DENDROBIUM MINE

End of Panel Groundwater Assessment: Longwall 11 (Area 3B)

FOR

South32 - Illawarra Coal

BY

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EXECUTIVE SUMMARY

HydroSimulations (HS) was engaged by Illawarra Coal (IC) to prepare an assessment of hydrogeological consequences of Longwall 11 extraction on groundwater conditions in Area 3B at Dendrobium Mine, as required under the conditions of mining approval.

Extraction of Longwall 11 commenced on 18 February 2015 (following the completion of Longwall 10) and was completed on 26 January 2016. Longwall 11 is the third panel to be extracted in Area 3B. This longwall had an extracted length of 2304 m, a void width of 305 m (including first workings) and an average extraction height of 3.83 m.

This groundwater assessment is based primarily on an examination of spatial and temporal responses measured in downhole vibrating wire piezometers, and comparison of observed groundwater head drawdowns with those anticipated by numerical groundwater modelling (HS, 2014; Coffey, 2012). In addition, the measured groundwater inflow to the mine has been compared to the flows anticipated by the numerical model. Variations in groundwater salinity have also been examined in several geological formations.

Mine inflow

At the completion of Longwall 11, the total mine inflow was about 8 ML/day (ML/d) after averaging 6.2 ML/d during Longwall 11 extraction. Mine inflow to Area 3B during the extraction of Longwall 11 averaged 3.6ML/d with standard deviation 0.7 ML/d. Modelled mine inflows agree well with those observed over the assessment period. Periods of high total mine inflow compared with the long-term trend tend to be correlated with high rainfall events and associated increased inflows to Area 3A and Area 2.

Groundwater quality

Groundwater salinity (as indicated by Electrical Conductivity – EC) shows no significant spatial variation in either Bulgo Sandstone or Hawkesbury Sandstone bores. There is a general increase in salinity with depth from the Hawkesbury Sandstone to the Bulgo Sandstone and down to the coal measures. Groundwater in the Hawkesbury Sandstone is variable but typically has an EC of between 80 and 500 µS/cm, whereas inflow to the mine typically has an EC in the range of 1000 to 3000 µS/cm. This is a natural phenomenon and indicates that groundwater inflow to the mine is dominated by groundwater from the deep geological strata. There is no evidence for adverse change to groundwater quality as a result of mining.

Groundwater levels

Groundwater levels are monitored by IC using an extensive network of vibrating wire piezometers that extend vertically from near the surface to within the coal measures. In the Wongawilli and Bulli coal seams, the lowest groundwater pressures occurred in the vicinity of Longwall 11 (as expected), although partial depressurisation above the longwall is evident prior to the start of Longwall 11 as a result of previous mining at Areas 3B and 3A, and at neighbouring mines.

The largest change in groundwater level (groundwater drawdown) during the extraction of Longwall 11 occurred within the Scarborough Sandstone and Bulgo Sandstone in Area 3B. This is attributed to subsidence induced fracturing above the extracted longwalls in Area 3B and resulting depressurisation of the fracture network. Incremental drawdown in the Bulgo Sandstone and Scarborough Sandstone was in the order of 40 m to 50 m, based on piezometers not damaged by mining induced movements. Drawdown decreases with

distance from the panel to approximately 5 m at a distance of 1 km from Longwall 11. The observed incremental drawdown is consistent with numerical model predictions.

In the lower Hawkesbury Sandstone, incremental drawdown of approximately 16 m was noted in a piezometer immediately adjacent to Longwall 11. Drawdown of ~10 m was noted in piezometers within the Hawkesbury Sandstone that overlie Longwalls 9 and 10. Depressurisation is largely restricted to the Longwall footprint, decreasing to zero (no identifiable drawdown during the period) at a distance of 1.2 km from the goaf. Piezometers in the Sandy Creek area (Area 2) show slight recovery of groundwater levels by up to 2 m during the reporting period. The observed drawdown in the lower Hawkesbury Sandstone in Area 3B due to the extraction of Longwall 11 is less than the modelled drawdown in the vicinity of the longwall, and of a similar magnitude elsewhere.

Of the four groundwater monitoring bores east of Area 3A (near Sandy Creek and Cordeaux Reservoir) for which Bulgo Sandstone TARP triggers are assessed;

- trigger Level 3 has been reached in S1870, with all Bulgo Sandstone piezometers recording groundwater levels lower than Cordeaux Reservoir lake level;

- while the other bores monitored for this TARP (S1867, S1992, S1994) remain at trigger Level 2, indicating two out of three piezometers are recording Bulgo Sandstone groundwater levels lower than Cordeaux lake level.

The numerical model predictions of groundwater inflow to the mine continue to match well with observed inflows, particularly in Area 3B. The model tends to slightly over-estimate groundwater drawdown in overlying strata, particularly in the deeper strata. Based on the requirements and requests of various agencies, e.g. Dams Safety Committee (DSC) and Department of Planning and Environment (DP&E), the updated groundwater model was completed in February 2016 and is currently under review.

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1 INTRODUCTION

HydroSimulations (HS) was engaged by Illawarra Coal (IC) to prepare an assessment of hydrogeological impacts of Longwall 11 extraction on groundwater conditions in Area 3B at Dendrobium Mine. HS was commissioned previously to prepare End of Panel reports for Longwall 6 (Heritage Computing (HC), 2011a), Longwall 7 (HC, 2012), Longwall 8 (HS, 2013), Longwall 9 (HS, 2014) and Longwall 10 (HS, 2015).

1.1 BACKGROUND

The 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 (WNSW). The three designated areas of extraction lie adjacent to the Cordeaux Reservoir: Area 1 (east), Area 2 (west), and Areas 3A and 3B (far west) (**Figure 1.1**). 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 has been mined at Mt Kembla to the east of Area 1.

Extraction of Longwall 11 within Dendrobium Mine Area 3B commenced on 18 February 2015 and was completed on 26 January 2016. This longwall had an extracted length of 2304 m[1], a void width of 305 m (including first workings) and an average extraction height of 3.83 m.

Longwall 11 is the third panel to be extracted in Area 3B. An earlier End of Panel report for Longwall 6 extraction in Area 3A (HC, 2011a) developed performance indicators for impacts on groundwater pressures and mine inflows in Area 3A, based on a local 3D numerical groundwater model that was used to give more quantitative predictions than was possible during Area 1 and Area 2 extraction.

The regional modelling report of Coffey (2012) was the basis for the *Area 3B Subsidence Management Plan* (SMP) application and subsequent approval. HydroSimulations (2014a) revised the Coffey (2012) groundwater model to include calibration to shallow (swamp) groundwater data and surface water (creek) flows, and assess potential mining effects on those surface systems. This 2014 revision addressed the Area 3B SMP approval conditions and provides the basis for this groundwater impact assessment.

1.2 HYDROGEOLOGY

Heritage Computing (2009) provides an assessment of groundwater conditions and local geology. This report was commissioned to investigate possible mechanisms for high mine inflow events that occurred in Area 2 in June 2007, February 2008 and June 2008. Coffey (2012) and HydroSimulations (2014) present further hydrogeological analysis and regional-scale numerical model development.

The stratigraphic framework or column adopted in the model is shown in **Figure 1.2** with typical thicknesses for the main geological formations.

A sketch of the conceptual hydrogeological model, provided in **Figure 1.3**, illustrates three distinct groundwater systems:

[1] 2219 m as measured in the maingate; 2222 m in the tailgate.

- Deep groundwater system;
- Shallow groundwater system; and
- Perched groundwater system (associated with shallow sandstone and swamps).

The extent of the groundwater model is shown in **Figure 1.4**. Two cross-sections of modelled stratigraphy are presented in **Figure 1.5** for a representative west-east section along the Longwall 9/Longwall 10 boundary and for a south-north section through Longwalls 9 10 and 11, Donalds Castle Creek to the north, and the southern arm of Avon Reservoir to the south.

Topographic relief will drive vertical groundwater flow near the ground surface, but at depth the alternation of aquifers and aquitards will promote horizontal groundwater flow at the base of permeable units. Along the escarpment to the south-east of Dendrobium Mine, water appears as seeps in cliff faces at the junction of formations with contrasting permeability.

Recharge to the aquifer system 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 Cordeaux and Avon Reservoirs to host formations at times of high water level.

Discharge from the aquifer system will occur naturally at the surface to creeks and to the reservoir as baseflow and seeps, and by evapotranspiration through vegetation. A local groundwater mound will develop beneath the sandstone hills with ultimate discharge to incised creeks and water bodies. For a study area of limited extent, lateral groundwater outflow will occur across down-gradient study area boundaries.

During the longwall mining process: immediately above a mined coal seam, rocks will collapse into the void to form a caved zone and cause changes to aquifer permeability and porosity. As the mining proceeds, a fractured zone will develop above the caved zone and aquifer properties will change with time. The overlying rocks in the fractured zone will have a higher vertical permeability and possibly enhanced horizontal permeability. Depending on the width of the longwall panels and the depth of mining, and an alternation of thick sandstone/claystone lithologies, there will be a ‘constrained’ zone in the overburden in which the strata sags with limited fracturing. This will tend to isolate the shallow aquifer system from stresses applied to the deep aquifers, although the aquifers will remain in hydraulic connection. Groundwater pressures will reduce towards atmospheric pressure at the base of the fractured zone.

In the HC (2014a) numerical model, higher permeabilities in the fractured zone are primarily applied up to and including the Bald Hill Claystone, although in some parts of Area 3B it is simulated to intersect the lower Hawkesbury Sandstone (see HydroSimulations, 2014a for full details).

2 MONITORING DATA

This section presents the monitoring data available for the groundwater assessment, and most of the discussion of the observed hydrological behaviour is presented in Section 0.

2.1 MANAGEMENT PLAN

Groundwater monitoring at Dendrobium Mine is conducted in accordance with the "Dendrobium Colliery Area 3B SMP Groundwater Management Plan" (October 2012).

The aims of the 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 2.1**.

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 significant database of groundwater pressures has been established and is updated routinely. The numbers of installed piezometers are (at August 2016):

- 65 in Area 1;
- 126 in Area 2;
- 140 in Area 3A; and
- 195 in Area 3B.

2.2 DEEP GROUNDWATER LEVELS

Time-series hydrographs for the deep aquifer system and for multi-level piezometer sites have been prepared for Area 3B and Area 3A. An illustrative selection is included in this report. Most VWPs at Dendrobium suffer from electromagnetic noise which causes spurious spikes in the data records. Noisy data are filtered and removed where practical.

As the Area 3B hydrographs are most relevant for the current assessment of the effect of the extraction of Longwall 11, a selection of Area 3B hydrographs is presented as **Figure 2.2** to **Figure 2.10** for monitoring Longwall 11. **Figure 2.16** to **Figure 2.19** are included to show monitoring near Sandy Creek and in Area 3A to the immediate east of Area 3B.

The hydrographs are drawn 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. The hydrographs include surface water hydrographs for the nearest water supply reservoir (Lake Cordeaux for Area 3A and Lake Avon for Area 3B hydrographs).

Maps showing contours of groundwater potentiometric head are presented for the Wongawilli Seam, Bulli Seam, Scarborough Sandstone, Bulgo Sandstone and lower Hawkesbury Sandstone at (or close to) the completion of Longwall 11 and the completion of Longwall 10 (**Figure 2. 20** to **Figure 2. 24**). Note that, where data records are incomplete or truncated (i.e. due to mining or lightning damage), values of potentiometric head at those locations are estimated or interpolated from previous data or data from adjacent sites (as indicated on the maps).

Maps showing the incremental change in potentiometric head between the end of the previous panel and the end of the most recent panel are shown in **Figure 2. 25** to **Figure 2.29**. The plots illustrate the estimated ***drawdown*** in potentiometric head during the mining of the most recent longwall.

2.3 MINE WATER BALANCE

The Groundwater Management Plan outlines the procedure for calculating a daily mine water balance from measurement of all water inflow and outflow components, with defined triggers and alarm levels. Flow meters, hygrometers, a microwave analyser and a weightometer are deployed to record water removed by pumping, water in the ventilation air, and moisture within run of mine (ROM) coal. Total inflow to the mine from groundwater is estimated by mass balance from those other flows that are accurately measured.

The total mine water balance from February 2005 is shown in **Figure 2.30** as daily volumes in kilolitres [kL/d] and as a 31-day (i.e. monthly) moving average. Time series plots of the mine water balance are shown for Area 3A and Area 3B in **Figure 2.31** from the commencement of Longwall 6, along with daily rainfall. Separate and combined balances are maintained for Area 3A and Area 3B. Area 3A balance is shown from the commencement of Longwall 6 and Area 3B balance is shown from 16 June 2012.

Table 2-1 presents mine inflow statistics for each Area from March 2007, when Longwall 3 commenced in Area 2, through to 26 January 2016 when Longwall 11 finished. For the period June 2012 (since the first workings in Area 3B) Area 3B has reported about 1.8 ML/d on average with a peak of 6.1 ML/d.

Table 2-1 Water Balance and Inflow Statistics for the Period 2007-2016 [in ML/day]

STATISTIC	AREA 1	AREA 2#	AREA 3A^	AREA 3B*	TOTAL
MEDIAN	0.45	1.05	2.40	1.87	4.00
MEAN	0.50	1.33	2.43	1.82	4.14
STANDARD DEVIATION	0.33	1.04	0.94	1.52	2.44
MINIMUM	-0.67	-1.41	-2.16	-2.37	-0.36
MAXIMUM	2.27	9.24	6.52	6.07	13.06

Data source: MineInflow_AS_EOP11.xlsx!Inflow

Notes: # Includes Area 3A up to 26 June 2010; ^ From 26 June 2010; * From 16 June 2012

Table 2-2 presents mine inflow statistics for each Area for the period over which Longwall 11 was extracted (18 February 2015 to 26 January 2016). Area 3B has reported about 3.6 ML/d on average with a peak of 6.1 ML/d.

Table 2-2 Dendrobium Mine Inflow during the Extraction of Longwall 11 [in ML/day]

STATISTIC	AREA 1	AREA 2#	AREA 3A^	AREA 3B*	TOTAL
MEDIAN	0.38	0.79	2.82	3.62	8.06
MEAN	0.37	1.17	2.80	3.64	7.97
STANDARD DEVIATION	0.16	0.95	0.79	0.71	1.51
MINIMUM	0.03	-0.36	0.27	0.18	2.55
MAXIMUM	0.87	4.45	5.42	6.07	11.83

Data source: MineInflow_AS_EOP11.xlsx!Inflow

Notes: # Includes Area 3A up to 26 June 2010; ^ From 26 June 2010; * From 16 June 2012

2.4 GROUNDWATER CHEMISTRY

Groundwater quality is monitored in Hawkesbury Sandstone bores at 14 sites and in Bulgo Sandstone at 10 sites in Area 3, as shown in **Figure 2.32**. There is one Scarborough Sandstone sample site in Area 2 at S1904 (DDH94).

The *Underground Water Sampling and Analysis Procedure* (DENP0048) outlines the routine analysis of water samples taken from underground workings, inter-seam boreholes, flooded adjacent mine workings, as well as surface stored waters and boreholes. 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 by HydroSimulations each month and reported to relevant government agencies. The water “fingerprints” are used to identify discrete water sources and identify if underground water contains a component of reservoir water or surface water.

As a gross indicator of water quality, average field electrical conductivity (EC), is displayed spatially in **Figure 2.32** for Hawkesbury Sandstone [HBSS] and Bulgo Sandstone [BGSS]. The latest groundwater quality samples (Longwall 10) indicate no significant change in groundwater quality in the Hawkesbury Sandstone or the Bulgo Sandstone as a result of mining at Area 3B.

A statistical summary of groundwater EC is presented in **Table 2-3** and with a box and whisker diagram to show distribution of EC at the varying sources of water at Dendrobium (**Figure 2.33**). Included are comparisons with the quality of goaf waters sampled in Area 2 (at Main Gate 5), Area 3A (from both the goaf and seeps) and Area 3B (from both the goaf and seeps). Groundwater samples that show evidence of influence from grout used in the construction of the piezometers (e.g. S1907 and S2197) are excluded from calculations and spatial plots. The influence of grout on groundwater samples is typically indicated by unusually high pH (>8.5), elevated EC and sometimes elevated Sulfate.

Table 2-3 Groundwater Electrical Conductivity Statistics [µS/cm]

STATISTIC	HAWKESBURY SANDSTONE*	BULGO SANDSTONE*	AREA2 GOAF [MAINGATE MG5]	AREA 3A GOAF	AREA3A SEEPS	AREA 3B GOAF	AREA 3B SEEPS
90% EXCEEDANCE	69	237.2	1059	754	1026	754	877.5
MEDIAN	113	444	1555	849	2230	849	2120
10% EXCEEDANCE	344	685.6	1803	1148.5	2330	1148.5	3720

* Grout seal-affected data excluded

Source: Prob_Salinity.xls

3 ASSESSMENT OF GROUNDWATER RESPONSE TO MINING

3.1 DEEP GROUNDWATER LEVELS

The analysis of deep groundwater levels is based on the following sets of illustrations:

- **Figure 2.2** to **Figure 2.5** - hydrographs associated with Longwall 9, Longwall 10 and Longwall 11 in Area 3B;
- **Figure 2.7** to
- **Figure** 2.10 - hydrographs over Area 3B;
- **Figure 2.11** and **Figure 2.12**- hydrographs between Area 3B and Avon Reservoir;
- **Figure 2.13** to **Figure 2.15** - hydrographs in Area 3A to the immediate east of Area 3B;
- **Figure 2.16** to **Figure 2.19**- hydrographs between Area 3A and Cordeaux Reservoir:
- **Figure 2. 20** to **Figure 2. 24** - head contour maps for the Wongawilli Seam, Bulli Seam, Scarborough Sandstone, Bulgo Sandstone and lower Hawkesbury Sandstone; and
- **Figure 2. 25** to **Figure 2.29** - drawdown contour maps for the Wongawilli Seam, Bulli Seam, Scarborough Sandstone, Bulgo Sandstone and lower Hawkesbury Sandstone.

3.1.1 AREA 3B: STRATA ABOVE MINED LONGWALLS

Depressurisation of the Bulli and Wongawilli seams started during Longwall 5 extraction (mid-late 2009; **Figure 2.2** to

Figure 2.10), propagating from Area 3A to almost all coal seam piezometers in Area 3B. This drawdown is less apparent in bore S2193/S2194 which is furthest from Area 3A (this bore is located in the southwest of Area 3B).

Bore S1910 (DDH105) is located immediately north of the development headings around the centre of Longwall 9 (**Figure 2.1**). All formations beneath the upper Hawkesbury Sandstone were affected by Longwall 9 extraction at this bore (**Figure 2.2**). Depressurisation of lower Hawkesbury, Bulgo and Scarborough Sandstones started to occur at different times after the Longwall 9 extraction commenced. There is an observed increasing time lag to the depressurisation response up through the strata: about three months in the lower Scarborough Sandstone, and about five months in the lower Hawkesbury Sandstone. The response of the coal seams occurred with very little time lag: about one to two months. This bore was sheared off before the commencement of Longwall 10. No further data are available.

Bore S1925 lies on a pillar between Longwall 11 and Longwall 12 (**Figure 2.1**). 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 2.3**). 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 at with the extraction of Longwall 9. The apparent recovery observed in the units below the Hawkesbury Sandstone during Longwall 11 extraction in can likely be attributed to an increase in water pressure due to compaction effects as the longwall face approached the bore. Prior to the shearing of the 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 2.1**). 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 2.4**). 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. The apparent short-term recovery in groundwater levels in the piezometers in the Bulli Seam, Scarborough Sandstone and Bulgo Sandstone in January 2014 is most likely an increase in water pressure due to compression effects as the longwall face (of Longwall 9) approached the bore. Aside from that transient compression effect, depressurisation has occurred at a fairly steady rate in the Bulli Seam, Scarborough Sandstone and Bulgo Sandstone from Longwall 7 until the bore shears in late 2014, likely due to subsidence caused by the passing of Longwall 10.

Bore S2192 lies north of Longwall 10 and over Longwall 9 (**Figure 2.1**). Only seven months of data were recorded since the commencement of Longwall 9, due to the bore becoming sheared due to subsidence following mining. 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 from either Longwall 9 or 10 (**Figure 2.5**). This is probably due to the time lags noted at bore S1910 for depressurisation to propagate up through the sequence.

S2009 directly overlies Longwall 12 (**Figure 2.1**) but shows large gaps in groundwater level data (from March 2010 to October 2014 and May to October 2015 (**Figure 2.6**)), 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. The deeper two Hawkesbury Sandstone sensors show a drawdown of about 5 m. Increasing head loss is seen in the units below the Hawkesbury Sandstone, with drawdowns of 10 m and 25 m occurring in the upper (185 m depth) and middle (221 m depth) Bulgo Sandstone piezometers. Heads in the lower Bulgo Sandstone (261 m depth) have dropped by about 35 m, which is nearly identical to the head loss seen in both the upper (295 m depth) and lower (309 m depth) Scarborough Sensors. The coal seams at S2009 have been depressurising since the beginning of observation due to mining of previous panels and mining elsewhere.

3.1.2 AREA 3B: STRATA OUTSIDE MINED LONGWALLS

Unlike what was observed in the closest bores to Longwall 11, Hawkesbury Sandstone heads to the south of active mining were less affected by Longwall 11 mining. Five VWPs recorded data in this area. Among them, Bore S2009 (EDEN 131) is the closest to Longwall 11, over Longwall 12, followed by Bore S1911 (DDH106), over proposed Longwall 13, followed by S2001 (DDH125), S1932 (DDH114) and S2193/S2194 (see **Figure 2.1**).

Heads in the lower Bulgo Sandstone dropped about 15 m at S1911 (**Figure 2.7**) and about 1 m at S1932 (DDH114) during the extraction of Longwall 11. An anomalously large head response was observed in the middle Bulgo Sandstone piezometer in bore S1911 (at 229.5 m below ground), compared with sensors above and below this sensor. The reason for this anomaly was investigated previously but remains unclear (see Hydrosimulations 2015a for a more detailed discussion). Other sensors show higher drawdown and earlier response to mining with increasing depth. The drawdown trend continued during Longwall 11.

Bore S1932 (**Figure 2.8**) to the south of Longwall 11 and directly overlying proposed Longwall 16 shows divergent trends in potentiometric level depending on the sensor depth.

Sensors in the 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 11. 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 (<10 m). Similar divergent sensor trends are evident in **Bore S2001** (**Figure 2.9**), 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 (HydroSimulations, 2015a).

At **S2194** no mining effect is observed in the upper Bulgo Sandstone (sensors at 111 m and 151 m depth) (

Figure 2.10). However, depressurisation has been occurring in the lower Bulgo Sandstone and Scarborough Sandstone since the beginning of observation in early 2013. During Longwall 11 extraction groundwater level in these units declined by about 20 m.

3.1.3 AVON RESERVOIR BORES

Bores S2313 (**Figure 2.11**) and S2314 (**Figure 2.12**) 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. None of the piezometers in either bore indicates a mining effect.

3.1.4 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.

