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 2012a) 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:

- 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.

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 GAB 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.

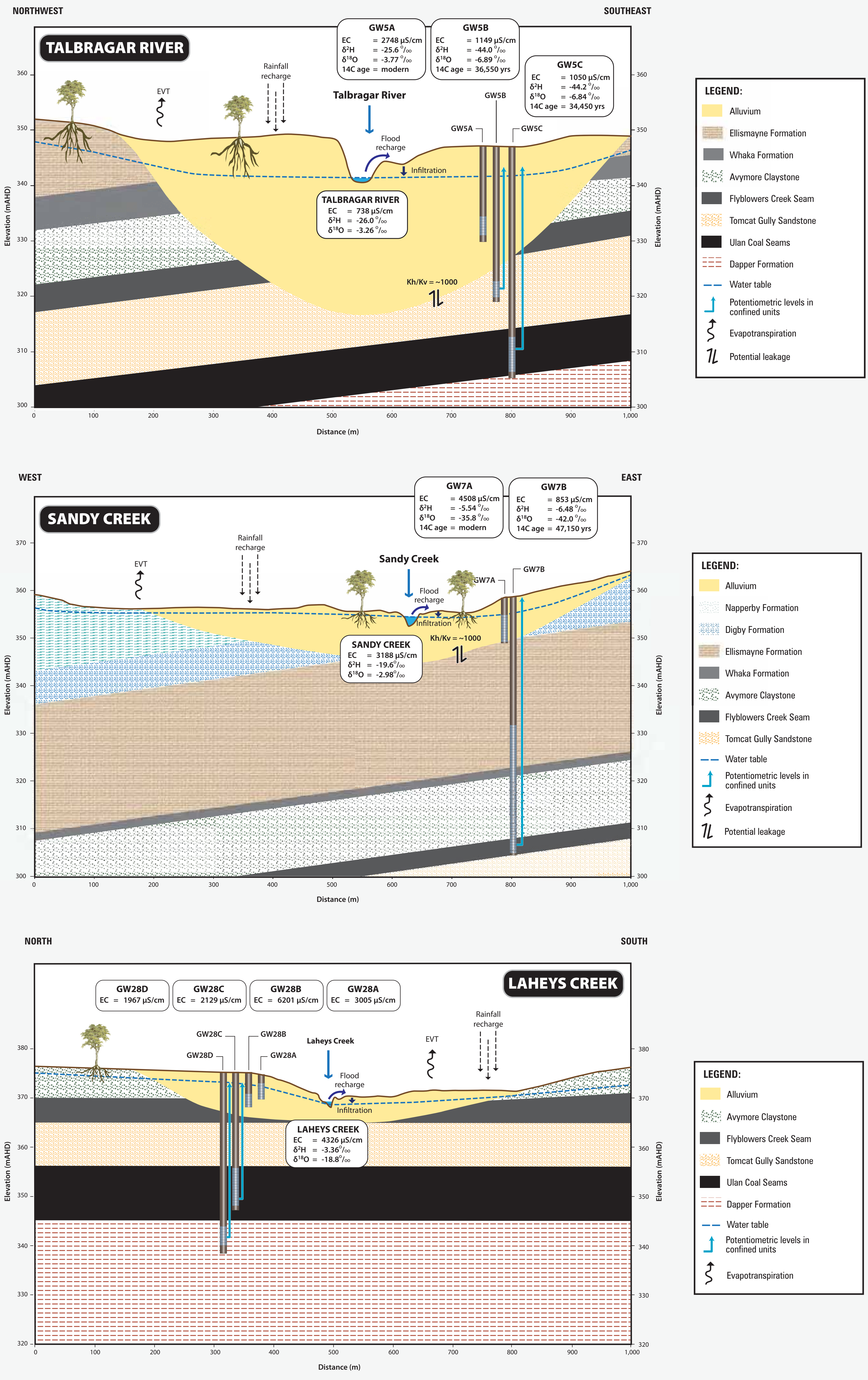


Figure 3.1 Conceptual hydrogeological cross-sections for Talbragar River, Sandy Creek and Laheys Creek

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
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	$5 \times 10^{-5} – 5 \times 10^{-3}$

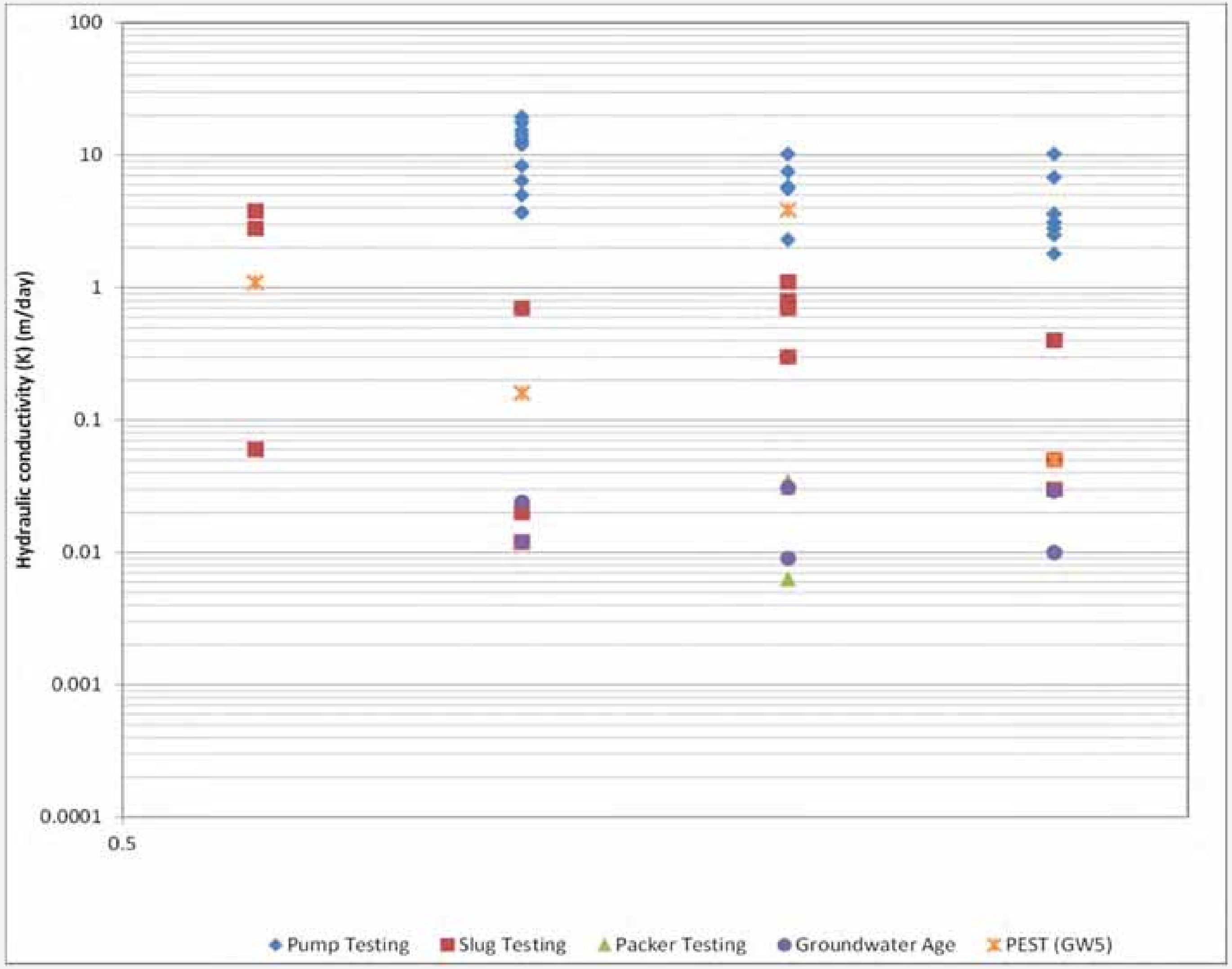


Figure 3.2 Estimated hydraulic conductivity

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 2012a). 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 2012a).

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 2012a).

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.

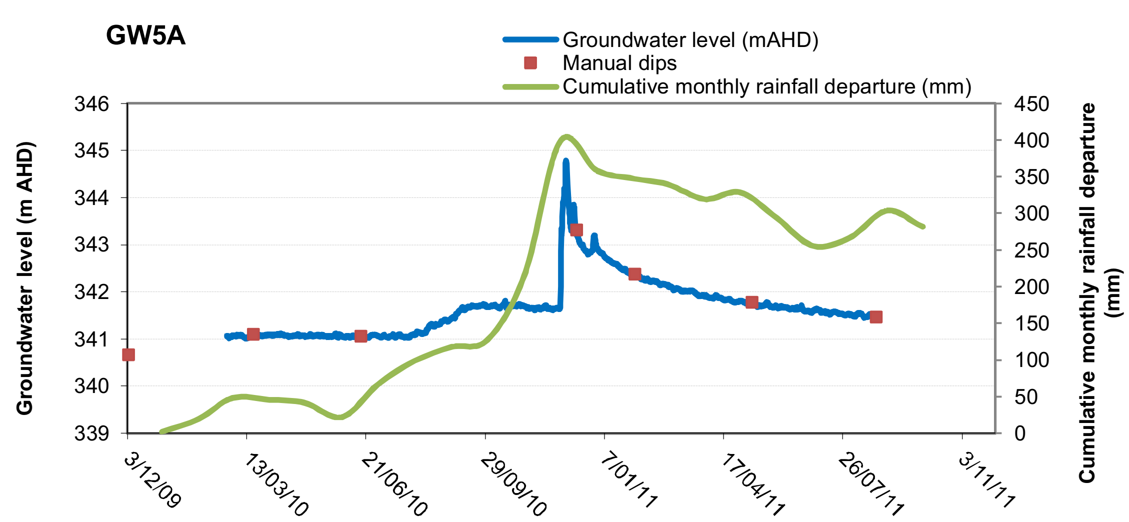
- Where alluvial deposits are developed along the stream and river courses, the connection between the Permo-Triassic aquifer and the alluvium aquifers is weak and the alluvium aquifers form distinct local aquifer systems. This is evidenced by the strong vertical hydraulic gradients across the alluvium interface and distinct isotopic composition and radiocarbon ages (Parsons Brinckerhoff 2012a).

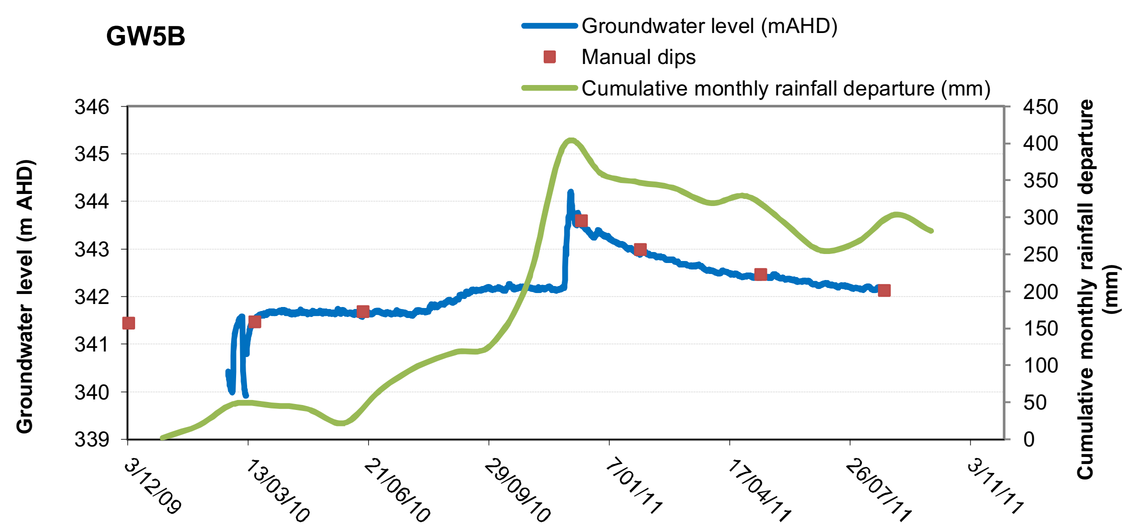
- Long-term (21-day) pumping tests at two locations (GW5 and GW7) confirm the low vertical conductivity of the alluvium deposits. Observed drawdown during those tests implies very low leakage rates and a horizontal to vertical permeability ratio in the order of 1,000 or more (Parsons Brinckerhoff 2012a).

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.





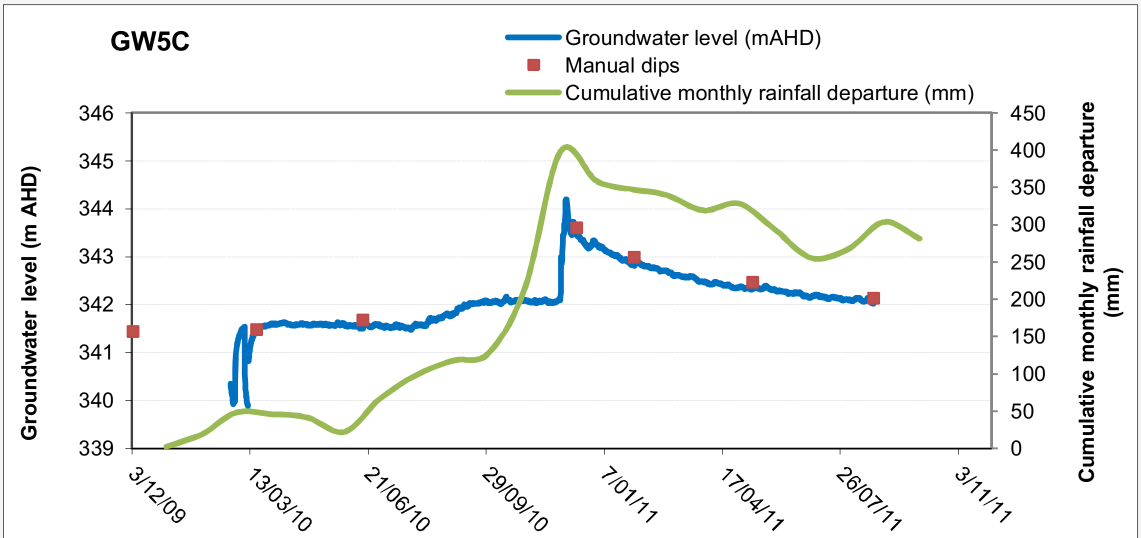
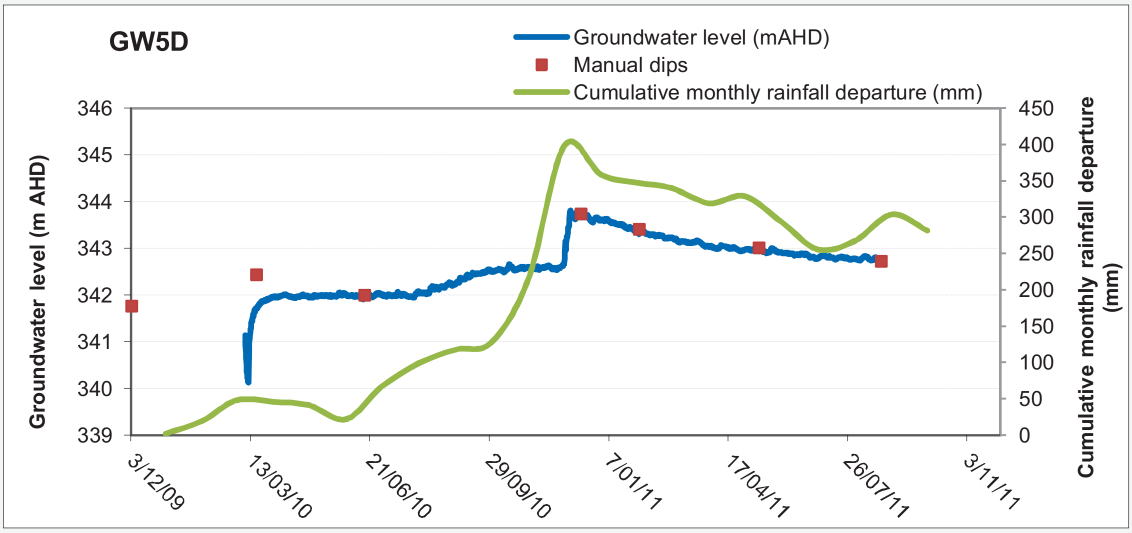
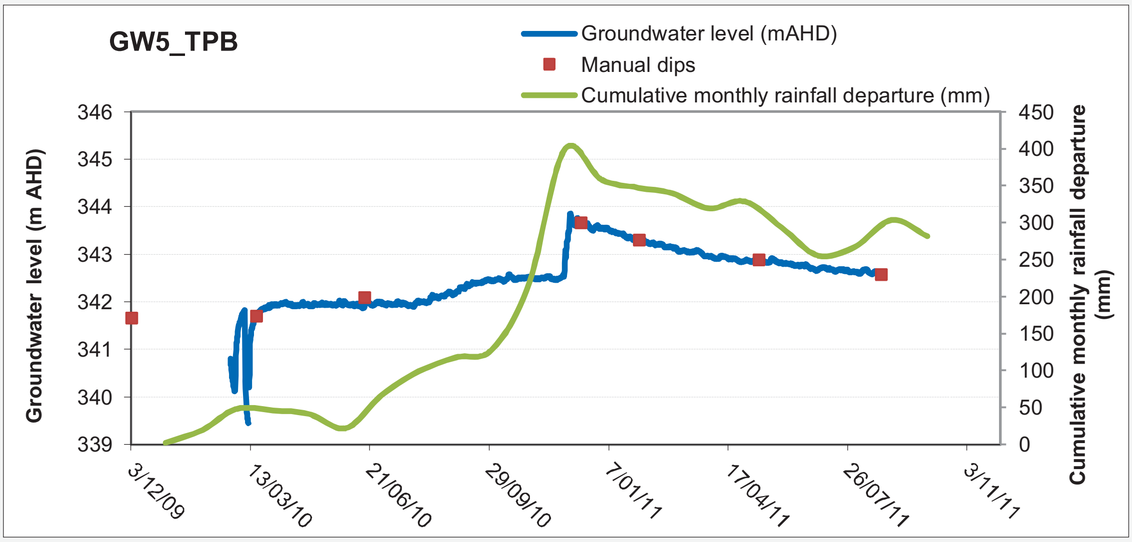


