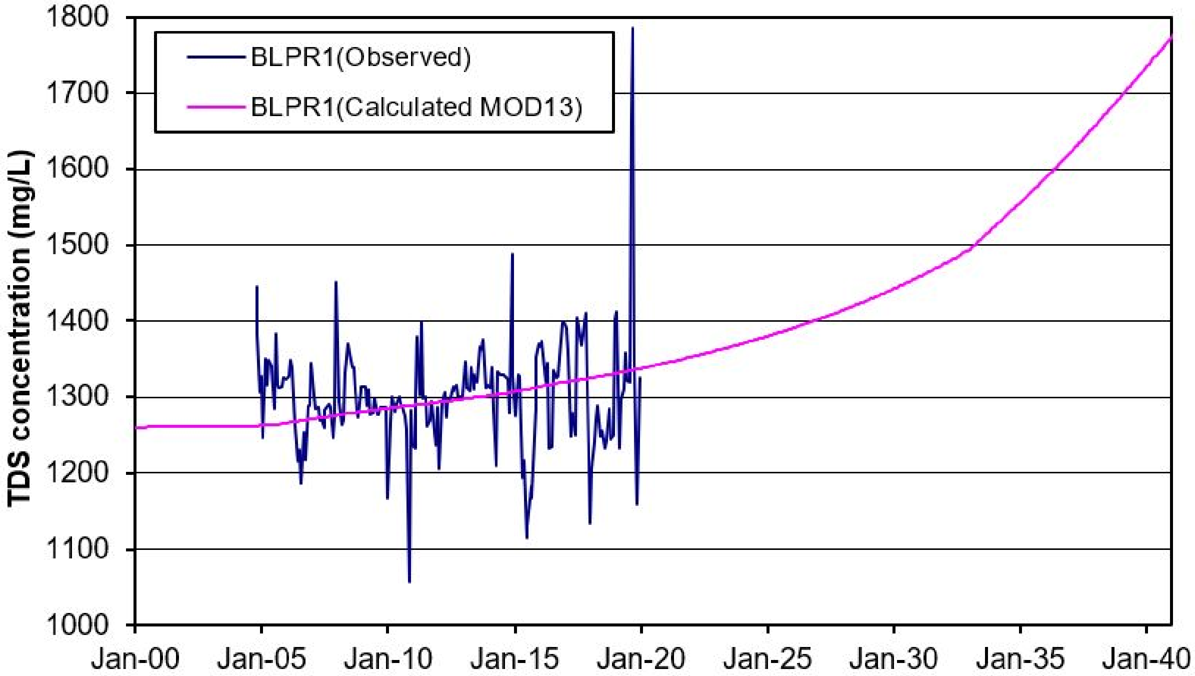


Figure 7-2: Modelled and observed TDS concentrations in the BCPB

7.3.5. Post-mining Water Levels

When ESB and BCPB pumping stops, groundwater levels at GW036553 are predicted to recover to around 166 m AHD in 10 years (about 30 m below 1998 water levels), and would continue to gradually recover over time, to a level that is dependent on the amount historically pumped, private bore usage following CGO closure, and climate. It may take significant periods of time for water levels to recover to levels seen in the late 1990s (prior to the drought and onset of extensive pumping) because of the low rate of media recharge and continuing pumping for agricultural purposes.

8. Predictive Uncertainty Assessment

A deterministic scenario analysis was carried out to assess model parameter and observational uncertainty.

As discussed in Section 6.3, in terms of hydraulic conductivity parameters, the model is most sensitive to the vertical hydraulic conductivity in the Lower Cowra Formation and the isotropic hydraulic conductivity in the Lachlan Formation. An assessment of parameter uncertainty was carried out by varying these parameters and assessing model predicted groundwater levels at GW036553 from 2020 to the end of mine life in 2040.

With reference to the hydraulic conductivity test results in Section 4.5.1 and considering variations in the hydraulic conductivity parameters such that the NRMSE between observed and modelled results remains less than 15%, the following four model runs were carried out to assess model parameter uncertainty:

- Upper Cowra Formation vertical hydraulic conductivity x 1.5.
- Upper Cowra Formation vertical hydraulic conductivity x 0.5.

- Lachlan Formation hydraulic conductivity x 1.5.
- Lachlan Formation hydraulic conductivity x 0.75.

The predicted drawdown at GW036553 is affected by the predicted pumping rate at private bores Billabong 3/6, Billabong 4 and Maslin. The pumping rate at these bores is generally higher in dry periods and generally lower during periods with above average rainfall. To provide an assessment of this observational uncertainty, the following two model runs were carried out, using the adopted model hydraulic conductivity parameters:

- Billabong 3/6, Billabong 4 and Maslin bore pumping rates (see Table 6) x 1.5.
- Billabong 3/6, Billabong 4 and Maslin bore pumping rates x 0.5.

Figure 8-1 shows the predicted groundwater levels at GW036553 from 2020 to 2040 for the four model parameter uncertainty cases and the two private bore pumping rate observational uncertainty cases.

Considering the worst case scenario for model parameter uncertainty, the water level at trigger piezometer GW036553 would be predicted to reach the effective trigger level (refer to Table 5) in late 2033. On the other hand, considering the best case scenario for model parameter uncertainty, the water level at GW036553 is predicted to be approximately 4 m higher than the effective trigger level in 2040.

The effects of the uncertainty in the rate of irrigator pumping from Billabong 3/6, Billabong 4 and Maslin are clearly evident. A 50% increase in the future pumping rate from these bores results in the predicted water level at GW036553 reaching the effective trigger level in 2026. This also shows the importance of climate on future groundwater availability. During periods of high irrigator pumping and drought, groundwater trigger levels for both the mine and irrigators will require management.

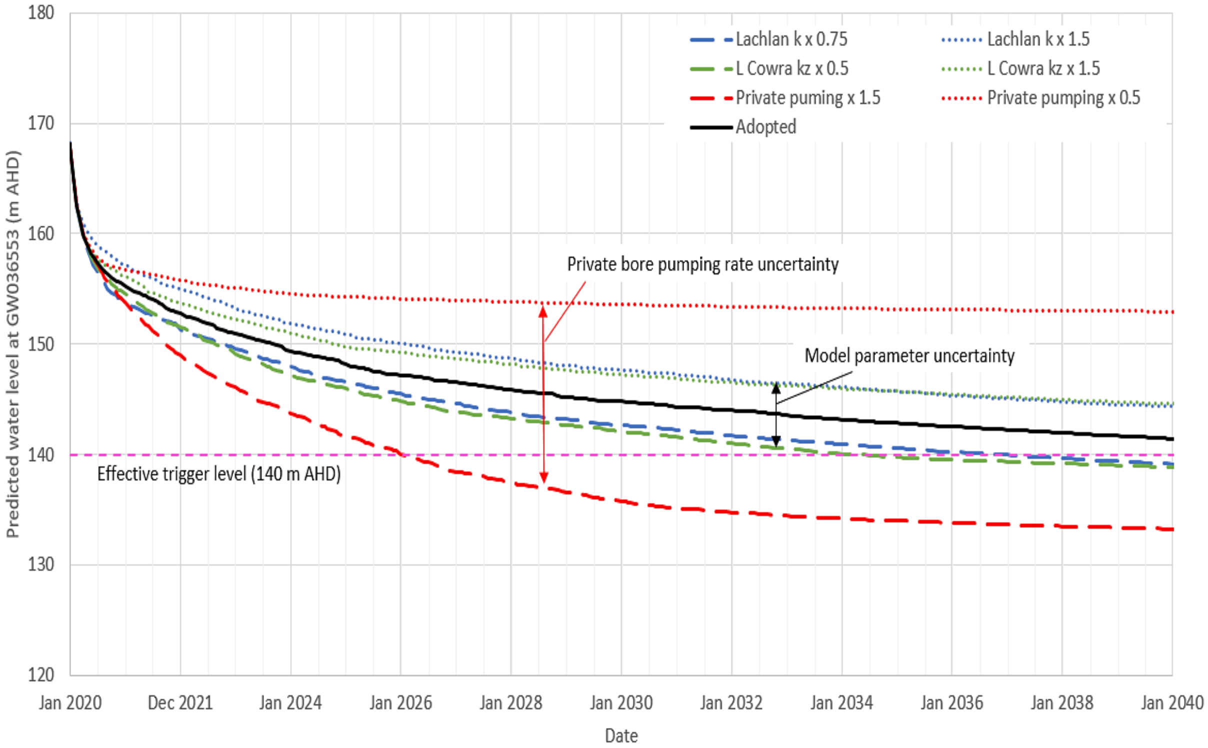


Figure 8-1: Predictive uncertainty for modelled groundwater levels at trigger piezometer GW036553

9. Summary and Conclusions

An existing model has been used to predict groundwater impacts associated with operation of the ESB and BCPB for the CGO Underground Development. Predictive simulation results are based on significant assumptions regarding high-extraction private water bores in the area.

9.1. Predictive Simulation Results

Over the period 1 July 2004 to 31 December 2019, the average total pumping rates at the largest groundwater extraction bores (4.1 ML/day at the BCPB, 2.8 ML/day at the Billabong bores, and 2.7 ML/day at the Maslin bore) have maintained water levels 1.5 m or more above the relevant trigger levels at the three DIW trigger piezometers. Pumping rates for the Billabong and Maslin bores, as used in verification analysis, involve significant assumptions.

Modelling results indicate that the BCPB can pump at a maximum rate of 4.0 ML/day, from 1 January 2020 to 30 June 2040 (with the ESB pumping at 1.5 ML/day), without causing the water level in trigger piezometer GW036553 to fall below the mitigation trigger level of 134 m AHD. The effects of pumping at this rate were also assessed at the locations of monitoring bores GW036597 and GW036611 located 15 km south of the mine borefield. At these locations the incremental effects of pumping from the mine bores at 4.0 ML/d from 1 January 2020 to 30 June 2040 were added to a measure of low recorded groundwater levels at these locations (based on the average of the lowest five events on record). The predicted groundwater levels for the impact of mine water use remained above the trigger levels for these monitoring bores.

Operation of the BCPB and ESB is governed by water levels at trigger piezometer GW036553. Water levels at trigger piezometers GW036597 and GW036611 do not govern the operation of the BCPB and ESB.

The trigger level for GW036553 (located near the mine borefield) is not predicted to be breached under the adopted model conditions, based on extraction at a uniform rate with time.

The response in the southern trigger piezometers is strongly dependent on usage and our information on actual and forecast usage by the irrigators is limited. In particular, the forecast irrigator use does not consider the “self-regulating” approach to pumping when the trigger levels are approached.

Considering the worst case scenario for model parameter uncertainty, the water level at trigger piezometer GW036553 would be predicted to reach the effective trigger level in late 2033. On the other hand, considering the best case scenario for model parameter uncertainty, the water level at GW036553 is predicted to be approximately 4 m higher than the effective trigger level in 2040.

The effects of the uncertainty in the rate of irrigator pumping from Billabong 3/6, Billabong 4 and Maslin are clearly evident. A 50% increase in the future pumping rate from these bores results in the predicted water level at GW036553 reaching the effective trigger level in 2026. This also shows the importance of climate on future groundwater availability. During periods of high irrigator pumping and drought, groundwater trigger levels for both the mine and irrigators will require management.

Maximum drawdowns at the end of the CGO mine life are predicted to be 40 m or less in the Lower Cowra Formation and 61 m or less in the Lachlan Formation within the BCPB. A maximum drawdown of about 32 m (in the Lower Cowra Formation) is modelled for GW029574, the only known water bore installed to a depth within the Lower Cowra Formation and 10 km to the south of the BCPB. However, the bore is 88 m deep and may be able to continue operation if the screen length is sufficiently long and optimally located.

Previous simple numerical transport simulation for Case 1 (where allowance is made for the departure of model drawdown from observation at the trigger bore near the BCPB – GW036553) predicts EC at BLPR1 will increase by about 40% or less, by 30 June 2040, from pre-mining concentrations.

At cessation of BCPB and ESB pumping, groundwater levels at GW036553 are predicted to recover to around 166 m AHD in 10 years (about 30 m below 1998 water levels), and would continue to gradually recover over time, to a level that is dependent on the volume historically pumped, private bore usage following mine closure, and climatic conditions.

9.2. Regulatory Considerations

9.2.1. Licence allocation for the BCPB

The following points summarise our understanding of the licensing situation for the CGO:

- Evolution currently holds 3650 units (ML) / annum in the Upper Lachlan Alluvial Zone 7 Management Zone within the Water Sharing Plan for the Lachlan Unregulated and Alluvial Water Sources 2012.
- Evolution would continue to extract groundwater from the Upper Lachlan Alluvial Water Source in accordance with existing licence entitlements, and in accordance with the contingency strategy as described in Section 8.2.3.