Bore S1879 (DDH92) 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 active Area 3B roadways and headings (**Figure 2.1**). The groundwater level hydrographs from the multilevel piezometers in this bore are presented in **Figure 2.13**. Significant 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. During the second half of Longwall 6 extraction, pressures also began to decline in the upper and lower Bulgo Sandstone but not in the Hawkesbury Sandstone. A similar but muted response can be observed in S1907 (**Figure 2.14**) which is located to the south of proposed Longwall 19 (**Figure 2.1**). S1879 shows stable potentiometric heads in most units during the mining of Longwall 11, whereas S1907 shows slight depressurisation in the Lower Bulgo Sandstone and Scarborough Sandstone.

Bore S1885 (**Figure 2.15**) is located near the southern edge of (future) Longwall 19 (and south of recent Longwall 8) in Area 3A. The Wongawilli Seam has been observed to depressurise prior to the mining of Area 3A, with the rate of depressurisation increasing during Longwall 5 extraction in early 2009. All formations from the Bulgo Sandstone down to the Wombarra Claystone show similar patterns of declining heads from 2007, with increasing depressurisation in late 2010 (Longwall 7), until the last available data in 2012.

3.1.5 AREA 3A GROUNDWATER MONITORING TARP

Groundwater levels in the Bulgo Sandstone at four bores near to Sandy Creek and Cordeaux Reservoir are the subject of a Trigger Action Response Plan (TARP) in the *Avon and Cordeaux Reservoir Management Plan* (Illawarra Coal, 2014). Groundwater level hydrographs for each bore, alongside the record of Cordeaux lake level are presented for the following bores;

- S1867 (**Figure 2.16**);
- S1870 (**Figure 2.17**);
- S1992 (**Figure 2.18**); and
- S1994 (**Figure 2.19**).

Currently trigger Level 3 has been reached at S1870 with all Bulgo Sandstone piezometers recording lower than lake level in Cordeaux Reservoir. The other bores monitored for this TARP remain at trigger Level 2, with two of three piezometers recording Bulgo Sandstone groundwater levels lower than Cordeaux lake level.

A summary of the recommendations and action as result of this TARP level can be found in **Section 3.5.**

3.1.6 CONTOURS OF POTENTIOMETRIC LEVEL

Each contour map in **Figure 2. 20** to **Figure 2. 24** shows the monitoring sites for which data was available for interpolation of water levels. Each of these figures presents two contour maps showing:

a) Water levels at the end of Longwall 11 - 26 January 2016; and
b) Water levels at the end of Longwall 10 - 20 January 2015.

Figure 2. 20 presents Wongawilli Seam water levels, and shows that the lowest heads in this formation are at the location of the extracted Area 3B Longwalls. After the completion of Longwall 11 the area of the lowest heads has expanded to the south and west compared to the spatial extent of reduced head at the end of Longwall 10. Otherwise the pattern is very similar to that at the end of Longwall 10.

In the Bulli Seam (**Figure 2. 21**), the head contour patterns are similar between the end of Longwall 10 and Longwall 11. An area of low head has propagated south-west toward Lake Avon at the western side of Area 3B during Longwall 11 extraction, where potentiometric head is in the order of 20 m lower than at the end of Longwall 10. The Scarborough Sandstone (**Figure 2. 22**) showed a similar pattern between the end of Longwall 10 and end of Longwall 11. An area of decreased head over, and to the south of Longwall 11 has formed, with lower heads propagating to the south and south-west as Area 3B mining progresses. Areas of elevated but stable head are present in Area 2 (near S1901) and in Area 3B (bores S1929 (above Longwall 10) and S1931 (east of Longwall 11)). This could be related to sedimentary (strata) facies changes in a south-easterly direction in this area, which are described by Illawarra Coal (2013).

Mapping of water levels in the Bulgo Sandstone (**Figure 2. 23**) shows two centres of low head above Areas 3A and 3B. At the end of Longwall 11, the extent of the low heads in the Bulgo Sandstone at Area 3B has intensified close to the extracted Longwall 11 panel, but has shown little change over Area 3A since the end of Longwall 10 extraction.

Head contour maps are presented for the lower Hawkesbury Sandstone in **Figure 2. 24.** The head patterns at the end of Longwall 11 show a decrease in head over Area 3B in comparison to the head patterns at the end of Longwall 10. This area of lower head is focussed over the middle of the extracted Longwall 11 panel and is in the order of 10 m lower than during mining of Longwall 10.

3.1.7 DRAWDOWN CONTOURS

Each contour map in

Figure 2. 25 to **Figure 2.29** shows the drawdown in potentiometric head between the end of Longwall 10 and the end of Longwall 11. Drawdown estimates are most reliable close to monitoring locations and are not reliable a large distance away.

Drawdown in the Wongawilli Seam (

Figure 2. 25) has stabilised since Longwall 10 extraction and shows moderate reductions (max 11 m at S1925) and some recovery (2 m at S1855) in groundwater level over the northern part of Area 3B. Most of the depressurisation has already been achieved by roadway development and the extraction of Longwall 9 and Longwall 10. The area to the south of Longwall 11 (i.e. in the footprint of future Longwalls 13-18) experienced greater drawdown (10-16 m). Water levels in the Wongawilli Seam in Area 3A appear to be in a stable condition with very minor (less than 2 m) drawdown and some minor recovery.

As for the Wongawilli Seam, the incremental drawdown in the Bulli Seam (

Figure 2. 26) through the extraction of Longwall 11 has stabilised since the end of Longwall 10, with reduction in groundwater level by about 5-15 m over most of Area 3B.

It is likely that the Bulli and Wongawilli Seams have fully depressurised in the vicinity of Area 3A and the current workings of Area 3B, and therefore show little drawdown effect from mining. The southern section of Area 3B shows the largest drawdown in these seams during Longwall 11 extraction which can be attributed to incomplete depressurisation.

Significant incremental drawdowns have been measured in the Scarborough Sandstone within the northern part of Area 3B with a maximum drawdown of 49 m at bore S2009, located to the south-west of Longwall 11 (

Figure 2. 27). The apparent drawdown of 77 m at S1925 is likely spurious and caused by shearing of the sensors during mining.

Figure 2. 27 also shows that Scarborough Sandstone water levels in Area 3A have mostly stabilised, with some areas showing recovery up to 10 m. The maximum drawdown of 27 m is located at the south-east corner of proposed Longwall 19. Water levels have stabilised at the south-western edge of Area 3A.

In the Bulgo Sandstone (

Figure 2. 28) the drawdown pattern is similar to that of the Scarborough Sandstone, with large drawdowns occurring over the extracted Area 3B longwall panels, focussed above the Longwall 11 panel. The maximum drawdown is in S2009 at 48 m. Less drawdown is seen in the Bulgo Sandstone in southern Area 3B, indicating that mining effects have not propagated far to the south. The incremental drawdown is generally minor (1-5 m) across Area 3A with some recovery at S1888 (16 m), and a maximum drawdown of 18 m at S1907.

In the lower Hawkesbury Sandstone (**Figure 2.29**), drawdown is again focussed above the extracted Longwall 11 panel with a maximum drawdown of 20 m observed at S1925.

Drawdown in the order of 10 m extends from the north of Longwall 9 to the south of Longwall 12, however only very minor effects are observed further to the south in Area 3B (little to no mining effect is observed south of Longwall 13). Drawdown in Area 3A ranges from 0 to 2 m and shows stable or recovering groundwater levels.

The largest difference in the drawdown responses between underlying and overlying strata is between the Bulgo Sandstone and Hawkesbury Sandstone, which may be due to the presence of the Bald Hill Claystone between these units. It is also consistent with the concept that vertical networks of mining related fracturing (i.e. the “Fractured Zone”, or “Zone A” of Forster, 1995) extends to within the upper part of the Bulgo Sandstone, and locally, the base of the Hawkesbury Sandstone.

3.2 MINE WATER BALANCE

Figure 2.31 shows the 31-day (i.e. monthly) running average of Area 3A and Area 3B mine inflows from the commencement of Longwall 6. Both Area 3B and Area 3A mine inflows steadily increased during the period of extraction of Longwall 11. During Longwall 11, mine inflow to Area 3B has averaged 3.64 ML/d with a standard deviation of 0.71 ML/d.

During the extraction of Longwall 11, the total peak mine inflow of 11.8 ML/day on 11 May 2015 was comprised of component rates for Area 1 (0.27 ML/d), Area 2(4.03 ML/d), Area 3A (3.84 ML/d) and Area 3B (3.69 ML/d). The maximum daily inflow for Area 3B during Longwall 11 extraction occurred on 4 January 2016, while peak inflow in Area 3A occurred on 5 October 2015 at 5.42 ML/day (**Table 2-2**).

It is evident from **Figure 2.31** that the rate of groundwater inflow, and the variations in inflow are different between mining areas. Groundwater inflows to Area 3B appear to be directly related to the area mined with apparently little consistent correlation with rainfall, whereas Area 3A (where mining has stopped) shows large variations in inflow that may be related to high rainfall events (with some delay). Groundwater inflow to Area 2 has similarly been shown to correlate with high rainfall events with a lag of 7 to 8 days (HC, 2009). The Heritage Computing (2009) report concluded that not all of the inflow during peak inflow events at Area 2 can be accounted for by rainfall infiltration, and suggested at the time that another (or additional) mechanism could be responsible.

The total underground water balance at Dendrobium is subject to a TARP based on volume and origin of mine inflow. Currently and throughout Longwall 11 extraction the TARP level remained below the Level 1 threshold. A summary of this can be found in **Section 3.5**.

3.3 GROUNDWATER CHEMISTRY

The plans of average groundwater electrical conductivity (EC) in **Figure 2.32** show no clear spatial pattern in the distribution of groundwater quality in Hawkesbury Sandstone and Bulgo Sandstone bores.

Erroneous and inconsistent field EC values are noted for the samples from bores S1907a (DDH103a) (167 m depth, Area 3A) and S1888 (Dend96b) (200 m depth, Area 3B) in the Bulgo Sandstone, and from bores S2197 (133 m, Area 3B) and S1888 (Dend96b) (48.5 m Area 3A) in the Hawkesbury Sandstone. This is a local bore-scale data error due to alkaline grout packing used either side of the bladder pumps at the time of installation. This type of cement-based alkaline grouting contaminates the groundwater slightly with locally highly alkaline water for a period. Therefore, this data has been omitted from the analysis.

Table 2-3 and the box and whisker plot in **Figure 2.33** show an increase in salinity with depth from the surface water sources to Hawkesbury Sandstone to the Bulgo Sandstone, and down to the goaf waters drawn from coal and from the overlying coal measure formations. There has been no evidence for adverse changes to groundwater quality as a result of mining.

3.4 COMPARISON WITH MODEL PREDICTIONS

3.4.1 DEEP GROUNDWATER LEVELS

Observed spatial patterns of drawdown in potentiometric head (as discussed in Section 3.1.7) were compared against modelled contours of drawdown (HS, 2014) for the Wongawilli Seam, Bulli Seam, Scarborough Sandstone, Bulgo Sandstone and lower Hawkesbury Sandstone. A summary of the comparison is in **Table 3-1**. In summary, observations of drawdown in Area 3B are generally consistent with numerical model predictions. There is a tendency for the model to over-estimate drawdown, particularly in the deeper geological strata.

Table 3-1 Comparison of Predicted and Observed Groundwater Levels in Area 3B

Predicted Impacts	Observed Impacts
Wongawilli Seam Large drawdowns (about 60 m) were expected in the Wongawilli Seam after Longwall 11 in the western parts of Longwall 11 of Area 3B. Smaller reductions in head were expected in the Wongawilli Seam at the previously mined longwalls due to substantial depressurisation having already occurred in these areas.	Small drawdowns (1-5 m) were observed in the northern part of Area 3B during Longwall 11 extraction, due to earlier extraction of, and depressurisation associated with, Area 3A, Longwall 9 and Longwall 10 mining. In southern Area 3B, 5-16 m of drawdown was observed in the Wongawilli Seam.
Bulli Seam Large drawdowns of about 100 m, focused over the mined panel, were predicted to occur in the Bulli Seam during the extraction of Longwall 11.	During Longwall 11, observed drawdowns in Bulli Seam were in the order of 10 m. This is significantly less than predicted, and is possibly due to greater depressurisation before Longwall 11 (and other Area 3B longwalls) commenced.
Scarborough Sandstone Large drawdowns of 60-80 m were predicted for the Scarborough Sandstone during the mining of Longwall11. Further south of Longwall 12 drawdown was expected to be around 10-40 m.	Near Longwall 11 observed drawdown within the Scarborough Sandstone was up to 77 m; this large focus of drawdown extended to Longwall 9 and south-west to Longwall 12. Observed drawdown generally ranged from 5-20 m further to the south of Longwall11.

Predicted Impacts	Observed Impacts
Bulgo Sandstone Drawdowns of up to 50 m were predicted in the Bulgo Sandstone over Longwall 11. Drawdown was predicted to decline towards southern Area 3B (~40 m above Longwall 12, ~20 m above Longwall 13 etc). Drawdown magnitude was predicted to decline to less than 10 m further to the south.	The observed drawdown in the Bulgo Sandstone during the mining of Longwall 11 was about 30-35 m above Longwall 11 and up to 48 m to the south-west above longwall 12. Further to the south of Longwall 11, there was generally no drawdown in eastern Area 3B and 20 m drawdown along the western edge near Avon Reservoir.
Hawkesbury Sandstone Maximum modelled drawdowns in the lower Hawkesbury Sandstone occurred above Longwall 12, in the range of 12-16 m.	In the lower Hawkesbury Sandstone, observed drawdowns ranged from 10-16 m over Longwall 11 and northern Area 3B Longwalls (9-12). Minimal drawdown was experienced in southern Area 3B.

3.4.2 MINE WATER BALANCE

Groundwater inflows to the mine in Area 3B during the extraction of Longwall 9, Longwall 10 and Longwall 11 are displayed as a probability distribution in **Figure 3.1**, where comparison is made with the corresponding inflows simulated using the model of HydroSimulations (2014). This comparison has been conducted at the time scale of the model. Modelled inflows are generally slightly higher than observed inflows, by less than 0.25 ML/d on average. The predicted average inflow is within 5% of what has been recorded. The respective median flows are 2.82 ML/d (observed) and 2.63 ML/d (modelled). HydroSimulations (2014) noted that simulated Dendrobium mine inflows are highly sensitive to the assumptions made regarding the height of the fractured zone above longwalls.

Figure 3.2 illustrates the measured and observed groundwater discharge in Area 3B during the extraction of Longwall 11. The match between observed and predicted remains very accurate (within 10% of observed, on average).

The groundwater model reported in HydroSimulations (2014) simulated a reduction in net baseflow to Avon Reservoir at the end of Longwall 11 of about 0.4 ML/d relative to a baseline (no-mining) simulation, as illustrated in **Figure 3.3**. This reduction comprises induced leakage from and reduced baseflow to the water body, in addition to reduced baseflow to, and increased leakage from, creeks discharging into the reservoir. The model simulated a sharp increase in baseflow reduction from the start of Longwall 9, compared to the modelled baseflow reduction rates during mining of Longwalls 6, 7 and 8. This is probably due to Area 3B longwalls being extracted from an area where only development headings (and no longwall extraction) had previously affected the groundwater system, and due to Longwall 9, Longwall 10 and Longwall 11 being located closer to Avon Reservoir than the previous longwall areas. HydroSimulations (2014) reported a modelled maximum future loss of water (i.e. leakage plus captured baseflow) from the Avon Reservoir due to mining of all Dendrobium workings of 0.94 ML/day.

The DSC specified the tolerable *leakage* of water from Avon Reservoir as being 1 ML/day. The modelled rate of leakage during Longwall 11 is less than 0.015 ML/d. Hence, the simulated effects on the Avon Reservoir are within the prescribed tolerable loss limit.

Generalisations of the simulation results have informed the predicted impacts listed in **Table 3-2** where comparison is made with observed impacts on the Avon Reservoir and on loss of water from aquifer storage.

Table 3-2 Comparison of Predicted and Observed Impacts on Mine Inflow in Area 3B

PREDICTED IMPACT	OBSERVED IMPACT
Average inflow to Area 3B was predicted to be 3.72 ML/d during the completion of Longwall 11.	During the completion of Longwall 11, actual inflows to Area 3B have averaged 3.6 ML/day with a standard deviation 0.7. ML/day.
Leakage of water from the Avon Reservoir to the underlying groundwater system due to mining of Area 3A and 3B voids was <0.015 ML/d*. Inclusive of baseflow capture, the modelled total reduction in water in the Avon Reservoir was up to 0.4 ML/d. This is less than 2% of average (2004-2013) environmental flow released from Avon Dam, and less than 1% of average evaporation from the lake.	As measured inflows are very similar to the modelled rates for Longwall 11, it is likely that actual losses will not have been significantly different from those predicted. Losses of such a small magnitude are difficult if not impossible to detect due to the large uncertainties in surface water flow measurements.

Datasource: DenV3TR058_A3Bzone_ZOT.xlsx! Area3A+3B (column M and N)

DenV3TR57_55_Reservoir_Inflow_Impacts.xlsx

DENDROBIUM\Tech\MineInflow\DenV3TR058_A3Bzone_ZOT_AS.xlsx

* This is leakage from the reservoir to the underlying groundwater only, and not inclusive of captured baseflow.

3.5 TARP COMPLIANCE

The following section summarises the relevant TARP compliances for Area 3A and Area 3B during Longwall 11 extraction.

Table 3-3 TARP compliance and necessary actions.

TRIGGER ACTION RESPONSE PLAN	CURRENT TARP LEVEL	CHARACTERISTICS OF LEVEL	ACTIONS
Principal TARP (Total Underground Water Balance Coupled with Sampling and Analysis) See **Figure 3.4**	Normal	≤ 0.5 ML/day stored water and ≤9ML/day total water imbalance	- No remedial action necessary - Monthly review meeting
Secondary TARP 4 (Area 3A Groundwater monitoring – Bores S1867, S1870, S1992, S1994)	Level 3	Piezometric Head measured in all Bulgo Piezometers (within a borehole) drops below Cordeaux Dam SWL	· Actions in Level 2 · Activate Level 1 Principal Monitoring Alarm: o Advise DSC and SCA o Increase sampling frequency to weekly. o Inspection of likely inflow points o Review all other monitoring inputs for anomalies, likely source and 'conduit' path. o Assess need for additional pumping capacity as required. o Monthly review meeting

4 CONCLUSION

The following conclusions are made with respect to the assessment of groundwater conditions following the completion of Longwall 11:

- As expected, the lowest heads in the Wongawilli Seam occurred in the vicinity of Longwall 11 and to the south and south-west of this longwall during the extraction of Longwall 11; depressurisation within Longwall 11 was substantially complete prior to mining due to development headings, as well as earlier extraction of Longwall 9 and Longwall 10 and Area 3A, however an additional drawdown of up to about 35 m was observed to the south-west of Longwall 11.
- Additional head reduction in the Bulli Seam during the extraction of Longwall 10, was slightly less than that in the Wongawilli Seam around Longwall 10, although the apparent peak drawdown was slightly higher (up to 45 m to the south-west of Longwall 11). Drawdown in the Bulli Seam above Longwall 9 and Longwall 10 was less than predicted.
- Compared to the drawdown experienced in the Scarborough Sandstone during Longwall 9 (up to 107 m), the drawdown that was experienced in that geological unit during Longwall 11 was close to what was observed during Longwall 10 extraction (maximum of about 30 m, both to north of Longwall 9 and to the south of Longwall 10). These observed drawdowns are less than predicted.
- The incremental drawdowns in the Bulgo Sandstone in Area 3B during the extraction of Longwall 11 were of slightly smaller magnitude than those in the Scarborough Sandstone, and drawdown in the Bulgo Sandstone was more confined to the footprint of the extracted Area 3B Longwalls (9, 10 and 11) and the immediate surrounds. Observed drawdowns are of a similar magnitude to predicted drawdown on the western side of Area 3B near to Lake Avon, although they were lower than modelled above Longwall 11.
- An increase in drawdown in the lower Hawkesbury Sandstone was observed in bores above and to the south of Longwall 11, with the maximum observed drawdown being 20 m. The magnitude of observed drawdown is lower than predicted in the areas above Longwalls 9-13, and similar in other areas.
- One of four bores subject to the Bulgo Sandstone TARP near Sandy Creek and Cordeaux Reservoir has reached trigger Level 3 (bore S1870). The remaining three bores are at trigger Level 2.
- Mine inflow to Area 3B during the extraction of Longwall 11 averaged 3.6 ML/d with standard deviation 0.7 ML/d. The predicted (modelled) inflows to Area 3B are well matched by the observed pattern of inflows, and within 3% of average inflow.
- Area 3B mine inflow reached a peak of 6.1 ML/day on 12 March 2016.
- No TARP level has been triggered in relation to the total underground water balance during Longwall 11 extraction.
- Based on field electrical conductivity measurements, there is no clear spatial pattern in the distribution of groundwater quality in Hawkesbury Sandstone and Bulgo Sandstone bores.
- There is a clear increase in salinity with depth from the Hawkesbury Sandstone to the Bulgo Sandstone and down to the goaf waters drawn from coal and overlying coal measure formations.
- The existing groundwater model predictions have been compared with observed drawdown and mine inflow for the Longwall 11 extraction period. The model predicted inflows, especially to Area 3B, with good accuracy, while groundwater drawdown is slightly over-estimated by the model. Based on the requirements and requests of various agencies (e.g. DSC) an updated groundwater model was completed by

HydroSimulations in February 2016, as per the *Groundwater Monitoring and Modelling Plan* for Dendrobium and is currently under review.

