3. Conceptualisation and model study plan

A detailed conceptual model of the assessment area was developed in conjunction with the numerical groundwater model. A conceptual model diagram showing the main features of the assessment area is shown in Figure 3.1. The conceptual model is described in detail in the Cobbora Coal Project – Groundwater Assessment (Parsons Brinckerhoff 2013a) and a summary is presented in Section 3.1 of this document. The construction of the numerical groundwater model is described in Section 3.2.

3.1 Conceptual model

3.1.1 Groundwater flow

Within the assessment area and immediate surrounds groundwater occurs within four regionally important groundwater systems:

1. the alluvium aquifer associated with unconsolidated sediments of the Talbragar River, and also minor alluvium associated with the tributaries to the Talbragar River (Sandy Creek and Laheys Creek)
2. the porous rock aquifer within the Permo-Triassic sediments of the Gunnedah-Oxley Basin
3. porous rock aquifers of Jurassic age
4. fractured rock aquifers within the metamorphic basement rocks of the Lachlan Fold Belt.

Of these, the first two aquifer systems are the most important in the assessment area with regard to groundwater and surface water impacts.

The Permo-Triassic coal measures and sandstone units form an open folded and faulted sequence of porous rocks that unconformably overlie the low permeability basement rocks of the Lachlan Fold Belt. Groundwater monitoring indicates that the Permo-Triassic rocks act essentially as a single (but heterogeneous) porous aquifer unit of low to moderate permeability. Within the major river and stream valleys, alluvial deposits comprising mostly sandy and gravelly clays form minor aquifers. Although the alluvium directly overlies the Permo-Triassic rocks, this study has shown that the alluvium aquifers are distinct systems that are locally recharged and hydraulically poorly connected to the regional Permo-Triassic aquifer.

Jurassic rocks associated with the Great Artesian Basin occur to the north of the Talbragar River. However, much of the Jurassic rocks in the assessment area are disconnected outliers and are considered part of the Gunnedah-Oxley Basin for water management purposes. The basal unit of the Jurassic rocks (Purlawaugh Formation) comprises shales and interbedded sandstones and therefore the aquifer units of the Jurassic formations are considered not to be hydraulically connected to the underlying Permo-Triassic aquifers.

Groundwater levels and flow direction are mainly influenced by geology and topography with the latter mainly controlling the location of major hydraulic boundaries: areas of recharge at outcrop along ridges and interfluves; and areas of discharge along major streams and rivers. Groundwater flow is also controlled locally by geology, stratigraphic dip, faulting and episodic flooding.

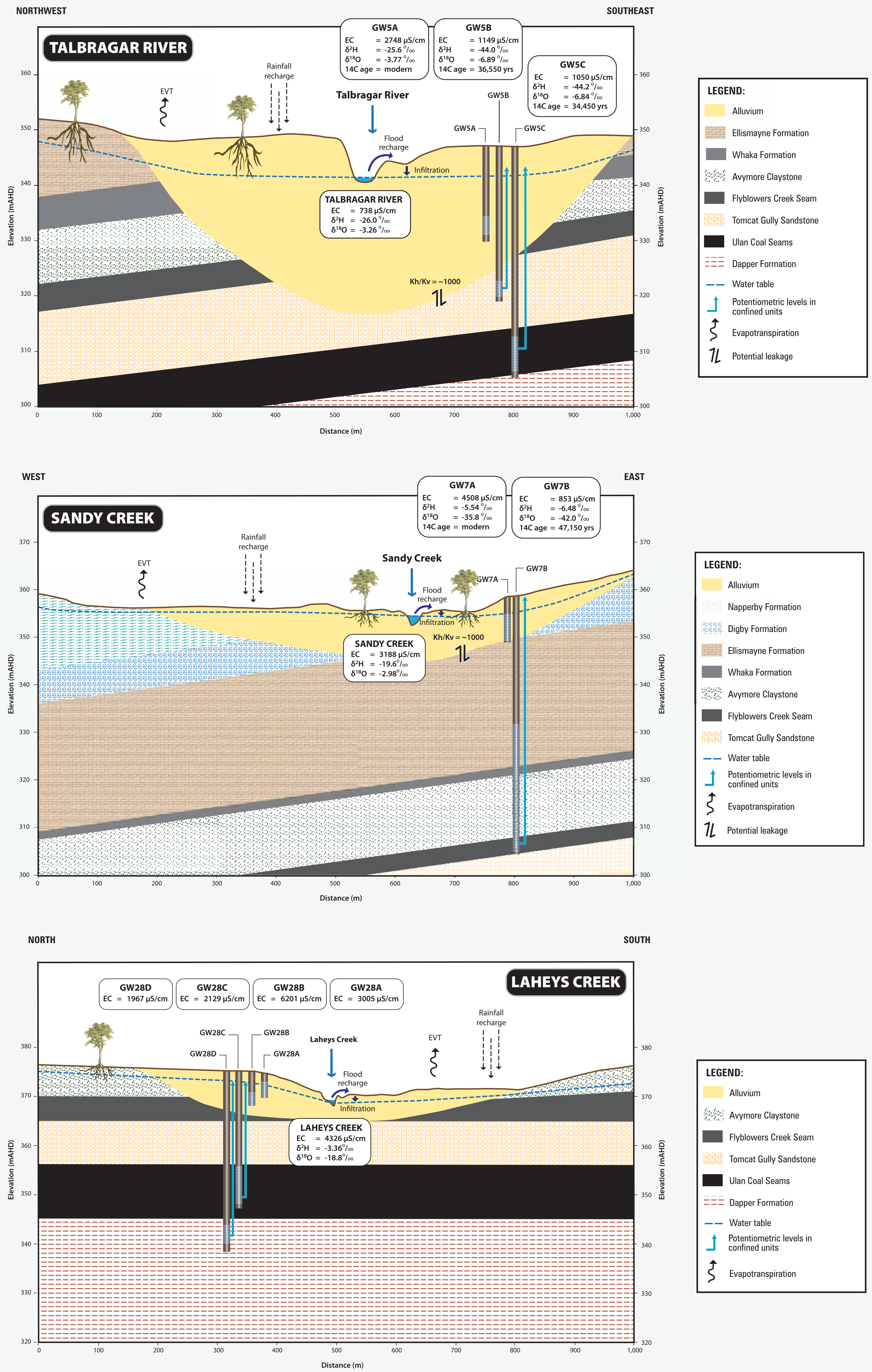


Figure 3.1 Conceptual hydrogeological cross-sections for Talbragar River, Sandy Creek and Laheys Creek

3.1.2 Aquifer properties

The hydrogeological units of relevance to the assessment area have been simplified for incorporation into the groundwater model as discrete model layers, as shown in Table 3.1. The simplification aims to combine formations assumed to have similar hydraulic characteristics.

Table 3.1 Hydrostratigraphic units assigned to the groundwater model

Hydrostratigraphic unit	NOW groundwater source areas	Geological formations
Alluvium		Alluvium
Jurassic*		Pilliga Formation, Purlawaugh Formation
Digby	Gunnedah-Oxley Basin (*Jurassic outliers are managed as part of the Gunnedah-Oxley Basin)	Napperby Formation, Digby Formation, Ellismayne Formation
Whaka		Whaka Formation, Avymore Claystone, Flyblowers Creek Seam
Tomcat		Tomcat Gully Sandstone
Ulan		Upper Ulan Seam, C-Marker Clay, Lower Ulan Seam
Dapper		Dapper Formation
[No flow]	Lachlan Fold Belt	Lachlan Orogen (assumed to be impermeable basement)

Estimates of hydraulic conductivity for the assessment area have been derived from the following sources:

- standard pumping tests
- packer tests
- slug tests
- hydrogeochemical analysis.

Table 3.2 shows the range of hydraulic conductivity values derived from these sources for the modelled layers in the assessment area. These data are presented in graphical form in Figure 3.2.

Table 3.2 Summary of hydraulic conductivity estimates

Layer	Estimated range of hydraulic conductivity values (m/d)			
	Pumping tests	Packer tests	Slug tests	Hydrogeochemical analysis (bulk estimate)
Alluvium	-	-	0.056–5.1	-
Jurassic	-	-	-	-
Digby	-	-	0.024–0.056	-
Whaka	-	0.0033–0.044	0.0031–0.0047	-
Tomcat	4–13	-	0.012–0.94	-
Ulan	2–12	-	0.27–1.6	0.009–0.031

Layer	Estimated range of hydraulic conductivity values (m/d)			
	Pumping tests	Packer tests	Slug tests	Hydrogeochemical analysis (bulk estimate)
Dapper	2–12	0.0050–0.069	0.027–0.4	-

The test pumping bores were installed with the aims of assessing dewatering requirements and potential water supply. Although drawdown data are available from nearby observation bores screened across single aquifer units, the production bores are each screened across several aquifers. If the permeability of the unit intercepted by a given observation bore is low compared to the interval spanned by the pumping bore, erroneously high hydraulic conductivity values will be obtained (Cook 2003). The same phenomenon precludes the derivation of reliable storativity estimates from the pumping test results.

Due to the level of inaccuracy associated with the pumping tests, the hydraulic conductivity values derived from slug testing and packer-testing are expected to be the most representative for each unit.

Using differences in groundwater age along an inferred groundwater flow line, groundwater velocities were estimated for the Ulan layer in the north-west of the model domain. These were used in conjunction with inferred hydraulic gradients to estimate hydraulic conductivity. This results in ranges of hydraulic conductivities that are substantially lower than those derived from either pumping test or slug test analyses.

The bulk hydraulic conductivity of the main hydrostratigraphic units in the assessment area are expected to be low to moderate (see Table 3.2), with estimated values ranging from 10^{-3} to 10^{0} m/d. The alluvium, Digby and Ulan units are expected to be the most permeable overall.

Reliable site-specific estimates of aquifer storage are not available for the assessment area. Literature derived values for specific yield and storativity are presented in Table 3.3, based on the lithologies of each unit and values given by Johnson (1967) and Krusemann and de Ridder (2000).

Table 3.3 Estimated range of aquifer storage values

Layer	Specific yield	Storativity
Alluvium	0.05–0.25	$5 \times 10^{-5} – 5 \times 10^{-3}$
Jurassic	0.01–0.3	$5 \times 10^{-5} – 5 \times 10^{-3}$
Digby	0.01–0.3	$5 \times 10^{-5} – 5 \times 10^{-3}$
Whaka	0.01–0.2	$5 \times 10^{-5} – 5 \times 10^{-3}$
Tomcat	0.05–0.3	$5 \times 10^{-5} – 5 \times 10^{-3}$
Ulan	0.01–0.3	$5 \times 10^{-5} – 5 \times 10^{-3}$
Dapper	2–12	$5 \times 10^{-5} – 5 \times 10^{-3}$

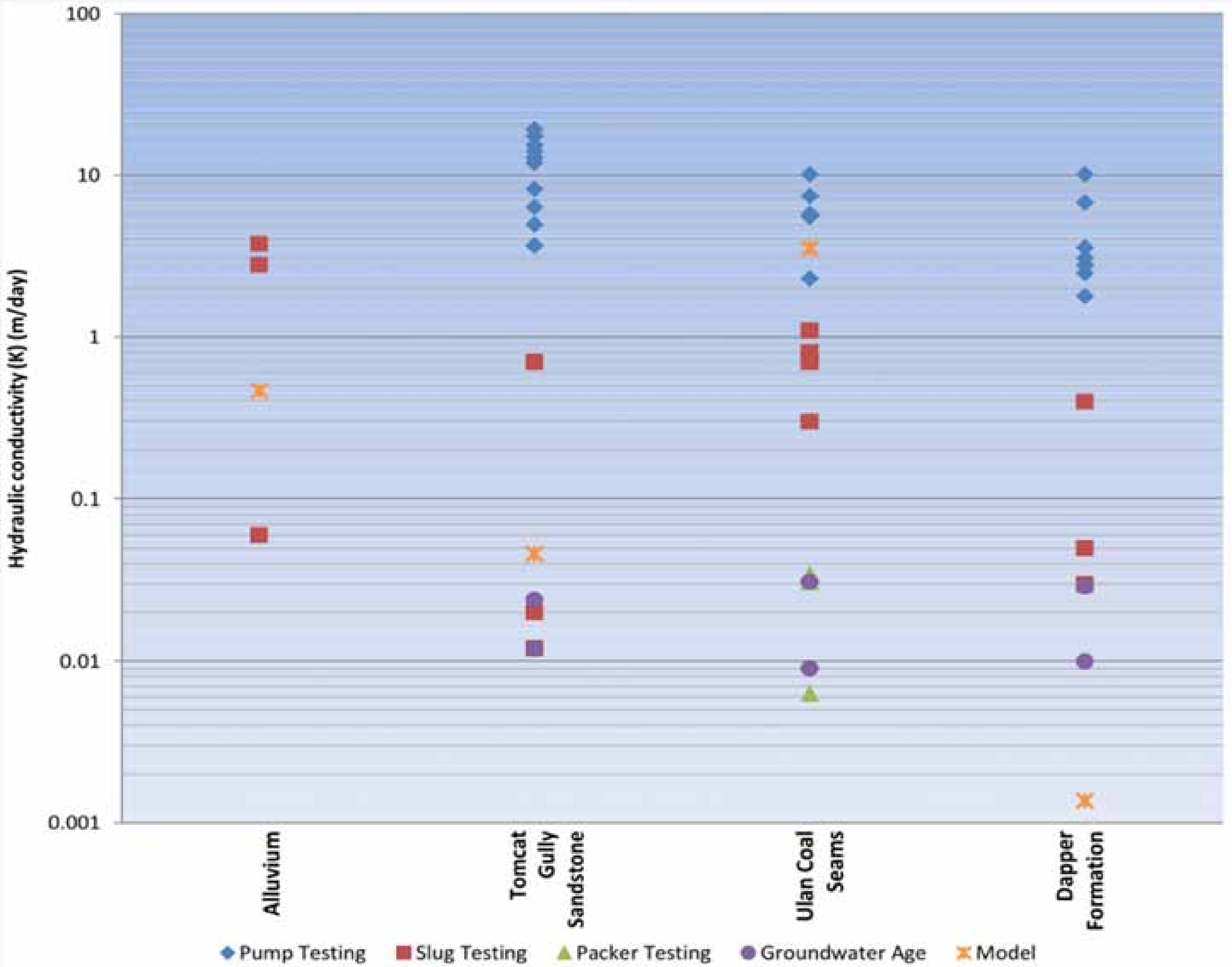


Figure 3.2 Estimated hydraulic conductivity

3.1.3 Recharge

Recharge is the term used to describe a source of water contributing to a groundwater system. Within the assessment area, the primary source of recharge to the groundwater system occurs through direct rainfall infiltration in the elevated areas of the upper catchment.

This conceptualisation is supported by the observed groundwater levels in the assessment area, which indicate flow of groundwater from topographic highs to low lying areas. Isotopic sampling (^{18}O and ^{2}H, and $^{87}Sr/^{86}Sr$) has confirmed that the most likely source of the groundwater for the bedrock aquifers is from rainfall (Parsons Brinckerhoff 2013a). In addition, radiocarbon age dating indicates that the age of groundwater increases along the flow paths from topographically high to low areas and/or following the stratigraphic dip. Long -term average rainfall for the assessment area, based on data from Bureau of Meteorology stations at Dunedoo (station 064009) and Gulgong (station 062013), is approximately 636 mm/a.

Unconfined alluvial systems will tend to be more heavily influenced in the short term by individual rainfall events and have higher infiltration rates than the exposed bedrock units (sandstones, claystones, coal seams etc.). The hydrographs presented in Figure 3.3A indicate that bores screened within the alluvium (e.g. GW5A, GW7A) respond more rapidly to heavy rainfall, while bores screened in deeper units show a more muted response (e.g. GW5D, GW7D).

Field observations indicate the presence of a thick weathered profile (up to 15 m thick) within the Napperby and Digby formations, which are exposed across the majority of the assessment area. Hydrographs from bores screened within the bedrock aquifers typically show a delayed and somewhat muted response to rainfall with the magnitude of responses reducing with increased screen depth (Parsons Brinckerhoff 2013a).

Analysis of stream and bore hydrographs suggests that the alluvium aquifer is heavily influenced by recharge from the Talbragar River and associated tributaries during floods. Additional sources of recharge for some aquifer units could occur via vertical leakage from the overlying/underlying strata. These processes are described in more detail in the accompanying Cobbora Coal Project - Groundwater Assessment (Parsons Brinckerhoff 2013a).

3.1.4 Groundwater – surface water interactions

Interaction between surface water and groundwater systems occurs though a variety of mechanisms, including:

- baseflow to streams and semi-permanent pools
- discharge at springs/seeps
- flood flow recharge to groundwater.

Surface water – groundwater interactions are complex and variable across the assessment area, and depend on the nature of the stream bed, alluvium and underlying aquifer.

The following general conclusions are drawn from the investigations carried out to date:

- Surveys of stream bed elevations and groundwater levels show that over lower elevation stretches of Sandy Creek, Laheys Creek and the Talbragar River, hydraulic gradients are towards the channel, indicating a potential for groundwater discharge to streams. In contrast, upper reaches of creeks are likely to be disconnected losing systems.

- All surface water channels cease to flow (including the Talbragar River) when rainfall is low (there is no significant baseflow component). This indicates that groundwater discharge from the main regional aquifer (Permo-Triassic units) is not a major contributor to surface water flows and the rapid recessions may instead indicate temporary storage in alluvium proximal to the channel.

- Hydrographs from monitoring bores adjacent to creek and river channels show sharp 'flashy' responses to high rainfall and flood events indicative of direct recharge from flood waters (see Figure 3.3A to Figure 3.3E). The surface water recharge signatures are noted mainly in the alluvium aquifers, but also the Permo-Triassic aquifer, where the alluvium deposits are thin or absent. These observations highlight the importance of periodic flood events in recharge of local and regional groundwater systems.

- Where alluvial deposits are developed along the stream and river courses, the connection between the Permo-Triassic aquifer and the alluvium aquifers is weak and the alluvium aquifers form distinct local aquifer systems. This is evidenced by the strong vertical hydraulic gradients across the alluvium interface and distinct isotopic composition and radiocarbon ages (Parsons Brinckerhoff 2013a).

- Long-term (21-day) pumping tests at two locations (GW5 and GW7) confirm the low vertical conductivity of the alluvium deposits. Observed drawdown during those tests implies very low leakage rates and a horizontal to vertical permeability ratio in the order of 1,000 or more (Parsons Brinckerhoff 2013a).

The creeks and rivers within the model domain are represented as MODFLOW RIV (river) boundaries, as opposed to DRN (drain) boundaries. This allows for the creeks and rivers to act as sources of recharge as well as net sinks for groundwater. All water courses within the model domain are ephemeral systems with no permanent baseflow (and are now known to provide recharge during flood events).

The groundwater model is intended to simulate long-term (average) trends in the groundwater system within the assessment area. As such, individual flood events have not been represented in the model. The values of river stage applied to the model do not vary over time and represent the long-term average interactions between groundwater and surface water bodies. This simulates the net effect of occasional flood events, with intervening periods of lower flow.

Prior to model calibration, a 20 m digital elevation model (DEM) of the assessment area was used to define the stage of each river boundary. Although this is a reasonable initial approximation, steeply sloping river banks are likely to lead to a range of elevations within a single DEM cell. This means that the DEM values could overestimate the river stage in some locations. The river stage elevations were refined as part of the calibration process to address this issue.

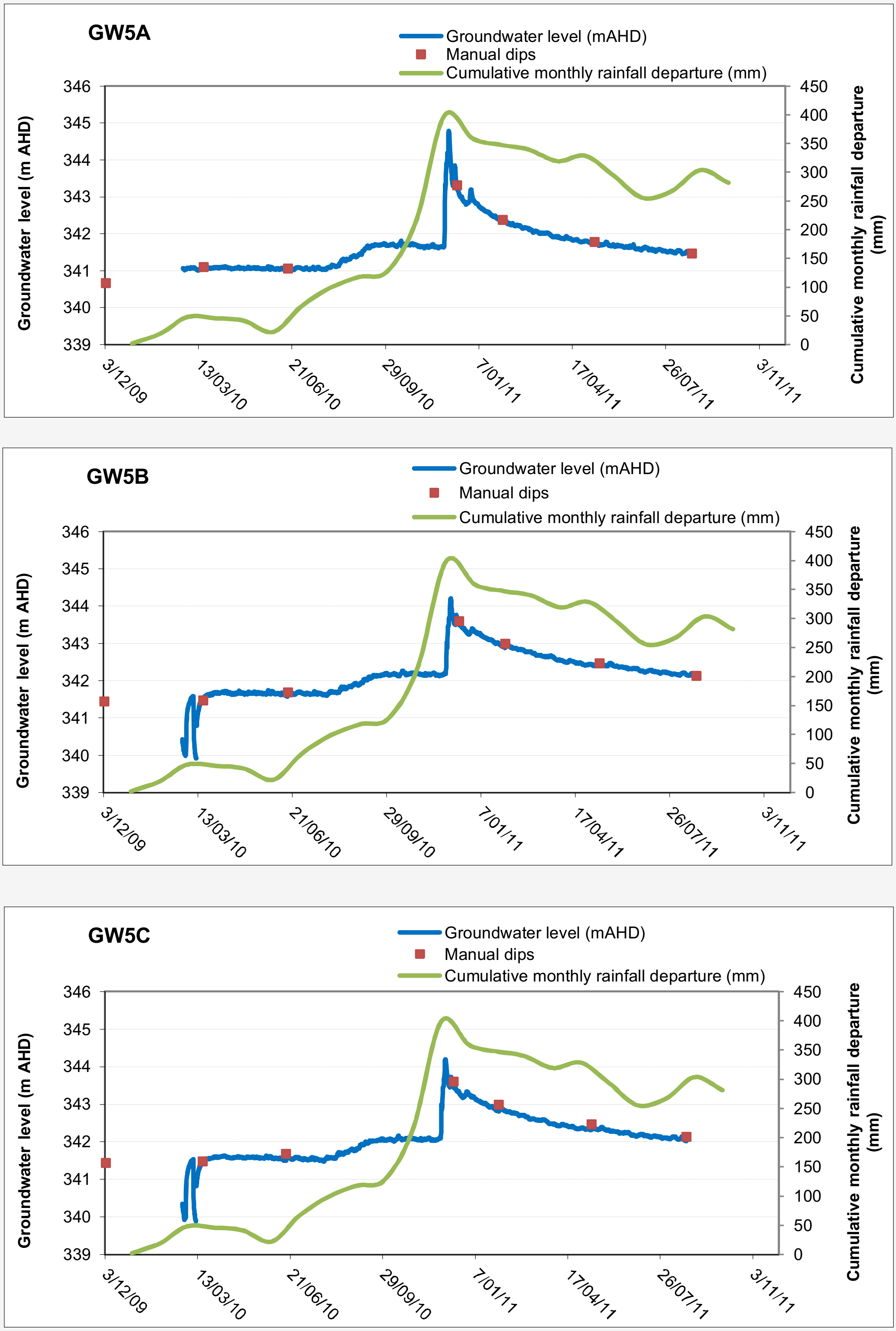
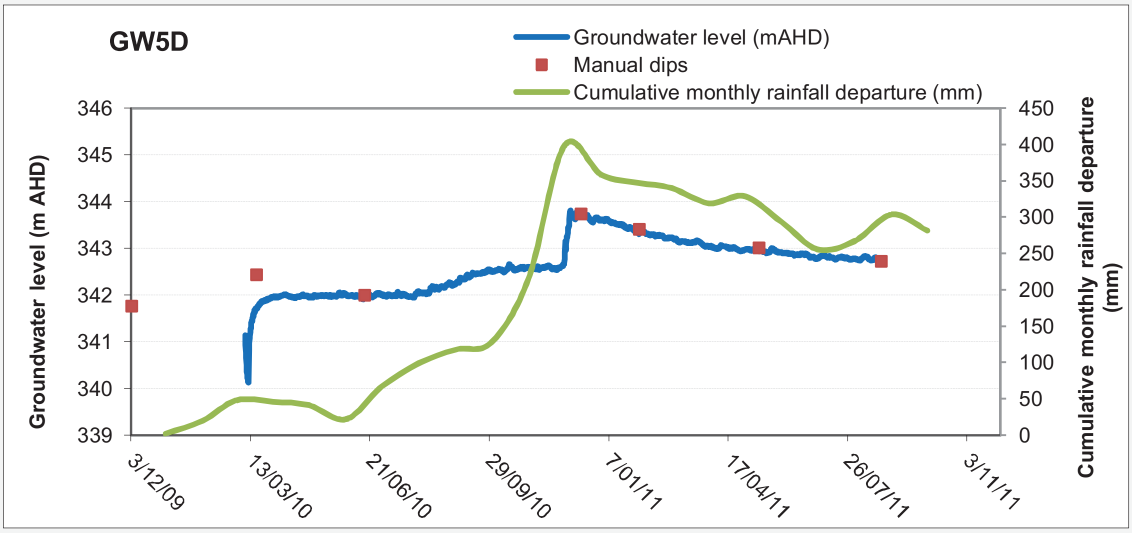
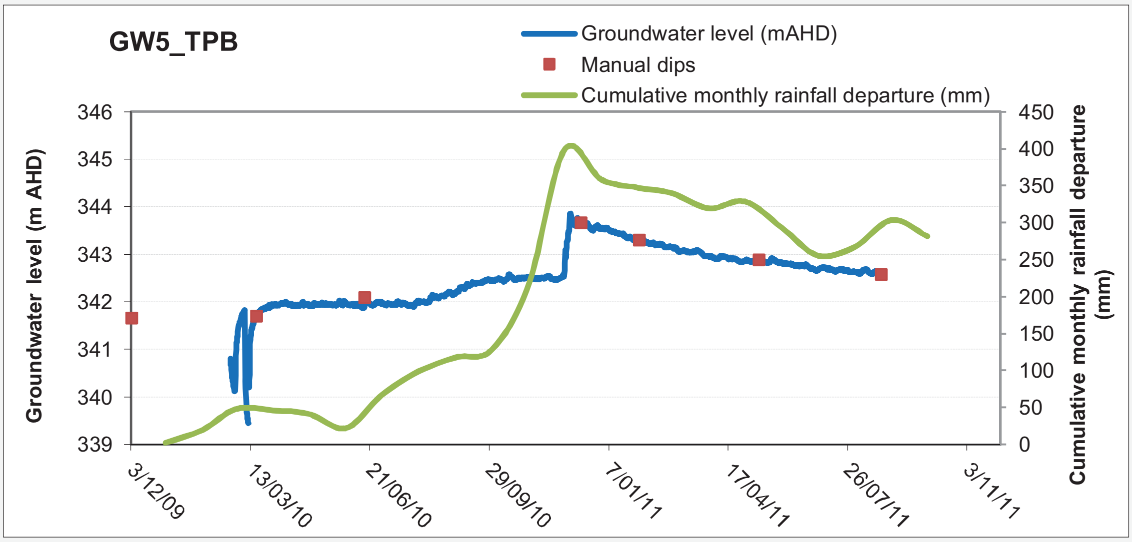


Figure 3.3A Hydrographs showing response to rainfall (GW5A, GW5B and GW5C)





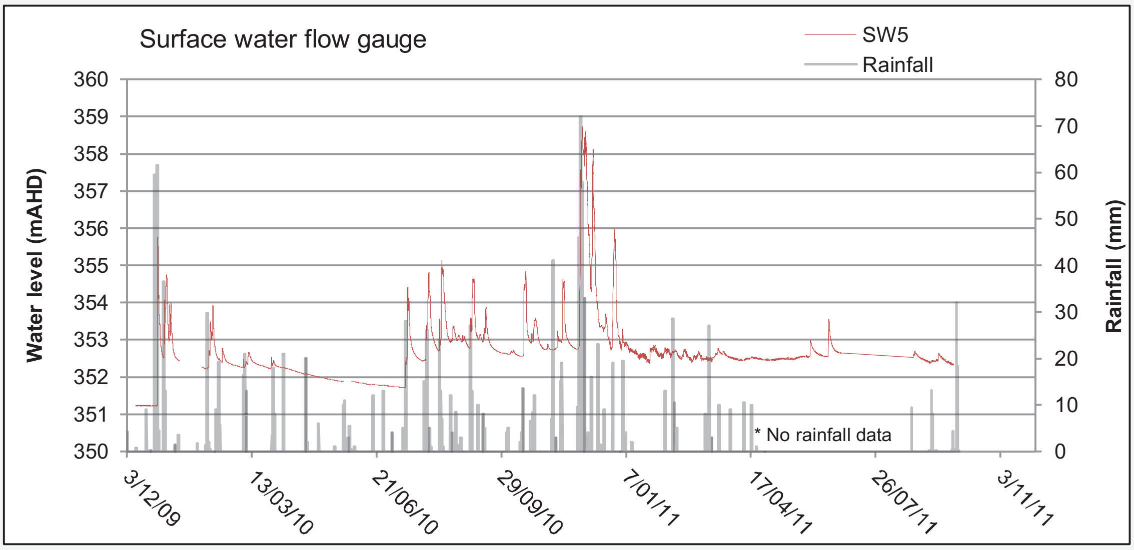


Figure 3.3B Stream discharge and hydrographs showing response to rainfall (GW5D, GW5TPB and SW5)

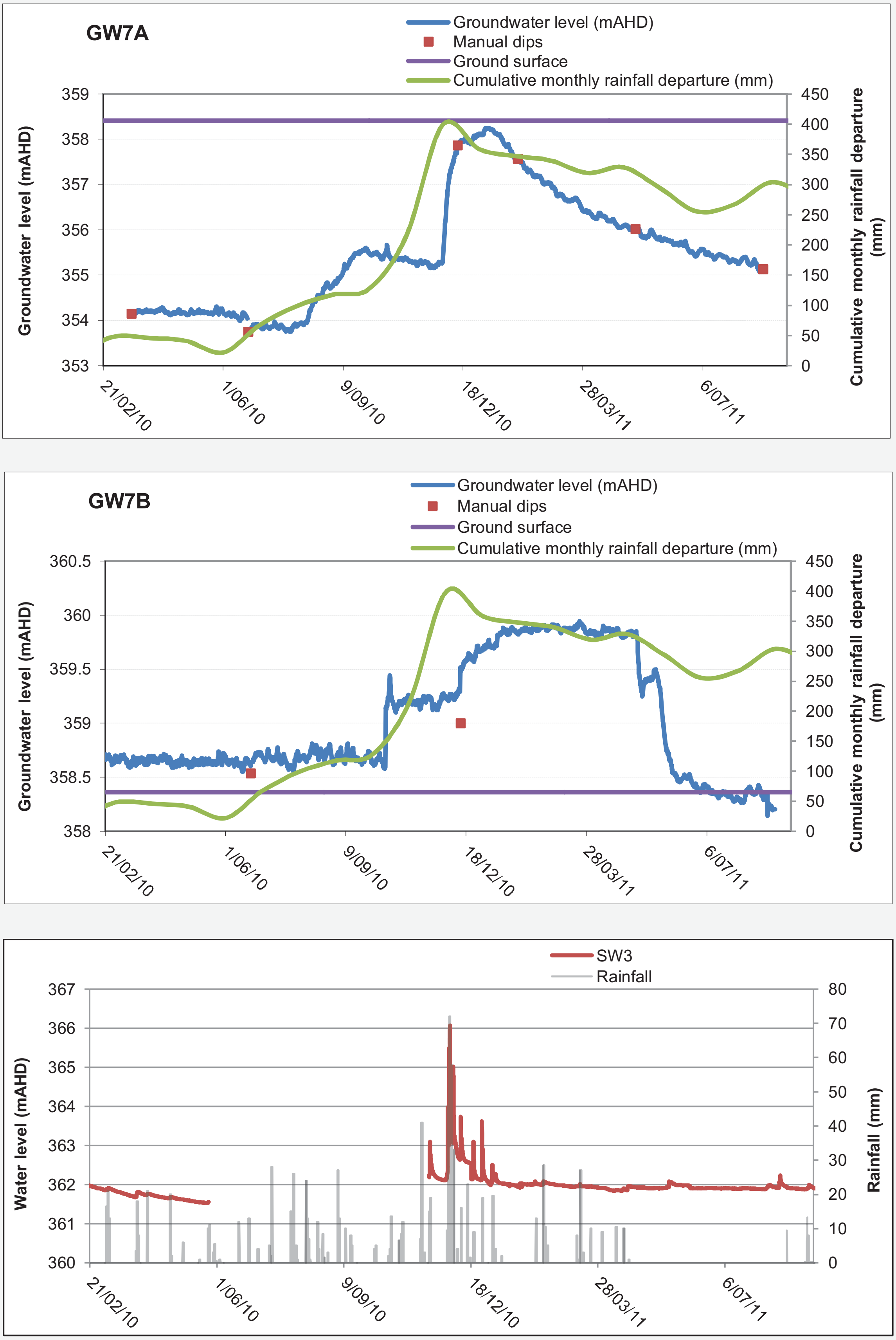


Figure 3.3C Stream discharge and hydrographs showing response to rainfall (GW7A, GW7B and SW3)