Figure 3.3A Hydrographs showing response to rainfall (GW5A, GW5B and GW5C)





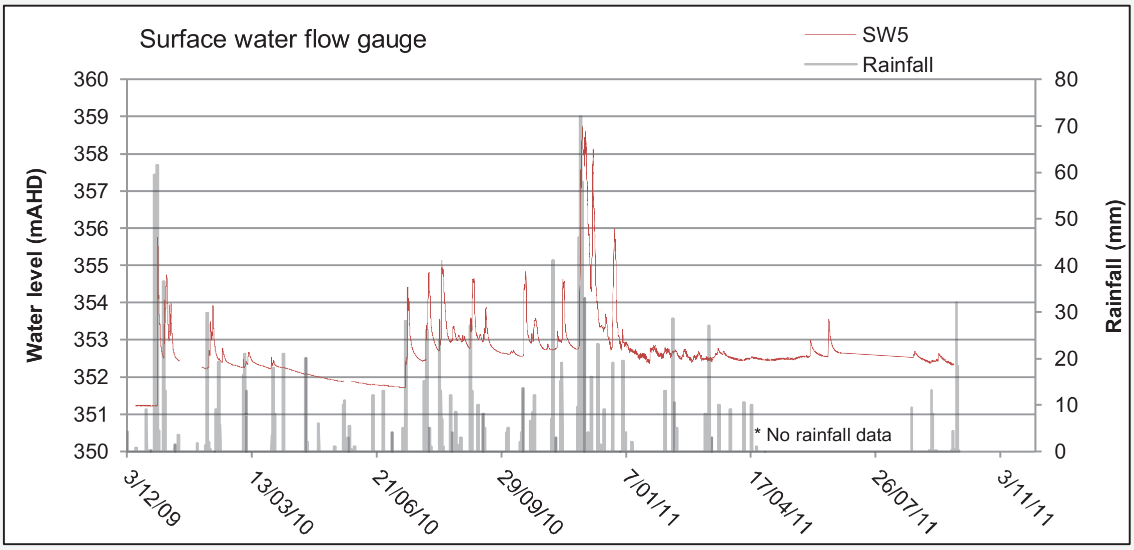
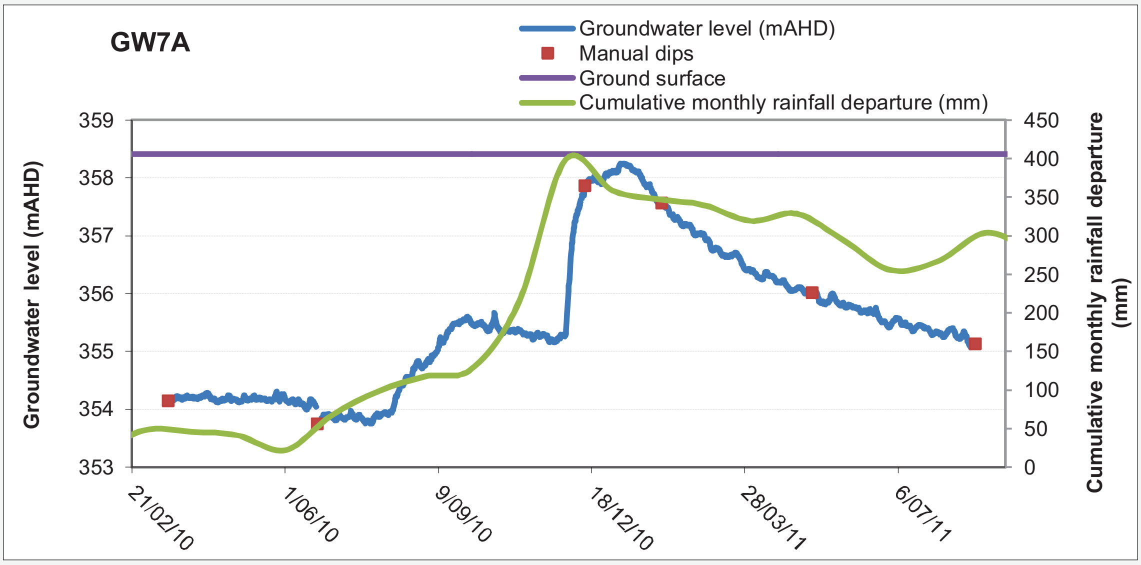
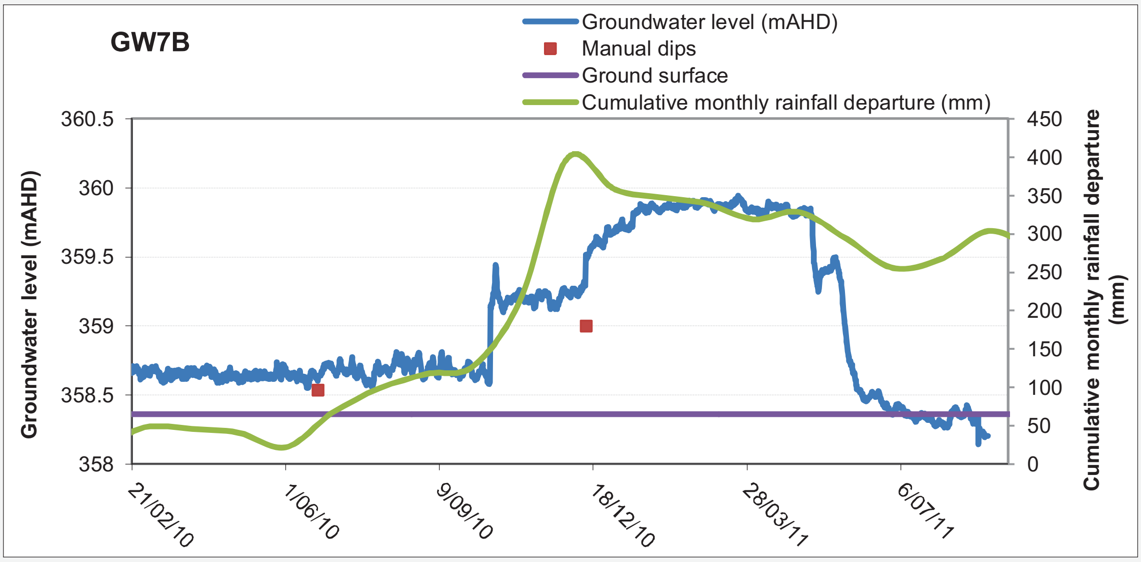


Figure 3.3B Stream discharge and hydrographs showing response to rainfall (GW5D, GW5TPB and SW5)





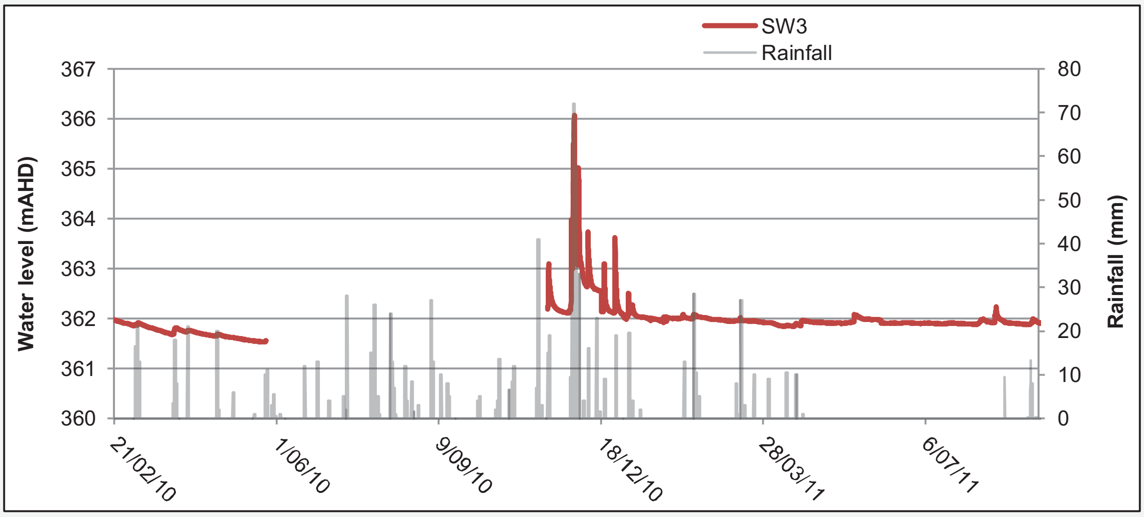
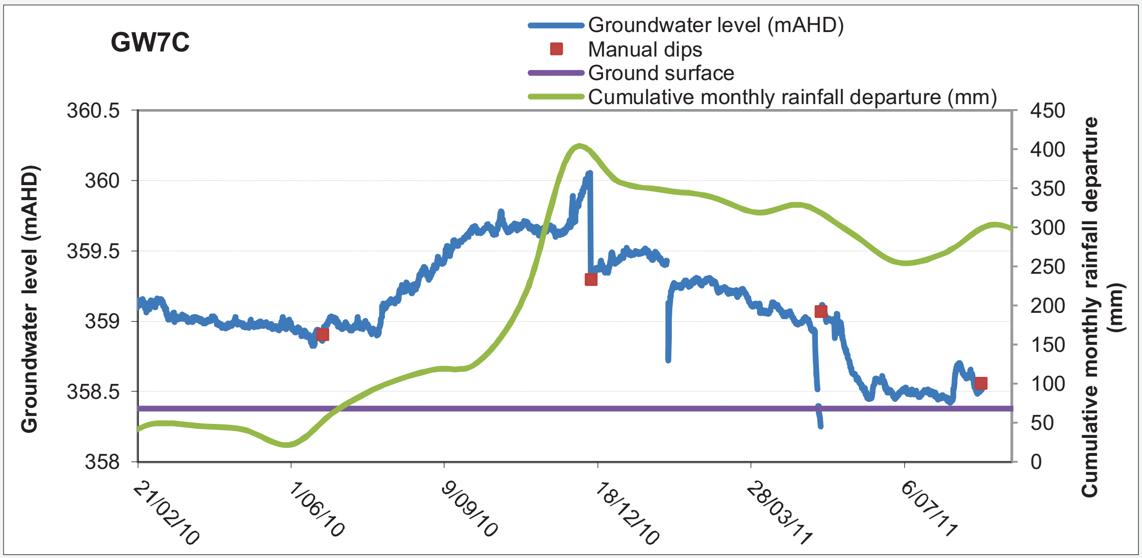
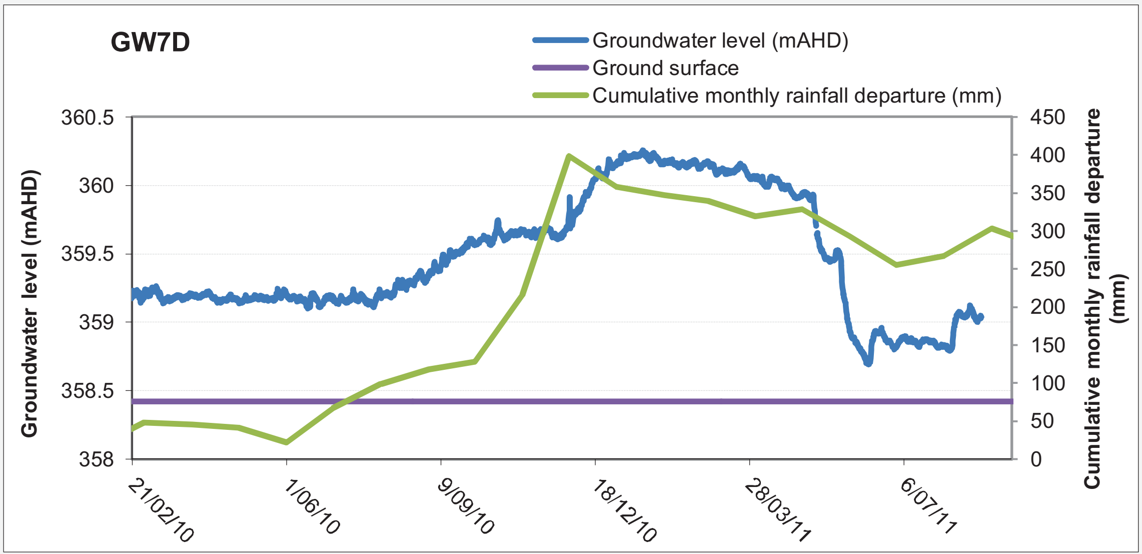


Figure 3.3C Stream discharge and hydrographs showing response to rainfall (GW7A, GW7B and SW3)