9.2.2. Aquifer Interference Policy

Merrick (2013) states that, according to Principle 14 of the NSW State Groundwater Policy Framework Document, “All activities or works that intersect an aquifer, and are not for the primary purpose of extracting groundwater, need an aquifer interference approval.” Since the BCPB and ESB are for the primary purpose of extracting, and using, groundwater, no aquifer interference approval is needed. However, use of the BCPB and ESB are subject to regulatory requirements according to other legal instruments that may be in force. Specifically, for the BCPB, a contingency strategy and mitigation measures are in place as discussed below.

9.2.3. Lachlan Formation Water Source

Contingency Strategy

The groundwater level in the Lachlan Formation in the BCPB area is monitored on a continuous basis by the DIW using its groundwater monitoring bore on Burcher Road (GW036553). Contingency measures have been developed for implementation when water levels reach an elevation of either 137.5 m AHD (Investigation Trigger Level) or 134 m AHD (Mitigation Trigger Level). These trigger levels were developed in consultation with DIW and other water users within the Bland Creek Palaeochannel, including stock and domestic users and irrigators. The following contingency measures are understood to be associated with each Trigger Level:

- In the event that the groundwater level in GW036553 is below 137.5 m AHD, one or more of the following contingency measures will be implemented in consultation with the DIW:
  - Investigate the groundwater level in the Trigalana bore (GW702286) or any other impacted stock and domestic bores.
  - Determine the pump setting in relevant stock and domestic bores.
  - Determine the drawdown rate in GW702286 and other impacted stock and domestic bores.
  - Develop an impact mitigation plan for impacted stock and domestic bores, and/or set up an alternative water supply for the owner of GW702286 and other owners of stock and domestic bores, if necessary.
- In the event that the groundwater level in GW036553 is below 134 m AHD, one or both of the following contingency measures will be implemented in consultation with the DIW:

- Alter the pumping regime to maintain the water level in the impacted stock and domestic bores.
- Maintain a water supply to the owner/s of impacted stock and domestic bores.

Mitigation Measures

Prior to the drought last decade, stock and domestic water supplies were generally drawn from surface water delivered through the JIL irrigation channel network. The reduced availability and increased cost of this water, driven by reduced rainfall from around 2002 onwards, led to establishment of stock/domestic bores which utilised the Lachlan Formation aquifer. Several consortia were established to share the costs of bore installation and to deliver the water across multiple properties. Barrick (the previous owner of CGO) was independently approached by various parties for assistance in upgrading the pumping systems such that their design capacity could be met independently of the abstraction from the Lachlan Formation. The known schemes are listed below (see Appendix E for locations):

- Moora Moora (GW702262).
- West Plains (GW702100).
- Trigalana (GW702286, also known as Trigalana West).
- Trigalana East.

Each of the schemes is understood to comprise the following key elements:

- A single bore equipped with a submersible pump.
- Above-ground storage tanks located near the bore.
- A surface-mounted pump to pressurise the pipeline system.
- A pipeline system with control valves at the user offtake.

The Muffet bore (GW701958) is understood to have provided stock water on a single property, through a solar-powered pumping system. Other private, single-farm systems are reported to be powered by solar, diesel, and mains powered pumps.

It is understood that the following measures were implemented by Barrick for ameliorating the impacts of pumping at the BCPB on stock/domestic bores:

- From 2006 to 2007:
  - Moora Moora: Replacement of the pump, installation of a new pump to a greater depth and upgrade of the electrical power supply to enable the system to maintain design flow.
  - West Plains and Trigalana: Provision of water through a metered polyethylene pipeline direct to the stock water tanks.
  - Muffet: Replacement of an existing solar powered submersible pump with a new pump of larger capacity, setting of the new pump to a greater depth, and upgrade of the solar panel array to increase its electrical output.
- During 2011:
  - West Plains: The bore failed and Barrick paid for replacement of the bore in mid-2011. The bore was operating by the fourth quarter of 2011.
  - Isolation of the West Plains and West Trigalana schemes from the direct supply of water from the BCPB pipeline (although water could still be supplied in an emergency since the pipelines remain in place).

9.2.4. Cowra Formation Water Source

Modelling results indicate a maximum predicted drawdown of about 32 m at bore GW029574, the only known water bore installed to a depth within the Lower Cowra Formation and within 15 km of the BCPB. It is located 10 km south of BCPB. The bore is 88 m deep and may be able to continue operation if the screen length is sufficiently long and optimally located. If not, contingency measures may be required for this bore.

10. Limitations

Predictive results are subject to the uncertainty inherent in numerical modelling. The numerical model is necessarily a simplification of the real system and relies on calibration to observation data to produce predictive results. The results are estimates only and may differ significantly from future observations. Actual future extraction from the BCPB and ESB may differ from that adopted for predictive simulations.

Further advice on the uses and limitations of this report is presented in the attached document, 'Important information about your Coffey Report'.

11. Recommendations

It is recommended that a statistical analysis be undertaken of the difference between modelled and observed hydrographs (residuals) at DIW trigger piezometers, so that an estimate for an offset to be applied to modelled hydrographs (to accommodate model over prediction) can be obtained for a reasonable probability (say 95% confidence). The probability may need to be negotiated with regulatory agencies. This analysis would require synchronisation of observed water level measurements to modelled output, using interpolation algorithms.

There is uncertainty about historical and future groundwater use by irrigators. As a result, predictions of groundwater level in areas of significant groundwater use for irrigation are uncertain. Mining impacts in these areas associated with proposed future mine operation were assessed. This assessment will need to be reviewed as information about water usage becomes available.

The Warrakimbo bore, located very close to the Maslin bore, is licensed for irrigation and has a large allocation. To match the observed GW036611 hydrograph troughs in November and December 2019, the Maslin bore was estimated to be pumping at 12 ML/day. Previous modelling assumed a pump capacity of 7 ML/day. The Warrakimbo bore may have been in use during these periods of low water levels and it is recommended that potential water usage from this bore is obtained.

Billabong 5 was completed on 23 December 2008 as a replacement for Billabong 1 and 2. The potential for this bore to have been used since 2008, or to be used in the future, is high. To match the observed GW036597 hydrograph troughs in March and November 2019, Billabong bores 4 and 6 were estimated to be pumping at 5 ML/day, a total rate of 10 ML/day. Previous modelling assumed a pump capacity of 4 ML/day. The Billabong 5 bore may have been in use during these periods of low water levels and it is recommended that potential water usage from this bore is obtained.

The numerical model requires updating and verification on a regular basis for it to be used as an effective predictive tool. Model recalibration may be necessary from time to time, using additional observations as they are collected.

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A TETRA TECH COMPANY

Important information about your **Coffey** Report

As a client of Coffey you should know that site subsurface conditions cause more construction problems than any other factor. These notes have been prepared by Coffey to help you interpret and understand the limitations of your report.

Your report is based on project specific criteria

Your report has been developed on the basis of your unique project specific requirements as understood by Coffey and applies only to the site investigated. Project criteria typically include the general nature of the project; its size and configuration; the location of any structures on the site; other site improvements; the presence of underground utilities; and the additional risk imposed by scope-of-service limitations imposed by the client. Your report should not be used if there are any changes to the project without first asking Coffey to assess how factors that changed subsequent to the date of the report affect the report's recommendations. Coffey cannot accept responsibility for problems that may occur due to changed factors if they are not consulted.

Subsurface conditions can change

Subsurface conditions are created by natural processes and the activity of man. For example, water levels can vary with time, fill may be placed on a site and pollutants may migrate with time. Because a report is based on conditions which existed at the time of subsurface exploration, decisions should not be based on a report whose adequacy may have been affected by time. Consult Coffey to be advised how time may have impacted on the project.

Interpretation of factual data

Site assessment identifies actual subsurface conditions only at those points where samples are taken and when they are taken. Data derived from literature and external data source review, sampling and subsequent laboratory testing are interpreted by geologists, engineers or scientists to provide an opinion about overall site conditions, their likely impact on the proposed development and recommended actions. Actual conditions may differ from those inferred to exist, because no professional, no matter how qualified, can reveal what is hidden by earth, rock and time. The actual interface between materials may be far more gradual or abrupt than assumed based on the facts obtained. Nothing can be done to change the actual site conditions which exist, but steps can be taken to reduce the impact of unexpected conditions. For this reason, owners should retain the services of Coffey through the development stage, to identify variances, conduct additional tests if required, and recommend solutions to problems encountered on site.

Your report will only give preliminary recommendations

Your report is based on the assumption that the site conditions as revealed through selective point sampling are indicative of actual conditions throughout an area. This assumption cannot be substantiated until project implementation has commenced and therefore your report recommendations can only be regarded as preliminary. Only Coffey, who prepared the report, is fully familiar with the background information needed to assess whether or not the report's recommendations are valid and whether or not changes should be considered as the project develops. If another party undertakes the implementation of the recommendations of this report there is a risk that the report will be misinterpreted and Coffey cannot be held responsible for such misinterpretation.

Your report is prepared for specific purposes and persons

To avoid misuse of the information contained in your report it is recommended that you confer with Coffey before passing your report on to another party who may not be familiar with the background and the purpose of the report. Your report should not be applied to any project other than that originally specified at the time the report was issued.

Interpretation by other design professionals

Costly problems can occur when other design professionals develop their plans based on misinterpretations of a report. To help avoid misinterpretations, retain Coffey to work with other project design professionals who are affected by the report. Have Coffey explain the report implications to design professionals affected by them and then review plans and specifications produced to see how they incorporate the report findings.

Data should not be separated from the report

The report as a whole presents the findings of the site assessment and the report should not be copied in part or altered in any way. Logs, figures, drawings, etc. are customarily included in our reports and are developed by scientists, engineers or geologists based on their interpretation of field logs (assembled by field personnel) and laboratory evaluation of field samples. These logs etc. should not under any circumstances be redrawn for inclusion in other documents or separated from the report in any way.

Geoenvironmental concerns are not at issue

Your report is not likely to relate any findings, conclusions, or recommendations about the potential for hazardous materials existing at the site unless specifically required to do so by the client. Specialist equipment, techniques, and personnel are used to perform a geoenvironmental assessment. Contamination can create major health, safety and environmental risks. If you have no information about the potential for your site to be contaminated or create an environmental hazard, you are advised to contact Coffey for information relating to geoenvironmental issues.

Rely on Coffey for additional assistance

Coffey is familiar with a variety of techniques and approaches that can be used to help reduce risks for all parties to a project, from design to construction. It is common that not all approaches will be necessarily dealt with in your site assessment report due to concepts proposed at that time. As the project progresses through design towards construction, speak with Coffey to develop alternative approaches to problems that may be of genuine benefit both in time and cost.

Responsibility

Reporting relies on interpretation of factual information based on judgement and opinion and has a level of uncertainty attached to it, which is far less exact than the design disciplines. This has often resulted in claims being lodged against consultants, which are unfounded. To help prevent this problem, a number of clauses have been developed for use in contracts, reports and other documents. Responsibility clauses do not transfer appropriate liabilities from Coffey to other parties but are included to identify where Coffey's responsibilities begin and end. Their use is intended to help all parties involved to recognise their individual responsibilities. Read all documents from Coffey closely and do not hesitate to ask any questions you may have.

Appendix A - Specific Capacity Analysis

Specific capacity (Sc) is the pumping rate divided by the drawdown in the pumped bore at a specified time. The time is usually taken as 1 day, since most tests are of this duration.

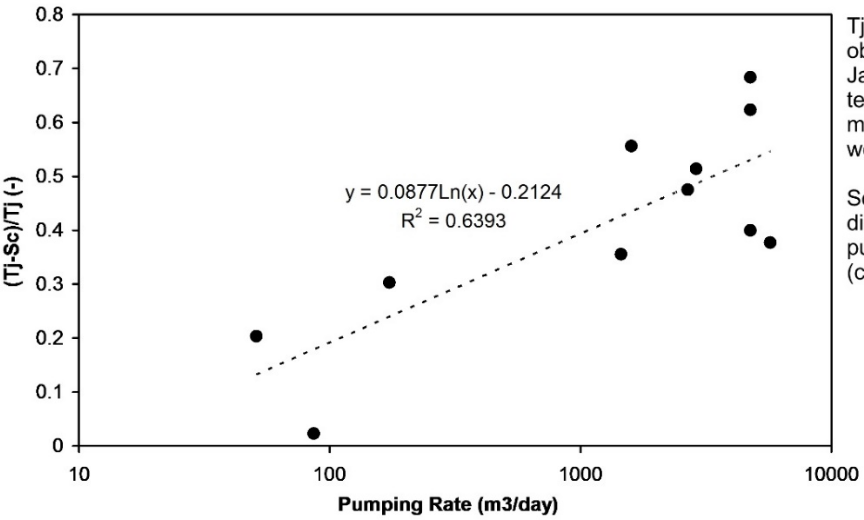
An analysis is undertaken using tests where temporal drawdown data are available. For each test, Sc is calculated at 1 day. Transmissivity (Tj) is interpreted from temporal drawdown at the pumped bore using the Cooper and Jacob (1946) method for confined conditions. The quantity (Tj – Sc)/Tj is then plotted against pumping rate and the relationship approximated with a trendline. This relationship is then used to convert Sc for tests where temporal drawdown is unavailable (the majority of government records). The method assumes the bores in the database are approximately similar in hydraulic behaviour (well loss component), and that dissimilarities in screened lithology are minor.