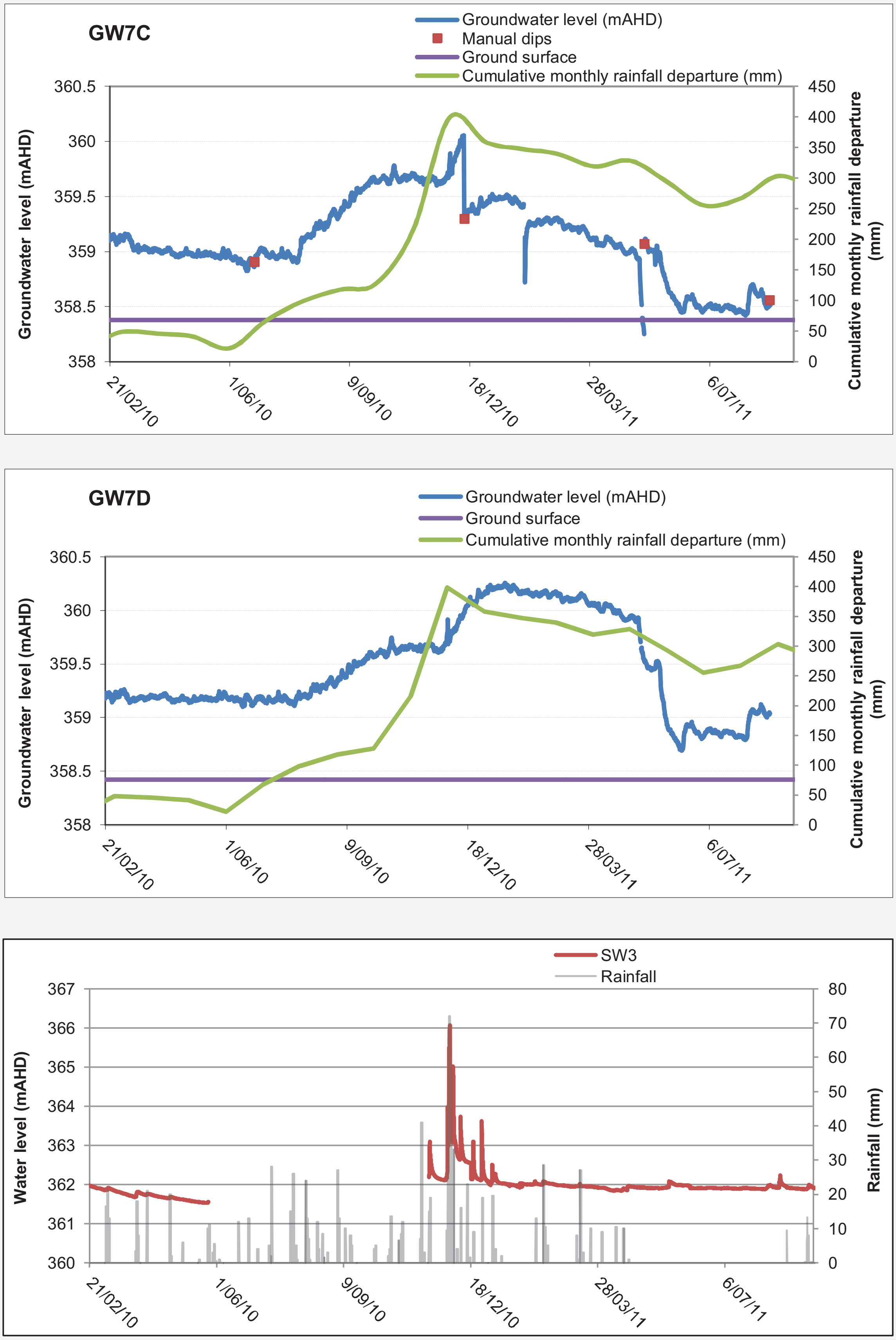
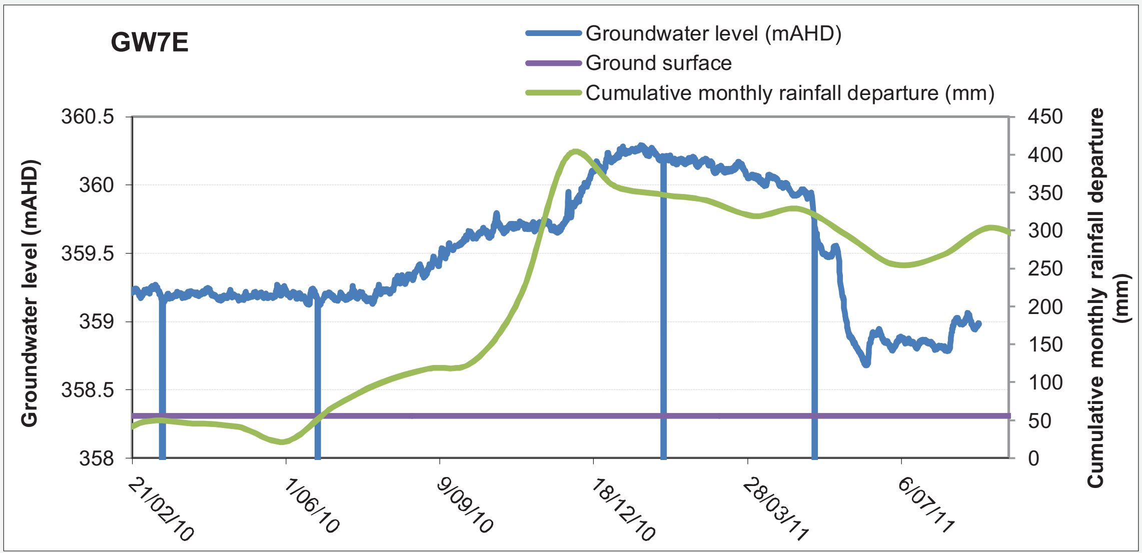
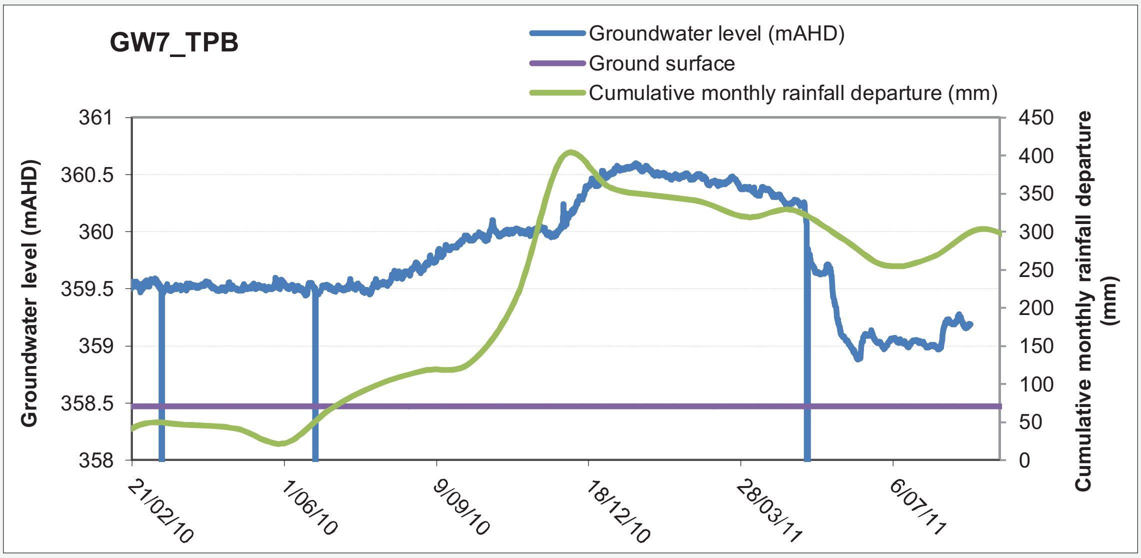


Figure 3.3D Stream discharge and hydrographs showing response to rainfall (GW7C, GW7D and SW3)





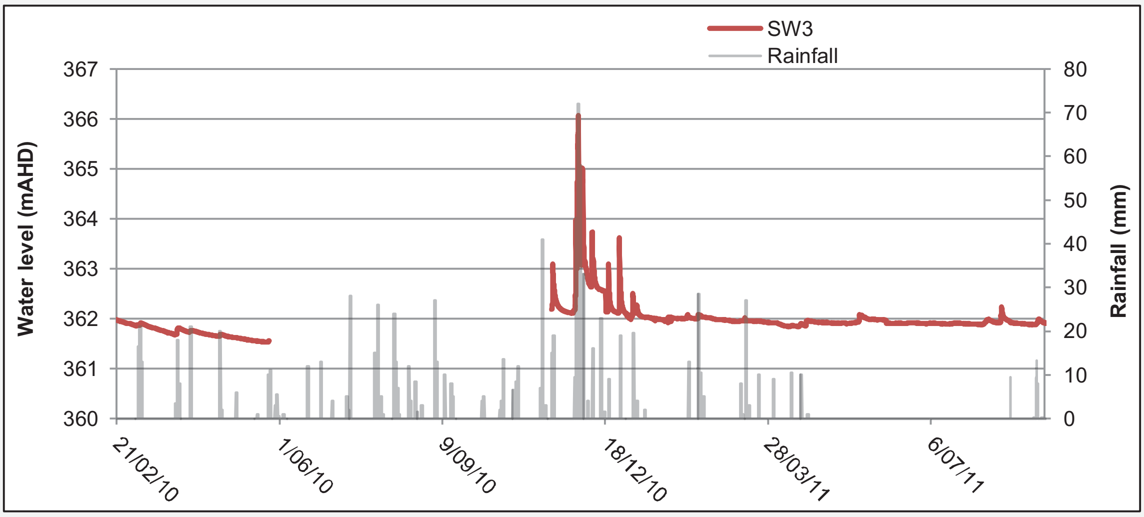


Figure 3.3E Stream discharge and hydrographs showing response to rainfall (GW7E, GW7TPB and SW3)

3.1.5 Discharge and evapotranspiration

Within the assessment area, groundwater discharge from springs and stream baseflow is considered to be a relatively minor component of the overall water budget. Baseflow in the Talbragar River and Sandy Creek is essentially zero during periods of low rainfall. However, it is assumed that many of the non-flowing semi-permanent pools along the creeks and rivers are sustained in part by some seepage from the alluvium and from the Permo-Triassic aquifer where it is exposed in the stream bed.

Groundwater contours and vertical hydraulic gradients near streams indicate that significant discharge must be occurring along the valley axes. It is assumed that the discharge is mainly through evapotranspiration, both as direct evaporation from the soil profile where groundwater is shallow, and transpiration by vegetation.

Evapotranspiration only occurs within a certain depth below the ground surface and the rate decreases with depth until an 'extinction depth' is reached, where essentially no loss to evapotranspiration occurs. The actual depth of influence for evapotranspiration depends on numerous factors, including plant type and root zone depth, soil compaction and soil or rock type. On a regional scale it is assumed that evapotranspiration could occur to depths of up to 5 m, but may be up to 10 m where deep rooted trees grow. Given that evapotranspiration rates are greater than average annual rainfall rates, and groundwater is relatively shallow in low lying areas, evapotranspiration is considered a major process by which water is removed from the groundwater system on a catchment wide scale.

Based on the available data (BoM 2005), average evapotranspiration in the assessment area is likely to be approximately 600 mm/a. This value represents the average annual 'areal actual' evapotranspiration (the evapotranspiration that occurs as a result of existing climatic conditions and is limited by the amount of rainfall) in the Climatic Atlas of Australia (BoM 2005). The average annual 'areal actual' evapotranspiration value applied is approximately 43% of the pan evaporation for the area (Parsons Brinckerhoff 2013a).

3.1.6 Groundwater use and mining impacts

Coal mining operations will involve stripping overburden and interburden units of the Permo-Triassic succession using excavators, and mining the economic coal seams. Overburden stripping and mining will be carried out in a series of mining strips and blocks that together define three mining areas: A, B and C. The deepest target seams are the Ulan Coal Seams that dip towards the west in the areas designated as mining areas A and B such that those mining areas will reach a total depth of 110 m below the surface. Those areas will therefore be mined below the water table and moderate amounts of groundwater inflow will occur. Within mining area C, the Ulan Coal Seams occur at shallower depths and the water table is considerably deeper (as it is located along a ridge); consequently, groundwater inflows will be considerably less than in mining areas A and B.

Active mining blocks, where they are below the water table, will need to be dewatered to allow safe operation of vehicles and machinery. Where inflows are low, dewatering may be achieved through the use of in-pit sumps and pumps. Where higher inflows are encountered, it may be necessary to install a number of dewatering bores to depressurise the coal measures prior to and during active mining. It is envisaged that this Project will employ a combination of these methods during mining of areas A and B. All three mining areas will receive inflows of surface runoff from local catchments and direct rainfall during larger rainfall events; these inflows will be managed using surface pumping equipment.

Mine inflow and dewatering will result in depressurisation of coal measures in the vicinity of the mining areas, which in turn will cause leakage from overlying units and lowering (drawdown) of the water table in affected areas. Leakage may also be induced from alluvium aquifers within the cone of depressurisation. Surface water bodies (streams, pools, springs), dependent ecosystems and nearby groundwater abstraction bores could be affected within the cone of depressurisation, depending on how well they are connected to the Permo-Triassic aquifer system. Such impacts may include losses of spring flow or baseflow (if present), vegetation stress and reductions in bore yield.

Broken and crushed waste rock is back-filled into previously mined voids. The broken waste rock piles will be more permeable and produce less surface runoff than the pre-existing ground surface, causing significantly higher rates of infiltration and recharge to groundwater on those backfilled areas (Mackie 2009). This will result in localised groundwater mounding in those areas (to some extent enhancing recovery of the mine-induced drawdown) and some increase in groundwater inflows to the mining areas. Section 3.2 outlines how these features are represented in the numerical model.

The final landform has been designed to minimise impacts to groundwater and surface water. Mining areas A and C will be backfilled to levels above the current groundwater levels, and will be free draining. Mining area B will be largely backfilled to above current groundwater levels but a small section will remain and will partially fill with water over time. The equilibrium lake level will be lower than the surrounding groundwater level and therefore impacts to surrounding surface and groundwater systems are minimised as groundwater will flow towards the lake and it will form a localised groundwater sink. More details are outlined in Cobbora Coal Project - Surface Water Assessment (Parsons Brinckerhoff 2013b).

3.2 Numerical model development

3.2.1 Modelling software

Parsons Brinckerhoff created a three-dimensional finite difference model using the Groundwater Vistas user interface. MODFLOW (McDonald & Harbaugh 1988) was used in conjunction with MODFLOW SURFACT (version 3) to allow for saturated and unsaturated flow conditions.

A MODFLOW-based model is a well-documented and widely used program, and is often used for open-cut mining projects. MODFLOW-SURFACT, or a finite element model such as FEFLOW, is appropriate for this type of mining assessment (Mackie 2009).

The Brooks-Corey vadose zone simulation type was chosen as part of the MODFLOW-SURFACT setup. The following values were used for all layers and were not optimised or changed during the modelling process:

- VANAL = 0.3 1/m
- VANBT = 1.2
- VANSR = 0.15
- BROOK = 2.

The MODFLOW-SURFACT package was used to add the known stability MODFLOW-SURFACT provides, rather than to accurately depict the unsaturated flow processes.

In addition, the MODFLOW-SURFACT package has an automatic time-stepping program that allows the time increments to be accelerated or slowed depending on how many iterations the solver requires to find a solution.

This package was used during transient calibration of the model and in predictive simulations as it allowed the model to accommodate sudden and significant changes in hydraulic gradient induced by mining operations.

3.2.2 Model complexity

The complexity of the groundwater model is consistent with the ‘impact assessment’ class, as described by the Murray Darling Basin Commission (MDBC 2001). It has moderate complexity and is suitable for predicting the impacts of the proposed operations and post-mining recovery. New national guidelines for modelling were released in July 2012 (Barnett et al, 2012) and are based on the previous MDBC modelling guidelines (MDBC 2001). The characteristics of the groundwater model are consistent with those of a Class 2 model, as described by the new national guidelines. The guidelines state that this type of model is suitable for estimates of mine dewatering and assessments of associated impacts.

The model was developed in finite difference format with uniform grid spacing and seven layers. The following sections of this document provide more specific details on model design and domain.

3.2.3 Model construction

The model domain (Figure 3.4) has an extent of 29 km x 50 km (1,458 km^2). The active mine area is located in the centre of the model domain and covers approximately 30 km^2.
The model area was divided into 502 rows and 290 columns, resulting in 145,580 cells per layer, and 1,019,060 cells in the entire seven-layer model. The resulting uniform grid has a spacing of 100 m by 100 m.

The model grid is orientated to the north-west to align the conceptualised primary groundwater flow direction in the Project catchment (north-west) with the model columns, which simplifies the numerical solutions.

Figure 3.4 shows the model domain and assigned boundary conditions, including the three mining areas in the proposed mine plan (mining areas A, B and C). Inactive cells have been assigned only at topographic divides and in areas where very low permeability geological units crop out. Inactive areas are the same for all layers.

Layers within the model do not solely represent one individual, simplified, geological unit. Geological units are represented in the model by parameterisation of hydraulic conductivity, storage and recharge. For example, Layer 1 is intended to simulate the alluvial systems throughout the model domain. Where alluvium exists, the cells have been assigned parameters associated with this unit. Where alluvium does not exist, the next sequential hydrostratigraphic unit interpreted to exist is represented by a change in hydraulic conductivity, recharge and storage. The hydrostratigraphic units assigned to the top layer of the model are shown in Figure 3.4.

The extent and top and bottom elevations for each hydrostratigraphic unit were calculated based on the following data sets:

- NOW bore data search
- Parsons Brinckerhoff's field program
- bore logs provided by Marston mining consultants
- digital elevation model of surface topography provided by Marston.

A general head (or head dependent flow) boundary was assigned where active cells are adjacent to model boundaries in the bedrock units. For the alluvium, constant head boundaries were used. Heads were adjusted for all boundaries during initial calibration to replicate a reasonable groundwater surface.

The model boundary distances were chosen so that drawdown in the predictive simulations would not reach the boundaries, and thus their influence would be minimised.
These assumed distances were adjusted through trial and error early in the steady state simulations to minimise irregular head contours along the model boundaries.

3.2.4 Model calibration

To refine estimates of aquifer properties and other model input parameters, Parsons Brinckerhoff calibrated the model to groundwater level data obtained during the groundwater monitoring program (Parsons Brinckerhoff 2013a).

A steady state was developed model to represent conditions near the beginning of the monitoring program (March 2010) when groundwater levels are assumed to have been close to their long-term average values. A transient model was then set up to investigate the response of the groundwater system to changes in rainfall during the monitoring program. This model provided information on the transient behaviour of the groundwater system in response to changes in applied stresses over time.

A total of 1,045 mm of rainfall was recorded during the 74-week monitoring program. This is equivalent to 739 mm/a and represents slightly wetter conditions than the long-term average rainfall for the site (i.e. 636 mm/a).

By modifying the input parameters of the model, the observed behaviour of the groundwater system could be replicated. Once a satisfactory fit was achieved, the model was used to predict the response of the groundwater system to mine dewatering. Section 4 of this report presents further details on model calibration.

3.2.5 Predictive simulations

3.2.5.1 Initial conditions

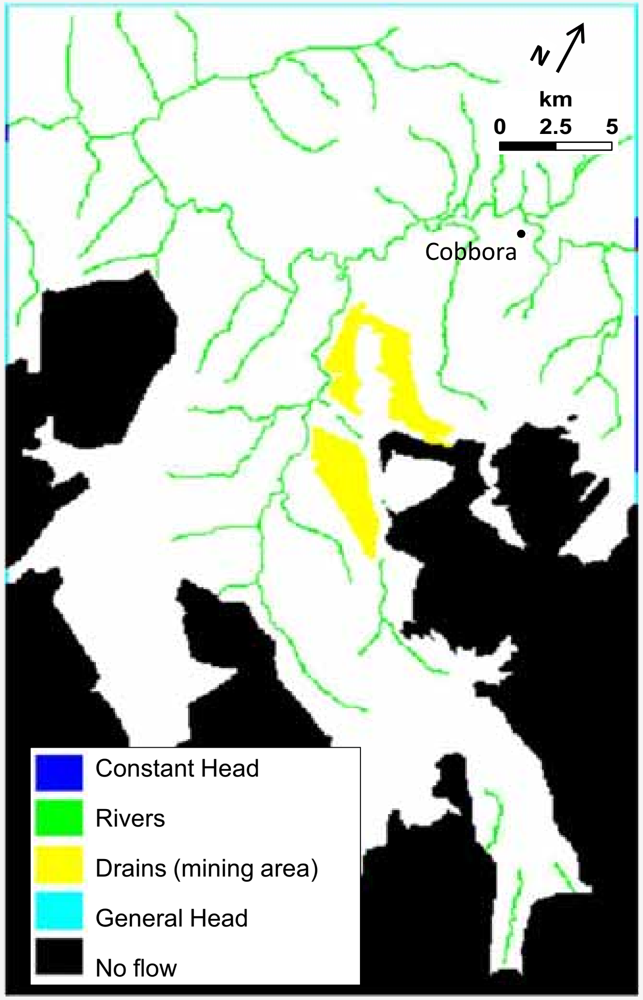
It is assumed that groundwater levels at the start of mining operations will be close to their long-term average values. The groundwater levels produced by calibration of the steady state model have therefore been used as the initial heads for the predictive simulations.

3.2.5.2 Time discretisation

Yearly stress periods have been implemented in the predictive simulations to represent the evolution of the mine void (Cobbora Holding Company 2011) during the proposed 21 years of mining and for a period of 100 years after the planned cessation of mining.

The model has simulated groundwater heads and flows at 3-monthly intervals during the period of mining operations, as well as at the end of each stress period (i.e. each year). Sudden 'spikes' in modelled inflows following the activation of drain cells at the start of each stress period can be accounted for by averaging simulated flows over the four output time intervals in each year of the simulation.

The model has also simulated groundwater heads and flows at the end of each stress period (i.e. year) following the end of the proposed mining activities.



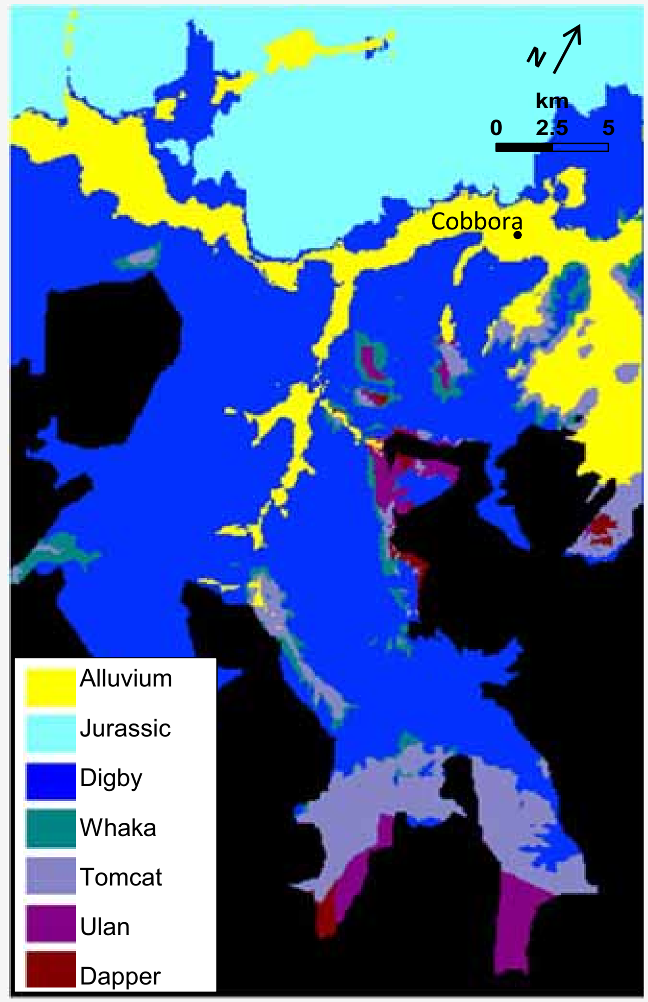


Figure 3.4 Model domain showing a) assigned boundary conditions and b) hydrostratigraphic units in layer 1

3.2.5.3 Rainfall and recharge

Long-term average rainfall for the assessment area, based on data from BoM stations at Dunedoo (station 064009) and Gulgong (station 062013), is approximately 636 mm/a. It is assumed that average rainfall conditions prevail over the period of the predictive simulation. Recharge as a proportion of average rainfall has been assigned based on the results of model calibration, which is described in Section 4 of this document.

3.2.5.4 Representation of mine void

Drain boundaries were assigned to the model to simulate dewatering of the mine void, based on the proposed mine plan supplied by CHC. The mine void comprises three mining areas: A, B and C. The drain boundaries in each model cell are active during the planned period of excavation at that location and for a year after excavations are planned to cease. The mining areas will be backfilled at the end of this period in accordance with the final landform and dewatering will cease. The invert elevation assigned to the drain cells corresponds to the planned base of the mine void. Drain cells with this elevation value were assigned to all layers above the mine void base.

The MODFLOW-SURFACT TMP add-on package was used to represent changes in material properties within the mine void caused by the removal and subsequent backfill of layers. The hydraulic conductivity of the backfill material was based on hydraulic testing data reported by Hawkins (2004), which indicates a wide range in permeability and storage characteristics for spoil material, but with a geometric mean hydraulic conductivity value of 1.5 m/d. A recharge value of 3.3% of rainfall was applied to the backfill material, based on the work of Mackie (2009). These values were used in the model to represent the horizontal hydraulic conductivity and recharge within the mine void following backfilling of excavated areas. The vertical hydraulic conductivity of the spoil is assumed to be an order of magnitude lower than the horizontal hydraulic conductivity. The spoil is assumed to be more homogeneous than the surrounding aquifers, which are expected to have vertical hydraulic conductivity values that are up to two orders of magnitude lower than their horizontal hydraulic conductivity.

Separate hydrostratigraphic units (HSUs) were assigned to the material backfilled each year in each of the seven model layers. In total, 147 HSUs were assigned to represent backfill over the 21 years of the proposed mine life.

The model simulates the residual mine void in mining area B, after proposed mining activities cease, using the Lake (MODFLOW 'Lak2') boundary condition, with a maximum elevation set to the median equilibrium lake level of 373.9 m AHD, as determined in Cobbora Coal Project - Surface Water Assessment (Parsons Brinckerhoff 2013b). In all other excavated areas, backfill material has been simulated using the time-varying properties module (TMP1). A lake bed thickness of 1 m has been applied, with a vertical hydraulic conductivity equal to the harmonic mean of vertical hydraulic conductivity in all overlying layers (2×10^{-4}) which is considered to be a conservative approach for lake bed conductance.

4. Calibration and sensitivity analysis

Calibration is the process by which the independent variables (parameters and boundary conditions) of a model are adjusted, within realistic limits, to produce the best match between simulated and measured data. The limits of variation for each variable are typically constrained by a range of measured values from site-specific hydrogeological investigations. When site-specific data are unavailable, references to similar published work is often appropriate. This Project used a combination of site-specific data and referenced data.

In consultation with the independent reviewer, Dr Noel Merrick, Parsons Brinckerhoff set a target calibration error (i.e. normalised root mean square (NRMS)) of no greater than 10%, with a 5% error being considered ideal.

The model was calibrated to both the long-term average (steady state) and the transient conditions observed during our field program. The final, transient, calibrated aquifer parameters are summarised in Table 4.1. For transient and predictive simulations, a long-term average rainfall of 636 mm/a was applied. The assigned evapotranspiration rate across the entire model domain is 600 mm/a and is based on the available data on average actual areal evapotranspiration (Bureau of Meteorology 2005). The depth below surface to which evapotranspiration is active in the model (i.e. the evapotranspiration extinction depth) was set at 5 m following model calibration.

Table 4.1 Spatially variable parameters across model domain

Layer(s)	Hydrogeological unit	K_h (m/d)	K_z (m/d)	S_y	S	Recharge (% of rainfall)
1	Alluvium	1	0.001	0.2	$5x10^{-4}$	2.9%
2	Jurassic	0.04	0.004	0.1	$3x10^{-4}$	0.46%
3	Digby	0.1	0.003	0.01	$5x10^{-5}$	0.64%
4	Whaka	0.004	$6x10^{-5}$	0.1	$5x10^{-4}$	0.46%
5	Tomcat Gully	0.008	$8x10^{-5}$	0.1	$5x10^{-4}$	0.46%
6	Ulan	0.3	0.003	0.1	$8x10^{-4}$	0.58%
7	Dapper	0.1	0.01	0.1	$8x10^{-4}$	0.46%

Notes:
K_h horizontal hydraulic conductivity
K_z vertical hydraulic conductivity
S storativity
S_y specific yield

Specific yield can be inferred from the response of an unconfined aquifer to changes in the elevation of the water table. As the water table lies within layers 1 to 3 (i.e. Alluvium, Jurassic and Digby) across most of the model domain, there is limited information with which to infer the specific yield of layers 4 to 7 (i.e. Whaka, Tomcat Gully, Ulan and Dapper). There are also limited data on water level variations in layer 2 (Jurassic). As a result, approximate values of specific yield have been assigned to these layers, based on lithological observations and published literature values (Kruseman & de Ridder 2000). Due to the wide variety of lithologies observed in each layer, a value of 0.1 is considered to be a representative average value in each case.

4.1 Calibration approach

The model was calibrated using a combination of manual calibration, BeoPEST (Schreuder 2009) and autosensitivity analysis.

In manual calibration, the user can change the values of individual model parameters between simulations, and by comparing calibration statistics, can assess changes in the quality of fit between model results and measured data. This approach can be useful in ensuring that changes to the input parameters are consistent with the conceptual understanding of the groundwater system.

BeoPEST is based on the parameter estimation software PEST (Doherty 2010). PEST automatically runs multiple model simulations to optimise the fit between model estimates and measured data. PEST automatically varies values of each input parameter within user-defined limits in order to find this solution. BeoPEST allows multiple PEST simulations to be run simultaneously on several different processors, minimising model run times. However, because the changes in model parameters are not explicitly chosen by the user, calibration using BeoPEST alone may produce parameter values which do not fit with the conceptual understanding of the groundwater system.

Sensitivity analysis is commonly used in groundwater modelling to identify those parameters that have the greatest influence on simulated groundwater levels. By investigating changes in the fit of the model to observed data, sensitivity analysis can:

- inform further calibration of the model, through greater focus on the most sensitive parameters
- provide information on the level of confidence in the model results, as a result of uncertainty in the values of input parameters.

Autosensitivity analysis can be implemented in Groundwater Vistas, allowing multiple model simulations to be initiated, based on user-defined variations in input parameters. This can quickly identify the parameters which have greatest influence on model calibration.

During calibration of the current model, the manual calibration and autosensitivity analysis were found to be the most effective methods for optimising the fit between model results and observed groundwater levels, while still ensuring that the model aligns with the conceptual understanding of the assessment area.

4.2 Steady state calibration

The steady state model simulates the groundwater system under long-term average conditions. The calibrated groundwater levels produced by the steady state simulation were used as initial heads for transient model calibration and the predictive simulation of mine dewatering. The results of steady state calibration were also used to provide initial estimates of hydraulic conductivity and recharge, before transient calibration was undertaken.

4.2.1 Dataset

Groundwater levels used for the steady state calibration were obtained from piezometers and test production bores installed for the Project (Parsons Brinckerhoff 2013a). Dataloggers were installed in these piezometers and test production bores in early 2010, providing four groundwater level measurements daily at each location.

A rainfall residual curve for the site is presented in Figure 4.1. The curve indicates that in early 2010 there is minimal net surplus or deficit of rainfall based on the long-term average, such that groundwater levels at this time are likely to be representative of the long-term average.

Groundwater level data is available from late March 2010 onwards for the majority of piezometers and test production bores included in the monitoring program. An average water level for the week beginning 24 March 2010 was calculated for each piezometer/test production bore and these data used to calibrate the steady state model. A summary of piezometers and test production bores, groundwater levels and geologic units is provided in Table 4.2. Insufficient data points were available for creating a pre-modelling water table elevation map or potentiometric surfaces for each layer.

Table 4.2 Summary of steady state dataset

Bore name	Screened unit(s)	Groundwater level (m AHD)
GW1	Alluvium	340.91
GW2A	Lower Ulan Seam	450.36
GW2B	Dapper Formation	451.07
GW2C	Dapper Formation	451.02
GW3_TPB	Whaka Formation, Avymore Claystone, Ulan Coal Seams, Dapper Formation	376.88
GW3B	Whaka Formation, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully Sandstone	376.04
GW3C	Tomcat Gully Sandstone	375.94
GW3D	Ulan Coal Seams	376.06
GW3E	Dapper Formation	376.07
GW4	Alluvium	343.64
GW5_TPB	Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	341.89
GW5A	Alluvium	341.08
GW5B	Tomcat Gully Sandstone	341.64
GW5C	Ulan Coal Seams	341.57
GW5D	Dapper Formation	341.91
GW6_TPB	Ellismayne and Whaka formations, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams	398.35
GW6A	Ellismayne and Whaka formations, Avymore Claystone, Flyblowers Creek Seam	395.70
GW6B	Tomcat Gully Sandstone	397.30
GW6C	Ulan Coal Seams	396.36
GW6D	Dapper Formation	397.63
GW7_TPB	Ellismayne and Whaka Formations, Avymore Claystone, Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	359.52
GW7A	Alluvium	354.20

Bore name	Screened unit(s)	Groundwater level (m AHD)
GW7B	Ellismayne and Whaka formations, Avymore Claystone, Flyblowers Creek Seam	358.66
GW7C	Tomcat Gully Sandstone	359.01
GW7D	Lower Ulan Seam	359.19
GW7E	Dapper Formation	359.20
GW9	Digby Formation	367.64
GW13A	Ellismayne and Whaka formations	382.60
GW15	Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams	402.48
GW16	Ulan Coal Seams	488.64
GW17	Tomcat Gully Sandstone	340.33
GW18	Purlawaugh Formation	330.22
GW19	Napperby Formation	328.45
GW20	Flyblowers Creek Seam, Tomcat Gully Sandstone, Ulan Coal Seams, Dapper Formation	327.68
GW21	Napperby Formation	321.89
GW22	Ulan Coal Seams, Dapper Formation	341.11
GW23	Napperby Formation	400.58

Steady state calibration was carried out to produce approximate estimates of hydraulic conductivity and recharge as a percentage of rainfall. These estimates were further refined as part of the transient calibration process (see Section 4.3).

4.2.2 Steady state water table

A map of water table elevations produced by the calibrated steady state model is shown in Figure 4.2A. The cross section in Figure 4.2B (A-A') passes through the planned locations of mining areas A and C; the cross-section in Figure 4.2C (B-B') passes through the planned location of mining area B. Groundwater flows are typically governed by the local topography and the presence of surface water features, with a general trend towards the north-west.

4.2.3 Water balance

The overall water balance for the steady state model is shown in Table 4.3. Rivers comprise the majority (54%) of total inflows, with the remaining inflows coming from distributed rainfall recharge (30%) and regional groundwater flow (16%). The dominant outflow from the model domain is evapotranspiration (58%). The remaining outflows are from regional groundwater flow (24%) and baseflow to surface water courses (18%), and are represented in the model by rivers. This water budget is considered to be consistent with the conceptual understanding of the groundwater systems.

Table 4.3 Steady state water balance

Boundary	In (m^3/d)	In (%)	Out (m^3/d)	Out (%)
Constant head	43	0%	1,009	2%
Rivers	24,302	54%	8,102	18%
Recharge	13,740	30%	0	0%
Evapotranspiration	0	0%	26,314	58%
General head	7,345	16%	9,976	22%
Total	**45,431**		**45,401**	
Error	**0%**			

The water balance discrepancy between calculated inflows and outflows is negligible (0.0007%).