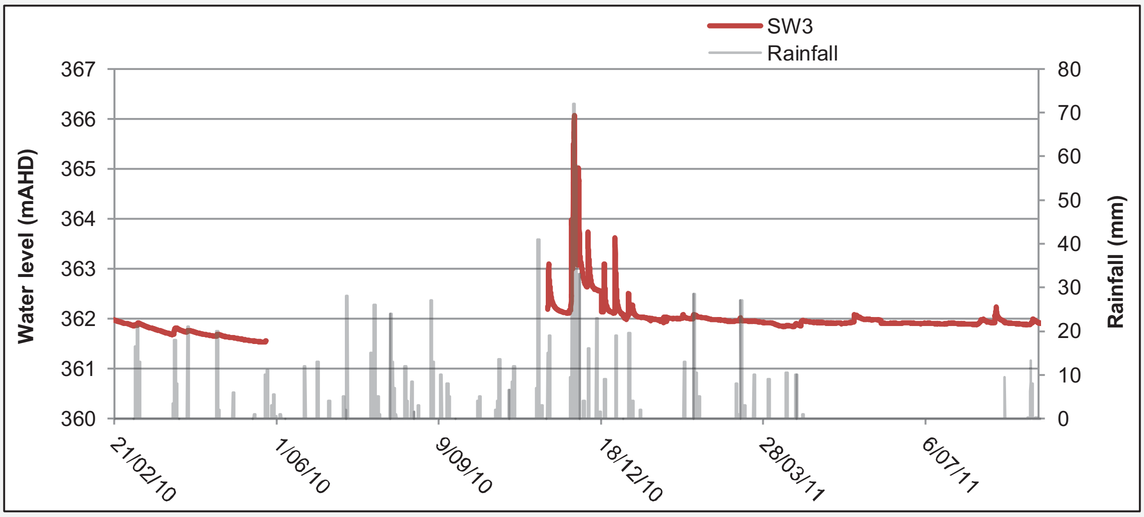


Figure 3.3D Stream discharge and hydrographs showing response to rainfall (GW7C, GW7D and SW3)

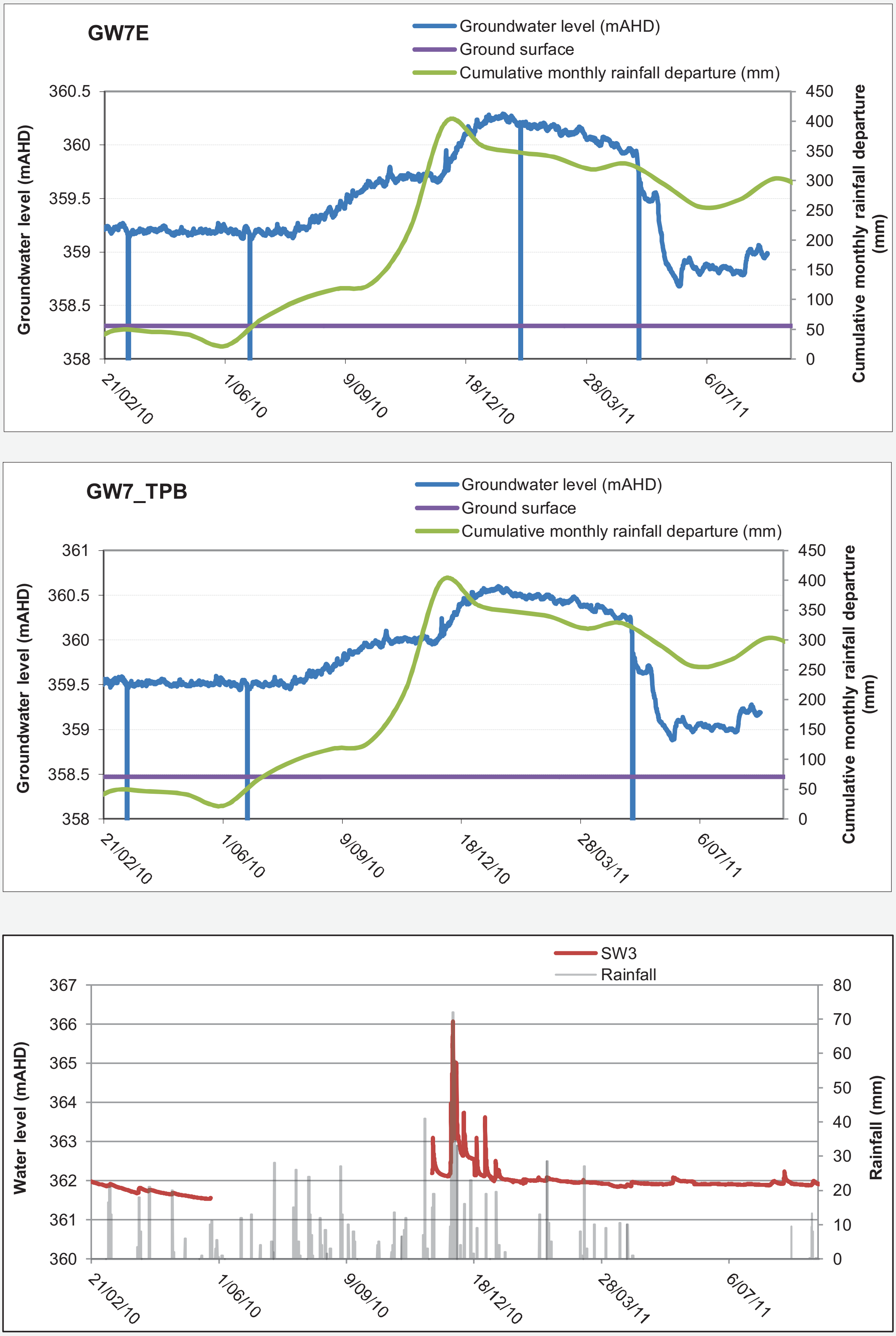


Figure 3.3E Stream discharge and hydrographs showing response to rainfall (GW7E, GW7TPB and SW3)

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 2012a).

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 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 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 2012b).

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, 2101) and are based on the previous MDBC modelling guidelines (MDBC 2001). The assessment and modelling for this project is consistent with the new national guideline.

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:

- NSW Office of Water (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 2012a).

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 50 years after the planned cessation of mining.

The model has simulated groundwater heads and flows at 100-day 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.

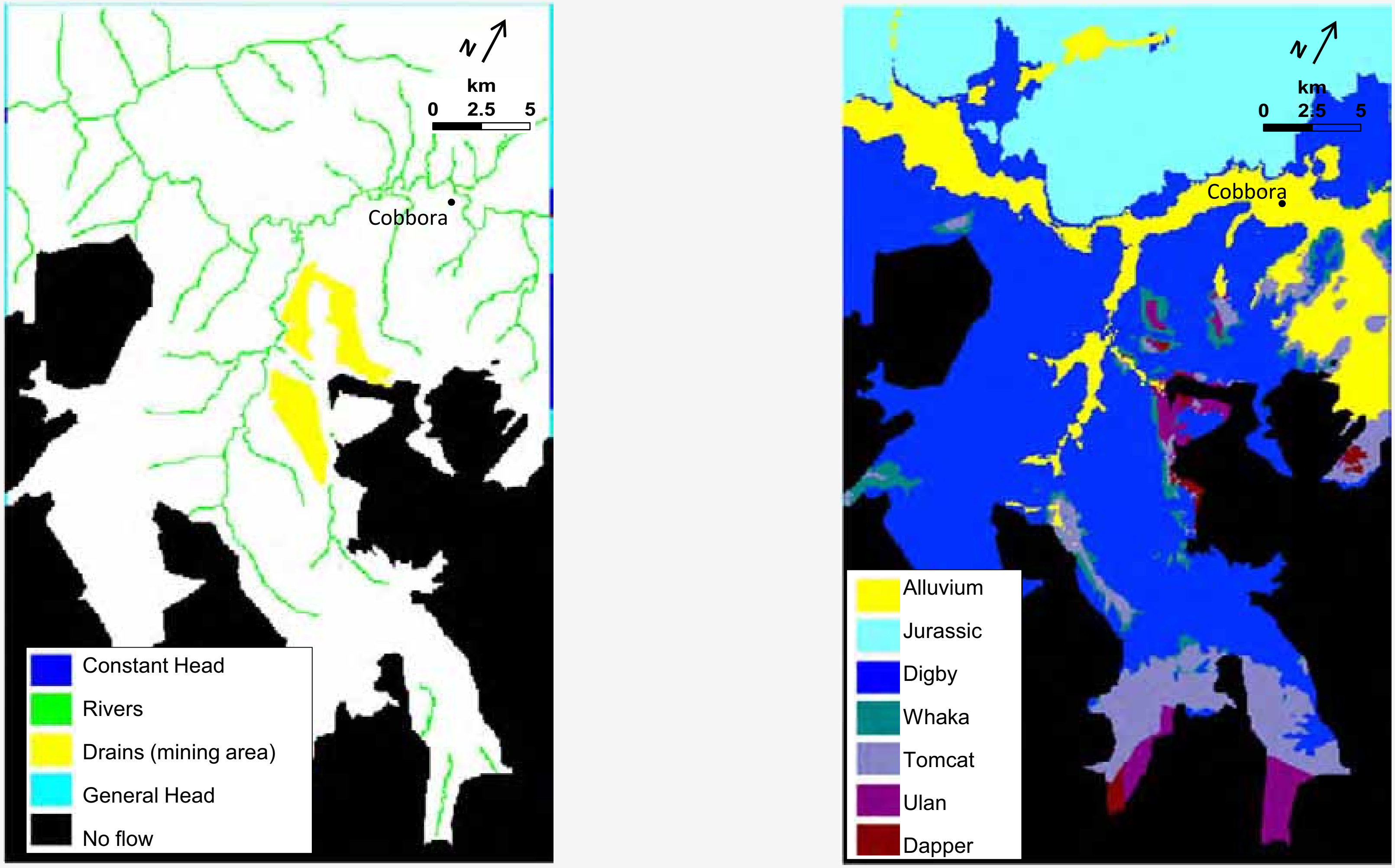


Figure 3.4 Model domain showing a) assigned boundary conditions and b) hydrostratigraphic units in layer 1

3.2.5.3 Rainfall and recharge

Long-term average rainfall for the assessment area, based on data from Bureau of Meteorology 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 properties used for the backfill material were based on the work of Mackie (2009), which indicates a geometric mean hydraulic conductivity value for spoil material of 3.2 m/d and an average recharge value of 3.3% of rainfall. 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 all excavated areas backfill material with the exception of the residual Pit B lake. The characteristics and lake level at Pit B is determined in the *Cobbora Coal Project - Surface Water Assessment* (Parsons Brinckerhoff 2012b).

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 2012a). 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 (mAHD)
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
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

Bore name	Screened unit(s)	Groundwater level (mAHD)
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 4.2. 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%).

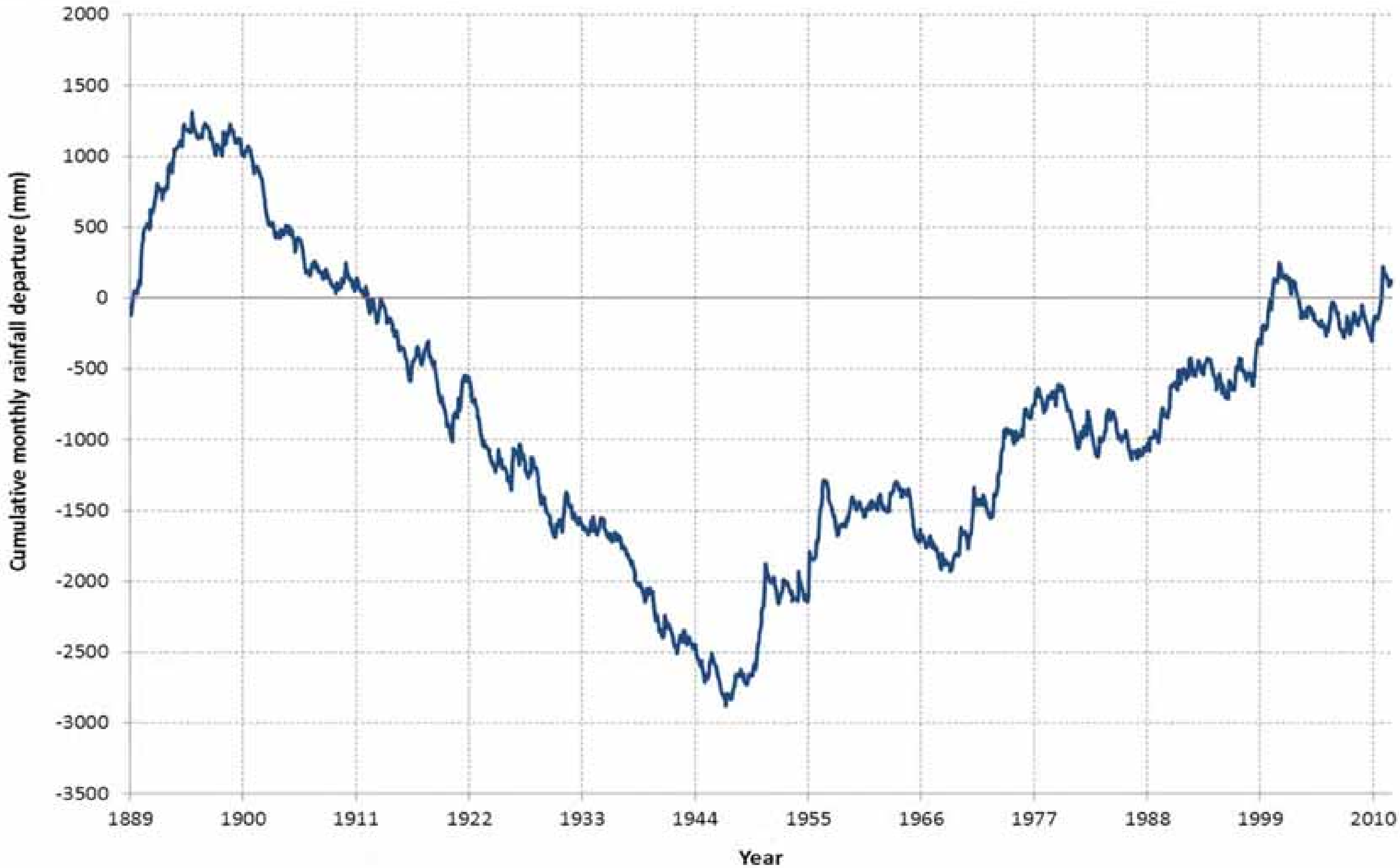


Figure 4.1 Cumulative monthly rainfall residual curve for the Project area since January 1889

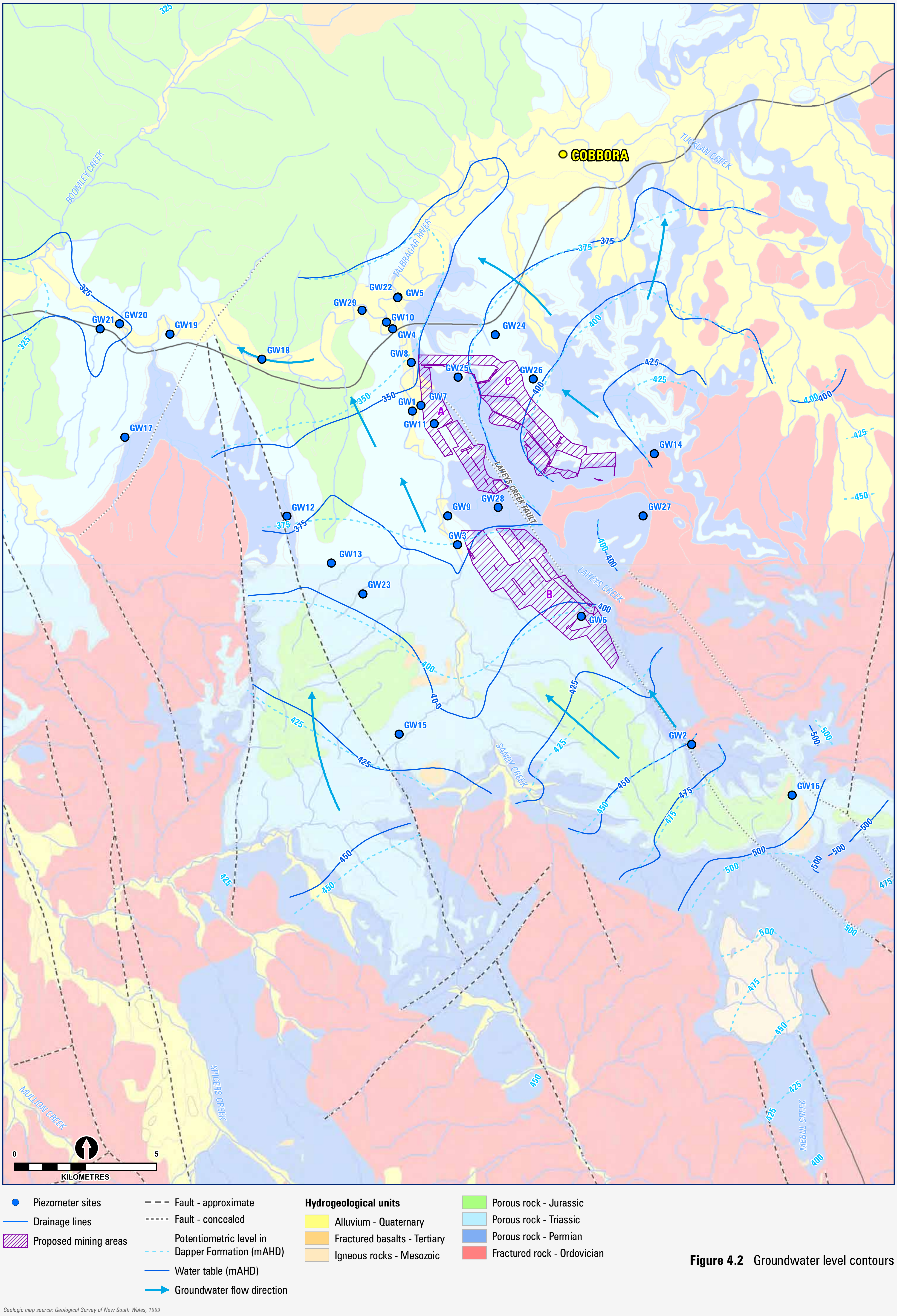


Figure 4.2 Groundwater level contours

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 2012a) 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%).

