South32 - Illawarra Coal

DENDROBIUM MINE

End of Panel Groundwater Assessment for Longwall 12 (Area 3B)

HGEO Pty Ltd
Date: April 2017
Project number: J21428
Report: D17261

DOCUMENT REGISTER

Revision	Description	Date	Comments
03	1st Draft	27/4/2017	
05	2nd Draft	08/5/2017	
06	Final	18/05/2017	

FILE

C:\OneDrive\HGEO\Projects\Dendrobium\04_Projects\03_EOP_Reports\EOP_LW12_Groundwater\D17261_S32_EOP_LW12_Groundwater_V06.docx

QUALITY CONTROL

Process	Staff	Signature	Date
Authors	Stuart Brown, Will Minchin		
Approved	Stuart Brown		18/5/2017

COPYRIGHT

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

This report provides an assessment of the hydrogeological effects of Longwall 12 extraction in Area 3B at Dendrobium Mine, as required under the conditions of mining approval. Extraction of Longwall 12 commenced on 22 January 2016 (following the completion of the adjacent Longwall 11) and was completed on 31 January 2017. Longwall 12 is the fourth panel to be extracted in Area 3B, with an extracted length of 2591 m, a void width of 305 m (including first workings) and an average extraction height of 3.8 m

Mine inflow

The average daily groundwater inflow to Area 3B during Longwall 12 extraction was 4.5 ML/d which represents approximately 60% of total mine inflow for the period. Inflows to Area 3B have increased over time in proportion to the total mined area since 2013 with no apparent correlation with rainfall events. There is evidence that this relationship changed during the mining of Longwall 12 with the development of an apparent correlation between Area 3B and 3A inflows (and presumably rainfall).

Groundwater quality

Groundwater salinity (as indicated by Electrical Conductivity – EC) shows a general increase in salinity with depth below the surface. However, there is no significant spatial variation in groundwater salinity in either Bulgo Sandstone or Hawkesbury Sandstone bores. There is no evidence for impacts to groundwater quality as a result of mining.

Groundwater levels

Mining of longwall 12 resulted in continued depressurisation of the target coal seam and overlying strata. The observed changes in groundwater levels are in line with numerical model predictions that support mining approvals.

As expected, the greatest depressurisation is within the Wongawilli Coal Seam, and decreases with height above the seam. Incremental drawdown in the Scarborough and Bulgo Sandstones is apparent in the areas immediately to the south-west of Longwall 12 and extending to S2194, located 1.8 km to the south of Longwall 12. Drawdown in the Hawkesbury Sandstone is spatially variable but largest above and immediately adjacent to Longwall 12, with some drawdown also evident at S2001, located 790 m to the south. For other groundwater monitoring sites (not over the goaf) the observed drawdown is negligible.

The numerical model developed by Hydrosimulations in 2014 and updated in 2016 was assessed to be accurate with respect to estimated deep groundwater levels at the end of Longwall 12. The model has a tendency to overestimate drawdown impacts in the Bulgo and Scarborough Sandstones and is therefore conservative.

Estimates based on the numerical model are that the net induced loss from Lake Avon at the end of Longwall 12 is less than 0.4 ML/d and within the tolerable loss limit of 1 ML/day prescribed by the Dams Safety Committee (DSC).

1. INTRODUCTION

HGEO Pty Ltd (HGEO) was engaged by Illawarra Coal (IC) to prepare an assessment of hydrogeological effects of Longwall 12 extraction in Area 3B at Dendrobium Mine, as required under the conditions of mining approval. Extraction of Longwall 12 commenced on 22 January 2016 (following the completion of the adjacent Longwall 11) and was completed on 31 January 2017. Longwall 12 is the fourth panel to be extracted in Area 3B, with an extracted length of 2591 m, a void width of 305 m (including first workings) and an average extraction height of 3.8 m.

Dendrobium Mine is located about 12 km west of Wollongong (NSW) in the Southern Coalfield and within the Metropolitan Special Catchment Area managed by WaterNSW. The three designated areas of extraction are Area 1 (east of Lake Cordeaux), Area 2 (west of Lake Cordeaux), and Areas 3A and 3B (between Lake Cordeaux and Lake Avon) (Figure 1). Coal is extracted from the Wongawilli Seam by longwall mining. Old workings in the Wongawilli Seam are located to the south at Elouera and Nebo, and to the east at Kemira. The overlying Bulli Seam was mined previously at Mt Kembla to the east of Area 1.

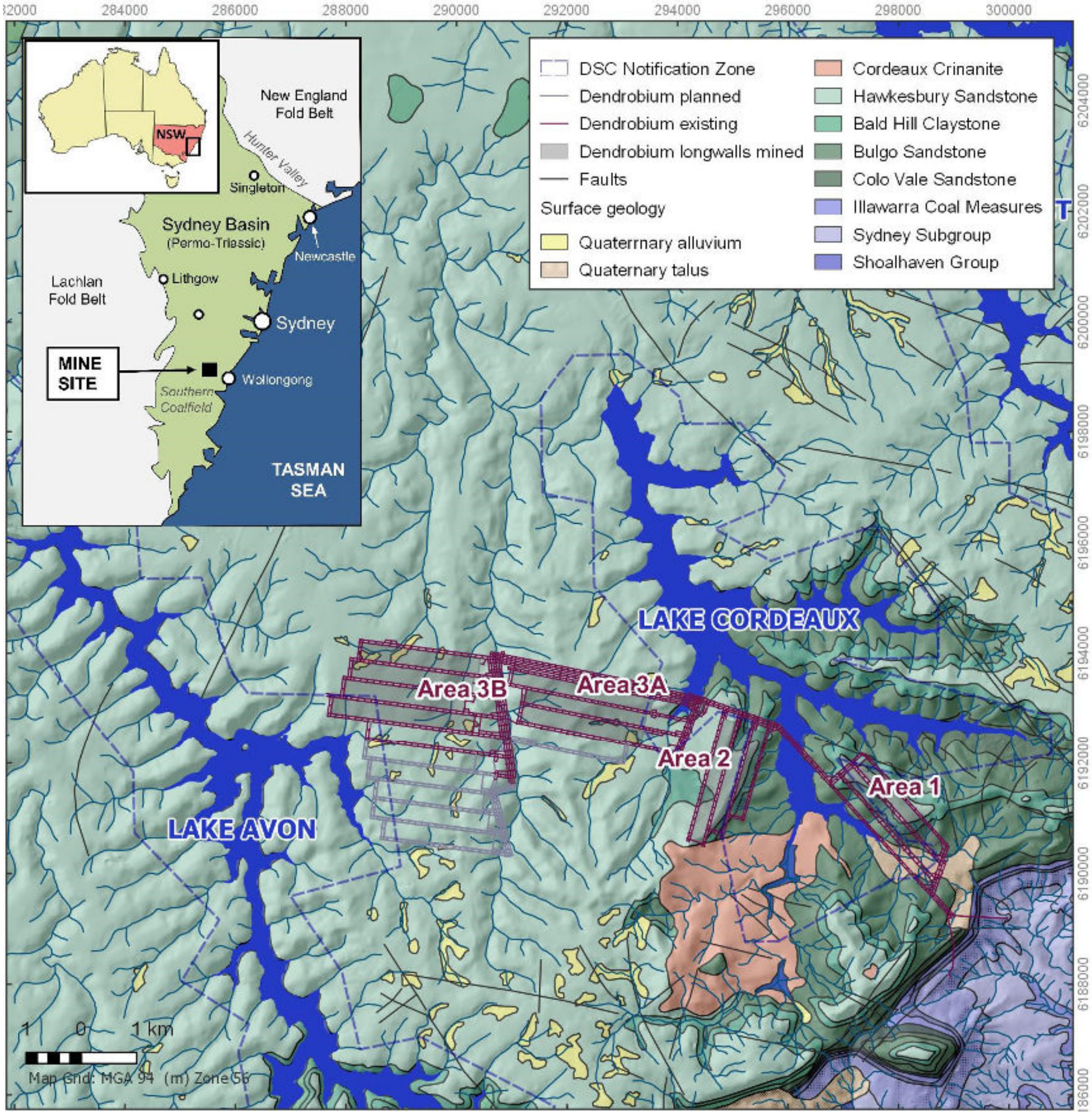

Figure 1. Location of Dendrobium Mine and surface geology

1.1 Hydrogeology

Dendrobium Mine is located within the Southern Coalfield which is one of the five major coalfields that lie within the Sydney Geological Basin. The stratigraphy of the Southern Sydney Basin is shown in Figure 2. The Basin is primarily a Permo-Triassic sedimentary rock sequence, underlain by undifferentiated sediments of Carboniferous and Devonian age. The Bulli and Wongawilli Coal Seams are the primary target seams in the top part of the Illawarra Coal Measures. The Coal Measures are overlain by Triassic sandstones, siltstones and claystones of the Narrabeen Group and the Hawkesbury Sandstone. The Hawkesbury Sandstone is the dominant outcropping formation across the mine area, but lower stratigraphic units (Bald Hill Claystone, Narrabeen Group) are exposed in deeply incised parts of Wongawilli Creek and along the south-eastern shores of Lake Cordeaux.

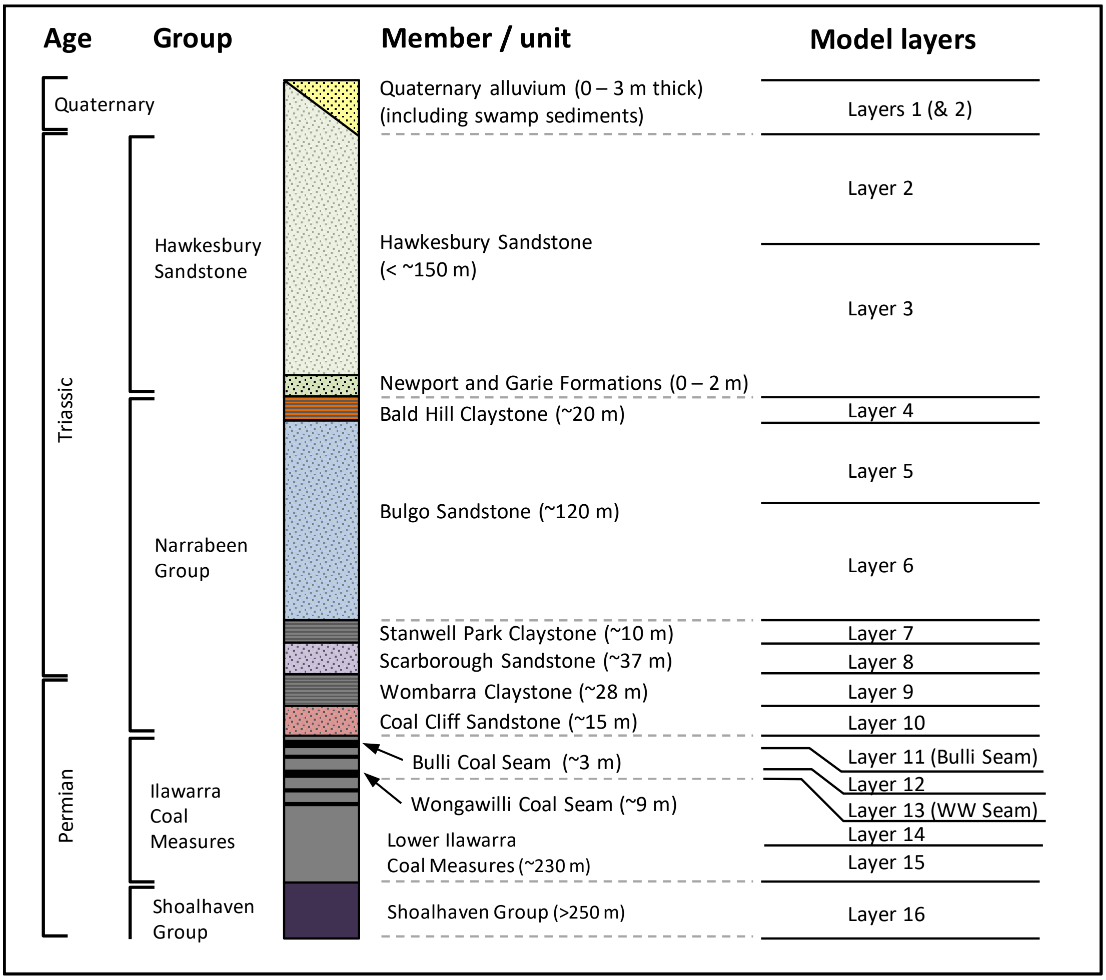

Figure 2. Stratigraphy of the Southern Coalfield and numerical model layers (of Hydrosimulations, 2016)

The hydrogeology of the area is described in previous groundwater assessments associated with Dendrobium Mine (e.g. Coffey, 2012; HydroSimulations, 2016; Parsons Brinckerhoff, 2014), and summarised below.

Three main groundwater systems are recognised:

1. Perched groundwater systems associated with swamps and shallow sandstone. These may be ephemeral and/or disconnected from the deeper groundwater systems;
2. Shallow groundwater systems: layered water-bearing zones within the saturated Hawkesbury Sandstone; and

3. Deeper groundwater systems within the Narrabeen Group and the Illawarra Coal Measures.

Recharge to the aquifer systems comes primarily from rainfall infiltration through outcropping formations, generally the Hawkesbury Sandstone in the western half of the Dendrobium mine area and the Bulgo Sandstone in the eastern half. There will be some recharge from the Reservoirs and streams to host formations at times of high water level and creek flooding.

Strong topographic relief and recharge drive vertical groundwater flow near the ground surface, but at depth the alternation of aquifers and aquitards promotes horizontal groundwater flow at the base of permeable units. In general, groundwater flow in shallow systems is strongly influenced by local topographical features such as streams and lakes, whereas deeper groundwater systems are influenced by regional topographic and drainage patterns (Toth 2009). Regional groundwater flow in the deeper sandstone units (pre-development) is predominantly northwest, towards the Nepean River system and away from the Illawarra escarpment.

Discharge from the (shallow) groundwater systems occurs naturally at the surface to creeks and to the reservoir as baseflow and seeps, and by evapotranspiration through vegetation. Along the escarpment to the south-east of Dendrobium Mine, groundwater discharge appears as seeps in cliff faces at the junction of formations with contrasting permeability.

1.2 Effects of mining

Extraction of coal using longwall methods commonly results in ground subsidence, deformation and fracturing of overlying strata and depressurisation of adjacent geological units (Peng and Chiang 1984). The distribution of fracturing and its effects on aquifer characteristics has been well documented from numerous case studies (Booth 1986; Forster and Enever 1992; Guo et al. 2007; Mills 2011; Tammetta 2013, 2014, 2016).

While authors differ slightly in their terminology, there is general agreement on the overall sequence and pattern of fracturing that develops above a longwall. Immediately above a mined coal seam, the roof collapses into the void to form a caved zone that extends tens of metres above the seam. As the mining proceeds, a network of connected fractures extends above the caved zone to a height above the seam that is largely dictated by the width and mining height of the panel relative to the depth of cover (Mills 2011). The development of fractures above (and below) the mined seam changes in aquifer properties; specifically, the permeability of the rock mass increases and groundwater pathways are potentially created between shallow and deeper groundwater systems. At Dendrobium Mine, the potential for induced connections between the mine and surface water catchments is of particular concern and is closely monitored. Subsidence and associated phenomena such as valley closure commonly result in increased surface cracking due to the unconfined nature of the surface rock. This type of surface cracking is typically limited to the top 10 to 20 m and may not be connected to the deeper fracture zones. Nevertheless, surface fracturing can affect shallow and perched groundwater systems, swamps and stream flow characteristics.

Calculations based on published geotechnical models indicate that the zone of connected fracturing above longwall panels in Area 3B is likely to extend to the top of the Bulgo Sandstone, and potentially to the base of the Hawkesbury Sandstone (HydroSimulations 2016a). This is supported by detailed investigations carried out above Longwall 9 before and after mining of that longwall (Parsons Brinckerhoff, 2014).

1.3 Numerical groundwater impact model

Regional numerical modelling by Coffey (Coffey, 2012) supported the *Area 3B Subsidence Management Plan* (SMP) application and subsequent approval. The model was revised and updated in 2014 (HydroSimulations, 2014) to include calibration to shallow (swamp) groundwater data and surface water (creek) flows, and again in 2016 (HydroSimulations 2016a). The latest revision addressed the Area 3B SMP approval conditions and provides the basis for this groundwater impact assessment.

The vertical extent of layers used to simulate the regional groundwater systems in the latest numerical model are shown in Figure 2. A cross section showing the modelled stratigraphy is presented in Figure 3.

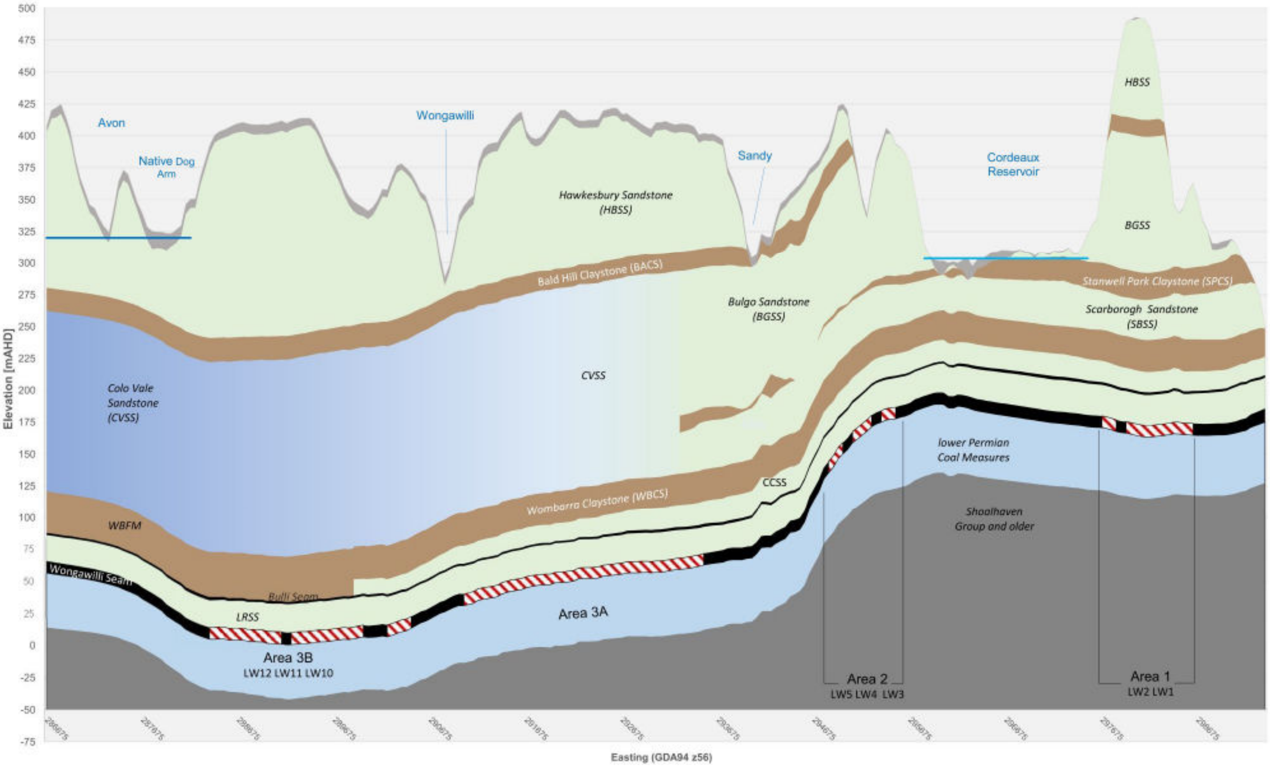

Figure 3. Cross-section (east-west) of the 2014 numerical model through Dendrobium Mine

2. MONITORING DATA

This section presents the monitoring data available for the groundwater assessment, and supports the discussion of the observed hydrological behaviour presented in Section 3.

2.1 Management Plan

Groundwater monitoring at Dendrobium Mine is conducted in accordance with the "Dendrobium Colliery Area 3B SMP Groundwater Management Plan" (South32, 2012) and the Area 3B Subsidence Management Plan (South32, 2015).