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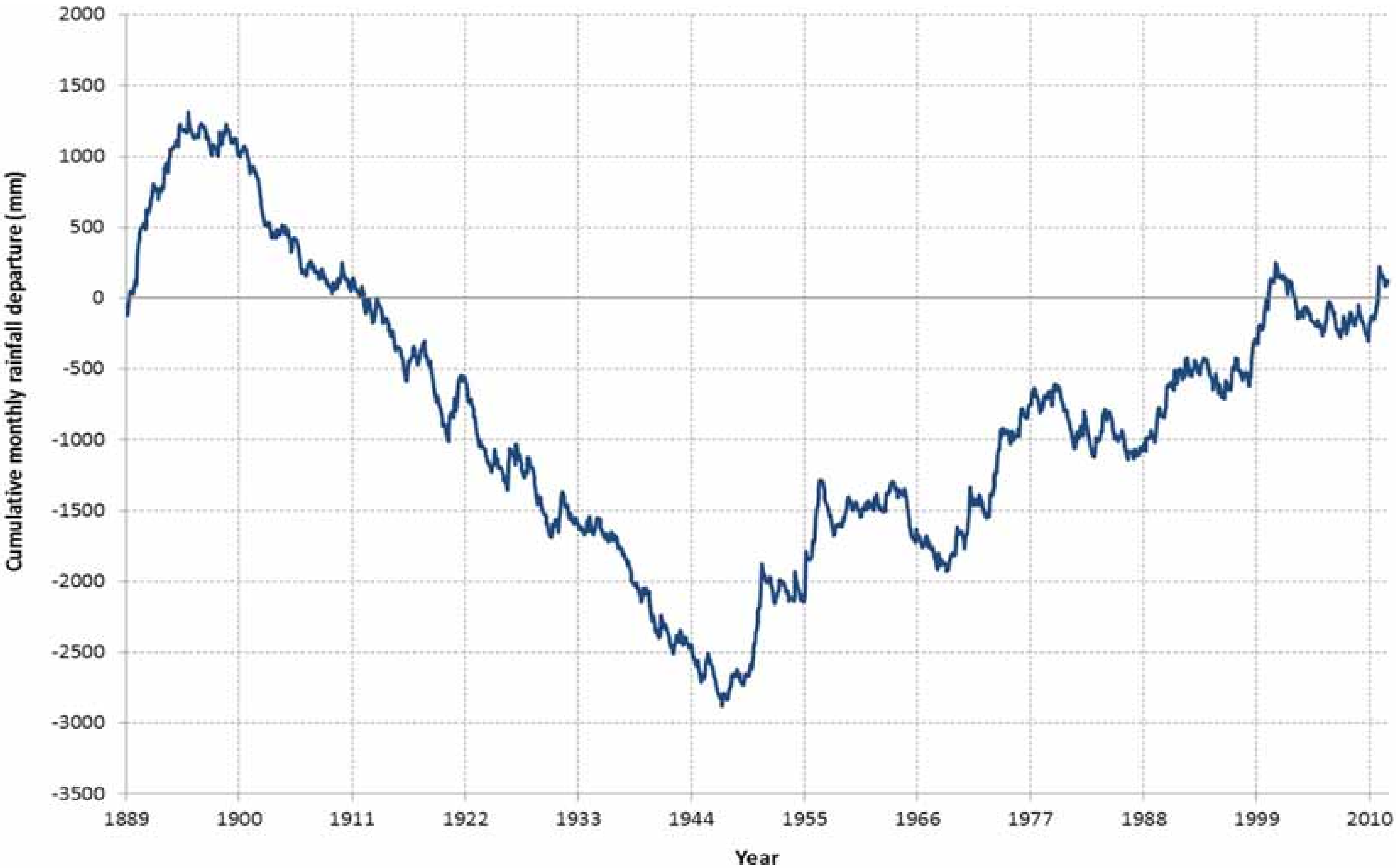
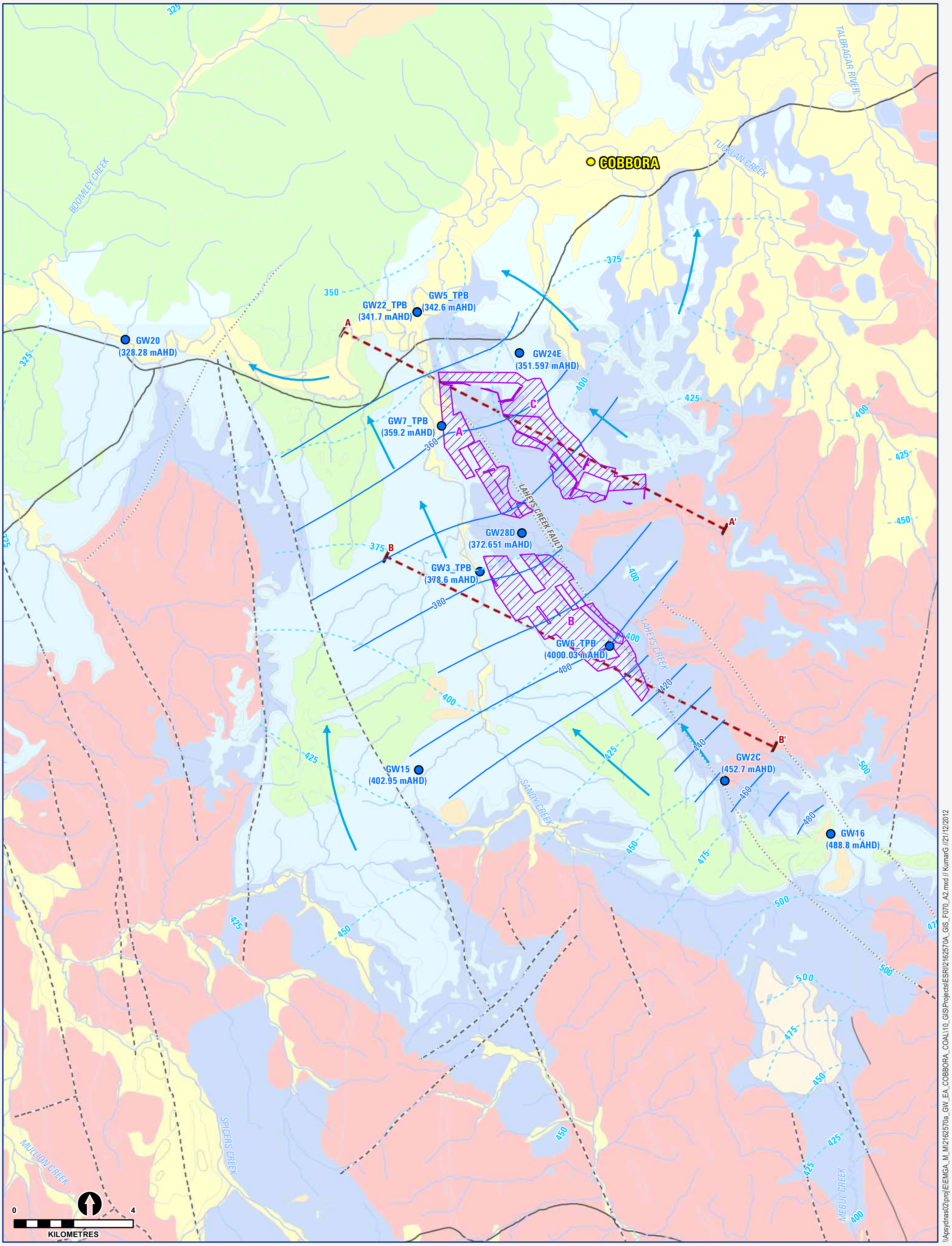


Figure 4.1 Cumulative monthly rainfall residual curve for the Project area since January 1889



Piezometer sites
Drainage lines
Fault - approximate
Fault - concealed
Proposed mining areas
Cross section
Water table elevation (mAHD)
Potentiometric level in the deep Ulan Coal Seam (mAHD)
Groundwater flow direction

Aquifer systems

Alluvium
Tertiary fractured basalts
Great Artesian Basin
Mesozoic igneous rocks
Porous rock - Triassic
Porous rock - Permian
Lachlan Fold Belt

Figure 4.2A Groundwater level contours

Geologic map source: Geological Survey of New South Wales, 1999

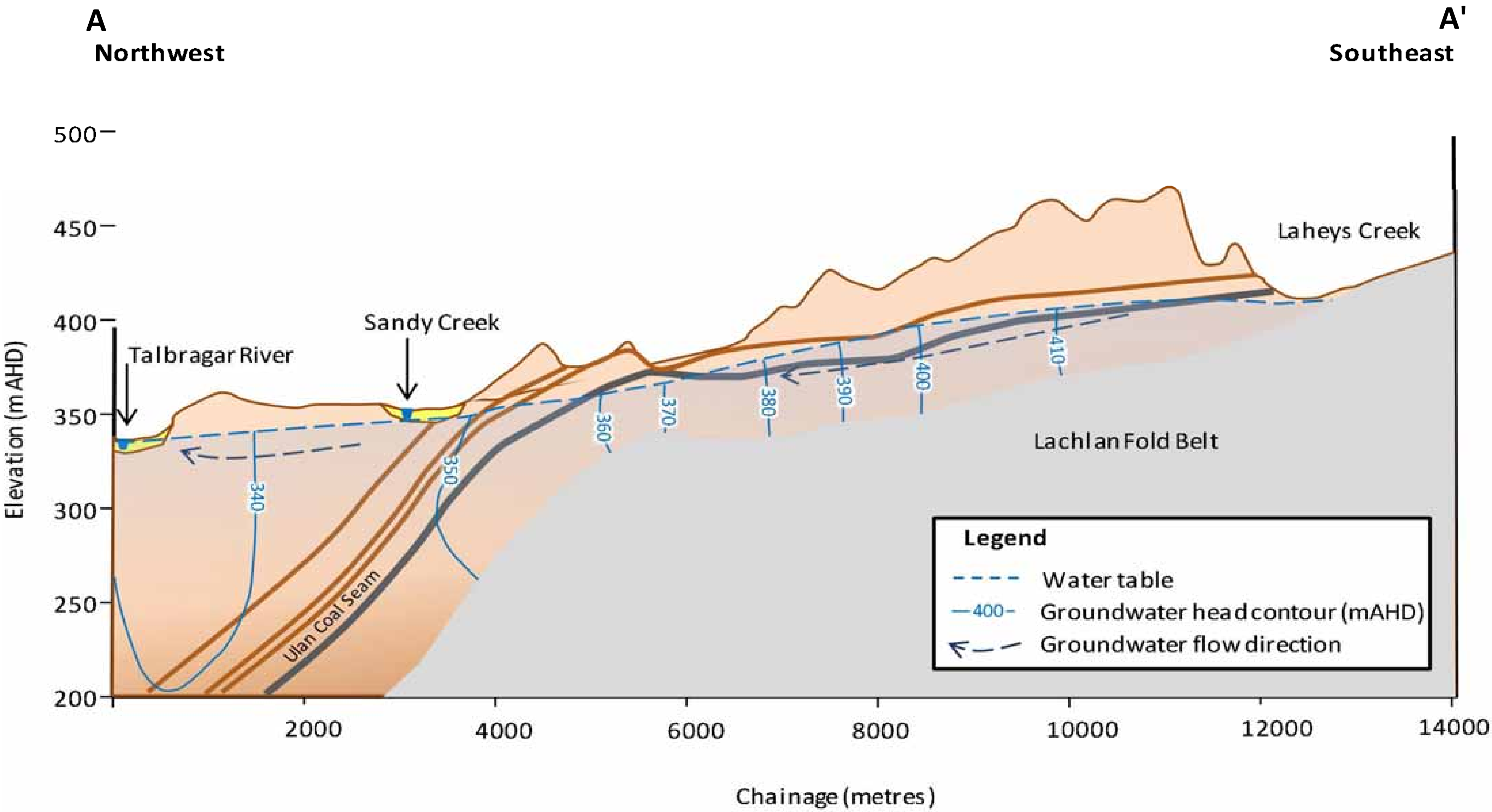


Figure 4.2B Groundwater heads across transect A-A'

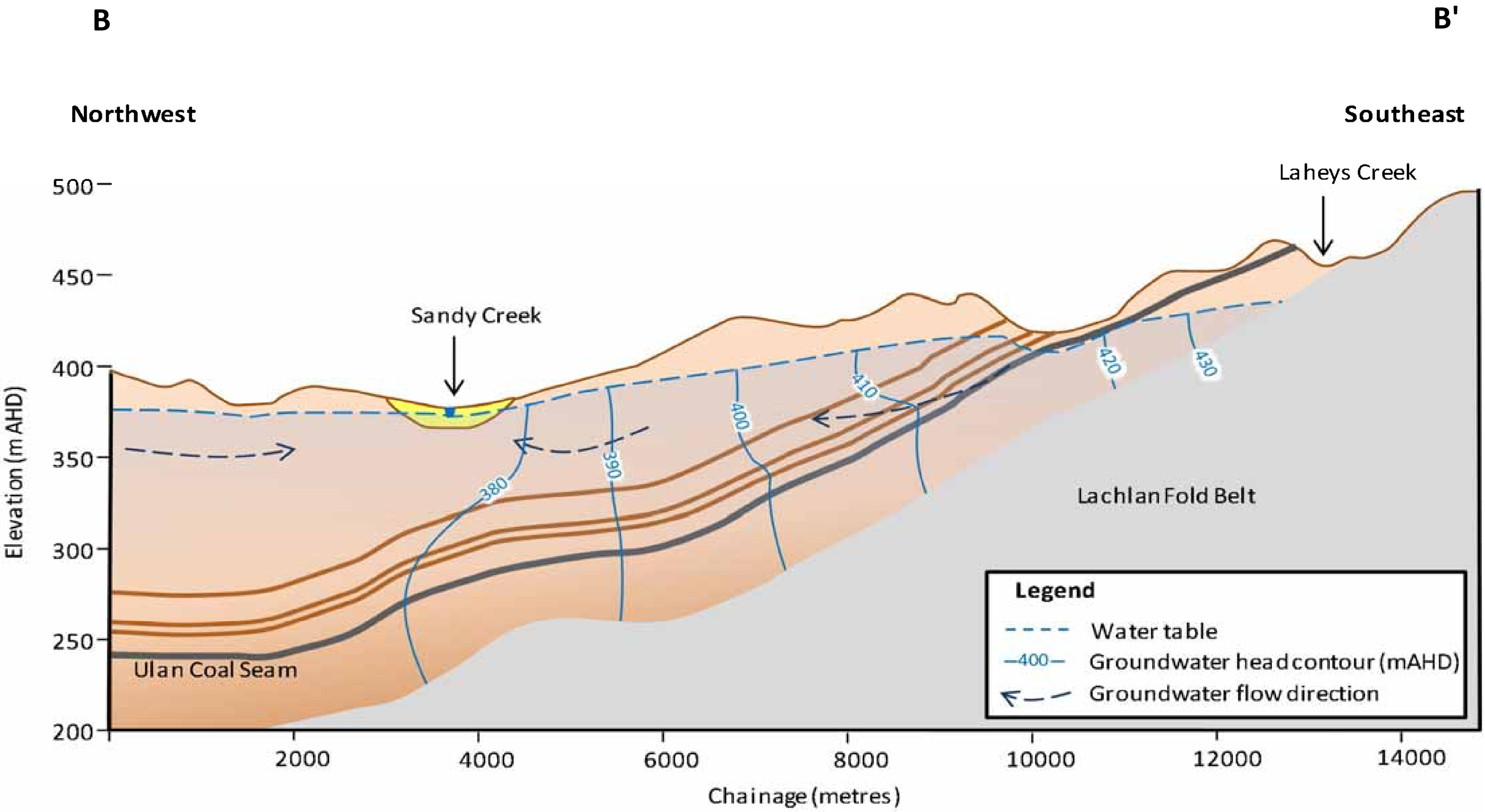


Figure 4.2C Groundwater heads across transect B-B'

4.2.4 Statistics

A summary table of calibration statistics using all data points is provided in Table 4.4. The normalised root mean square error for the steady state calibration is 2.53%, which is well within the target calibration error of 5%. The relationship between modelled and observed groundwater levels is presented graphically in Figure 4.3

Table 4.4 Calibration statistics for steady state model

Statistic	Value	Bore/screened unit
Number of data points	37	
Maximum residual (m)	-11.32	GW1A/Digby Formation
Minimum residual (m)	0.17	GW22_TPB/Digby Formation
Residual mean (m)	-0.63	
Absolute residual mean (m)	3.26	
Standard error of the estimate (m)	0.68	
Root mean square (RMS) (m)	4.22	
Normalised RMS (%)	2.53	

4.2.5 Sensitivity analysis

The autosensitivity package within Groundwater Vistas allows multiple simulations to be run, based on user-defined changes in a chosen set of input parameters. This process was used to investigate:

- which parameters exert the greatest control over model calibration
- the values of these parameters that optimise model calibration
- the extent to which uncertainty in model input parameters may influence model results.

The autosensitivity analysis was implemented by setting the values of the following parameters to 50%, 100% and 150% of their calibrated estimates in each of the seven main hydrogeological units, as listed in Table 4.1:

- horizontal hydraulic conductivity
- recharge rate
- evapotranspiration rate
- evapotranspiration extinction depth.

Due to the greater uncertainty associated with vertical hydraulic conductivity, values of this parameter were set to 10%, 100% and 1000% of their calibrated estimates.

A detailed summary of the sensitivity results are provided in Table A.1 and Table A.2 of Appendix A. In general, the steady state model was found to be insensitive to most parameters. This is likely to be due to the large number of surface water bodies within the assessment area, which are conceptualised in the model to act as constant head boundaries over the long term. The sensitivity of groundwater levels to changes in aquifer properties is likely to be reduced near these features.

The model is sensitive to the horizontal conductivity of the Digby Formation, Ulan Coal Seams and Dapper Formation, with improved calibration arising from increased values of these parameters. The model was also found to be sensitive to recharge and vertical hydraulic conductivity in the Digby Formation and to the evapotranspiration extinction depth.

Although these results indicate that the model calibration may be improved by altering the values of some parameters, the conceptual model of the assessment area (Parsons Brinckerhoff 2013a) and the results of transient calibration (see Section 4.3) were also considered in setting parameter values. The values chosen represent a balance between these factors, ensuring that the model is physically realistic and closely matches the observed groundwater level data.

4.3 Transient calibration

4.3.1 Dataset

Data from the bores used in steady state calibration (see Table 4.2) was used to calibrate the transient model. Weekly averages of groundwater levels in each bore were calculated over a 74-week period between 24 March 2010 and 24 August 2011. These were used to produce the transient calibration dataset.

Groundwater levels produced by the steady state model were used as initial heads for the period of transient calibration.

4.3.2 Water balance

Table 4.5 provides the volumetric water balance over the period of the transient model. Groundwater storage over the period of transient calibration shows a net increase, reflecting wetter-than-average conditions.

Table 4.5 Transient water balance (average of all time steps)

Boundary	In (m^3/d)	In (%)	Out (m^3/d)	Out (%)
Storage	46,382	24%	78,462	40%
Constant head	98	0%	1,477	1%
Rivers	30,038	15%	13,952	7%
Recharge	112,492	57%	0	0%
Evapotranspiration	0	0%	91,806	47%
General head	6,975	4%	10,283	5%
Total	**195,985**		**195,981**	
Error	**0%**			

Inflows in the model are dominated by recharge (57%), with a further 15% of inflows coming from surface water bodies. Regional groundwater flows account for 4% of model inflows, while 24% of inflows come from the release of groundwater from storage.

Evapotranspiration is the main outflow from the transient model, accounting for 47% of flows. Increases in storage (40%) also account for a significant proportion of outflows in the model, reflecting the above-average rainfall and high recharge occurring at this time. Other outflows include baseflow to surface water bodies (7%) and regional groundwater flows (6%).

The water balance discrepancy between calculated inflows and outflows over the transient calibration period is negligible (0.002%).

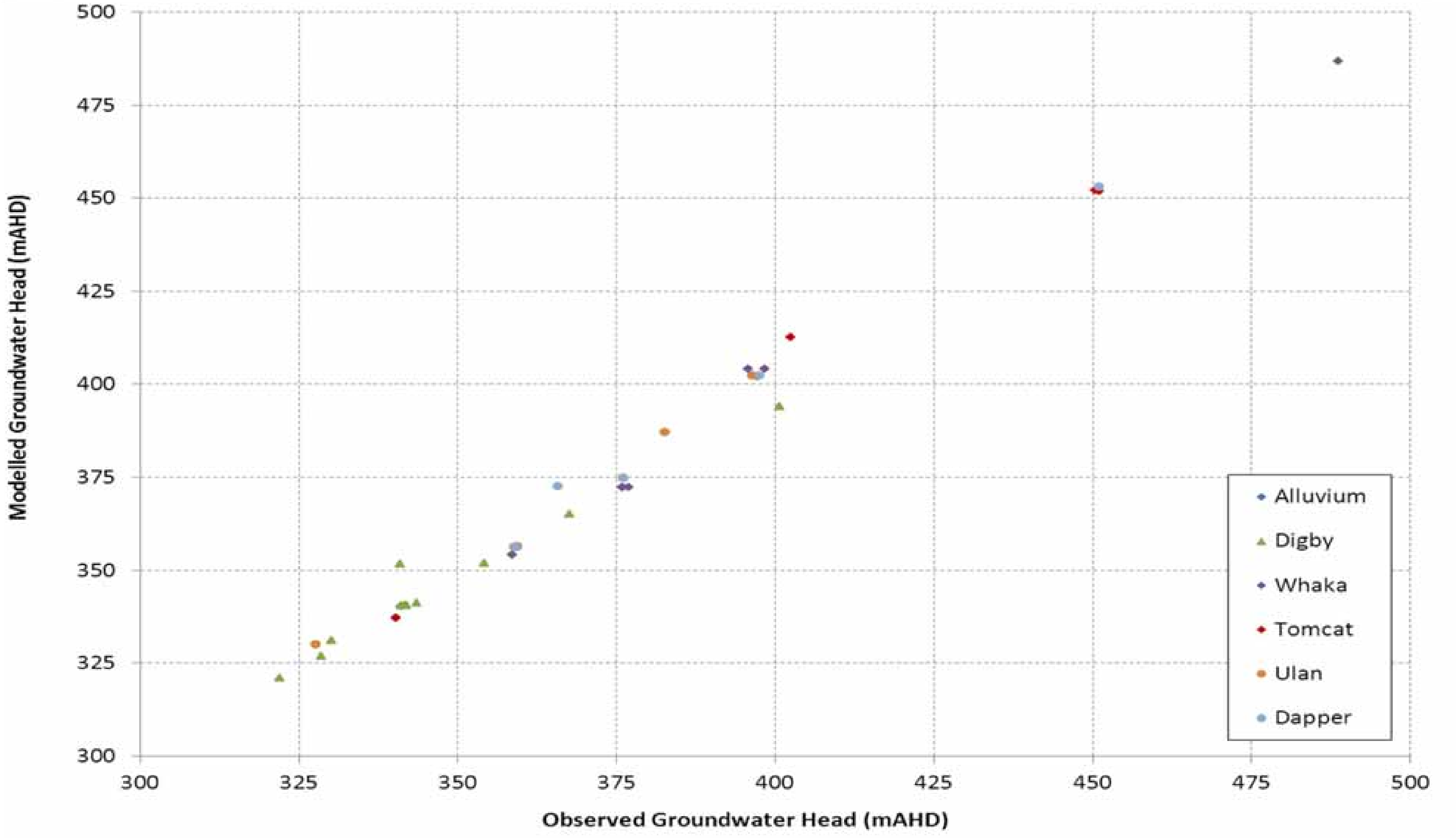


Figure 4.3 Relationship between modelled and observed groundwater heads for the steady state model

4.3.3 Statistics

Table 4.6 summarises calibration statistics for the transient model using all data points. The overall relationship between modelled and observed groundwater levels is presented graphically in Figure 4.4.

Table 4.6 Calibration statistics for transient model

Statistic	Value	Bore/screened unit
Number of data points	2725	
Maximum residual (m)	-12.00	GW15/Dapper Formation
Minimum residual (m)	0.00	GW2B/Dapper Formation
Residual mean (m)	-1.01	
Absolute residual mean (m)	3.19	
Standard error of the estimate (m)	0.08	
Root mean square (RMS) (m)	4.32	
Normalised RMS (%)	2.59	

Individual hydrographs for selected bores are shown in Figure 4.7A-E. The model matches observed water levels and variations very closely at some locations. However, in some bores the variability of the model does not match field observations. Within the same hydrostratigraphic unit, model variability may be too high in one bore and too low in another. This indicates a degree of heterogeneity within the local geology, which has not been replicated by the model. The model does closely match the average behaviour of each unit.

4.3.4 Sensitivity analysis

Initial estimates of the model input parameters were based on the results of steady state calibration, in conjunction with hydraulic testing and groundwater age data that Parsons Brinckerhoff collected in the assessment area. Autosensitivity analysis was carried out to further refine these estimates and to investigate the sensitivity of the model to changes in the following parameters:

- horizontal hydraulic conductivity
- vertical hydraulic conductivity
- specific yield
- recharge rate
- evapotranspiration rate
- evapotranspiration extinction depth.

Changes in these parameter values were applied to each of the seven main hydrogeological units, as listed in Table 4.1. Vertical hydraulic conductivity was varied by an order of magnitude during the sensitivity analysis; the values of the other parameters were varied by +/- 50%.

The model calibration was found to be relatively insensitive to the majority of input parameters, with only small variations in normalised root mean square values. As with the steady state model calibration, this is likely to be due to the large number of surface water bodies within the assessment area, which are conceptualised in the model to act as constant head boundaries over the long term.

The model was most sensitive to vertical hydraulic conductivity in the Whaka Formation, and to vertical hydraulic conductivity, specific yield and recharge in the Digby Formation. As few data are available on variations in the water table in layers 2 and 4 to 7, the transient model is not sensitive to specific yield values in these layers. A summary of the results of the autosensitivity analysis is presented in Table A.3 and Table A.4 of Appendix A.

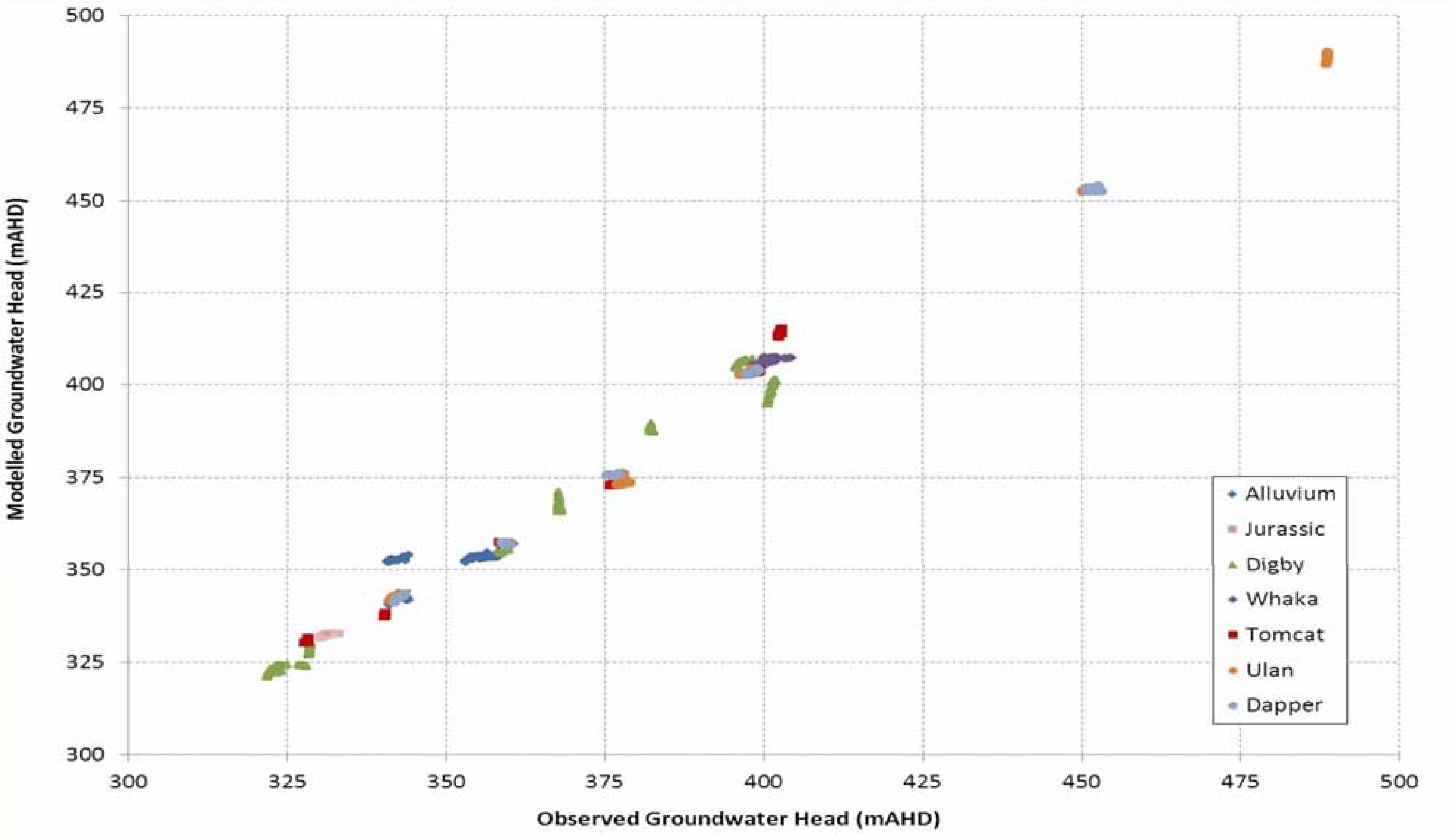


Figure 4.4 Relationship between modelled and observed groundwater heads for the transient model

Figure 4.5A Selected hydrographs showing observed versus calibrated transient groundwater heads

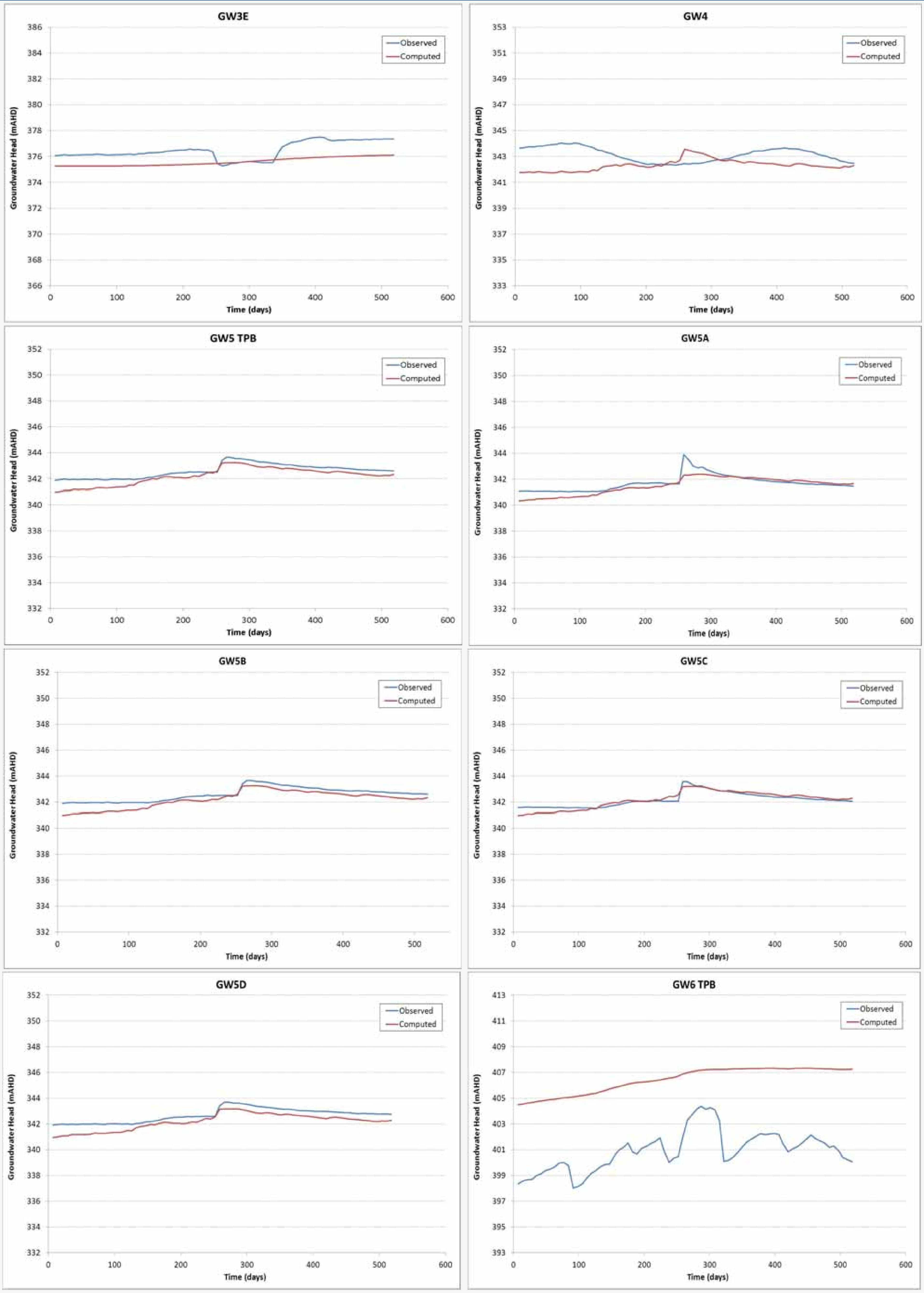


Figure 4.5B Selected hydrographs showing observed versus calibrated transient groundwater heads