Table 1 lists the pumping tests (from 9 bores) used to find a relationship, and Figure 1 shows the resulting relationship. For some tests, the drawdown at 1 day was either unavailable or could not be estimated. This adds additional approximation to the fitted line.

Table 1. Bore tests used for specific capacity analysis.

Bore	Screened Formation	Regist-ration Number	Pump-ing Rate (m3/day)	Test Duration (hours)	Tj* (m2/day)	Interpretation	Specific Capacity			(Tj-Sc)/Tj
							Draw-down (m)	Time	Sc (m2/day)	
CGO BCPB Bore 1	Lachlan	GW701660	2894	0.4	662	Coffey 2008	9.0	1 day	322	0.514
CGO BCPB Bore 2	Lachlan	GW701659	4752	24	870	Coffey 2008	9.1	1 day	522	0.400
CGO BCPB Bore 3	Lachlan	GW701658	4752	24	1242	Coffey 2008	12.1	1 day	393	0.684
CGO BCPB Bore 4	Lachlan	GW701657	4752	24	870	Coffey 2008	14.5	1 day	328	0.623
BLRP2 Test 1	Lachlan		2678	48	460	Coffey 1994 (G255/18-AD)	11.1	1 day	241	0.476
BLRP2 Test 2	Lachlan		5702	168	482	Coffey 1995 (G255/24-AJ)	19.0	1 day	300	0.377
Duff 2009	Lower Cowra	GW702230	1452	91	98	GCS 2010 (BARR010)	23.0	End	63	0.356
Duff 2004	Lower Cowra	GW702230	1597	24	104	Coffey 2008	34.6	1 day	46	0.556
PBA	Upper Cowra		173	53	248	Coffey 1994 (G375/1-AF)	1.0	End	173	0.303
PBB	Upper Cowra		86	5	243	Coffey 1994 (G375/1-AF)	0.4	End	237	0.023
PBC	Upper Cowra		51	44	76	Coffey 1994 (G375/1-AF)	0.8	End	61	0.203

*Tj = Transmissivity using Cooper Jacob (1946) method.



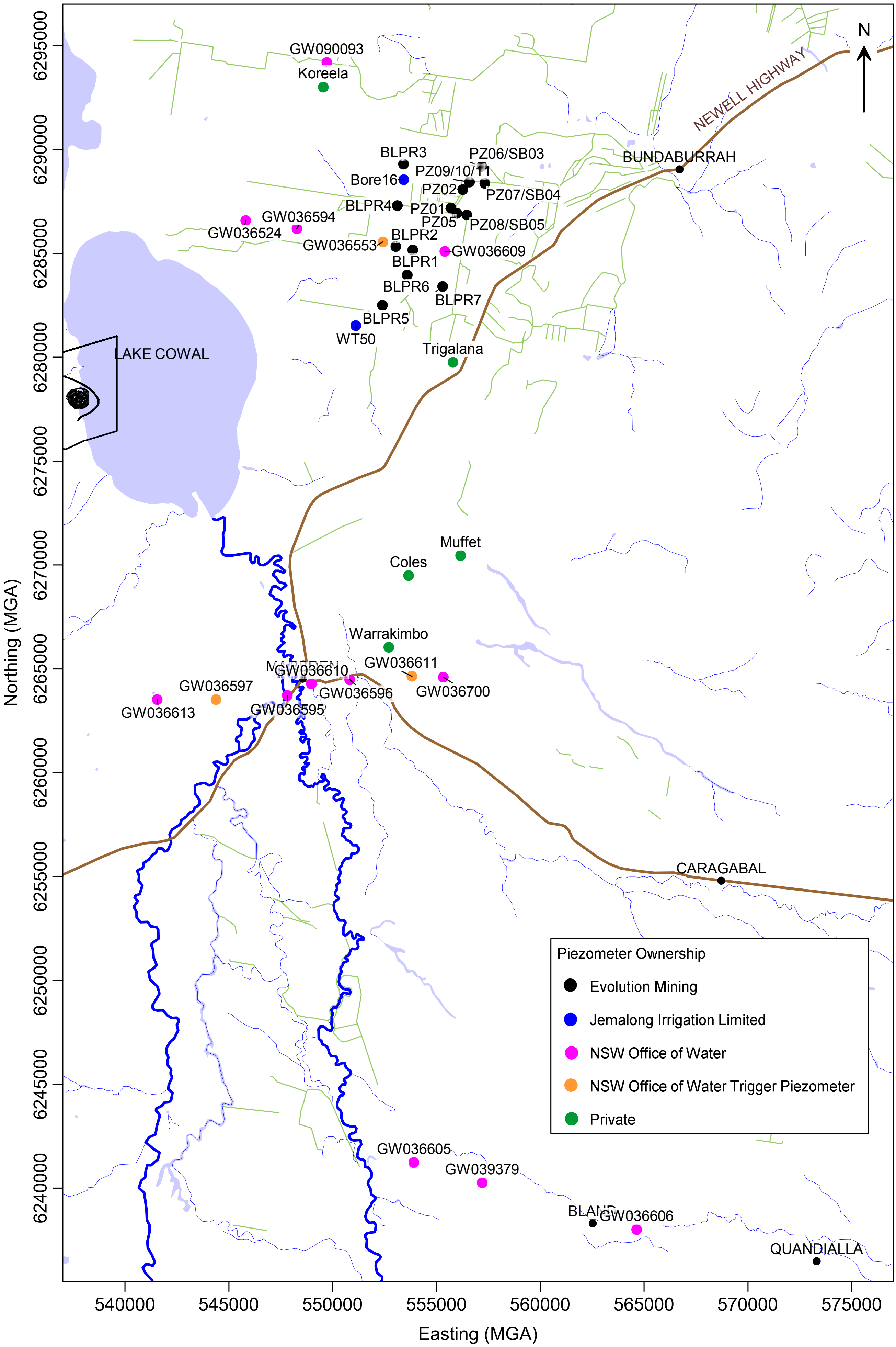
Tj denotes the transmissivity obtained using the Cooper and Jacob (1946) method using temporal drawdown measurements from the pumped well.

Sc denotes the pumping rate divided by the drawdown in the pumped well at a specified time (commonly 1 day).

Figure 1. Results of specific capacity analysis for tests in Table 1.

Appendix B - Groundwater Monitoring Network

Bland Creek Palaeochannel Monitoring Piezometer Network



Bland Creek Palaeochannel Monitoring Bore Network

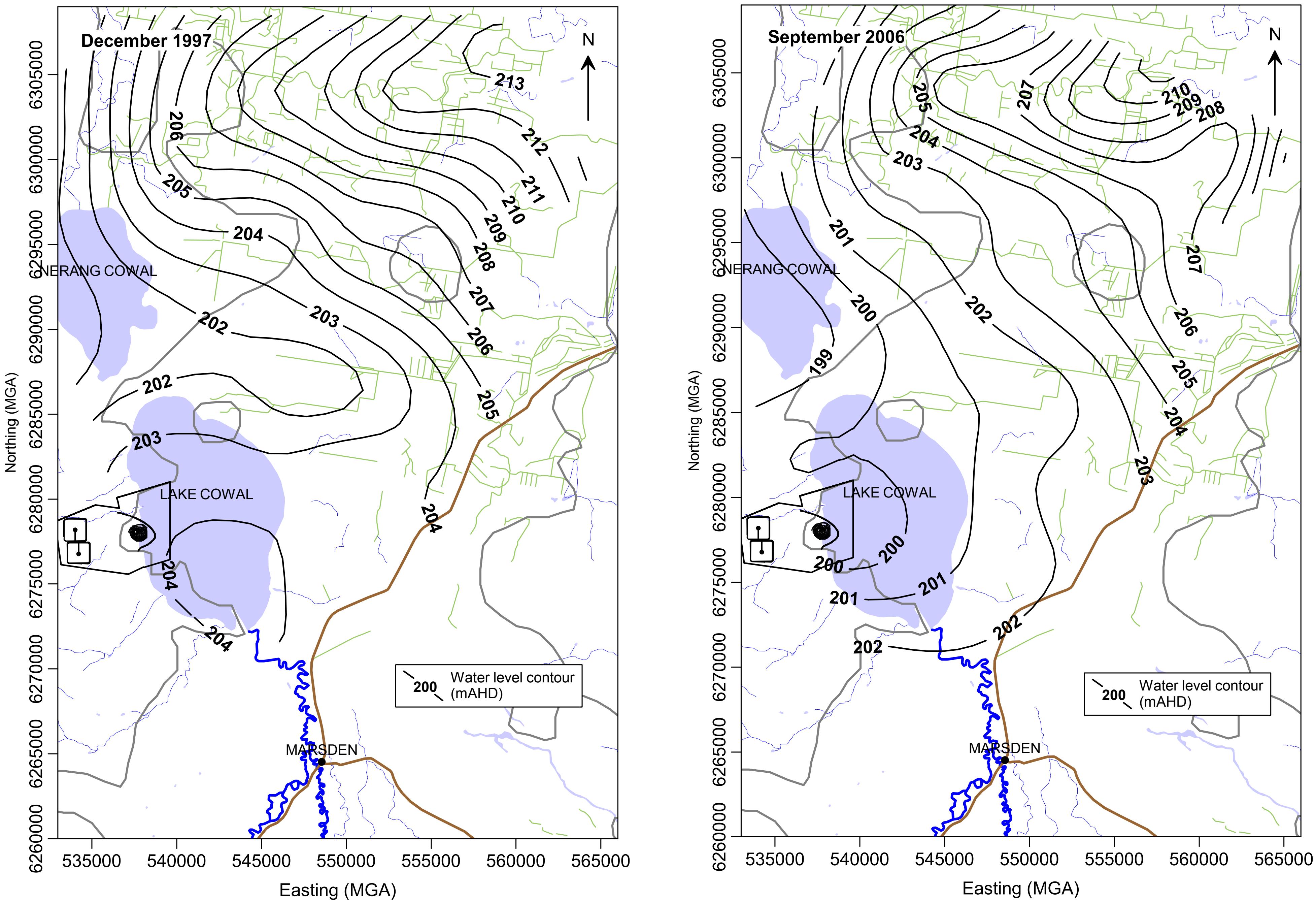
Piezometer / Bore	Owner	Collar Elevation (mAHD)	Easting (mMGA)	Northing (mMGA)	Stratum	Screen (mbgl)		Comment
						From	To	
BLPR1-Ln	Evolution	211.14	553858	6285166	Ln	102	110	BCPB monitoring
BLPR2-Ln	Evolution	209.16	553044	6285330	Ln	106	126	BCPB monitoring
BLPR3-LC	Evolution	210.50	553417	6289305	LC	72	84	BCPB monitoring
BLPR4-Ln	Evolution	210.77	553117	6287305	Ln	94	110	BCPB monitoring
BLPR5-Ln	Evolution	209.61	552392	6282505	Ln	107	120	BCPB monitoring
BLPR6-Ln	Evolution	210.09	553592	6283955	Ln	97	115	BCPB monitoring
BLPR7-Ln	Evolution	210.47	555292	6283405	Ln	103	133	BCPB monitoring
PZ01-UC/LC	Evolution	210.71	555703	6287188	UC/LC	20	80	ESB Monitoring. Decommissioned May 2012.
PZ02-UC/LC	Evolution	210.69	556267	6288075	UC/LC	18	78	ESB Monitoring.
PZ05-UC/LC	Evolution	211.05	555984	6286935	UC/LC	18	78	ESB Monitoring.
PZ06	Evolution	212.09	557239	6289189				ESB Monitoring. Screen interval unknown. Probably UC/LC or LC.
PZ07	Evolution	211.80	557343	6288365				ESB Monitoring. Screen interval unknown. Probably UC/LC or LC.
PZ08	Evolution	210.97	556465	6286840				ESB Monitoring. Screen interval unknown. Probably UC.
PZ09-UC	Evolution	211.19	556580	6288433	UC	13	16	ESB Monitoring
PZ10-LC	Evolution	211.19	556584	6288435	UC/LC	48	51	ESB Monitoring
PZ11-LC	Evolution	211.33	556588	6288437	LC	60	64	ESB Monitoring
SB03	Evolution	211.57	557116	6289198	UC/LC	46	64	ESB Monitoring (outfitted as pumping bore but not pumped)
SB04	Evolution	211.68	557324	6288376	LC	59	65	ESB Monitoring (outfitted as pumping bore but not pumped)
SB05	Evolution	211.06	556447	6286849	LC	58	64	ESB Monitoring (outfitted as pumping bore but not pumped)
Bore16-UC	JIL	211.06	553425	6288550	UC	Water table		Screen interval unknown. Straddles water table.
WT50-UC	JIL	208.56	551121	6281522	UC	Water table		Screen interval unknown. Straddles water table.
GW036524-UC	DIW	207.37	546337	6286862	UC	15	17	Backfilled 89 m. Water levels appear to be representative.
GW036553-Ln	DIW	209.33	552434	6285773	Ln	118	126	
GW036594-LC	DIW	208.79	549558	6286186	LC	69	71	Pipes in same drillhole, but SWLs not the same.
GW036594-UC	DIW	208.79	549558	6286186	UC	11	15	Pipes in same drillhole, but SWLs not the same.
GW036595-LC	DIW	209.32	547929	6263905	LC	85	87	Backfilled 45 m. SWLs appear to be representative.
GW036596-LC	DIW	209.27	550938	6264661	LC	64	66	Pipes in separate drillholes.