The aims of the Groundwater Management Plan are to:

- Monitor groundwater levels and quality, commencing at least one year prior to mining affecting the system;
- Project potential groundwater changes during mining (short term) and post-mining (long term) with particular attention to the effect of changes to groundwater regime, impact on the catchment yield and interaction with the stored waters;
- Identify hydraulic characteristics of overlying and intercepted groundwater systems, and determine changes to groundwater systems due to coal extraction and dewatering operations;
- Report any pumping tests and groundwater/surface water simulation studies; and
- Collect water level data from all agreed groundwater-monitoring locations.

The groundwater-monitoring locations for Areas 3B are shown in Figure 4. Designated monitoring bores are fitted with single or multi-level vibrating wire piezometers (VWPs) that record groundwater pressures each hour (typically). The recorded data are subsequently converted to fluid pressure head (m) and potentiometric head (mAHD). A list of all piezometers installed in Areas 2 and 3 are listed in Appendix C.

2.2 Deep groundwater levels

Deep groundwater responses to mining are assessed primarily through the use of time-series hydrographs for multi-level piezometer sites (VWPs). Most VWPs at Dendrobium suffer from electromagnetic noise which causes spurious spikes in the data records. Noisy data are filtered and removed where practical. Hydrographs and analysis are presented in Section 3.1.

Hydrographs are plotted in terms of ***potentiometric head*** (mAHD). Potentiometric head can be thought of as the theoretical level to which water would rise in a bore that is open to an aquifer at a given elevation, and is calculated by adding the measured pore pressure (at the VWP, expressed in m of water) to the elevation of the sensor (in m AHD). The potentiometric head in a confined aquifer system can be (and often is) different to the water table elevation at the same location.

Hydrographs presented in this assessment include surface water hydrographs for the nearest water supply reservoir (Lake Cordeaux for Area 3A and Lake Avon for Area 3B hydrographs). Note also that individual hydrograph traces are presented as dotted lines at times when the ***pressure head*** is below a threshold of 5 m. The pressure head is the absolute pore pressure at the sensor expressed in m of water. When the pressure head is below that threshold it is an indication that the rock matrix is approaching complete desaturation at the location of the sensor. This condition is not always apparent from plots of total piezometric head alone.

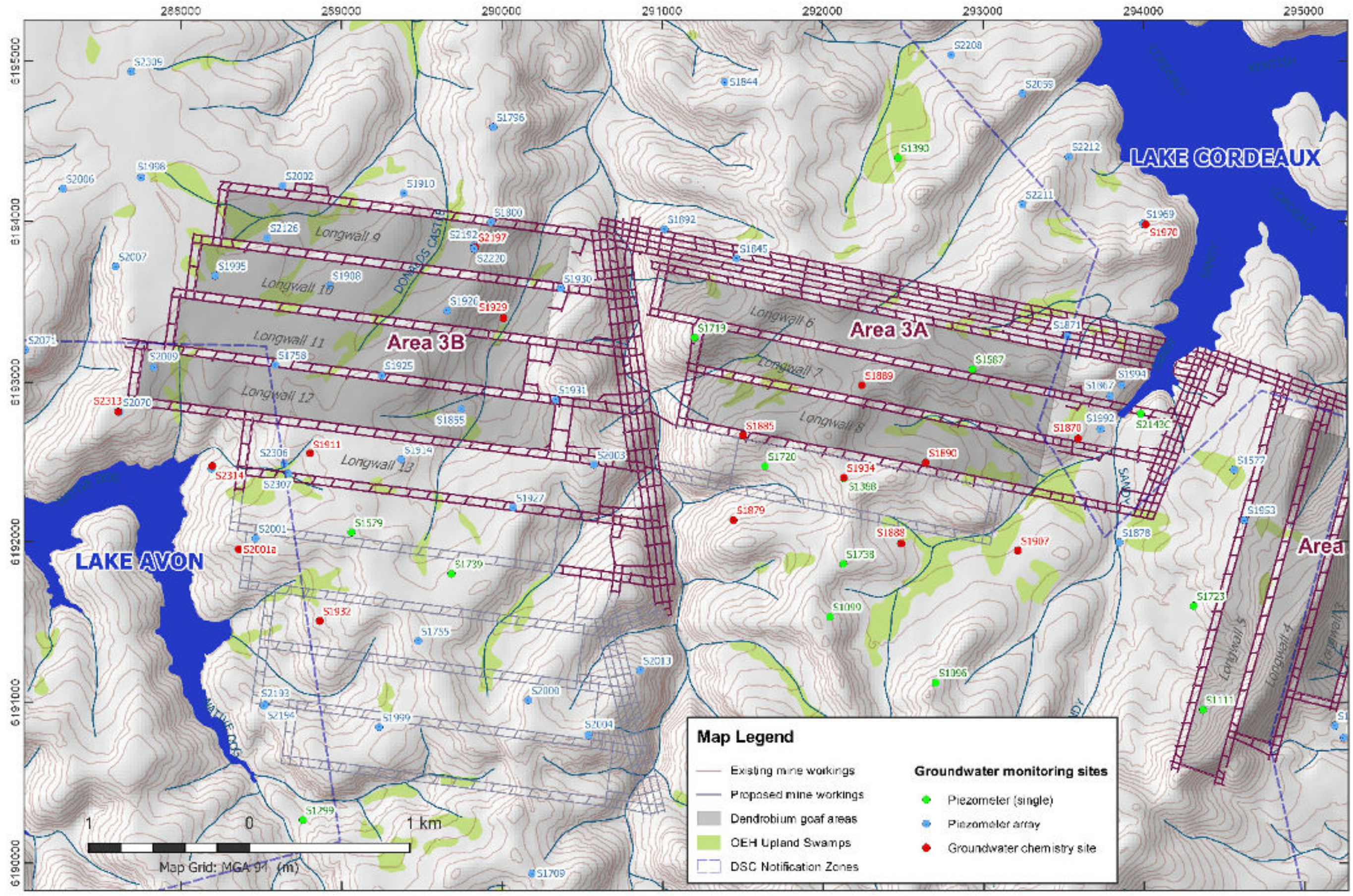

Figure 4. Deep groundwater monitoring network around Areas 2, 3A and 3B

Assessment of the spatial distribution of piezometric head and pressure drawdown over the reporting period is carried out using annotated and coloured symbols on a map. ***Drawdown*** (in metres) is simply the difference in potentiometric head between the previous reporting period (longwall) and the current reporting period. In contrast to previous assessments, contours of head and drawdown are not presented. This is because interpolated values in sparsely monitored areas are subject to a large amount of uncertainty. As with previous assessments where data records are incomplete or truncated (i.e. due to mining or lightning damage), values of potentiometric head at those locations are interpolated or extrapolated (as appropriate) from previous data or data from adjacent sites (as indicated on the maps). Extrapolation is only carried out up to 2 years after a site becomes inactive, after which no data are reported for that location. Spatial plots are presented and discussed in Section 3.3.

2.3 Mine water balance

All movements of water via pumping stations is monitored and controlled in real-time through the System Control and Data Acquisition (SCADA) system, and used to calculate a daily mine Water Balance. The Water Balance is an accurate measure of all water that enters, circulates and leaves the mine, including via air moisture and coal moisture content. Mine water seepage (groundwater inflow), which cannot be directly measured, is determined by mass balance for each goaf and is therefore known to a reasonable accuracy. Key metrics of the Mine Water Balance are reported against Trigger Action Response Plan (TARP) levels to the DSC fortnightly.

In this assessment, the estimated groundwater inflow component of the mass balance is presented as time-series hydrographs and compared with rainfall trends and model predictions. Analysis of water balance trends for the reporting period is presented in Section 3.

2.4 Groundwater chemistry

Groundwater chemistry sampling sites relevant to this assessment are shown in Figure 4, and listed in Table 1. Currently there are seven sampling bores in Area 3B containing 13 individual sampling pumps screened within the Hawkesbury and Balgo Sandstone. Most sampling sites are located between the mined and planned longwalls of Area 3B and the eastern shores of Lake Avon. Two sites (S2197, S1929) monitor water quality adjacent to the WC21 tributary to Wongawilli Creek. A total of eight sampling bores with 15 individual pumps are located in Area 3A. The Scarborough Sandstone is monitored at two locations: S1904 (Area 2) and S1970 (Area 3C).

Table 1. Groundwater chemistry monitoring bores

Bore ID	Alt. ID	Mine Area	Number of sampling pumps			Last Sampled
			Hawkesbury Sandstone	Bulgo Sandstone	Scarborough Sandstone	
S1886	DEN94	2			3	Jun-2016
S1870	DEN85	3A	2	1		Jul-2016
S1879	DEN92	3A	2	1		Nov-2016
S1885	DEN93	3A	2	1		Jun-2012
S1888	DEN96	3A	2	1		Jan-2014
S1889	DEN97	3A	2	1		Jul-2011
S1890	DEN98	3A	1	1		Jun-2012
S1907	DEN103	3A	2	1		Jun-2015
S1934	DEN115	3A	2			Apr-2014
S1911	DEN106	3B	2	1		Aug-2013
S1929	DEN111	3B	2	1		Nov-2015
S1932	DEN114	3B	3			Dec-2015
S2001a	DEN125A	3B	2	1		Nov-2015
S2197		3B	1	1		Apr-2013
S2313	Avon 1	3B	2	1		Sep-2016
S2314	Avon 2	3B	2	1		Feb-2017
S1970	DEN118A	3C	1	1	1	Jun-2015

In addition to samples collected from bores, groundwater samples are routinely collected from underground workings, inter-seam boreholes and flooded adjacent mine workings, as described in the *Underground Water Sampling and Analysis Procedure* (DENP0048). Water is analysed for chemistry (major and minor ions), algae and isotopes of carbon, hydrogen and nitrogen. Weekly water samples are taken from the current longwall panel (roof and face) and from water pumped from the goaf. Monthly water samples are taken from the main discharge points of the mine and from completed longwall panels. The results of the sampling are reviewed each month and reported to the DSC. More than 2400 water samples have been collected and analysed since 2003, providing an excellent baseline for ongoing assessment and a basis for chemically “finger printing” waters from various sources.

In this assessment, average field electrical conductivity (EC), is used as a general indicator of water quality (salinity). Water salinity varies according to its source (see Figure 5) and, in general, groundwater salinity tends to increase with the depth below the surface; groundwater in the Hawkesbury Sandstone (HBSS) tends to be relatively fresh (median EC = 120 µS/cm) whereas mine seepage water is distinctly more brackish (median EC of seepage in Areas 3A and 3B ~ 2200 µS/cm). Beneficial water use categories based on the ANZECC water quality guidelines (ANZECC, 2000) are shown for reference only. Groundwater quality is assessed further in Section 3.4.

Samples collected from bores can sometimes be influenced by residual grout or bentonite leachate from the construction of the piezometer. Typically, this is indicated by elevated or anomalous EC, pH, sulfate, or Ca/Na ratios. Samples that show chemical evidence of influence by grout or bentonite are excluded from assessment.

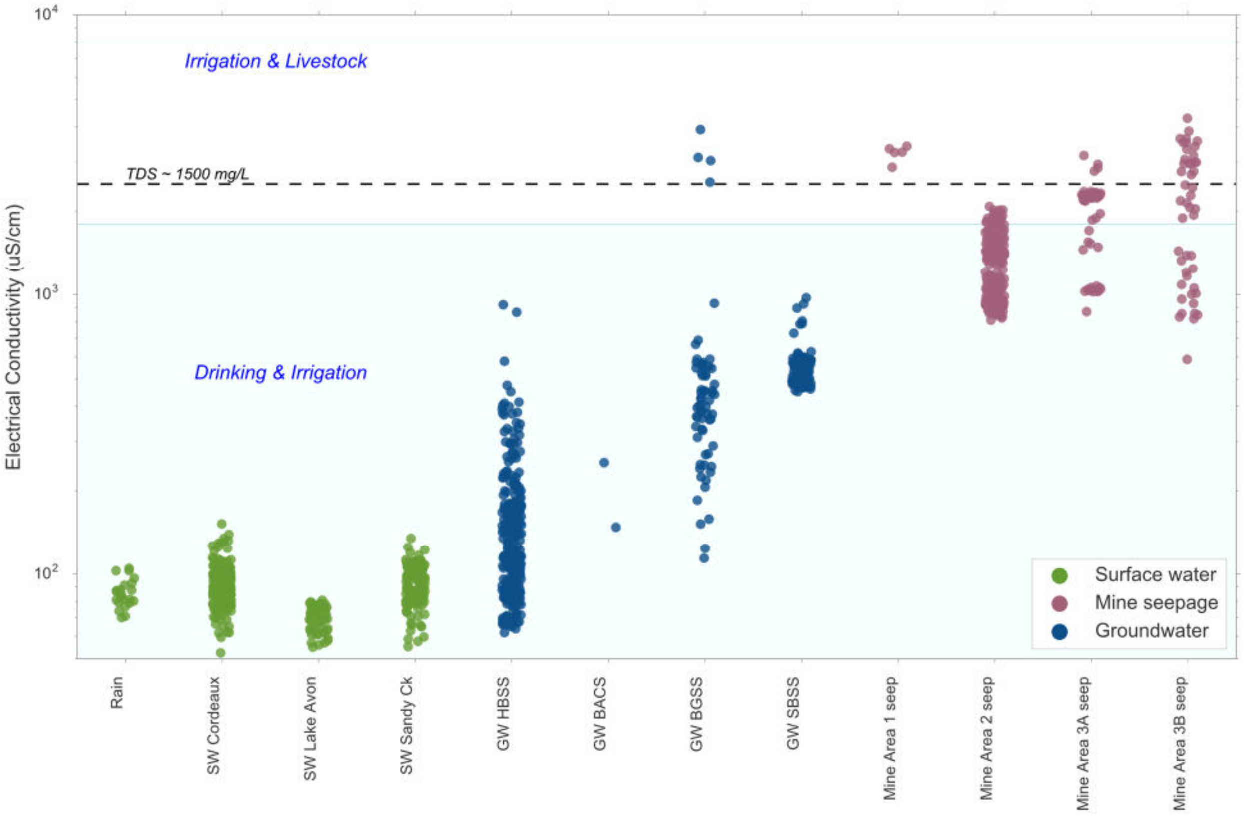

Figure 5. Strip plot showing the range in EC of surface water, groundwater and mine inflow

3. ASSESSMENT OF GROUNDWATER RESPONSE TO MINING

3.1 Mine water balance

Table 2 presents mine inflow statistics (as indicated by pump-out data) for each Area for the period over which Longwall 12 was extracted (22 January 2016 to 31 January 2017). The average daily inflow to Area 3B during Longwall 12 extraction was 4.5 ML/d which represents approximately 60% of total mine inflow for the period.

Table 2. Dendrobium Mine Inflow during the Extraction of Longwall 12 (in ML/day)

STATISTIC	AREA 1	AREA 2	AREA 3A	AREA 3B	TOTAL
MEAN	0.56	0.79	1.55	4.48	7.39
STANDARD DEVIATION	0.43	0.45	0.64	0.73	1.28
MINIMUM	0.01	0.03	0	2.53	4.34
MAXIMUM	1.90	4.20	4.73	8.13	10.59

Time-series plot of total groundwater inflow to Dendrobium Mine as determined from the mine water balance is shown in Figure 6 as daily volumes in kilolitres (kL/d) and as a 30-day moving median. The mine water balance for Areas 3A and 3B are shown in Figure 7.

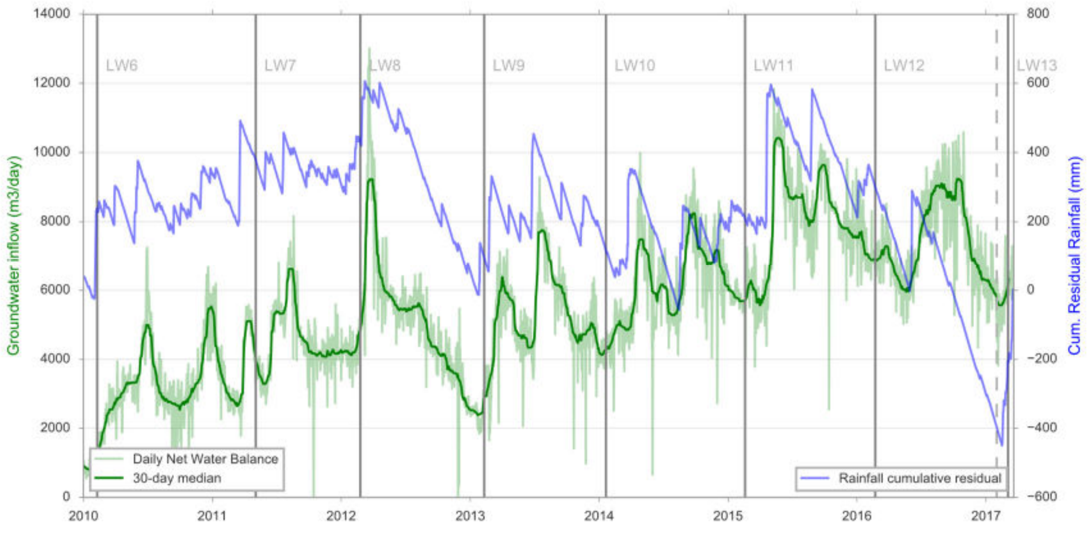

Figure 6. Groundwater inflow from water balance for all mine areas (kL/day)

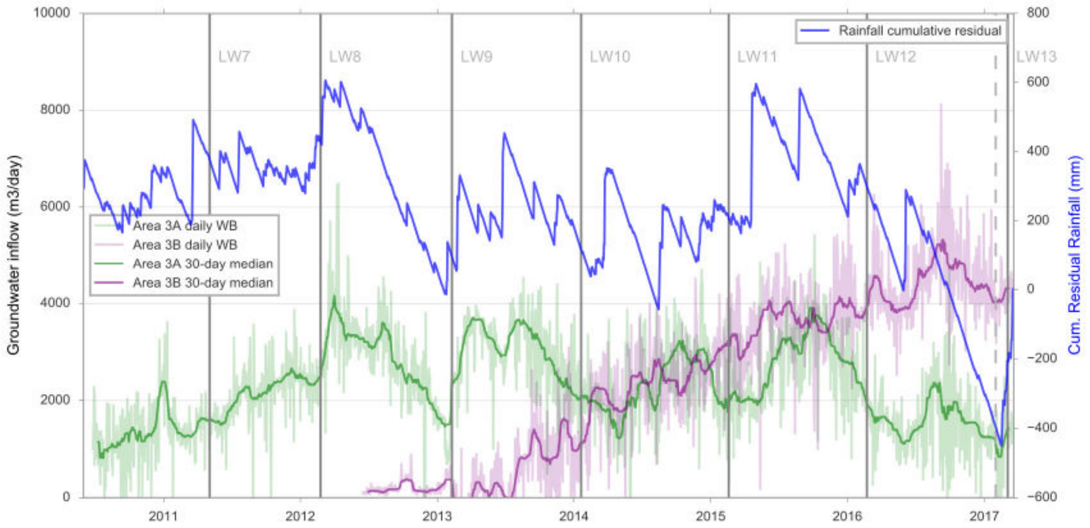

Figure 7. Groundwater inflow to the mine for Areas 3A and 3B (kL/d)

Groundwater ingress to Area 3B has increased steadily since the start of mining (2013), and correlates approximately with the total area mined. However, the overall rate of increase appears to have slowed during the mining of Longwall 12, and may represent a departure from the area-inflow relationship, as was seen at Area 3A after Longwall 7 was completed. In contrast to Areas 2 and 3A, the rate of inflow to Area 3B has not previously correlated with high rainfall events. During Longwall 12, inflows to Area 3B appear to be correlated with Area 3A, which itself shows a lagged response to high rainfall events. Again, this correlation may represent a departure from previous water balance characteristics at Area 3B.

3.2 Deep groundwater levels – time-series hydrographs

Representative hydrographs from VWP arrays are presented and discussed below. Hydrograph plots are presented in Appendix A.

3.2.1 Area 3B: Strata above mined longwalls

Piezometer arrays over or immediately adjacent to the goaf footprint invariably shear and are rendered inoperable due to mining subsidence effects. Nevertheless, many piezometers provide useful information as mining approaches. In the case of Longwall 9, sheared piezometer S2192 was replaced with S2220 allowing continued monitoring of shallow groundwater systems over the goaf. Review of Area 3B piezometers indicates that depressurisation of the Bulli and Wongawilli seams started during Longwall 5 extraction (mid-late 2009), propagating from Area 3A to almost all coal seam piezometers in Area 3B (HydroSimulations 2016b).