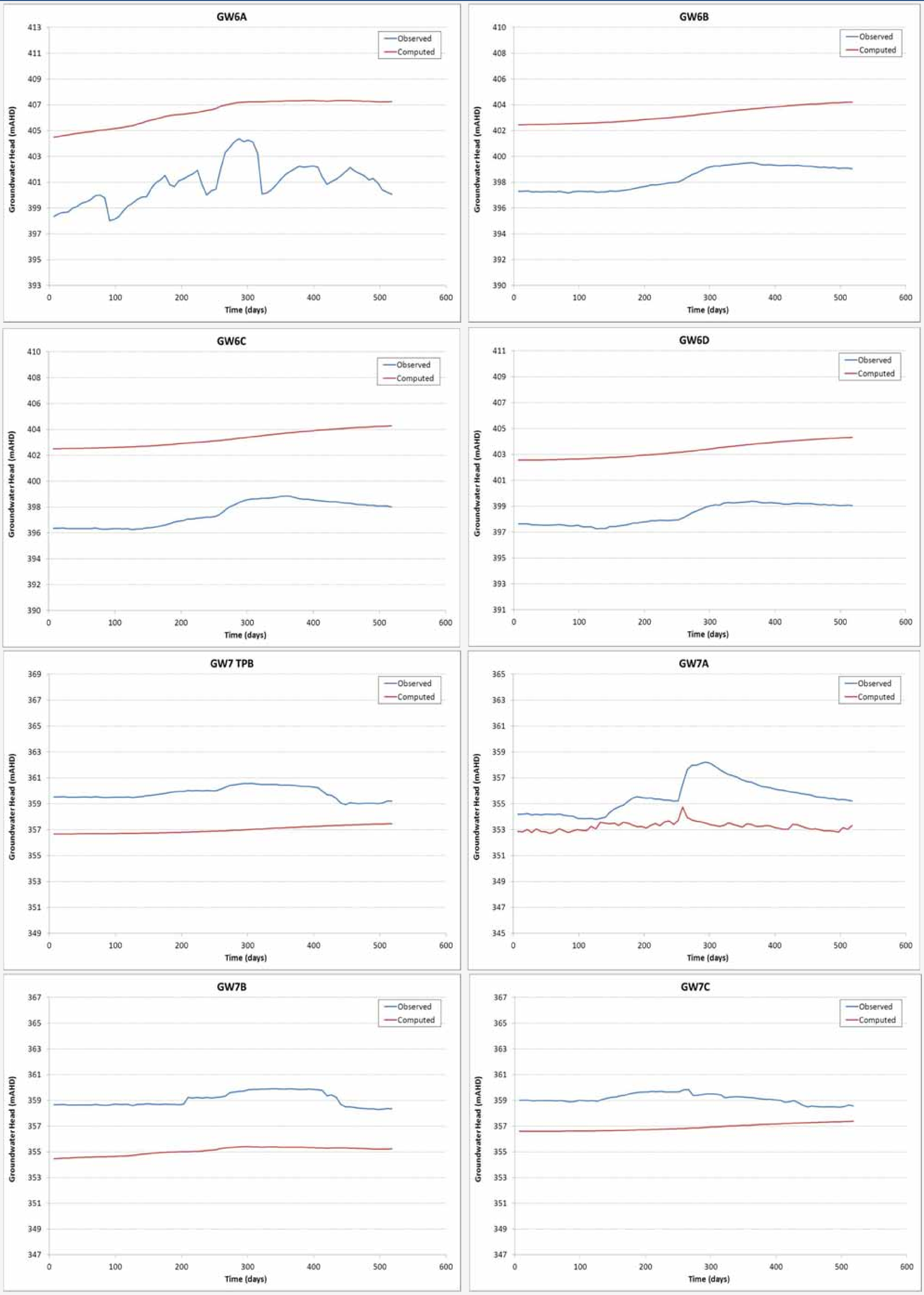


Figure 4.5C Selected hydrographs showing observed versus calibrated transient groundwater heads

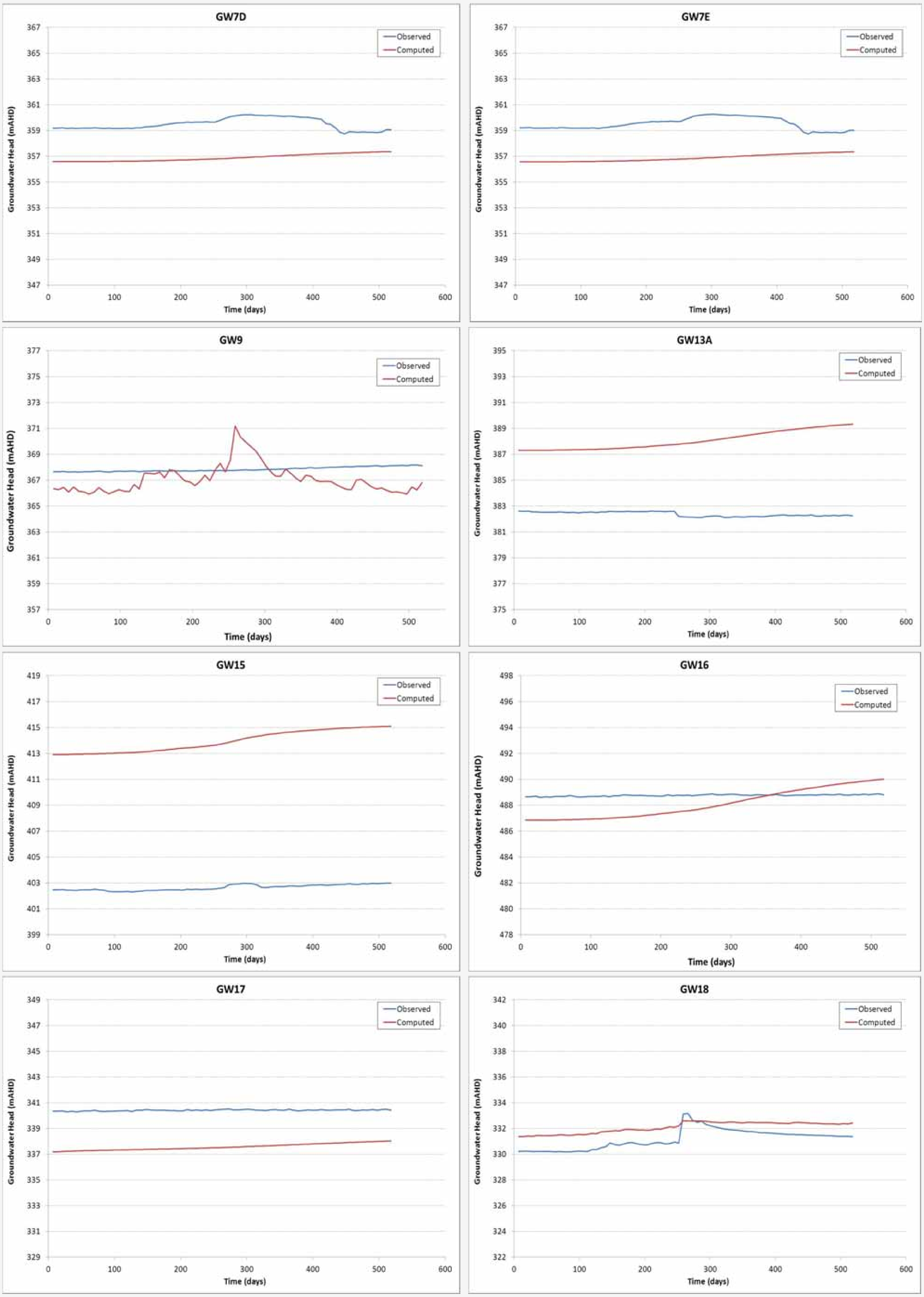


Figure 4.5D Selected hydrographs showing observed versus calibrated transient groundwater heads

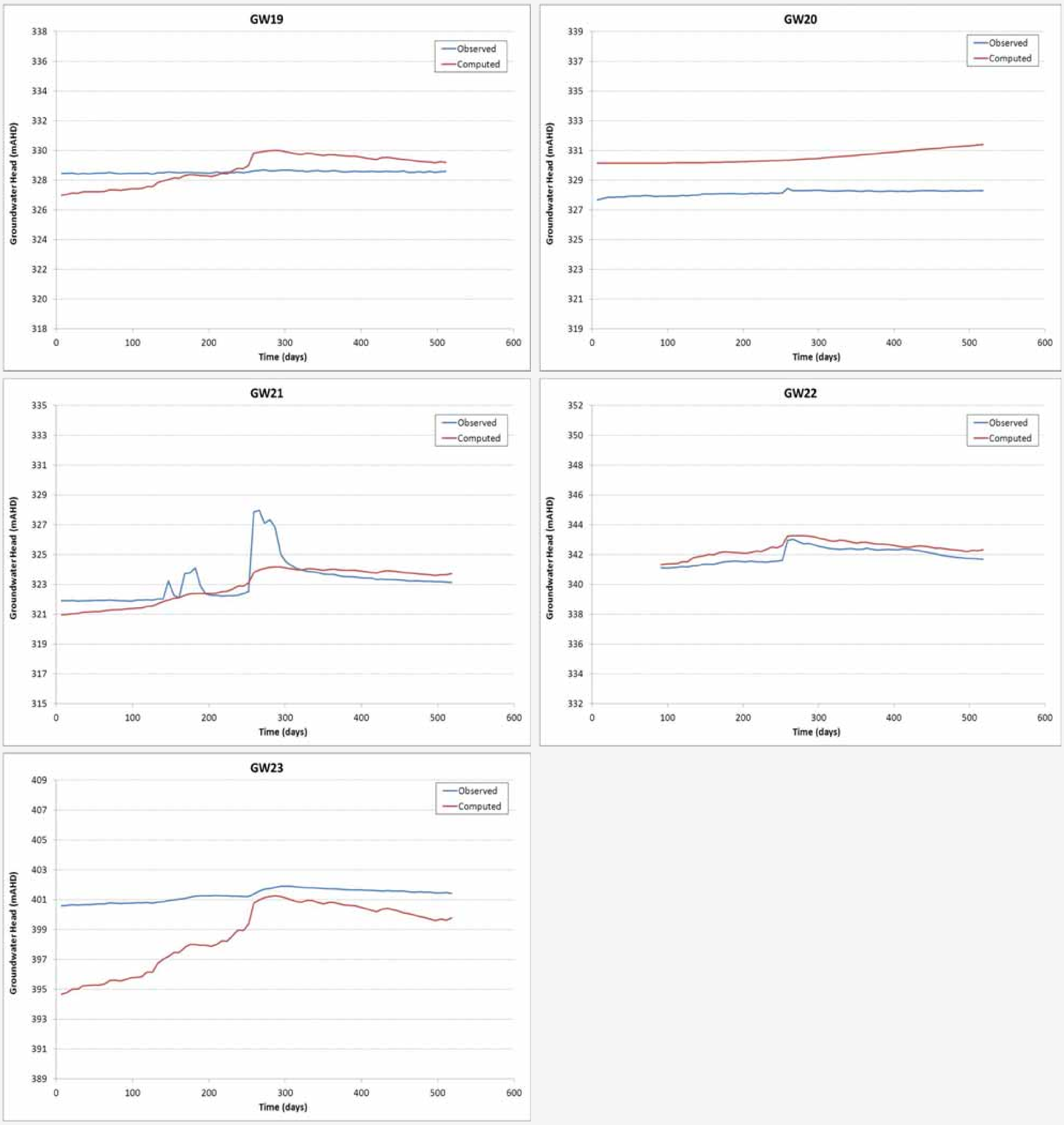


Figure 4.5E Selected hydrographs showing observed versus calibrated transient groundwater heads

5. Model predictions and analysis

5.1 Predicted mine inflow rates

Predicted mine inflow (dewatering) rates during the proposed period of mining (2015 to 2035) are presented in Table 5.1 and Figure 5.1 for the three proposed mining areas: A, B and C. Mining area B accounts for approximately half of all inflows to the mine. The largest inflow rates occur between 2021 and 2032, with total flows typically more than 2,000 ML/a during this period.

Table 5.1 Summary of estimated mine inflow rates

Year	Dewatering rates (ML/a)			
	Mining area A	Mining area B	Mining area C	Total
2015	24	107	0	130
2016	191	329	23	544
2017	297	465	61	824
2018	368	600	101	1,069
2019	331	591	108	1,030
2020	446	767	183	1,396
2021	875	1,001	231	2,107
2022	733	1,325	381	2,439
2023	912	1,067	357	2,336
2024	883	1,202	369	2,455
2025	950	1,196	369	2,515
2026	452	1,444	550	2,447
2027	254	1,361	530	2,144
2028	592	1,614	596	2,802
2029	645	1,517	527	2,690
2030	637	1,237	529	2,403
2031	801	821	403	2,025
2032	1,228	803	52	2,082
2033	278	633	33	944
2034	195	631	337	1,162
2035	0	31	0	31

* This table illustrates mine inflow during active mining only. Following the end of mining in area B (at year 2033) the process of groundwater recovery commences and inflow rate calculations for the recovery is presented and discussed in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012).

It should be noted that these dewatering estimates are the theoretical pit inflow rates derived from the applied drain cells in MODFLOW. It is anticipated that active dewatering (pumping from the void) may be significantly less than the predicted dewatering volume due to the effects of evaporation. Evaporative losses have been taken into account in the mine water balance presented in Cobbora Coal Project - Surface Water Assessment (Parsons Brinckerhoff 2013b).

Enhanced recharge is predicted to occur within the mine spoil material as a result of the higher permeability and lower runoff coefficient of the spoil. This enhanced recharge will report to the mine pit and form part of the total dewatering volume as shown in Table 5.2.

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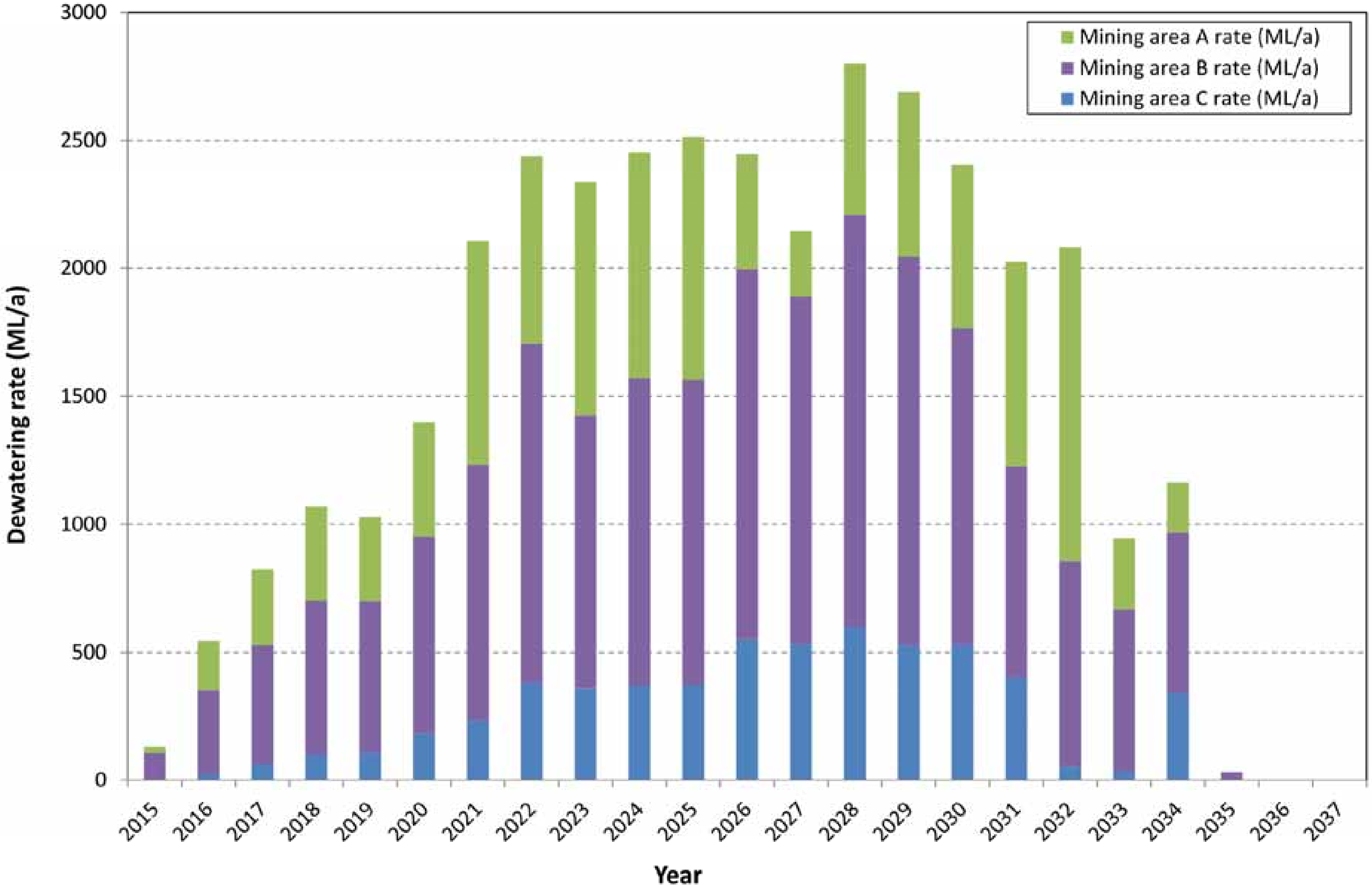

Figure 5.1 Predicted dewatering rates in each mining area

\\APSYDNAS02\proj\E\EMGA_M_M\2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F074_A2.mxd // SaflianK // 16/01/2013

5.1.1 Sources of inflows

The sources of groundwater inflows to the mine have been inferred based on changes in storage within each of the seven main hydrostratigraphic units in the model (not including excavated material within the proposed mining areas) and the estimated reduction in river flows. The results presented in Figure 5.2 show the net changes in storage resulting from the combined effects of mine inflows and increased recharge as a result of the placement of backfill material following mining. The Ulan and Dapper hydrostratigraphic units are the biggest contributors to mine inflows in the model, with predicted cumulative storage losses of up to 6,500 and 6,100 ML respectively towards the end of mining.

Predicted cumulative storage losses within the alluvium reach a maximum value of approximately 720 ML. This constitutes 0.3% of the estimated 220,000 ML (220 GL) of available groundwater storage in the alluvium within the model domain (ignoring stagnant water stored in ‘dead-end’ pores). The estimate is based on the calculated volume of the alluvium aquifer below the water table, and an assumed specific yield of 20%.

The model results indicate a maximum reduction in river flows of approximately 480 ML/a, which occurs in 2036 following the end of mining operations (based on the change in total river inflows minus total river outflows within the model). This constitutes 0.9% of the average annual flow in the Talbragar River of 54,427 ML/a (Parsons Brinckerhoff 2013b). The model results predict that approximately 65% of the total reduction in surface water flows during mining is due to increased outflows from rivers to the surrounding groundwater system (induced recharge), with reductions in baseflow accounting for the remaining 35%.

5.1.2 Net groundwater usage

The placement of backfill material within the mine void is expected to increase the volume of recharge within the mining areas and contributes to the predicted dewatering rates listed in Table 5.1. River losses also contribute to the total required dewatering rate. Net groundwater usage, as presented in Table 5.2 below, has been estimated based on the predicted mine dewatering rates, minus the river losses (as those losses are accounted for in surface water) and minus the contribution of enhanced recharge. This represents the net volume of groundwater usage as a result of mining activities.

Net groundwater usage is predicted to be close to 2,000 ML/a between 2021 and 2030, reaching a maximum value of 2,202 ML/a in 2028. These values are slightly higher than the groundwater storage losses shown in Figure 5.2. The overall lowering of the water table within the model domain is predicted to reduce evaporation from groundwater and slightly reduce storage losses. As a conservative measure, the mitigating effects of reduced evaporation have not been included in estimating groundwater usage. The average groundwater usage over the life of the mine is predicted to be 1,272 ML/a.

Table 5.2 Net groundwater usage during mining

Year	Dewatering rate (ML/a)	Enhanced recharge (ML/a)	River losses (ML/a)	Net groundwater usage (ML/a)
2015	130	31	4	95
2016	544	34	42	468
2017	824	45	80	698
2018	1,069	47	125	897
2019	1,030	49	160	820
2020	1,396	67	184	1,145
2021	2,107	84	215	1,808
2022	2,439	105	239	2,095
2023	2,336	126	265	1,946
2024	2,455	143	292	2,019
2025	2,515	161	317	2,037
2026	2,447	177	341	1,929
2027	2,144	195	364	1,585
2028	2,802	219	382	2,202
2029	2,690	239	397	2,053
2030	2,403	258	416	1,729
2031	2,025	279	431	1,315
2032	2,082	301	445	1,336
2033	944	323	459	162
2034	1,162	330	469	363
2035	31	275	474	0

* Note: Enhanced recharge is the component of mine pit inflow that is attributed to additional recharge of rainfall into the adjacent spoils as a result of the high permeability and low runoff coefficient of the spoils.

5.2 Predicted drawdown

The maximum drawdown extent in both the water table aquifer and Ulan Coal Seams is shown in Figure 5.3A and Figure 5.3B respectively, along with the locations of privately owned groundwater bores in the assessment area. This represents the maximum predicted drawdown at each location within the model domain, and has been derived from predicted drawdown values across a range of time steps within the model.

Groundwater inflows to the mining areas are expected to lead to maximum lowering of the water table of up to 90 m in mining area B (with maximum lowering of groundwater levels in mining area A and mining area C of 60 m and 40 m respectively) (see Figure 5.3A). The 1 m drawdown contour is predicted to extend up to 5.5 km to the south of the mine and nearly 6 km to the west of mining area A. Drawdown to the north and east is less extensive, with the 1 m drawdown contour predicted to lie within 4 km of the mining areas.

Drawdown (depressurisation) is predicted to extend over a greater area in the Ulan Coal Seams than in the water table aquifer (see Figure 5.3B). The 1 m drawdown contour is predicted to lie approximately 6 km to the west of mining areas A and B. The extent of drawdown to the south, north and east of the mining areas is similar to that predicted for the water table aquifer.

Maps of drawdown in the water table aquifer and Ulan Coal Seams at individual time slices are shown in Figure 5.5 to 5.8. These show the predicted drawdown after 5 years, 10 years and 21 years of mining (i.e. the end of proposed mining activities), as well as predicted drawdown 20 and 100 years after the proposed mining activities cease. Cross-sections showing predicted groundwater levels through the mining areas are shown for the end of mining and post-mining periods (Figures 5.6C&D to 5.8C&D).

After 5 years, water levels within mining area B are expected to be lowered by up to 63 m. The resulting drawdown in the water table aquifer is expected to be largely confined within the mining areas, although some drawdown of water levels is predicted within the alluvium immediately adjacent to the mining areas (see Figure 5.5A). The 1 m drawdown contour within the Ulan Coal Seams is predicted to extend up to 2 km to the west of the mining areas (see Figure 5.5B).

After 10 years, water levels in mining area B are expected to be up to 74 m lower. The resulting 1 m drawdown contour in the water table aquifer (see Figure 5.7A) is predicted to extend up to 3 km from the mining area boundary. The alluvium immediately adjacent to the void is expected to experience drawdown of several metres in some localised areas. The 1 m drawdown contour in the Ulan Coal Seams is predicted to extend up to 4 km to the south and west of the mining areas.

At the end of mining after 21 years, the maximum drawdown is approximately 73 m in mining area B (see Figure 5.9A). The extent of drawdown is close to its maximum in both the water table aquifer (see Figure 5.9A) and Ulan Coal Seams (see Figure 5.9B). Storage losses within the alluvium and reductions in river flow are predicted to be greatest at this point. The cross-sections in Figures 5.6C and 5.6D highlight the hydraulic gradient between Sandy Creek and the adjacent mining areas, such that surface water will flow into the groundwater system in these areas.

As the greatest lowering of water levels is expected to occur within mining area B, most drawdown is expected to focus around this area. Figure 5.3 to 5.8 indicate lower predicted values of drawdown near mining areas A and C as a result of lower inflow volumes.

The model predicts that, 20 years after the cessation of mining activity, lowering of groundwater levels will be primarily confined to within 3.5 km of the mining area boundaries, although residual drawdown is predicted to occur within 5.5 km of the void lake in mining area B (see Figure 5.7). Enhanced recharge through the mine spoil material is expected to lead to a slight increase in groundwater levels in the north-west of mining area A.

Figure 5.7C shows that, in mining area A, groundwater levels are predicted to have recovered to above the level of Sandy Creek, such that the creek will receive groundwater discharge. In mining area B, it is predicted that water will continue to flow from Sandy Creek towards the pit lake (Figure 5.7D).

The extent of drawdown 100 years after the cessation of mining is shown in Figure 5.8. The presence of continued drawdown in some areas is attributed to evaporative losses from the pit lake and from the shallow subsurface in areas where ground levels have been lowered. This is shown by the cross-sections in Figure 5.8C and Figure 5.8D.

The water levels in the lake are expected to increase over time following the cessation of mining as groundwater levels recover. The water level in the lake is expected to have reached an equilibrium state 100 years after the end of mining, as evaporation from the lake is balanced by inflows from groundwater, rainfall and surface run-off (Parsons Brinckerhoff, 2013b).

Enhanced recharge through the mine spoil material is expected to lead to a slight increase in groundwater levels in the north-west of mining area B.

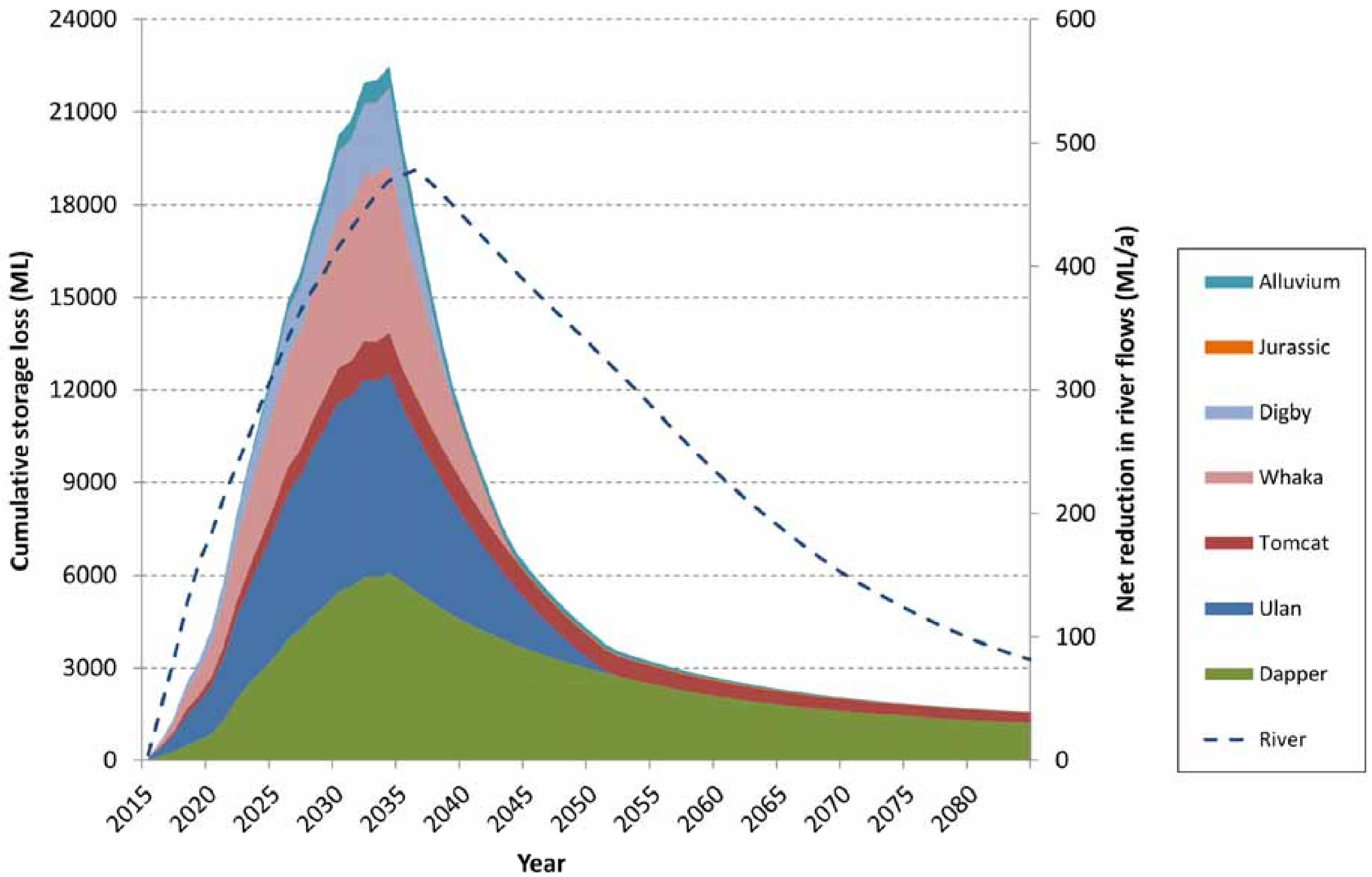

Figure 5.2 Predicted storage and river water losses from mine dewatering

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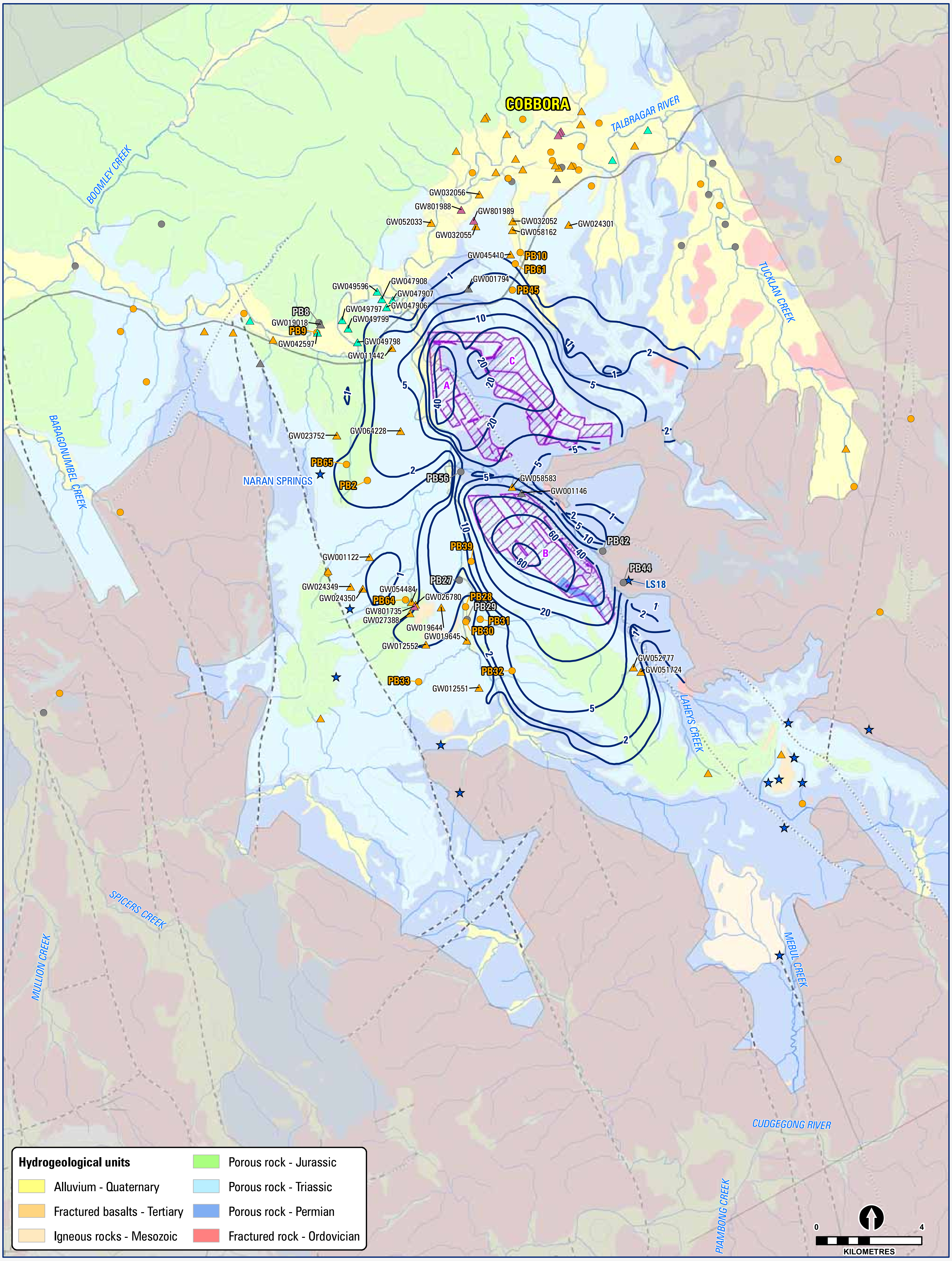
CHC PTY LTD



Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

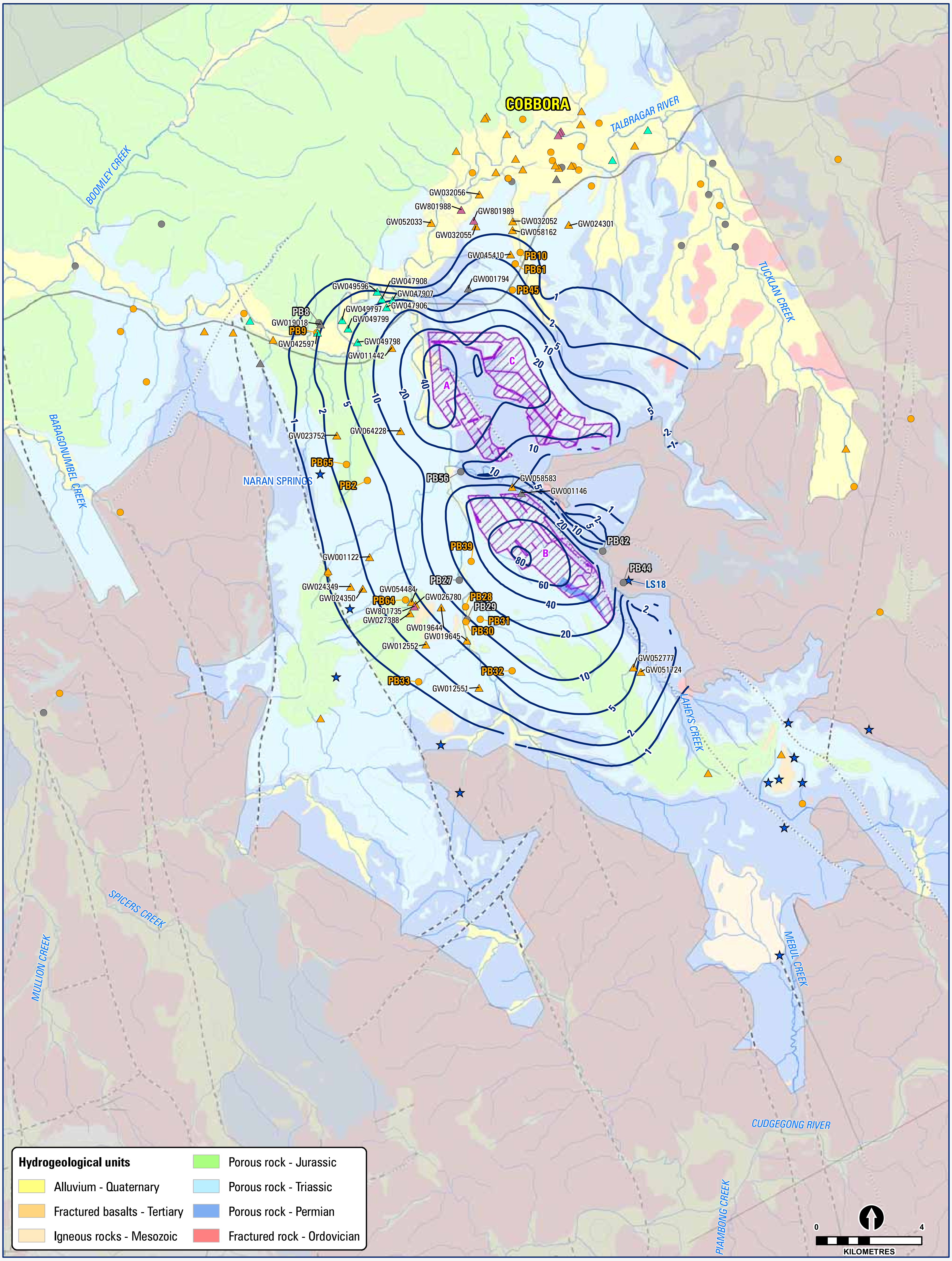
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location

- Maximum predicted drawdown (m)

Figure 5.3A Maximum predicted drawdown in the water table aquifer

Geologic map source: Geological Survey of New South Wales, 1999

\\Apsydnas02\proj\E\EMGA_M_M\2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F059_A3.mxd Salliank 10/01/2013



Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location

- Maximum predicted depressurisation (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.3B Maximum predicted depressurisation in the Ulan Coal Seams

\\Apsydnas02\proj\E\EMGA_M_M\2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F053_A3.mxd Salliank 10/01/2013

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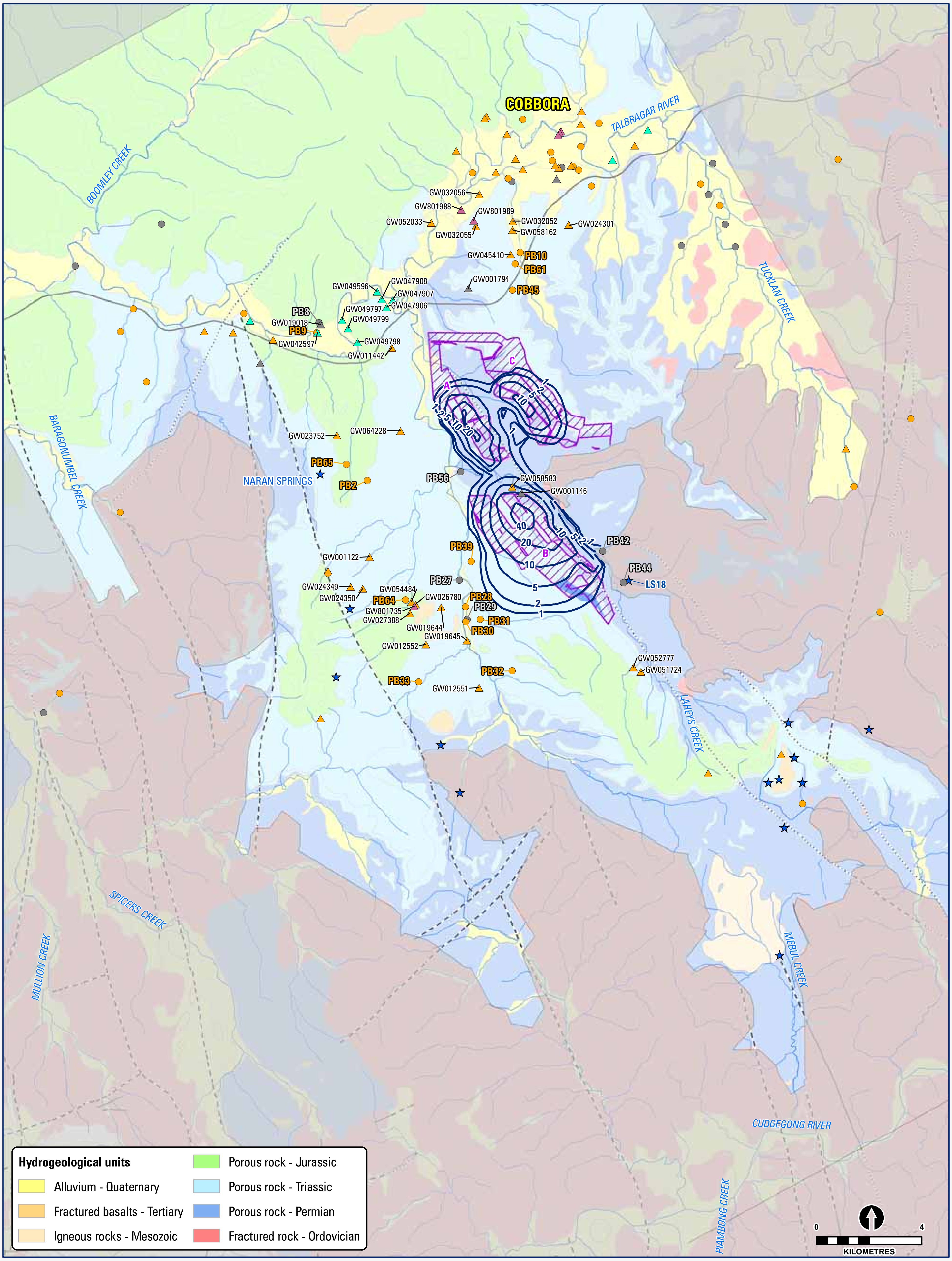
COBBORA COAL PROJECT
CHC PTY LTD



Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location
- Predicted drawdown (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.4A Drawdown in the water table aquifer after 5 years of mining

\\Apsydnas02\proj\E\EMGA_M_M\2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F060_A3.mxd Salliank 10/01/2013

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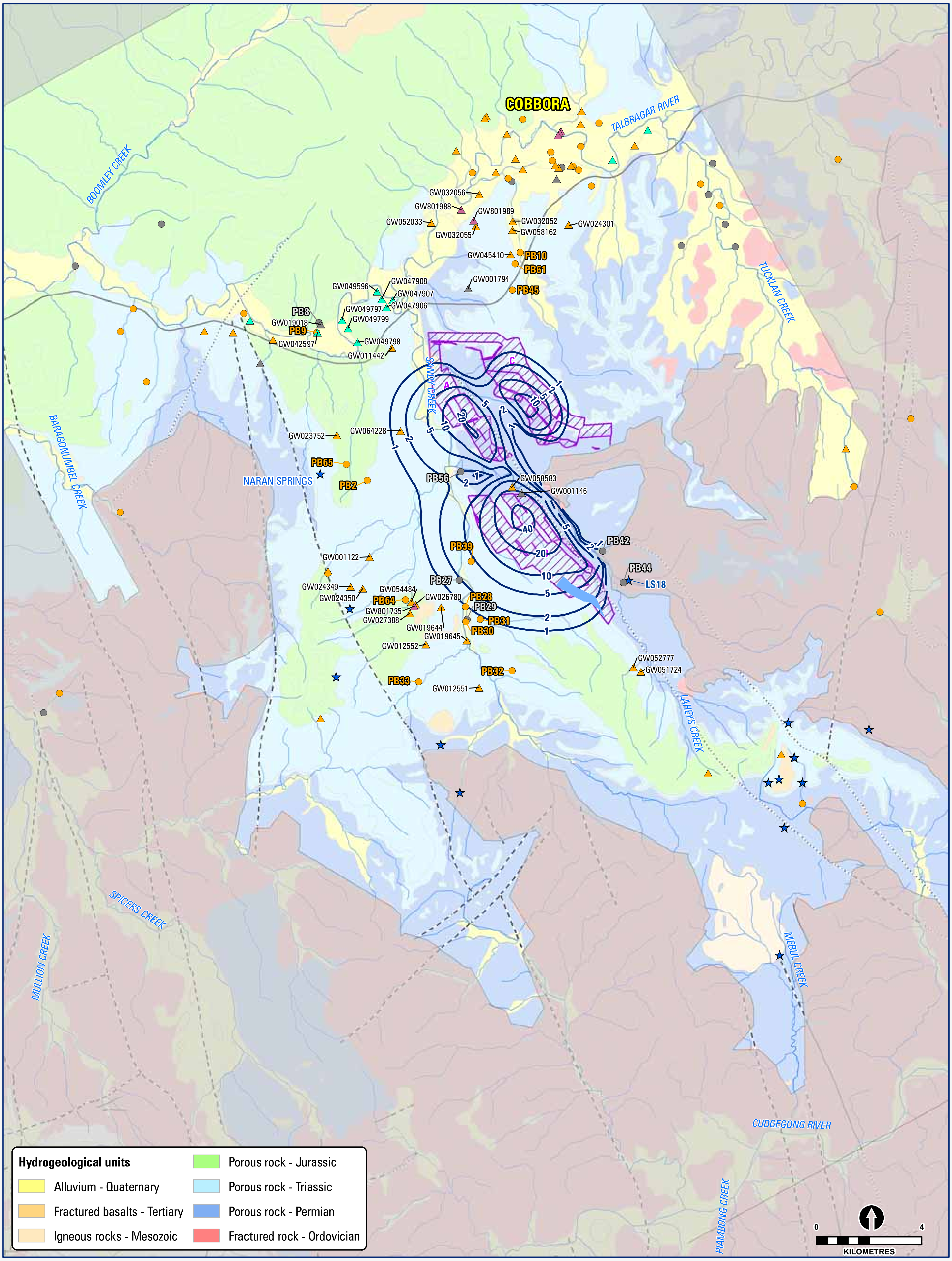
COBBORA COAL PROJECT
CHC PTY LTD



Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

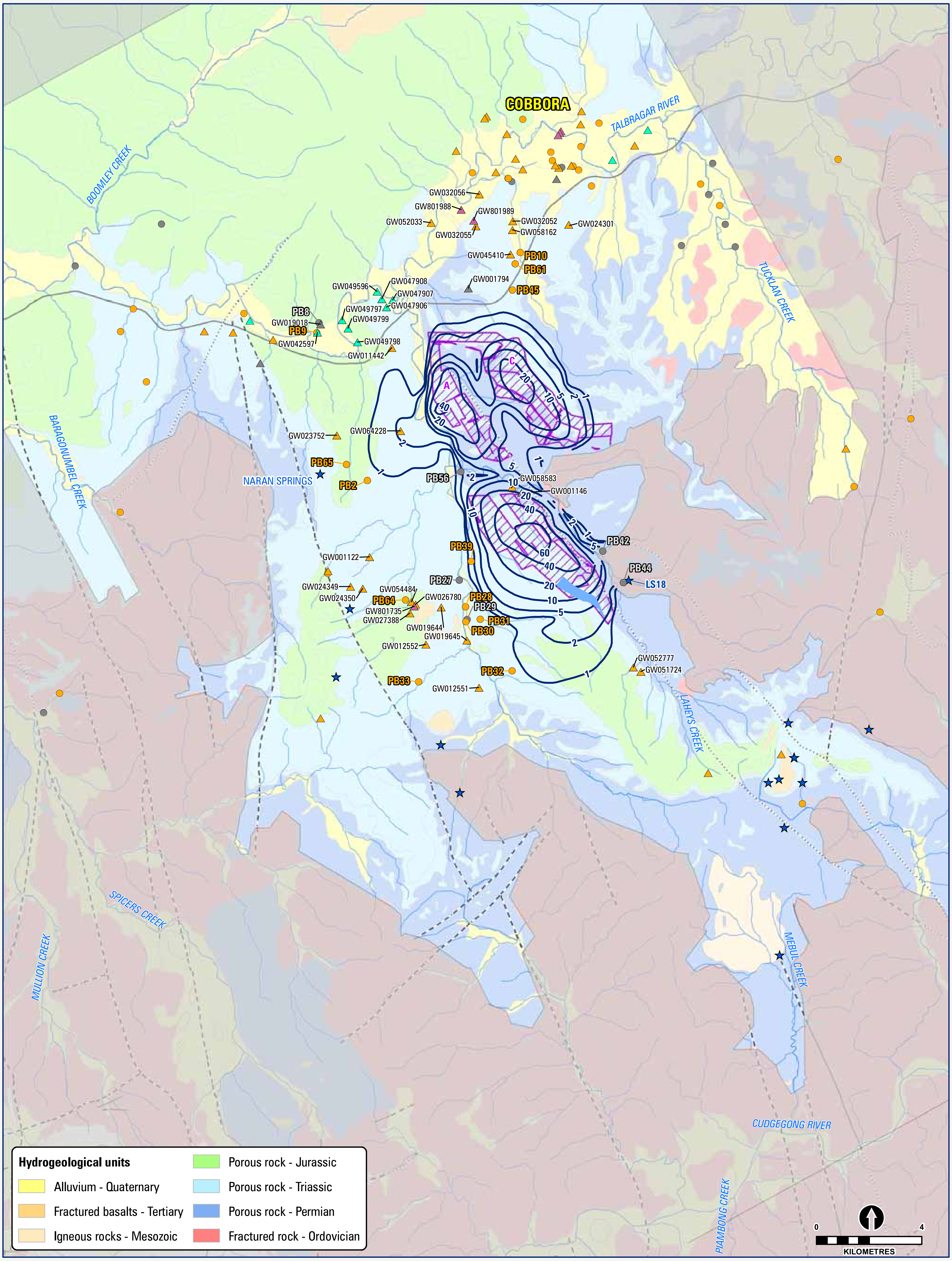
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location

- Predicted depressurisation (m)

Figure 5.4B Depressurisation in the Ulan Coal Seams after 5 years of mining

Geologic map source: Geological Survey of New South Wales, 1999

\\Apsydnas02\proj\E\EMGA_M_M\2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F054_A3.mxd Salliank 10/01/2013



Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

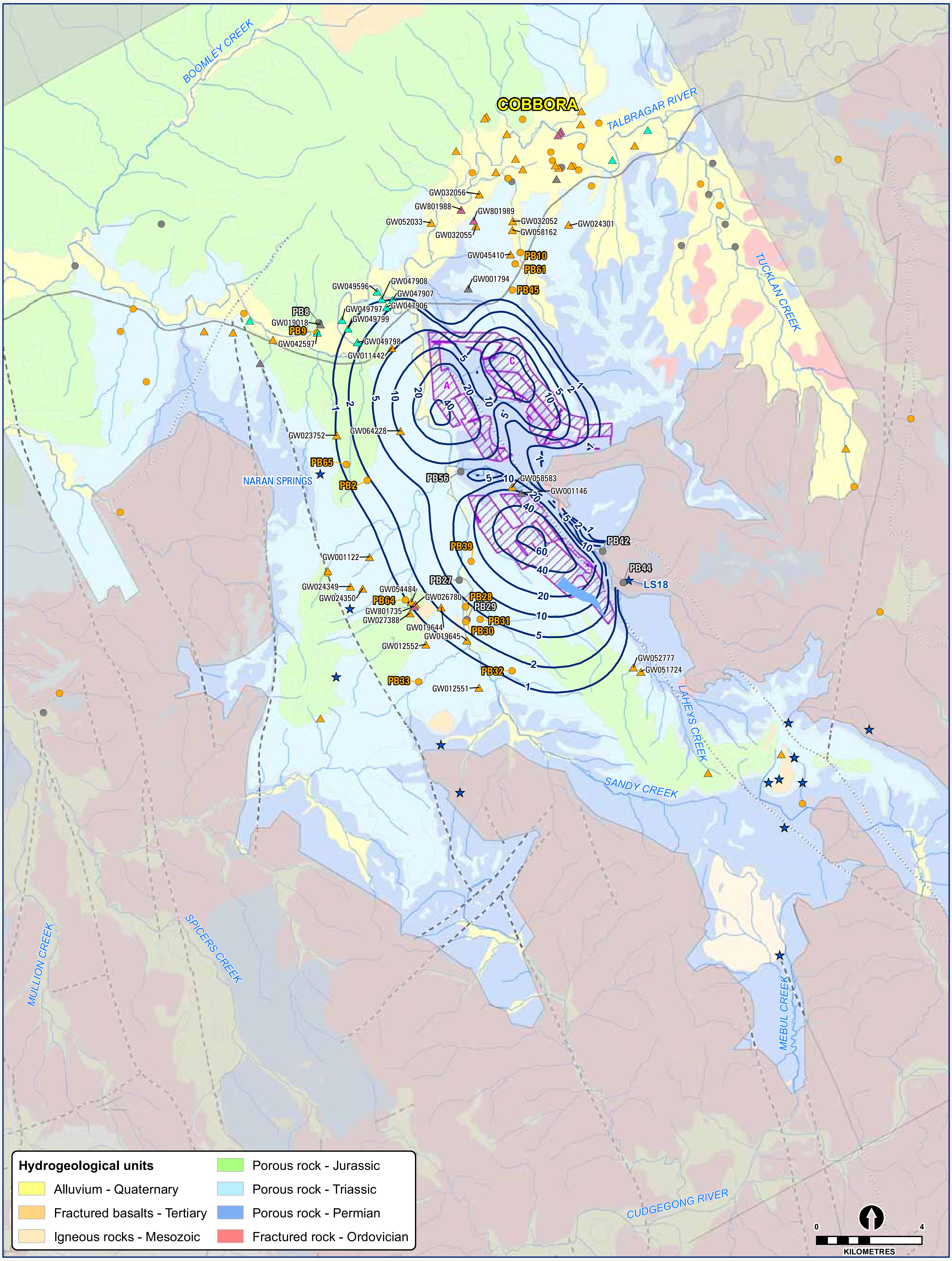
- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location

- Predicted drawdown (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.5A Drawdown in the water table aquifer after 10 years of mining



Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location
- Predicted depressurisation (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.5B Depressurisation in the Ulan Coal Seams after 10 years of mining

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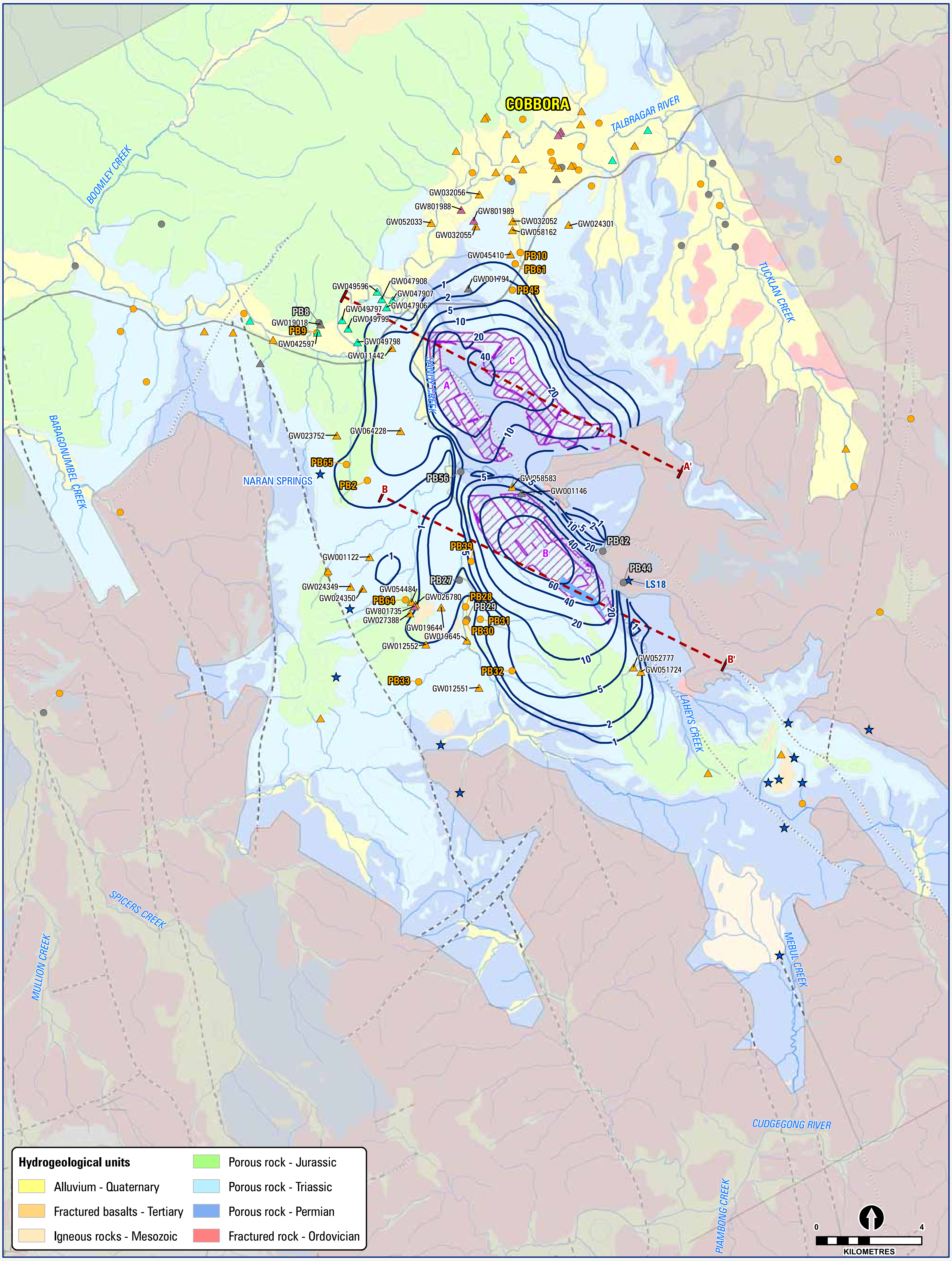

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Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Cross section
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location
- Predicted drawdown (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.6A Drawdown in water table aquifer after 21 years of mining / end of mining

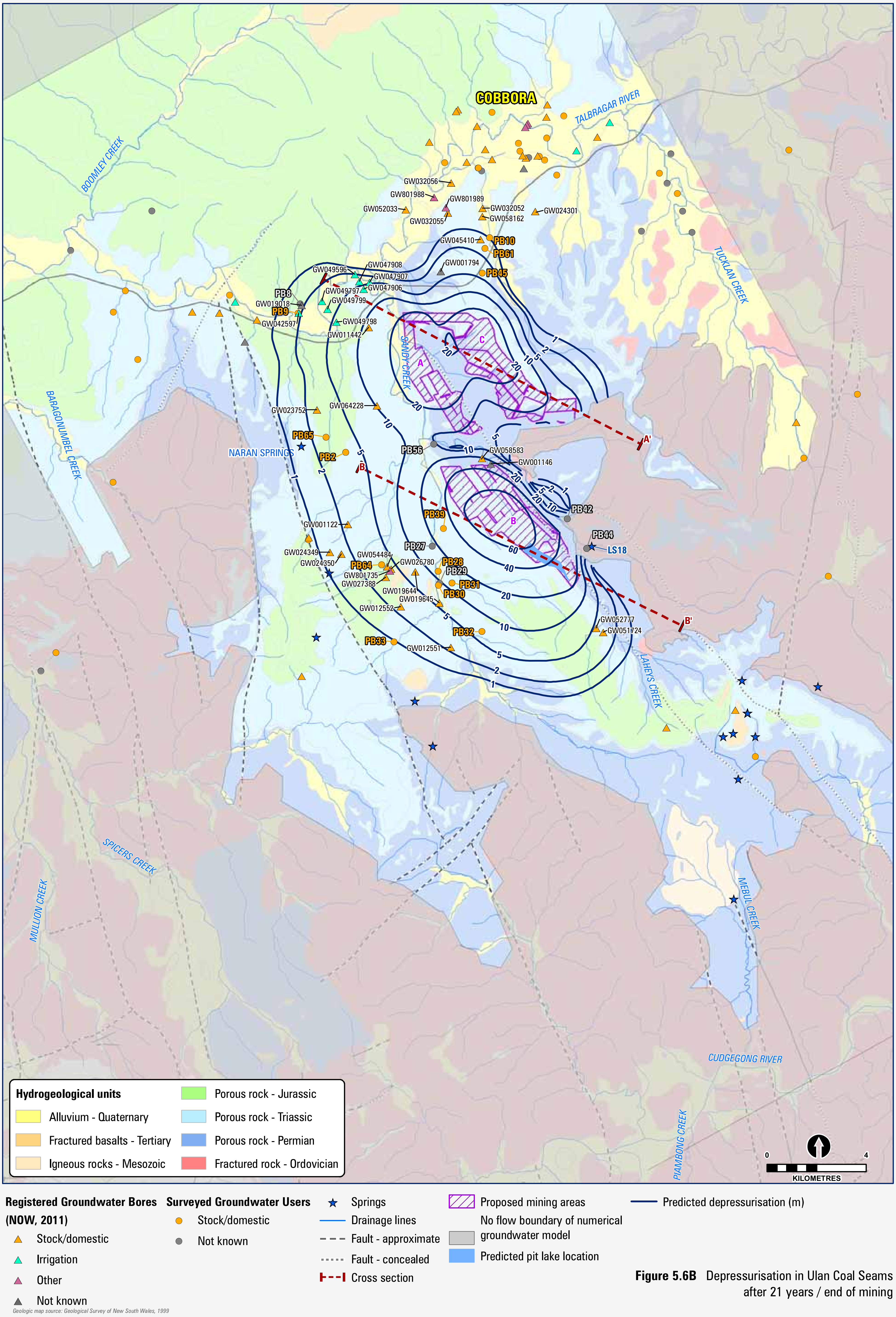

Figure 5.6B Depressurisation in Ulan Coal Seams after 21 years / end of mining

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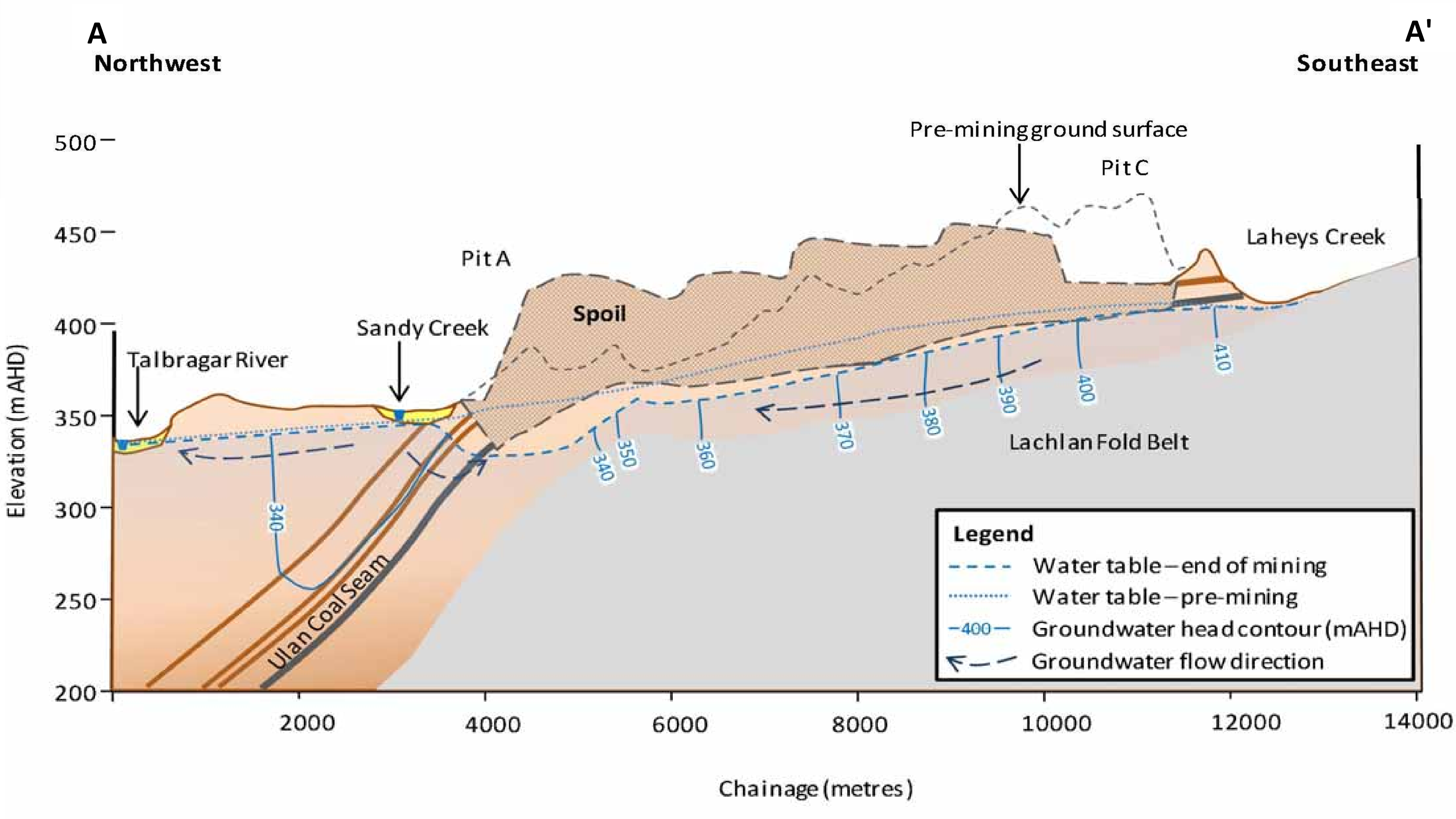


Figure 5.6C Groundwater heads across transect A-A' after 21 years / end of mining

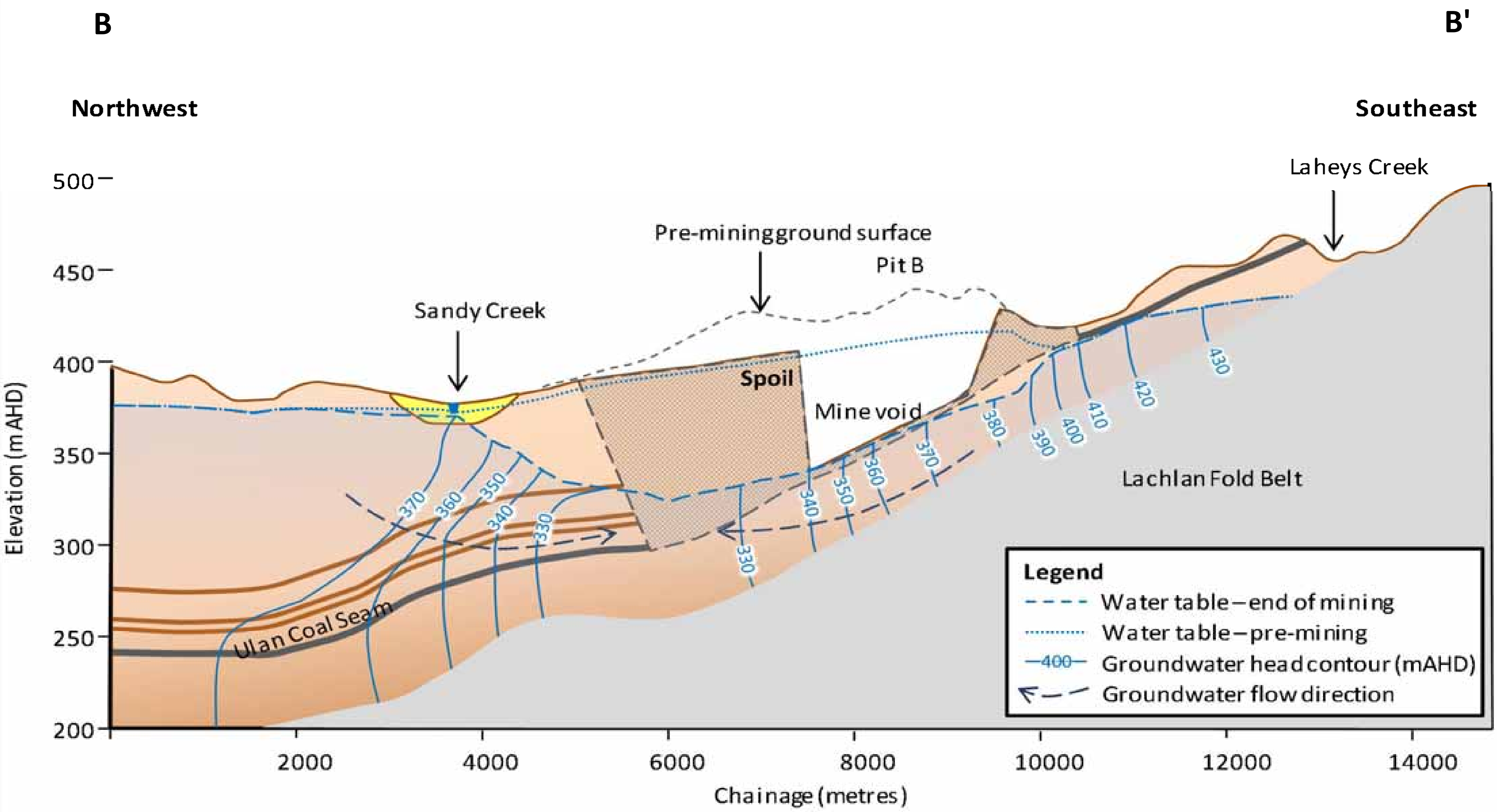
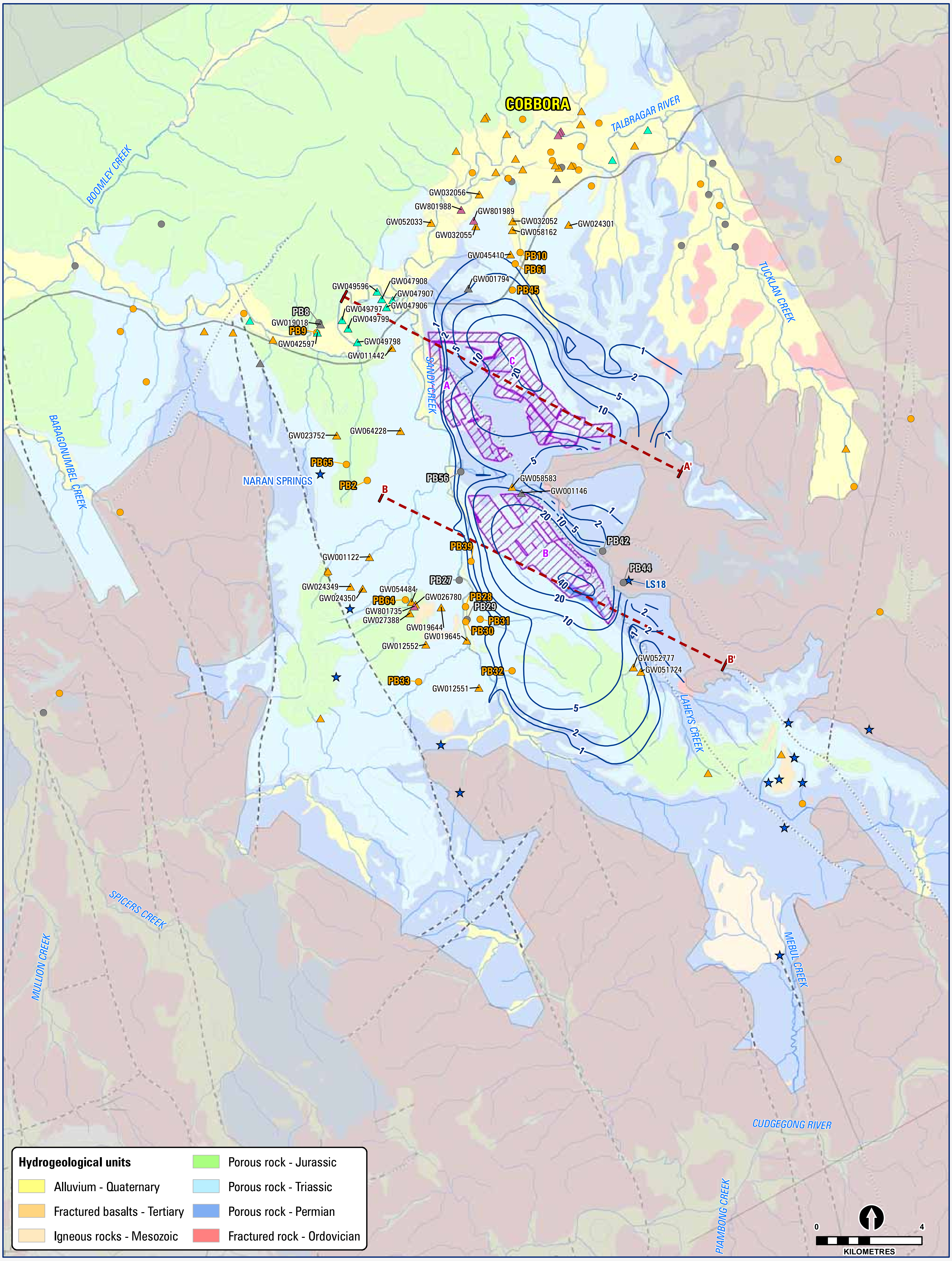