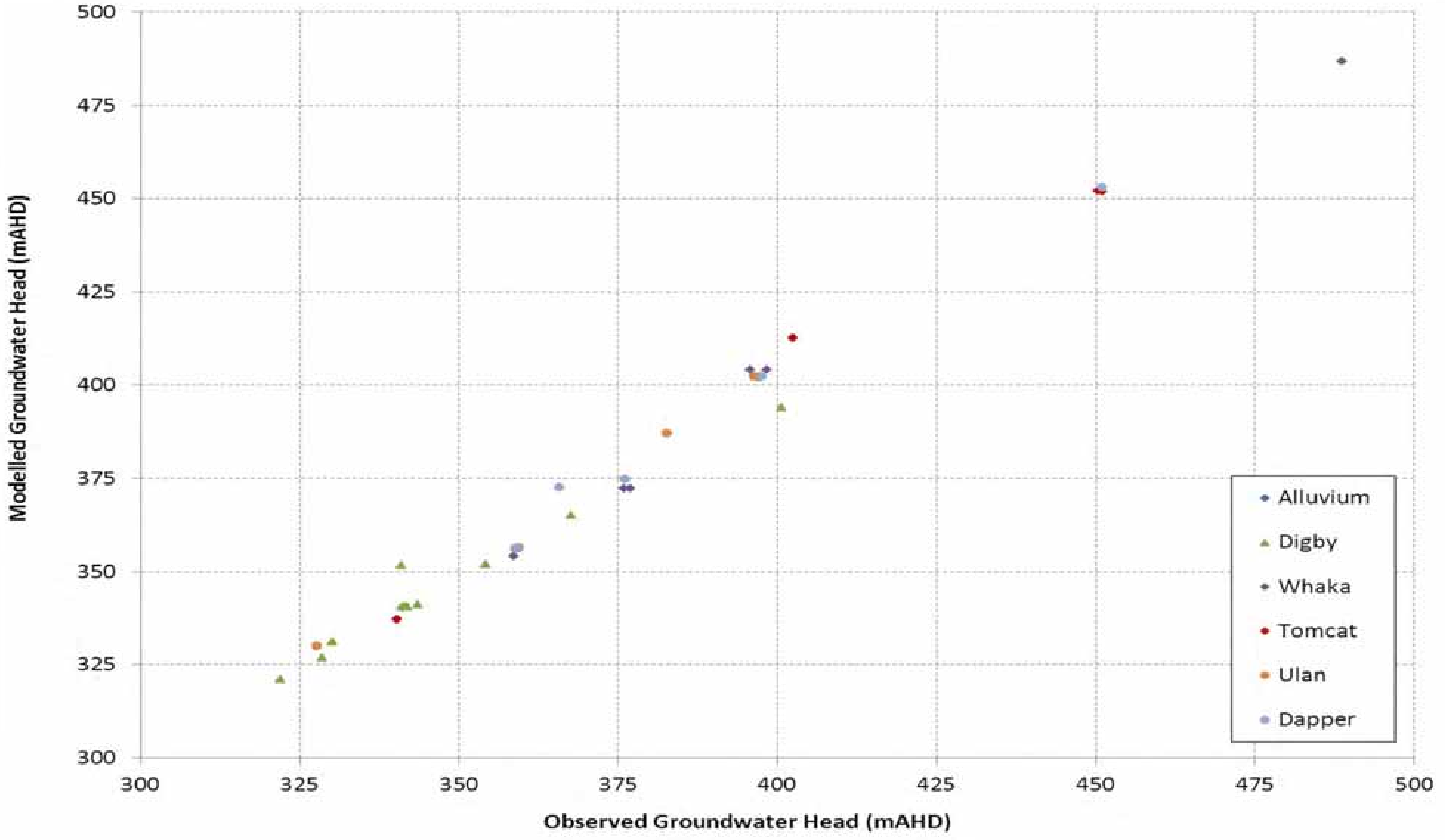


Figure 4.3 Relationship between modelled and observed groundwater heads for the steady state model

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 4.5A-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

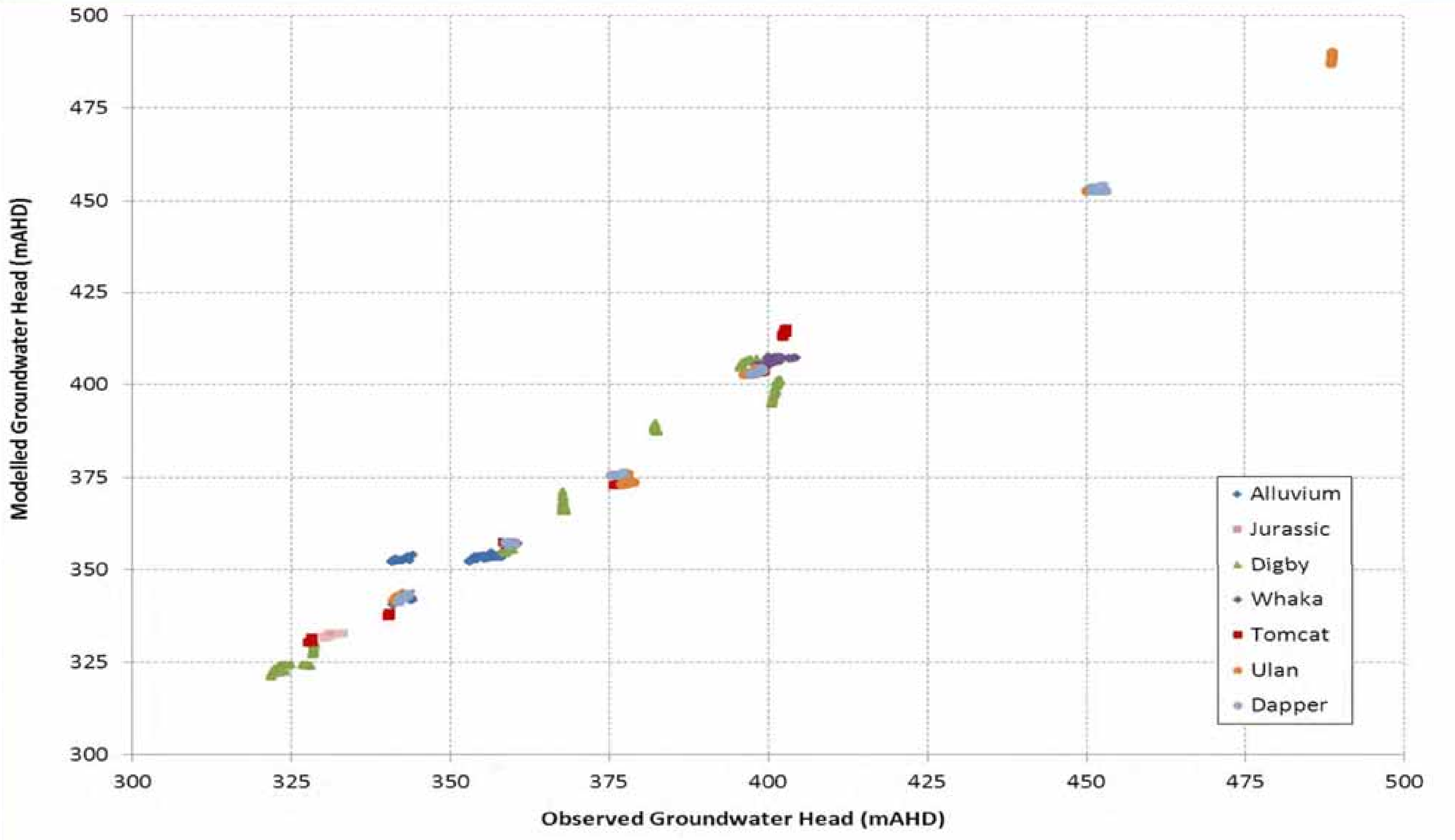


Figure 4.4 Relationship between modelled and observed groundwater heads for the transient model

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

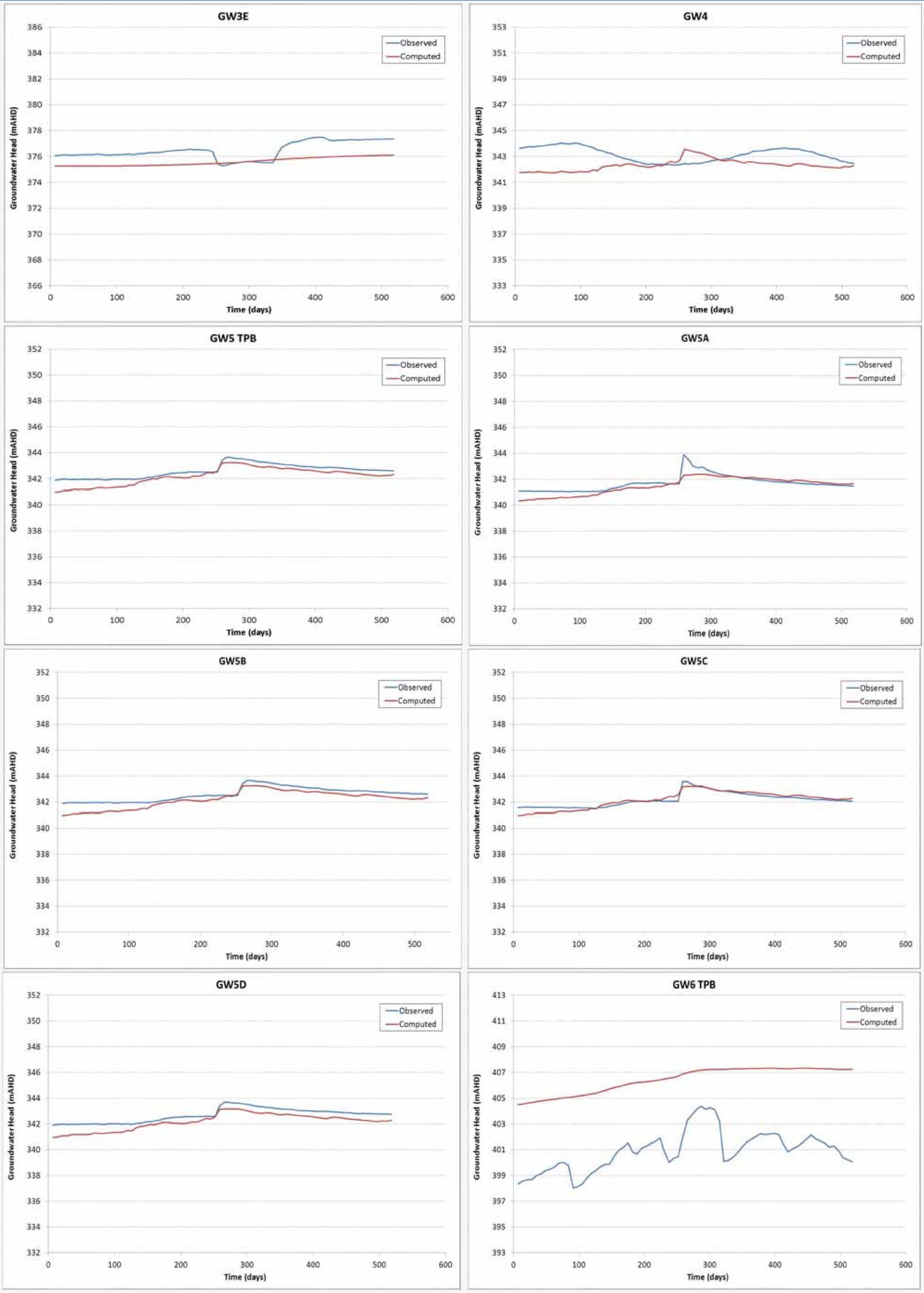


Figure 4.5B Selected hydrographs showing observed versus calibrated transient groundwater heads

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

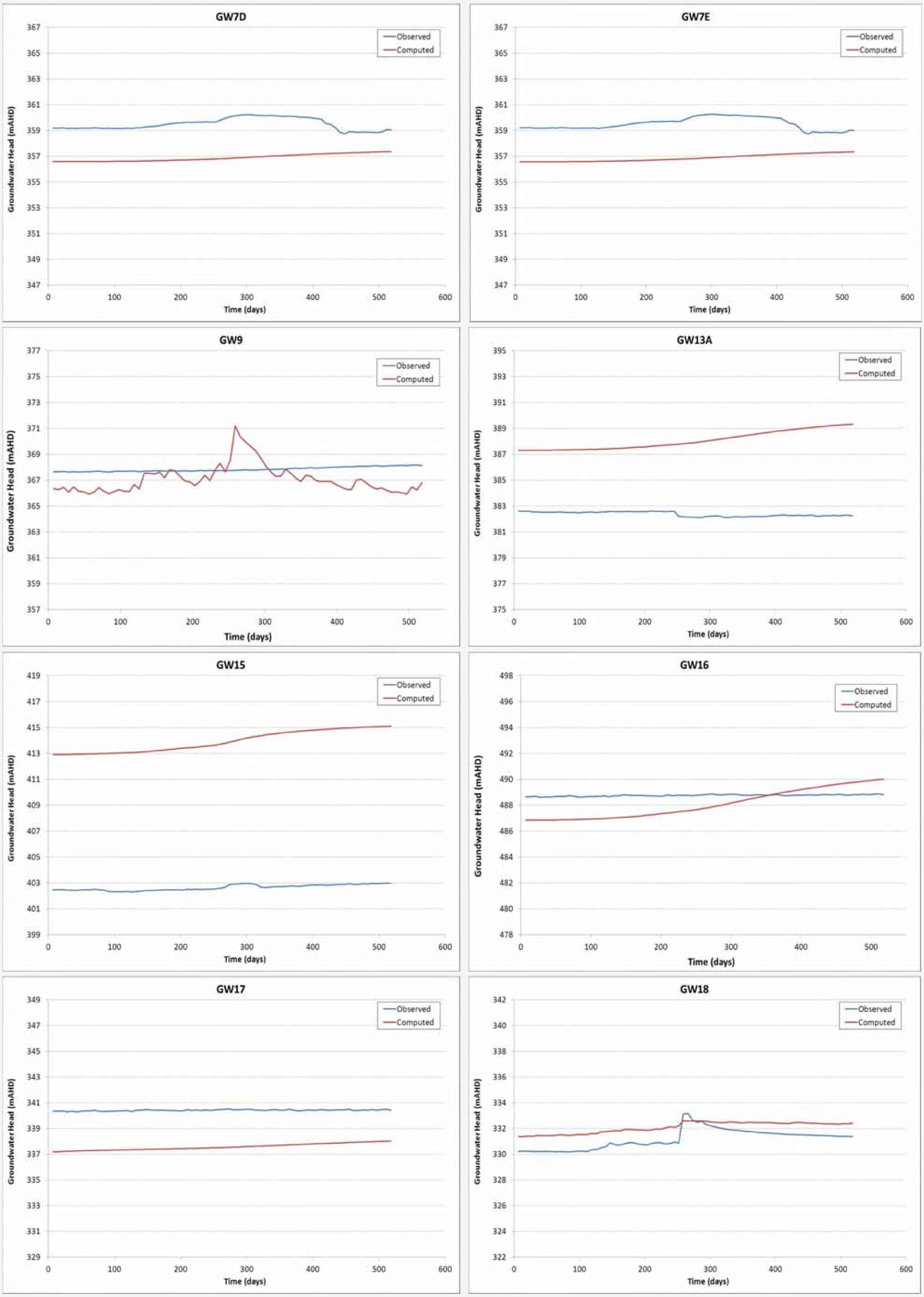


Figure 4.5D Selected hydrographs showing observed versus calibrated transient groundwater heads