Bore S1910 is located immediately north of the development headings around the centre of Longwall 9. The Bulli and Wongawilli Coal Seams were affected by earlier mining at Area 3A. Rapid depressurisation in all formations occurred in the months leading up to the passage of Longwall 9 by S1910 (Figure 11). Depressurisation of lower Hawkesbury, Bulgo and Scarborough Sandstones started at different times after Longwall 9 extraction commenced. There is an increasing time lag to the depressurisation response from the deepest to the uppermost strata: the lag is about three months in the lower Scarborough Sandstone, and about five months in the lower Hawkesbury Sandstone. The array was sheared off before the commencement of Longwall 10 and no further data are available after October 2013.

Bore S1925 lies on a pillar between Longwall 11 and Longwall 12 (Figure 4). Except for the upper Hawkesbury Sandstone sensor at 10 m depth all other strata were affected by the extraction of Area 3B longwalls, including the Hawkesbury Sandstone sensor at 144 m depth (Figure 12). Groundwater levels in all units below and including the lower Bulgo Sandstone (at 295 m depth) have shown gradual decline in groundwater level since the commencement of Longwall 6, with the shallower Bulgo Sandstone (202 m depth) and Hawkesbury Sandstone (at 144 m depth) units showing mining related drawdown commencing with the extraction of Longwall 9. Prior to the shearing of S1925 in September 2015, 20 m of drawdown can be observed in the lower Hawkesbury Sandstone sensor, with cumulative drawdown since the beginning of Area 3B mining about 50 m.

Bore S1929 (DDH111) is located directly above Longwall 10 (Figure 4). Except for the upper Hawkesbury Sandstone at 8.5 m depth, all other strata were affected by Longwall 9 and Longwall 10 mining, including the Hawkesbury Sandstone at 76 m depth (Figure 13). Groundwater levels in the Bulli and Wongawilli Seams showed gradual drawdown since the commencement of Longwall 6, while shallower strata have exhibited some depressurisation during Longwall 6 or 7. Aside from transient compression effects (apparent increased in head), depressurisation has occurred at a fairly steady rate in the Bulli Seam, Scarborough Sandstone and Bulgo Sandstone from Longwall 7 until the array was sheared in late 2014 during Longwall 10.

Bore S2192 lies along the midline of Longwall 9 (Figure 4). Only seven months of data were recorded before the piezometer array was sheared when the site was undermined (Figure 14). Although there is limited data, it is evident that the Bulgo Sandstone and Stanwell Park Claystone were affected by the extraction of Longwall 9, however there is no clear evidence of mining effects in the Hawkesbury Sandstone at 50 m depth. The array was replaced by **S2220** (Figure 15) with sensors in the Hawkesbury Sandstone only. The hydrographs for S2220 show that groundwater pressures in the Hawkesbury have been stable during Longwall 11 and 12 with no evidence for progressive drawdown. The uppermost sensor (50 m depth) records less than 5 m pressure head and the formation may be unsaturated at that depth. The sensors show variable responses to rainfall with the 96 m sensor showing most response. These data suggest that groundwater in the Hawkesbury Sandstone at this location consists of a series of perched aquifers that are poorly connected to each other and appear isolated from depressurisation in the underlying formations.

S2009 directly overlies Longwall 12 but there are large gaps in groundwater level data (Figure 16), making it difficult to determine when mining related impacts occurred in the area. However, the relatively continuous readings during Longwall 11 extraction allow for interpretation during this period. All sensors except the shallowest Hawkesbury Sandstone piezometer at 68.5 m depth, show some mining effect related to the extraction of Longwall 11, with drawdown effects increasing with depth during Longwall 11. The array was sheared shortly after the start of Longwall 12.

S1914 is located near the midline of Longwall 13 and records changes in groundwater pressure as mining has progressed south (Figure 17). Progressive depressurisation is evident in all formations as mining approached the piezometer, starting in all formations beneath the Hawkesbury Sandstone when mining commenced at Area 3A. Depressurisation accelerated in late 2016 as Longwall 12 passed by the piezometer (215 m at closest approach), with approximately 16 m, 34 m and 106 m drawdown recorded in the Hawkesbury, Bulgo and Scarborough Sandstones respectively.

3.2.2 Area 3B: Strata outside mined longwalls

Six piezometer arrays record groundwater levels in strata outside of the mined longwall footprint (excluding the Avon monitoring bores and S1914 discussed above). These include S2006 (to the west of Longwall 9) and S1911, S1927, S2001, S1932 and S2194 to the south of Longwall 12 (see Figure 4).

S2006 is located approximately 1 km west of Longwall 9 in Area 3B. Progressive depressurisation is apparent in all strata below (and including) the base of the Hawkesbury Sandstone from the time of installation in 2010 (Longwall 6) (Figure 18). Superimposed on the gradual depressurisation trend, all sensors except the upper two Hawkesbury Sandstone sensors record several metres of drawdown in the months following the start of Longwalls 11 and 12. The upper two Hawkesbury Sandstone sensors appear unaffected by mining and record a gradual increase in groundwater levels since the end of Longwall 10. Due to the distance of S2006 from the longwalls, piezometric heads in all monitored formations remain above 250 m AHD (equivalent to within the Hawkesbury Sandstone) and heads in the upper Hawkesbury Sandstone remain above the mean level of Lake Avon.

S1911 is located along the midline of Longwall 13 and 210 m south of Longwall 12 goaf. Progressive depressurisation is apparent in all formations since Longwall 6, with magnitude of drawdown increasing with sensor depth (Figure 19). As with Piezometer S1914, relatively rapid depressurisation occurred in most strata as Longwall 12 passed the piezometer in mid-2016. Sensors within the Bulgo Sandstone (229.5 m depth) and Scarborough Sandstone (318 m) record pressure heads approaching zero from the latter half of 2015. As noted previously (HydroSimulations 2016b), the piezometric head recorded in the middle Bulgo Sandstone (229.5 m) is anomalously low compared with sensors positioned above and below.

Bore S1932 (Figure 20) to the south of Longwall 12 and directly overlying proposed Longwall 16 shows divergent trends in potentiometric level depending on the sensor depth. Sensors in the lower Hawkesbury Sandstone show minor drawdown over the course of mining in Areas 3A and 3B. Deeper sensors located within the Coal Cliff Sandstone (318.2 m depth) and lower Scarborough Sandstone (281 m) show steady and continuing drawdown during Longwall 12. In contrast, sensors at intermediate depths (between the Bulgo Sandstone and Scarborough Sandstone) show initial depressurisation towards the end of Longwall 5, then apparent recovery of potentiometric levels during Longwall 8. Only slight drawdown in these intermediate piezometers is apparent during Longwall 11 and 12. Similar divergent sensor trends are evident in **Bore S2001** (Figure 21), also located to the south of Longwall 11, although the timing of recovery is later in S2001. The apparent recovery in some sensors may be due to a temporary compression effect associated with subsidence.

At **S2194** (south-western corner of Area 3B), progressive depressurisation is apparent in the deeper strata (to the base of the Bulgo Sandstone) since the start of Longwall 9, and this has continued throughout Longwall 12 (Figure 22). In contrast, sensors in the upper Bulgo Sandstone (111 m and 151 m depth) and the Hawkesbury Sandstone record little if any drawdown response until approximately half way through Longwall 11 (July - October 2015). From that time, slight depressurisation is recorded in the upper Bulgo Sandstone and possibly the lower Hawkesbury Sandstone. During Longwall 12, average head in the Bulgo Sandstone declined by 11.5 m (Figure 36).

3.2.3 Avon reservoir bores

Bores S2313 (Figure 23) and S2314 (Figure 24) were installed in October 2015 between proposed Area 3B longwalls and Avon Reservoir, each with two sensors in the Hawkesbury Sandstone and one in the Bulgo Sandstone.

S2313 records depressurisation in the lower Hawkesbury Sandstone and upper Bulgo Sandstone in the months following the start of Longwall 12, with depressurisation continuing in the Bulgo Sandstone following that initial effect. Piezometric head in the lower Hawkesbury and upper Bulgo Sandstones has been below the full supply level (FSL) of Lake Avon (320.2 m AHD) since installation. Groundwater in the upper Hawkesbury Sandstone appears unaffected by mining and remains perched with a piezometric level well above that of Lake Avon. However, note that the pressure head is < 5 m at this sensor, possibly indicating unsaturated or seasonally perched conditions.

S2314 records a transient depressurisation effect in the upper Bulgo Sandstone in the months following the start of Longwall 12 with piezometric heads not fully recovering by the end of Longwall 12 . Piezometric heads in the Hawkesbury Sandstone appear unaffected by mining. As with S2313, there is a downward hydraulic gradient at this location with only groundwater levels in the upper Hawkesbury above Lake Avon FSL (320.2 m AHD). Increases in piezometric head in all sensors in March 2017 is presumably in response to the very high rainfall in that month. Anomalous responses to rainfall events, particularly in the 75 m deep sensor were assessed in a separate report (HGEO, 2017) and are likely due to settlement in the piezometer construction materials following installation.

3.2.4 Longwall 19 (east of Area 3B)

Longwall 19 is located to the south of Longwall 8 and on the southern edge of Area 3A. It is planned for extraction after completion of Area 3B.

S1879 is located near the south-western end of Longwall 19 in Area 3A, and about 600 m southeast of the current southern-most extent of Area 3B roadways and headings. Decline in potentiometric head began in early 2009, associated with Area 2 Longwall 5 extraction, at much the same rate in all formations from the Wongawilli Seam to the upper Scarborough Sandstone (Figure 25**)**. During the second half of Longwall 6 extraction, pressures also began to decline in the upper and lower Bulgo Sandstone, followed by a slight decline in pressure in the lower Hawkesbury Sandstone during Longwall 8. Piezometric levels have remained stable in all strata since the end of Longwall 10 (early 2015).

S1907 which is located to the south of proposed Longwall 19 shows a similar but muted response (Figure 26). Piezometric heads were relatively stable in all monitored strata during Longwall12.

S1934 (Figure 27) has sensors only within the Hawkesbury Sandstone and only two of those sensors have been operational since late 2013 (at 38 m and 65 m depth). Neither sensor shows drawdown response to mining since that time.

The piezometer array at S1885 failed due to subsidence associated with Longwall 8 (2012) but records progressive depressurisation in all strata below the Hawkesbury Sandstone prior to shearing.

3.3 Deep groundwater levels – spatial patterns

The spatial distribution of piezometric heads and drawdown in piezometric head due to mining is shown in two sets of maps (Appendix B):

1. The average piezometric head is shown at each piezometer operational within the last 2 years as of the end of Longwall 12 (Figure 28 to Figure 32), and

2. The change (drawdown) in average piezometric head between the end of Longwall 11 and the end of Longwall 12 (Figure 33 to Figure 37).

For piezometers that ceased operation within the last two years, or where there are gaps in the data, values have been extrapolated (or interpolated) as appropriate.

3.3.1 Groundwater levels (piezometric head)

The piezometric head data at each piezometer are aggregated (averaged) for each of the following formations: Wongawilli Coal Seam, Bulli Coal Seam, Scarborough Sandstone, Bulgo Sandstone and Hawkesbury Sandstone (Figure 28 through Figure 32). This provides an overview of groundwater conditions across Areas 3A and 3B as of the end of Longwall 12.

The Wongawilli coal seam becomes depressurised well in advance of mining (Figure 28). As expected, piezometric heads are lowest immediately to the south of the current longwall, but generally increase towards the south, away from active mining. Depressurisation is greater to the south of mining than indicated by piezometers to the west (e.g. S2007). This is likely due to the additional depressurisation effects of the Elouera Mine immediately to the south of Dendrobium. Similar depressurisation patterns are apparent in the Bulli Coal Seam (Figure 29). Piezometric head in the Bulli Coal Seam is generally higher than in the (currently mined) Wongawilli Coal Seam across Areas 3A and 3B. However, the opposite is true of piezometers to the north of Area 2 along the western edge of Lake Cordeaux. This is likely due to depressurisation from previous Bulli Coal Seam workings to the east of Area 3A (Kemira).

The Scarborough Sandstone (Figure 30) is depressurised in the vicinity of the mined areas and to the south of Longwall 12. Although no piezometers remain intact above the goaf areas, it is likely that subsidence related fracturing propagates above the Scarborough Sandstone and that it is fully depressurised in those areas.

Piezometric heads have declined in the Bulgo Sandstone at almost all piezometers across the mining domain, but to a lesser extent than the underlying strata. Mining effects on groundwater levels in the Hawkesbury Sandstone are variable. Piezometric levels in the Hawkesbury Sandstone appear low and affected by mining drawdown in piezometers overlying and close to the goaf areas, but remain elevated and potentially perched at most piezometers outside of the mined areas. As described in Section 3.1, there is evidence for perching in the Hawkesbury Sandstone (at least locally) within the goaf footprint. The Avon bores (S2313 and S2314) are possible exceptions to this; however, there is no baseline data to allow comparison with conditions prior to mining at Area 3B.

3.3.2 Groundwater drawdown during Longwall 12

Changes in piezometric head between the end of Longwall 11 and the end of Longwall 12 are shown for the Wongawilli Coal Seam, Bulli Coal Seam, Scarborough Sandstone, Bulgo Sandstone and Hawkesbury Sandstone in Figure 33 through Figure 37.

Drawdown in the Wongawilli and Bulli Coal seams has extended south of the active mining areas. However, the incremental drawdown for Longwall 12 is relatively minor, since the seams were depressurised well in advance of mining over a broad area.

Drawdown in the Scarborough and Bulgo Sandstones is apparent in the areas immediately to the south-west of Longwall 12 and extending to S2194, located 1.8 km to the south of Longwall 12. Drawdown in the Hawkesbury Sandstone is spatially variable but largest above and immediately adjacent to Longwall 12, with some drawdown also evident at S2001, located 790 m to the south. Elsewhere drawdown is negligible.

There is a marked difference in the magnitude and pattern of drawdown response between the Bulgo Sandstone and the overlying Hawkesbury Sandstone. This is consistent with the concept that vertical networks of mining related fracturing extend to the upper part of the Bulgo Sandstone, but do not (everywhere) extend above the base of the Hawkesbury Sandstone which retains perched aquifer systems in many areas.

3.4 Groundwater chemistry

Previous reviews have shown that there is no clear spatial pattern in the distribution of groundwater quality in Hawkesbury Sandstone and Bulgo Sandstone bores. Groundwater salinity (EC) for all samples collected from monitoring bores in Areas 3A and 3B are summarised in Table 3. As with previous reviews, the groundwater salinity tends to increase with depth.

The average EC for all samples collected are: 167 µS/cm for the Hawkesbury Sandstone, 617 µS/cm for the Bulgo Sandstone and 512 µS/cm for the Scarborough Sandstone. It should be noted that Scarborough Sandstone outcrops at monitoring bore S1886 and therefore represents shallow groundwater. The data provide no evidence for adverse changes to groundwater quality as a result of mining.

Table 3. Summary of EC measurements at monitoring bores

Bore ID	Alt ID	Depth (m)	Unit	Mean EC (µS/cm)		Samples	
				LW11	LW12	LW11	LW12
S1879	DEN92	10	Hawkesbury Sandstone		66		2
S1879	DEN92	58			179		2
S1911	DEN106B	10		188		1	
S1929	DEN111A	44					
S1932	DEN114	10		115		1	
S1932	DEN114	98		146		1	
S1934	DEN115	55					
S2001	DEN125A	63		159		1	
S2001	DEN125A	106		222		1	
S1870	DEN85A	10		72	70	1	1
S1870	DEN85A	16.5		79	77	1	1
S1888	DEN96	7.3			83		2
S2313		54		83	116	2	1
S2313		138		186	174	2	1
S2314		30		164	160	2	2
S2314		75		173	160	2	2
S2321		68			294		1
S2321		137			391		1
S2332		68			399		1
S2332		131			268		1
S1929	DEN111A	204	Bulgo Sandstone				
S1888	DEN96	200			581		4
S2313		194		*	*	2	1
S2314		128		*	654	2	2
S1886	DEN94	22	Scarborough Sandstone		511	0	1
S1886	DEN94	30			510	0	1
S1886	DEN94	38			515	0	1

Note: * Results affected by bentonite pack near pump intake and not reported

3.5 Comparison with model predictions

3.5.1 Deep groundwater levels

In this section observed deep groundwater levels are compared with those predicted in the groundwater impact model (HydroSimulations 2016a). The comparison was carried out by extracting the predicted heads at representative sensors as of the end of Longwall 12 from the original model output files (provided by HydroSimulations), and plotting those heads against the observed heads at the same sensors (as presented in Section 3.3). It is therefore an independent assessment of the ongoing accuracy of the 2016 model predictions.

Thirteen piezometers were selected for comparison on the basis of their distribution across the site and their likelihood of providing ongoing monitoring data for future assessments (S1878, S1911, S1914, S1932, S2001, S2006, S2070, S2078, S2194, S2306, S2307, S2313 and S2314). Importantly, piezometers adjacent to Lake Avon (S2313, S2314, S2001, S2194) were included to allow assessment of the strata separating the mine from the stored waters of Lake Avon.

Figure 8 is a plot of the modelled and observed heads as of the end of Longwall 12. The data are coloured according to the formation, and bores that are located adjacent to Lake Avon are highlighted. Data for an accurate and well calibrated model should cluster along the diagonal 1:1 line. Points plotting above the line indicate that observed heads are higher than predicted (i.e. the model over-predicts drawdown and is conservative), while points that plot below the line indicate that the model under-predicts drawdown at those locations.

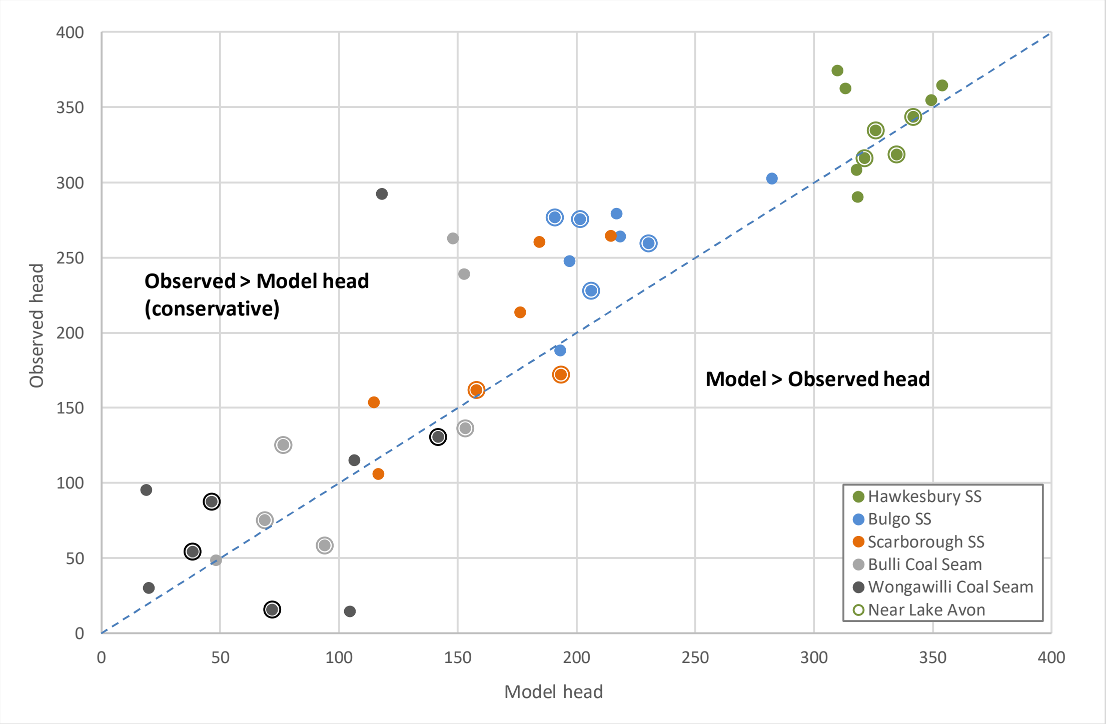

Figure 8. Observed versus model predicted heads at the end of Longwall 12

The following are concluded from the comparison in Figure 8:

- Most points plot very close to, or above the 1:1 line indicating that the model continues to provide accurate predictions of head, but tends to overpredict drawdown in the Bulgo Sandstone and parts of the Scarborough Sandstone.