Figure 5.6D Groundwater heads across transect B-B' after 21 years / end of mining



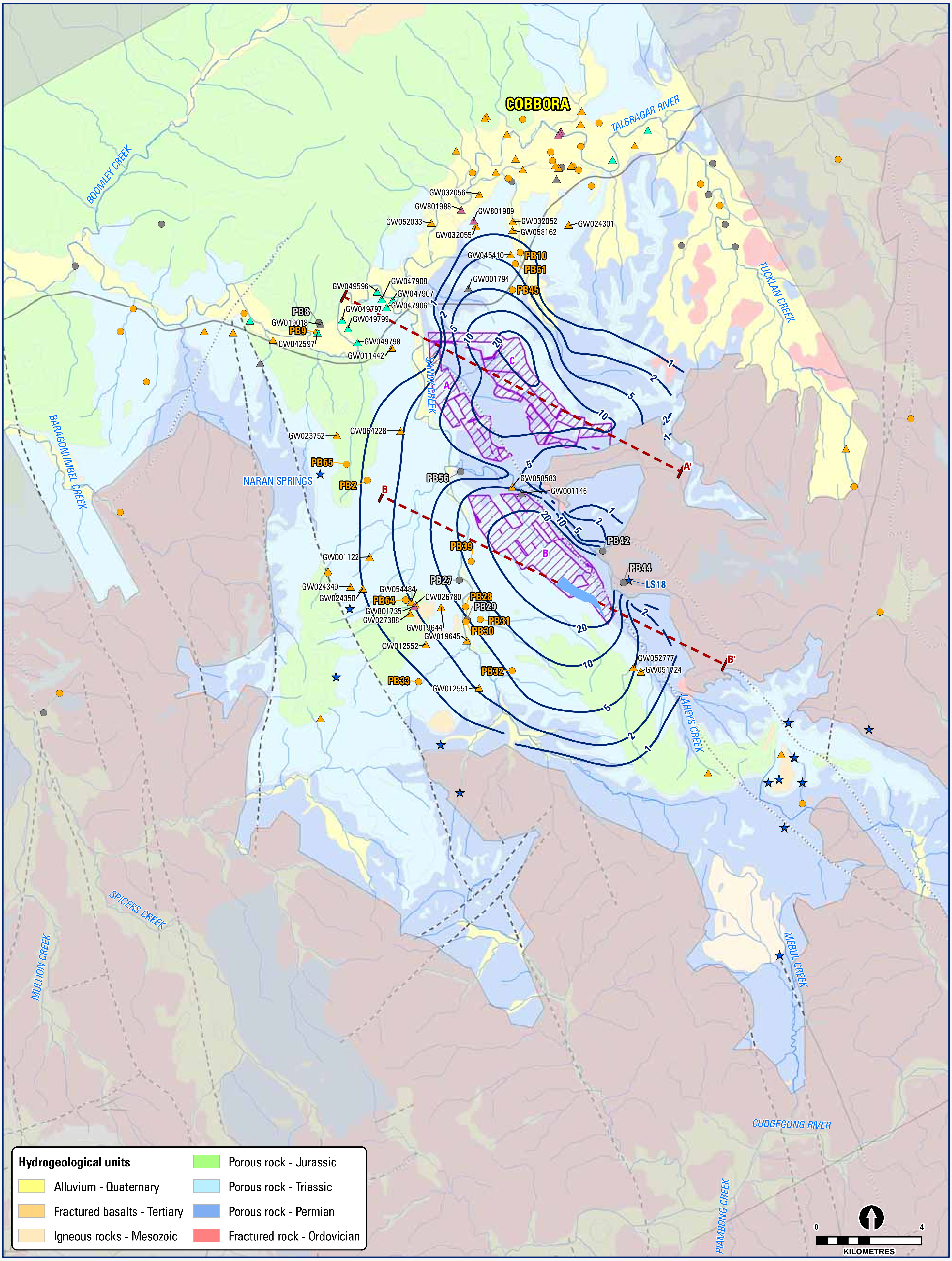
Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Cross section
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location
- Predicted drawdown (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.7A Drawdown in the water table aquifer 20 years after end of mining



\\Apsydnas02\proj\E\EMGA_M_M\2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F057_A3.mxd Salliank 10/01/2013

Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Cross section
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location
- Predicted depressurisation (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.7B Depressurisation in the Ulan Coal Seams 20 years after end of mining

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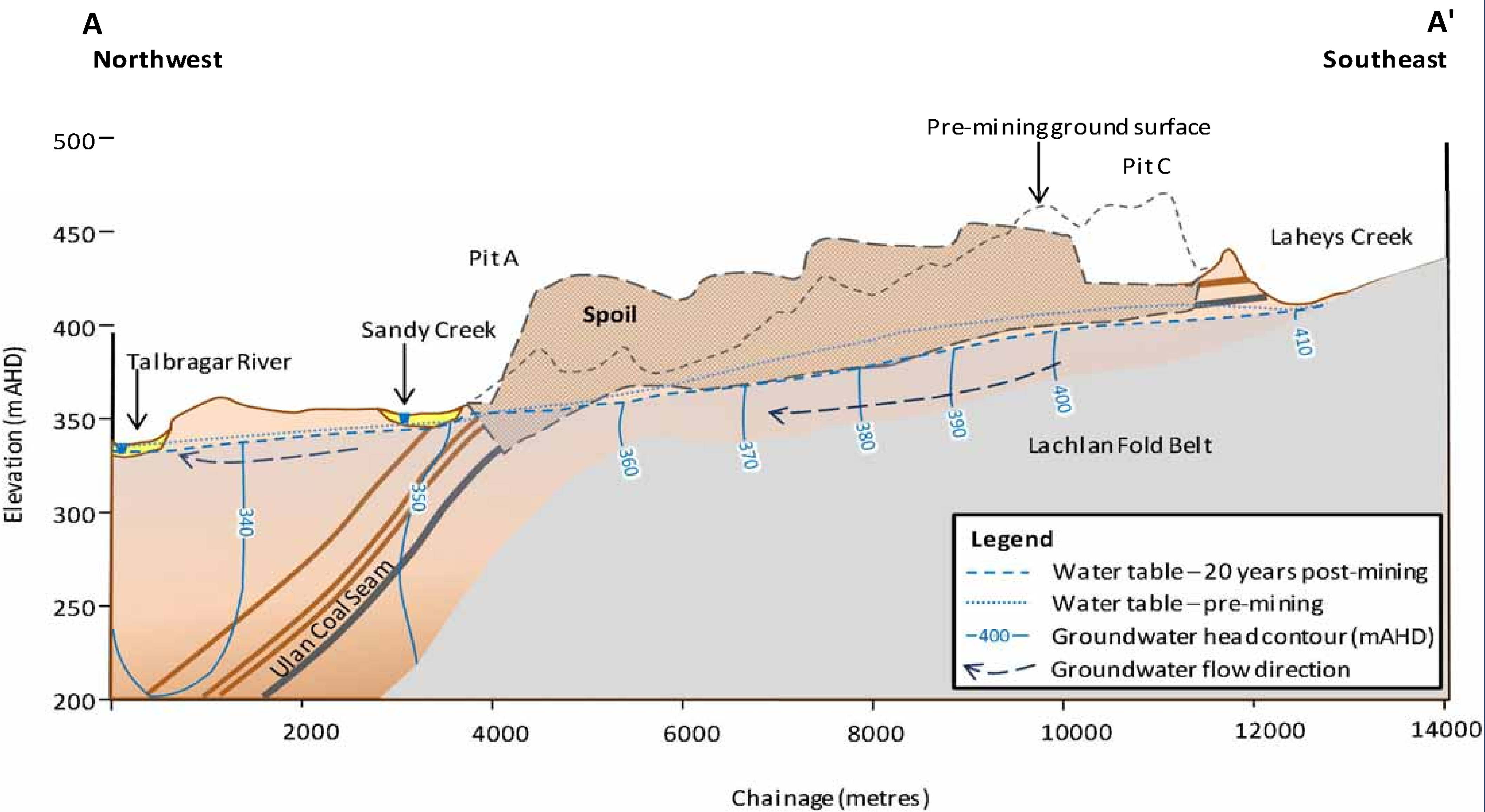

Figure 5.7C Groundwater heads across transect A-A' 20 years after end of mining

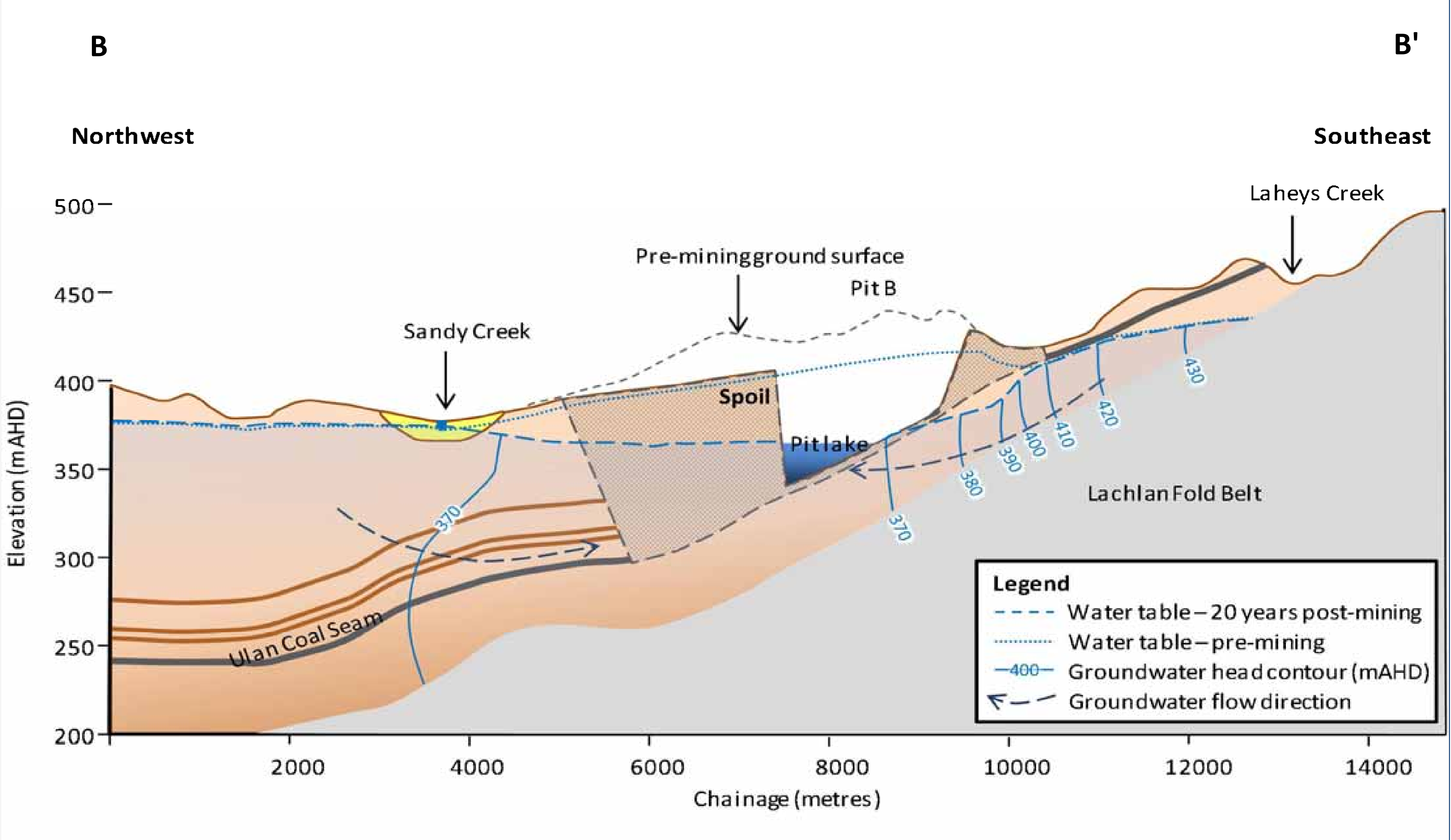

Figure 5.7D Groundwater heads across transect B-B' 20 years after end of mining

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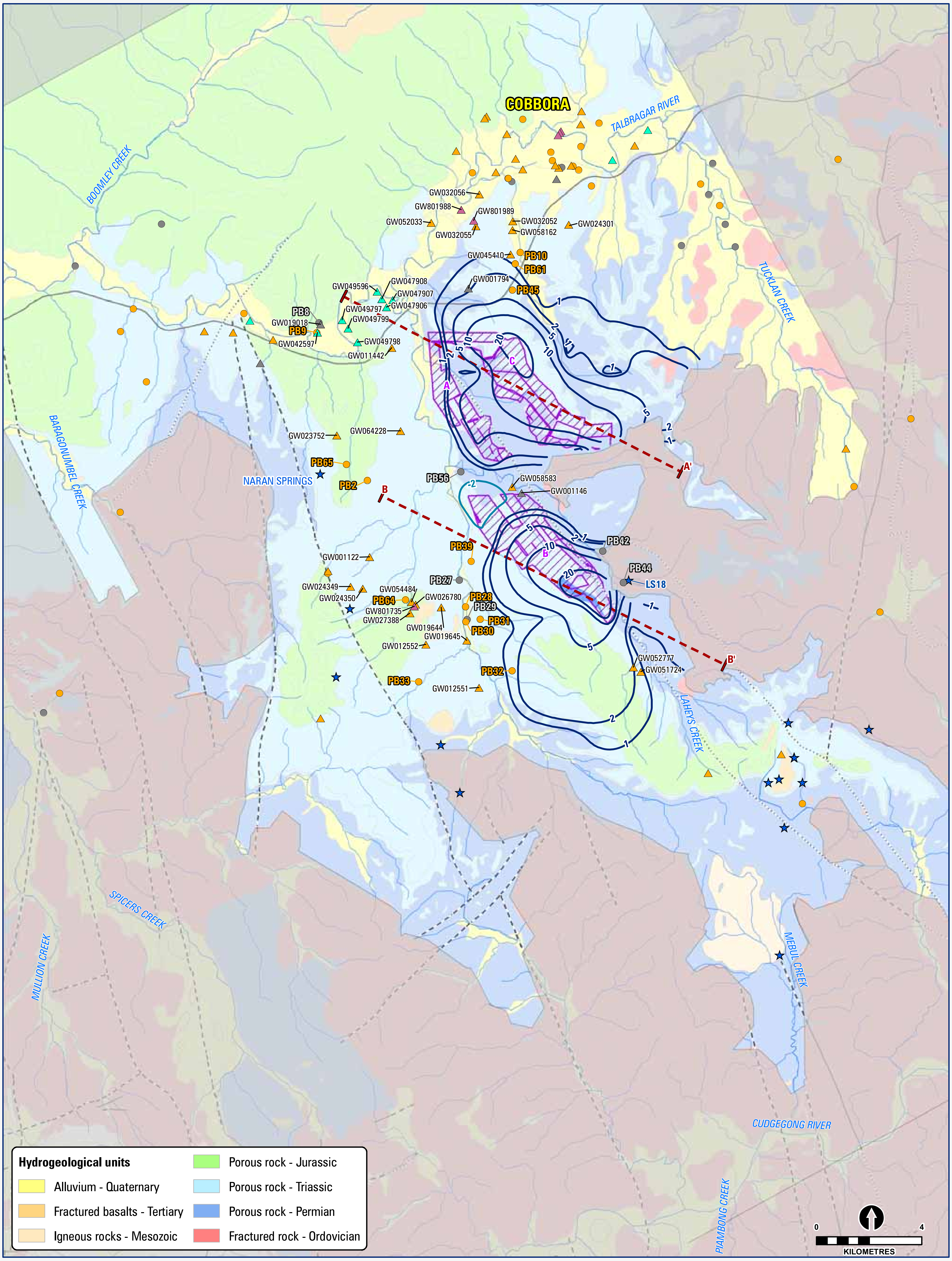
CHC PTY LTD



Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Cross section

- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location

- Predicted drawdown (m)
- Predicted negative drawdown (m)

Geologic map source: Geological Survey of New South Wales, 1999

Figure 5.8A Drawdown in the water table aquifer 100 years after end of mining

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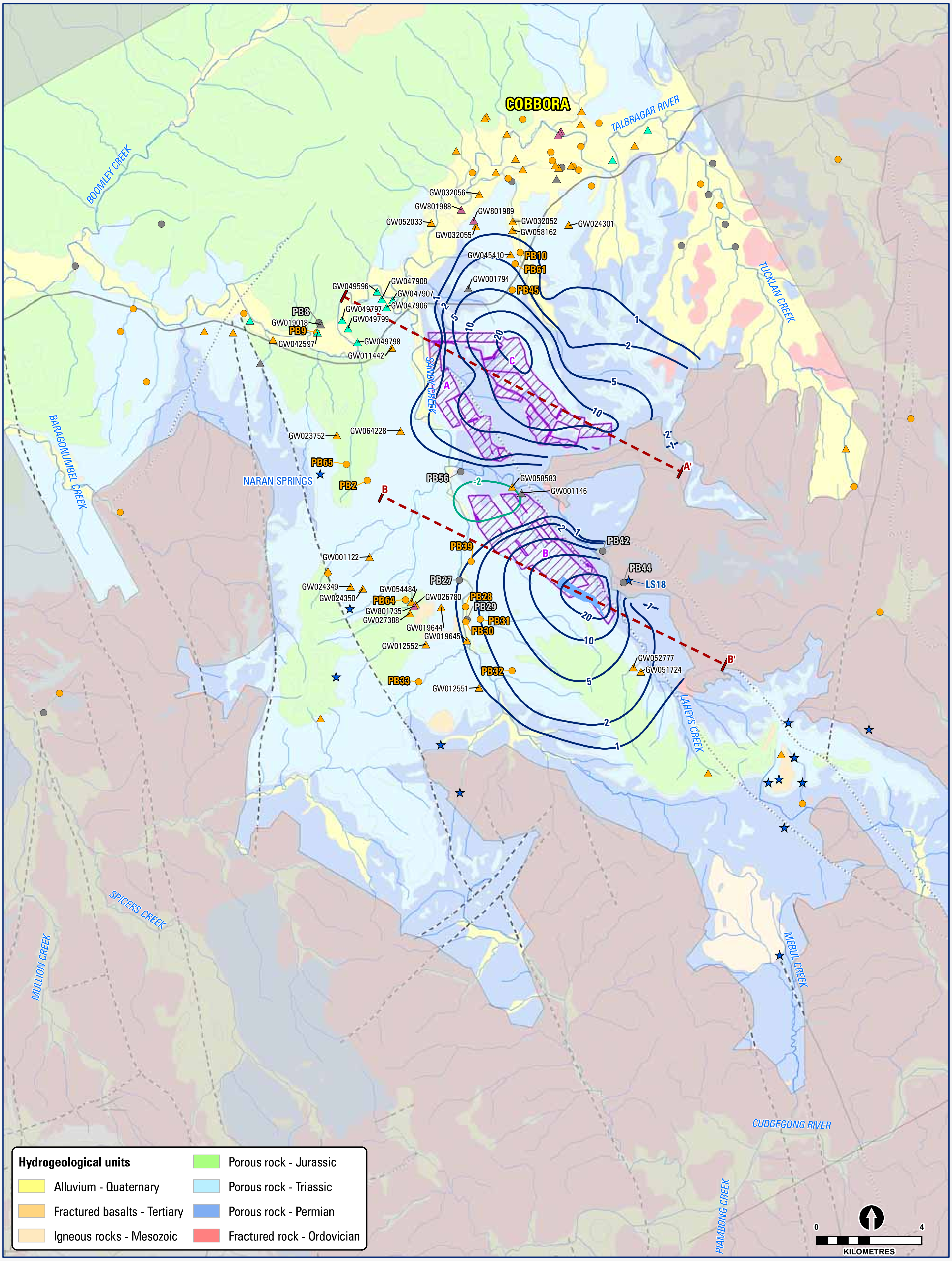
COBBORA COAL PROJECT
CHC PTY LTD



Hydrogeological units
- Alluvium - Quaternary
- Fractured basalts - Tertiary
- Igneous rocks - Mesozoic
- Porous rock - Jurassic
- Porous rock - Triassic
- Porous rock - Permian
- Fractured rock - Ordovician

Registered Groundwater Bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Cross section
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Predicted pit lake location
- Predicted depressurisation (m)
- Predicted negative depressurisation (m)

Geologic map source: Geological Survey of New South Wales, 1999

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Figure 5.8B Depressurisation in the Ulan Coal Seams 100 years after end of mining

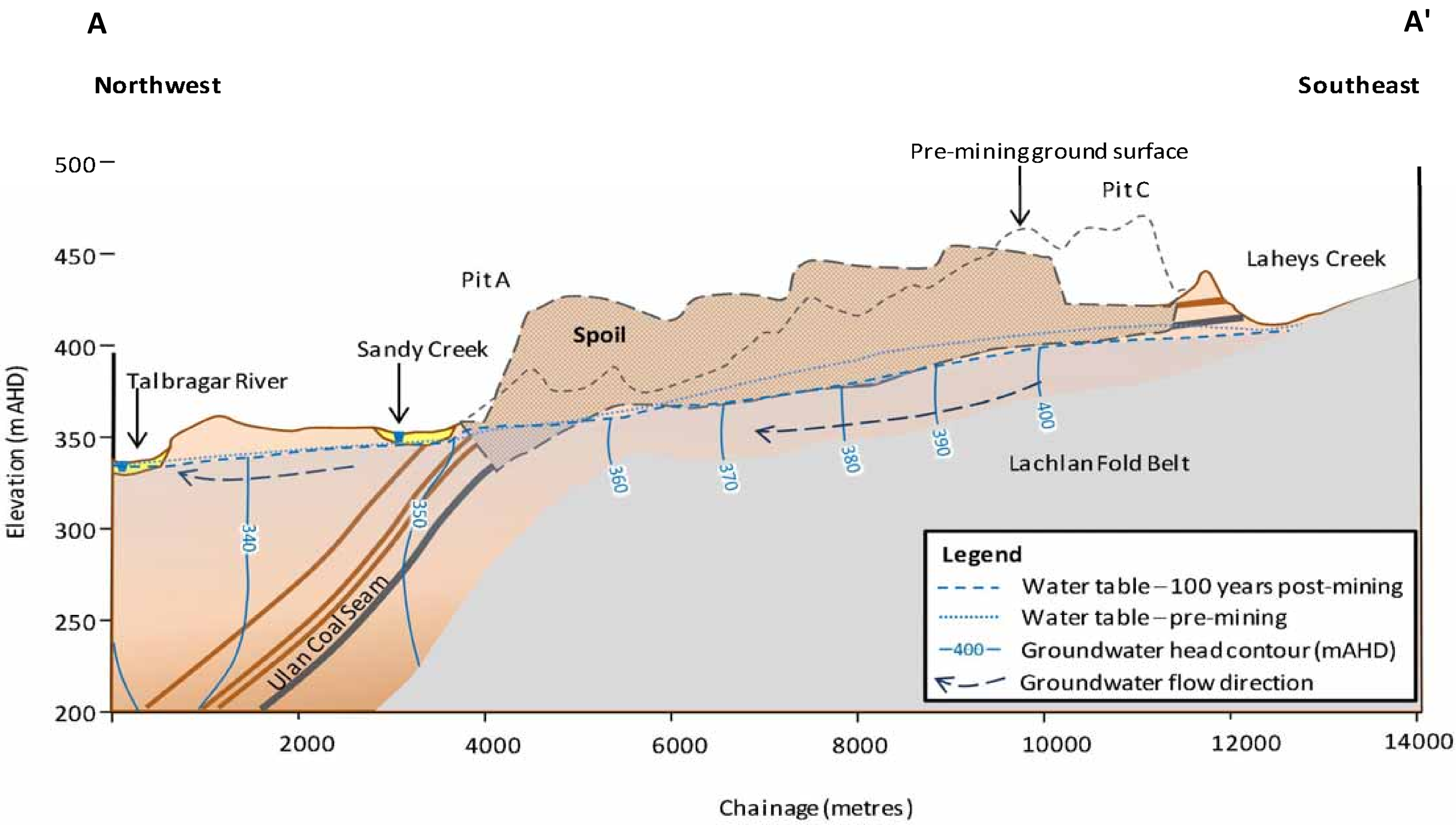


Figure 5.8C Groundwater heads across transect A-A' 100 years after end of mining

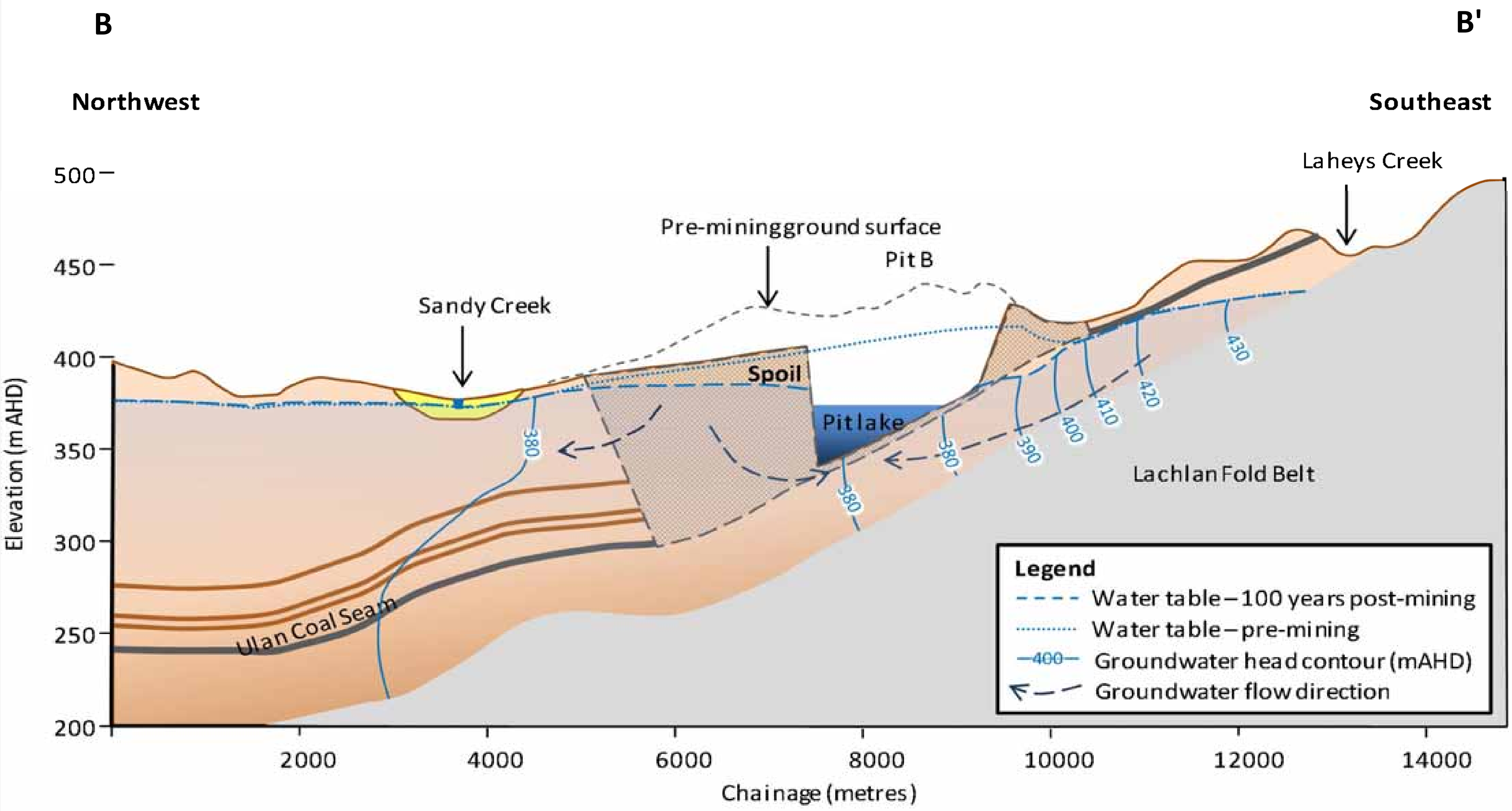


Figure 5.8D Groundwater heads across transect B-B' 100 years after end of mining

5.2.1 Predicted impacts on local groundwater bores

Existing groundwater bores identified as part of a hydrocensus in the assessment area (Parsons Brinckerhoff 2013a) are shown in Figure 5.9, along with the locations of other privately owned registered bores. Figure 5.10 shows model hydrographs for hydrocensus bores with a maximum predicted drawdown of more than 2 m resulting from mine dewatering. Table 5.3 provides further details on these bores. This threshold has been assigned in line with the Aquifer Interference Policy (DTIRIS 2012), which defines a maximum drawdown of less than 2 m as 'minimal impact'.

Ten of the thirteen bores with predicted drawdowns >2 m are owned by CHC. PB32, GW012551 and GW801735 are not owned by CHC. GW801735 shows a maximum drawdown of 2.2 m, predicted to occur in 2037, with residual drawdown decreasing to less than 2 m by 2042. PB32 shows a maximum drawdown of 5.1 m, predicted to occur in 2038, with drawdown of more than 2 m predicted until about 2083. GW012551 shows a maximum drawdown of 2.4 m, predicted to occur in 2041, with residual drawdown decreasing to less than 2 m by 2055. This long-term drawdown is due to the presence of the residual mine void near the southern edge of mining area B.