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FIGURES

- Figures 1.1 to 1.5
- Figures 2.1 to 2.27
- Figures 3.1 to 3.3

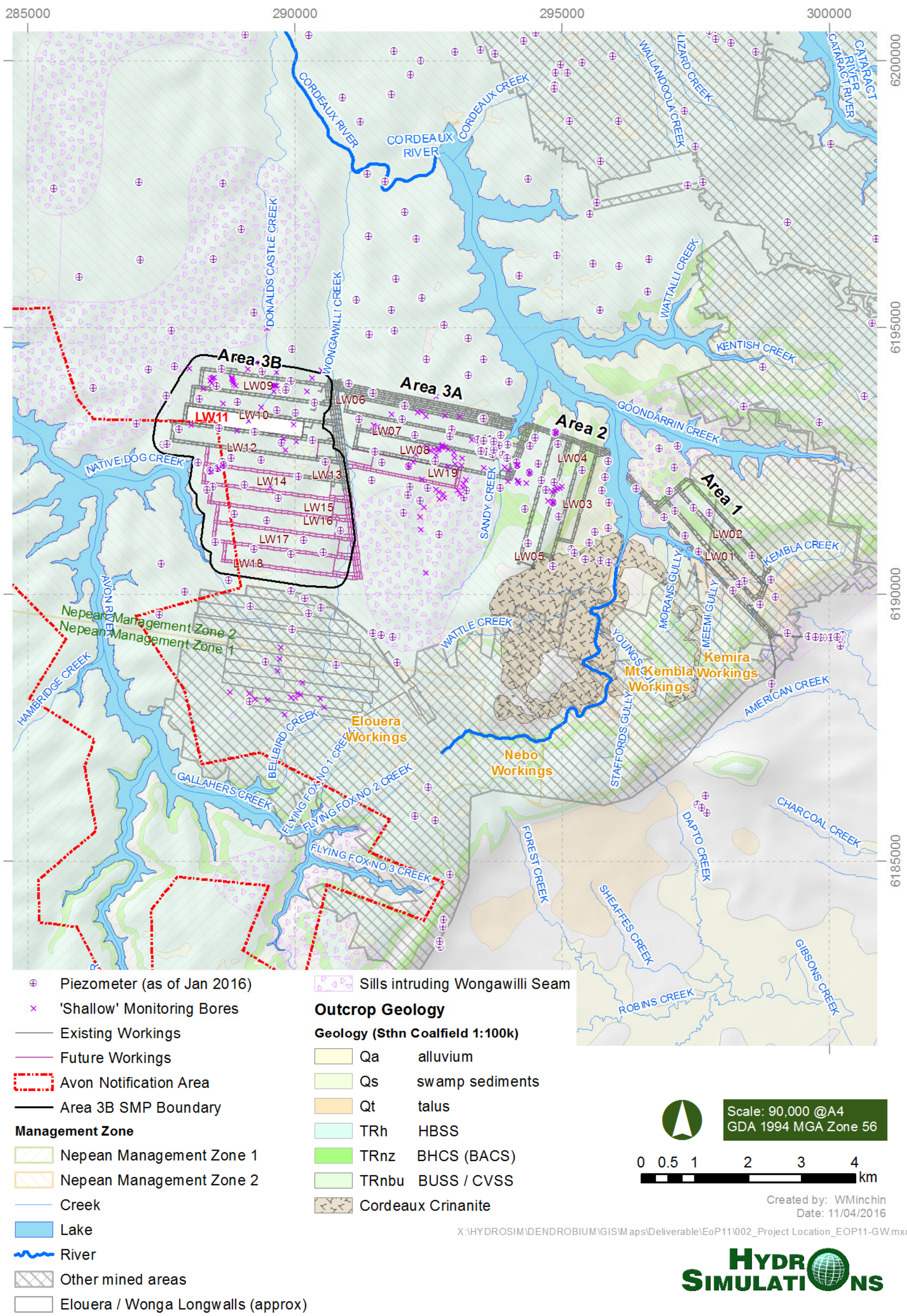

Figure 1.1 **Location Plan for Dendrobium Mine**

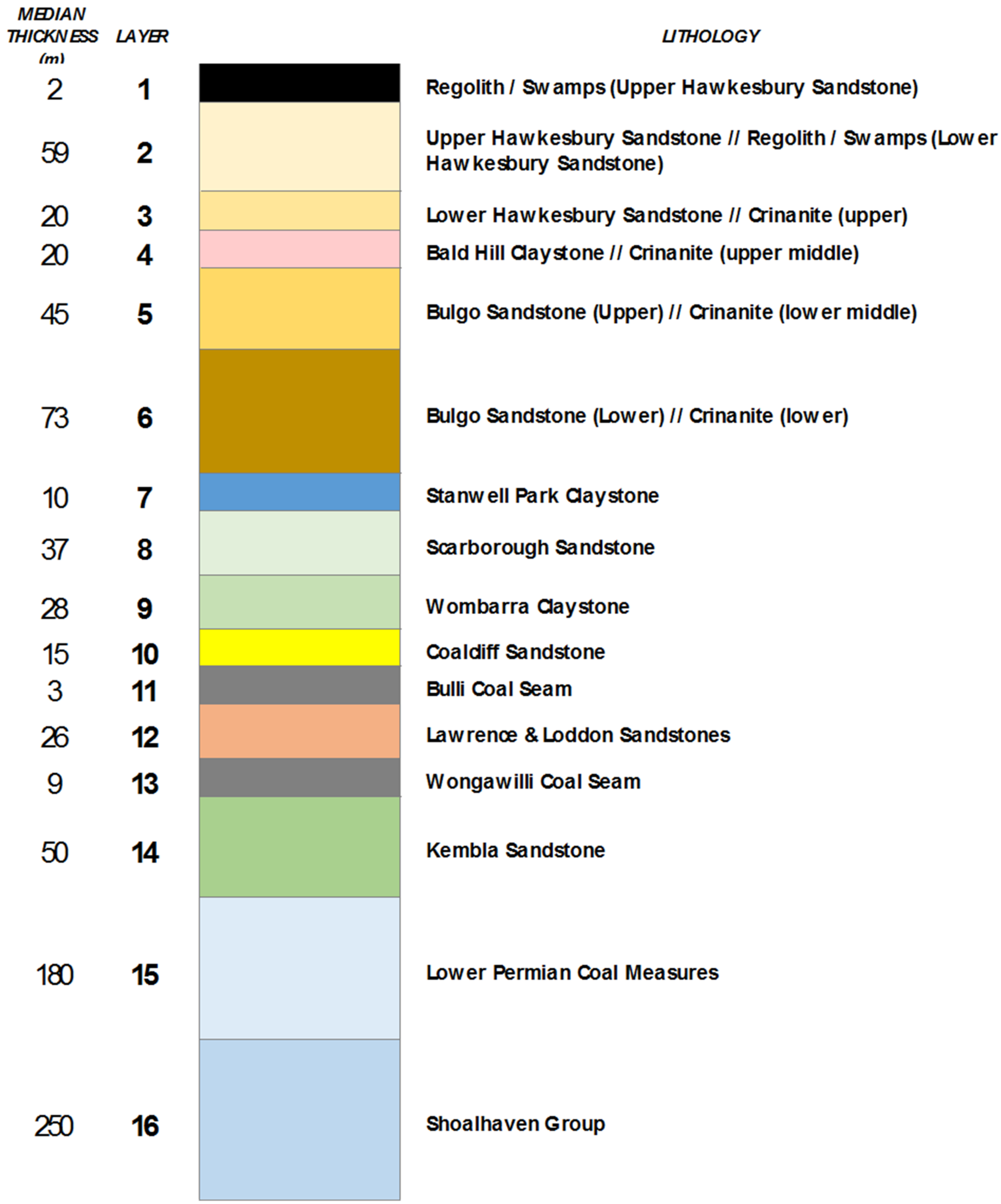

Figure 1.2 Stratigraphic section and numerical model layers

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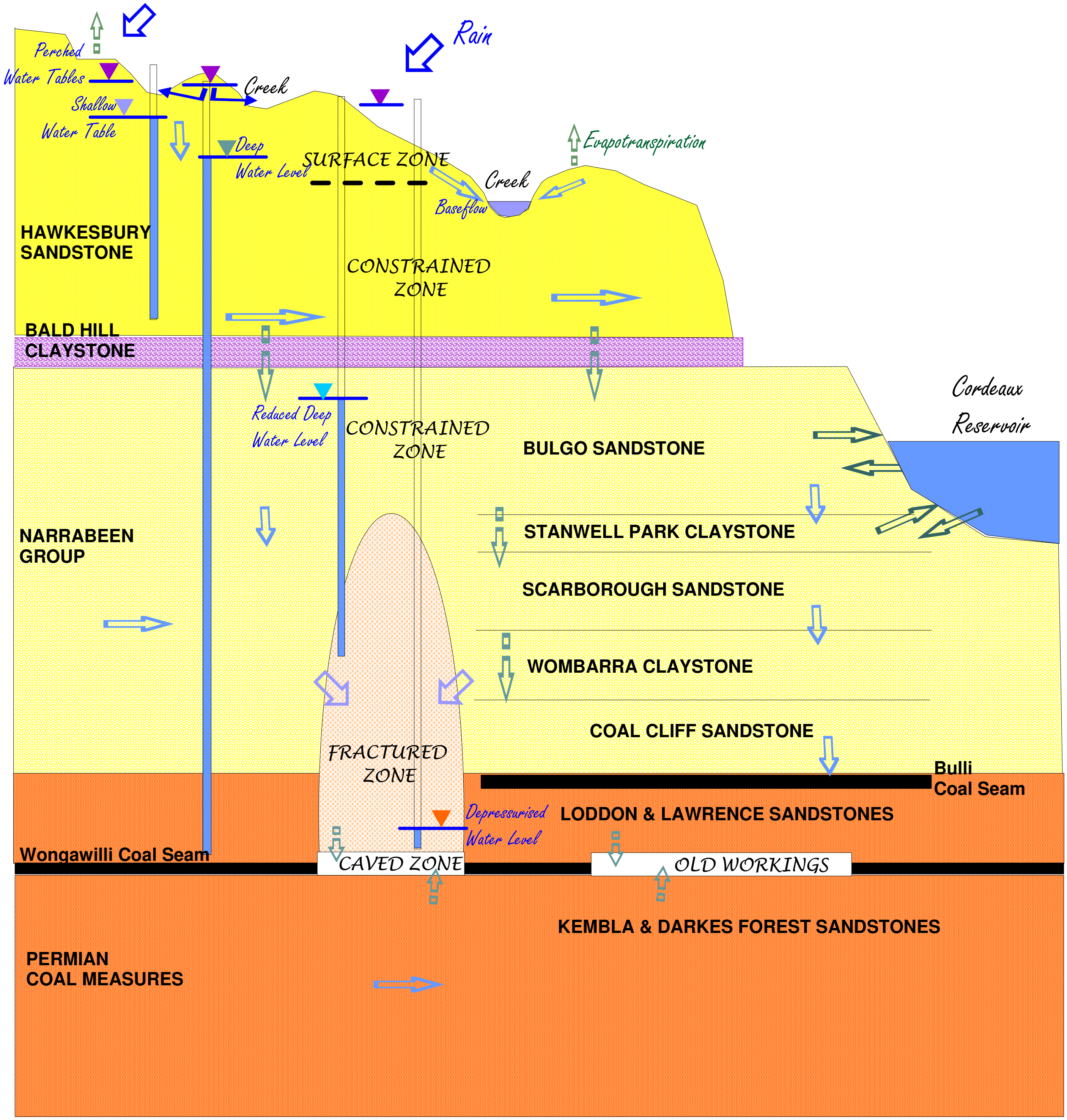


Figure 1.3 **Conceptual hydrogeological model**

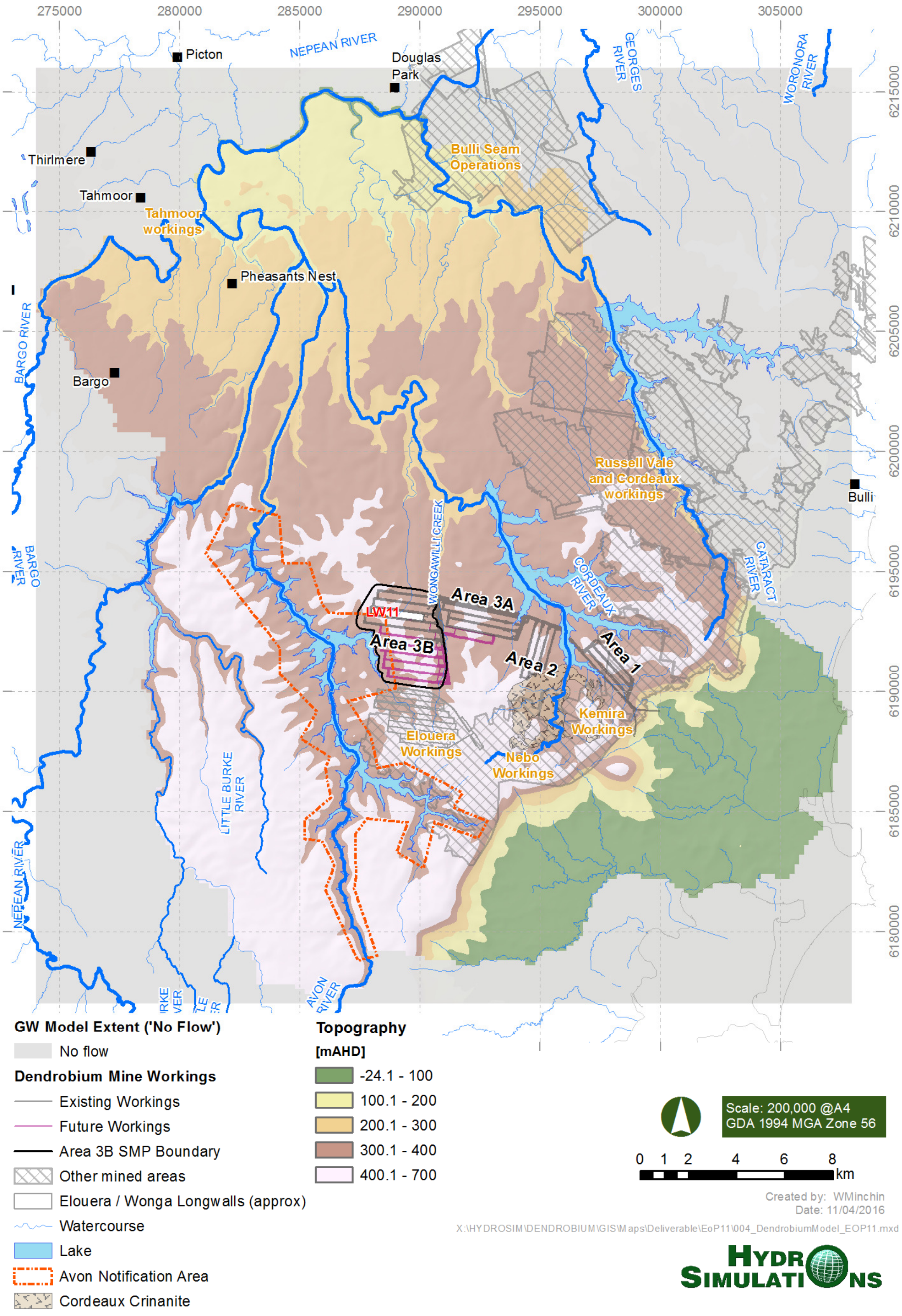


Figure 1.4 **Full model extent showing surface topography and cross-section locations**

see D:\HydroSim\BHP003\WP\HC2014_15_Figures_RevA\Figure 1.4 003_Model Extent.pdf

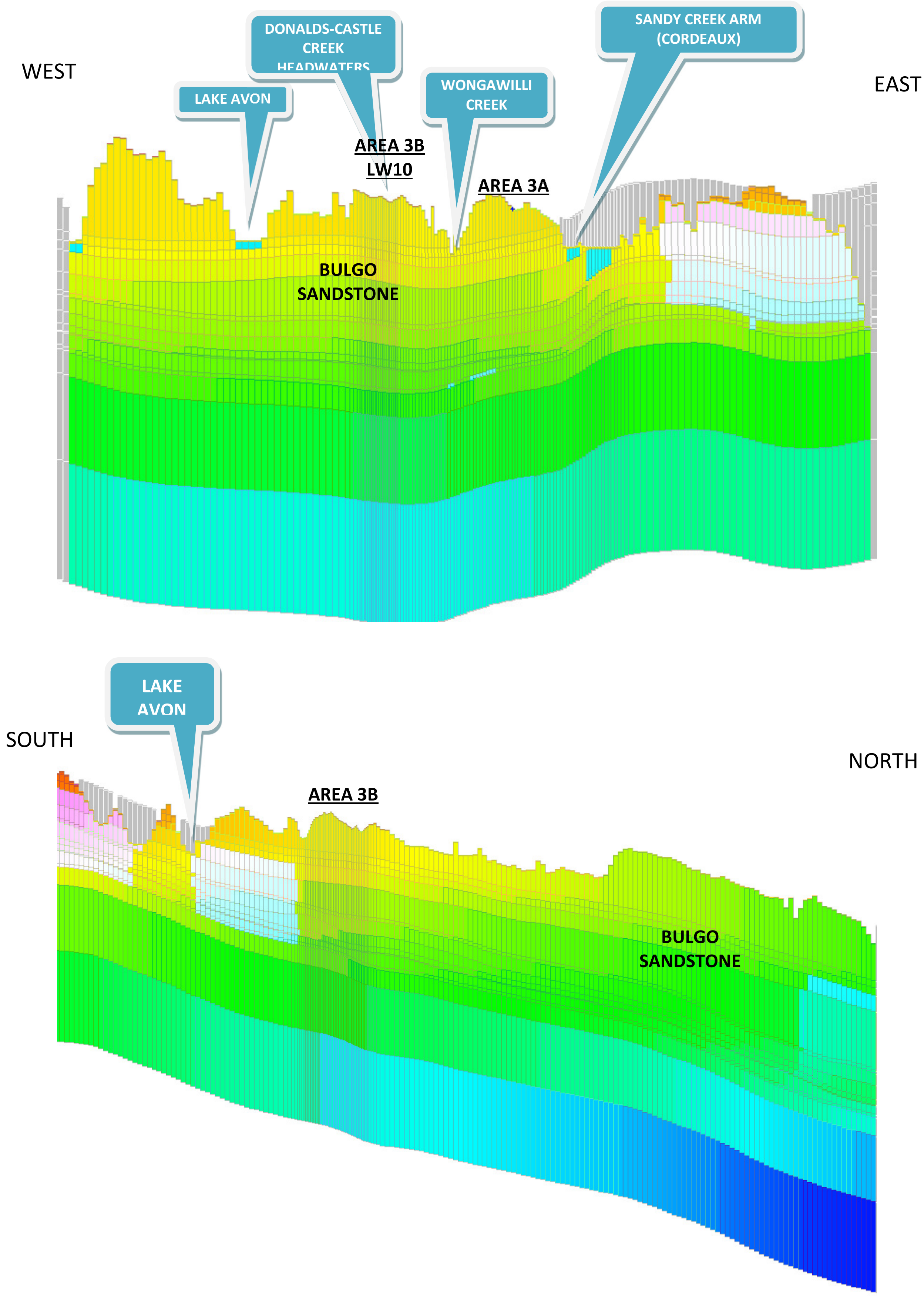


Figure 1.5 Model cross-sections through Area 3B Longwall 10

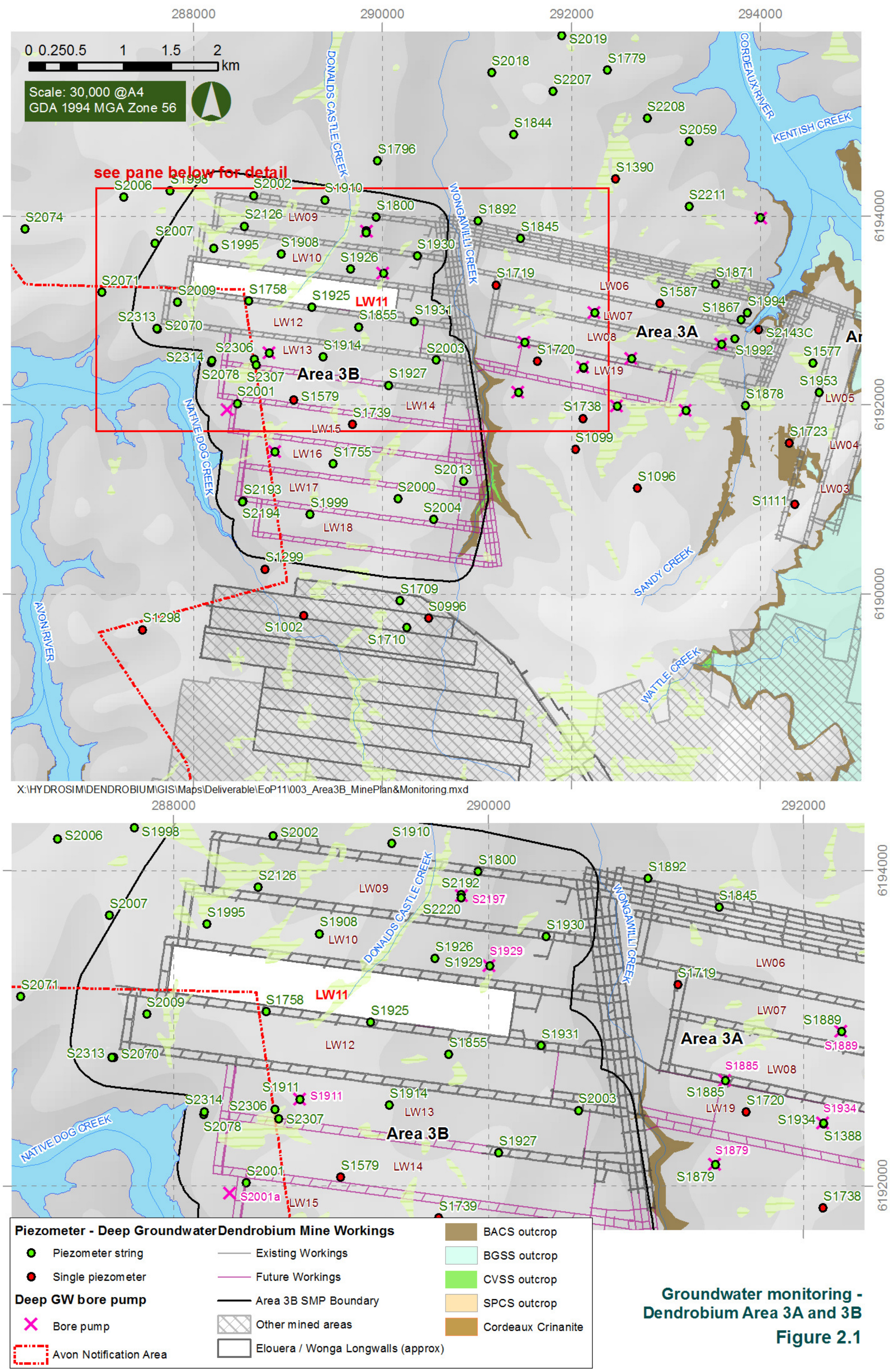


Figure 2.1 **Groundwater monitoring - Dendrobium Area 3A and 3B**

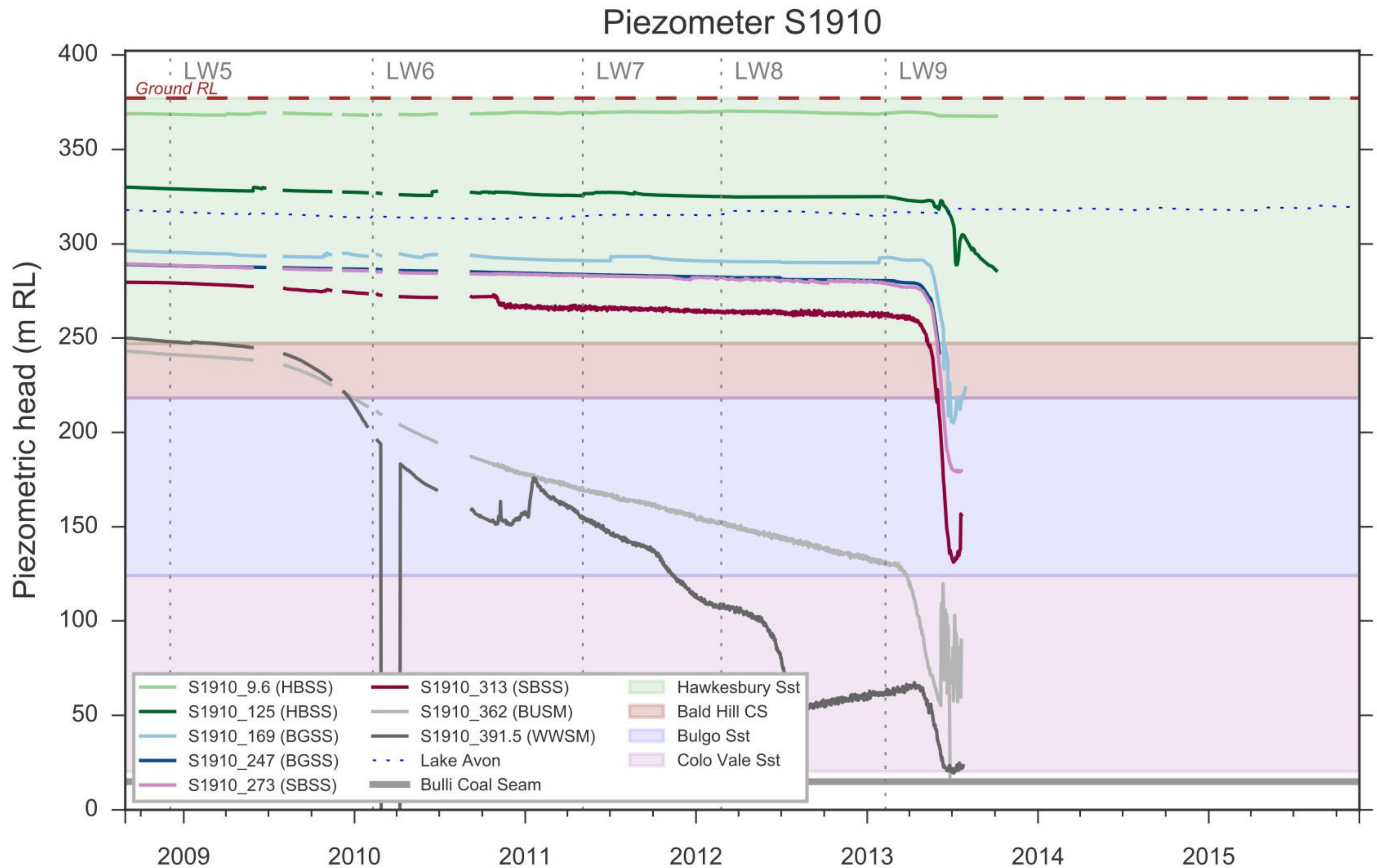


Figure 2.2 Groundwater hydrographs for Bore S1910 (north of Longwall 9)