- The observed decrease in head with stratigraphic depth is well replicated by the model suggesting that model parameters of horizontal and vertical permeability are appropriate.
- Model and observed heads for Hawkesbury Sandstone piezometers adjacent to Lake Avon plot very close to the 1:1 line, providing an assurance that the model predictions are accurate in this important area.
- The combination of the points above imply that estimates of leakage from, or loss of base-flow to, Lake Avon are likely also to be reasonably accurate.

3.5.2 Mine water balance

Figure 9 is a plot of the modelled and observed groundwater inflow to Area 3B during the extraction of Longwall 12. The numerical model is set up with stress periods corresponding to the originally planned longwall start and end dates (approximately yearly). It is clear that the model tends to over-predict inflow to Area 3B, which is conservative with respect to impact assessment.

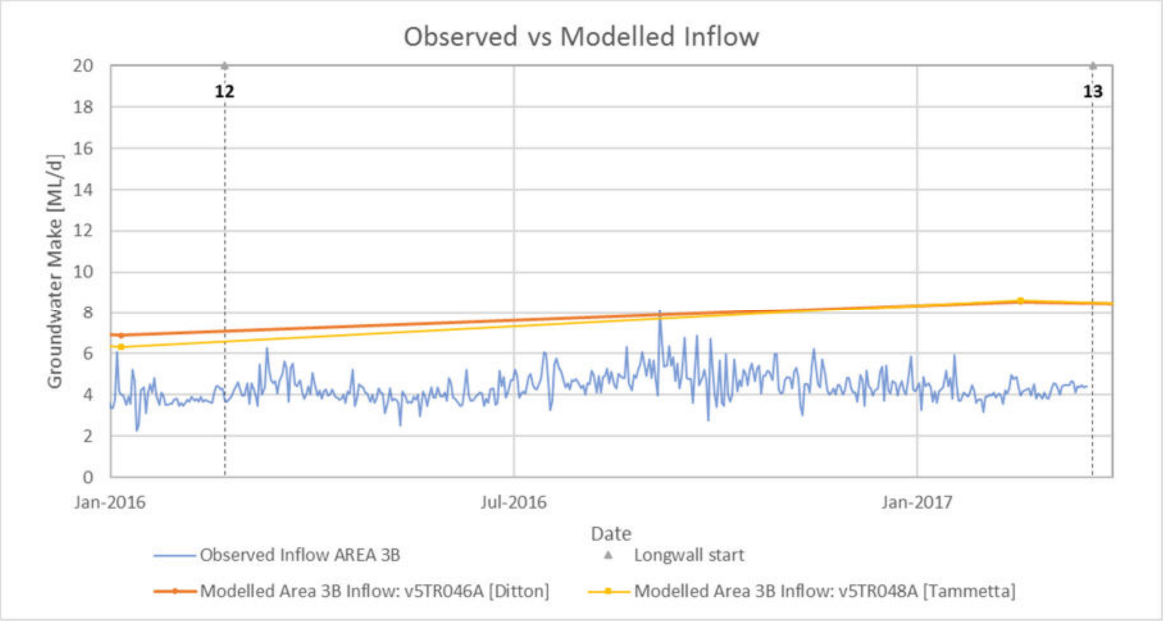

Figure 9. Observed versus model predicted mine groundwater inflow to mine Area 3B

3.5.3 Loss of baseflow to Lake Avon

Numerical model predictions of the net loss (seepage) from Lake Avon as of the end of Longwall 12 are shown in Figure 10. This reduction comprises induced leakage from, and reduced seepage to, the Lake, relative to pre-mining conditions.

The estimated net loss from the reservoir at the end of Longwall 12 is less than 0.4 ML/d and therefore within the tolerable loss limit of 1 ML/day prescribed by the DSC (DSC 2014).

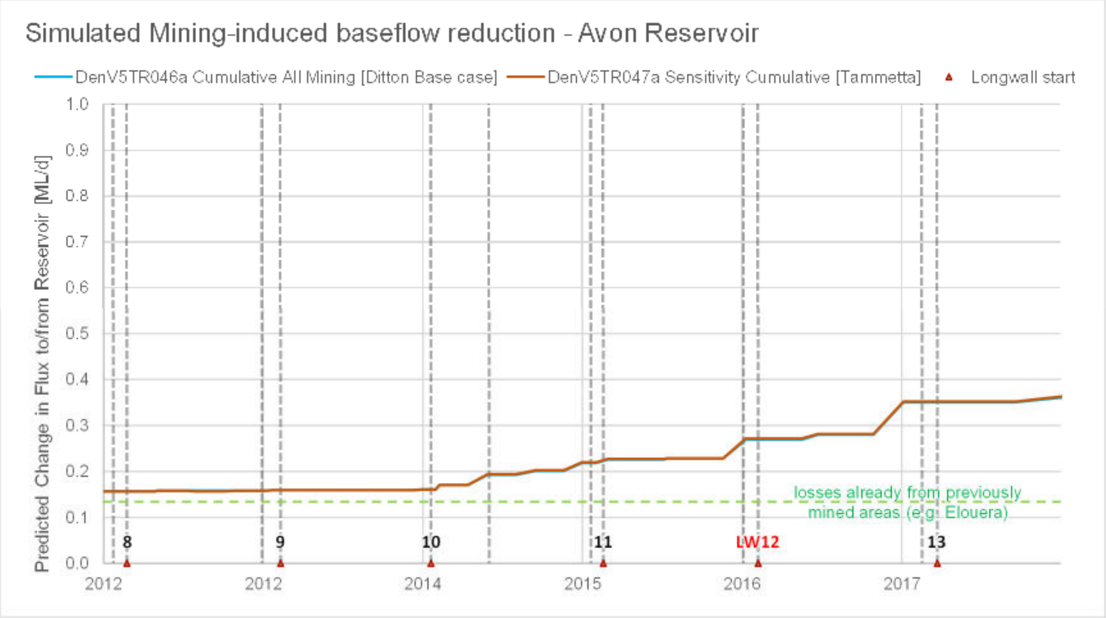

Figure 10. Model estimates of mine-induced reduction of baseflow to Lake Avon

4. CONCLUSION

The following conclusions are made with respect to the assessment of groundwater conditions following the completion of Longwall 12:

- Mining of longwall 12 resulted in continued depressurisation of the target coal seam and overlying strata. The observed changes in groundwater levels are in line with numerical model predictions that support mining approvals.
- As expected, the greatest depressurisation is within the Wongawilli Coal Seam, and decreases with height above the seam. Incremental drawdown in the Scarborough and Bulgo Sandstones is apparent in the areas immediately to the south-west of Longwall 12 and extending to S2194, located 1.8 km to the south of Longwall 12.
- Drawdown in the Hawkesbury Sandstone is spatially variable but largest above and immediately adjacent to Longwall 12, with some drawdown also evident at S2001, located 790 m to the south. Elsewhere observed drawdown is negligible.
- There is a marked difference in the magnitude and pattern of drawdown response between the Bulgo Sandstone and the overlying Hawkesbury Sandstone. This is consistent with the concept that connected vertical networks of mining related fracturing extend to the upper part of the Bulgo Sandstone, but do not (everywhere) extend above the base of the Hawkesbury Sandstone which retains perched aquifer systems in many areas.
- The average daily groundwater inflow to Area 3B during Longwall 12 extraction was 4.5 ML/d which represents approximately 60% of total mine inflow for the period. Inflows to Area 3B have increased in proportion to the total mined area since 2013 with no apparent correlation with rainfall events. There is evidence that this relationship changed during the mining of Longwall 12 with the development of an apparent correlation between Area 3B and 3A inflows (and presumably rainfall).
- There is no clear spatial pattern in the distribution of groundwater quality in Hawkesbury Sandstone and Bulgo Sandstone bores, as indicated by electrical conductivity measurements. Available data provide no evidence for groundwater quality impacts from mining.
- The numerical model developed by Hydrosimulations in 2014 and updated in 2016 was assessed to be accurate with respect to estimated deep groundwater levels at the end of Longwall 12. The model has a tendency to overestimate drawdown impacts in the Bulgo and Scarborough Sandstones and is therefore conservative.
- Estimates based on the numerical model are that the net loss from Lake Avon at the end of Longwall 12 is less than 0.4 ML/d and within the tolerable loss limit of 1 ML/day prescribed by the DSC.

5. REFERENCES

ANZECC (2000) Australian water quality guidelines for fresh and marine waters. Australian and New Zealand Environment and Conservation Council, Canberra

Booth CJ (1986) Strata movement concepts and the hydrogeolgoical impact of underground coal mining. Ground Water 24:507–515.

Coffey (2012) Groundwater study at Area 3B, Dendrobium Coal Mine: Groundwater modelling.

DSC (2014) Letter from the Dams Safety Committee to Illawarra Coal dated 10/03/2014 regarding Dendrobium mining within Avon Notification Area tolerable limit of risk of storage loss.

Forster I, Enever J (1992) Hydrogeological response of overburden strata to underground mining, Central Coast, NSW. NSW Office of Energy

Guo H, Adhikary D, Gaveva D (2007) Hydrogeological response to longwall mining. Australian Coal Industry's Research Program (ACARP)

HGEO (2017) Dendrobium Mine - Review of groundwater monitoring at S2314 as of December 2016. Sydney, NSW

HydroSimulations (2016a) Dendrobium Area 3B Groundwater assessment.

HydroSimulations (2014) Dendrobium Area 3B groundwater model revision: Swamps, stream flows and shallow groundwater data.

HydroSimulations (2016b) Dendrobium Mine End of Panel Groundwater Assessment: Longwall 11 (Area 3B).

Mills KW (2011) Developments in understanding subsidence with improved monitoring. In: Proceedings of the Eighth Triennial Conference on Management of Subsidence, 2011. Mine Subsidence Technological Society, Pokolbin, NSW, pp 25–41

Parsons Brinckerhoff (2014) Groundwater responses to mining of Longwall 9 at area 3B, Dendromium.

Peng SS, Chiang HS (1984) Longwall mining. Wiley, New York

South32 (2012) Dendrobium Mine Groundwater Management Plan. South32 Illawarra Coal

South32 (2015) Dendrobium Area 3B Subsidence Management Plan Volume 2: Subsidence Management Plan (Rev B). South32 Illawarra Coal

Tammetta P (2013) Estimation of the Height of Complete Groundwater Drainage above Mined Longwall Panels. Groundwater 52:826–826. doi: 10.1111/gwat.12253

Tammetta P (2014) Estimation of the Change in Hydraulic Conductivity Above Mined Longwall Panels. Groundwater 53:122–129. doi: 10.1111/gwat.12153

Tammetta P (2016) Estimation of the Change in Storage Capacity above Mined Longwall Panels. Groundwater 54:646–655. doi: 10.1111/gwat.12405

Toth J (2009) Gravitational systems of groundwater flow: Theory, evaluation, utilization. Cambridge University Press, Cambridge, UK