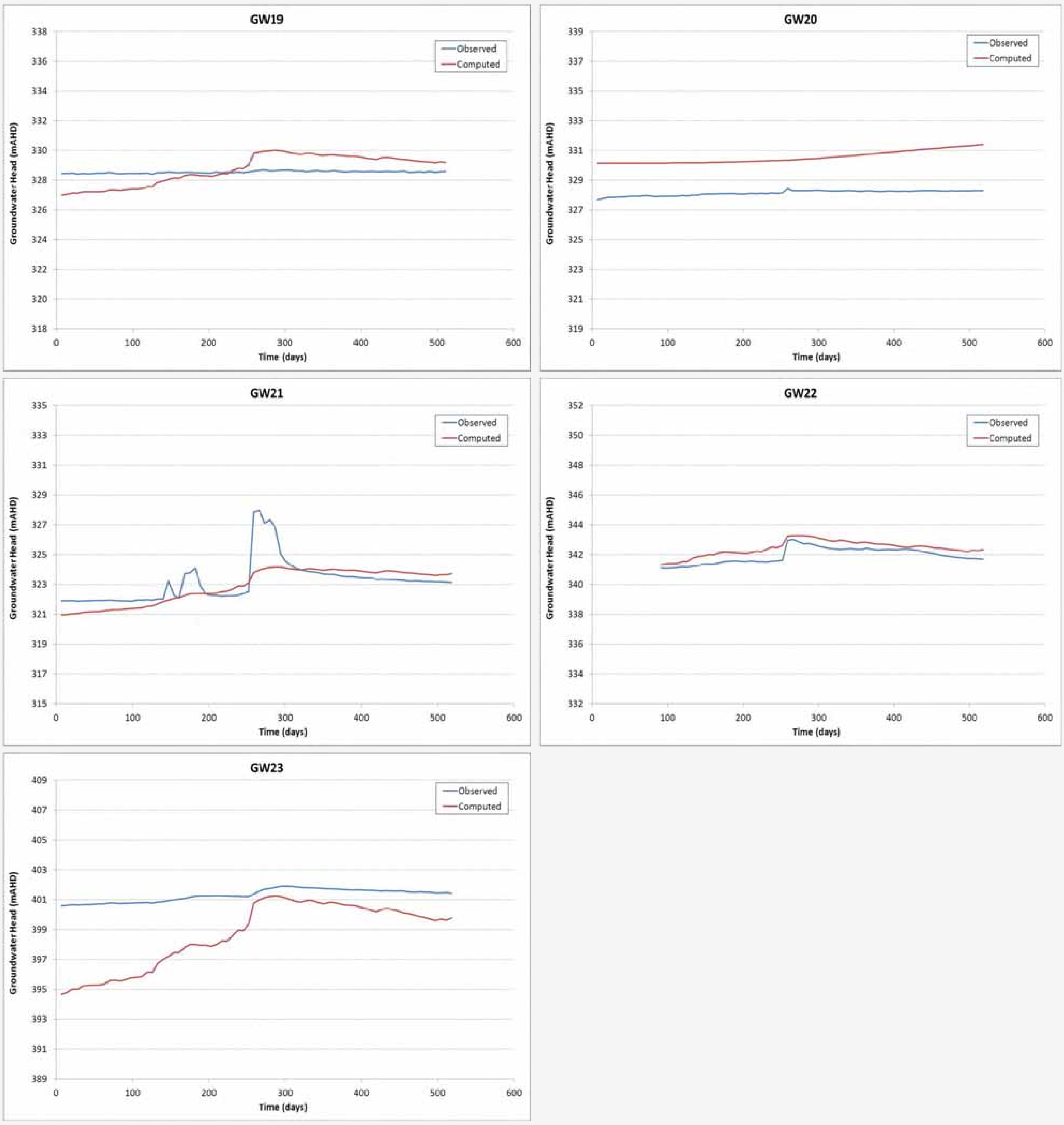


Figure 4.5E Selected hydrographs showing observed versus calibrated transient groundwater heads

5. Model predictions and analysis

5.1 Predicted mine inflow rates

Predicted mine inflow 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 2020 and 2031, with total flows typically more than 1,000 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	1	37	0	38
2016	124	277	4	404
2017	309	372	20	701
2018	283	524	79	886
2019	258	615	4	878
2020	282	611	129	1,022
2021	454	611	226	1,291
2022	281	626	122	1,030
2023	456	642	130	1,227
2024	611	679	246	1,537
2025	607	968	79	1,654
2026	180	1,120	249	1,550
2027	276	970	304	1,550
2028	20	989	357	1,366
2029	94	569	313	976
2030	281	734	326	1,340
2031	491	962	322	1,775
2032	219	242	374	835
2033	109	*	166	275
2034	184	*	64	248
2035	186	*	162	348

* 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)

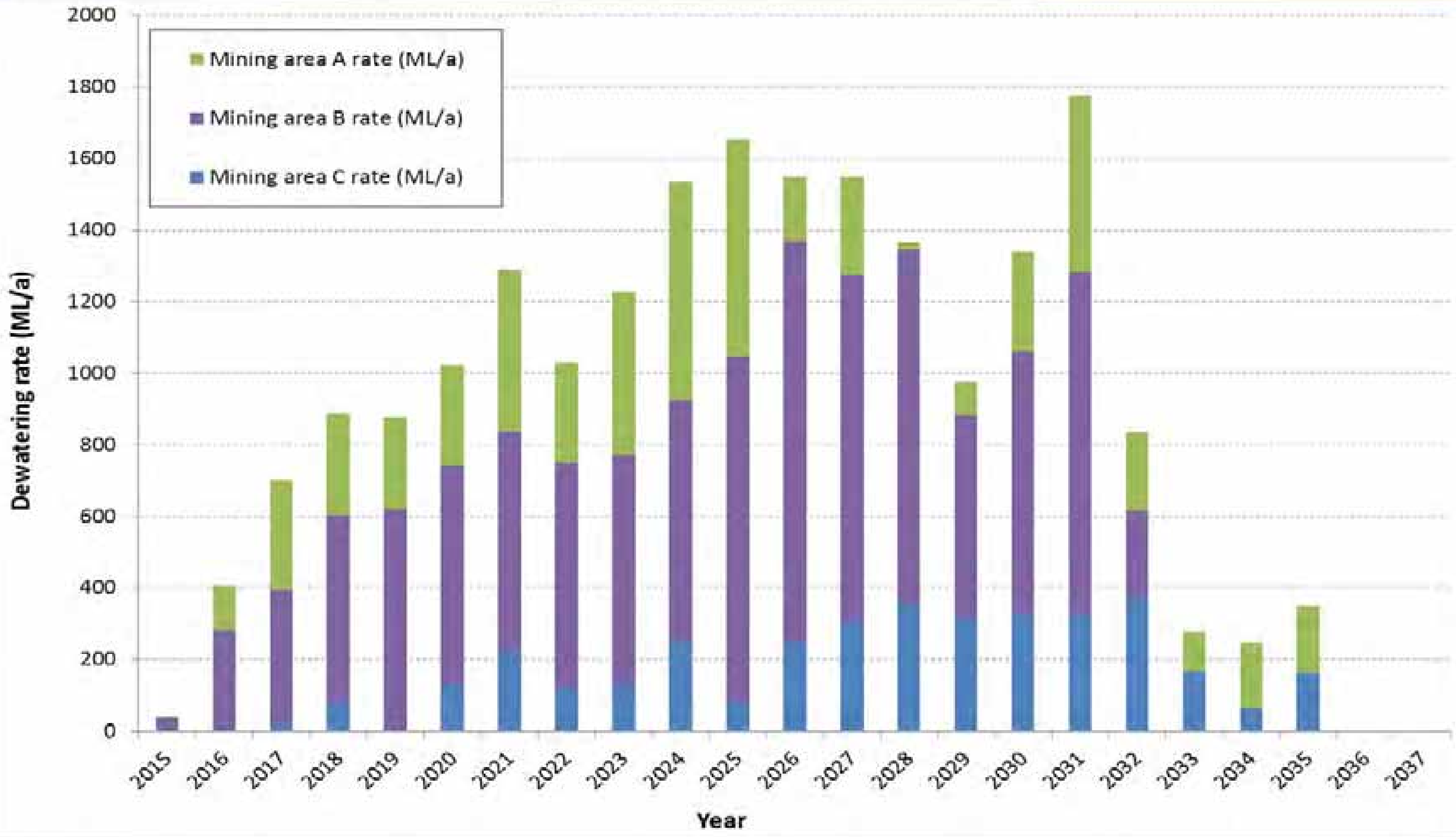


Figure 5.1 Predicted dewatering rates in each mining area

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 2,000 ML in each unit by the end of mining in 2035.

Predicted cumulative storage losses within the alluvium reach a maximum value of nearly 300 ML. This constitutes 0.1% 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 280 ML/a, which occurs towards the end of mining operations (based on the change in total river inflows minus total river outflows within the model). This constitutes 0.5% of the average annual flow in the Talbragar River of 54,427 ML/a (Parsons Brinckerhoff 2012b). The model results predict that approximately 70% of the total reduction in surface water flows is due to increased outflows from rivers to the surrounding groundwater system (induced recharge), with reductions in baseflow accounting for the remaining 30%.

Additional inflows in the model come from dewatering of material within the mining area, including recharge to this material prior to excavation and recharge through backfill.

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 85 m in mining area B (with maximum lowering of groundwater levels in mining area A and mining area C of 49 m and 35 m respectively) (see Figure 5.3A). The 1 m drawdown contour is predicted to extend up to 5 km to the south of the mine and nearly 4 km to the west of mining area A. Drawdown to the north and east is far less extensive, with the 1 m drawdown contour predicted to lie within 3 km of the mining areas.

Drawdown 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 5 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 5.4 to 5.7. 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 years after the proposed mining activities cease.

After 5 years, water levels within mining area B are expected to be lowered by up to 62 m. The resulting drawdown in the water table aquifer is expected to be largely confined within the final void boundary, although some drawdown of water levels is predicted within the alluvium immediately adjacent to the mining areas (see Figure 5.4A). 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 5.4B).

After 10 years, water levels in mining area B are expected to be up to 77 m lower. The resulting 1 m drawdown contour in the water table aquifer (see Figure 5.5A) is predicted to extend up to 2 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 39 m in mining area B (see Figure 5.6A). The extent of drawdown is close to its maximum in both the water table aquifer (see Figure 5.6A) and Ulan Coal Seams (see Figure 5.6B). Storage losses within the alluvium and reductions in river flow are predicted to be greatest at this point.

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 5.7 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 groundwater will have largely recovered to levels similar to pre-mining levels over much of the model domain, but there will be some residual drawdown, particularly within approximately 2 km of the Pit B lake (see Figure 5.7). Following 50 years of recovery a new equilibrium will largely have occurred. Pit B lake will form a local groundwater sink whereby net groundwater inflow to the lake will occur over the long term.

The recovery of groundwater levels after mining is largely due to the following:

- The enhanced recharge for areas that are backfilled in accordance with the recommendations in Mackie 2009, which is modelled.
- The creeks being defined as net recharge areas over the longer term. This is consistent with the isotopic signatures obtained during the field investigations. It also corresponds with the rapid recharge response in the alluvium following rainfall and high flow events. The model uses this information for these sections of creeks.
- Model parameters are based on thorough field investigations, and published literature.