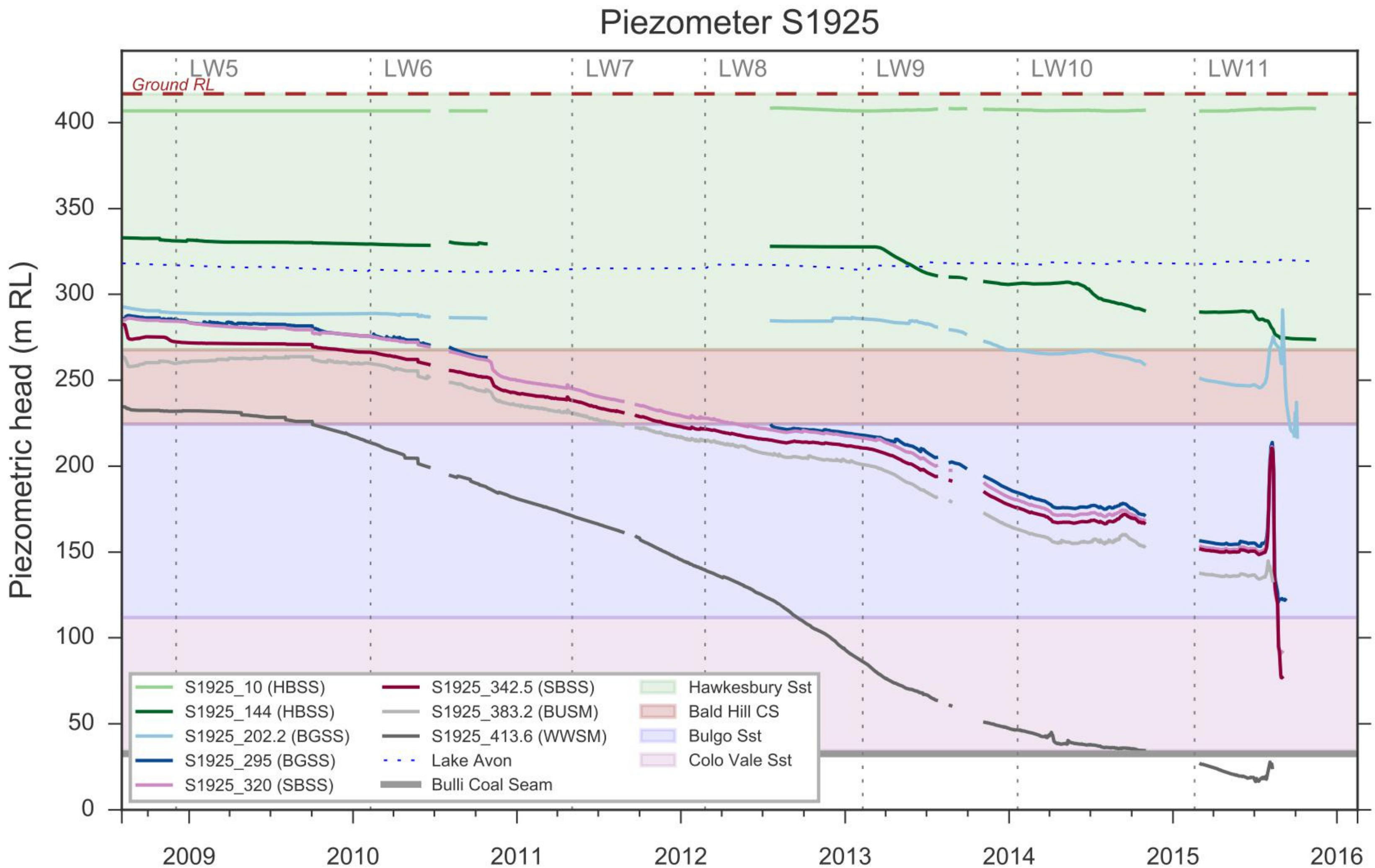


Figure 2.3 Groundwater hydrographs for Bore S1925 (between Longwalls 11 and 12)

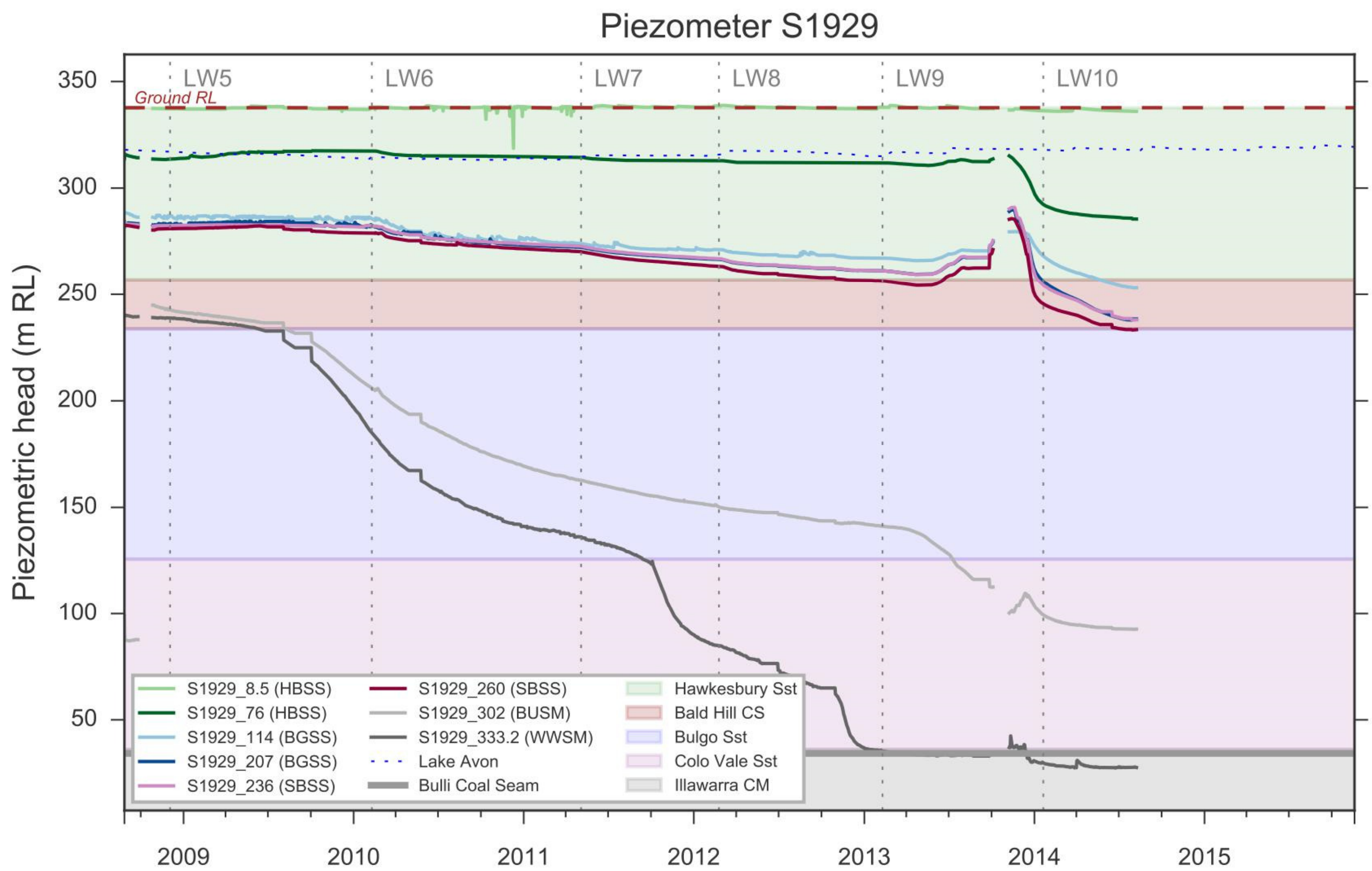


Figure 2.4 **Groundwater hydrographs for Bore S1929 (overlying Longwall 10)**

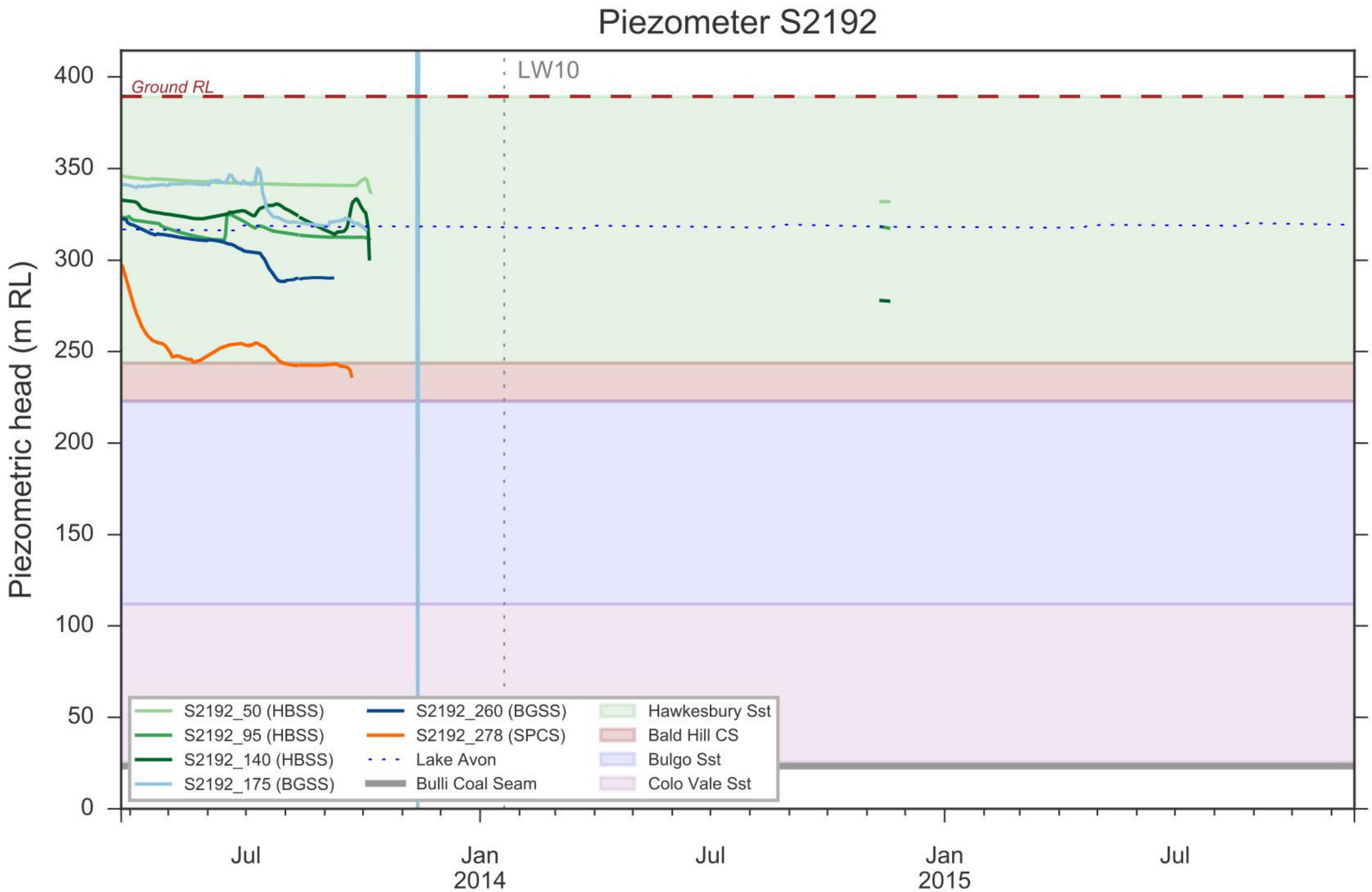


Figure 2.5 **Groundwater hydrographs for Bore S2192 (Overlying Longwall 9)**

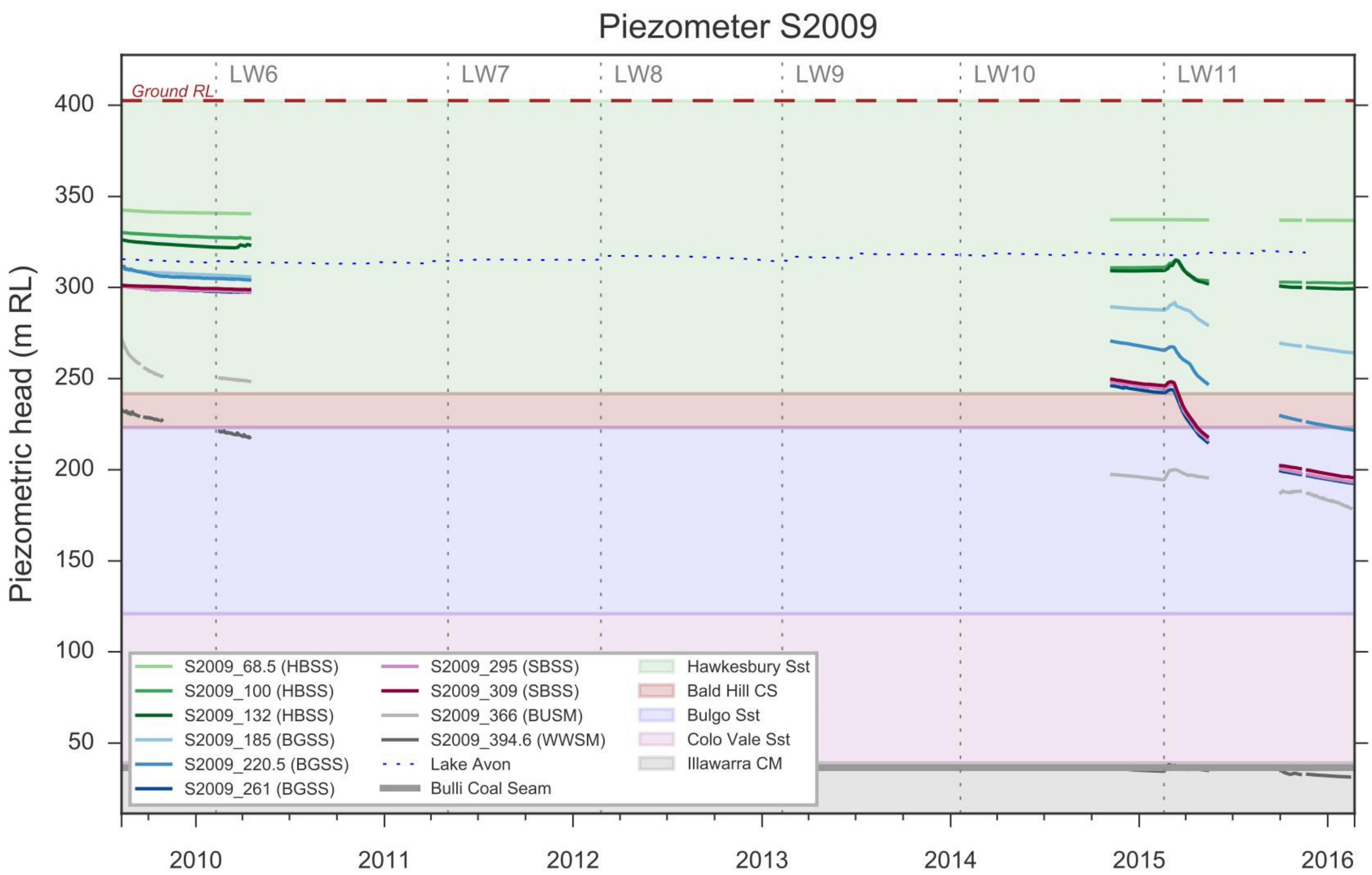


Figure 2.6 **Groundwater hydrographs for Bore S2009 (overlying western Longwall 12)**