APPENDIX A: HYDROGRAPHS

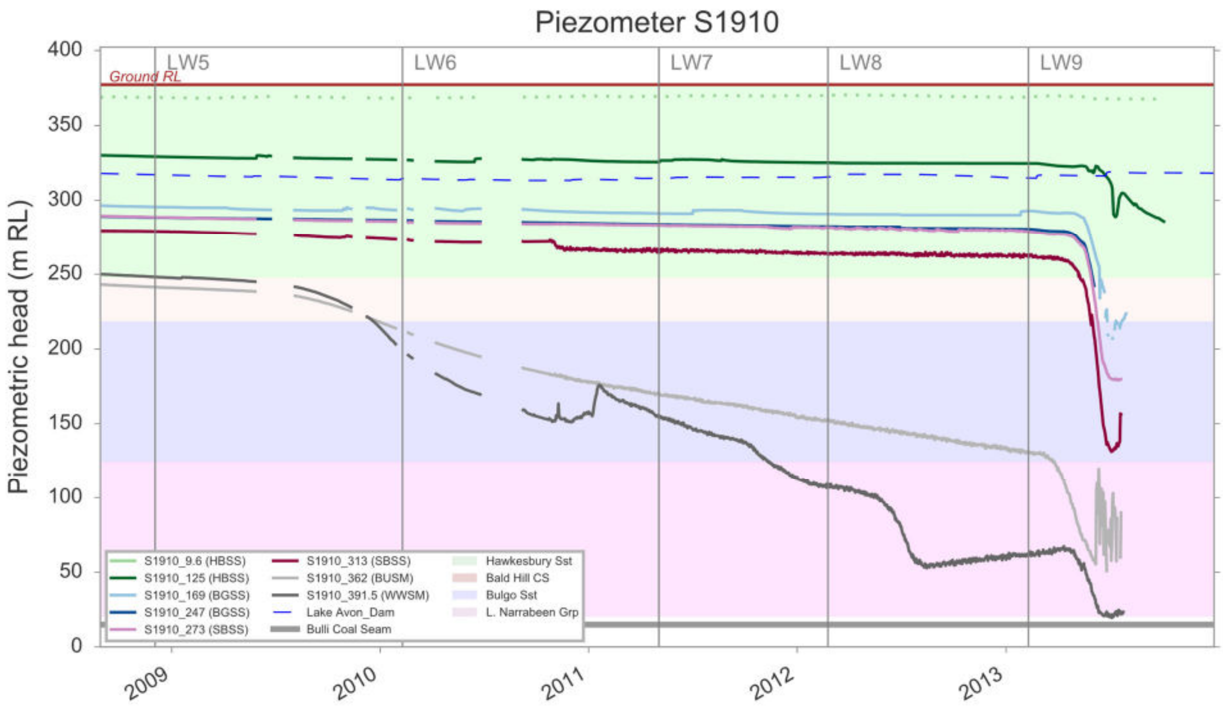

Figure 11. Hydrograph for vibrating wire piezometer S1910

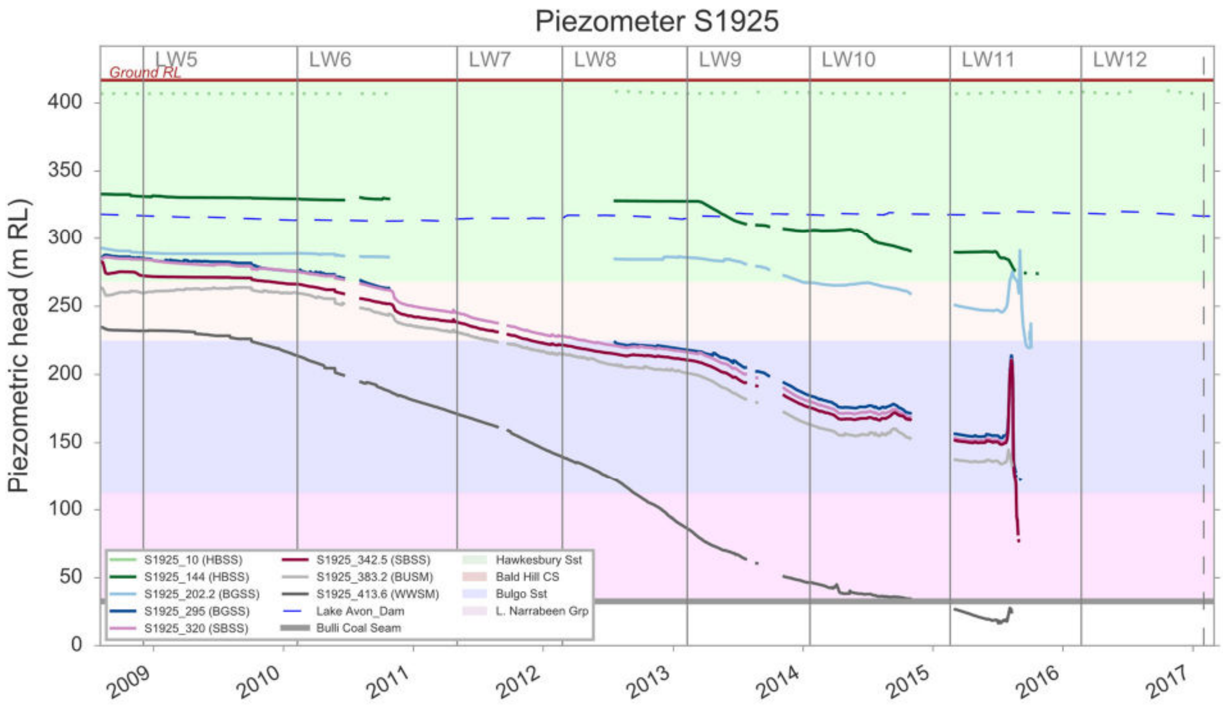

Figure 12. Hydrograph for vibrating wire piezometer S1925

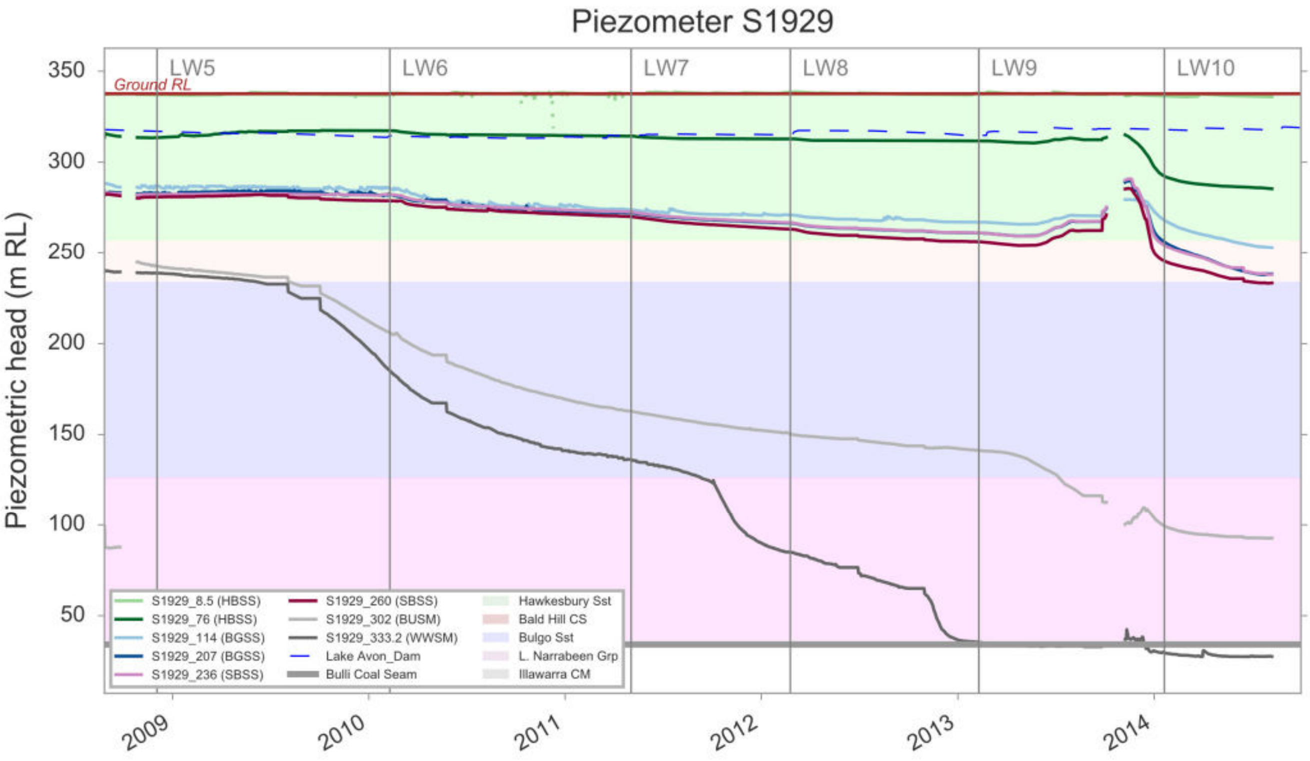

Figure 13. Hydrograph for vibrating wire piezometer S1929

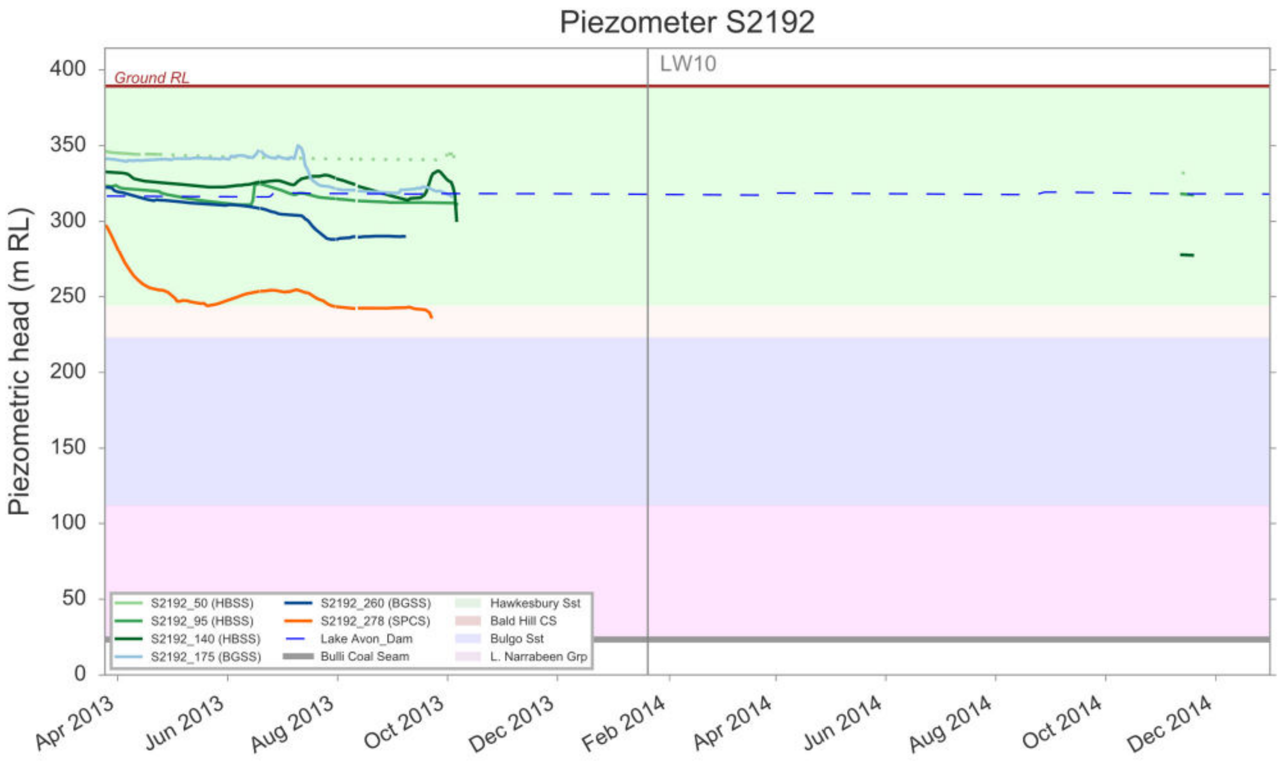

Figure 14. Hydrograph for vibrating wire piezometer S2192

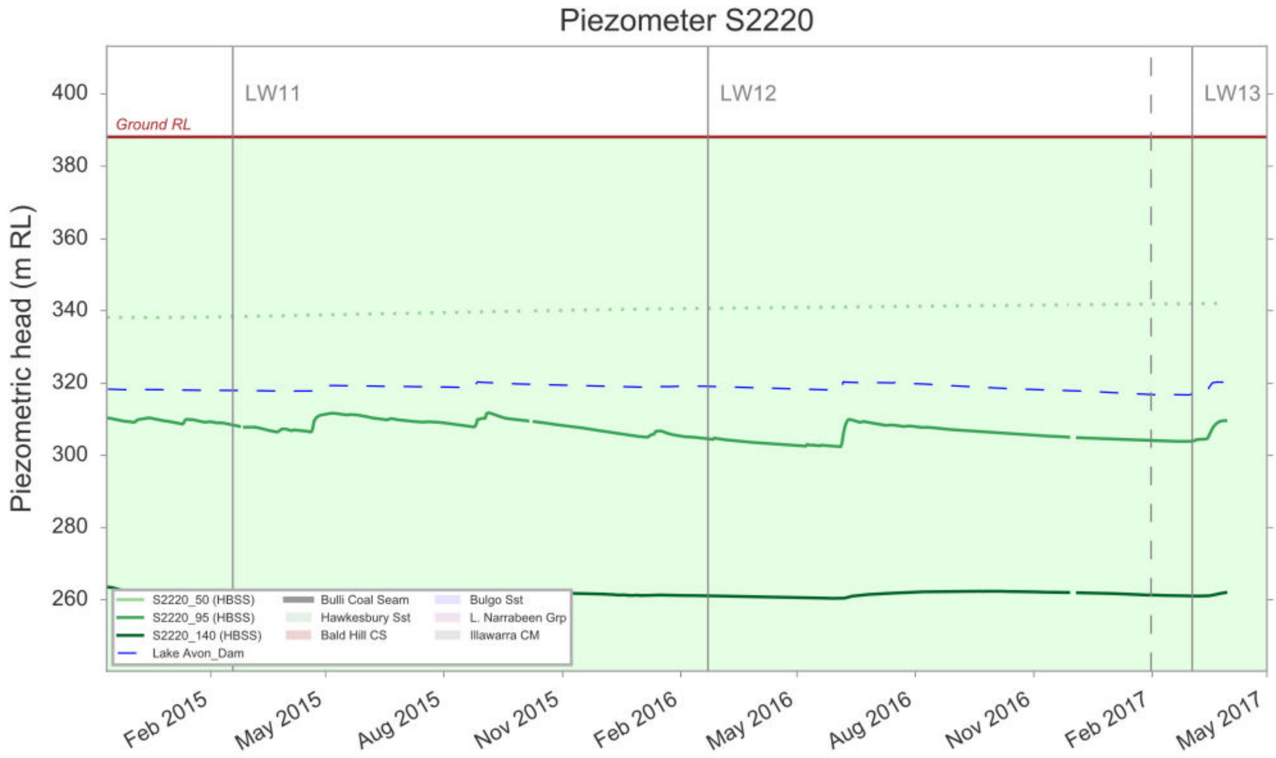

Figure 15. Hydrograph for vibrating wire piezometer S2220

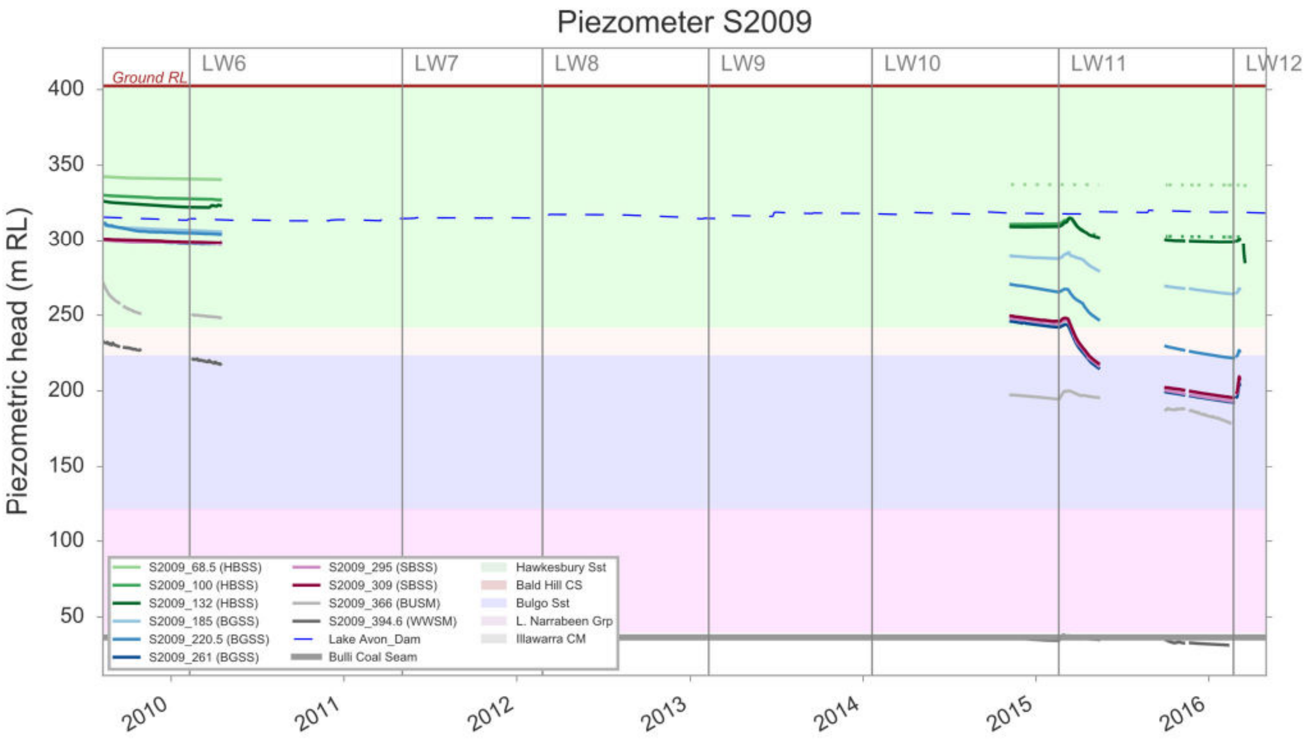

Figure 16. Hydrograph for vibrating wire piezometer S2009

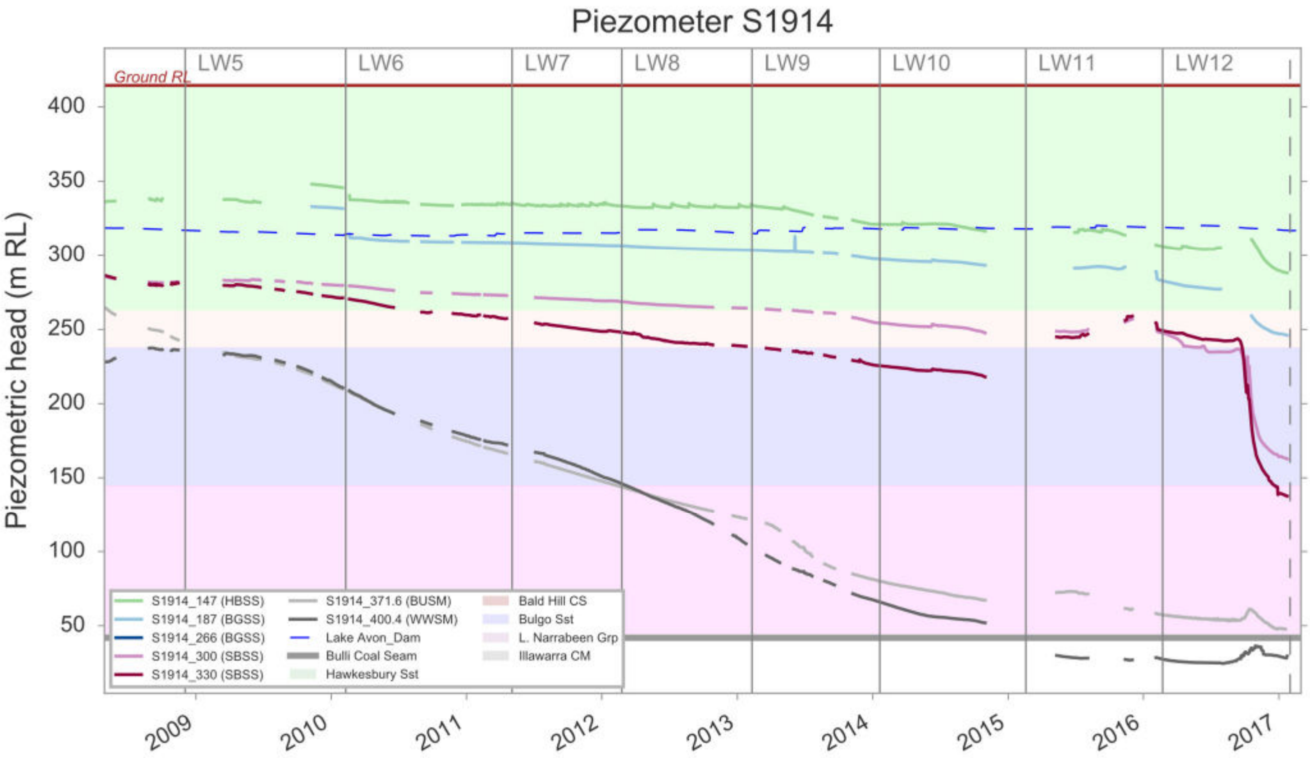

Figure 17. Hydrograph for vibrating wire piezometer S1914

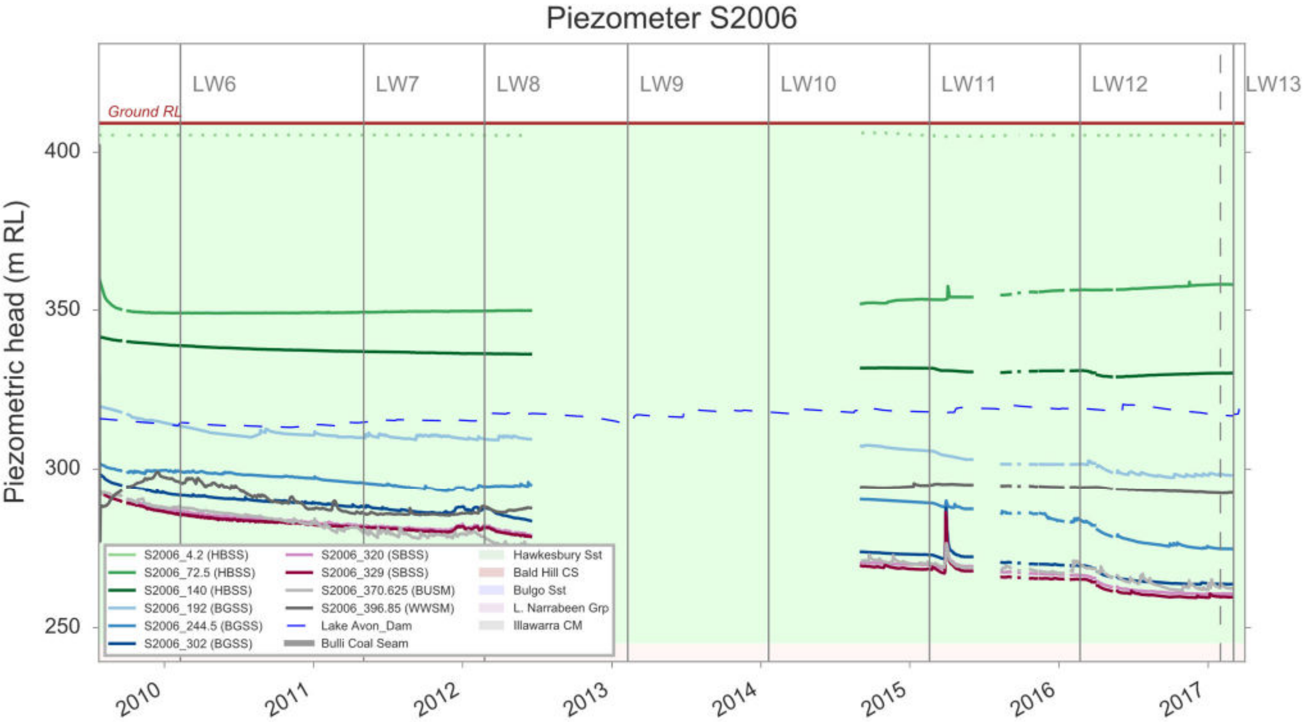