Piezometer / Bore	Owner	Collar Elevation (mAHD)	Easting (mMGA)	Northing (mMGA)	Stratum	Screen (mbgl)		Comment
						From	To	
GW036596-Ln	DIW	209.00	550938	6264661	Ln	85	87	Pipes in separate drillholes.
GW036597-Ln	DIW	209.81	544505	6263713	Ln	95	99	Pipes in same drillhole. SWLs same as 36597-LC. Only Ln screen used.
GW036605-Ln	DIW	221.11	554028	6241420	Ln	80	86	
GW036606-Ln	DIW	234.18	564753	6238189	Ln	99	105	
GW036609-Ln	DIW	210.92	554624	6285396	Ln	106	113	
GW036610-LC	DIW	209.33	549088	6264456	LC	64	68	Backfilled 45 m. Water levels appear to be representative.
GW036611-Ln	DIW	209.09	553937	6264823	Ln	107	113	
GW036613-LC	DIW	213.41	541663	6263705	LC	35	45	Backfilled 33 m. Screen in UC but SWLs interpreted as LC.
GW036700-LC	DIW	209.03	555433	6264788	LC	65	75	No backfill.
GW039379-Ln	DIW	223.99	557312	6240441	Ln	74	100	Directly coincident with 36604-Ln (36604-Ln not used).
GW090093-LC	DIW	210.19	549832	6294377	LC	60	66	Pipes in separate drillholes.
GW090093-Ln	DIW	210.12	549832	6294377	Ln	130	136	Pipes in separate drillholes.
GW090093-UC	DIW	210.05	549832	6294377	UC	5	11	Pipes in separate drillholes.
Coles (GW701579)	Private	209.20	553767	6269660	Ln	107	110	
Koreela (GW702262)	Private	212.80	549449	6293272	Ln	117	125	Also in model as a pumping bore.
Muffet (GW701958)	Private	209.00	556272	6270630	Ln	88	93	Also in model as a pumping bore.
Trigalana (GW702286)	Private	208.30	555900	6279959	Ln	102	113	Also in model as a pumping bore.
Warrakimbo (GW701681)	Private	208.00	552812	6266221	Ln			Very close to Maslin Pumping Bore.

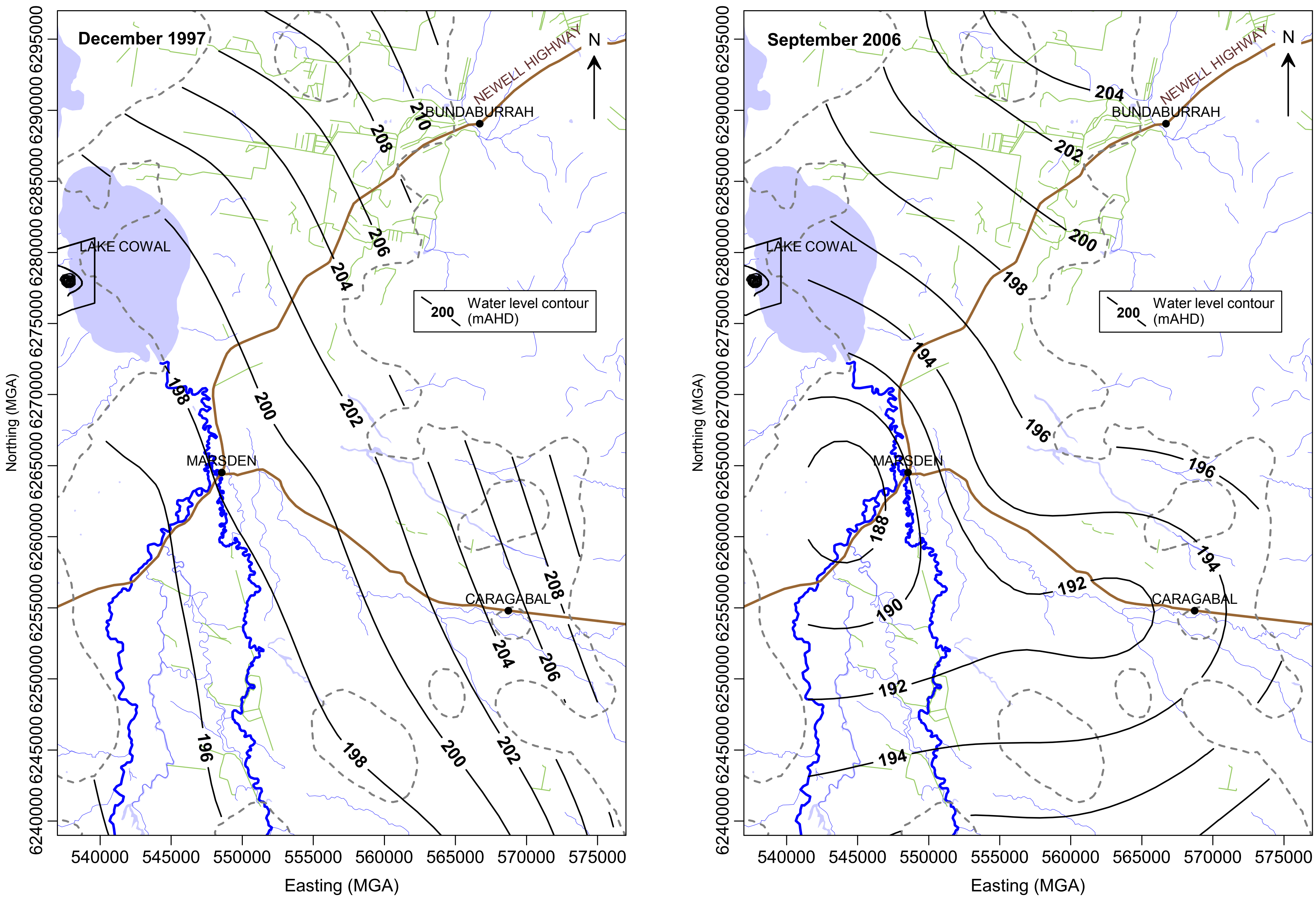
Glossary: JIL denotes Jemalong Irrigation Limited. mbgl denotes metres below ground level. UC denotes Upper Cowra Formation. LC denotes Lower Cowra Formation. Ln denotes Lachlan Formation. SWL denotes standing water level.

Appendix C – Interpolated Hydraulic Head Surfaces

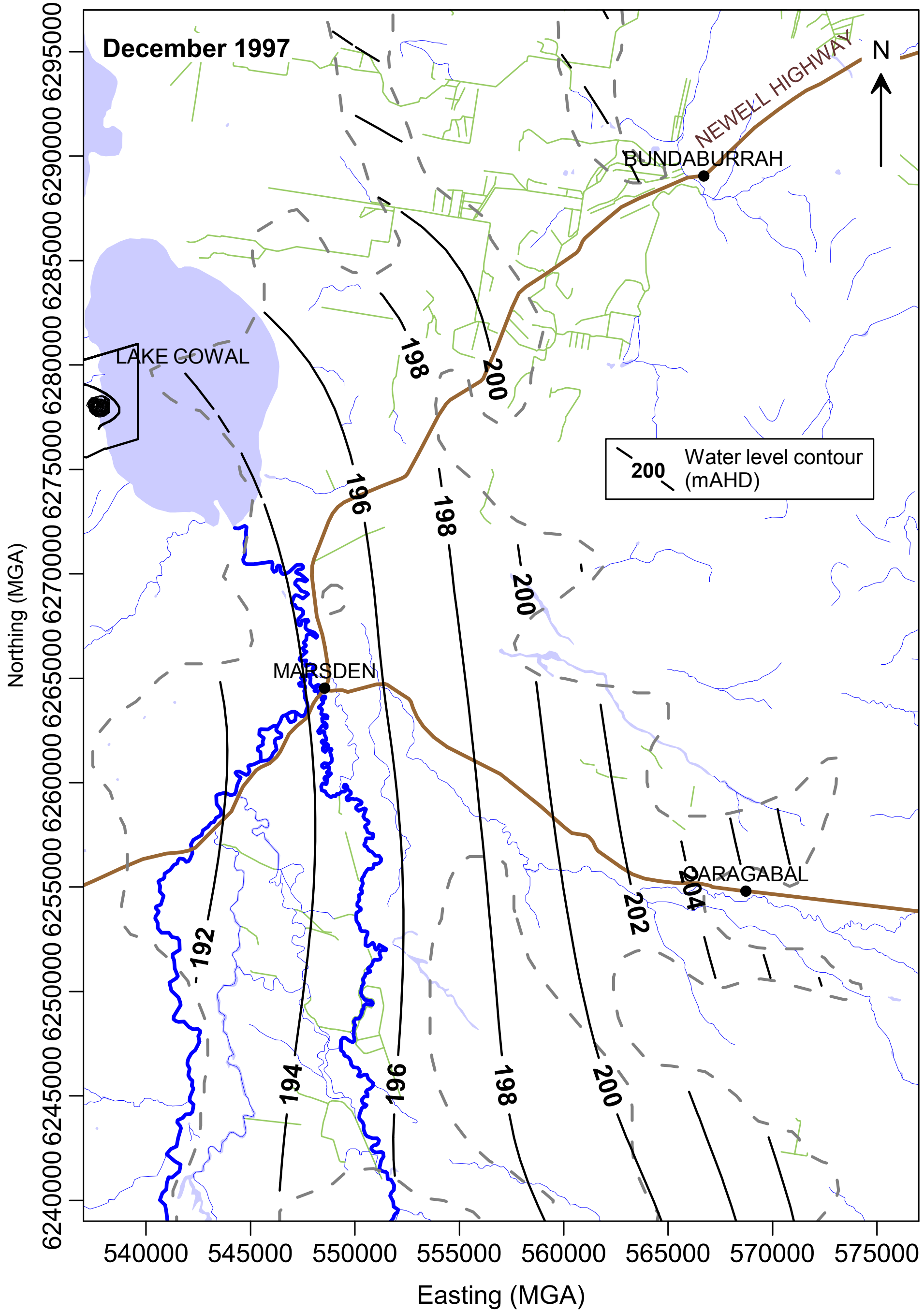
Interpolated Hydraulic Head Surfaces for the Upper Cowra Formation