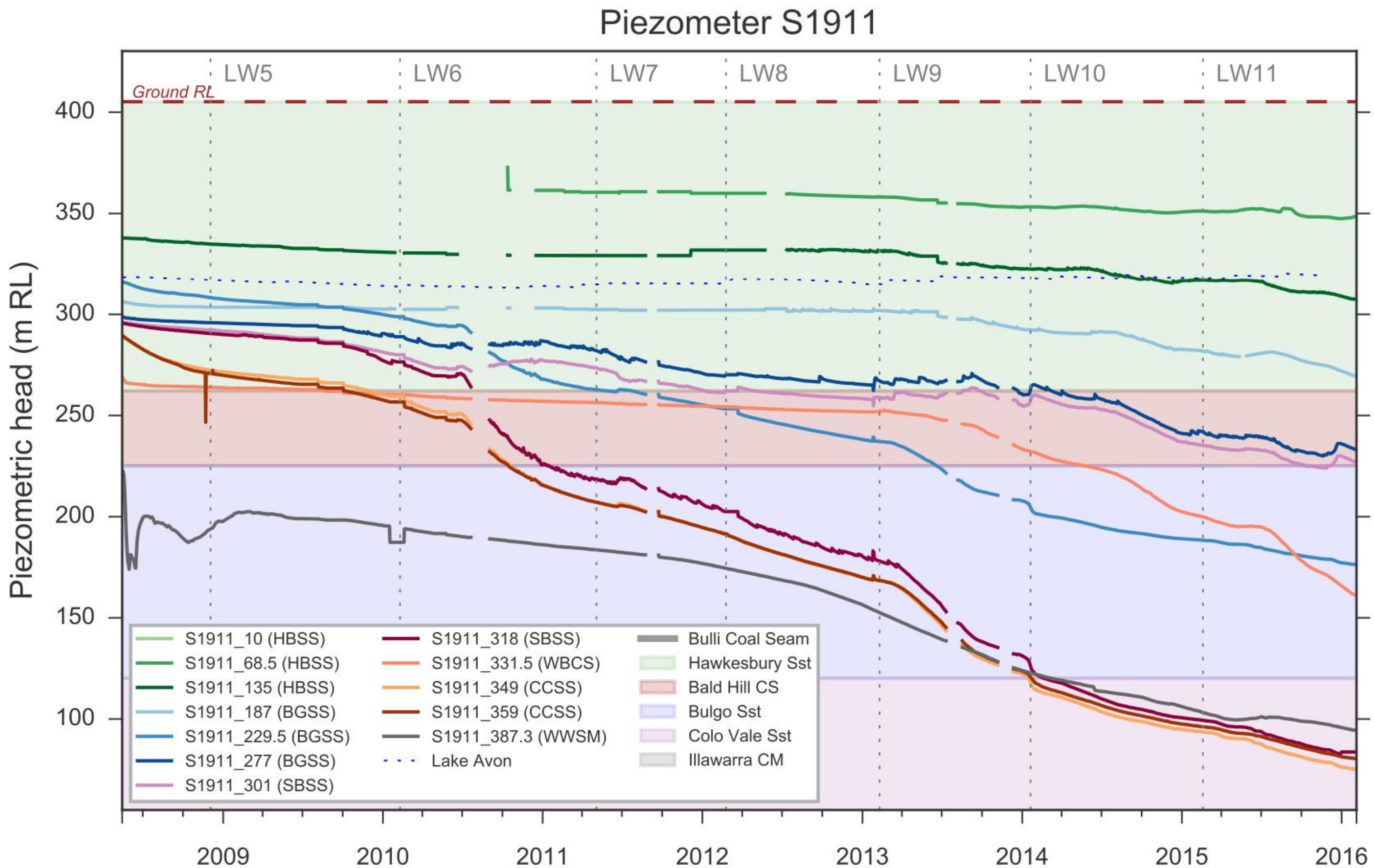


Figure 2.7 **Groundwater hydrographs for Bore S1911 (overlying Longwall 13)**

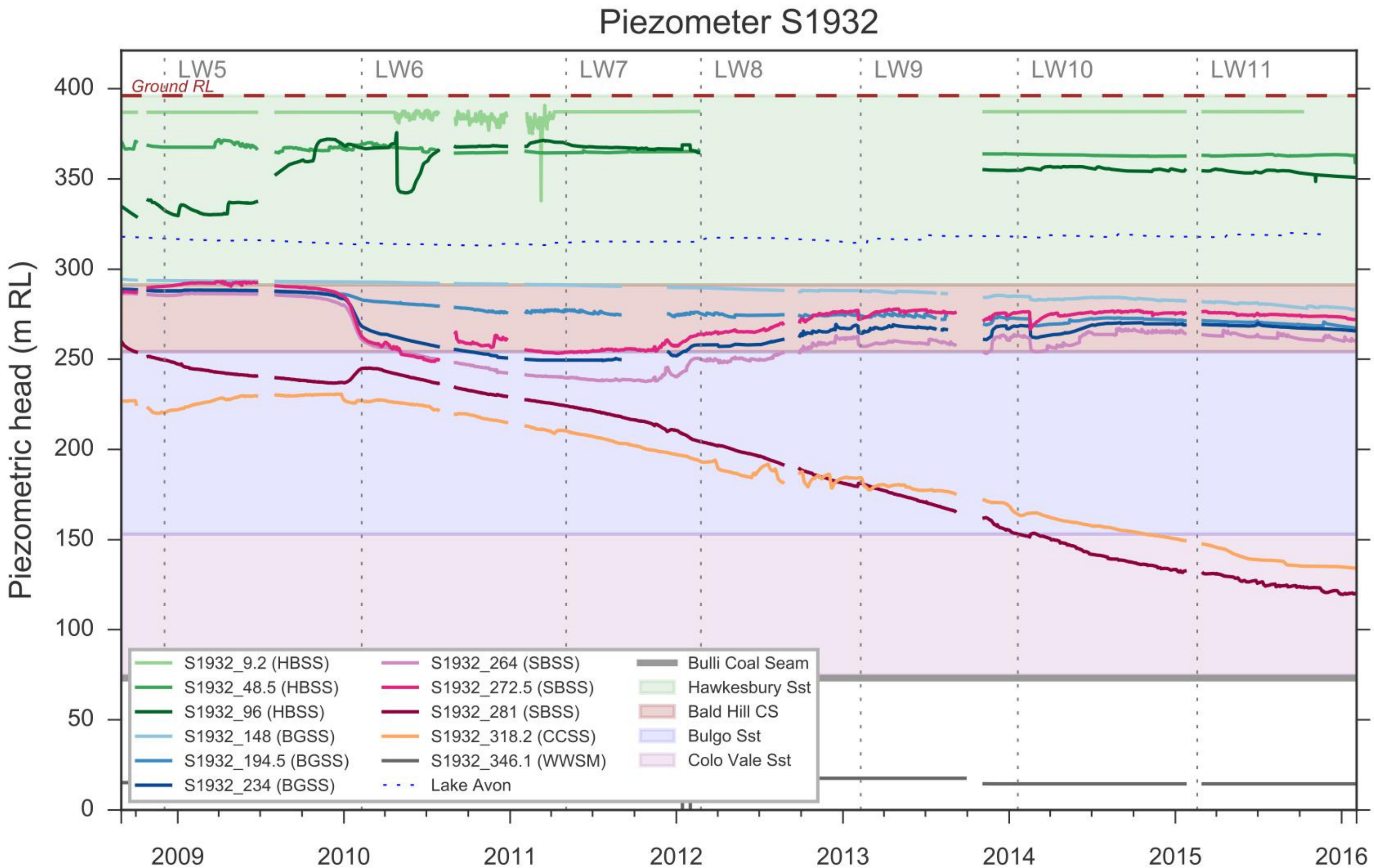


Figure 2.8 **Groundwater hydrographs for Bore S1932 (overlying Longwall 16)**

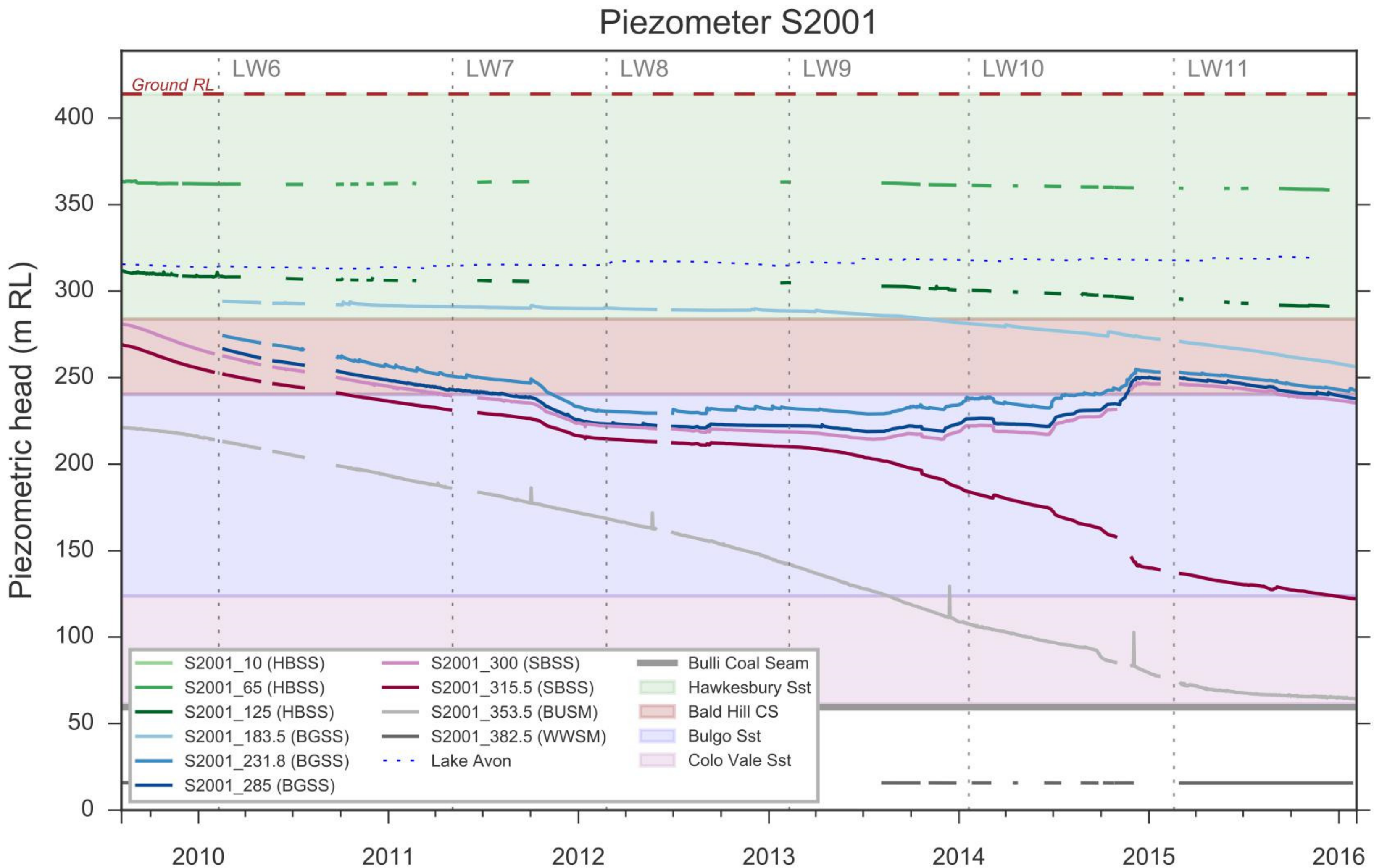


Figure 2.9 **Groundwater hydrographs for Bore S2001 (Near Longwall 15 and Avon Reservoir)**

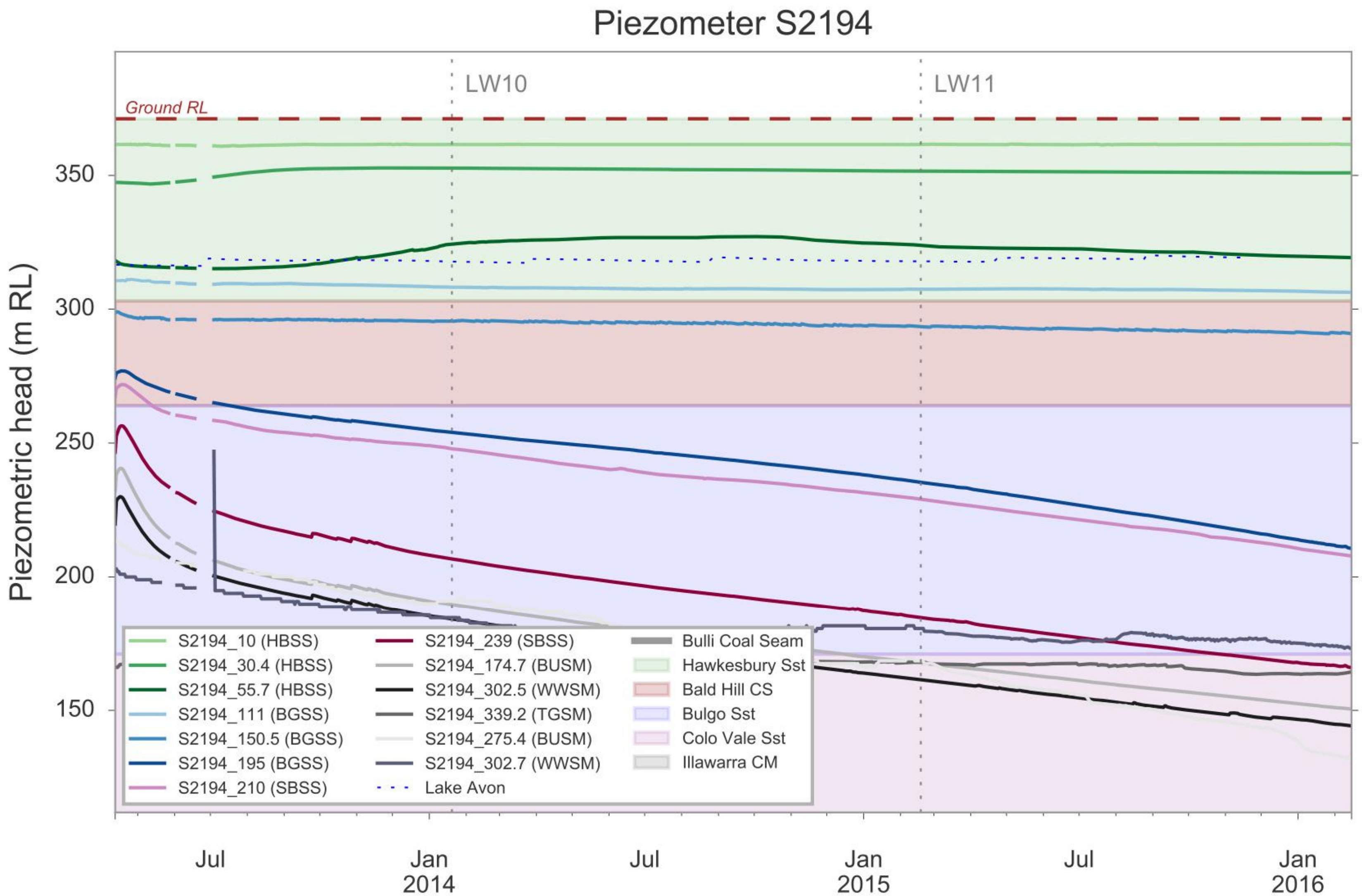


Figure 2.10 Groundwater hydrographs for Bore S2194 (South of Longwall 17)

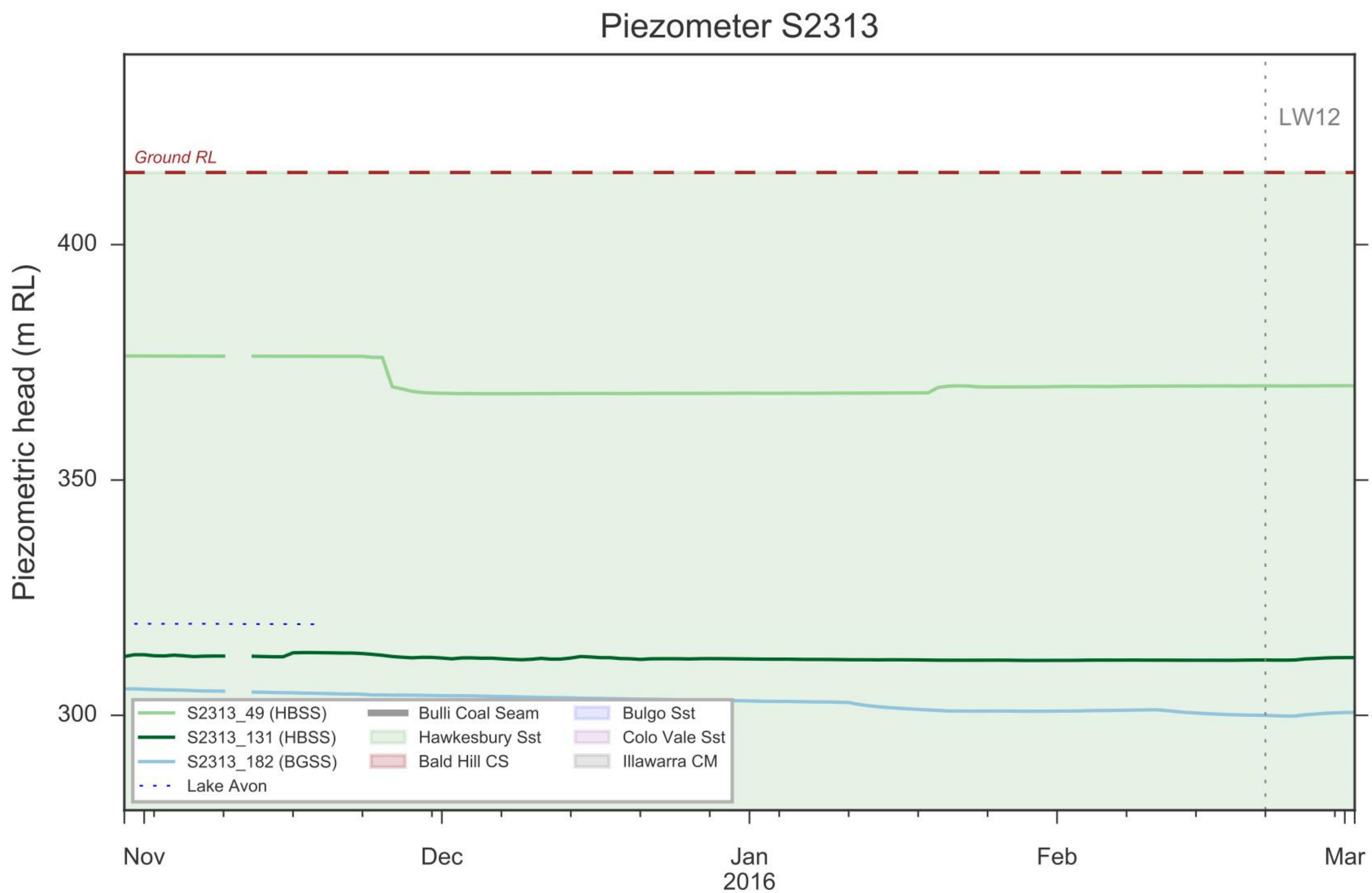


Figure 2.11 **Groundwater hydrographs for Bore S2313 (between Longwall 12 and Avon Reservoir)**

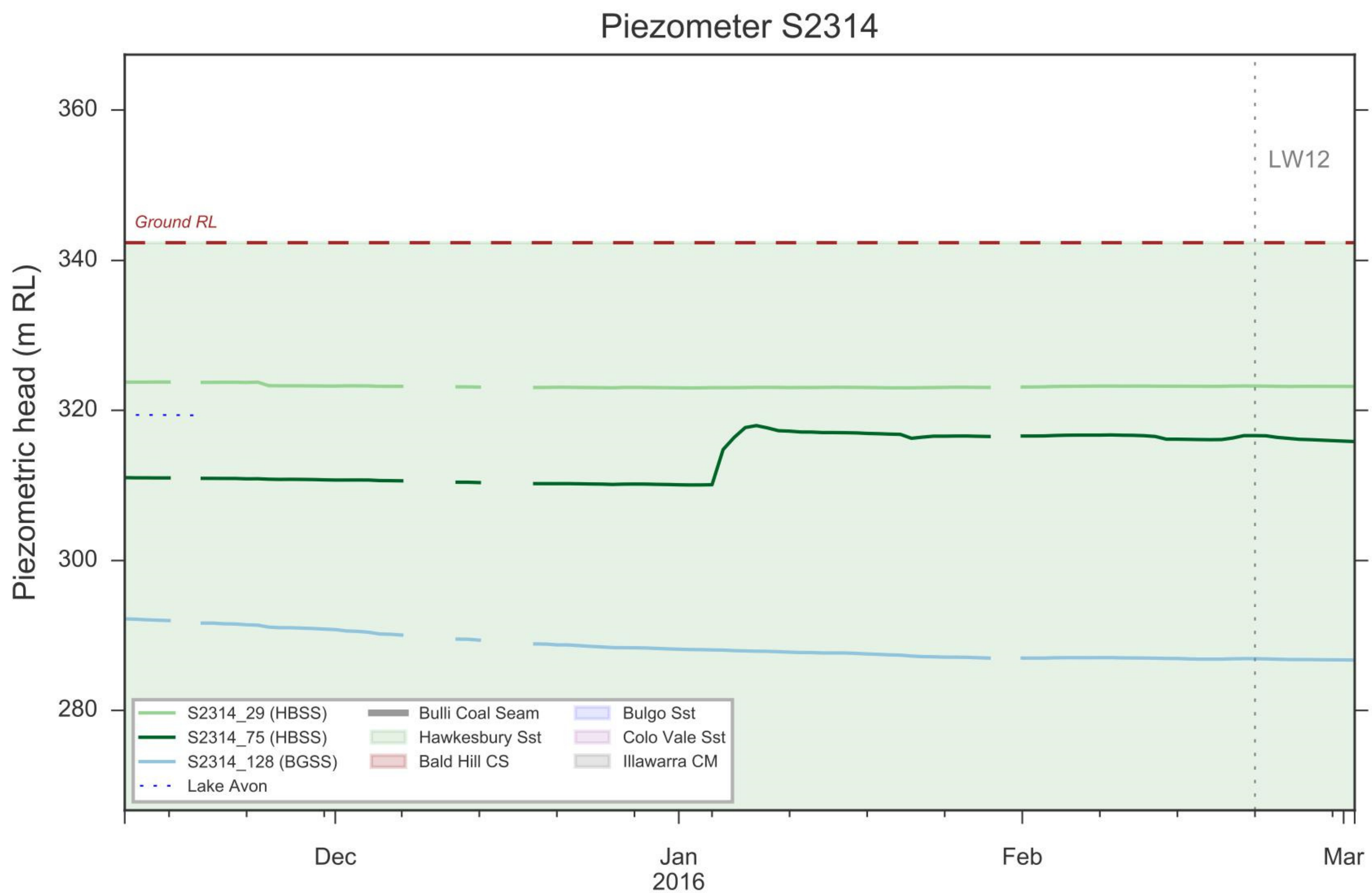


Figure 2.12 **Groundwater hydrographs for BoreS2314 (between Avon Reservoir and Longwall 13)**