Figure 18. Hydrograph for vibrating wire piezometer S2006

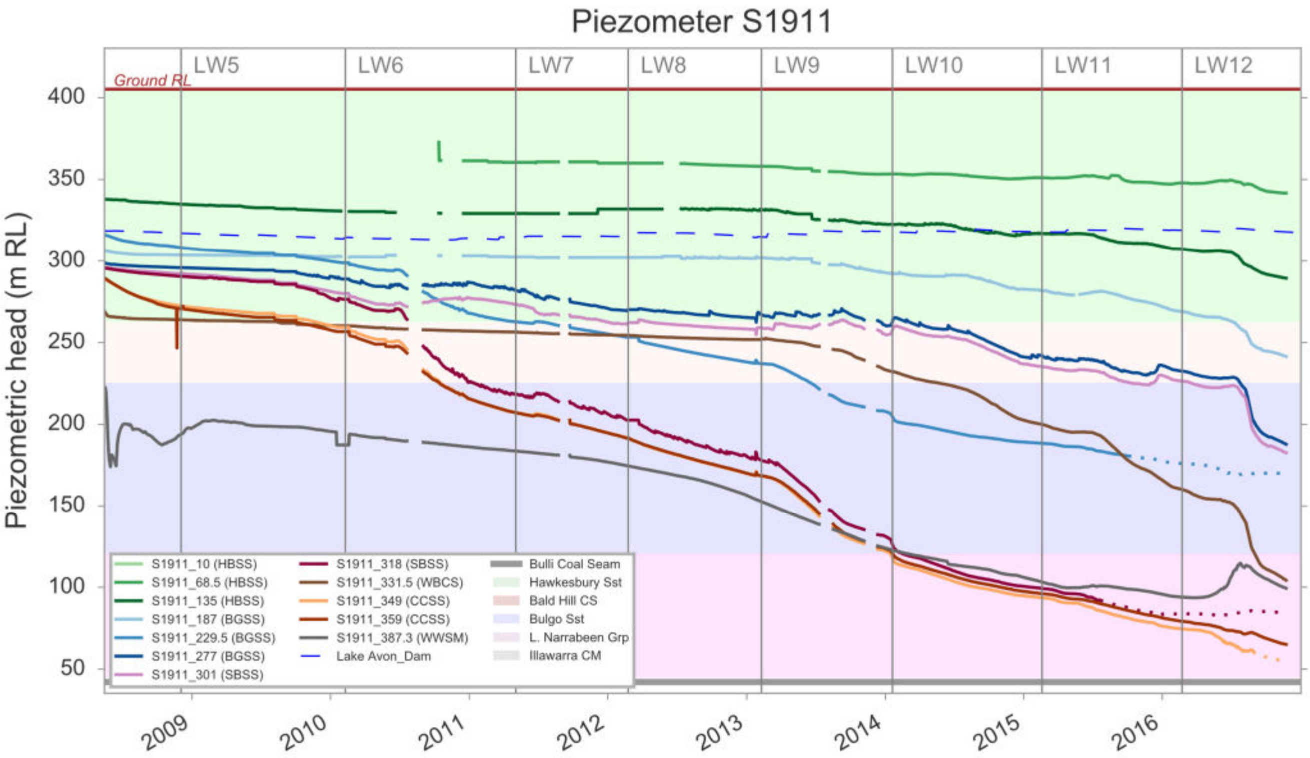

Figure 19. Hydrograph for vibrating wire piezometer 1911

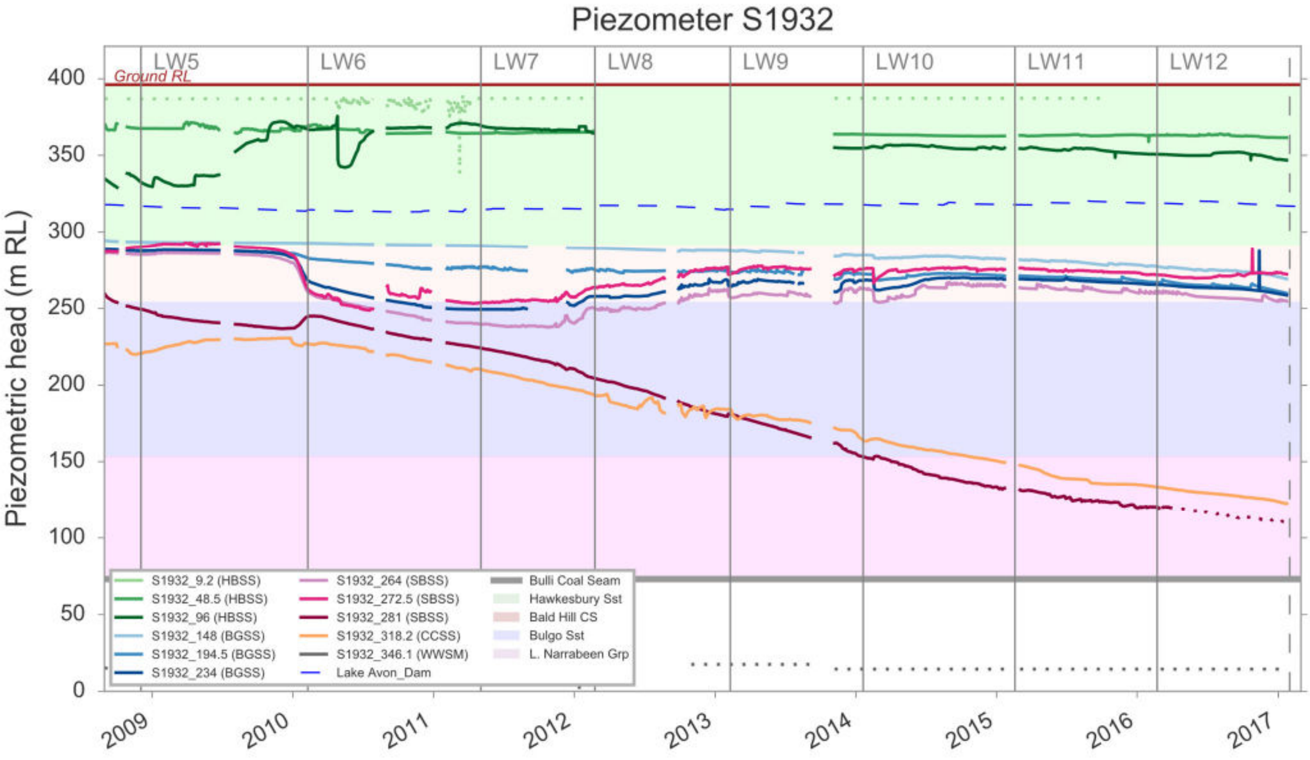

Figure 20. Hydrograph for vibrating wire piezometer S1932

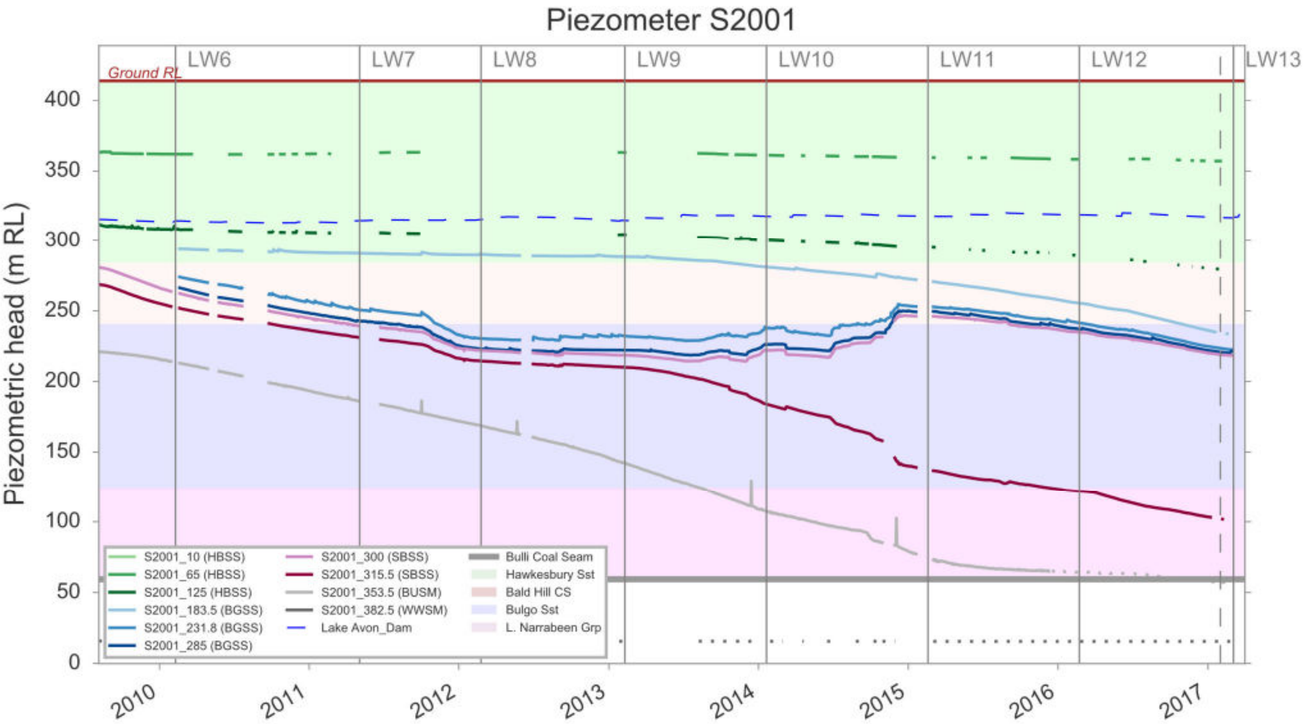

Figure 21. Hydrograph for vibrating wire piezometer 2001

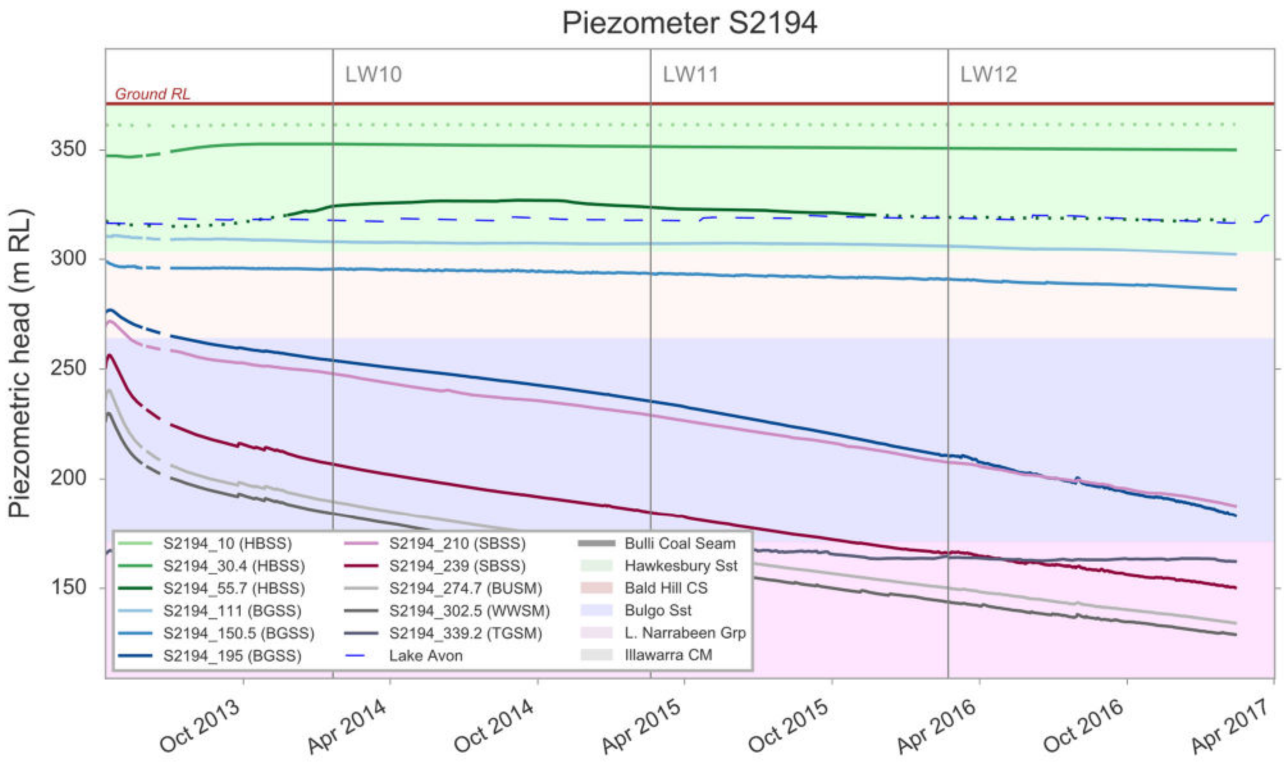

Figure 22. Hydrograph for vibrating wire piezometer S2194

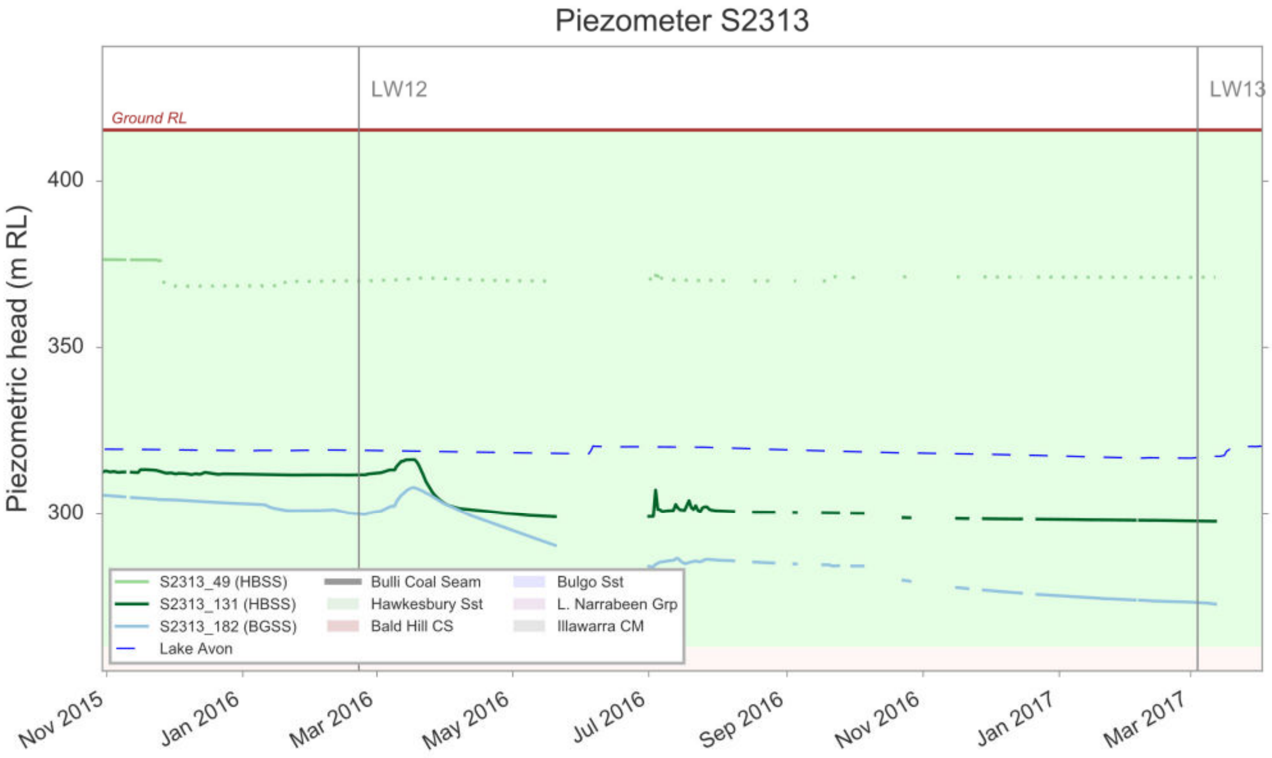

Figure 23. Hydrograph for vibrating wire piezometer S2313

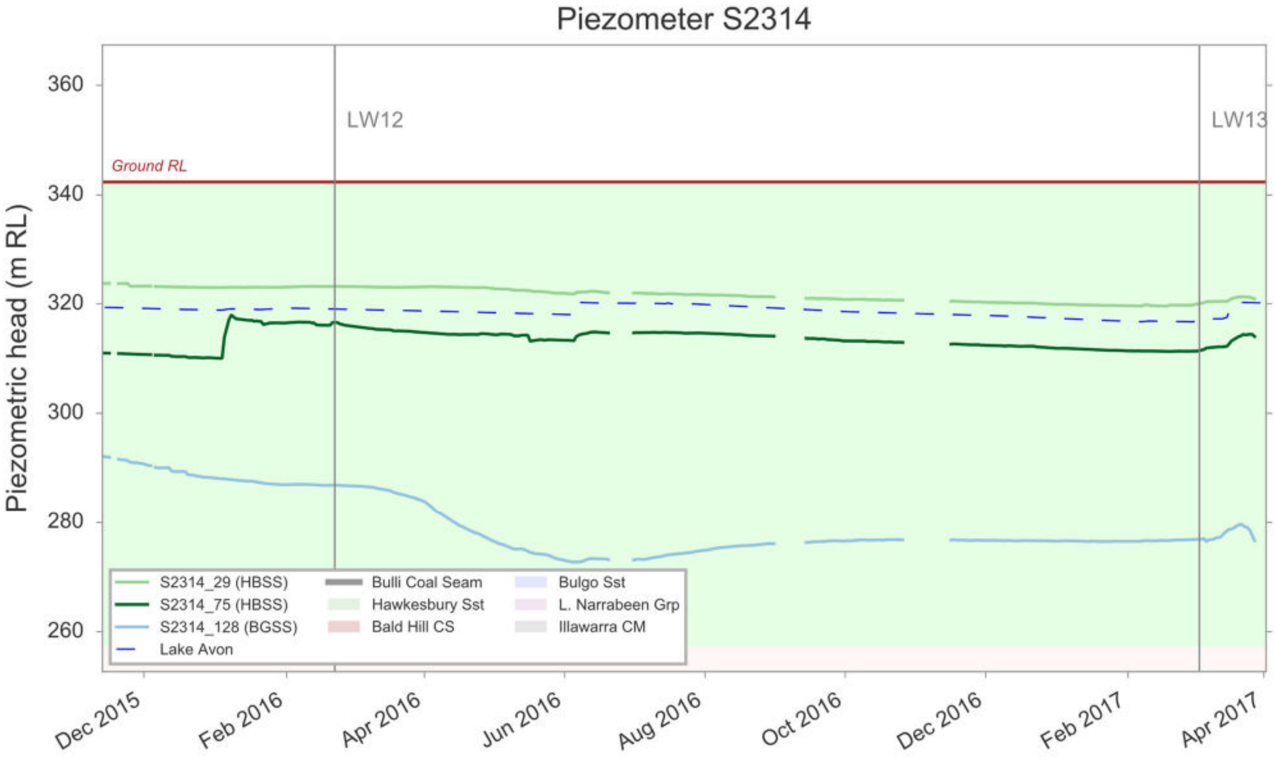

Figure 24. Hydrograph for vibrating wire piezometer S2314

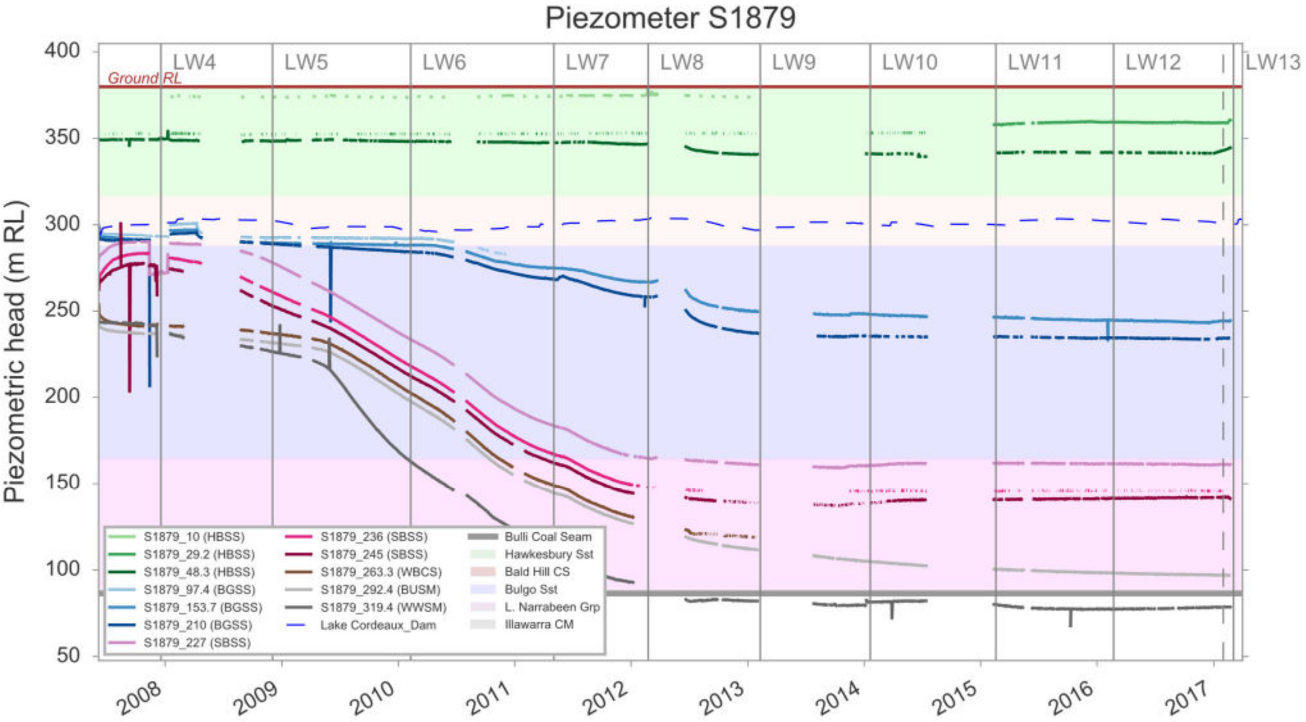

Figure 25. Hydrograph for vibrating wire piezometer S1879

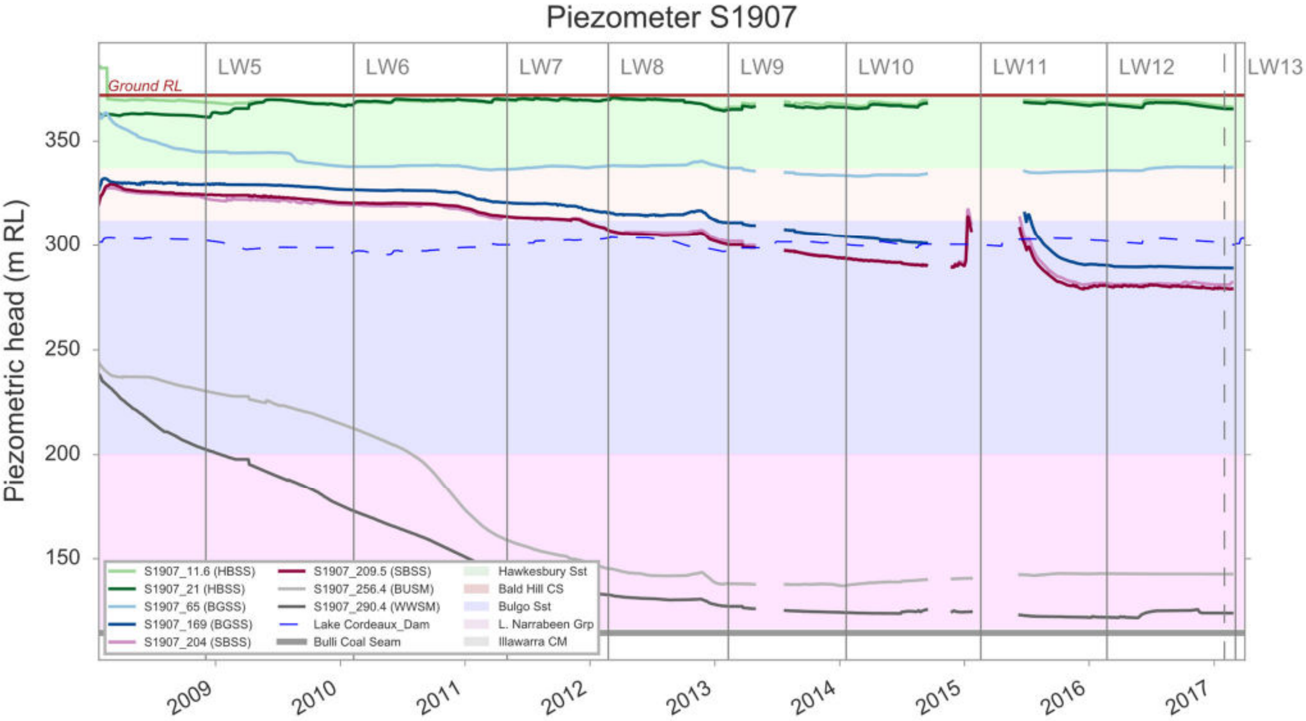