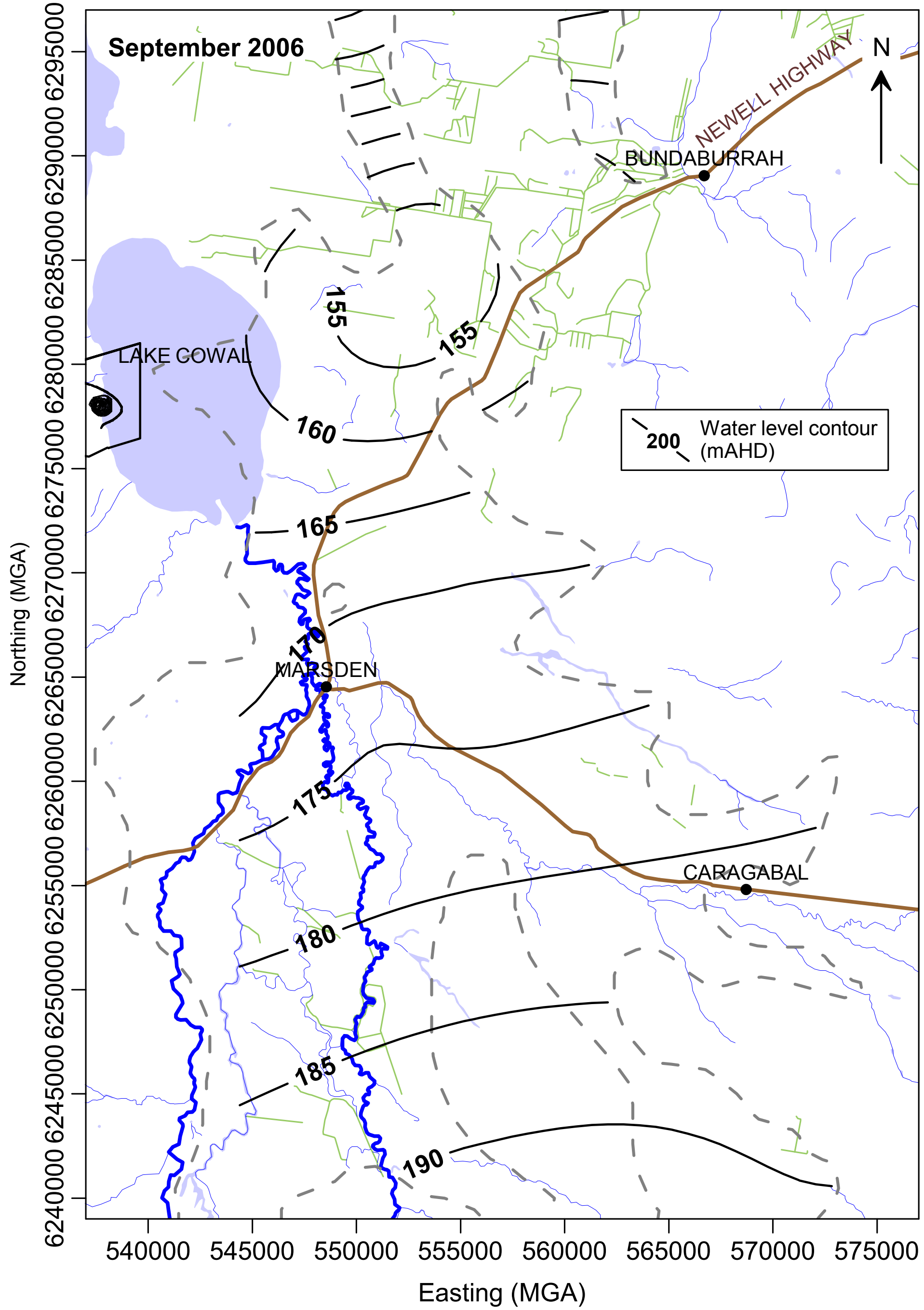


Interpolated Hydraulic Head Surfaces for the Lower Cowra Formation



Interpolated Hydraulic Head Surfaces for the Lachlan Formation





Appendix D - Groundwater Electrical Conductivity Averages

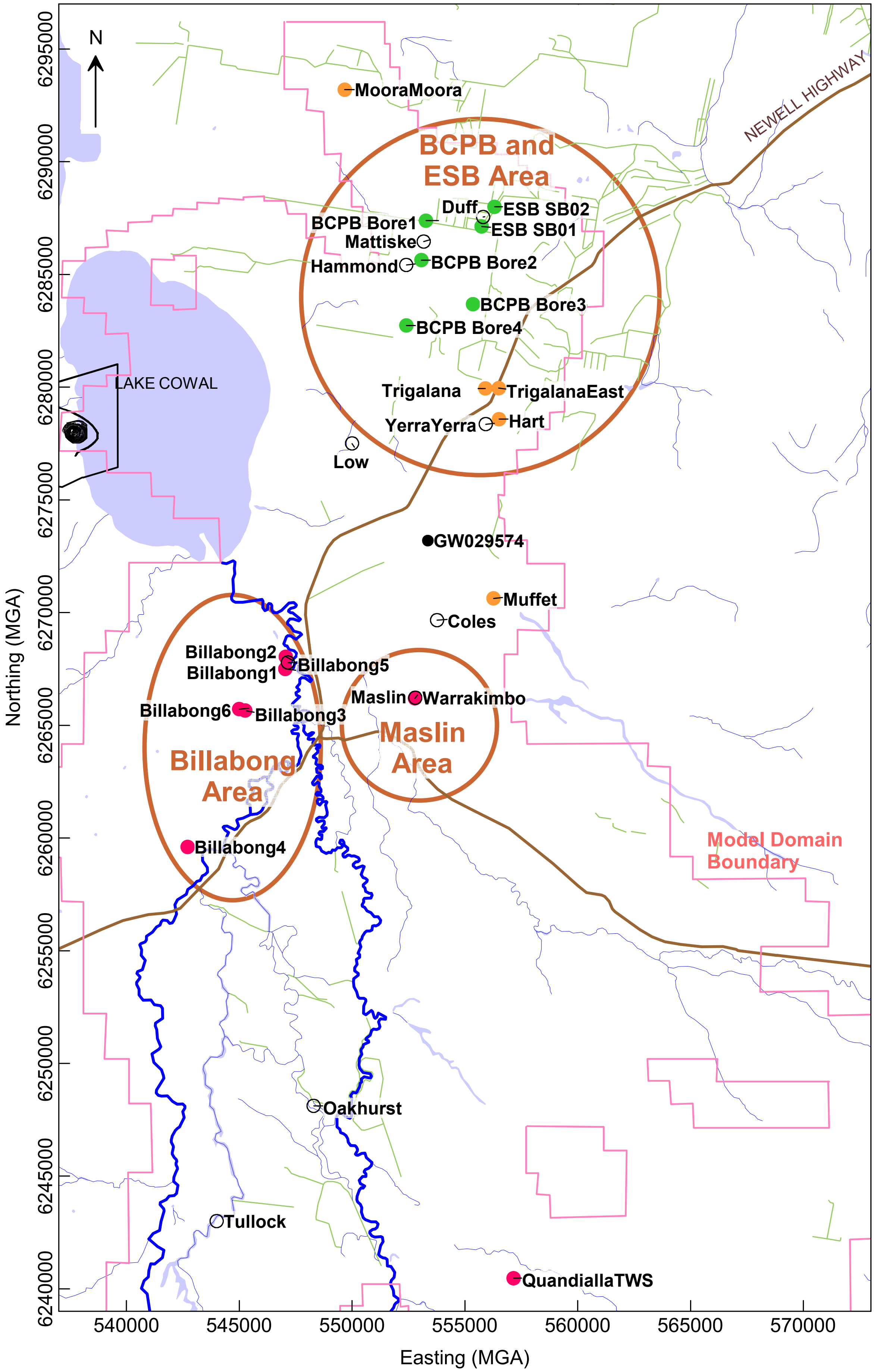
Groundwater Electrical Conductivity Database

Bore	Log-Average EC (uS/cm)	Average EC minus one standard deviation* (uS/cm)	Average EC plus one standard deviation* (uS/cm)	Depth (mbgl)	Data Source
BLPR1 (2004 to 2016)	1933	1848	2023	106	BLPR series averages. Barrick / EM.
BLPR2 (2004 to 2016)	2400	1733	3323	116	
BLPR3 (2004 to 2016)	4979	4810	5153	78	
BLPR4 (2005 to 2016)	2038	1878	2211	102	
BLPR5 (2005 to 2016)	2473	2305	2653	114	
BLPR6 (2004 to 2016)	1917	1831	2007	106	
BLPR7 (2004 to 2016)	1826	1598	2086	118	
P414B (2004 to 2008)	41055	38554	43720	13	Mine Site averages. Barrick / EM.
P417B (2004 to 2008)	32621	29238	36395	11	
P418B (2004 to 2008)	44208	41971	46564	13	
PDB1B (2004 to 2008)	49494	48600	50404	17	
PZ02 (2010 to 2016)	26170	24688	27741	48	ESB averages. Barrick / EM.
PZ05 (2010 to 2016)	6064	4114	8937	48	
PZ09 (2013 to 2016)	24866	23188	26666	15	
PZ10 (2013 to 2016)	9921	8544	11519	50	
PZ11 (2013 to 2016)	13444	11896	15193	62	
SB01 (2011 to 2012)	13258	12404	14171	60	
SB02 (2011 to 2012)	24150	23577	24737	56	
BCPB Bore1	2210			98	BCPB Pumping Bores 1 to 4. Barrick / EM.
BCPB Bore2	2060			90	
BCPB Bore3	1950			94	
BCPB Bore4	3690			93	
BLPR2	1350			116	Coffey report G255/18-AD (1994). Sampled 6 Jan 1994.
BLPR2	1500			116	Coffey report G255/18-AD (1994). Sampled 6 Mar 1994.
BLPR2	1550			116	Coffey report G255/24-AJ (1994). Sampled 12 Apr 1994.
BLPR2	1540			116	Coffey report G255/24-AJ (1994). Sampled 24 Nov 1994.
BLPR4	2020			102	Coffey report G255/24-AJ (1994). Sampled 12 Aug 1994.
BLPR5	610			114	Coffey report G255/24-AJ (1994). Sampled 12 Aug 1994.
BLPR7	1820			118	Coffey report G255/24-AJ (1994). Sampled 12 Aug 1994.
GW036524	50300			15	Government Piezometers (Anderson et al. 1993 and government records).
GW036528	35100			10	
GW036528	22700			38	
GW036528	10570			51	
GW036528	9990			51	
GW036551	35900			4	
GW036551	24700			27	
GW036551	2750			40	
GW036552	11000			33	
GW036552	615			64	
GW036552	1451			101	
GW036553	2100			85	
GW036553	1850			121	
GW036553	1846			121	
GW036554	17000			13	
GW036554	1050			43	
GW036554	351			56	
GW036563	39600			19	
GW036594	45600			13	
GW036594	27400			70	
GW036595	14490			86	
GW036595	14300			86	
GW036596	3100			85	
GW036597	544			18	
GW036597	2370			78	
GW036597	1864			95	
GW036609	1990			106	
GW036610	14550			64	
GW036611	1857			109	
GW036611	1655			109	
GW036613	31700			48	

Green shading indicates single measurement only.
* in log space.

Appendix E - Pumping Bores

Bland Creek Palaeochannel Pumping Bores



- EM CGO bore (active in model).
- Private bore active in model. Usage data available to June 2010, or decommissioning, whichever earlier (except for Billabong 1, where supplied usage data ends June 2004, but bore was decommissioned in March 2006).
- Private bore active in model. No usage data available but necessarily included in model (from 2007) for calibration and predictive periods. Usage estimates supplied by Lachlan Valley Users Group.
- Private bore inactive in model (no usage data available).

Bland Creek Palaeochannel Pumping Bore Manifest (excludes basic rights bores and includes only those in the model domain).

Table 1. Active Pumping Bores in the Model Domain.

Bore Number and/or Name	Owner	Easting (m MGA)	Northing (m MGA)	Ground Elevation (m AHD)	Collar Elevation (m AHD)	Screen Interval (m bgl)		Screened Stratum	Allocation (ML/year)	Comment
						From	To			
Bore1 (GW701660)	Evolution	553276	6287386	209.7	210.4	95	116	Ln	3650	BCPB. Commenced 2004.
Bore2 (GW701659)		553071	6285635	208.7	209.4	92	125	Ln		
Bore3 (GW701658)		555360	6283678	209.4	210.1	107	128	Ln		
Bore4 (GW701657)		552408	6282736	208.5	209.2	108	117	Ln		
SB01 (GW703944)		555740	6287128	210.7	211.3	54	66	LC		ESB. Commenced February 2010
SB02 (GW703943)		556315	6288003	210.6	211.5	45	66	UC/LC		
GW029094 (Billabong 1)	Private	547041	6267503			100	107	Ln	2000	Decommissioned in March 2006. To have been replaced by Billabong 5 in 2008.
GW057974 (Billabong 2)		547180	6268021			96	108	Ln		Decommissioned in March 2004. To have been replaced by Billabong 5 in 2008.
GW701646 (Billabong 3)		545012	6265729		208.0	98	109	Ln		Decommissioned in late 2008. Replaced by Billabong 6.
GW702127 (Billabong 4)		542922	6259675		210.0	108	123	Ln		Commenced October 2005. Replacement for Billabong 1 and Billabong 2.
GW703639 (Billabong 6)		545000	6265720			98	110	Ln		Commenced after 30 June 2008. Replacement for Billabong 3.
GW701267 (Maslin)		552731	6266198				125[1]	Ln	2000	
GW701454 (QuandiallaTWS)		557158	6240472			98	106	Ln	266	
GW701958 (Muffet)		556272	6270630			88	93	Ln	100	Sand pack from 87 m to 95 m bgl.
GW702013 (Hart)		556515	6278585			102	109	Ln		
GW702262 (MooraMoora)		549449	6293272		212.8	117	125	Ln		Also known as Koreela / McDonald.
GW702286 (Trigalana)		555900	6279959		208.3	102	113	Ln		Also known as the Fuge bore.
Trigalana East		556501	6279959				110[2]	Ln		

1. Completed depth (screen details unavailable).
2. Screen base is an estimate based on structure contour surfaces developed for modelling.
Glossary: m bgl denotes metres below ground level. UC denotes Upper Cowra Formation. LC denotes Lower Cowra Formation. Ln denotes Lachlan Formation. SWL denotes standing water level.

Table 2. Pumping Bores in the Model Domain for which no usage data are available (designated inactive in the model).