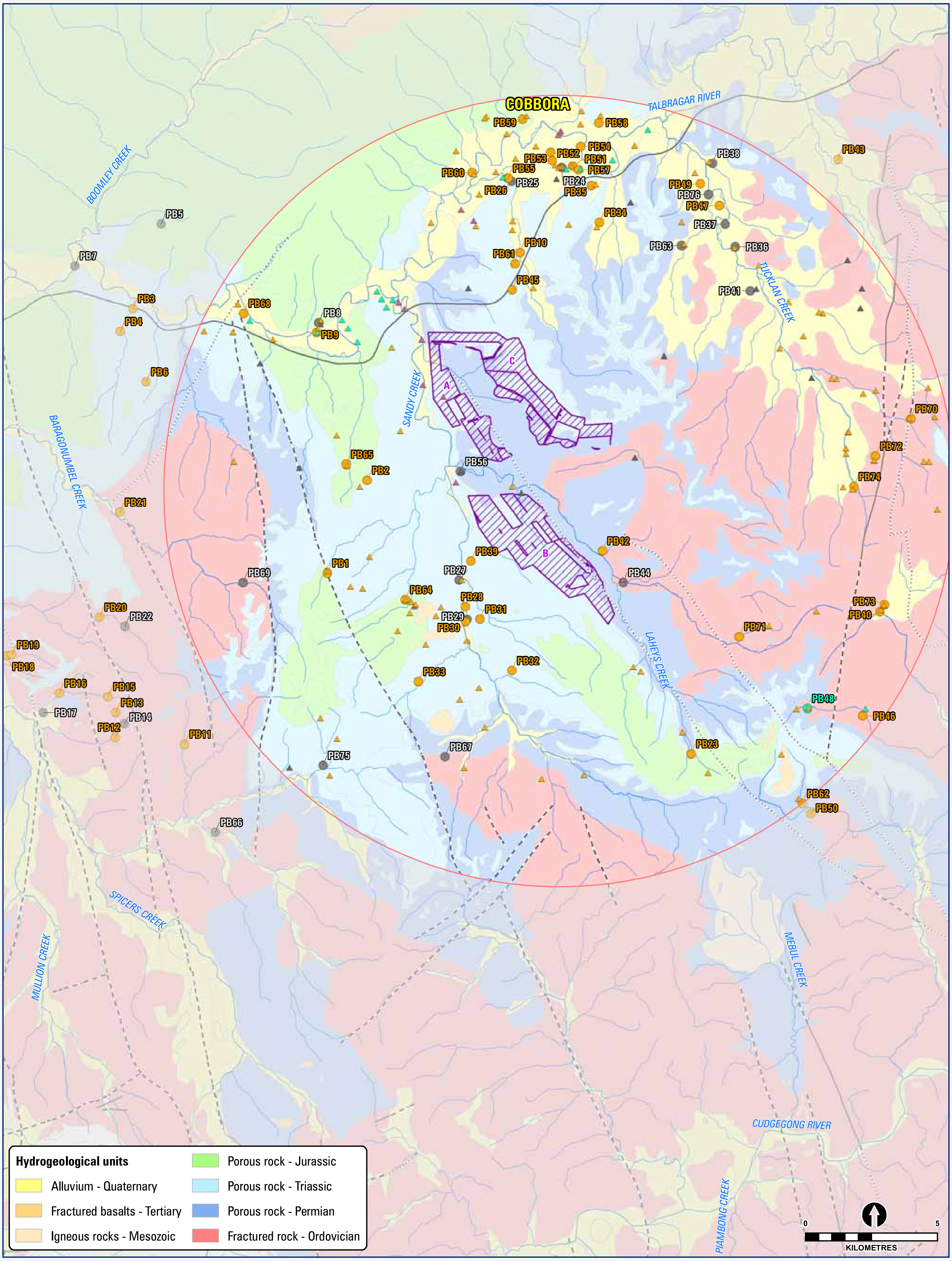
Most private bores show predicted drawdown values of less than 2 m throughout the period of mining activities and beyond.

Table 5.3 Privately owned bores where drawdown exceeds 2 m

Bore	Ownership	Coordinates (MGA Zone 55)		Predicted maximum drawdown (m)	Likely screened unit	Approximate bore depth
		Easting (m)	Northing (m)			
PB32*	Private	710912	6431760	5.1	Triassic (porous rock aquifer)	44.7
PB39*	CHC	709354	6435914	30	Permian (porous rock aquifer)	100
PB45*	CHC	710921	6446204	3.4	Triassic (porous rock aquifer)	Unknown
PB56*	CHC	708965	6439307	3.1	Triassic (porous rock aquifer)	18
GW001146	CHC	711270	6438510	30	Permian (porous rock aquifer)	18.8
GW001794	CHC	709254	6446255	2.1	Triassic (porous rock aquifer)	32.3
GW011442	CHC	706349	6444003	3.4	Triassic (porous rock aquifer)	14.6
GW012551	Private	709649	6431117	2.4	Triassic (porous rock aquifer)	36.8
GW058583	CHC	710907	6438733	21	Permian (porous rock aquifer)	53.3
GW051724	CHC	715790	6431728	4.5	Triassic	77.5

Bore	Ownership	Coordinates (MGA Zone 55)		Predicted maximum drawdown (m)	Likely screened unit	Approximate bore depth
		Easting (m)	Northing (m)			
					(porous rock aquifer)	
GW052777	CHC	715506	6431888	5.5	Triassic (porous rock aquifer)	77.5
GW064228	CHC	706679	6440854	3.7	Triassic (porous rock aquifer)	64
GW801735	Private	707198	6434204	2.2	Triassic (porous rock aquifer)	120

* registered bore number unknown, MGA – Map Grid Australia



Registered groundwater bores (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed groundwater bores
- Stock/domestic
- Irrigation
- Not known

Drainage lines
Fault - approximate
Fault - concealed
Proposed mining areas

Figure 5.9 Groundwater bores

\\Apsydnas02\proj\E\EMGA_M_M\2162570a_GW_EA_COBBORA_COAL\10_GIS\Projects\ESRI\2162570A_GIS_F067_A2.mxd Salliank 10/01/2013

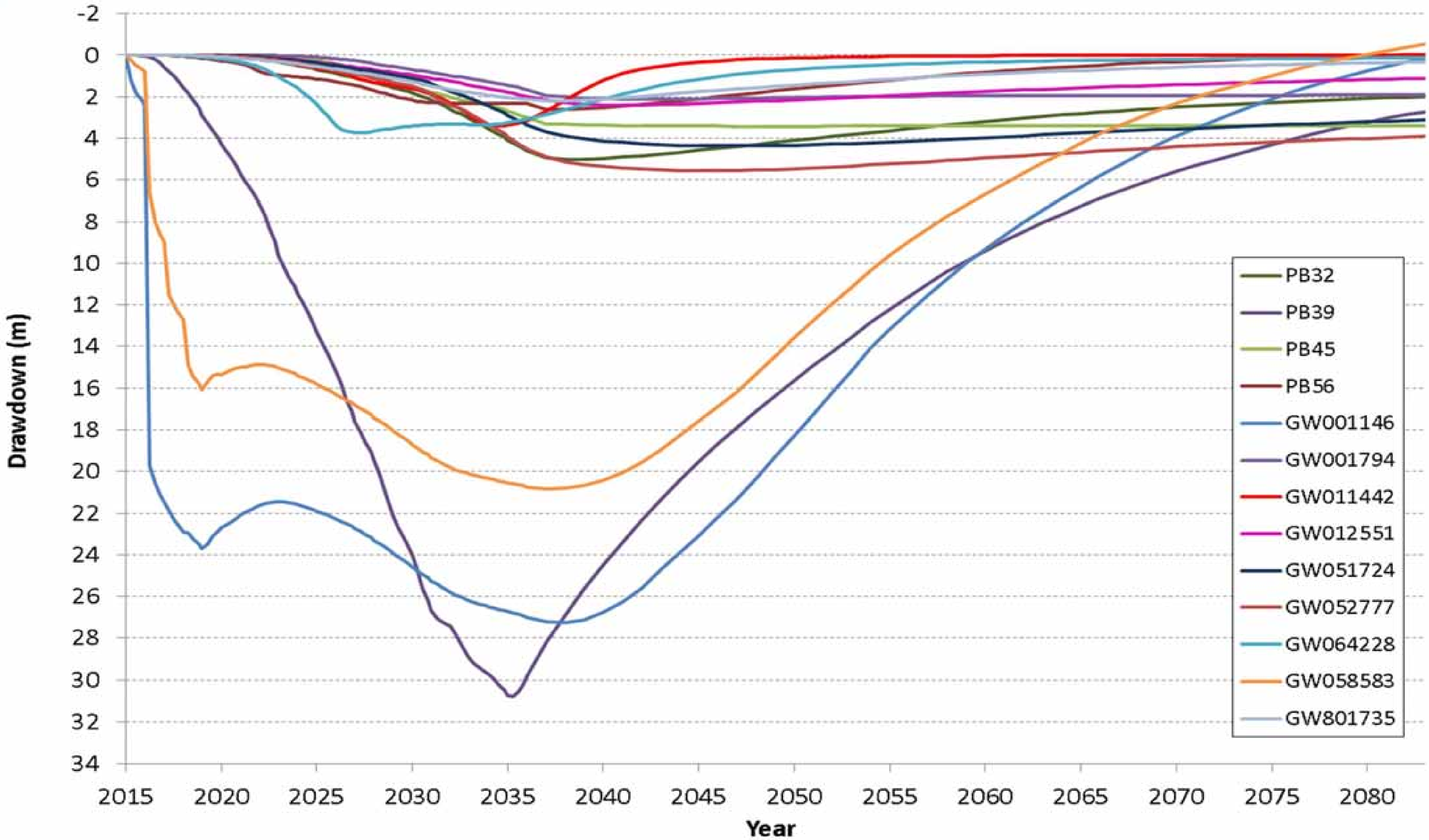


Figure 5.10 Hydrographs of groundwater bores with >2 m drawdown

5.2.2 Final void and post-mining recovery

The recovery in groundwater levels following mining will be influenced by the presence of the pit lake in mining area B and the presence of backfill material, which is expected to be significantly more permeable than the original geology. This increased permeability is expected to reduce groundwater levels in the vicinity of mining area C, where groundwater levels currently rise steeply away from nearby creeks.

The pit lake in mining area B is expected to receive groundwater inflows following the cessation of mining activity. The predicted groundwater inflows for a range of lake stage values during post-mining recovery are presented in Table 5.4 below. These were used to inform the Cobbora Coal Project - Surface Water Assessment (Parsons Brinckerhoff 2013b), where further modelling was undertaken to assess the effects of rainfall, surface runoff and evaporation on lake stage. The calculated inflows increase as the lake stage increases which seems counterintuitive. However this is a function of the differential recovery of the groundwater relative to the filling of the pit lake. The model predicts that initial inflows will be low because there will be a broad cone of drawdown related to mining that will take several decades to recover. As the groundwater levels recover, there will be in increase in the lake-ward gradient and therefore inflow, despite the gradual filling of the lake.

The lake is predicted to reach a steady state when the stage reaches 373.9 m AHD (i.e. inflows from groundwater, average rainfall and surface runoff are equal to average evaporative losses). The estimated groundwater inflow to the void lake at equilibrium (approximately 270 ML/a) will be ongoing and should be taken into account in groundwater licence provisions.

Table 5.4 Groundwater inflow rates to pit lake

Lake stage (m AHD)	Groundwater inflow rate (ML/a)
348	5
353	45
358	104
363	172
368	218
373	268

The effects of the pit lake on groundwater levels can be seen in plan view and cross-section in Figures 5.7 and 5.8.

5.3 Uncertainty analysis of mine inflow estimates

An analysis was conducted to assess the model response to changes in the most sensitive input parameters. The most significant parameters with respect to mine inflows and drawdown are in relation to the Ulan Coal Seams and the properties of the backfill material. The largest component of dewatering is due to groundwater sourced from the Ulan unit and the groundwater system was found to be sensitive to the hydraulic conductivity of this unit during calibration (Appendix A). The permeability and storage characteristics of the spoil material are not well quantified at this stage and there is potential for some heterogeneity. Accordingly, the following parameter variations were applied to the model:

- +/- 50% change to the hydraulic conductivity of the Ulan coal seams
- +/- 50% change to the hydraulic conductivity of the backfill material.

The effects of these parameter variations are shown in Table 5.5 below.

Table 5.5 Results of uncertainty analysis

Parameter	Base model	+50% Ulan K	-50% Ulan K	+50% backfill K	-50% backfill K
Average river losses (ML/a) (2015-2085)	260	308	201	211	194
Maximum river losses (ML/a) (2015-2085)	480	579	349	494	453
Average mine dewatering rate during mine life (ML/a)	1,694	1,835	1,527	1,820	1,583
Maximum mine dewatering rate (ML/a)	2,802	3,017	2,543	3,068	2,564
Average groundwater usage during mine life (ML/a)	1,272	1,339	1,188	1,391	1,168
Maximum groundwater usage (ML/a)	2,202	2,319	2,057	2,457	1,974
Maximum drawdown (m) – PB32	5.1	6.2	3.8	5.1	4.9
Maximum drawdown (m) – GW012551	2.4	3.5	1.3	2.4	2.3
Maximum drawdown (m) – GW801735	2.2	3.1	1.2	2.2	2.1

The analysis indicates that mine dewatering rates and groundwater usage may vary by up to 12% as a result of the above parameter variations. As a conservative approach, estimates of groundwater inflow into the final void are assumed to have a coefficient of variation of 15%. That is, for the purpose of the stochastic modelling of the filling of the final void (Parsons Brinckerhoff 2013b), the groundwater inflow component has been applied in a probabilistic manner with a mean equal to that shown in Table 5.4, and with a standard deviation of 15% of the estimate.

The model results indicate that the pit lake will remain a groundwater sink under all scenarios until it reaches an equilibrium condition.

6. Model limitations and assumptions

The numerical model created for the assessment is considered fit for purpose and provides realistic estimates for Project objectives. When using the predictions for planning purposes the model's limitations need to be considered.

The model relies on data collected from a finite number of locations over a discrete time interval. Due to natural geological and climatic variations, there is some uncertainty regarding the properties of the groundwater system in locations where data have not been collected and under conditions not encountered during the monitoring period.

For the current stage of planning and approvals, the uncertainties described above are considered normal and are typically addressed during the planning and operational phases as more information becomes available.

7. Conclusions and recommendations

As part of the groundwater assessment for the proposed Cobbora Coal Project (the Project), Parsons Brinckerhoff developed a numerical groundwater model of the assessment area to quantitatively assess the likely impacts from the proposed mining operation. This document describes the development and results of the model.

The results of the predictive modelling are summarised as follows:

- Mine inflow rates are predicted to peak at approximately 2,800 ML/a after 14 years of mining, with inflow rates of approximately 2,000 ML/a or more between 7 years and 18 years after mining commences. Approximately half of all inflows are expected to occur in mining area B.
- Net groundwater usage during the proposed mine life is predicted to be close to 2,000 ML/a between 2021 and 2030, reaching a maximum value of approximately 2,200 ML/a in 2028.
- Predicted cumulative storage losses within the alluvium reach a maximum value of approximately 720 ML. This constitutes 0.3% of the estimated 220,000 ML (220 GL) of available groundwater storage in the alluvium aquifer within the model domain.
- The model results indicate a maximum reduction in river flows of approximately 480 ML/a, which occurs in 2036 following the end of mining operations. This constitutes 0.9% of the average annual flow in the Talbragar River.
- Thirteen privately owned groundwater bores in the area are expected to experience drawdown of more than 2 m during the life of the mine. Only three of these bores (PB32, GW012551 and GW801735) are not on land owned by Cobbora Holding Company Pty Ltd (CHC). PB32 shows a maximum drawdown of 5.1 m, predicted to occur in 2038, with drawdown of more than 2 m predicted until about 2083. GW012551 shows a maximum drawdown of 2.4 m, predicted to occur in 2041, with residual drawdown decreasing to less than 2 m by 2055. GW801735 shows a maximum drawdown of 2.2 m, predicted to occur in 2037, with residual drawdown decreasing to less than 2 m by 2042. CHC will continue to model and monitor groundwater during and after the life of the mine. If a bore not owned by CHC is significantly affected, CHC will address the issue at its own cost.

An analysis was conducted to assess the model response to changes in the most sensitive input parameters. The following parameter variations were applied to the model:

- +/- 50% change to the hydraulic conductivity of the Ulan Coal Seams
- +/- 50% change to the hydraulic conductivity of the backfill material.

The analysis indicates that mine dewatering rates and groundwater usage may vary by up to 12% as a result of the above parameter variations.

The model relies on data collected from a finite number of locations over a discrete time interval. Due to natural geological and climatic variations, there is some uncertainty regarding the properties of the groundwater system in locations where data have not been collected and under conditions not encountered during the monitoring period. This is a normal aspect of any groundwater modelling exercise.

To reduce the level of uncertainty in the prediction of groundwater related impacts, Parsons Brinckerhoff recommends that groundwater levels and mine dewatering inflows continue to be monitored throughout the life of the mine. This should be done in conjunction with further groundwater modelling, to refine predictions of future impacts.

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Appendix A

Sensitivity analyses

Sensitivity analyses

Table A.1 Steady state model sensitivity assessment (parameters)

Parameters	Calibrated values	Input values			Normalised root mean square values		
		Multipliers			Multipliers		
		0.5	1	1.5	0.5	1	1.5
Conductivity (Kx, Ky – m/d)							
Zone 1	1	0.5	1	1.5	2.52%	2.53%	2.54%
Zone 2	0.04	0.02	0.04	0.06	2.53%	2.53%	2.53%
Zone 3	0.1	0.05	0.1	0.15	2.77%	2.53%	2.41%
Zone 4	0.004	0.002	0.004	0.006	2.54%	2.53%	2.52%
Zone 5	0.008	0.004	0.008	0.012	2.53%	2.53%	2.53%
Zone 6	0.3	0.15	0.3	0.45	2.67%	2.53%	2.44%
Zone 7	0.1	0.05	0.1	0.15	2.59%	2.53%	2.48%
		Multipliers			Multipliers		
		0.1	1	10	0.1	1	10
Conductivity (Kz – m/d)							
Zone 1	0.001	1e-4	0.001	0.01	2.53%	2.53%	2.54%
Zone 2	0.004	4e-4	0.004	0.04	2.48%	2.53%	2.53%
Zone 3	0.003	3e-4	0.003	0.03	2.47%	2.53%	2.57%
Zone 4	6e-5	6e-6	6e-5	6e-4	2.67%	2.53%	2.72%
Zone 5	8e-5	8e-6	8e-5	8e-4	2.54%	2.53%	2.51%
Zone 6	0.003	3e-4	0.003	0.03	2.55%	2.53%	2.53%
Zone 7	0.01	0.001	0.01	0.1	2.54%	2.53%	2.53%

Table A.2 Steady state model sensitivity assessment (boundary conditions)

Boundary conditions	Calibrated values	Input values			Normalised root mean square values		
		Multipliers			Multipliers		
		0.5	1	1.5	0.5	1	1.5
Recharge (% rainfall)							
Zone 1	2.9	1.45	2.9	4.35	2.54%	2.53%	2.53%
Zone 2	0.46	0.23	0.46	0.69	2.53%	2.53%	2.53%
Zone 3	0.64	0.32	0.64	0.96	2.52%	2.53%	2.78%
Zone 4	0.46	0.23	0.46	0.69	2.53%	2.53%	2.53%
Zone 5	0.46	0.23	0.46	0.69	2.54%	2.53%	2.53%
Zone 6	0.58	0.29	0.58	0.87	2.53%	2.53%	2.53%
Zone 7	0.46	0.23	0.46	0.69	2.53%	2.53%	2.53%
Evapotranspiration (ET)							
ET rate (mm/a)	600	300	600	900	2.58%	2.53%	2.52%
Extinction depth (m)	5	2.5	5	7.5	2.78%	2.53%	2.50%

Table A.3 Transient model sensitivity assessment (parameters)

Parameters	Calibrated values	Input values			Normalised root mean square values		
		Multipliers			Multipliers		
		0.5	1	1.5	0.5	1	1.5
Conductivity (Kx, Ky – m/d)							
Zone 1	1	0.5	1	1.5	2.59%	2.59%	2.59%
Zone 2	0.04	0.02	0.04	0.06	2.59%	2.59%	2.59%
Zone 3	0.1	0.05	0.1	0.15	2.61%	2.59%	2.58%
Zone 4	0.004	0.002	0.004	0.006	2.59%	2.59%	2.58%
Zone 5	0.008	0.004	0.008	0.012	2.59%	2.59%	2.59%
Zone 6	0.3	0.15	0.3	0.45	2.61%	2.59%	2.57%
Zone 7	0.1	0.05	0.1	0.15	2.59%	2.59%	2.59%
		Multipliers			Multipliers		
		0.1	1	10	0.1	1	10
Conductivity (Kz – m/d)							
Zone 1	0.001	1e-4	0.001	0.01	2.61%	2.59%	2.59%
Zone 2	0.004	4e-4	0.004	0.04	2.59%	2.59%	2.59%
Zone 3	0.003	3e-4	0.003	0.03	2.49%	2.59%	2.61%
Zone 4	6e-5	6e-6	6e-5	6e-4	2.44%	2.59%	2.98%
Zone 5	8e-5	8e-6	8e-5	8e-4	2.59%	2.59%	2.61%
Zone 6	0.003	3e-4	0.003	0.03	2.59%	2.59%	2.59%
Zone 7	0.01	0.001	0.01	0.1	2.59%	2.59%	2.59%
		Multipliers			Multipliers		
		0.5	1	1.5	0.5	1	1.5
Storativity (S)							
Zone 1	5e-4	2.5e-4	5e-4	7.5e-4	2.59%	2.59%	2.59%
Zone 2	3e-4	1.5e-4	3e-4	4.5e-4	2.59%	2.59%	2.59%
Zone 3	5e-5	2.5e-5	5e-5	7.5e-5	2.59%	2.59%	2.59%
Zone 4	5e-4	2.5e-4	5e-4	7.5e-4	2.61%	2.59%	2.57%
Zone 5	5e-4	2.5e-4	5e-4	7.5e-4	2.60%	2.59%	2.58%
Zone 6	8e-4	4e-4	8e-4	0.0012	2.61%	2.59%	2.57%
Zone 7	8e-4	4e-4	8e-4	0.0012	2.60%	2.59%	2.58%
Specific yield (Sy)							
Zone 1	0.2	0.1	0.2	0.3	2.59%	2.59%	2.59%
Zone 2	0.1	0.05	0.1	0.15	2.59%	2.59%	2.59%
Zone 3	0.01	0.005	0.01	0.02	2.69%	2.59%	2.56%
Zone 4	0.1	0.05	0.1	0.15	2.59%	2.59%	2.59%
Zone 5	0.1	0.05	0.1	0.15	2.59%	2.59%	2.59%
Zone 6	0.1	0.05	0.1	0.15	2.59%	2.59%	2.59%
Zone 7	0.1	0.05	0.1	0.15	2.59%	2.59%	2.59%

Table A.4 Transient model sensitivity assessment (boundary conditions)

Boundary conditions	Calibrated values	Input values			Normalised root mean square values		
		Multipliers			Multipliers		
		0.5	1	1.5	0.5	1	1.5
Recharge (% rainfall)							
Zone 1	2.9	1.45	2.9	4.35	2.59%	2.59%	2.60%
Zone 2	0.46	0.23	0.46	0.69	2.59%	2.59%	2.59%
Zone 3	0.64	0.32	0.64	0.96	2.52%	2.59%	2.67%
Zone 4	0.46	0.23	0.46	0.69	2.59%	2.59%	2.59%
Zone 5	0.46	0.23	0.46	0.69	2.59%	2.59%	2.59%
Zone 6	0.58	0.29	0.58	0.87	2.59%	2.59%	2.59%
Zone 7	0.46	0.23	0.46	0.69	2.59%	2.59%	2.59%
Evapotranspiration (ET)							
ET rate (mm/a)	600	300	600	900	2.60%	2.59%	2.59%
Extinction depth (m)	5	2.5	5	7.5	2.65%	2.59%	2.61%

Appendix I

Peer Review

HERITAGE COMPUTING REPORT

PEER REVIEW OF THE COBBORA COAL PROJECT GROUNDWATER ASSESSMENT

FOR

PARSONS BRINCKERHOFF

GPO Box 5394, SYDNEY NSW 2001

By

Dr N. P. Merrick

Report Number: HC2012/5
Date: February 2012

DOCUMENT REGISTER

REVISION	DESCRIPTION	DATE	COMMENTS
A	DRAFT	26 FEBRUARY 2012	Original
B	DRAFT FINAL	28 FEBRUARY 2012	Updated references

TABLE OF CONTENTS

1.0 INTRODUCTION

This report provides a peer review of the groundwater assessment for the Cobbora Coal Project conducted by Parsons Brinckerhoff for Cobbora Holding Company Pty Ltd.

The Cobbora coal resource is a large unallocated deposit in the Western Coalfield to the west of existing Ulan, Moolarben and Wilpinjong coal mines. It lies to the east of Dubbo and 15 km to the west of Dunedoo. An open-cut operation is being investigated as a source of coal for Hunter Valley power stations operated by Macquarie Generation, Delta Electricity and Eraring Energy.

As part of the Environmental Assessment (EA) for the mine, a numerical groundwater model has been developed to inform the groundwater assessment for the project. The groundwater model is to assess possible environmental impacts of the mine and provide indicative mine inflow estimates.

2.0 SCOPE OF WORK

This reviewer was requested to conduct a peer review of the groundwater assessment and the groundwater model. There are firm guidelines for reviewing groundwater models but not for associated groundwater assessments. For that reason, the checklists in the Australian groundwater flow modelling guidelines have been used for both assessments.

3.0 MODELLING GUIDELINES

The review has been structured according to the checklists in the Australian Flow Modelling Guideline (MDBC, 2001). This guide, sponsored by the Murray-Darling Basin Commission, has become a *de facto* Australian standard but is currently under review. This reviewer was one of the three authors of the guide, and is the person responsible for creating the peer review checklists. The checklists have been well received nationally, and have been adopted for use in the United Kingdom, California and Germany.

The modelling has been assessed according to the 2-page Model Appraisal checklist in MDBC (2001). This checklist has questions on (1) The Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. For the groundwater assessment component, only the first three sections are relevant.

It should be recognised that the effort put into a modelling study is very dependent on timing and budgetary constraints that are generally not known to a reviewer.

4.0 EVIDENTIARY BASIS

The primary documents on which this review is based are:

1. *Parsons Brinckerhoff (2012) Groundwater Assessment. Draft Report for Cobbora Holding Company Pty Ltd. 72p (plus Figures and 6 Appendices).February 2012.*

2. *Parsons Brinckerhoff (2012) Cobbora Coal Project Groundwater Model - Technical Report. Draft Report for Cobbora Holding Company Pty Ltd. 32p (plus Figures and 2Appendices).25 January 2012.*

No other documentation was considered.

The reviewer attended one progress meeting at the Sydney premises of Parsons Brinckerhoff on 15 November 2011.

There have been numerous emails in the style of progress reports received by the reviewer during the course of the review, with comments supplied in return.

An interim review on 10 February 2012 (by email) would have initiated changes to both reports that are subsequent to the review presented here. Many of the comments made here could have been addressed in the final reports issued by Parsons Brinckerhoff.

Electronic copies of the model files have not been examined.

5.0 PEER REVIEW

In terms of the modelling guidelines, the Cobbora Coal numerical groundwater model developed by Parsons Brinckerhoff is best categorised as an *Impact Assessment Model* of medium complexity, as distinct from an *Aquifer Simulator* of high complexity. This classification is derived from the MDBC guideline. Document #2 acknowledges the role of the MDBC guideline and nominates the intended model as being of *moderate* complexity.

The Australian best practice guide (MDBC, 2001) describes the connection between model application and model complexity as follows:

- Impact Assessment model - a moderate complexity model, requiring more data and a better understanding of the groundwater system dynamics, and suitable for predicting the impacts of proposed developments or management policies.

This contrasts with a more demanding level of complexity:

- Aquifer Simulator - a high complexity model, suitable for predicting responses to arbitrary changes in hydrological conditions, and for developing sustainable resource management policies for aquifer systems under stress.

The completed model appraisal checklist is presented in Table A1 (at the back of this report) for the Groundwater Assessment Report [Document #1] and in Table A2 for the Model Technical Report [Document #2]. The main findings are discussed in Section 6.

6.0 DISCUSSION

6.1 THE GROUNDWATER ASSESSMENT REPORT

Document #1 is a high quality document of about 70 pages length, plus figures and appendices. It is well structured, well written and the graphics are of high quality. Some figures had faulty symbols and legends when converted to PDF format. At the time of the review, the report was missing the Executive Summary.

The report serves well as a standalone document, with no undue dependence on earlier work.

The report includes sections on legislation, licensing and the existing environment which the reviewer understands to be outside the terms of reference for this review. The intent of the review is to examine the groundwater investigation program for sufficiency with primary emphasis on the credibility of the modelling.

It is the reviewer's opinion that the field investigation program has been sufficient for the purpose of an environmental assessment. The investigations have included: new drilling and extra piezometers and test production bores; geophysical logging; hydraulic testing by several methods; groundwater level monitoring; water quality sampling; environmental isotope sampling; investigation of groundwater-surface water interactions; groundwater dependent ecosystem surveys; a land-based geophysical survey; and a bore census.

The objectives of the groundwater assessment are summarised clearly in the Scope of Works in Section 1.2. It is the reviewer's opinion that the study has satisfied the stated objective.

The report provides a summary of modelling results and addresses in more detail the potential environmental impacts suggested by the modelling. There is a statement in Section 7.3 ("Baseflow to rivers/creeks") that "Reduced flow of groundwater to surface water bodies is expected to make up a much smaller component of the 280 ML/yr indicated by the model" because "surface water bodies are a net source of water to the groundwater system". It should have been possible for the model to separately account for reductions in baseflow and increases in stream leakage due to mining.

The comments on groundwater quality impacts in Section 7.5 seem more concerned with the change in mine water quality than regional effects on aquifers and receptors.

The report concludes with plans for monitoring and mitigation. Section 9 mentions one of the risks being "final void groundwater inflows", but this has not been assessed with the model.

One point of difference between the groundwater assessment report and the model report is that the former states that "Rapid recharge during flood events is therefore an important recharge mechanism...". However, the model does not simulate flood recharge explicitly, but allows some implicit recharge by keeping active continuously watercourses that are ephemeral.

Extra comments on *The Report* can be found in Table A1.

6.2 THE MODEL REPORT

Document #2 is a well structured and well written document of about 30 pages length. The graphics are of good quality but not all figures were available at the time of the review.

Although the report is associated with its companion report [Document #1], not much prior knowledge is assumed. As a result, this report comes close to being a standalone document. The field and conceptualisation aspects of the groundwater assessment are summarised succinctly, rather than merely referenced. However, the conceptual model graphic should be repeated in this report. It is listed in the List of Figures but it was not included in the report as reviewed.

The objective of the groundwater assessment is stated to be:

> *"...to identify and quantify the potential impacts of the proposed mining operation on the groundwater regime, and to propose mitigation and contingency measures, where applicable, for those impacts that are likely to be unacceptable."*

By inference, the objective of the modelling study is the same. The mitigation and contingency measures, however, appear only in Document #1.

Water balance reporting is more comprehensive for steady-state modelling than for transient calibration. For the latter, only the last time step is considered. This is of little use, except for final pit inflows, and an average water balance over the 18 months of calibration would have been more informative. For scenario predictions over the life of the mine, there is no overall water balance summary. Only pit inflow rates are presented year by year. An average water balance should indicate which of the natural processes might change significantly in providing the water discharges to the pit. For example, is the water coming primarily from storage, or from reduced evapotranspiration (ET), or reduced baseflow?

Extra comments on *The Report* can be found in Table A2.

6.3 DATA ANALYSIS

This study is based on two stages of field investigations, culminating in the drilling of 53 piezometers and five test production bores. Aquifer testing has been done by means of pumping tests, slug tests, and packer tests. No core measurements were taken. Extensive water quality and environmental isotope sampling has been undertaken. Conceptualisation and model calibration have been able to draw on about 18 months of baseline groundwater level data. There is still a lack of knowledge of groundwater levels at the edges of the model area, and assumptions have had to be made there in the setting of boundary condition water levels.

In addition, a transient electromagnetic (TEM) survey was commissioned to aid the interpretation of alluvial boundaries and thicknesses.

The aquifer system appears to be under no significant stress, but fluctuations in the water table have reached about 3 m at some locations due to strong rainfall events and/or stream flow. It is not easy to comment on whether deep formations show any response to climate stresses, as the field hydrographs in Appendix E are not classified according to depth or lithology. Some hydrographs reveal artesian pressures; the typical magnitide of the head difference between Permian units and alluvium should be stated.

Groundwater head contours and flow directions are established for the water table and the Dapper Formation, showing clearly the potential for artesian conditions along Sandy Creek and the Talbragar River. This diagram of field contours is misrepresented in Document #2 as a map of simulated contours.

A map of posted field depths to water would have been useful to assess the likely importance of ET.

The baseline monitoring period includes a fortunate high rainfall event in December 2010. Document #1 compares groundwater responses at all 46 hydrographs with rainfall residual mass. Document #2 examines 11 hydrographs and compares them with rainfall residual mass, rain events and stream stage.

The natural fluctuation in water levels from rain should be stated in support of the adopted threshold level for predicted drawdown impacts.

Extra detailed comments on *Data Analysis* can be found in Table A1 and Table A2.

6.4 CONCEPTUALISATION

There is a very good description and justification for the conceptual model of the area in Document #1.

Illustrative pre-mining conceptual model graphics are shown in Figure 5.15 for sections across Talbragar River, Sandy Creek and Laheys Creek. Inclusion of a modified section for post-mining conditions would be informative to the reader to indicate how groundwater flow directions will change. The same or similar diagram should appear in Document #2; although referenced, it was not included in the report at the time of review. There are conceptual cross-sections in Section 2 of Document #2, but they are meant to show geological complexity rather than recharge-discharge processes.

A conceptual model diagram can serve a dual purpose for displaying the magnitudes of the water budget components derived from data sources or from simulation. This has not been done in this case.

The hydrostratigraphy adopted for modelling (7 layers) seems appropriate.

Extra detailed comments on *Conceptualisation* can be found in Table A1 and Table A2.

6.5 MODEL DESIGN

The model is based on a highly respected advanced version of MODFLOW simulation software called MODFLOW-SURFACT (version 3) within the Groundwater Vistas graphic user interface (GUI). This choice minimises dry cell issues encountered with Standard-MODFLOW, and allows more robust solution. The time-varying TMP facility of SURFACT has been used rather than the alternative method of time-slices to allow incorporation of dynamic backfilling in the model.

The option for fully-unsaturated flow has been invoked, more for numerical stability than for serious modelling of unsaturated conditions.

The model grid discretisation is sufficiently fine (uniform 100 m x 100 m cells). The model grid consists of 502 rows and 290 columns across a rotated grid, covering 29 km east-west and 50 km north-south. The total number of model cells is just over 1 million. Normally, modellers regard 1 million cells as a practical upper limit.

The boundary conditions are not well controlled. While there is a reasonable assumption of inactive cells in the more elevated areas where older formations outcrop, there is poor control at model edges in the northern half of the model where some cross-boundary flow can be expected. A general-head boundary is reasonable, but there is no firm knowledge of the magnitude of those heads as there is no water level data in those areas.

Internal boundary creeks and the Talbragar River are represented reasonably as continuously active model "river" (RIV) cells. Normally, time-varying river stages would be placed in a model during transient calibration, but in this case that has not been done, presumably because of the substantial distance from the nearest active stream gauge and the lack of firm data on local river and creek levels. On the one hand, continuously active river cells would over-estimate potential rechage along ephemeral streams. On the other hand, maintenance of steady water levels would under-estimate flood recharge events. Document #1 considers flood recharge an important component of the water balance. Document #2 has not simulated floods explicitly but offers a compromise mechanism by deliberately sustaining recharge from creeks at times when they are dry.