Figure 26. Hydrograph for vibrating wire piezometer S1907

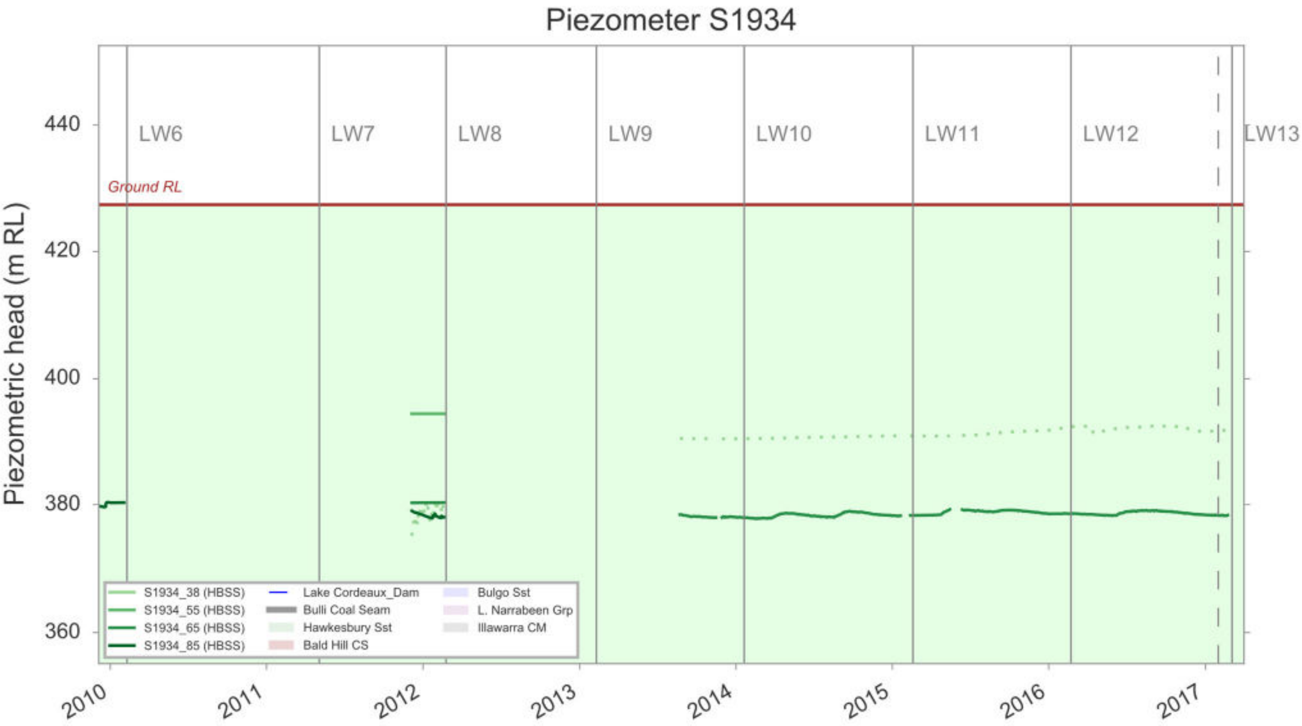

Figure 27. Hydrograph for vibrating wire piezometer S1934

APPENDIX B: SPATIAL PLOTS

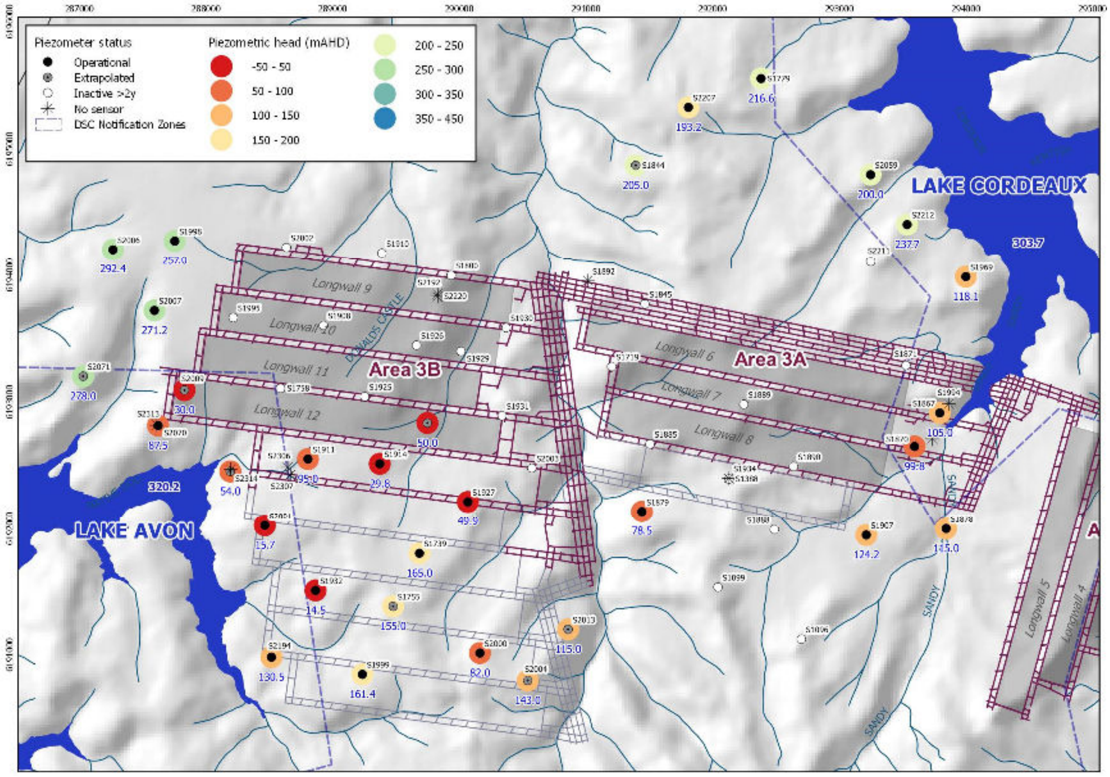

Figure 28. Average piezometric head in the Wongawilli Coal Seam at the end of LW12

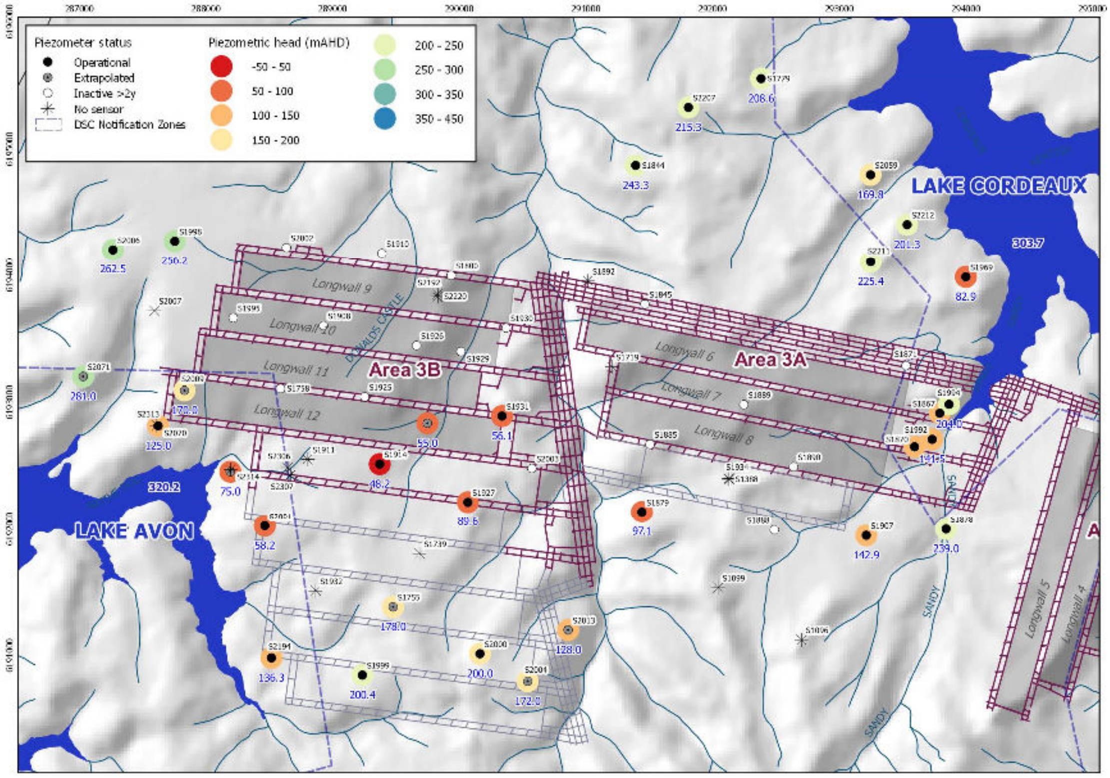

Figure 29. Average piezometric head in the Bulli Coal Seam at the end of LW12

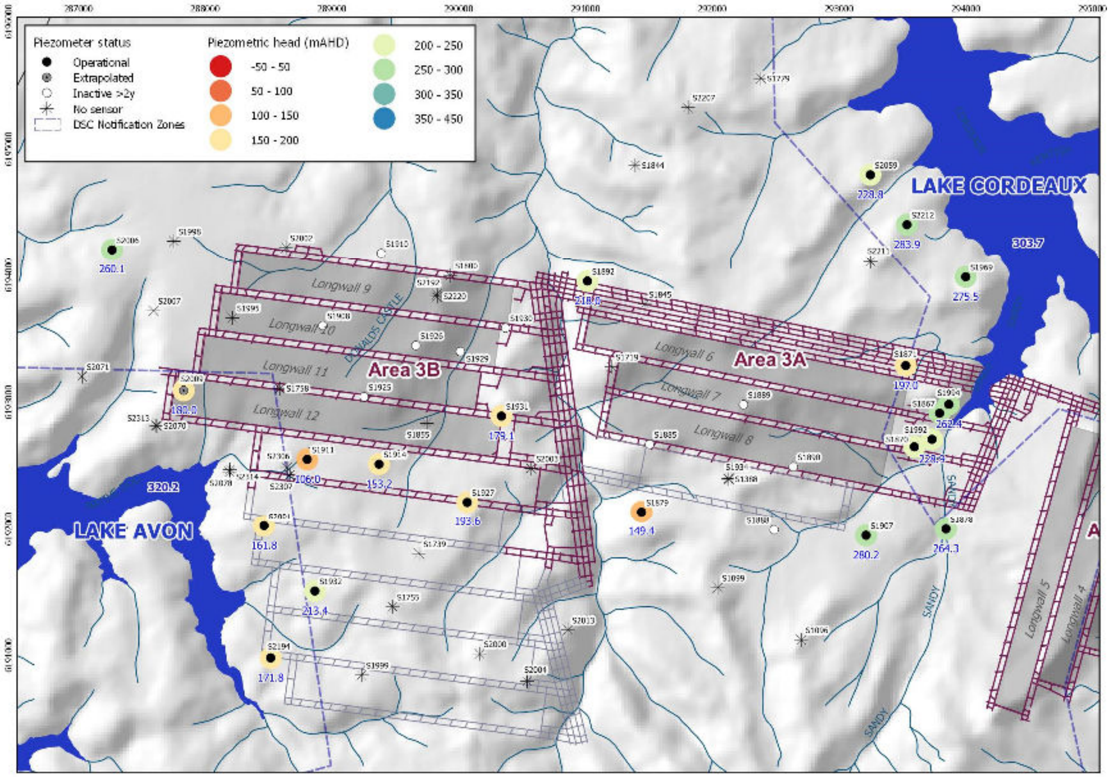

Figure 30. Average piezometric head in the Scarborough Sandstone at the end of LW12

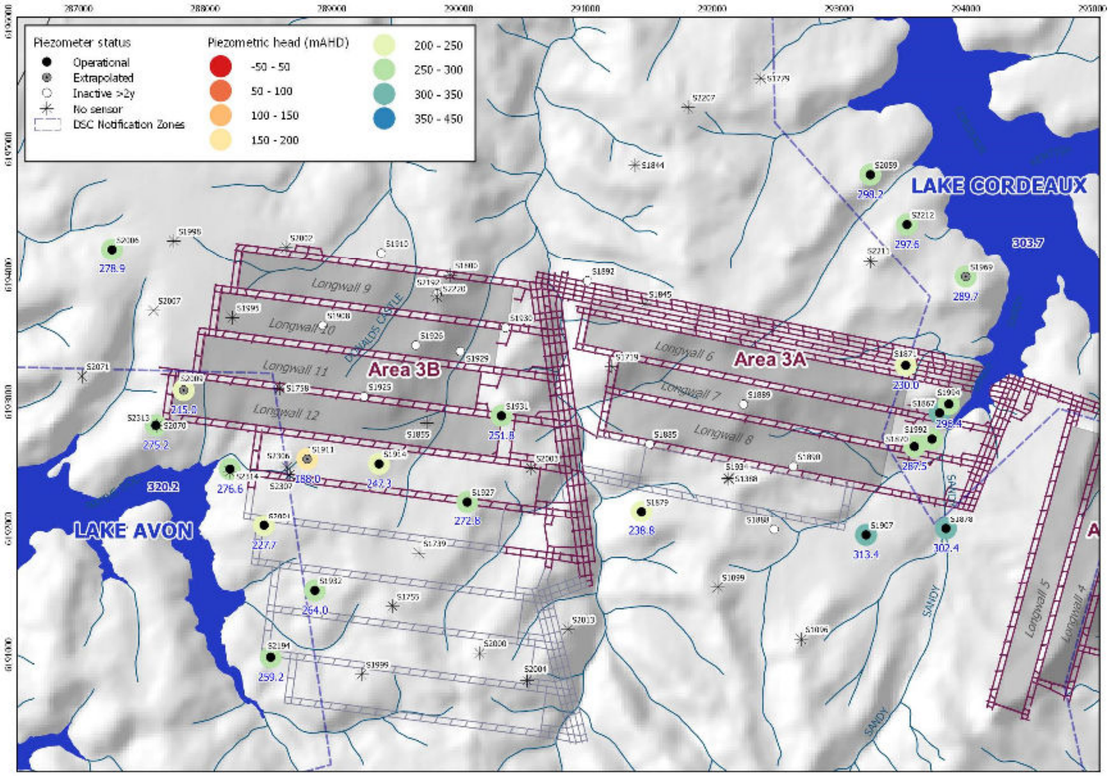

Figure 31. Average piezometric head in the Bulgo Sandstone at the end of LW12

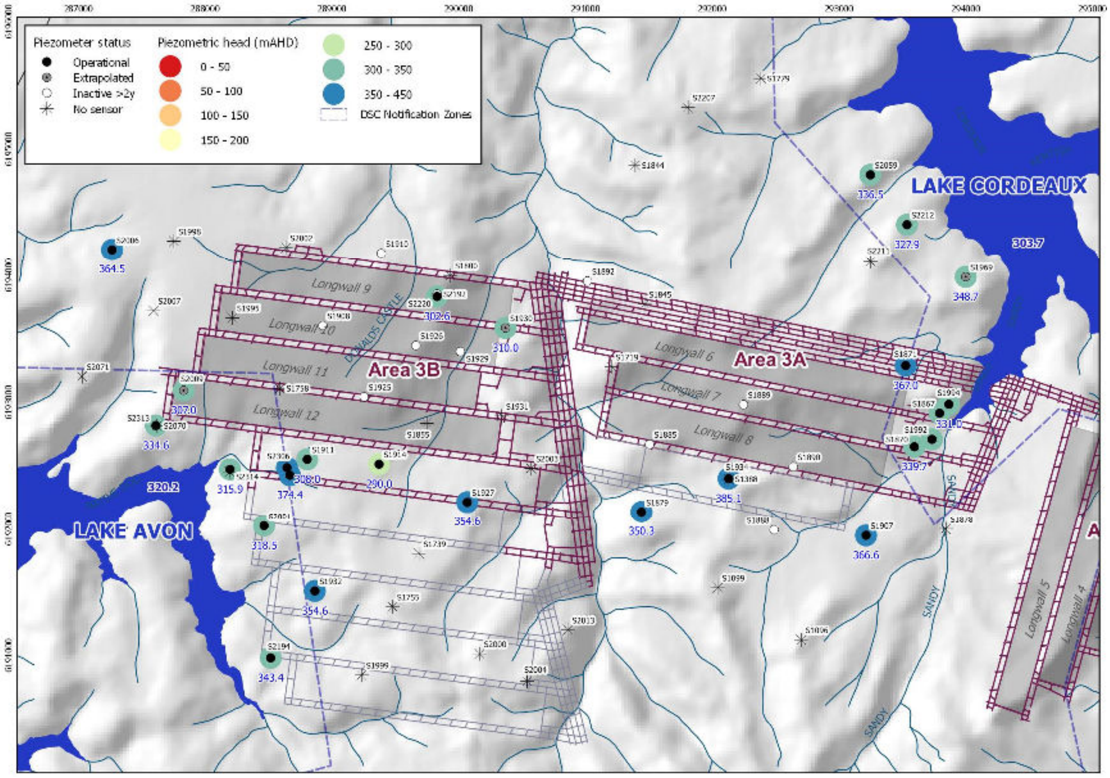

Figure 32. Average piezometric head in the Hawkesbury Sandstone at the end of LW12