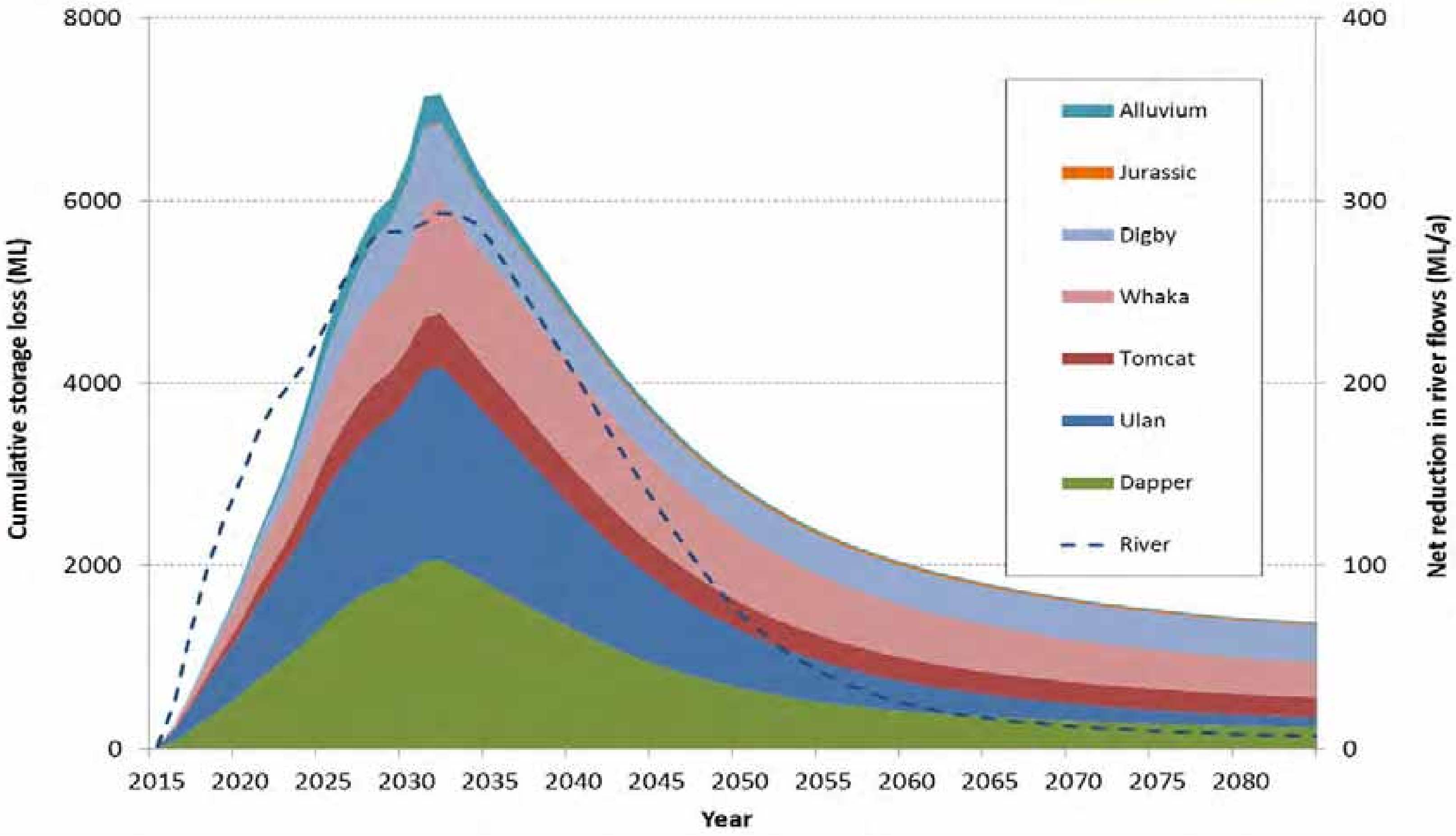
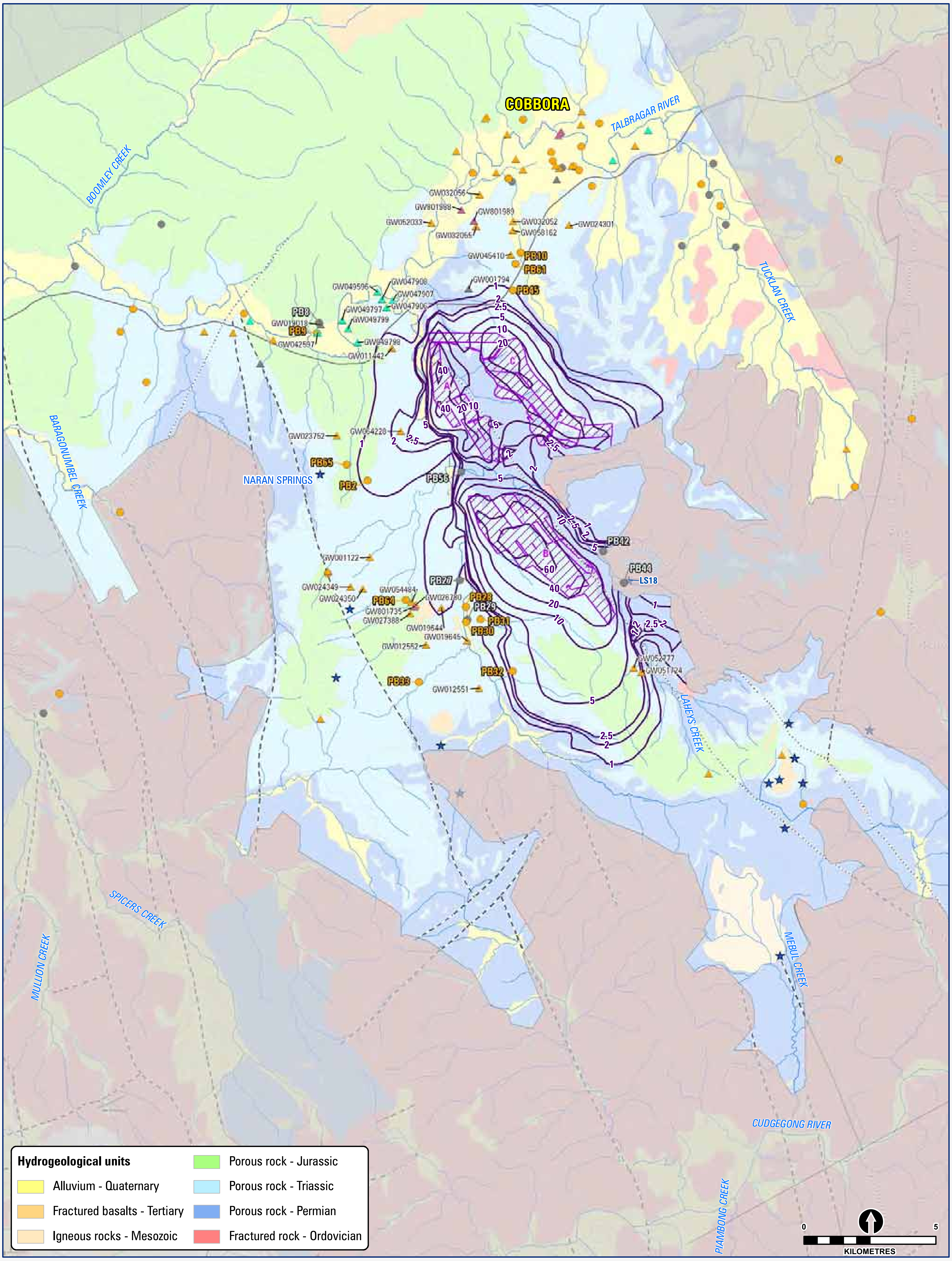


Figure 5.2 Predicted storage and river losses from mine dewatering



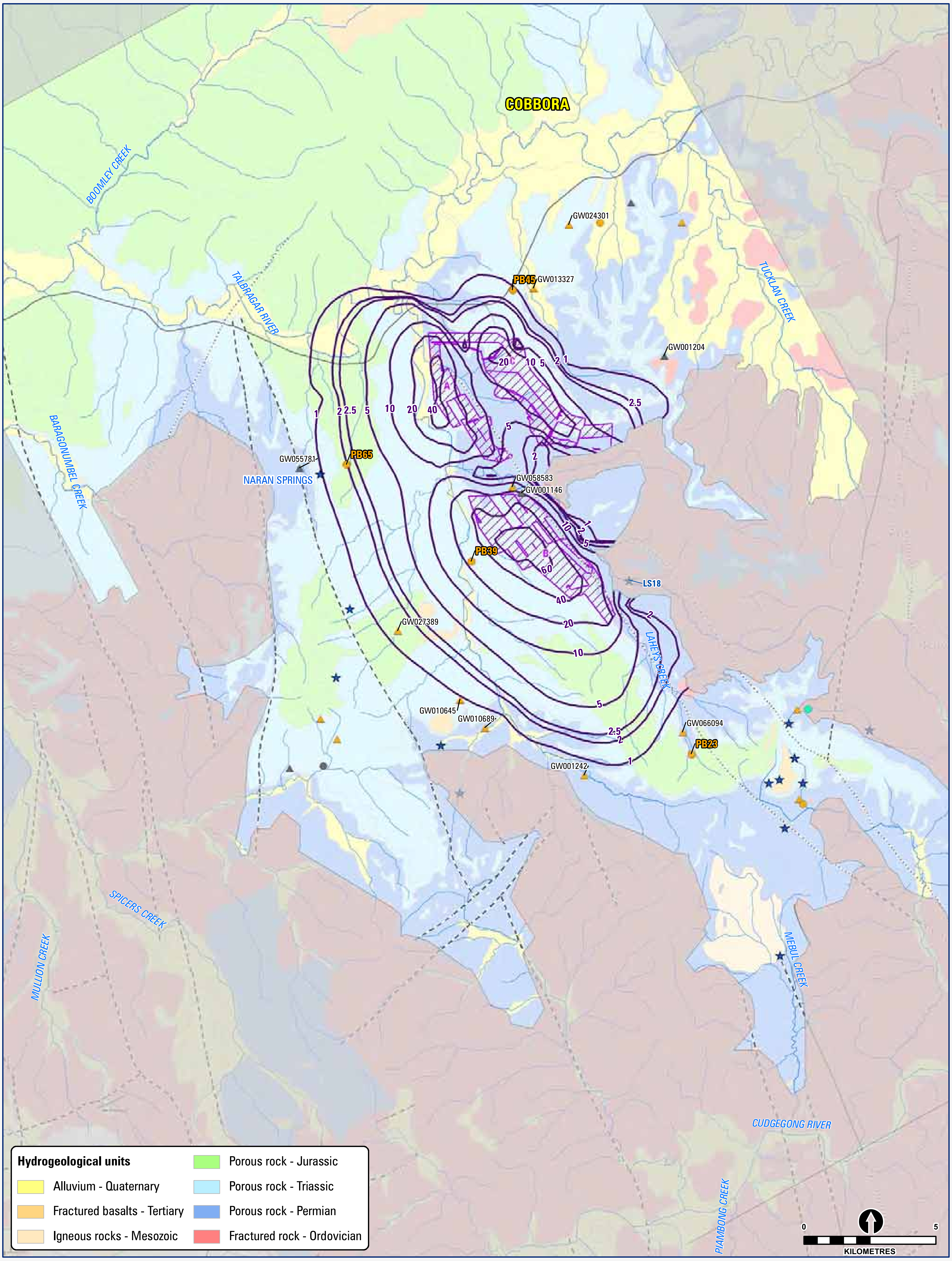
Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Irrigation
- Other
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Not known

- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed
- Proposed mining areas
- No flow boundary of numerical groundwater model
- Maximum predicted drawdown (m)

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

Figure 5.3A Maximum predicted drawdown in water table aquifer



Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Irrigation
- Not known

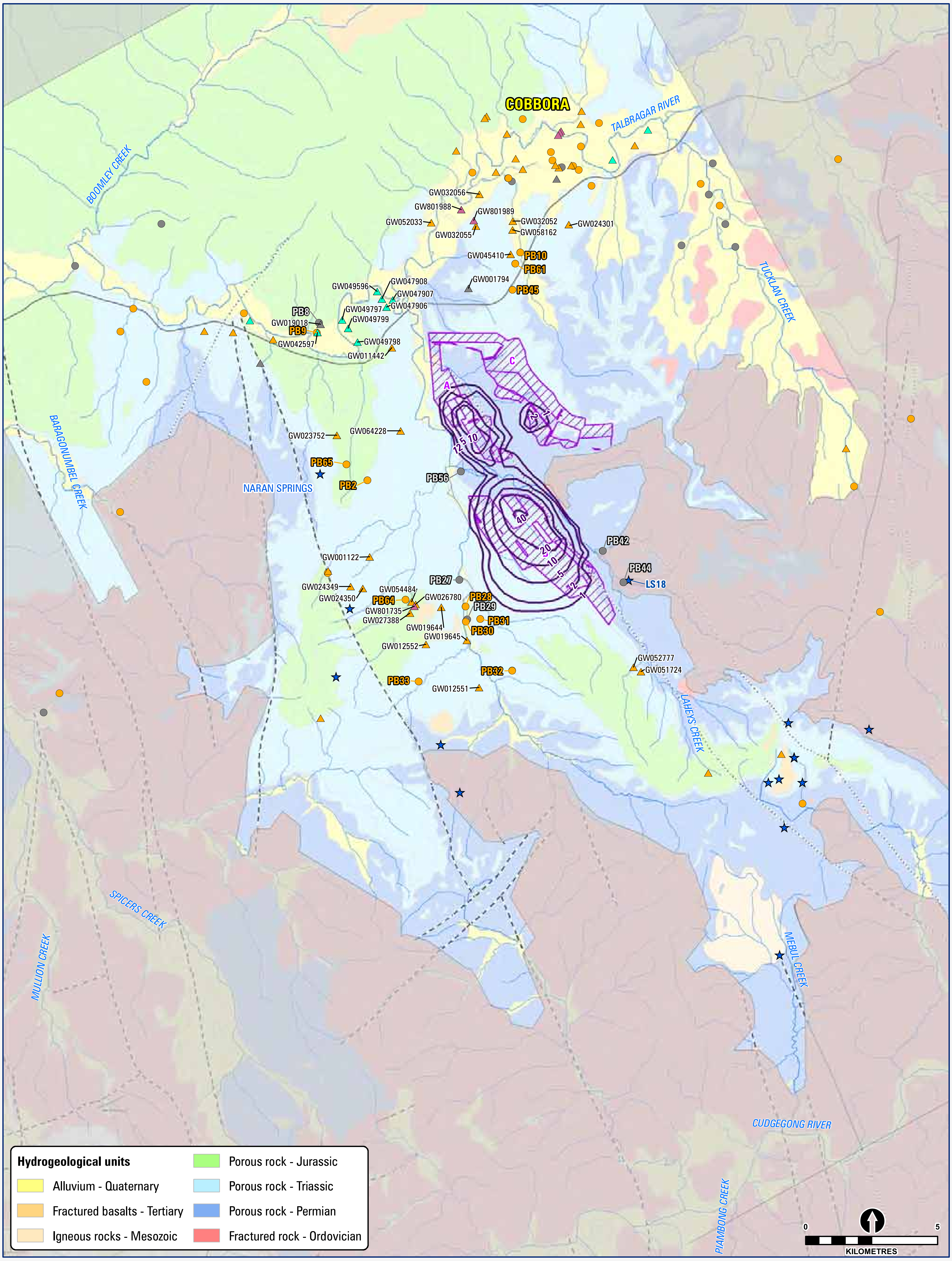
- Springs
- Drainage lines
- Fault - approximate
- Fault - concealed

- Proposed mining areas
- No flow boundary of numerical groundwater model
- Maximum predicted depressurisation (m)

Figure 5.3B Maximum predicted depressurisation in the Ulan Coal Seams

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_F029_A2.mxd SuansriR 03/05/12



Registered Groundwater Bore (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

- Maximum predicted drawdown (m)

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

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

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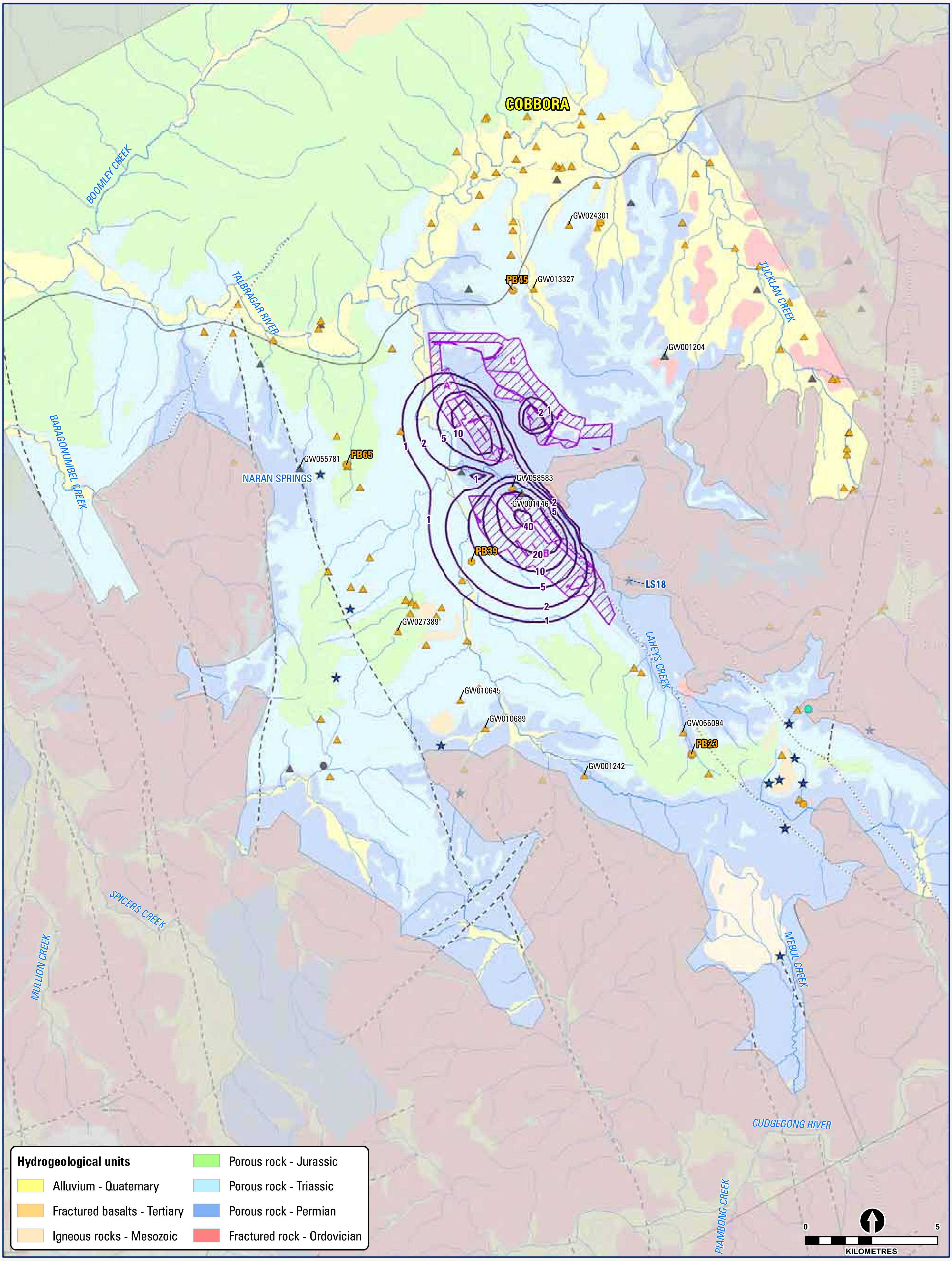