As MODFLOW represents ET by a linear decay function (with depth), use of a maximum ET value close to potential evapotranspiration (PET) is likely to be too high in the model. A value closer to half the PET rate would give a better linear approximation to what in reality would be an exponential decay curve. The sensitivity analysis following transient calibration shows that the maximum ET rate could be reduced without affecting calibration performance.

A weekly stress period has been used for transient calibration, and an annual step for prediction over the life of the mine.

Extra detailed comments on *Model Design* can be found in Table A2.

6.6 CALIBRATION

Several lines of evidence are provided in Document #2 in support of steady-state calibration in the form of a scatter plot and RMS performance statistics. The steady-state performance is measured at 2.7 %RMS and 4.4mRMS, which is satisfactory. To demonstrate good spatial calibration, a simulated groundwater level map should have been offered for comparison with the observed/interpolated contour map.

Transient calibration evidence is provided also by a scatter plot and RMS performance statistics, with examples of a few hydrographic matches. The transient performance is measured at 2.4 %RMS and 4.1mRMS, which is quite good. However, not all hydrographic matches are presented. Of the eight comparisons that are presented, only two are particularly good (in alluvium at Bore GW5A) and in the Digby Formation (at Bore GW5B). The others generally suffer from offsets in absolute value, although trends are generally good. Without seeing the full set of hydrographic matches, or a residuals map, it is not possible to say which areas of the model are well calibrated or which natural processes are well replicated.

The modelling report has not given specific attention to replication of vertical hydraulic gradients or artesian pressures. It is not clear if the model performs well in this regard.

Extra detailed comments on *Calibration* can be found in Table A2.

6.7 VERIFICATION

There is insufficient transient data for a verification dataset.

6.8 PREDICTION

Prediction is run for one scenario consisting of a single mine plan with average steady climatic conditions. This is normal practice. Missing is a simulation of equilibrium groundwater conditions when the final void reaches a stable water level.

Annual stress periods and progressive updating of backfill extent and permeability are acceptable ways of representing mining progression with spoil emplacement (time-varying material properties). Reasonable spoil properties are applied, although they are uncertain.

In representing the mine void by "drain" cells in the basal coal seam, it is not clear whether drain cells were applied also to overlying layers which would in reality be excavated. In a model, they are likely to be given perched water tables unless deliberately dewatered.

A recovery run has been done for 50 years with drawdown results presented after 20 years. It is not clear how the final void was handled in this case. Was it left with host parameters, or filled with spoil and allowed to develop a water table? What storage properties were assumed? The timeframe for full or partial recovery is not clear, but it can be determined from recovery hydrographs in Figure 5-9.

Modelling suggests that the current mine plan will cause less than 1 m drawdown in the alluvium at the Talbragar River, for both the base case scenario and a high-inflow scenario. The drawdown extent is expected to remain localised close to the mine footprint with about 5 km maximum propagation to the south.

From four to 10 private bores are expected to experience more than 2.5 m drawdown during the life of the mine. However, some of these bores appear close to the 1 m drawdown contour on the maximum predicted drawdown contour map (Figure 5.3). The drawdown map does not seem to be consistent with the hydrographs displayed in Figure 5-9. Is it that the drawdown map is for the water table only, and the hydrographs apply to deeper formations?

Extra detailed comments on *Prediction* can be found in Table A2.

6.9 SENSITIVITY ANALYSIS

Sensitivity analysis is done thoroughly on both steady-state and transient models using the traditional perturbation method. The tested parameters are: horizontal and vertical hydraulic conductivity (all layers); rainfall recharge; ET rate and extinction depth. Storage coefficient and specific yield (all layers) have also been assessed by perturbing the transient model.

The steady-state analysis found the most sensitive parameters to be the horizontal permeability of the Digby and Dapper Formations and the Ulan Seam; rain recharge rate; and ET extinction depth. The transient analysis surprisingly showed no sensitivity to anything.

One criticism is that the vertical permeability was not perturbed far enough. This should be altered by an order of magnitude either way, rather than a factor of two. The base case model has 0.1 m/d for the vertical permeability of alluvium, but a local area model found a value of 0.001 m/d. Sensitivity analysis should explore these extremes.

Extra comments on *Sensitivity Analysis* can be found in Table A2.

6.10 UNCERTAINTY ANALYSIS

Uncertainty in Ulan Coal permeability (horizontal and vertical) has been explored by a factor of 2.7 increase in both. The model outputs have been examined for incremental effects on pit inflow, drawdown extent, baseflow and storage.

Pit inflow was found to increase by 44% for a 170% change in inputs. Other environmental incremental effects were found to be minor except for a doubling in maximum reduction in river flows. However, the effect remains less than 1% of annual Talbragar River flow.

7.0 CONCLUSION

The focus of this peer review has been on the sufficiency of the groundwater investigation program and the credibility of the conceptualisation of the groundwater system and subsequent regional modelling.

It is the reviewer's opinion that the field investigation program has been sufficiently comprehensive for the purpose of an environmental assessment. The investigations have included: piezometer installations (53); drilling of test production bores (5); hydraulic testing by several methods; groundwater level monitoring; water quality sampling; environmental isotope sampling; investigation of groundwater-surface water interactions; groundwater dependent ecosystem surveys; land-based and downhole geophysical surveying; and a bore census. The baseline groundwater level dataset has a length of about 18 months.

The objectives of the groundwater assessment are summarised clearly in the Scope of Works in Section 1.2. It is the reviewer's opinion that the study has satisfied the stated objectives.

The conceptual model and the numerical model have been developed competently. The stated modelling objective, to identify and quantify the potential impacts of the proposed mining operation on the groundwater regime, has been achieved satisfactorily.

The performance statistics suggest that the Cobbora groundwater model is well calibrated. However, there are offsets in absolute level of several metres on average. Without more information being supplied, it is not clear if there are some areas of the model that are better calibrated than others.

One aspect of modelling that has not been done is the final void analysis. This would examine the final equilibrium water levels and flow directions after the final void fills with water to a stable level. However, a 50-year recovery simulation has been done but it is not clear what assumptions were made for the pit void.

Modelling suggests that the current mine plan will cause less than 1 m drawdown in the alluvium at the Talbragar River, for both the base case scenario and a high-inflow scenario. The drawdown extent is expected to remain localised close to the mine footprint with about 5 km maximum propagation to the south.

From four to 10 private bores are expected to experience more than 2.5 m drawdown during the life of the mine.

8.0 REFERENCES

MDBC (2001). Groundwater flow modelling guideline. Murray-Darling Basin Commission. URL: www.mdbc.gov.au/nrm/water_management/groundwater/groundwater_guides

Parsons Brinckerhoff (2012) Groundwater Assessment. Draft Report for Cobbora Holding Company Pty Ltd. 72p (plus Figures and 6 Appendices).February 2012.

Parsons Brinckerhoff (2012) Cobbora Coal Project Groundwater Model - Technical Report. Draft Report for Cobbora Holding Company Pty Ltd. 32p (plus Figures and 2Appendices).25 January 2012.

Table A1. MODEL APPRAISAL: Groundwater Assessment Report

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			Page 1: Scope of works.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Impact Assessment Model, medium complexity. Reference to MDBC guide.
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Only pit inflows. Full water balance in companion report.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			
1.5	Are the model results of any practical use?			No	Maybe	Yes			Based on comprehensive investigation program, valid conceptualisation and subsequent modelling.
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Comprehensive groundwater investigation and drilling program.
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			There is a field contour map (Fig.5.7) for water table & Dapper Fm. Field values of depth to water would be useful to assess ET.
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Rainfall residual mass is presented. Floods mentioned as important but hard to quantify.
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			ETmax could be high, as BoM has average annual actual ET about 600 mm/a. This study has 1400mm/a max declining to 5m depth.
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			Groundwater hydrographs are compared with rainfall residual mass for 46 bores. Better comparison in companion report is extended to rain events and stream stage. State natural fluctuation from rain.

2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			All bores used (46); 2800 measurements for transient calibration.
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				In summary, ML/d could be shown in addition to GL/a.
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			Section 5.7
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Good pre-mining diagrams (Figure 5.15). A post-mining diagram could be included to show changed interactions.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				Reasonable aggregation of stratigraphic layers.

Table A2. MODEL APPRAISAL: Groundwater Model Report

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
1.0	THE REPORT								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			Page 1: potential impacts.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Impact Assessment Model, medium complexity. Reference to MDBC guide.
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			Reported for steady-state and transient, showing % breakdown for calibrated models. Transient is final time step, not averaged over 1.5 years. Only pit inflow provided for life-of-mine simulations.
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			A good model, sensible predictions.
1.5	Are the model results of any practical use?			No	Maybe	Yes			Some uncertainty due to greenfield project.
2.0	DATA ANALYSIS								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			Parallel groundwater investigation and drilling program. Covered in companion report.
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			There is a field contour map (Fig.5.7) in the companion report for water table & Dapper Fm. The same figure appears in the model report as "simulated"(Fig.4.2) - this is not correct. Field values of depth to water would be useful to assess ET.
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Rainfall residual mass is presented. Floods mentioned as important in companion report but not explicitly modelled.
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			ETmax could be high, as BoM has average annual actual ET about 600 mm/a. This study has 1400mm/a max declining to 5m depth.

2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	**Very Good**			11 Groundwater hydrographs are compared with rain events, residual mass and stream stage. State natural fluctuation from rain. 18 months baseline data.
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	**Yes**			All bores used (unstated number); 2800 measurements for transient calibration; 38 points for steady state.
2.7	Have consistent data units and standard geometrical datums been used?			No	**Yes**				In summary, ML/d could be shown in addition to GL/a.
3.0	CONCEPTUALISATION								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	**Yes**			
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	**Very Good**			Section 3.
3.3	Is there a graphical representation of the modeller's conceptualisation?		**Missing**	Deficient	Adequate	Very Good			Figure 3.1 in list of figures but not included. Good diagrams in companion report. There are conceptualisation cross-sections in Section 2.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	**No**				Reasonable aggregation of stratigraphic layers.
4.0	MODEL DESIGN								
4.1	Is the spatial extent of the model appropriate?			No	Maybe	**Yes**			1.02million cells; 100mx100m cells. 7 layers. 29kmx50km, 502rows x 290 columns. Weekly time scale for transient calibration; yearly for scenarios.
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	**Adequate**	Very Good			Poor control on boundaries due to absence of data. Far enough away to be not impacting on the solution. GHB in each layer for top half of model.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	**Yes**			MODFLOW-SURFACT & TMP with Gw Vistas GUI. Minimises dry cell issues.

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0, 3, 5)	COMMENT
5.0	CALIBRATION								
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			*Steady-state*: %RMS; scatterplot; no contour map. *Transient*: %RMS; scatterplot; some hydrograph comparison but not enough. Mostly manual calibration.
5.2	Is the model sufficiently calibrated against spatial observations?		Missing	Deficient	Adequate	Very Good			Field contours are not compared with simulated contours. Good statistics. Are vertical head differences replicated?
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Good statistics. Not enough hydrographs are compared - not grouped to illustrate response in alluvium or rock; rain or stream stresses. Some large offsets in water levels. Good amplitude and timing response to rain events.
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			Consistent with field studies. ET rate is high - no allowance for linear MODFLOW algorithm.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Steady-state: 2.7%RMS, 4.4mRMS. Transient: 2.4%RMS, 4.1m RMS.
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Stream stage not varied with time. Offsets probably due to K distribution.
6.0	VERIFICATION								
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	Adequate	Very Good			Not enough transient data for any to be reserved.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			
7.0	PREDICTION								

7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Only long-term average rain and river stage.
7.2	Have multiple scenarios been run for operational /management alternatives?		Missing	Deficient	Adequate	Very Good			Just base case scenario – one mine plan. No final void simulation.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			18 months calibration; 21 years prediction.
7.4	Are the model predictions plausible?			No	Maybe	Yes			Intuitively reasonable results. The 2.5m drawdown threshold (on hydrographs) should be related to natural fluctuation magnitude. Apparent inconsistency with drawdown at private bores on contour map and time-series hydrographs.
8.0	SENSITIVITY ANALYSIS								
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			Thorough conventional sensitivity analysis on steady-state and transient models: Kx, Kz, recharge, both ET parameters; S & Sy. Kz not perturbed enough.
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			List of RMS statistics. Steady-state sensitive to Kx of Digby, Ulan, Dapper; recharge rate; ET depth. Transient surprisingly insensitive to everything.
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			Done for high-inflow scenario: Ulan seam Kx and Kz increased 2.7 times. Assessment of changes in pit inflow, drawdown extent, baseflow, storage.
9.0	UNCERTAINTY ANALYSIS								
9.1	If required by the project brief, is uncertainty quantified in any way?		Missing	No	Maybe	Yes			Quantitative for coal seam permeability: 44% increase in inflow for 170% increase in permeability; minor addition to environmental effects.
	TOTAL SCORE								PERFORMANCE:

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28 June 2012

Our ref: 2162570C LT_1079

Phil Towler
Associate Director
EMGA Mitchell McLennan
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20 Chandos Street
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Dear Phil

External peer review of the groundwater assessment and modelling reports for the Cobbora Coal Project

In accordance with the scope of works presented to Cobbora Holding Company Pty Limited, an independent external peer review of the draft Groundwater Assessment Report and Groundwater Model Technical Report was carried out by Dr Noel Merrick (Heritage Computing).

Dr Merrick is a former lecturer in groundwater and groundwater modelling at the University of Technology Sydney and is a recognised industry expert in groundwater modelling and impact assessment in NSW. Dr Merrick undertook the peer review of the draft reports and provided his comments in a report entitled Peer Review of the Cobbora Coal Project Groundwater Assessment, dated February 2012.

The reviewer concluded that in his opinion the field investigation program was *sufficiently comprehensive for the purpose of an environmental assessment*, and that *the conceptual and numerical models were developed competently*. The reviewers report offered a number of comments and suggestions for improvement of the final report. Parsons Brinckerhoff addressed these comments in the final versions of the Groundwater Assessment and Groundwater Modelling reports. The following table provide the list of review comments provided by Dr Merrick and how they have been addressed in the final reports.

Table 1 Reviewer comments on the draft Groundwater Assessment report and Parsons Brinckerhoff responses

Item	Reviewer comment	Report ref.	Parsons Brinckerhoff response
1	"It should have been possible for the model to separately account for reductions in baseflow and increases in stream leakage due to mining."	P4, Para 1	Noted. Text revised and made more explicit regarding partitioning of stream losses.
2	"final void groundwater flows…have not been assessed with the model"	P4, Para 3	The groundwater model was revised and re-run to include residual voids and equilibrium lake levels during post-mining recovery phase. Results were incorporated into the final report. Pit void filling and water quality has been assessed in the surface water report.

Item	Reviewer comment	Report ref.	Parsons Brinckerhoff response
3	"The model does not simulate flood recharge explicitly, but allows some implicit recharge by keeping active continuously watercourses that are ephemeral."	P4, Para 4	Acknowledged. Text in modelling report updated to describe the RIV cells and assumptions. RIV boundaries are steady state on the assumption that the model is used to assess average conditions and long term impacts and recovery.
4	"The conceptual model graphic…was not included in the report as reviewed."	P4, Para 7; see also item 3.3 in Table A2	Conceptual model cross section included in final report.
5	"There is no overall water balance summary. Only pit inflow rates are presented year by year."	P5, Para 1	Water balance summaries are provided for the steady state and transient model simulations.
6	"There is still a lack of knowledge of groundwater levels at the edges of the model area, and assumptions have had to be made there in the setting of boundary condition water levels."	P5, Para 3	Acknowledged. There is little regional data at the model margins. Reasonable estimates of groundwater levels have been used in those locations based on available regional bore information. This is unlikely to affect the magnitude of simulated drawdown.
7	"A map of posted field depths to water would have been useful to assess the likely importance of ET."	P5, Para 7	Noted. This information is included in tables provided.
8	"The natural fluctuation in water levels from rain should be stated in support of the adopted threshold level for predicted drawdown impacts."	P5, Para 9	Text revised; 2.5 m cut-off justified by observed natural groundwater level variation
9	"A conceptual model diagram … has not been done in this case."	P6, Para 4	See Item 4, above
10	Time-varying river stages [have not been implemented in this model], presumably because of the substantial distance from the nearest active stream gauge and the lack of firm data on local river and creek levels."	P7, Para 2	See item 3, above.
11	"Potential evapotranspiration (PET) is likely to be too high in the model. A value closer to half the PET rate would give a better linear approximation to what in reality would be an exponential decay curve."	P7, Para 3	Noted. The model was re-run with the appropriate PET value (600 mm/a)
12	"To demonstrate good spatial calibration, a simulated groundwater level map should have been offered for comparison with the observed/interpolated contour map."	P7, Para 6; see also Item 2.2 in Table A2	Contours of water table elevation and the piezometric surface in the Ulan Coal Seam are shown in Figure 4.2 of the Modelling Report.
13	Regarding the transient calibration: "not all hydrographic matches are presented…[many simulated hydrographs] generally suffer from offsets in absolute value, although trends are generally good".	P7, Para 7	All hydrographs are now included in Figure 4.5 of the Model Report. Some absolute offsets are acknowledged; however in the transient calibration, trends are considered more important.

Item	Reviewer comment	Report ref.	Parsons Brinckerhoff response
14	"The modelling report has not given specific attention to replication of vertical hydraulic gradients or artesian pressures. It is not clear if the model performs well in this regard."	P8, Para 2	Contours of water table elevation and the piezometric surface in the Ulan Coal Seam are shown in Figure 4.2 of the Modelling Report. The implied vertical head differences are consistent with field observations.
15	"It is not clear whether drain cells were applied also to overlying layers which would in reality be excavated."	P8, Para 7	Text revised to clarify - DRN cells are applied to all layers above the base of the pit during excavations, with invert levels at the base of the excavation
16	"It is not clear how the final void was handled in this case. Was it left with host parameters, or filled with spoil and allowed to develop a water table? What storage properties were assumed?"	P8, Para 8	Text updated to clarify; backfilled spoil was assigned appropriate parameters that are different to the host rock.
17	"The drawdown map does not seem to be consistent with the hydrographs displayed in Figure 5-9."	P9, Para 1	Amended; drawdown in the hydrographs relate to corresponding model layers. Drawdown contours now included for both water table aquifer and Ulan Coal Seams
18	In the sensitivity analysis, "the vertical permeability was not perturbed far enough."	P9, Para 5	Acknowledged. The model was re-run with Kz = 0.001 and sensitivity analysis extended. Final results are from the revised model.
19	"One aspect of modelling that has not been done is the final void analysis."	P10, Para 6	See item 2, above.
20	Model verification is not included.	Item 6.1 in Table A2; see also P8, Para 4.	Insufficient historical data are available to carry out model verification as described in the MDBC guidelines. This is typical in areas that do not have a long irrigation history and associated groundwater monitoring records.

Yours sincerely

Stuart Brown
Principal Hydrogeologist
Parsons Brinckerhoff

REVIEW

Our Ref:
HC2012/16

Date:	29 July 2012	
To:	**Stuart Brown** **Principal Hydrogeologist** **Parsons Brinckerhoff** Level 27, Ernst & Young Centre 680 George Street GPO Box 5394 SYDNEY NSW 2001 Tel: (02) 9272 5406 Email: SBrown@pb.com.au	
From:	Dr Noel Merrick	
Re:	Peer eview - Cobbora Coal Project Groundwater Assessment	

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This note is provided in response to your email dated 12 July 2012 which requested an update of my previous peer review report for the Cobbora Coal Project Groundwater Assessment. A comprehensive peer review report was issued on 28 February 2012 according to the MDBC Groundwater Flow Model Guideline and its associated checklists. The review was made on the Technical Report draft dated 25 January 2012, and on components of the Groundwater Assessment draft dated February 2012.

You have made available final reports dated 4 May 2012 for both reports. As changes in the reports are of an incremental nature, this review letter is also offered as incremental to the original peer review report (Heritage Computing Report HC2012/5).

Groundwater Assessment Report

The final report now includes an Executive Summary and several expanded sections, especially those related to water sharing plans and water licensing matters. In the original peer review, an opinion was expressed that the field investigation program had been sufficient for the purpose of an environmental assessment. That is still the case.

The peer review report made comments on the need for more consideration of water quality impacts, final void inflows and flood recharge. These aspects have all been addressed in the final report.

Other comments in the peer review report checklists referred to summary statements regarding the groundwater modelling exercise. They are examined below.

Groundwater Model Technical Report

The original peer review report included a number of criticisms, the most substantial being:

1. Not all groundwater hydrographs were analysed for cause-and-effect, or exhibited for calibration performance;
2. A water level contour map (for the water table and the Dapper Formation) was presented as if it were a simulated steady state map, but the same figure was presented in the Groundwater Assessment Report as a field contour map;
3. No depth to water spot values or averages were presented to assist in conceptualising the importance of the evapotranspiration process;
4. The adopted evapotranspiration rate was considered (by the reviewer) to be too high;
5. There was inadequate consideration of the significance of flooding as a source of recharge;
6. The calibration period water balance was presented for the last time step rather than averaged over the 74 weeks of calibration;
7. For the prediction scenario, no complete water balance was offered;
8. The sensitivity analysis considered only a narrow range for vertical hydraulic conductivity; and
9. No final void equilibrium analysis was done, although a 50-year recovery simulation was reported.

These matters have now been addressed in the following ways:

1. More hydrographs are now shown and they are examined in five different groupings;
2. The water level map inconsistency has not been resolved;
3. No additional depth to water information has been provided;
4. The evapotranspiration rate has been reduced substantially in accordance with BoM estimates of actual evapotranspiration for the project area;
5. There is now discussion of the contribution of flooding at several places in the report;
6. A water balance averaged across the calibration period is presented. However, there is an unexplained inconsistency in the relative rainfall recharge volumes for steady state and calibration models;
7. There is still no overall water balance for the prediction scenario. There is discussion and quantification of mine inflow, net baseflow loss and losses from storage in each layer of the model, but no consideration of changes in evapotranspiration volumes or the additional recharge that enters the groundwater system through the spoil footprint;
8. The sensitivity analysis has been repeated for an order of magnitude variation (higher and lower) in vertical hydraulic conductivity. This prompted a revision of the findings on sensitivity: *"The model was most sensitive to vertical hydraulic conductivity in the Whaka Formation, and to vertical*

hydraulic conductivity, specific yield and recharge in the Digby Formation"; and

9. A steady state final void equilibrium analysis has been done by setting void water level at a constant (undisclosed) elevation. There is no reporting on the results of this analysis, but it is understood that this matter is addressed in the surface water hydrology assessment report (not seen by this reviewer). It would be normal practice to include in the groundwater assessment report a statement on final groundwater fluxes and a final watertable contour map to illustrate groundwater flow directions and to show clearly whether the void would act as a groundwater sink. There is comment that the lake would be a flow-through system, which implies a water quality risk to the alluvial water source (as foreshadowed in the Groundwater Assessment Report). The likelihood of that risk deserves consideration.

There remain a couple of editorial matters:

- Section 3.2.5.4 has an incomplete sentence: "*This allowed for groundwater to recover to levels that approach in all other excavated areas, backfill material has been simulated.*"
- Section 7 notes there are only two private bores with excessive predicted drawdown, but Section 5.2.1 and the Groundwater Assessment Report recognise six bores.
- Table 3.3 has specific yield "2-12" for the Dapper Formation (should be 0.02-0.12).

The assessments were completed prior to the release of a second draft of the Aquifer Interference Policy, and new National Groundwater Modelling Guidelines. In light of the revised Aquifer Interference Policy, a drawdown threshold of 2.0 m would have been better than the adopted 2.5 m drawdown. The introduction of new modelling guidelines has no material effect on the assessment or the review.

Apart from the few issues identified above, the revised assessment has considered and addressed comments in the original peer review report. Fundamentally, the conceptual hydrogeological model and the numerical groundwater model have been developed competently. The stated modelling objective, to identify and quantify the potential impacts of the proposed mining operation on the groundwater regime, has been achieved satisfactorily.

Yours sincerely,

Dr Noel Merrick

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A+ GRI Rating: Sustainability Report 2010

6 August 2012

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Associate Director
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Dear Phil

Re: Peer review of Cobbora Groundwater Assessment by Noel Merrick - Response

At the request of EMGA Mitchel McLennan (EMM), Dr Noel Merrick provided an updated review of the Cobbora Coal Project Groundwater Assessment Report and Technical Modelling Report. This letter provides our responses and additional information to address specific comments raised by the updated review.

Dr Merrick provided a detailed review of the draft reports in February 2012. The reports were then revised on the basis of Dr Merrick's and other's comments and included with the Environmental Assessment Report that was submitted for adequacy review in July 2012. Dr Merrick's latest review (dated 29 July 2012) relates to the revised Groundwater Assessment and Technical Modelling Reports.

It is noted that Dr Merrick's review finds that the groundwater assessment and numerical model were developed in a competent manner and that the modelling objective, *to identify and quantify the potential impacts of the proposed mining operation on the groundwater regime*, was achieved satisfactorily.

The review identified several items that require clarification. These are summarised in Table 1 below, together with responses from the groundwater assessment team.

Table 1 Responses to reviewer comments

Item*	Reviewer comment	Response by Parsons Brinckerhoff
2	Water level map inconsistency.	A contour map showing observed groundwater elevation contours is included in the revised report.
3	Depth to water information not provided.	A depth to water map is provided in relation to the potential groundwater availability to ecosystems in the revised Groundwater Assessment Report.
6	Water balance for calibration period and apparent inconsistency of recharge.	The transient calibration period included a period of unusually high rainfall (March 2010 – August 2011) compared with the long term average. In order to simulate the observed increases in groundwater levels and aquifer storage over the calibration period, it was necessary to increase recharge during the transient calibration.

Item*	Reviewer comment	Response by Parsons Brinckerhoff
7	Overall water balance for the prediction scenario not provided.	Simulated mine inflow rates were derived by processing model groundwater flows from multiple geological layers and zones surrounding each pit. The raw data sets are too large and complex to present in the report and therefore only the relevant components of the water balance are presented in the revised Groundwater Assessment Report).
9	Comments relating to final void	The section relating to the final landform and groundwater recovery has been significantly revised in the final Groundwater Assessment Report. Comments by Dr Merrick have now been addressed. Specifically, maps showing the simulated water table elevation 20 years and 50 years after the end of mining are included in the revised report.

* Item numbers relate to those listed in Dr Merricks updated review (29 July 2012; pages 2 and 3).

Dr Merrick noted that the assessment adopted a drawdown threshold of 2.5 m, whereas the Draft Aquifer Interference Policy refers to a threshold of 2 m. The Aquifer Interference Policy has not been formally adopted by Government and this assessment was carried out prior to the release of the second draft of the Policy. The drawdown threshold adopted in the Groundwater Assessment Report was based on the average annual water table fluctuation in monitoring bores across the site. In the absence of specific Policy guidance, the 2.5 m threshold is considered appropriate for assessment at this location.

It is noted that the editorial issues referred to in Dr Merrick's review (page 3) were resolved and corrected prior to submission of the final Groundwater Assessment and Technical Modelling Reports.

Yours sincerely

Stuart Brown
Principal Hydrogeologist
Parsons Brinckerhoff

Reference

Parsons Brinckerhoff, 2012. Cobbora Coal Project – Water balance and surface water management system. Unpublished report for Cobbora Holding Company, June 2012.

Appendix J

Groundwater management plan framework

Groundwater Management Plan Framework

This document sets out a framework for the management of groundwater prior to and during the life of the Cobbora Coal Mine. The framework is intended as a first step in the management of groundwater for the operational mine, and draws upon the groundwater investigations carried out to date. Specifically the framework draws upon information set out in the *Groundwater Assessment* (PB, 2012) report, prepared as part of the Environmental Assessment process.

The framework below sets out the sections that may be included in a groundwater management plan for the mine, and the information that will constitute each section.

1 Introduction

1.1 Background

- Project details.
- Site location details including summary of climate/topography/land use.

1.2 Purpose and scope

- Details of the groundwater management plan.
- Date of commencement and details of the life of the groundwater management plan.
- Areas the groundwater management plan applies.

2 Objectives and legislative requirements

2.1 Objectives

- Details of the aim of the groundwater management plan.

2.2 Legislative requirements

- Details of the relevant legislation and development consent conditions (discussed in Section 2 of the Groundwater Assessment, PB 2012).

2.3 Environmental protection licence

- Licence conditions for the project and the relevant licence details.

2.4 Guidelines

- Introduction of key guidelines relevant to the preparation and implementation of the groundwater management plan.

3 Characteristics of groundwater resources

- Hydrogeological descriptions of aquifers present in the area (described in Section 5 of the Groundwater Assessment, PB 2012);
    - the alluvium aquifer associated with unconsolidated sediments of the Talbragar River, and also minor alluvium associated with the tributaries to the Talbragar River (Sandy Creek and Laheys Creek)
    - the porous rock aquifer within the Permo-Triassic sediments of the Gunnedah-Oxley Basin
    - porous rock aquifers of Jurassic age

- fractured rock aquifers within the metamorphic basement rocks of the Lachlan Fold Belt.

4 Groundwater monitoring program

4.1 Focus of monitoring program

The groundwater monitoring network and program will focus primarily on the identified impacts as predicted by the Groundwater Assessment (PB, 2012). Based on the predicted impacts the monitoring network will be refined to focus on;

- Drawdown of groundwater levels and pressures within the alluvium and porous rock aquifers in the assessment area (Section 7.1 of Groundwater Assessment):
    - The alluvium aquifer of the Talbragar River to the north east of the project Area. Specifically the monitoring of alluvium between the upstream alluvial irrigators (Collaburragundry-Talbragar Valley Alluvium Water Source) and the area of the alluvium aquifer predicted to be impacted by mining (new monitoring bores).
    - The Talbragar River alluvium aquifer adjacent to the mine site (existing bores GW5A, GW4, GW10).
    - The Talbragar alluvium aquifer downstream of the proposed mine location (new monitoring bore adjacent to one of the existing porous rock bore GW19).
    - Several additional monitoring bores to the west and south of the mining areas constructed into the Permo-Triassic units between existing private groundwater users and the mining areas (existing GW2, and new monitoring bores).
    - New nested monitoring bores to the west of current Site 6 between Pit B and Sandy Creek to monitor long-term groundwater level and quality changes. This site would provide valuable data during mining and also be critical to monitor the recovery of groundwater levels between Pit lake B and Sandy Creek.
- Reduced groundwater discharge to creeks and loss of potential groundwater availability to ecosystems (Sections 7.3 and 7.4 of Groundwater Assessment):
    - Semi-permanent pools along Sandy Creek, Laheys Creek and the Talbragar River which are likely sustained by seepage from the alluvial aquifers, and potentially also the Permo-Triassic aquifer where they outcrop in the stream beds (six new monitoring sites).
    - Naran Springs (one new monitoring bore screened into the base of the Jurassic rock, and one into the underlying Permian Ulan Seam).
    - Additional porous rock and alluvium aquifer monitoring bores between the mining area A and the Talbragar River to monitor groundwater levels and quality between the former pits and river.

- Reduction in available groundwater for identified existing groundwater users within the assessment area (Section 7.2 of Groundwater Assessment):

    - The groundwater assessment indicates a number of registered groundwater users may be potentially impacted by the Project. To ensure the Project does not result in undue impact on the availability and quality of groundwater supplies to neighbouring landholders, all potentially impacted bores will be fully assessed prior to the commencement of mine operations, and where required, each bore will have trigger levels set for groundwater quality (electrical conductivity) and groundwater availability (water level). These bores will be monitored as part of the overall mine monitoring network.

- Monitoring of mine water dams and general groundwater quality (Section 7.5 of Groundwater Assessment):

    - To ensure early detection of any groundwater contamination, new shallow monitoring bores should be installed adjacent to mine water dams and overburden stockpiles that contain potentially contaminated water or waste rock materials.

    - New monitoring bores (and/or existing where present) should be installed upstream and downstream, and adjacent to the Pit B in the alluvium to monitor groundwater level and quality changes.

4.2 Monitoring plan procedures

4.2.1 Groundwater levels

- Procedures for measurement of groundwater levels.

Where monitoring of groundwater level drawdown impacts are the priority, permanent groundwater level data loggers will be installed. At all other monitoring sites groundwater levels will be monitored manually on a regular basis. The monitoring plan will take into account mitigation measures outlined in Section 9.1 of the Groundwater Assessment (PB, 2012) for groundwater level management.

4.2.2 Groundwater quality

- Listed analytical parameters for groundwater monitoring and details of sampling and QA/QC procedures. Details of acid mine drainage potential.

The groundwater quality monitoring program will be designed based on the requirements of each monitoring site, e.g. shallow monitoring bores around waste rock stockpiles will be monitored for analytes which indicate acid mine drainage potential, while the more regional monitoring bores will be monitored for changes to baseline quality results. The monitoring plan will take into account mitigation measures outlined in Section 9.2 of the Groundwater Assessment (PB, 2012) for groundwater quality management.

4.1 Frequency of monitoring and procedures

- Details of monitoring point locations and frequency of monitoring events.

Detailed table listing all monitoring bores, respective locations (GPS), monitoring bore purpose, construction details and monitoring frequency. The list of monitoring bores that constitute the current monitoring network and their construction details are provided in Table 4.1 of the Groundwater Assessment (PB, 2012).

4.2 Data management

- Details of data co-ordination, review and quality control procedures.

4.3 Assessment criteria

- Details of the relevant guidelines and trigger values for groundwater level drawdown and groundwater quality.

It is proposed that soft trigger levels for groundwater levels and quality be developed immediately prior to mining commencing. Trigger levels should not necessarily be fixed for the life of the mine operation, but should be developed in collaboration with nearby groundwater users, the NSW Office of Water and other professionals including ecologists.

5 Mitigation measures and response plans

- Details of the mitigation measures and response plans prepared for: exceedance of trigger values, emergency spills and clean-up, acid potential of the waste rock, leaching of minerals to the groundwater system and groundwater seepage to the mine pits.

6 Plan implementation

6.1 Key responsibilities and procedures

- Responsibilities and procedures will be outlined for the implementation of the groundwater management plan. An action plan with timeline will be included.

6.2 Reporting and review

- Groundwater monitoring report details will be provided including: contents, time frames and review procedures.
- Details of the review and revision procedures for the groundwater management plan.

7 References

Parsons Brinckerhoff, 2012, Groundwater Assessment, prepared for Cobbora Holding Company Pty Ltd.