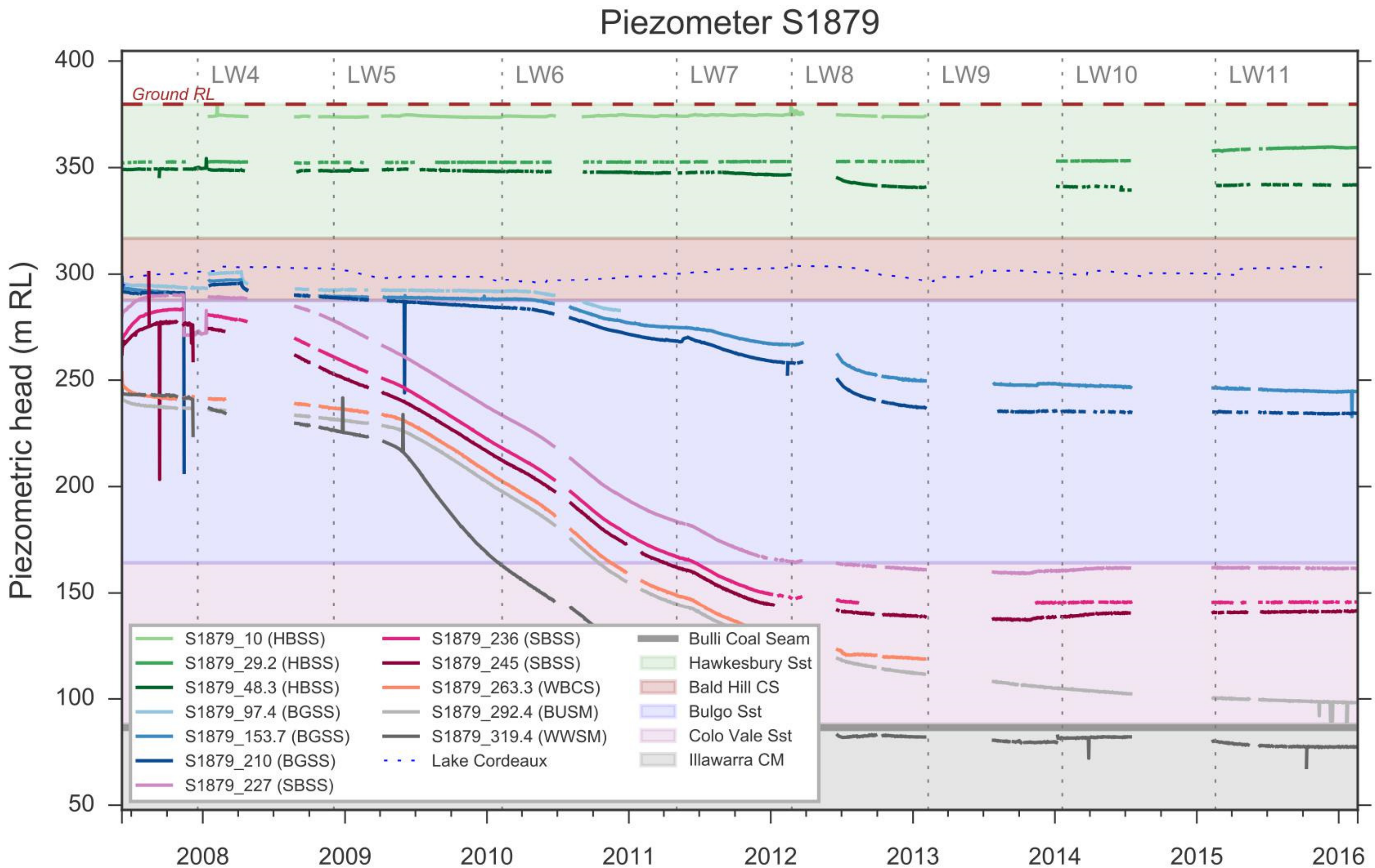


Figure 2.13 **Groundwater hydrographs for Bore S1879 (south of Area 3A)**

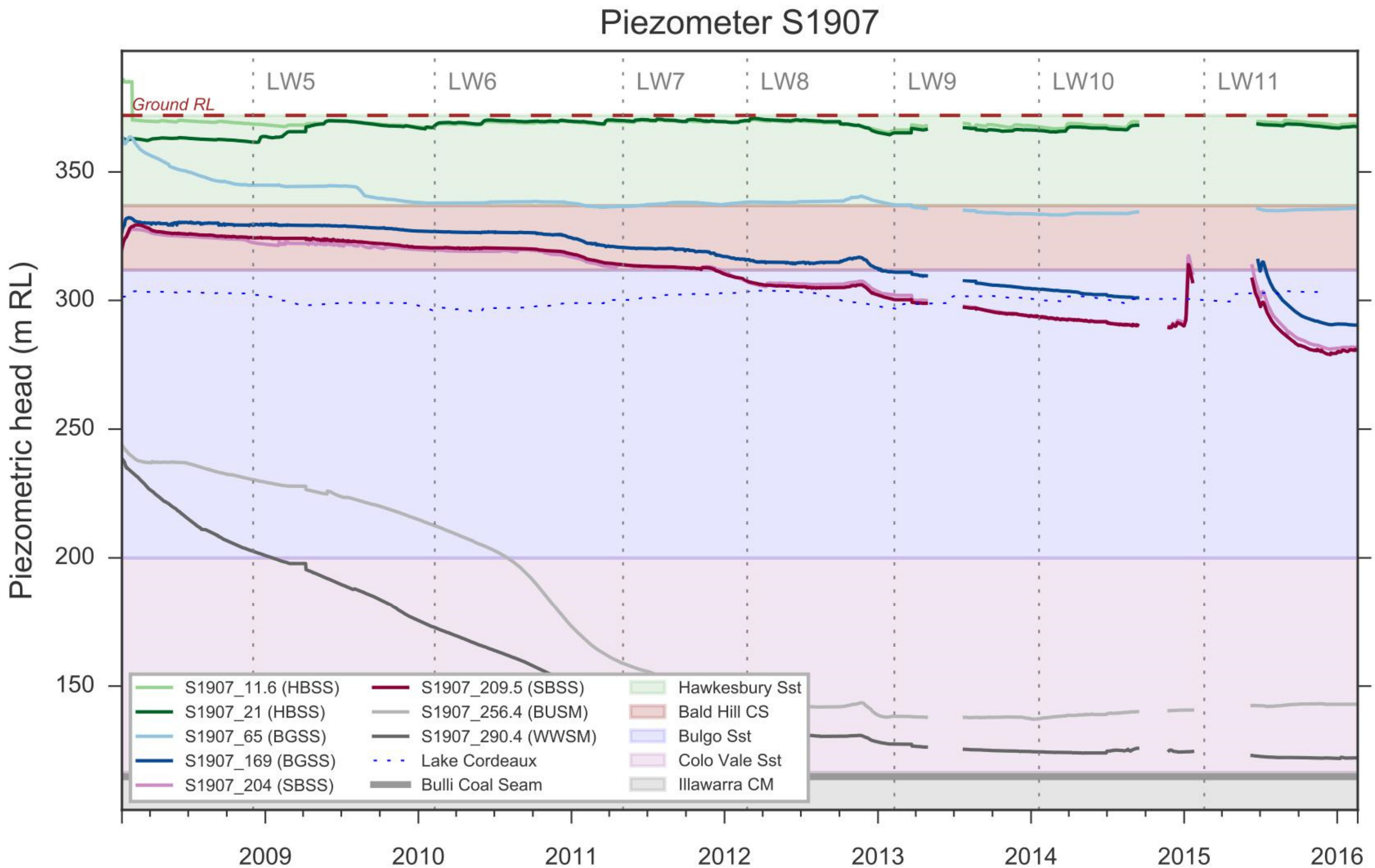


Figure 2.14 **Groundwater hydrographs for Bore S1907 (south of Area 3A)**

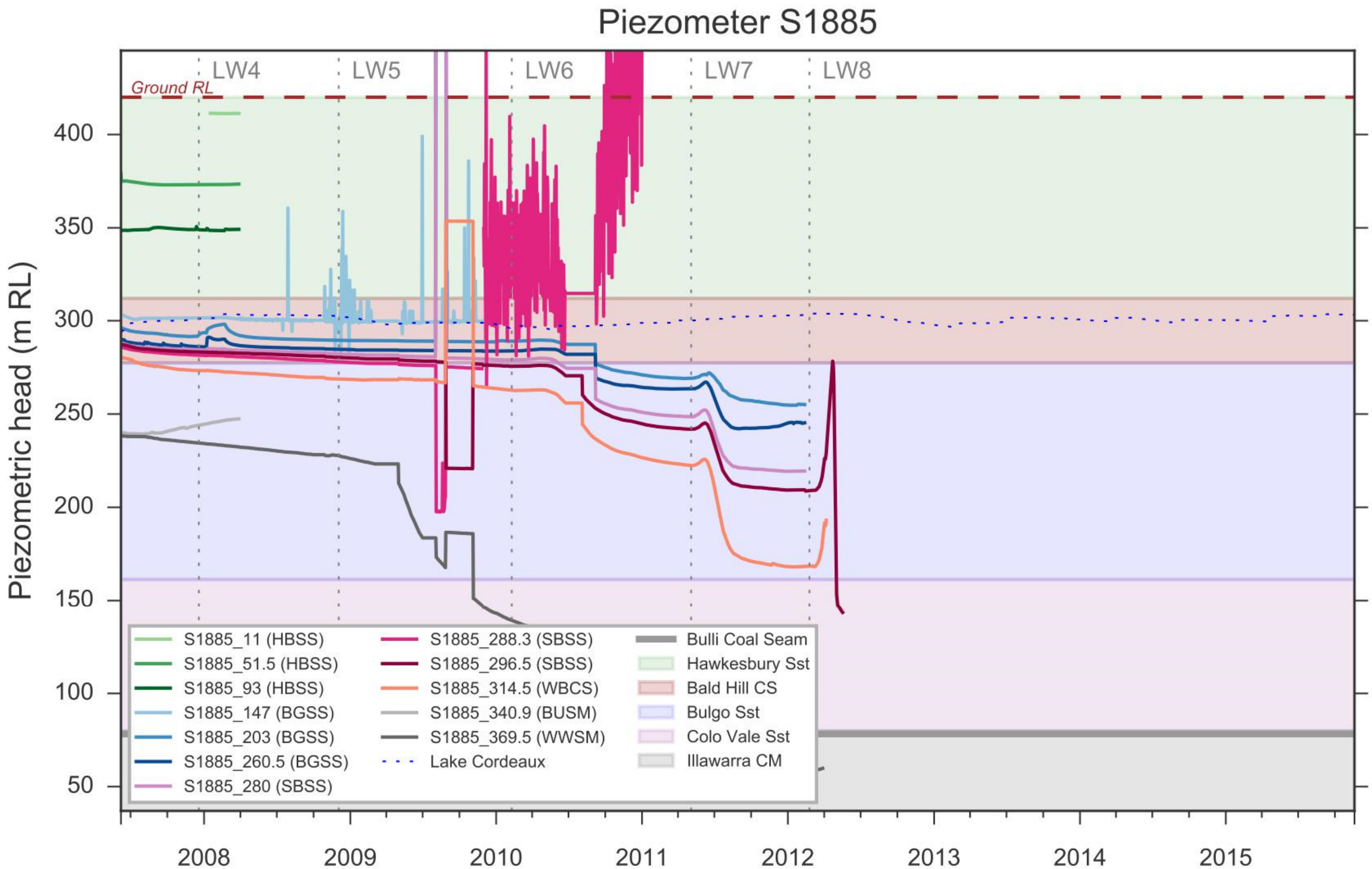


Figure 2.15 **Groundwater hydrographs for Bore S1885 (south of Area 3A)**

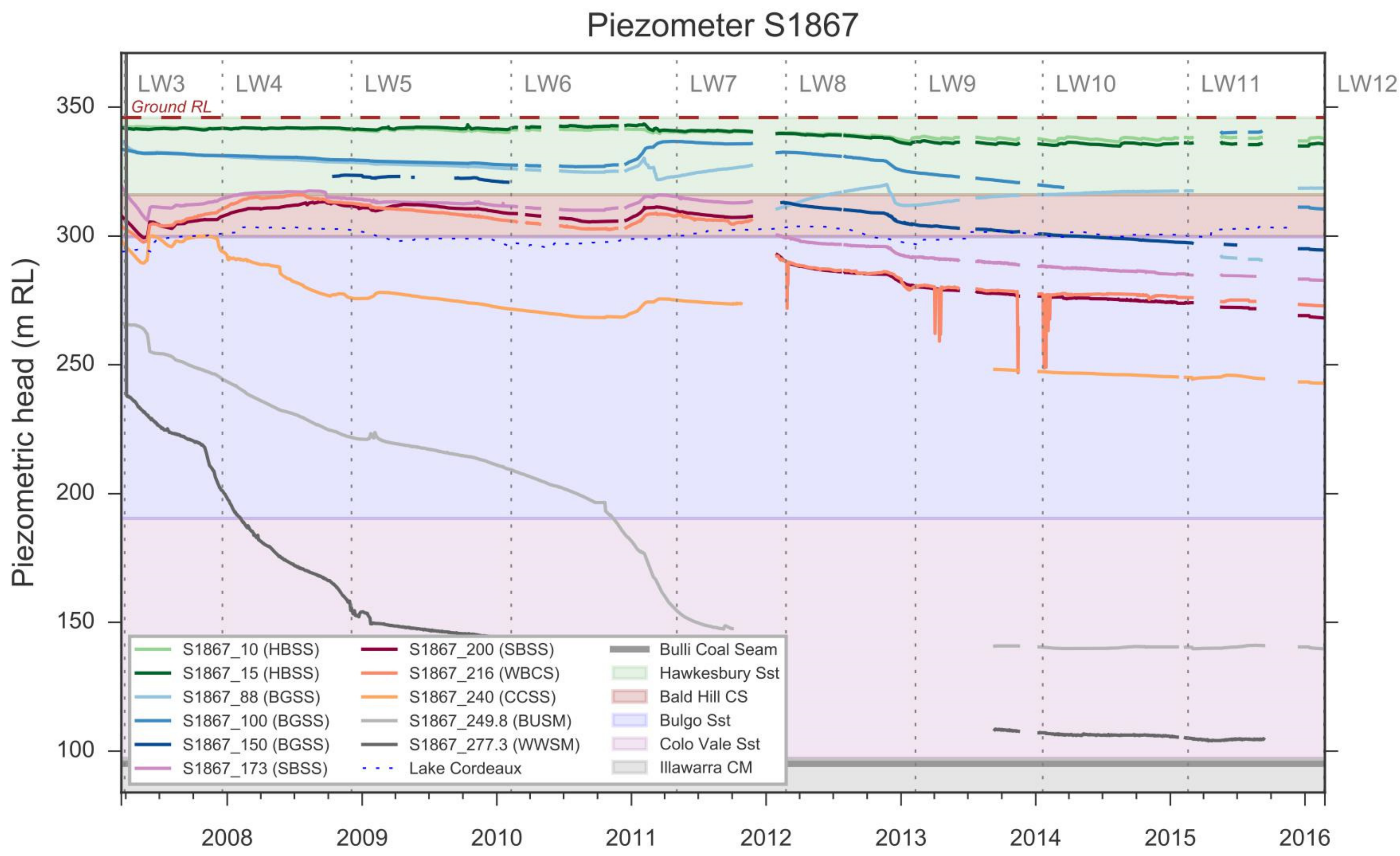


Figure 2.16 **Groundwater hydrographs for Bore S1867 (near Sandy Creek)**

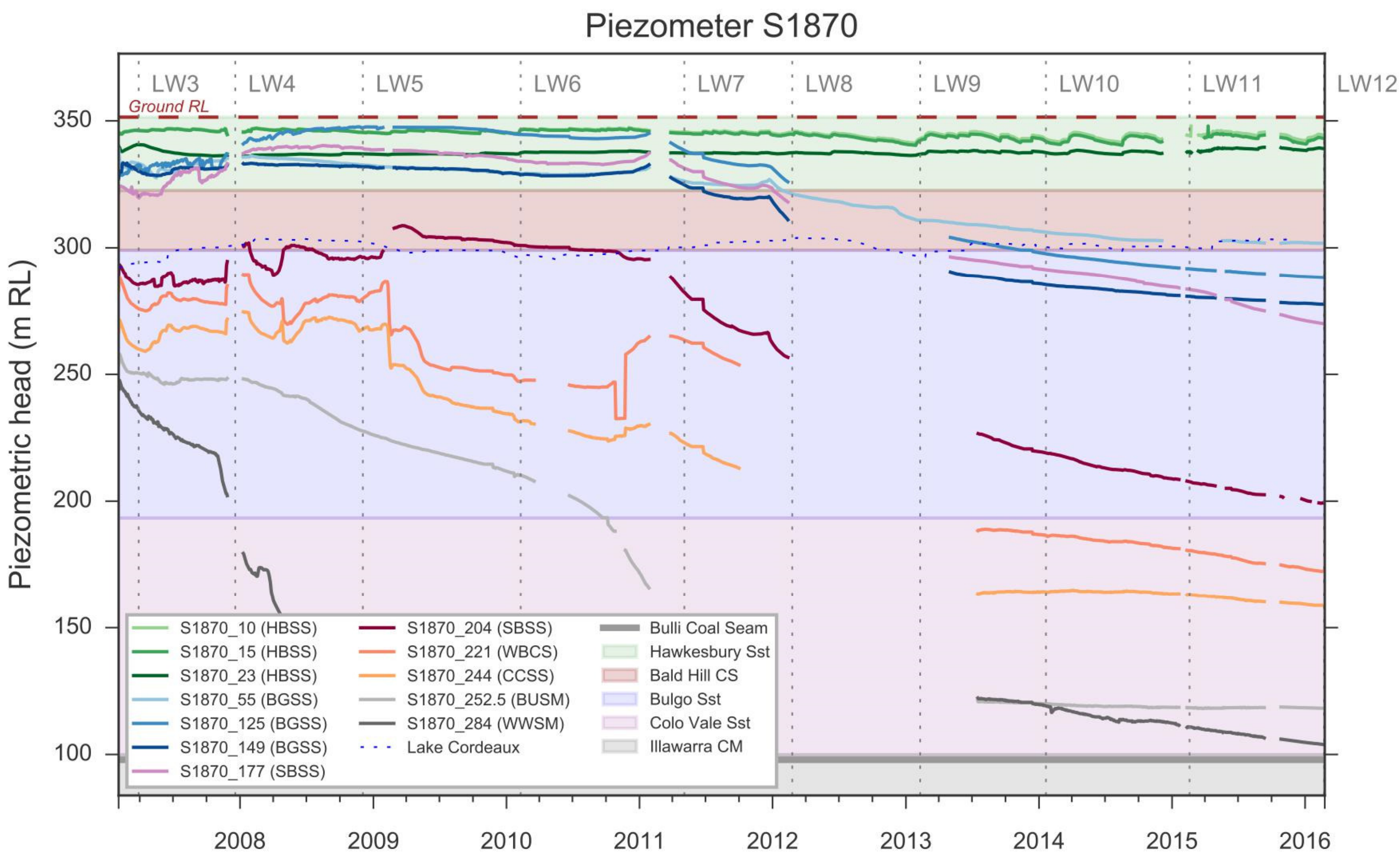


Figure 2.17 Groundwater hydrographs for Bore S1870 (near Sandy Creek)

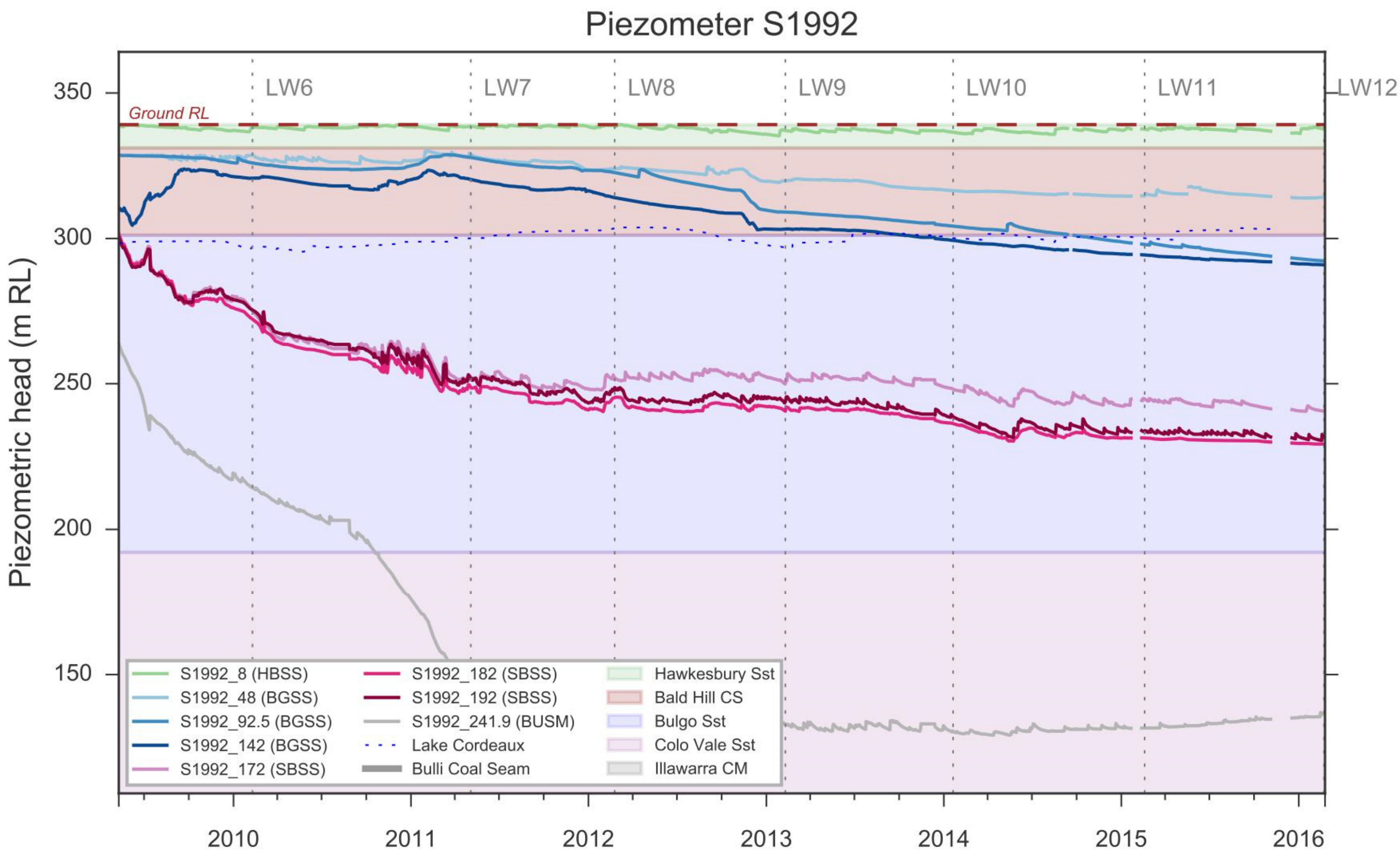


Figure 2.18 **Groundwater hydrographs for Bore S1992 (overlying Longwall 7)**

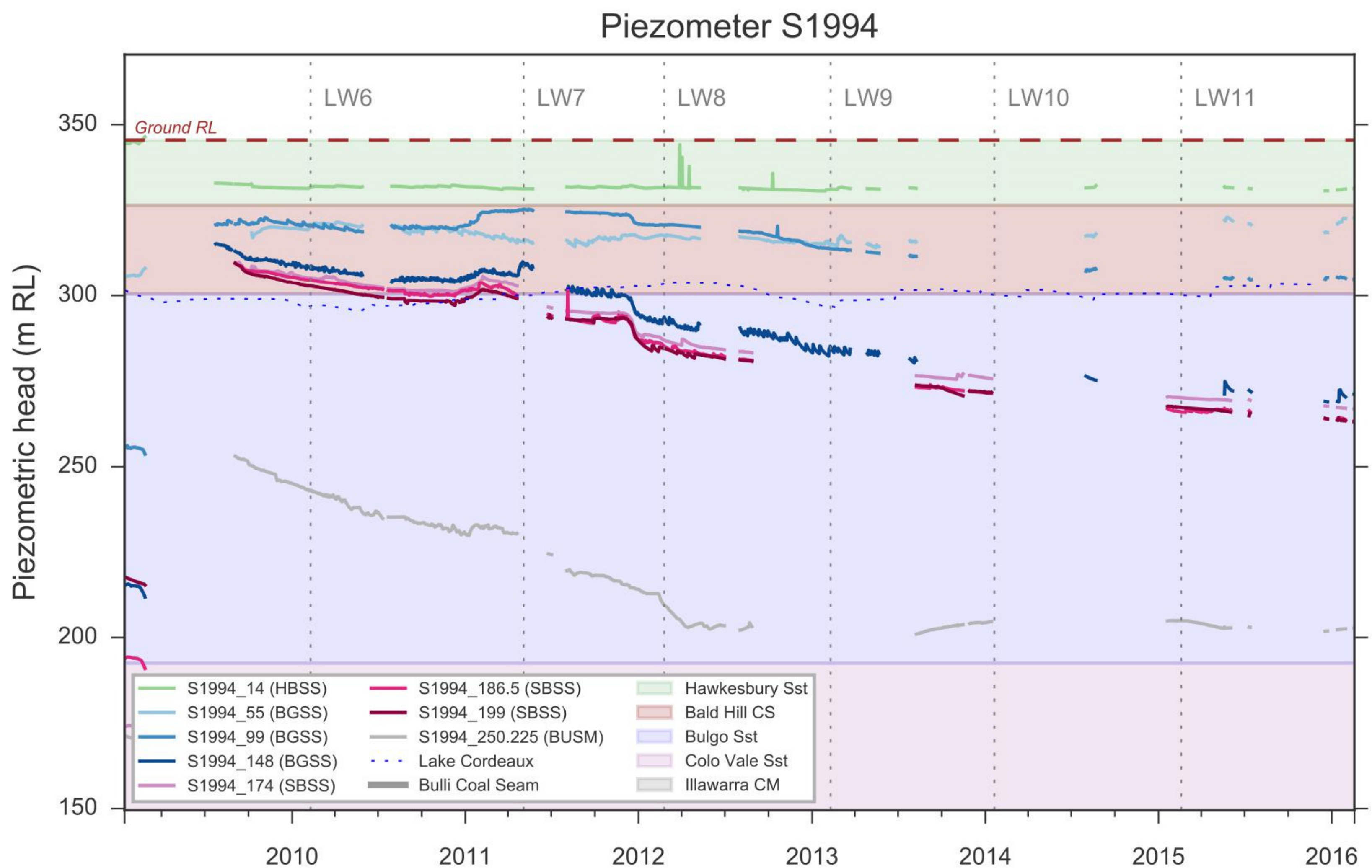


Figure 2.19 Groundwater hydrographs for Bore S1994 (Near Longwall 6 and Cordeaux Reservoir)