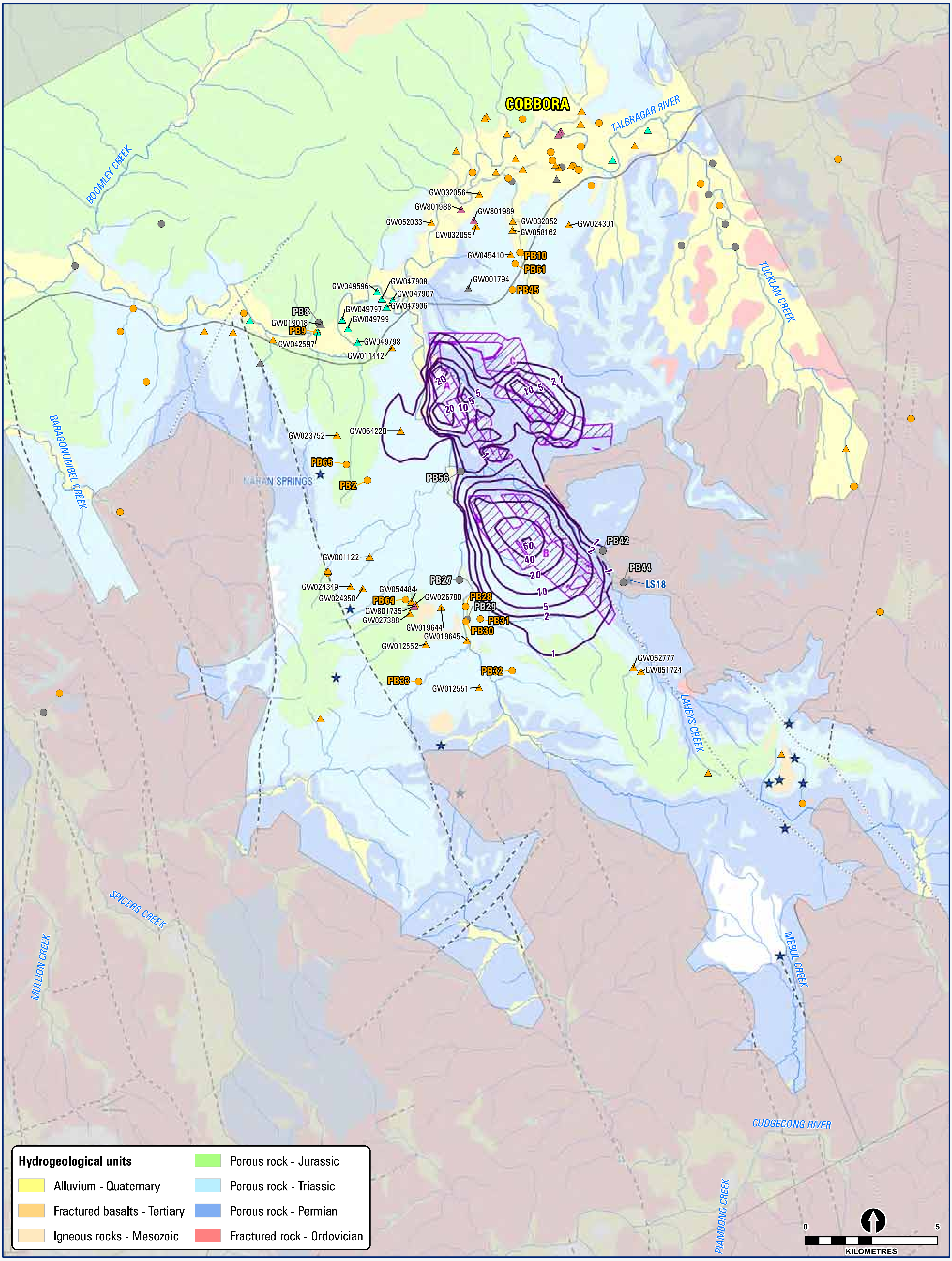
Registered Groundwater Bore (NOW, 2011)
- Stock/domestic
- Not known

Surveyed Groundwater Users
- Stock/domestic
- Irrigation
- Not known

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

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

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



Registered Groundwater Bore (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 drawdown (m)

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

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

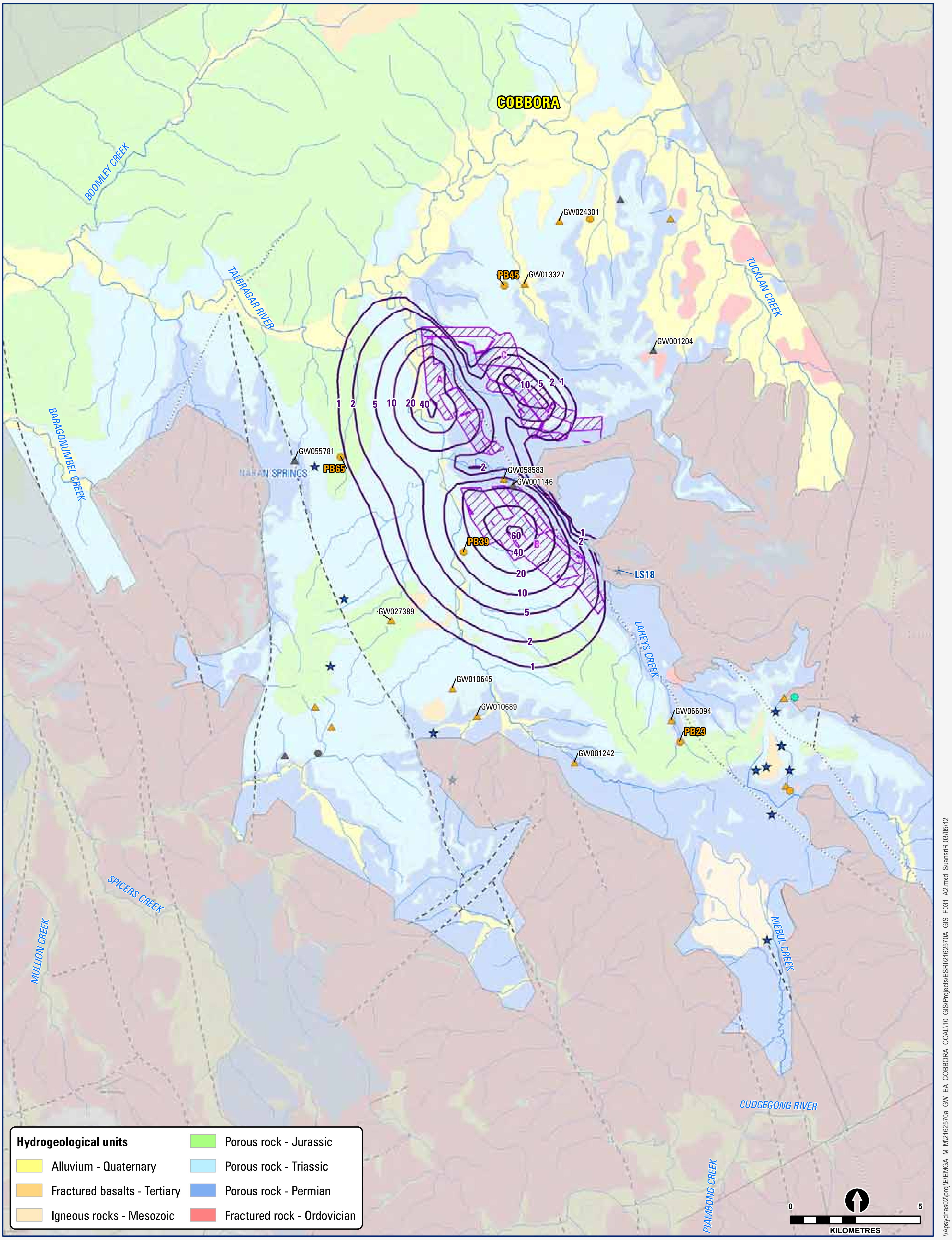
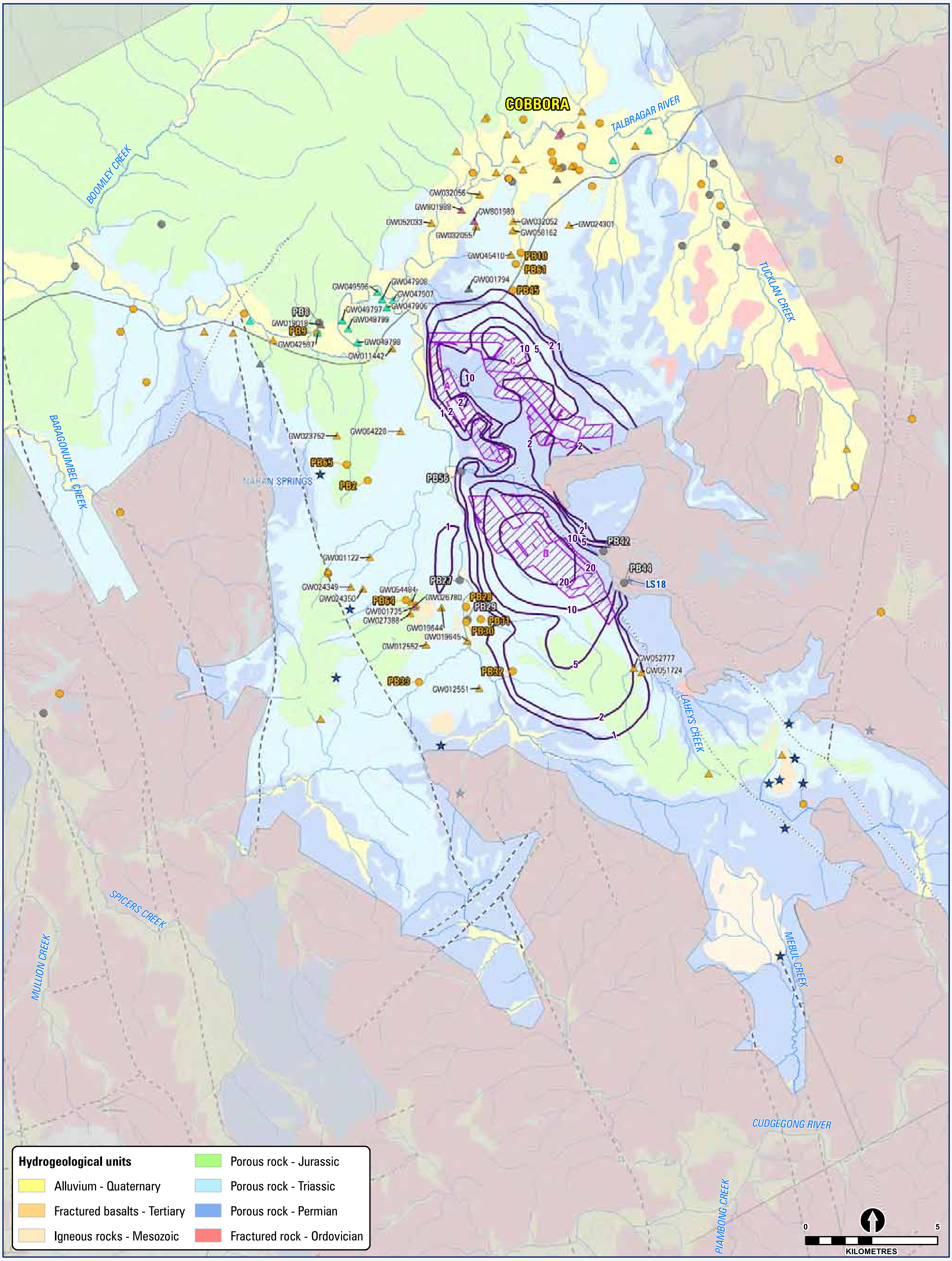


Figure 5.5B Depressurisation in Ulan Coal Seams after 10 years of mining

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



Registered Groundwater Bore (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 drawdown (m)