Bore Number and/or Name	Owner	Easting (m MGA)	Northing (m MGA)	Ground Elevation (m AHD)	Collar Elevation (m AHD)	Screen Interval (m bgl)		Screened Stratum	Allocation (ML/year)	Comment
						From	To			
GW701579 (Coles)	Private	553767	6269660			107	111	Ln		
GW701681 (Warrakimbo)		552812	6266221			96	111	Ln		Used as an observation bore until 2006.
GW702100 (Hammond)		552407	6285421			107	115	Ln		
GW702230 (Duff)		555812	6287547				66[1]	UC/LC		Pump tested for ESB.
GW702285 (Mattiske)		553174	6286458			105	114	Ln	1960	
GW703303 (YerraYerra)		555926	6278354			109	114	Ln		Sand pack from 60 to 115 m bgl.
GW703389 (Oakhurst)		548300	6248113				40[1]	UC/LC		
GW703638 (Billabong 5)		547160	6267785			90	108	Ln		Replacement for Billabong 1 and 2.
Low		550000	6277500						2000	Licence application lodged
Tullock		544000	6243000						2000	Licence application lodged

1. Completed depth (screen details unavailable).
Glossary: m bgl denotes metres below ground level. UC denotes Upper Cowra Formation. LC denotes Lower Cowra Formation. Ln denotes Lachlan Formation. SWL denotes standing water level.

Appendix F - Bland Creek Palaeochannel Numerical Groundwater Flow Model

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Figures

Bland Creek Palaeochannel Numerical Groundwater Flow Model

1. Structure

The model active area covers about 1,800 km^2. Figure 1 shows the calculated extents of the Upper Cowra, Lower Cowra, and Lachlan Formations, and the boundary of the modelled area (for the uppermost model layer).

Figure 2 shows the modelled areas for each of the three model layers. The total extents of the Cowra and Lachlan Formations (calculated from borehole data and bedrock outcrop) are also shown in Figure 2 as the darker lines. The model areas do not extend to the extremities of the calculated total extents of the sediments since in these areas the sediments in each formation thin out considerably and practical limits were applied to the model boundaries. The model grid consists of a uniform mesh of 50 m by 50 m cells over the Bland Creek Palaeochannel Borefield (BCPB) area (covering an area of about 36 km^2) gradually expanding to a maximum cell size of 1 km by 1 km at the edges of the model area. Cell dimensions increase by a factor of 1.2 between cells to maintain model stability and allow accurate calculation of heads.

The groundwater system is simulated using three layers as follows:

- Layer 1: The Upper Cowra Formation (unconfined). The base of the Upper Cowra is set to 47 m below ground level based on hydraulic conductivity (K) data and downhole gamma logs from bores in the vicinity of the BCPB.
- Layer 2: The Lower Cowra Formation (confined / unconfined).
- Layer 3: The Lachlan Formation (confined / unconfined).

The Upper Cowra Formation has one parameter zone (see Figure 2). The Lower Cowra Formation has three parameter zones (northern, central, and southern) of approximately equal extent, broadly based on geology. The Lachlan Formation has two parameter zones representing:

- High K sands and gravels close to and within the deeper parts of the palaeochannel.
- Lower K, finer-grained sediments that generally occur further away from the deeper parts of the paleaochannel and surround the high K sands and gravels.

K measurements indicate that bedrock K is probably about 1000 times lower, at the same depth, than the high K part of the Lachlan Formation in the deeper parts of the palaeochannel (about 100 m depth). Therefore, bedrock in the Bland Creek Palaeochannel underlying the alluvial sequence has been assumed to be impermeable for the purpose of numerical simulation, and has not been modelled. This is considered reasonable since the rock occurs at burial depths exceeding 100 m (significantly lowering its hydraulic conductivity), and is separated from the alluvial sequence by a low K clay palaeosol of several metres thickness.

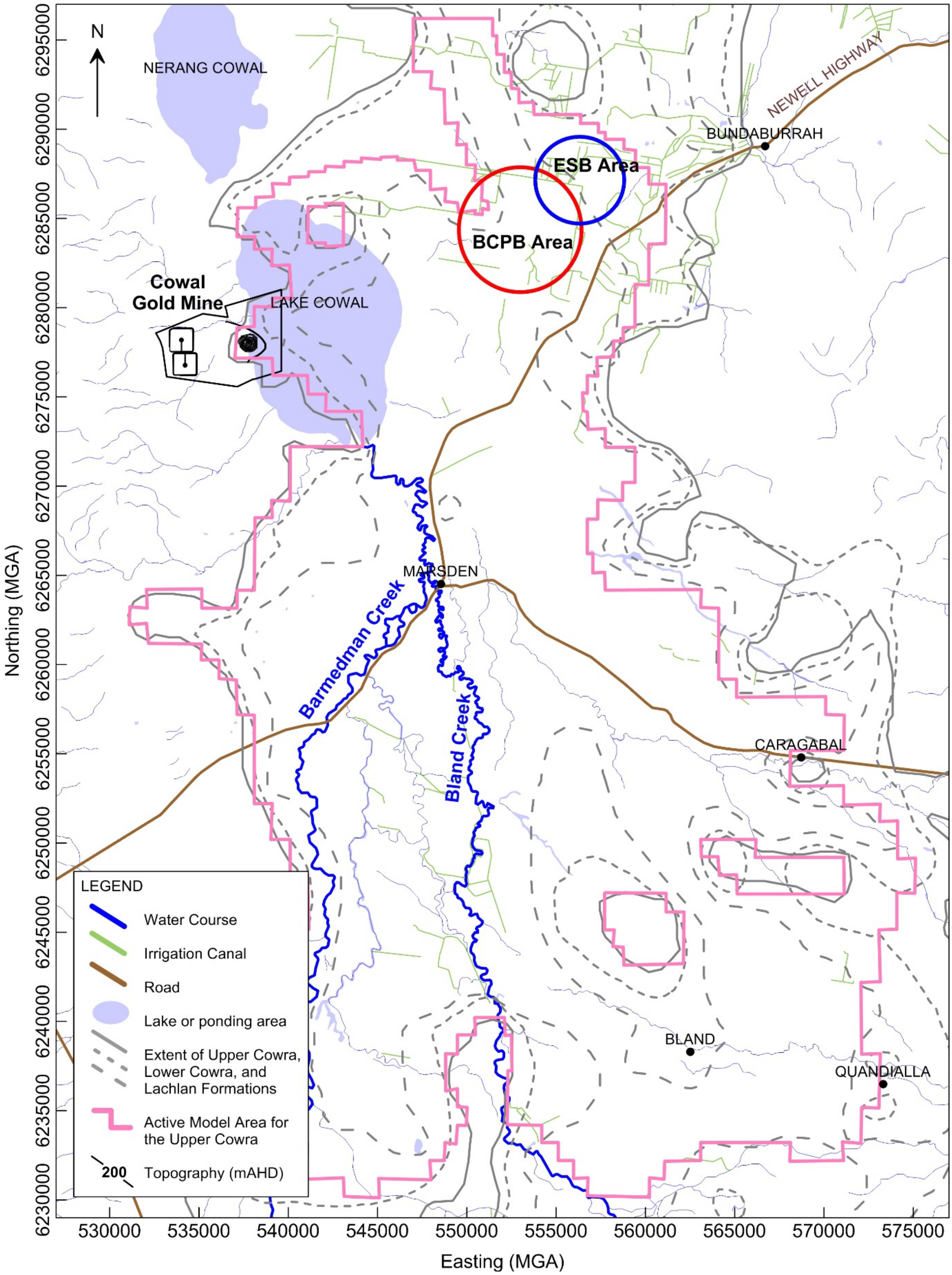
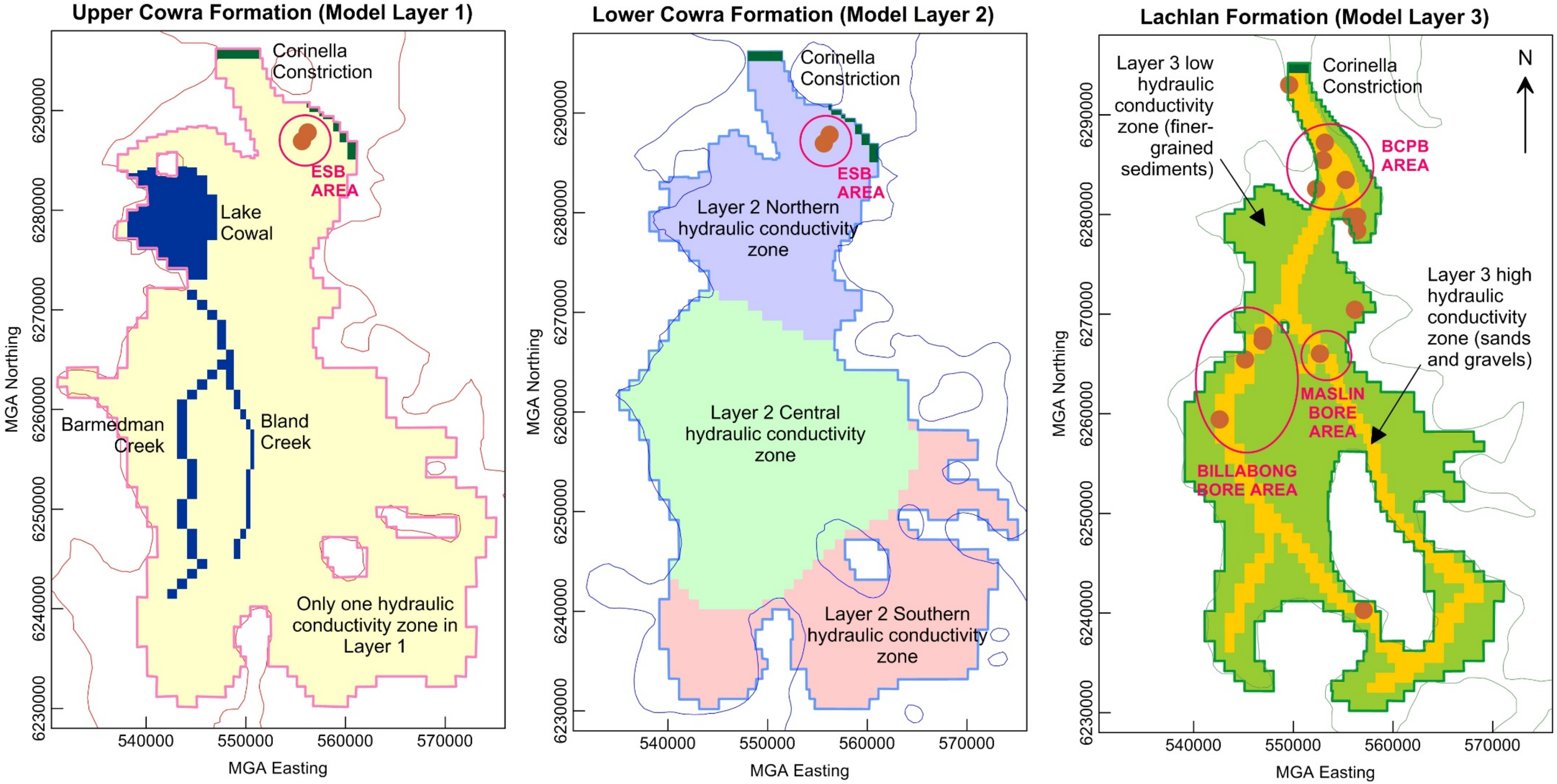


Figure 1. Model domain boundary.



NOTE:
1. Thicker lighter-coloured lines indicate model layer boundaries.
2. Thinner darker-coloured lines indicate interpreted total extents of the formations (to zero thickness).
3. Storativity parameter zones are the same as K parameter zones.

BOUNDARY CONDITIONS:
- General Head
- River or lake
- Pumping well

Figure 2. Layer parameter zones and boundary conditions.

2. Boundary conditions

Model boundary conditions are illustrated in Figure 2 and described below.

Rainfall recharge is applied at a uniform percentage of incident rainfall (on a daily, monthly, or yearly basis, depending on stress period size) over the entire extent of the Cowra Formation in the model domain.

The northern boundary of the model was chosen at a point where narrowing of the Bland Creek Palaeochannel is interpreted to occur in the Lachlan Formation at the Corinella Constriction (see Figure 2). Including the area to the north of this point and beyond would have involved the added complexity of treatment of the Lachlan Valley groundwater system and the associated groundwater interactions. To allow groundwater flow across this boundary, a general head condition was applied in all three layers. The general head boundary conditions assigned at this location allow aquifer flow to enter and leave the model at a rate proportional to the difference in head across the boundary.

Parameters for the general head boundaries were initially calculated by assuming that the Lachlan River and Goobang Creek to the north act as ultimate hydraulic controls, and calculating the conductances based on average cell widths, distances to these boundaries from the Corinella Constriction, and estimated layer hydraulic conductivities over this distance. Conductances were then varied slightly during calibration based on the hydrograph for the Koreela bore and government monitoring piezometer GW090093 (see Appendix B of the main report).

Based on a review of stream flow and river stage data from the Government Pinneena database, and field observations, the following water courses have been included in the model using the River package:

- Barmedman and Bland Creeks near Lake Cowal.
- Lake Cowal.

These water courses were selected based on groundwater hydrographs and duration of water flow. Riverbed elevations were assessed from topographic maps, digital elevation data, and stream gauging station survey information. These data were used to assign smoothly-varying riverbed elevations over the model area for the creeks and Lake Cowal. River water level heights were obtained from the Pinneena database. Water levels for Lake Cowal were estimated from data presented in the Cowal Gold Project Environmental Impact Statement (North Limited 1998).