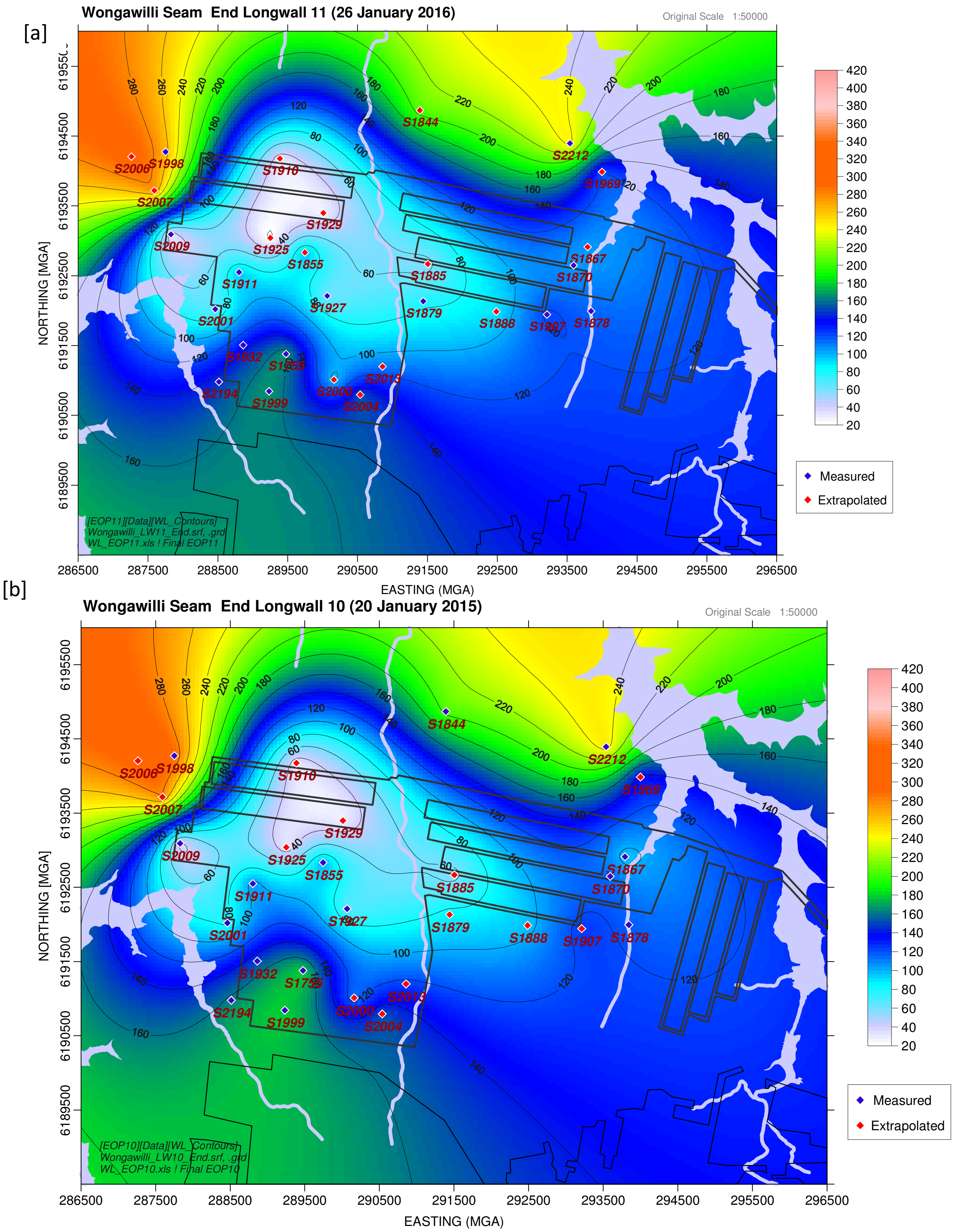


Figure 2. 20 **Observed and interpolated potentiometric head contours (mAHD) for the Wongawilli Seam: [a] End of Longwall 11; [b] End of Longwall 10**

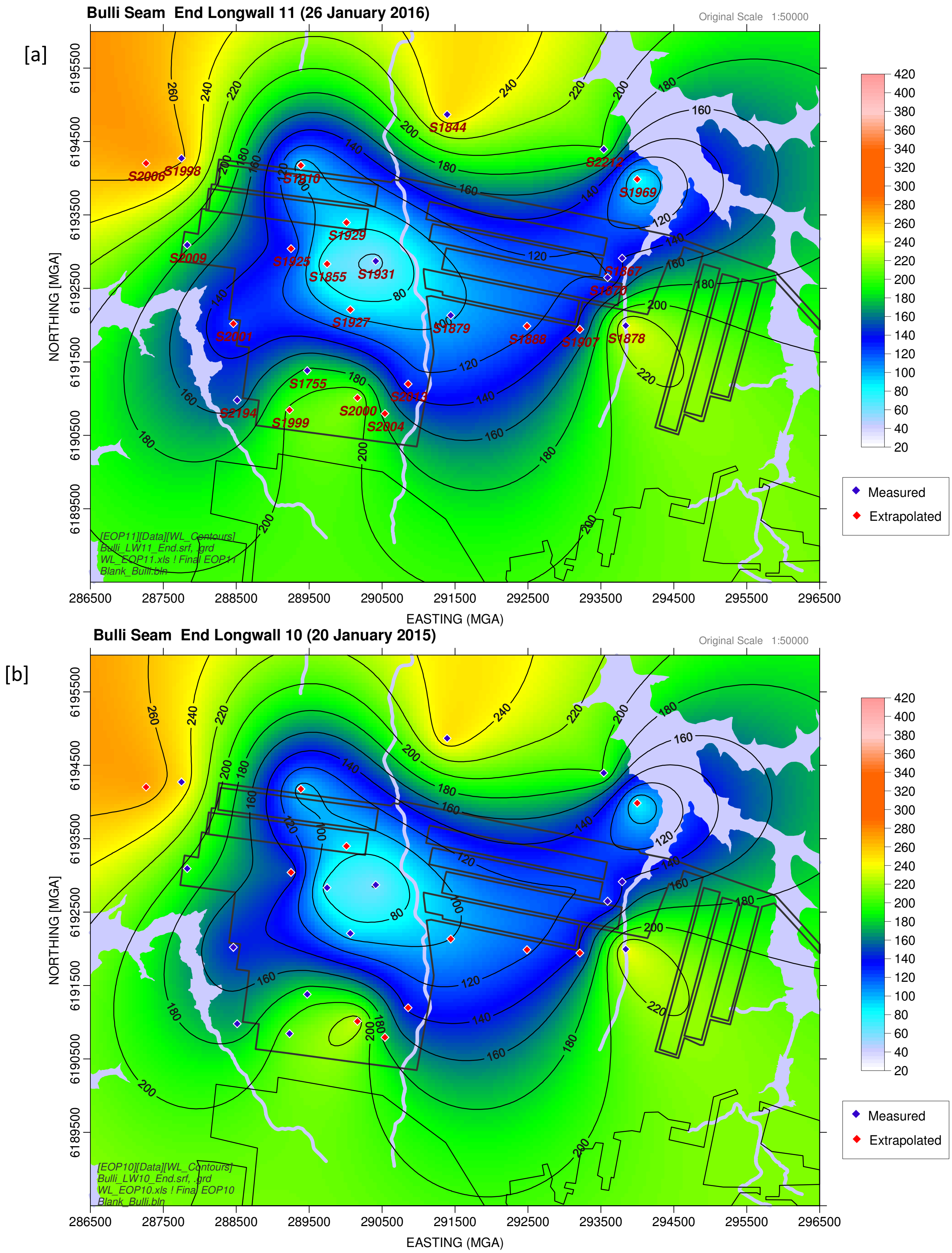
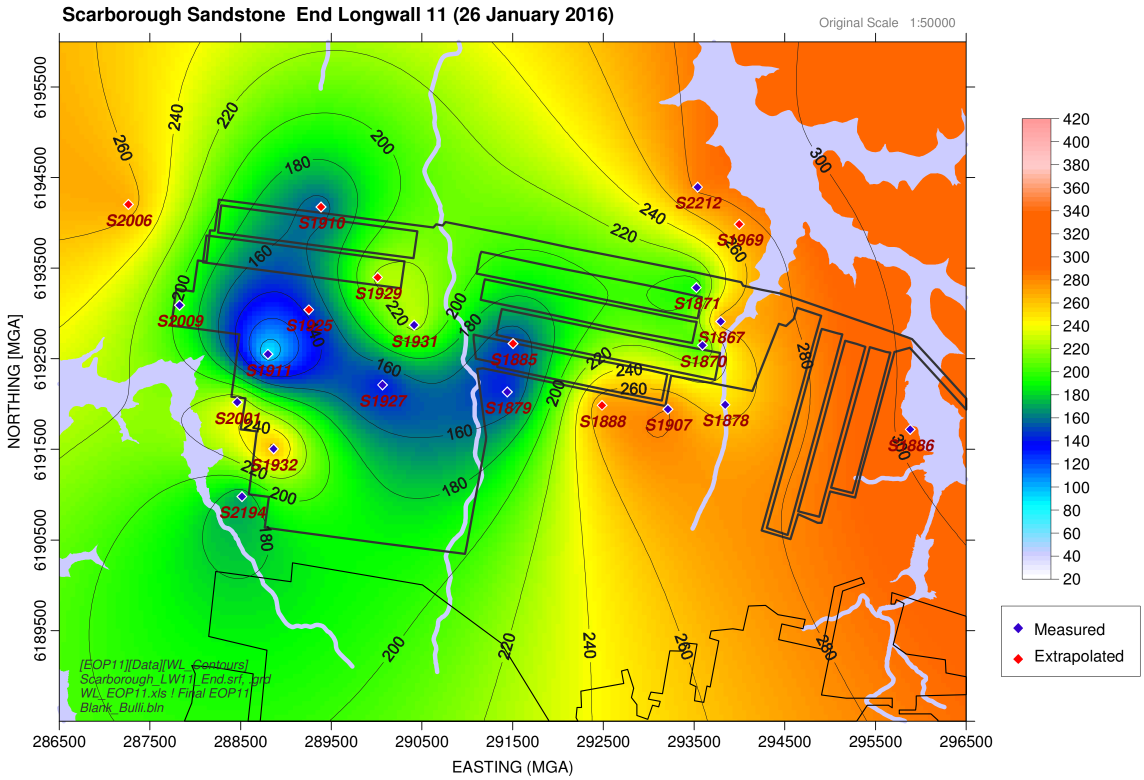
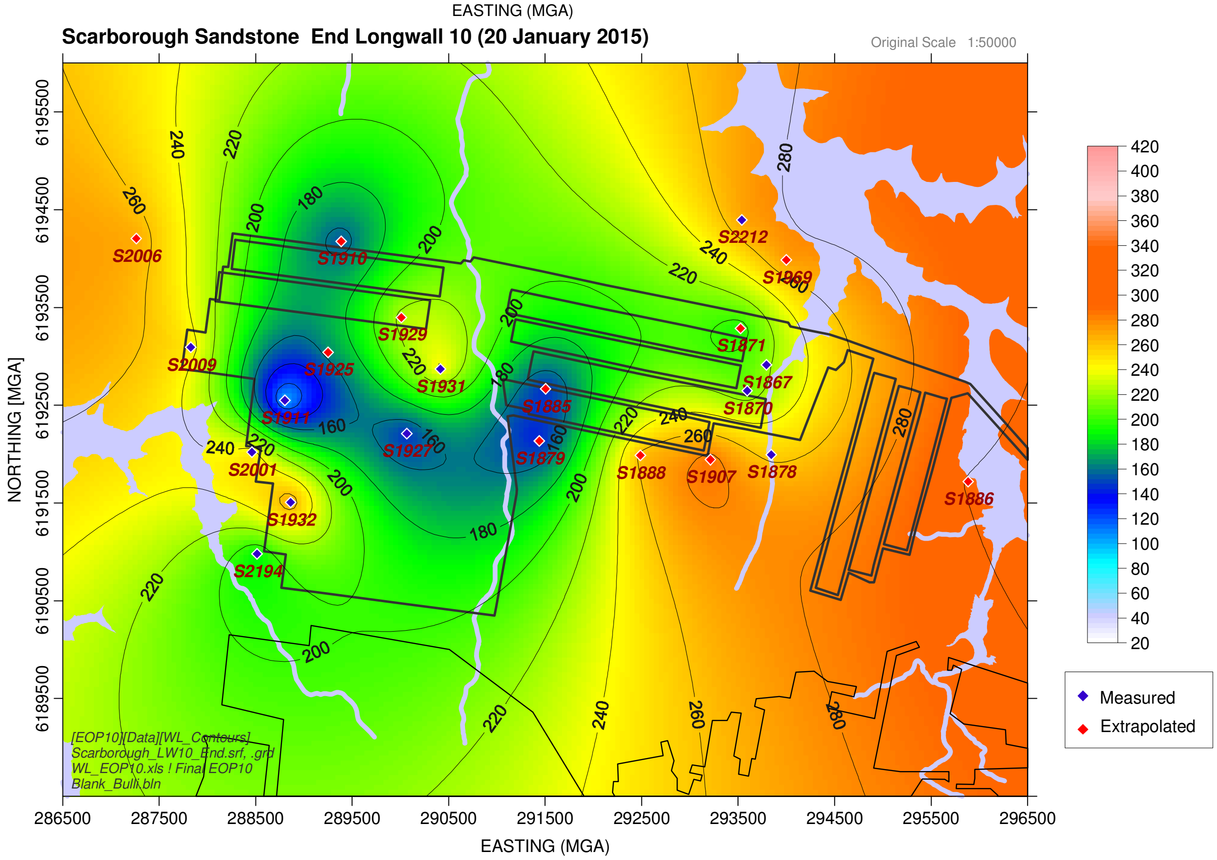


Figure 2. 21 **Observed and interpolated potentiometric head contours (mAHD) for the Bulli Seam: [a] End of Longwall 11; [b] End of Longwall 10.**

[a]





[b]

Figure 2. 22 Observed and interpolated potentiometric head contours (mAHD) for the Scarborough Sandstone: [a] End of Longwall 11; [b] End of Longwall 10

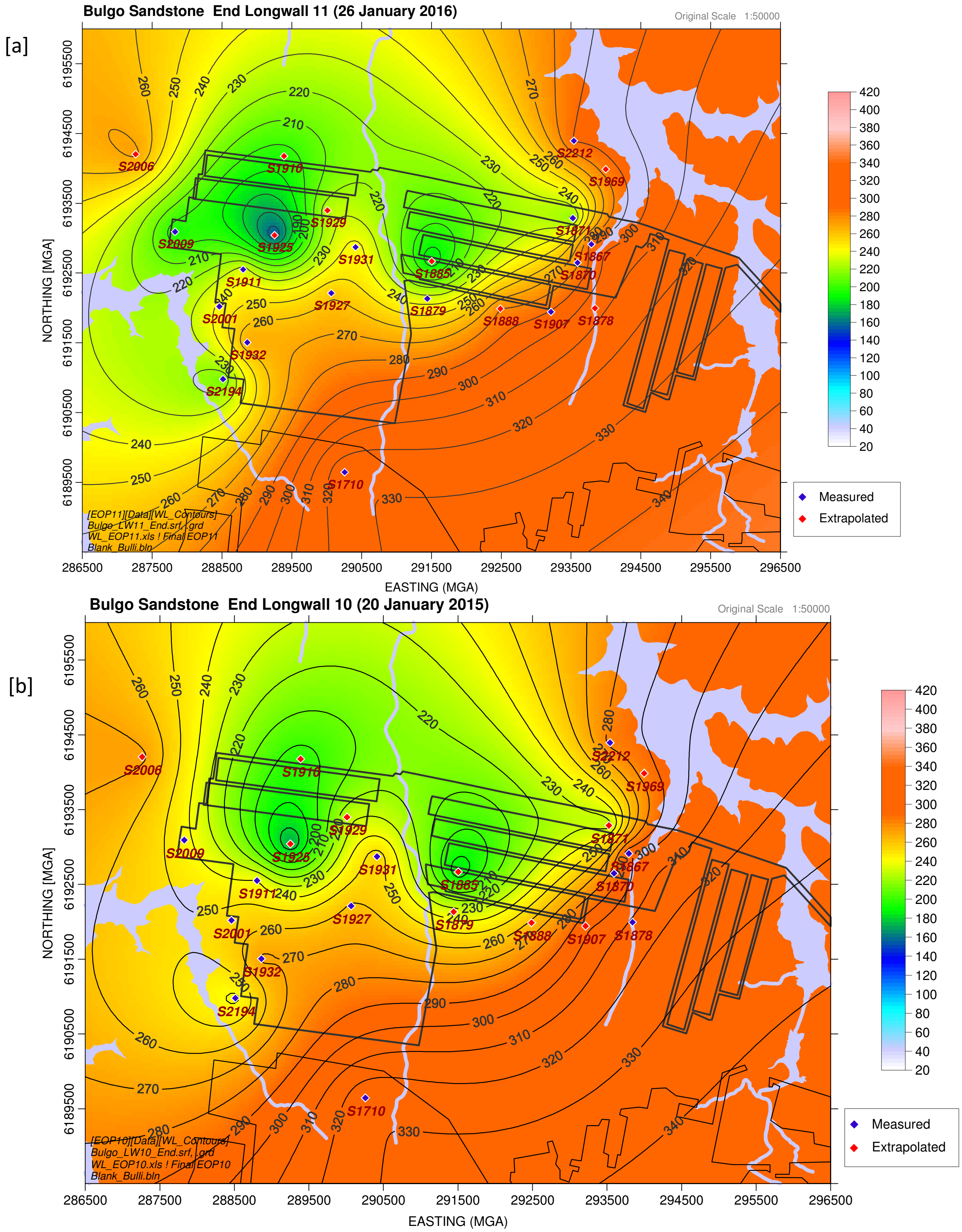


Figure 2. 23 Observed and interpolated potentiometric head contours (mAHD) for the Bulgo Sandstone: [a] End of Longwall 11; [b] End of Longwall 10

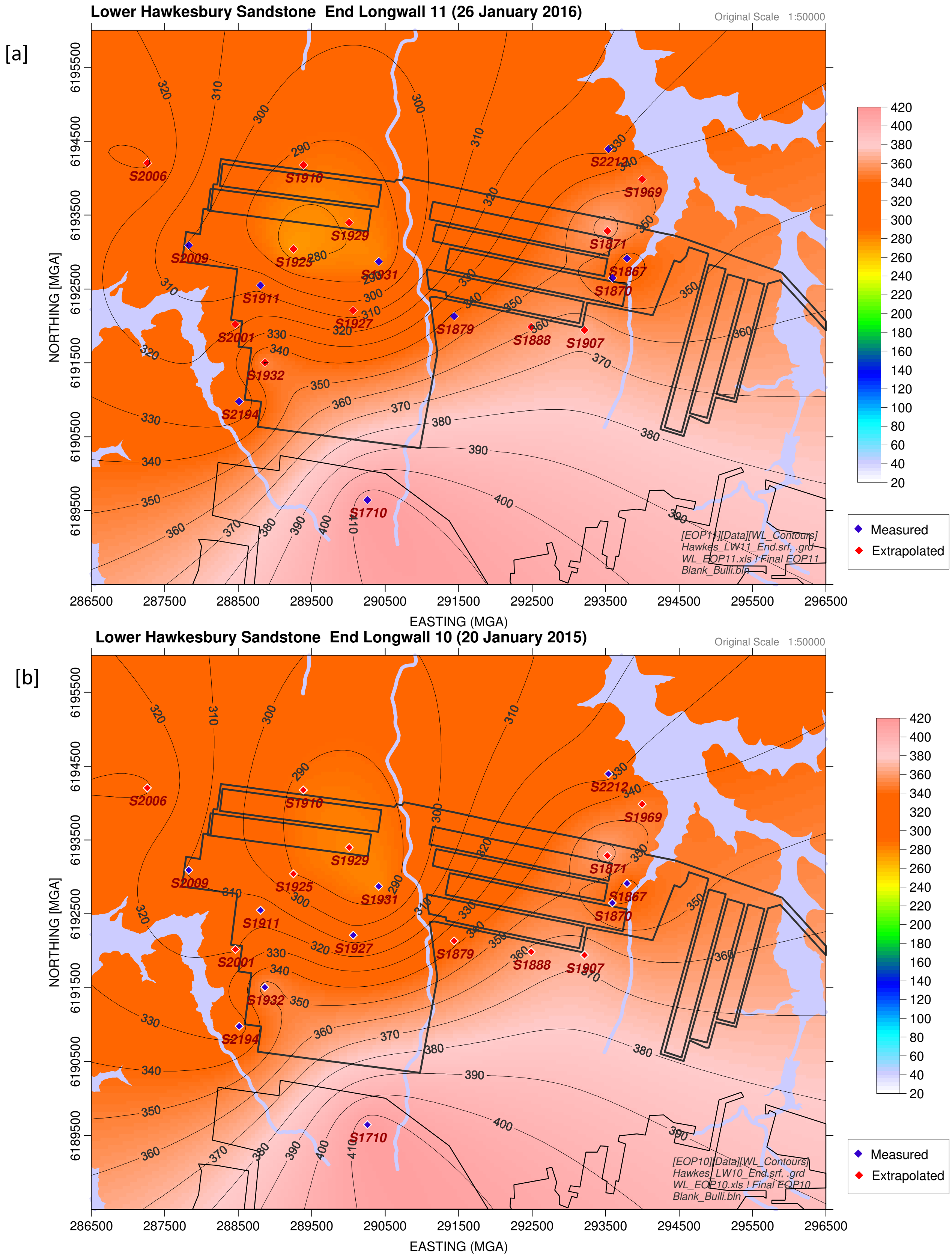


Figure 2. 24 Observed and interpolated potentiometric head contours (mAHD) for the lower Hawkesbury Sandstone: [a] End of Longwall 11; [b] End of Longwall 10

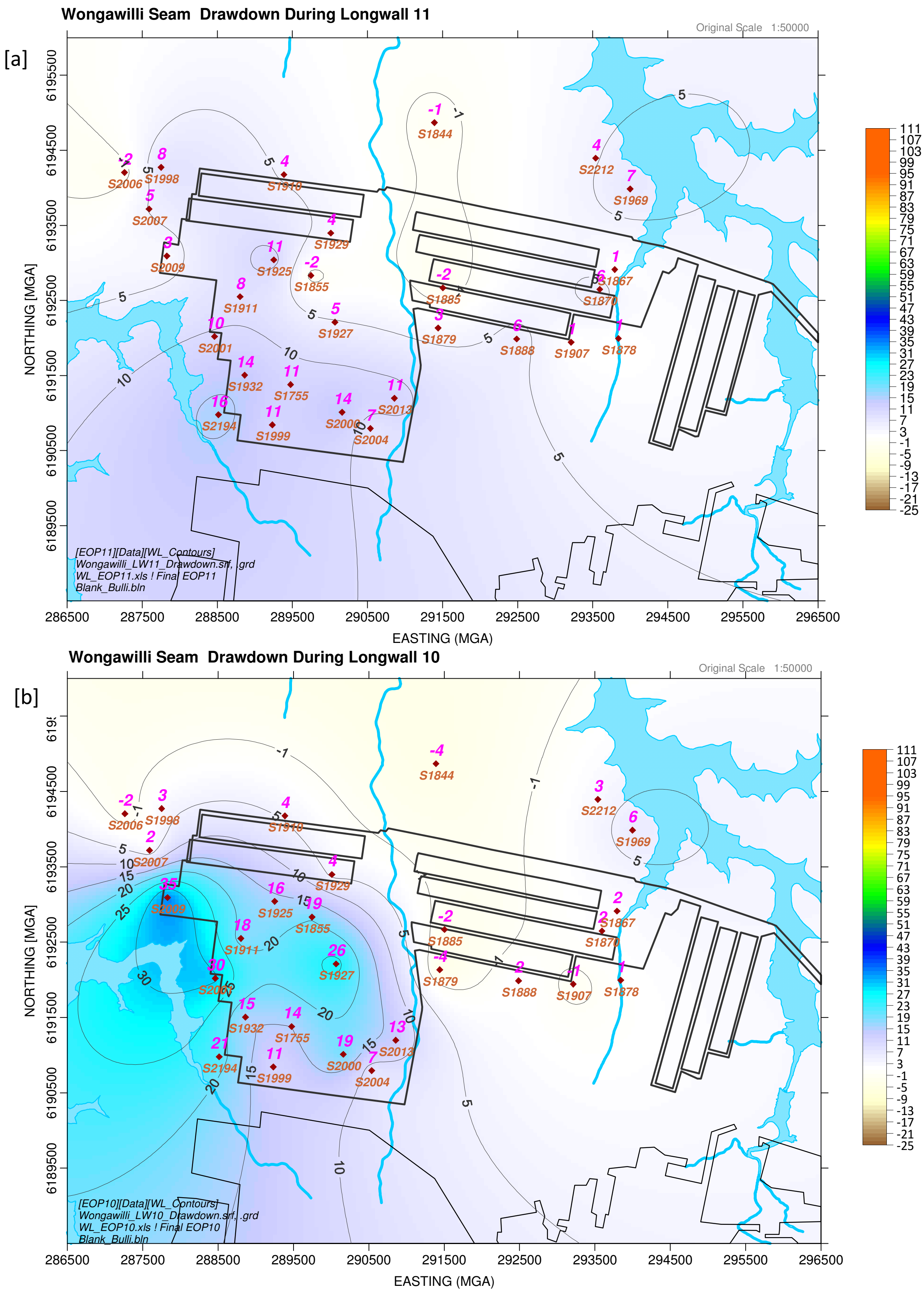


Figure 2. 25 **Observed and interpolated drawdown (m) in the Wongawilli Seam: [a] during the extraction of Longwall 11 [b] during the extraction of Longwall 10.**