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

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

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PARSONS BRINCKERHOFF

COBBORA COAL PROJECT
CHC PTY LTD

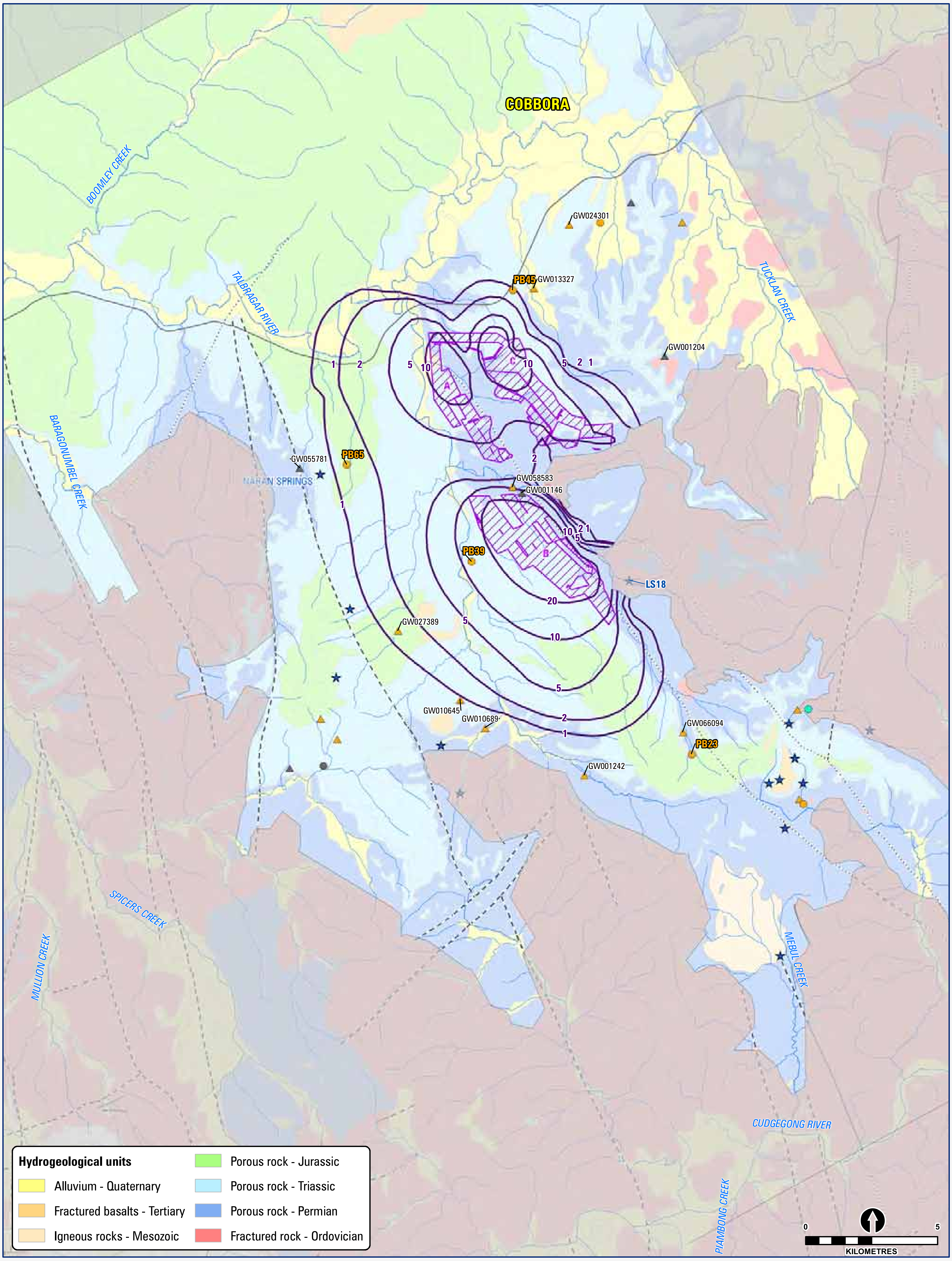
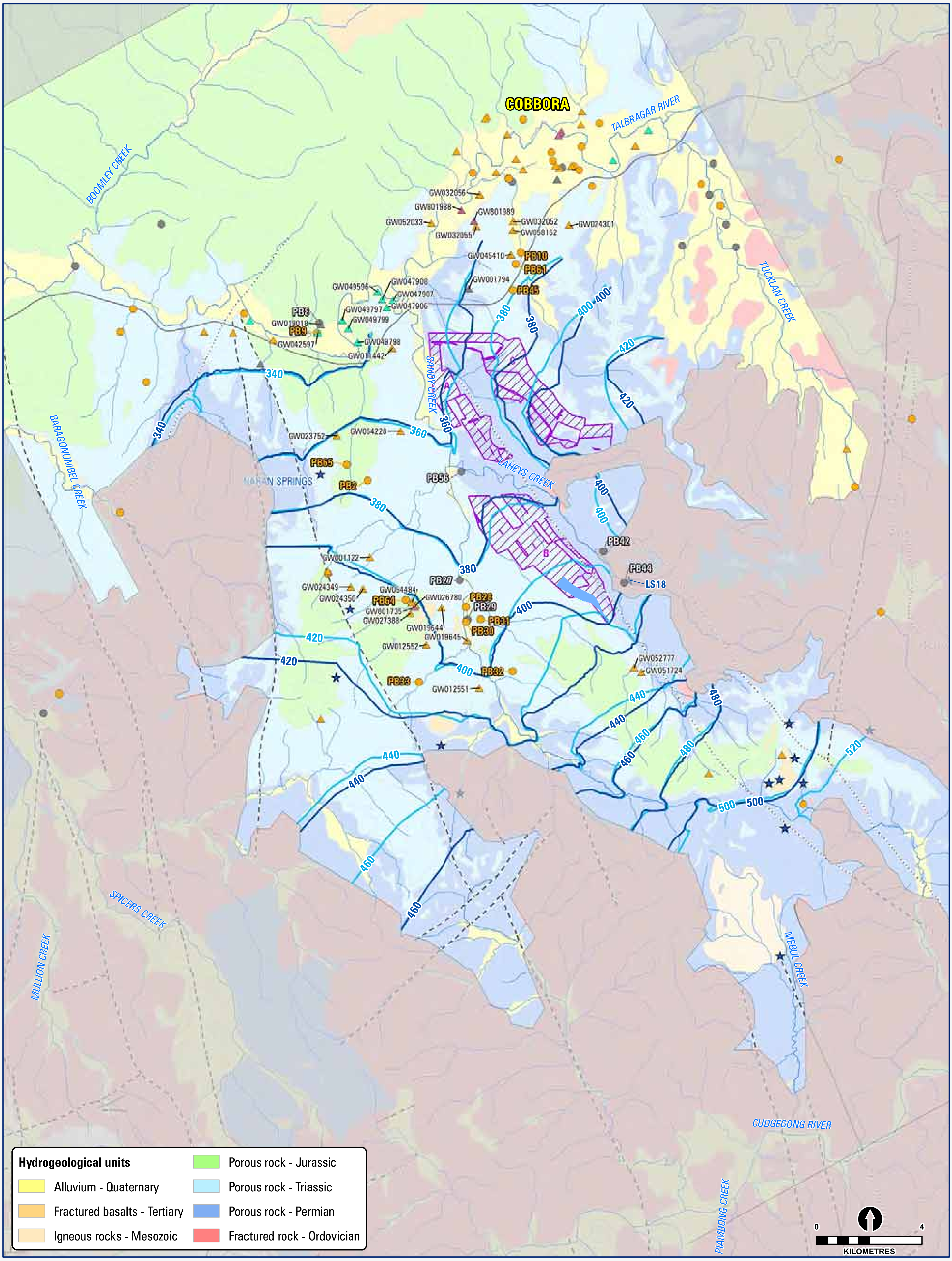


Figure 5.6B Depressurisation in Ulan Coal Seams after 21 years/end of mining

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_F032_A2.mxd SuansnR 03/05/12



Registered Groundwater Bore (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
- Water table (mAHD) pre-mining
- Water table (mAHD) 20 years after end of mining

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

Figure 5.7 Predicted groundwater levels 20 years after end of mining

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5.2.1 Predicted impacts on local groundwater bores

Existing groundwater bores identified as part of a hydrocensus in the assessment area (Parsons Brinckerhoff 2012a) are shown in Figure 5.8, along with the locations of other privately owned registered bores. Figure 5.9 shows model hydrographs for hydrocensus bores with a maximum predicted drawdown of more than 2.5 m resulting from mine dewatering. Table 5-2 provides further details on these bores. This drawdown threshold (2.5 m) is likely to represent the natural range of groundwater levels in the assessment area. Groundwater levels in the piezometers/test production bores used during transient calibration of the model varied by an average of 2.3 m during the 74-week monitoring period, which had slightly more rainfall than the assessment area's long-term average (see Section 3.2.4).

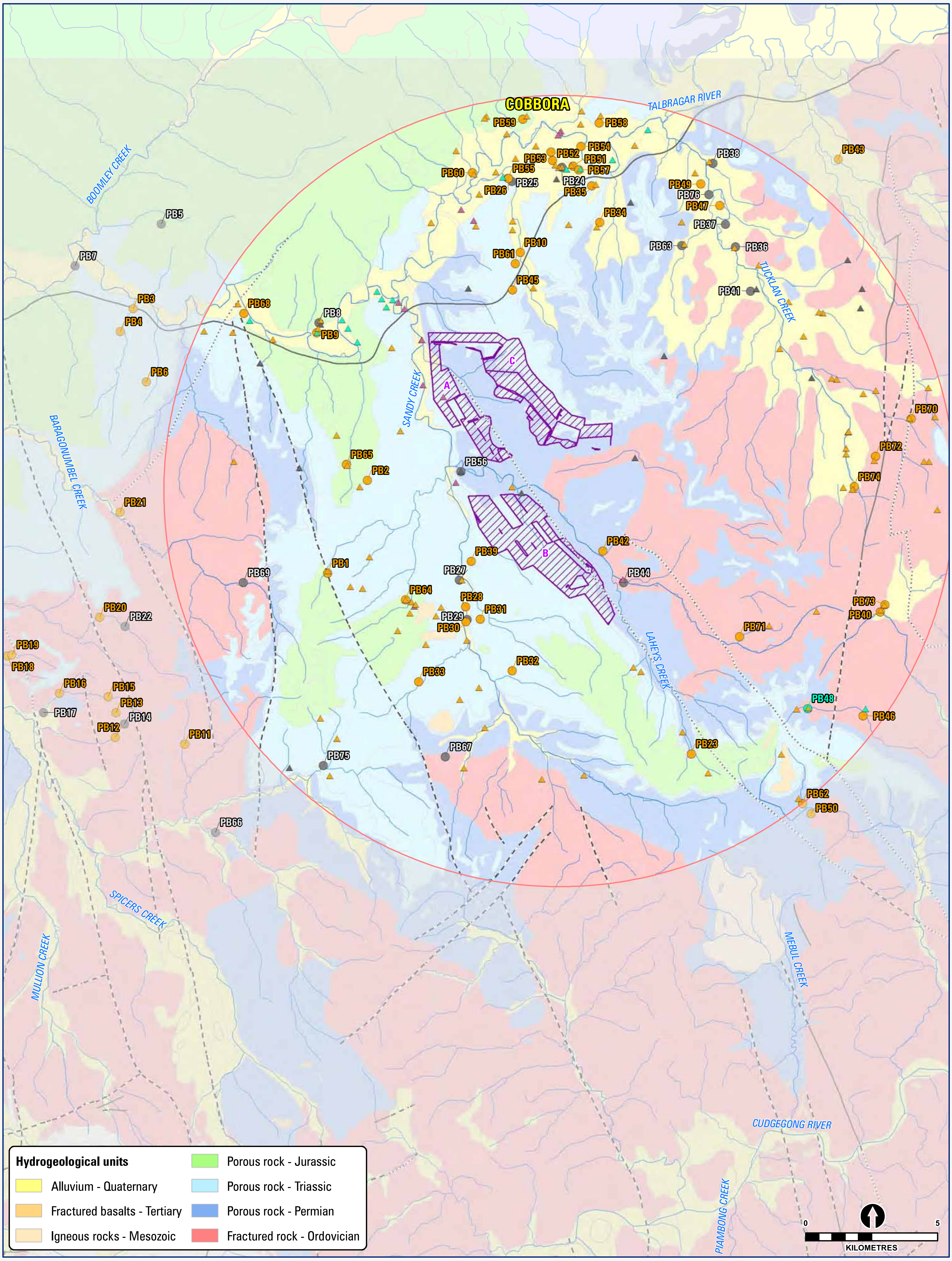
Five of the six bores with predicted drawdowns >2.5 m are owned by CHC. The one bore not owned by CHC, PB32, shows a maximum drawdown of 2.9 m predicted to occur in 2033, with drawdown of close to 2.5 m predicted until at least 2080. This long-term drawdown is due to the presence of the residual mine void near the southern edge of mining area B.

Most private bores show predicted drawdown values of less than 2.5 m throughout the period of mining activities and beyond.

Table 5.2 Privately owned bores where drawdown exceeds 2.5 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	2.9	Triassic (porous rock aquifer)	44.7
PB39*	CHC	709354	6435914	23	Permian (porous rock aquifer)	100
GW001146	CHC	711270	6438510	25.8	Permian (porous rock aquifer)	18.8
GW058583	CHC	710907	6438733	15	Permian	53.3
GW051724	CHC	715790	6431728	4.1	Triassic (porous rock aquifer)	77.5
GW052777	CHC	715506	6431888	4.9	Triassic (porous rock aquifer)	77.5

* 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 5.8 Groundwater bores

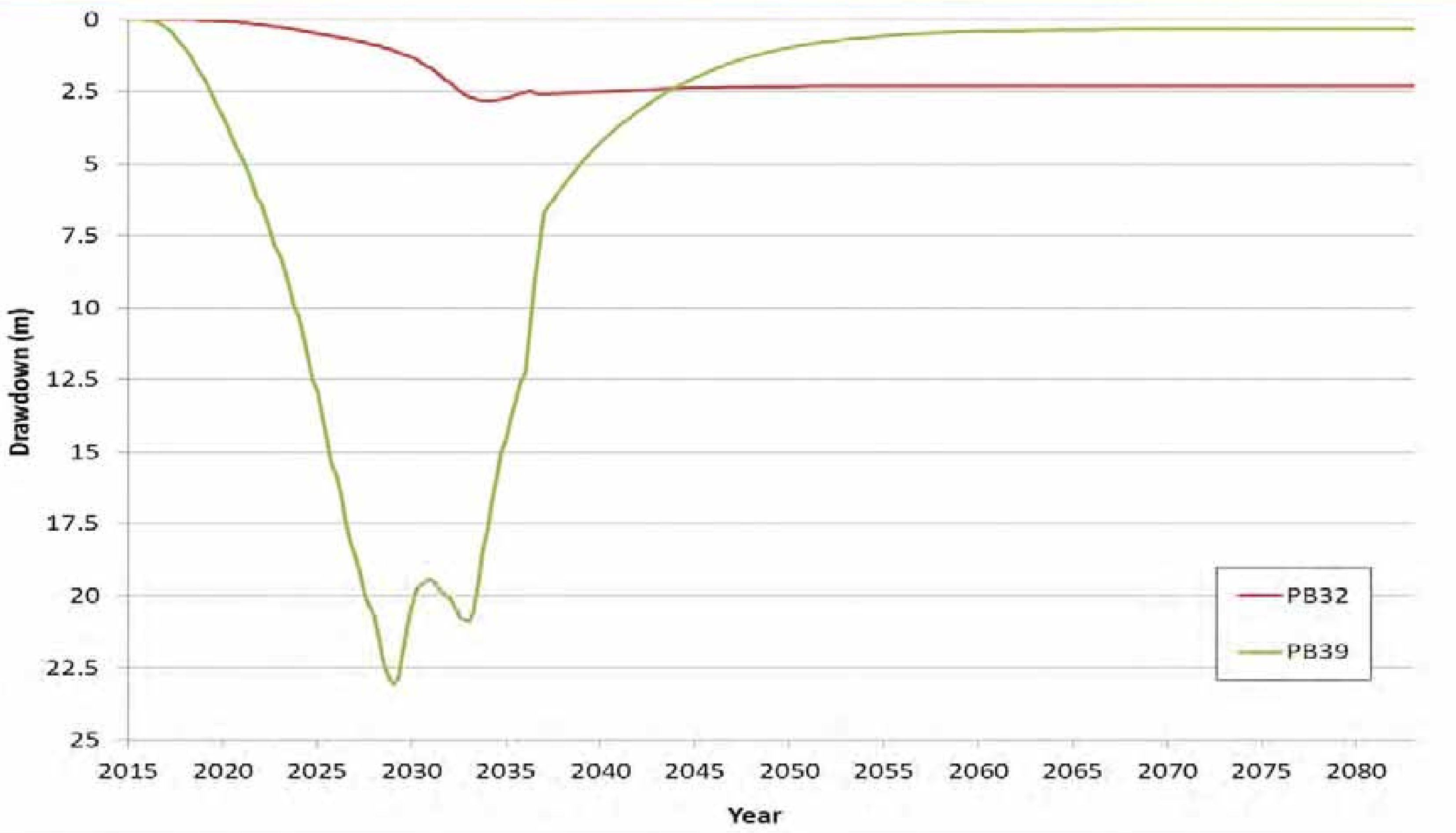


Figure 5.9 Hydrographs of groundwater bores with >2.5 m drawdown

5.3 Sensitivity analysis of mine inflow estimates

Because of the inherent uncertainty in estimating representative aquifer properties from a finite number of data points, Parsons Brinckerhoff conducted a sensitivity analysis on the predictive model to obtain give a high-end estimate of inflow rates. As the largest component of mine inflows in the model comes from the Ulan unit, a sensitivity analysis was based on an increase in the horizontal hydraulic conductivity from 0.3 m/d to 0.8 m/d and vertical hydraulic conductivity from 0.003 m/d to 0.008 m/d. Under this scenario, the predicted mine inflow rates may be higher by approximately 47% over the period of peak groundwater inflow between 2021 and 2031.

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 1,775 ML/a after 16 years of mining, with inflow rates of approximately 1,000 ML/a or more between 6 years and 16 years after mining commences. Approximately half of all inflows are expected to occur in mining area B.
- The Ulan and Dapper units (Gunnedah-Oxley Basin aquifer) are expected to provide the greatest volume of water to the mine pit, with predicted cumulative storage losses of up to 2,000 ML in each by the end of mining in 2035.
- Predicted cumulative storage losses within the alluvium reach a maximum value of nearly 300 ML. This constitutes 0.1% 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 280 ML/a, which occurs towards the end of mining operations. This constitutes 0.5% of the average annual flow in the Talbragar River.
- Of the private bores assessed in the assessment area (Parsons Brinckerhoff 2012a) only six private bores are expected to experience drawdown of more than 2.5 m during the life of the mine, five of which are on CHC owned land. 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.

Sensitivity analysis was conducted on the model to assess the effects of uncertainties in aquifer properties on model predictions. As the Ulan Coal Seams are expected to be the biggest contributor of inflows to the pit, a sensitivity analysis was run based on the horizontal hydraulic conductivity of this unit being increased from 0.3 m/d to 0.8 m/d (vertical hydraulic conductivity increased from 0.003 m/d to 0.008 m/d). Under this scenario, the predicted mine inflow rates may increase by approximately 47% over the period of peak groundwater inflow between 2021 and 2031.

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%