Leakage from Lake Cowal is expected to flow in a northwesterly direction, out of the model active area. To the northwest of Lake Cowal lies Nerang Cowal and a thin cover of surface soil overlying rock. In the model, flow of lake leakage is not possible from the lake to the northwest (because the Upper Cowra Formation is not present there), therefore the calibrated conductance of the lake bed material allows only that flow which reports to the active area of the Upper Cowra Formation in the model.

The CGO Western Saline Borefield (WSB) is located in the mine lease and is included in a separate local groundwater model for the mine lease area, and is not included in the regional model of the current work. The WSB pumps from the Upper Cowra Formation only, at relatively small rates, and is considered unlikely to significantly affect drawdown in the Upper Cowra, Lower Cowra, or Lachlan Formations further east.

The CGO mine pit is included in the separate local groundwater model and is not included in the regional model. The mine pit is located on the western margin of the regional model and intersects alluvial sediments, saprolite (clay), and fractured media. The alluvial sediments are the equivalent of the Upper Cowra Formation. They have been slightly impacted by drainage into the mine pit. The

Lower Cowra and Lachlan Formations are not present at the mine site. The drawdown in the Upper Cowra Formation from pit drainage has been small and localised, and is considered unlikely to significantly affect drawdown in the Upper Cowra, Lower Cowra, or Lachlan Formations further east. Drawdown in the saprolite, saprock, and fresh rock from drainage at the mine pit is not likely to influence groundwater processes in the active model area, apart from the localised effect near the pit of inducing vertical drainage from the Upper Cowra Formation (in addition to lateral drainage towards the pit face).

18 pumping bores are active in calibration, verification, or predictive model simulations. These comprise six Evolution bores (4 at the BCPB and 2 at the ESB) and 12 private bores. Appendix E of the main report lists these bores and their details. Low-extraction basic rights bores (used for stock and domestic purposes) are not included.

2.1. Recharge and discharge processes

Model recharge processes are:

- Rainfall recharge.
- Leakage from rivers (Bland Creek and Lake Cowal).
- Flow into the model from the Corinella Constriction in all layers.

Model discharge processes are:

- Groundwater extraction from the Upper Cowra, Lower Cowra, and Lachlan Formations.
- Leakage to rivers (Bland Creek and Lake Cowal).
- Flow out of the model to the Corinella Constriction in all layers.

Evaporation is not modelled because the average depth of the water table in the Upper Cowra Formation is around 5 m over the majority of the model domain, and below the extinction depth typical for the land use, surface lithology, and climate of the area.

Intermittent recharge from flooding from remnant ponds outside the water course channels is not modelled in calibration simulations since no flooding was known to have occurred in the area during the model calibration period. However, the calibrated riverbed conductances and rainfall recharge would incorporate the effect of this process where it may have occurred but was not explicitly identified in observations.

3. Media properties

Calibrated model media properties are listed in Table 1.

Initial estimates for riverbed conductance were based on consideration of values used for river systems in the Lower Namoi Valley groundwater flow model (Merrick 1989). The Lower Namoi Valley and Bland Creek Palaeochannel display many similar characteristics such as climate, subsurface media types, and river types.

Automated parameter estimation conducted as part of the 2006 modelling process indicated that the calibrated values for various parameters were considered defensible and appropriate based on site-specific observations, published studies, and model formulation. A finding of the estimation study was that in the more southerly parts of the model domain the vertical leakance in the Cowra Formation was likely to be lower than the calibrated value of the 2006 model. It was considered that, based on available data, the vertical leakance between the Cowra and Lachlan Formations was likely to decrease in a southerly direction. This finding was taken into account by dividing the Lower Cowra Formation into three zones (northern, central, and southern) of approximately equal extent, broadly based on geology, so that vertical leakance could be varied between zones.

Table 1. Calibrated model media properties.

Parameter	Model Zone					
	Upper Cowra	Lower Cowra (North)	Lower Cowra (Central)	Lower Cowra (South)	Lachlan (Low Conductivity)	Lachlan (High Conductivity)
Lateral Hydraulic Conductivity (m/day)	1	2	1	1	3	28
Average Thickness over Model Area (m)	35	34	34	34	30	30
Average Transmissivity over Model Area (m^2/day)	35	68	34	34	90	840
Vertical Hydraulic Conductivity (m/day)	6×10^{-5}	1×10^{-5}	6×10^{-6}	1×10^{-5}	3	28
Specific Storage (m^{-1})	N/A	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}	1.5×10^{-5}
Specific Yield	0.04	N/A	N/A	N/A	N/A	N/A
General Head Boundaries						
External Head (mAHD)	198	196	N/A	N/A	N/A	196
Conductance (m^2/day)	1	1	N/A	N/A	N/A	25
River Bed Conductance (m^2/day):						
Bland and Barmedman Creeks	10	N/A	N/A	N/A	N/A	N/A
Lake Cowal	5	N/A	N/A	N/A	N/A	N/A
Rainfall Recharge (% of average annual rainfall)	1.0	N/A	N/A	N/A	N/A	N/A

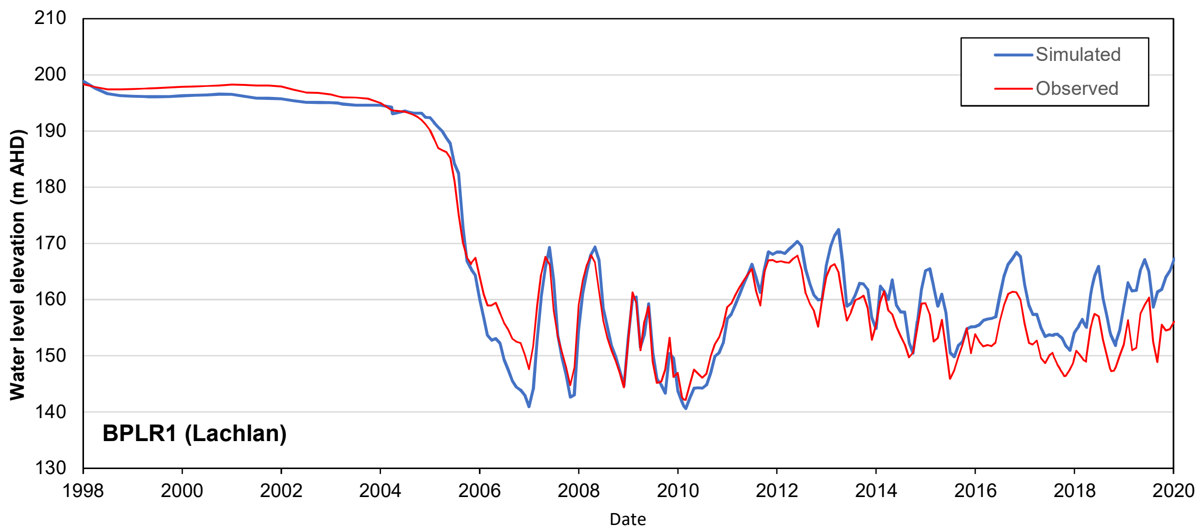
Assuming an average river channel width of 20 m (including overbank ponds), an average river reach of 1200 m in each cell, and 0.2 m of barrier material in the river bottom, the calibrated riverbed conductance for Bland and Barmedman Creeks is equivalent to a vertical hydraulic conductivity for the river bed barrier material of 9×10^{-5} m/day. For Lake Cowal leakage occurs over the entire area of each cell so the riverbed conductance is equivalent to a vertical hydraulic conductivity in the lake bed material of 1×10^{-6} m/day. This compares favourably with results from laboratory analysis of lakebed sediments indicating an average vertical hydraulic conductivity of 5.0×10^{-7} m/day (Hawkes

1998), allowing for upscaling from a laboratory sample scale to a regional scale. Hydraulic test results in Hawkes (1998) also indicate an average lateral hydraulic conductivity for the lake bed material of 5.5 x 10^{-5} m/day for one location on the lake.

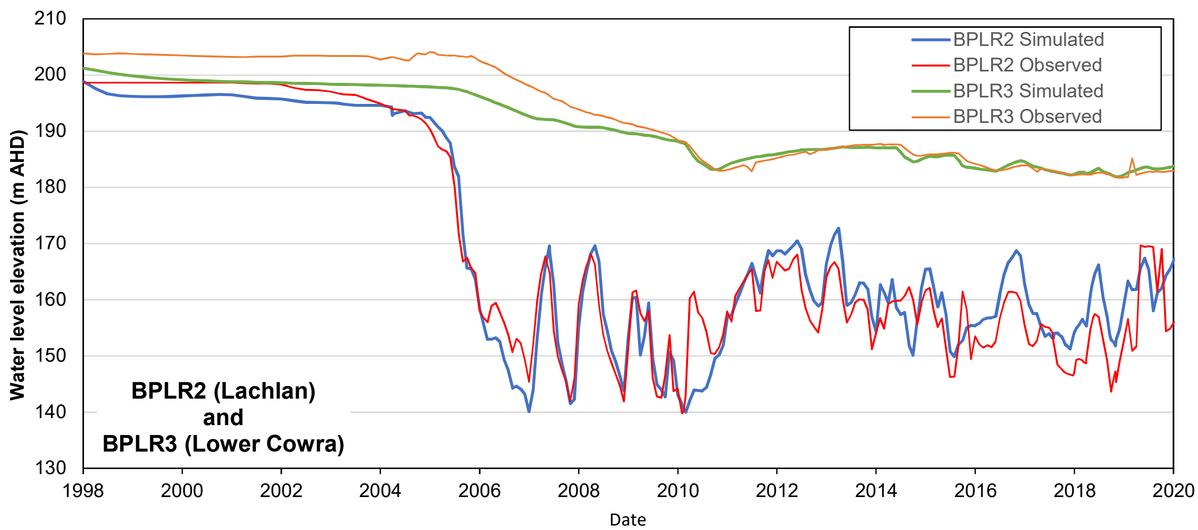
Rainfall recharge is calibrated to 1% of annual rainfall and compares favourably with other estimates for the area (between 0.3% and 2%). It is an overall average for the model area, mostly comprising recharge from rainfall and irrigation, but also likely to contain a small component representing seepage from shallow, higher conductivity rock on the fringes of the alluvial sediments. It is also likely that the calibrated value includes the effects of intermittent ponding associated with water courses.

The calibrated specific storage (1.5 x 10^{-5} m^{-1}) compares favourably with pump test results (average of around 9 x 10^{-6} m^{-1}).

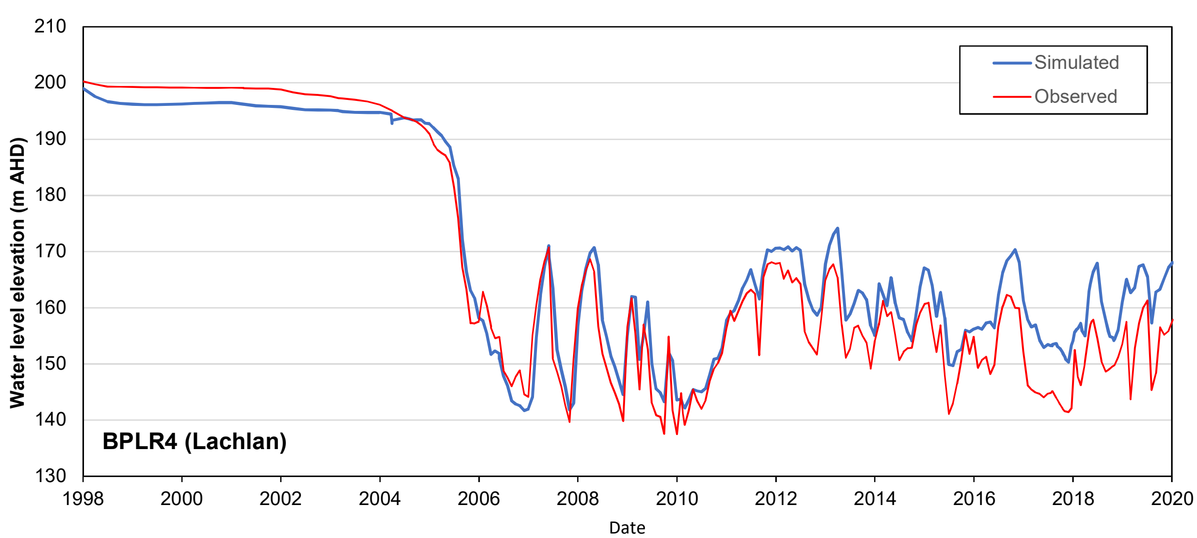
Appendix G - Verification Hydrographs



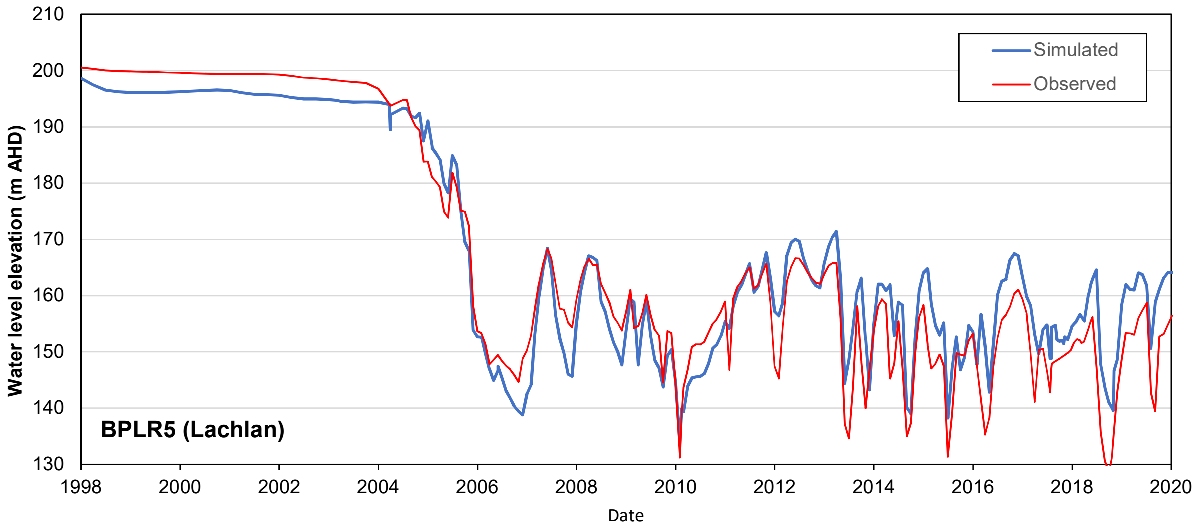
Simulated
Observed
BPLR1 (Lachlan)
Water level elevation (m AHD)
Date