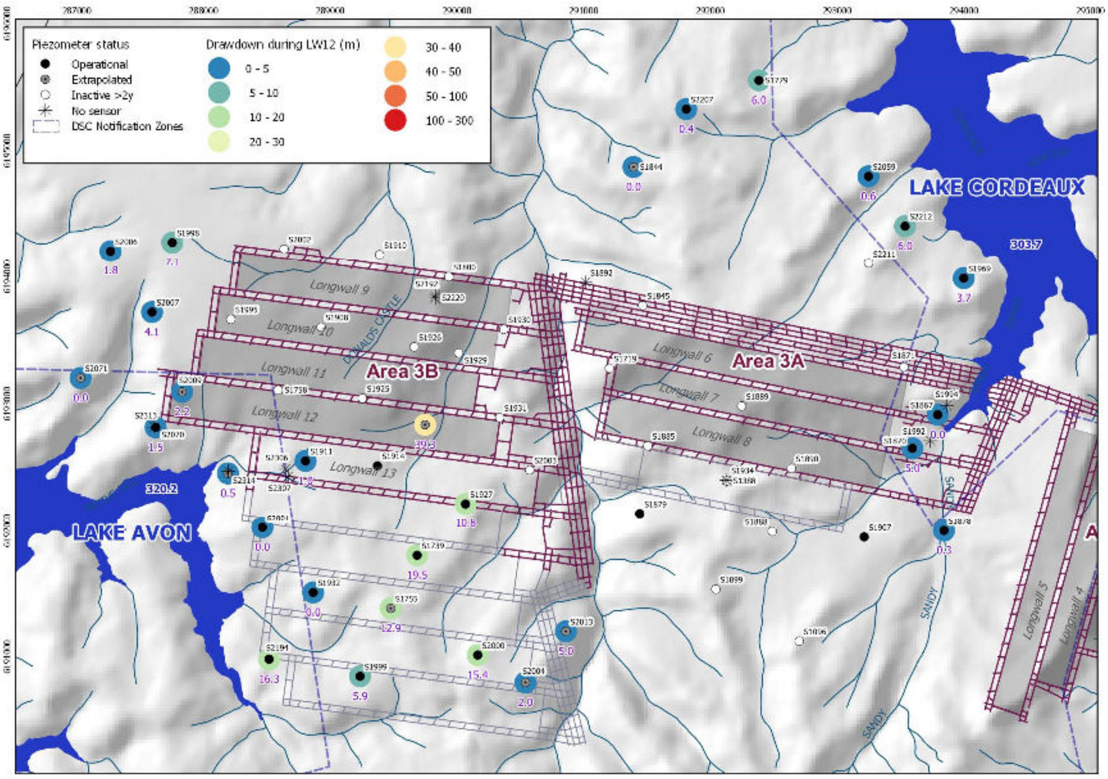

Figure 33. Drawdown in piezometric head in the Wongawilli Coal Seam during LW12

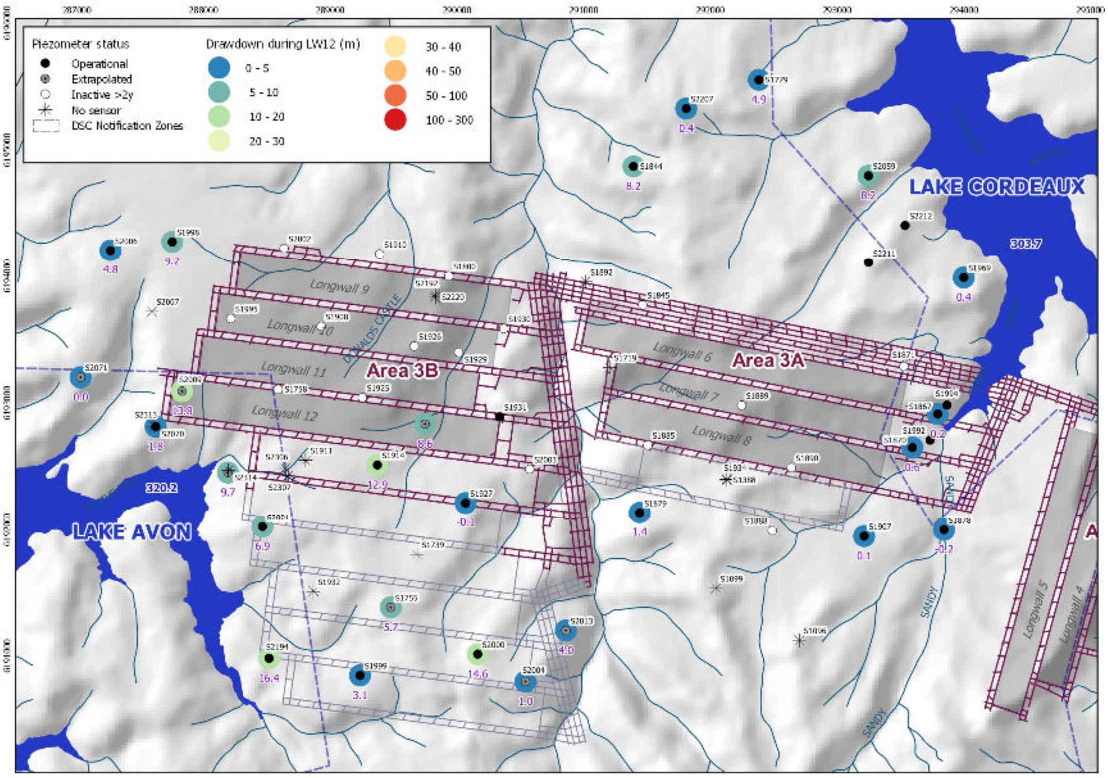

Figure 34. Drawdown in piezometric head in the Bulli Coal Seam during LW12

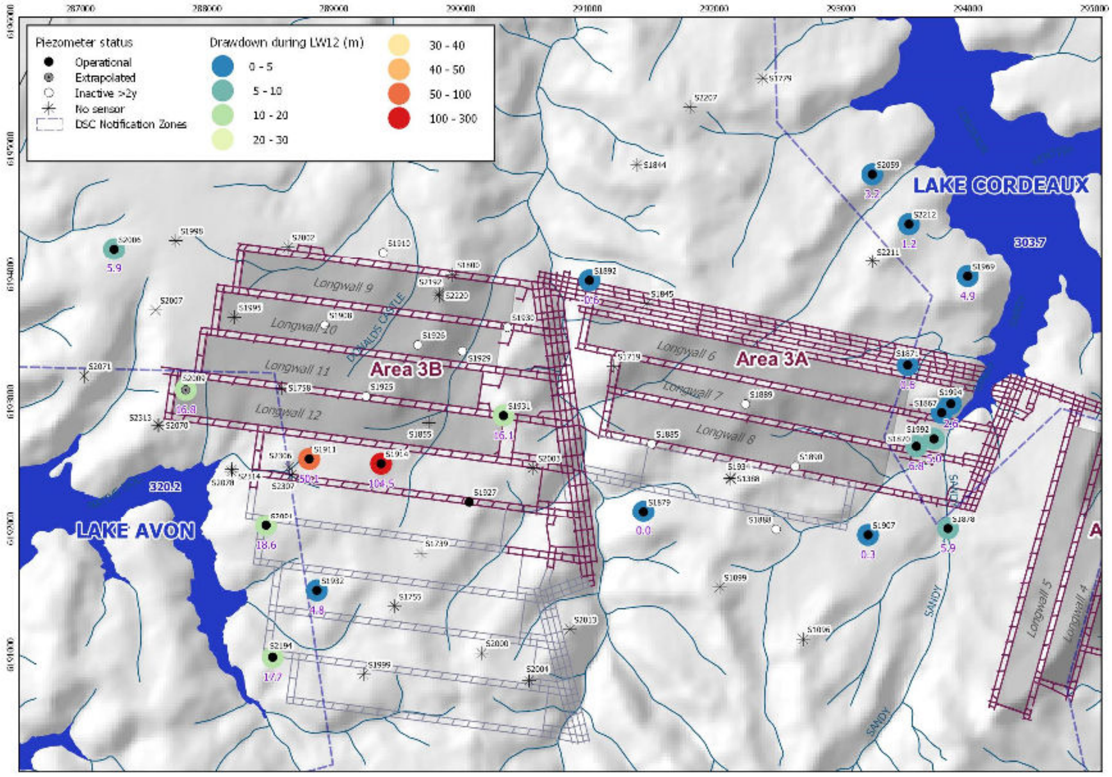

Figure 35. Drawdown in piezometric head in the Scarborough Sandstone during LW12

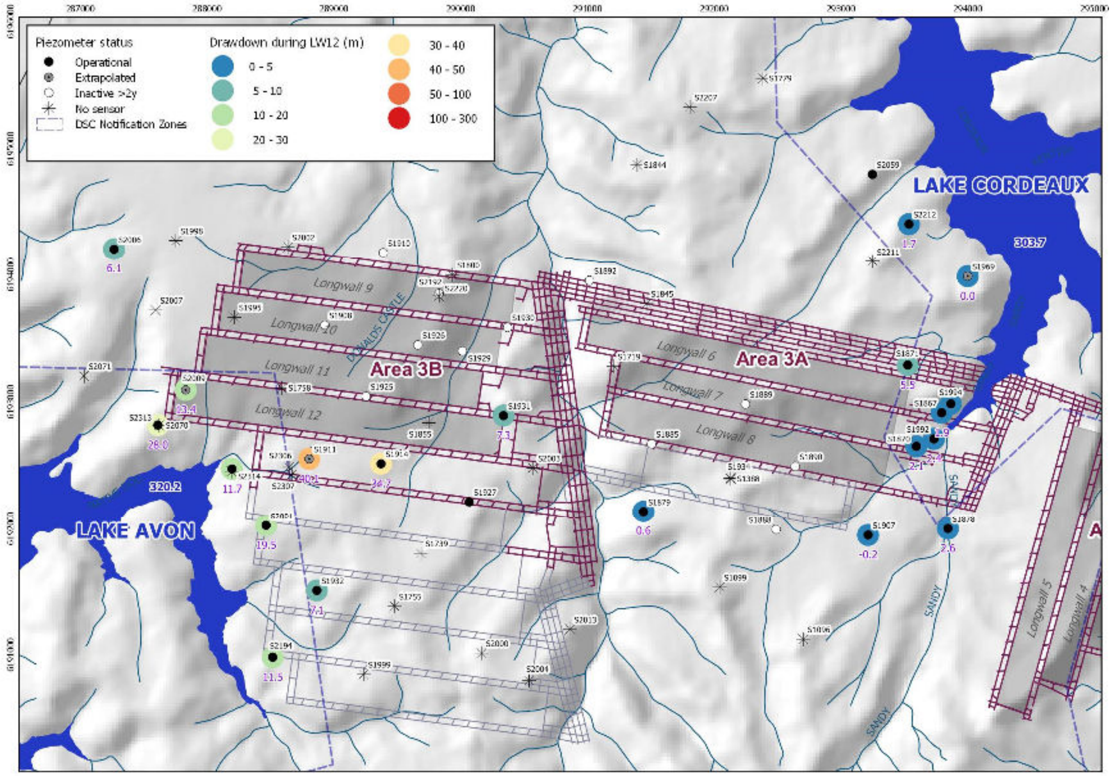

Figure 36. Drawdown in piezometric head in the Bulgo Sandstone during LW12

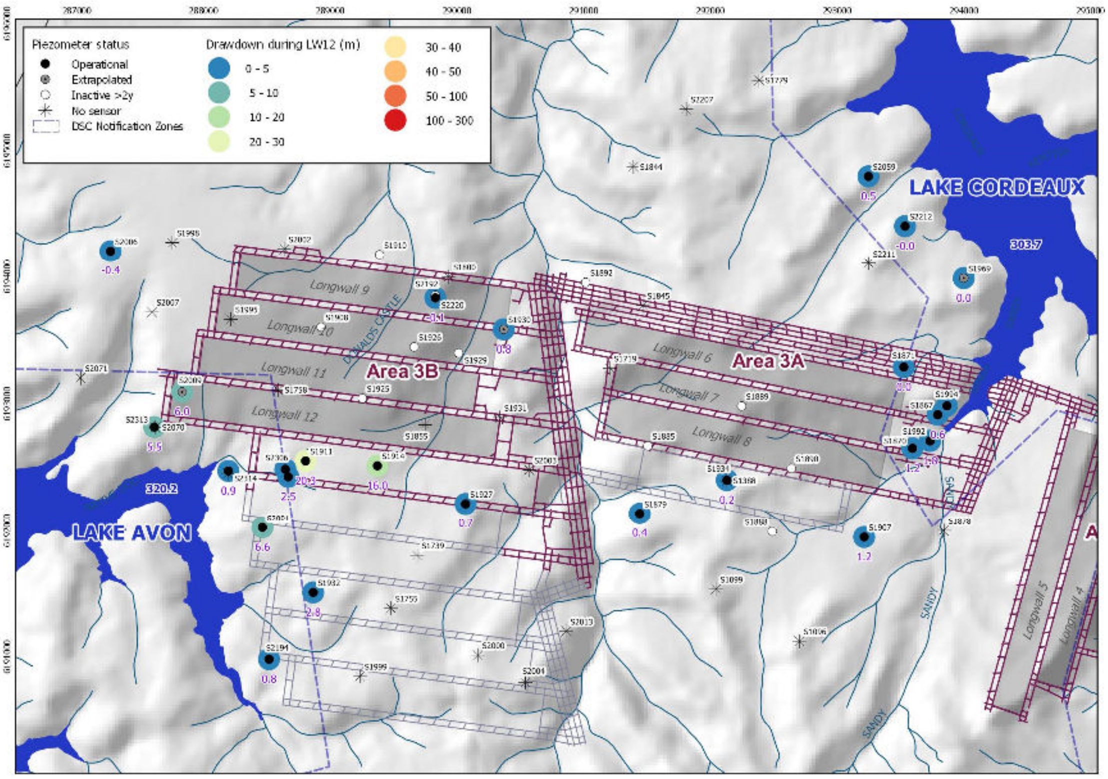

Figure 37. Drawdown in piezometric head in the Hawkesbury Sandstone during LW12

APPENDIX C: LIST OF PIEZOMETERS (AREAS 2 AND 3)

Bore_ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_ Area	Sensors	First_record	Last_record	Years
S1096	DDH 19	292699.6	6191120.9	435.10	3A	1	2007-11-22	2010-02-24	2.3
S1099	DDH 22	292040.9	6191530.9	429.90	3A	1	2006-12-06	2010-01-28	3.1
S1388	DDH 29	292128.9	6192392.9	427.60	3A	1	2006-04-04	2010-01-22	3.8
S1390	DDH 31	292469.3	6194395.7	375.20	3C	1	2005-03-22	2015-01-22	9.8
S1579	DDH 40	289061.3	6192056.3	423.10	3B	1	2005-01-14	2015-07-29	10.5
S1587	DDH 41	292934.4	6193080.4	412.00	3A	1	2005-01-28	2009-11-02	4.8
S1719	DDH 56	291202.0	6193277.0	413.60	3A	1	2005-06-16	2010-02-17	4.7
S1739	DDH 62	289683.6	6191798.7	423.71	3B	1	2005-09-02	2017-01-19	11.4
S1755	DDH 64	289475.4	6191380.2	433.30	3B	2	2006-01-10	2016-02-03	10.1
S1758	DDH 65	288586.6	6193106.9	408.80	3B	2	2006-01-25	2006-09-13	0.6
S1779	DDH 67	292381.4	6195550.6	368.70	3C	2	2006-04-04	2017-01-18	10.8
S1796	DDH 69	289946.6	6194587.4	398.60	3B	1	2006-02-15	2017-01-23	10.9
S1800	DDH 70	289933.4	6193996.5	392.50	3B	2	2006-04-24	2006-09-10	0.4
S1844	DDH 76	291391.1	6194868.8	375.62	3C	2	2006-08-22	2017-04-10	10.6
S1845	DDH 77	291464.0	6193770.0	399.69	3A	2	2006-11-29	2010-01-04	3.1
S1855	DDH 82	289746.5	6192833.2	366.64	3B	2	2006-12-11	2016-07-27	9.6
S1867	DDH 84	293792.6	6192912.5	345.97	3A	11	2007-03-20	2017-03-25	10.0
S1870	DDH 85	293593.2	6192648.2	351.46	3A	12	2007-02-02	2017-02-01	10.0
S1871	DDH 86	293525.0	6193287.1	375.64	3A	12	2007-02-17	2016-08-23	9.5
S1878	DDH 91	293842.3	6191994.3	337.10	3A	11	2007-04-24	2017-02-22	9.8
S1879	DDH 92	291440.3	6192133.4	379.74	3A	12	2007-06-07	2017-02-22	9.7
S1885	DDH 93	291504.4	6192667.9	420.00	3A	12	2007-06-07	2012-05-17	4.9
S1888	DDH 96	292486.5	6191987.4	381.30	3A	8	2007-05-31	2015-07-01	8.1
S1889	DDH 97	292244.8	6192980.4	435.44	3A	8	2007-06-02	2011-08-10	4.2
S1890	DDH 98	292637.3	6192490.5	407.10	3A	8	2007-07-31	2012-08-07	5.0
S1892	DDH 99	291014.1	6193952.0	356.10	3A	8	2008-08-07	2016-10-19	8.2
S1907	DDH 103	293212.2	6191943.1	371.94	3A	8	2008-01-25	2017-02-22	9.1
S1908	DDH 104	288925.9	6193601.4	405.73	3B	8	2008-05-16	2014-05-01	6.0
S1910	DEN 105	289387.4	6194176.3	377.20	3B	8	2008-08-29	2013-10-04	5.1
S1911	DEN 106	288802.8	6192549.4	405.16	3B	12	2008-05-15	2016-11-22	8.5
S1914	DEN 107	289370.0	6192511.9	414.52	3B	8	2008-04-29	2017-01-23	8.7
S1925	DDH 108	289251.6	6193041.1	416.71	3B	8	2008-08-04	2017-01-23	8.5
S1926	DDH 109	289660.4	6193444.9	408.95	3B	8	2008-08-27	2014-08-08	5.9
S1927	DDH 110	290066.0	6192211.0	414.80	3B	8	2008-05-16	2017-01-23	8.7
S1929	DDH 111	290010.6	6193398.1	337.71	3B	8	2008-08-27	2014-08-08	5.9
S1930	DDH 112	290367.3	6193582.9	353.11	3B	12	2008-10-29	2016-11-22	8.1
S1931	DDH 113	290335.6	6192889.9	396.40	3B	9	2008-08-11	2017-04-10	8.7
S1932	DDH 114	288863.3	6191505.4	396.12	3B	12	2008-08-30	2017-01-23	8.4

Bore_ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_ Area	Sensors	First_record	Last_record	Years
S1934	DDH 115	292128.0	6192398.0	427.51	3A	4	2009-12-05	2017-02-22	7.2
S1967	EAW26	284811.5	6215000.5	124.90	3C	11			
S1969	DEN 118	293998.1	6193985.7	368.52	3C	11	2009-08-12	2016-12-05	7.3
S1992	DEN 119	293732.1	6192706.8	339.12	3A	8	2009-05-10	2017-03-29	7.9
S1994	DEN 120	293865.2	6192982.4	345.49	3A	8	2009-01-13	2017-01-01	8.0
S1995	DEN 121	288212.4	6193662.3	404.45	3B	2	2009-06-12	2014-01-28	4.6
S1998	DEN 122	287750.6	6194273.1	410.52	3B	2	2009-06-11	2017-02-19	7.7
S1999	DEN 123	289232.8	6190843.7	406.43	3B	2	2009-07-10	2017-02-27	7.6
S2000	DEN 124	290161.4	6191011.2	441.98	3B	2	2009-07-10	2016-08-01	7.1
S2001	DEN 125	288462.6	6192020.0	413.88	3B	10	2009-08-06	2017-02-28	7.6
S2002	DEN 126	288633.4	6194222.1	399.97	3B	2	2009-07-21	2012-02-19	2.6
S2003	DEN 127	290571.1	6192478.0	409.42	3B	2	2009-08-04	2014-03-01	4.6
S2004	DEN 128	290538.5	6190794.8	443.48	3B	2	2010-10-13	2015-10-07	5.0
S2006	DEN 129	287263.2	6194204.3	409.11	3B	10	2009-07-24	2017-02-27	7.6
S2007	DEN 130	287590.8	6193718.9	405.80	3B	2	2009-06-17	2017-01-19	7.6
S2009	DEN 131	287828.2	6193092.0	402.53	3B	10	2009-08-10	2016-03-24	6.6
S2010	DEN 132	292273.2	6196658.1	374.20	3C	1	2009-08-20	2017-01-20	7.4
S2011	DEN 133	292055.1	6197166.1	371.71	3C	2	2009-07-21	2017-01-20	7.5
S2013	DEN 134	290857.7	6191198.2	399.74	3B	2	2009-07-22	2015-10-16	6.2
S2059	DEN 148	293245.7	6194795.1	380.79	3C	12	2011-08-16	2017-04-13	5.7
S2070	DEN 150	287619.3	6192813.2	414.69	3B	2	2013-05-15	2017-02-27	3.8
S2071	DEN 151	287027.2	6193200.9	443.07	3B	2	2010-05-05	2015-05-14	5.0
S2078	DEN 154	288190.0	6192451.9	342.01	3B	2	2010-06-20	2016-11-22	6.4
S2126	[Decom]	288536.6	6193897.9	397.65	3B	2			0
S2143C		293984.0	6192803.4	335.79	3A	1	2011-08-03	2013-07-23	2.0
S2192		289826.7	6193848.7	389.32	3B	6	2013-03-25	2014-11-18	1.7
S2194		288514.9	6190978.8	371.13	3B	11	2013-04-13	2017-02-12	3.8
S2207		291807.6	6195324.3	416.78	3C	2	2013-08-07	2017-01-09	3.4
S2288	S2208	292801.1	6195037.3	344.08	3C	7	2014-12-19	2017-03-21	2.3
S2211		293247.0	6194106.0	397.73	3C	2	2013-10-03	2017-02-28	3.4
S2212		293534.8	6194402.9	369.20	3C	10	2013-10-11	2017-04-12	3.5
S2220	AQ5	289827.2	6193830.7	388.11	3B	6	2014-11-12	2017-03-30	2.4
S2306	Swamp Bore 3	288643.3	6192483.7	395.51	3B	4	2015-09-16	2017-02-13	1.4
S2307	Swamp Bore 4	288665.9	6192424.6	394.50	3B	4	2015-09-16	2017-02-13	1.4
S2313	Avon 1	287609.0	6192815.5	415.28	3B	3	2015-10-30	2017-03-12	1.4
S2314	Avon 2	288193.5	6192470.3	342.36	3B	3	2015-11-13	2017-03-28	1.4