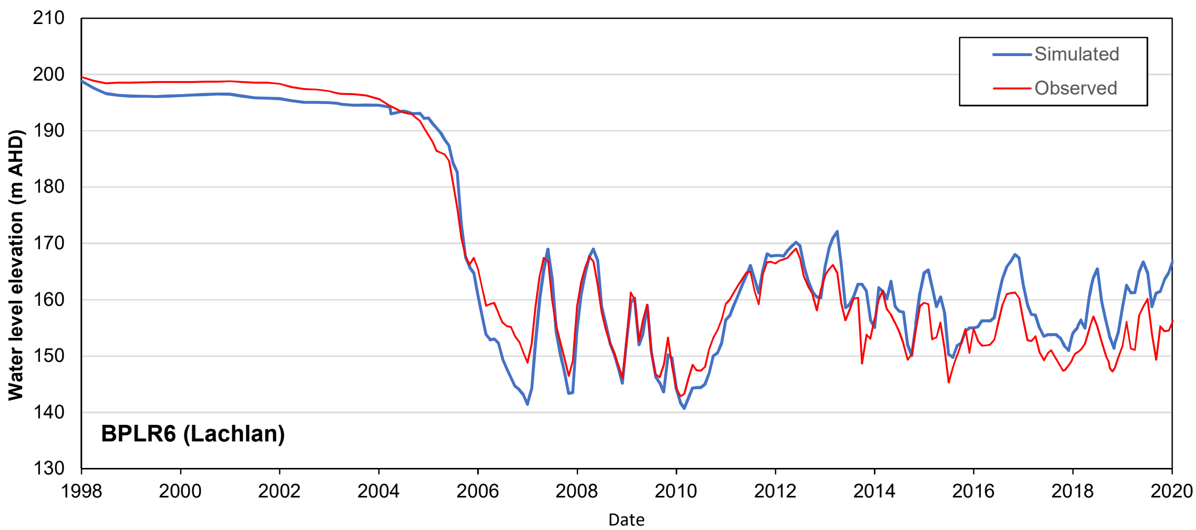


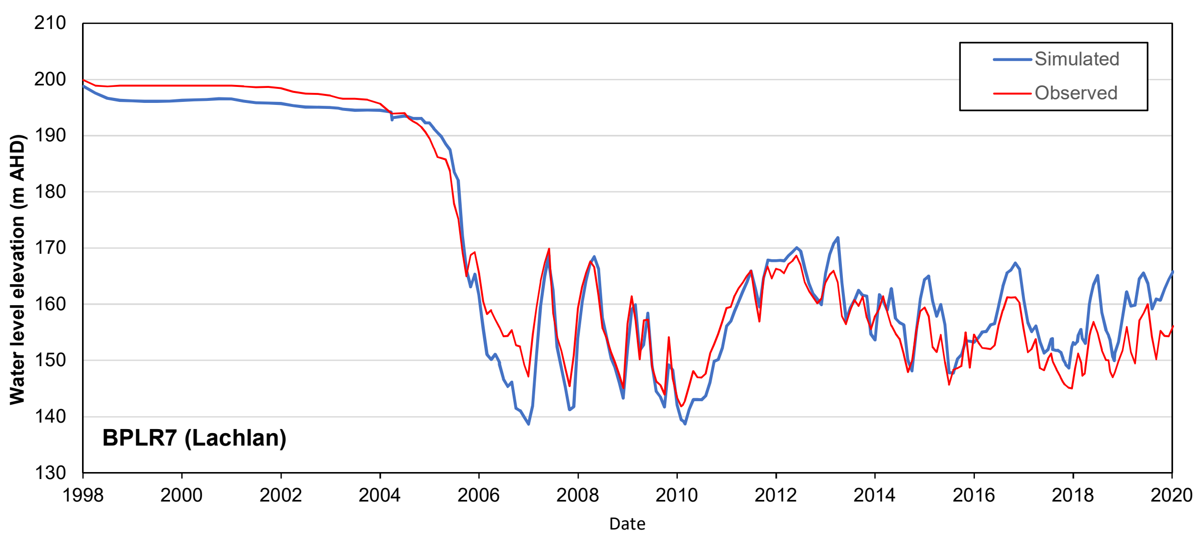
BPLR2 Simulated
BPLR2 Observed
BPLR3 Simulated
BPLR3 Observed
BPLR2 (Lachlan)
and
BPLR3 (Lower Cowra)
Water level elevation (m AHD)
Date

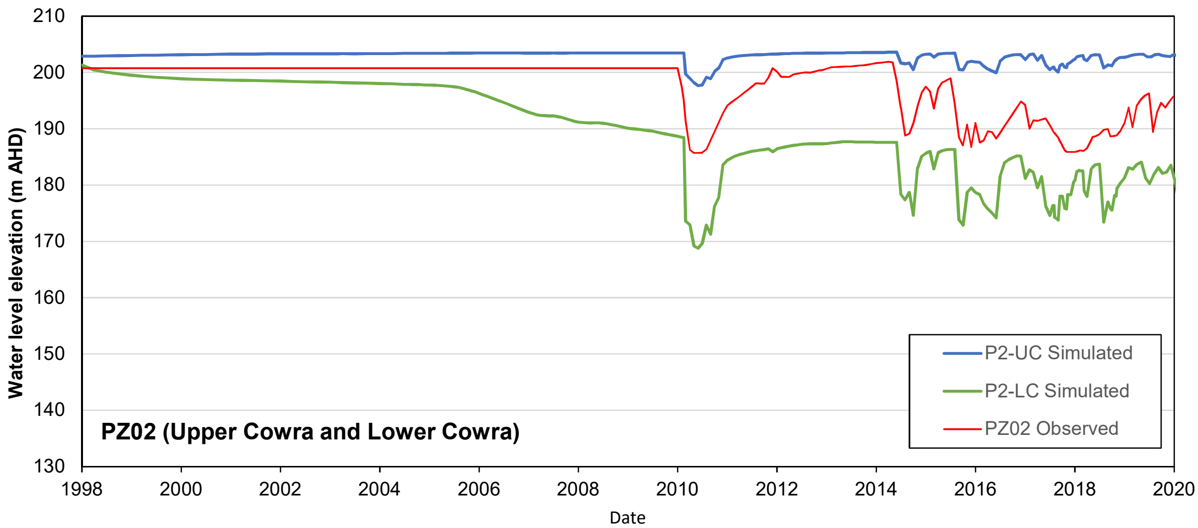


Simulated
Observed
BPLR4 (Lachlan)
Water level elevation (m AHD)
Date


210
200
190
180
170
160
150
140
130
Water level elevation (m AHD)
Simulated
Observed
BPLR5 (Lachlan)
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Date


210
200
190
180
170
160
150
140
130
Water level elevation (m AHD)
Simulated
Observed
BPLR6 (Lachlan)
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Date

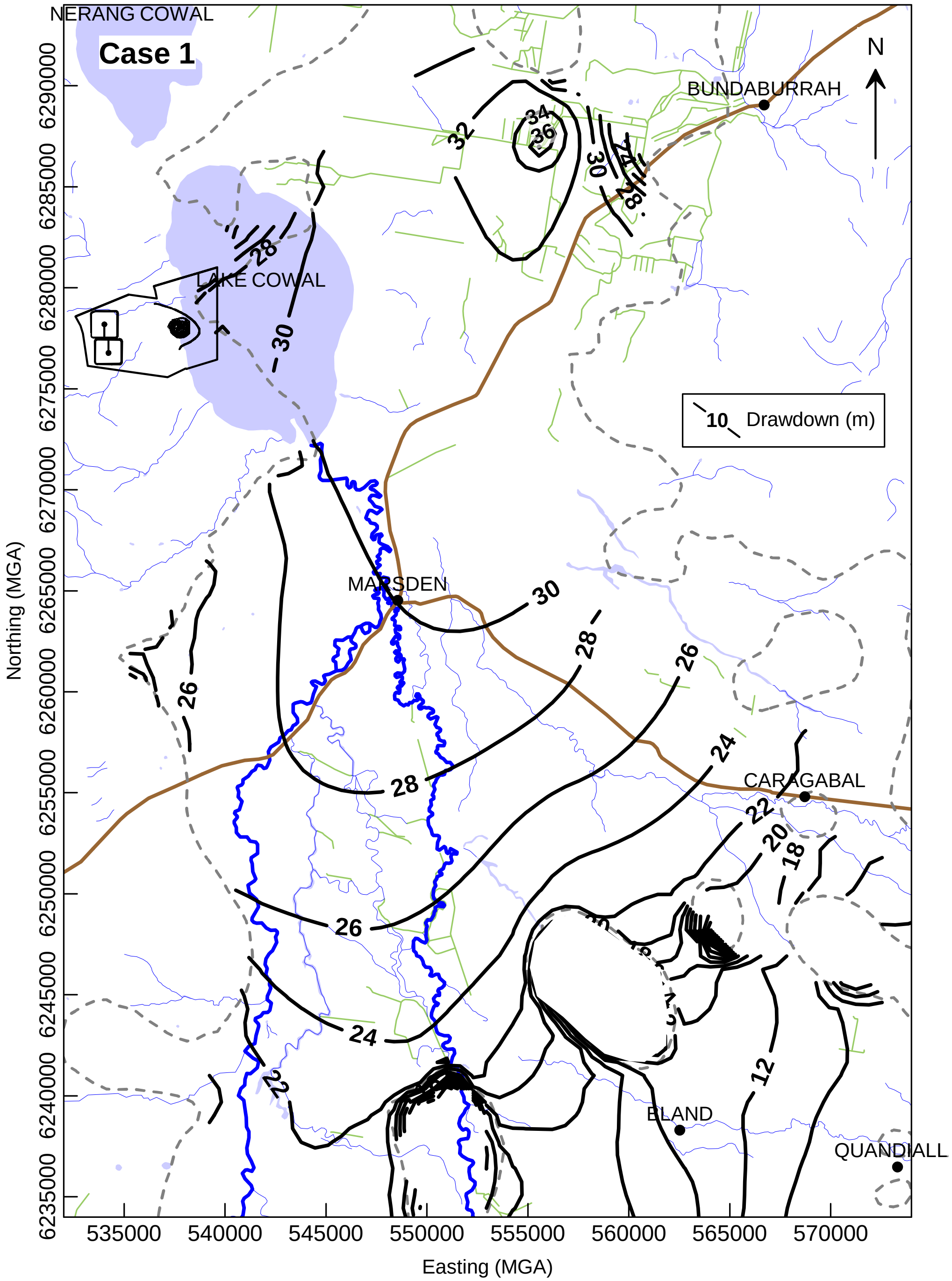

210
200
190
180
170
160
150
140
130
Water level elevation (m AHD)
Simulated
Observed
BPLR7 (Lachlan)
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Date



210
200
190
180
170
160
150
140
130
Water level elevation (m AHD)
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
Date
PZ02 (Upper Cowra and Lower Cowra)
P2-UC Simulated
P2-LC Simulated
PZ02 Observed

Appendix H - Drawdown in the Lower Cowra and Lachlan Formations at the end of BCPB and ESB Operation (30 June 2040)

Drawdown in the Lower Cowra Formation at the end of BCPB and ESB Pumping (30 June 2040)



Drawdown in the Lachlan Formation at the end of BCPB and ESB Pumping (30 June 2040)