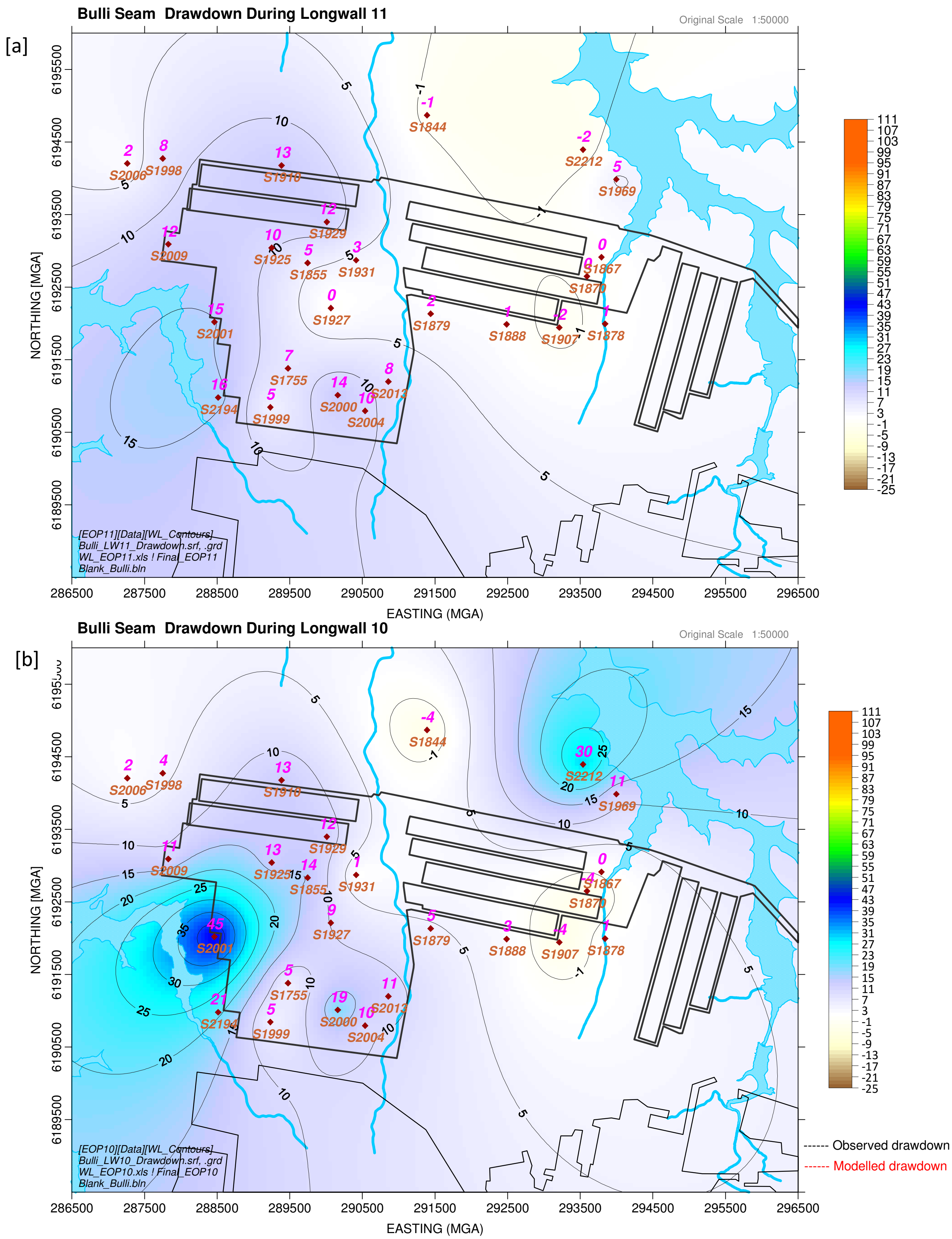


Figure 2. 26 Observed and interpolated drawdown (m) in the Bulli Seam: [a] during the extraction of Longwall 11 [b] during the extraction of Longwall 10.

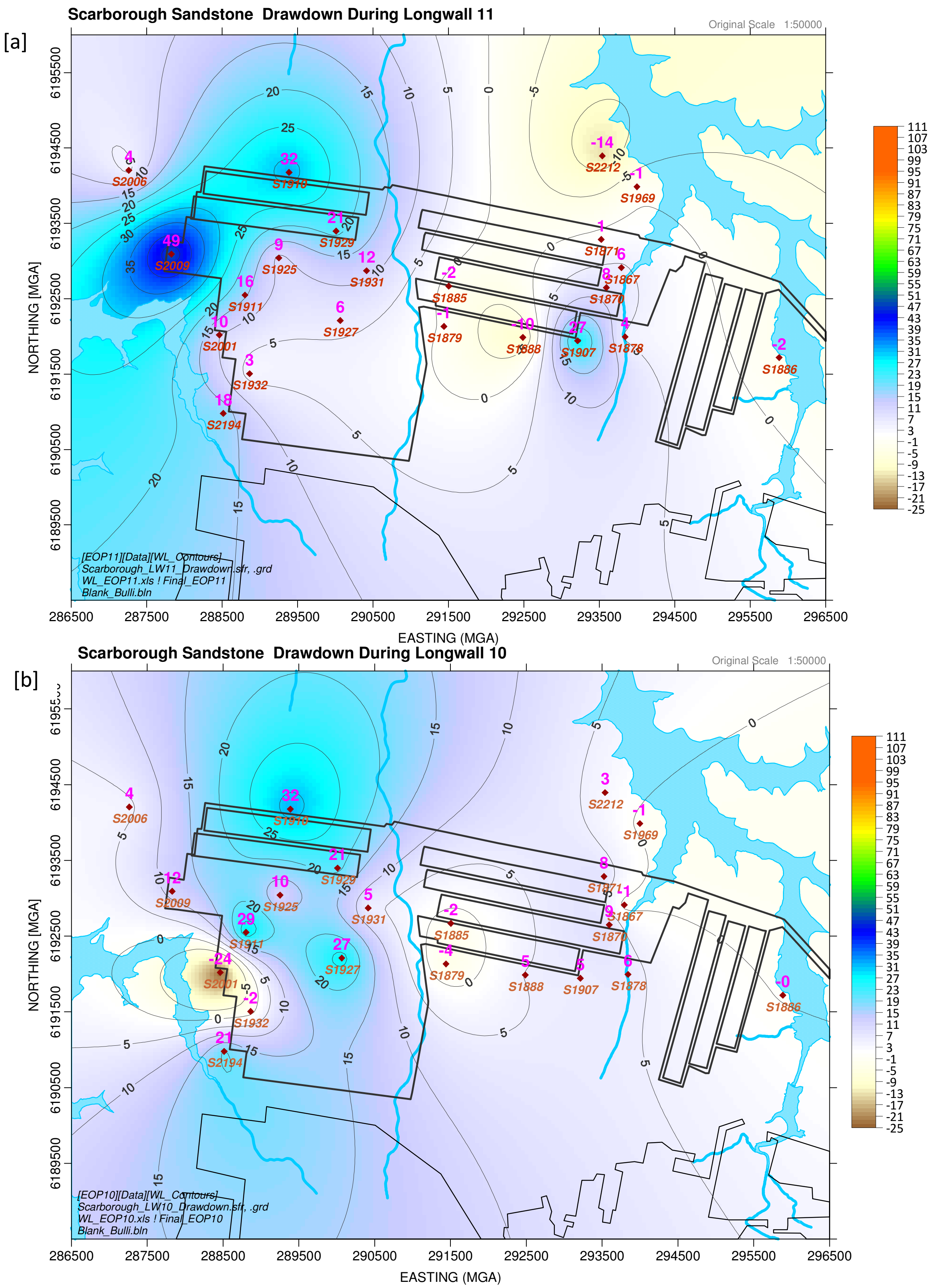


Figure 2. 27 Observed and interpolated drawdown (m) in the Scarborough Sandstone: [a] during the extraction of Longwall 11 [b] during the extraction of Longwall 10.

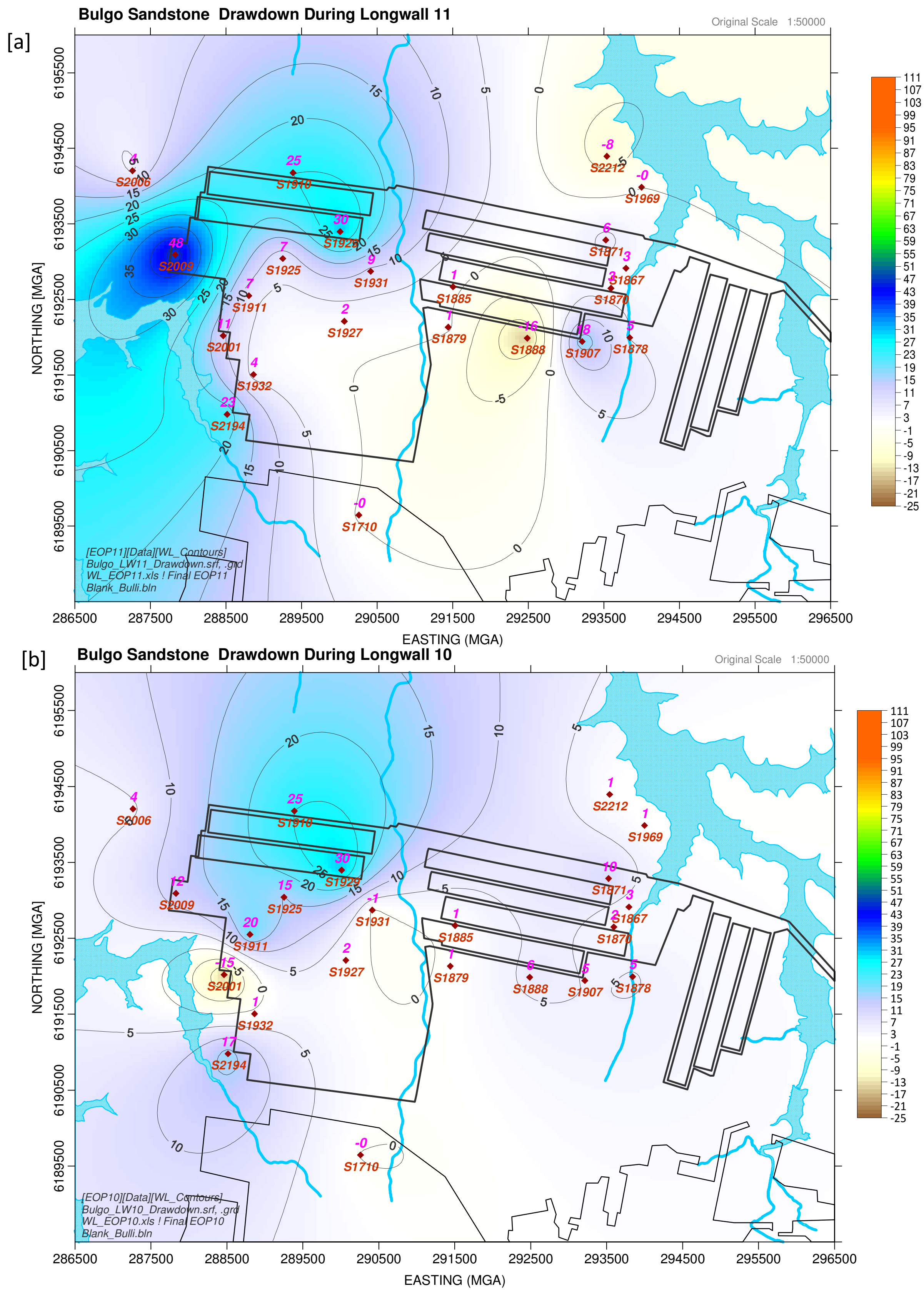
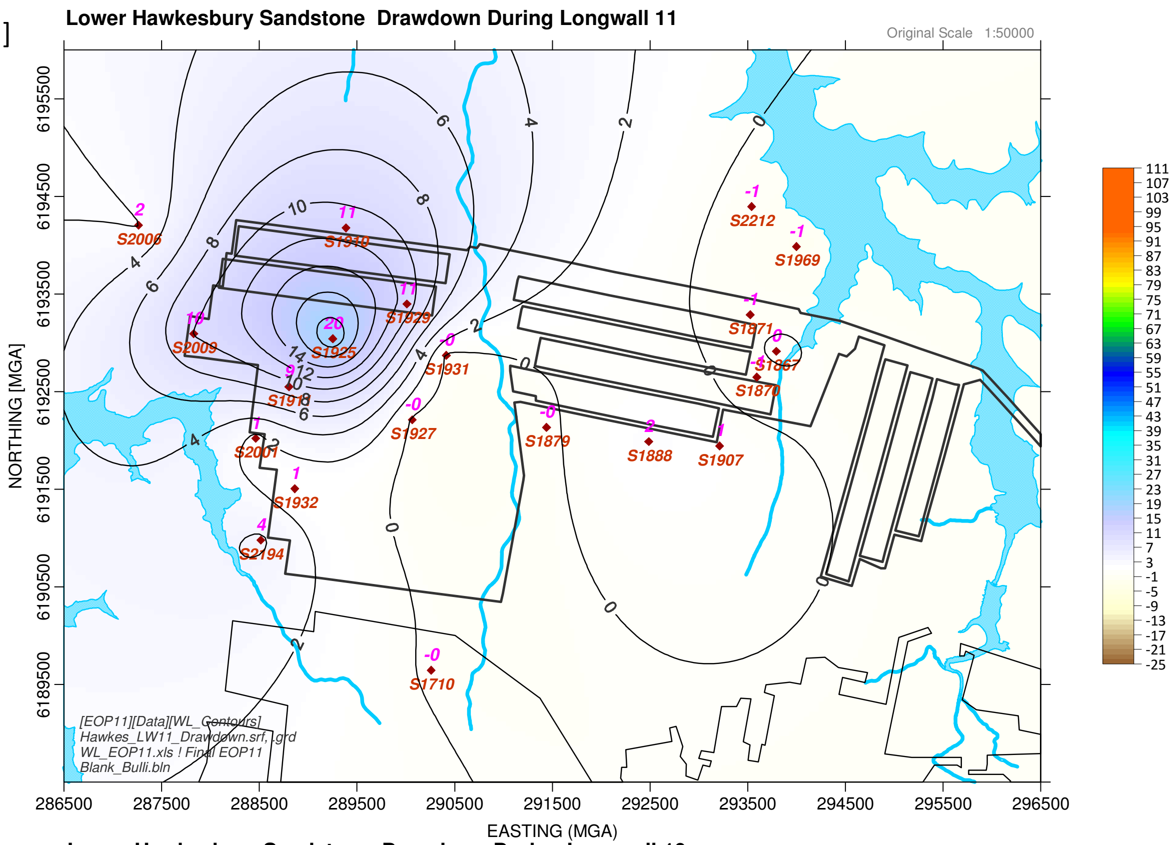


Figure 2. 28 Observed and interpolated drawdown (m) in the Bulgo Sandstone: [a] during the extraction of Longwall 11 [b] during the extraction of Longwall 10.

[a]



[b]

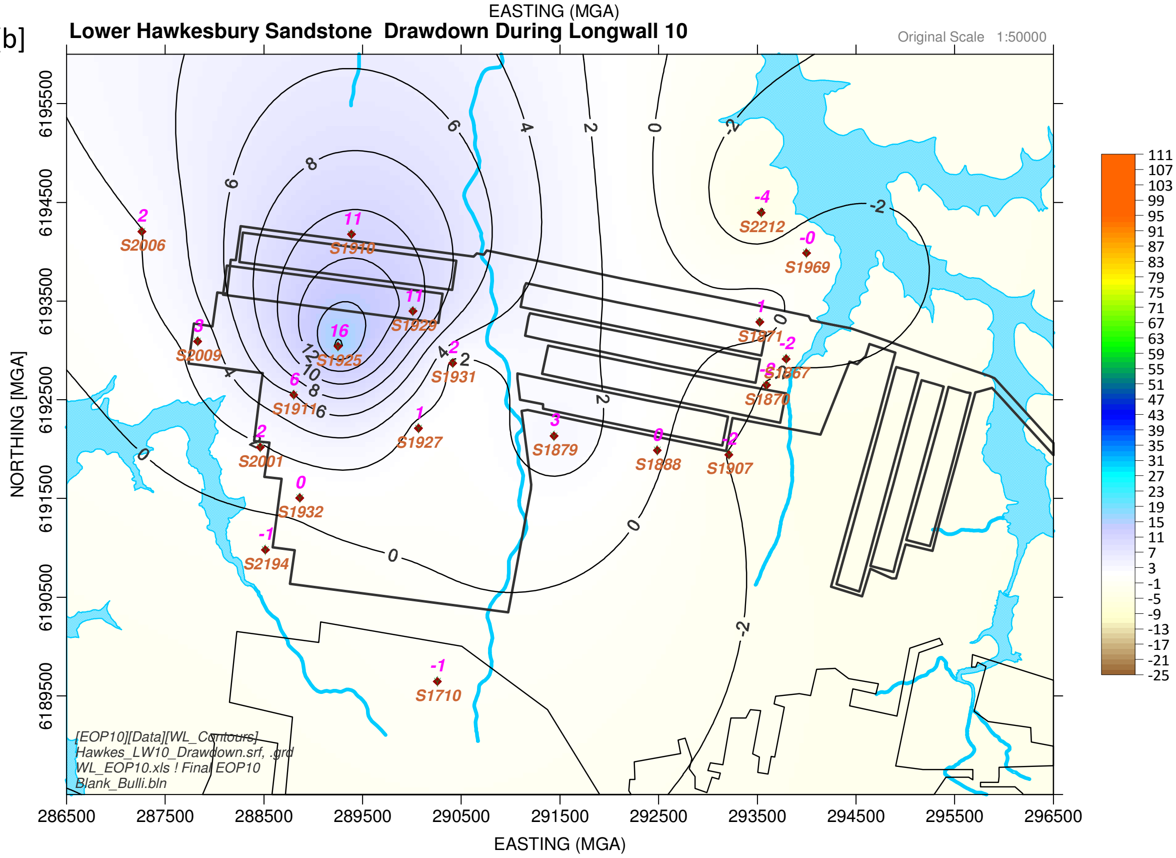


Figure 2.29 Observed and interpolated drawdown (m) in the lower Hawkesbury Sandstone: [a] during the extraction of Longwall 11 [b] during the extraction of Longwall 10.

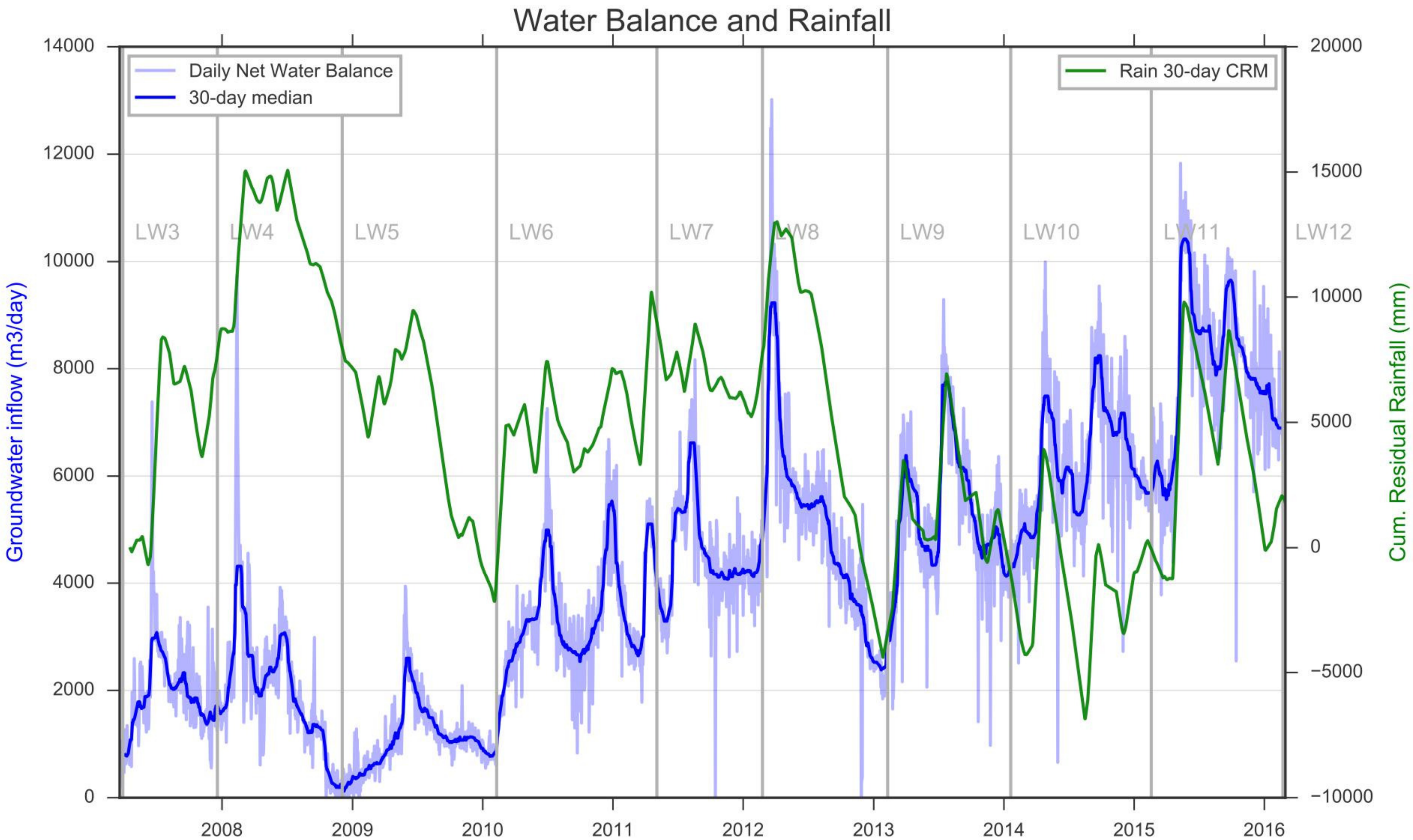


Figure 2.30 **Total measured water balance for Dendrobium Mine [kL/day]**

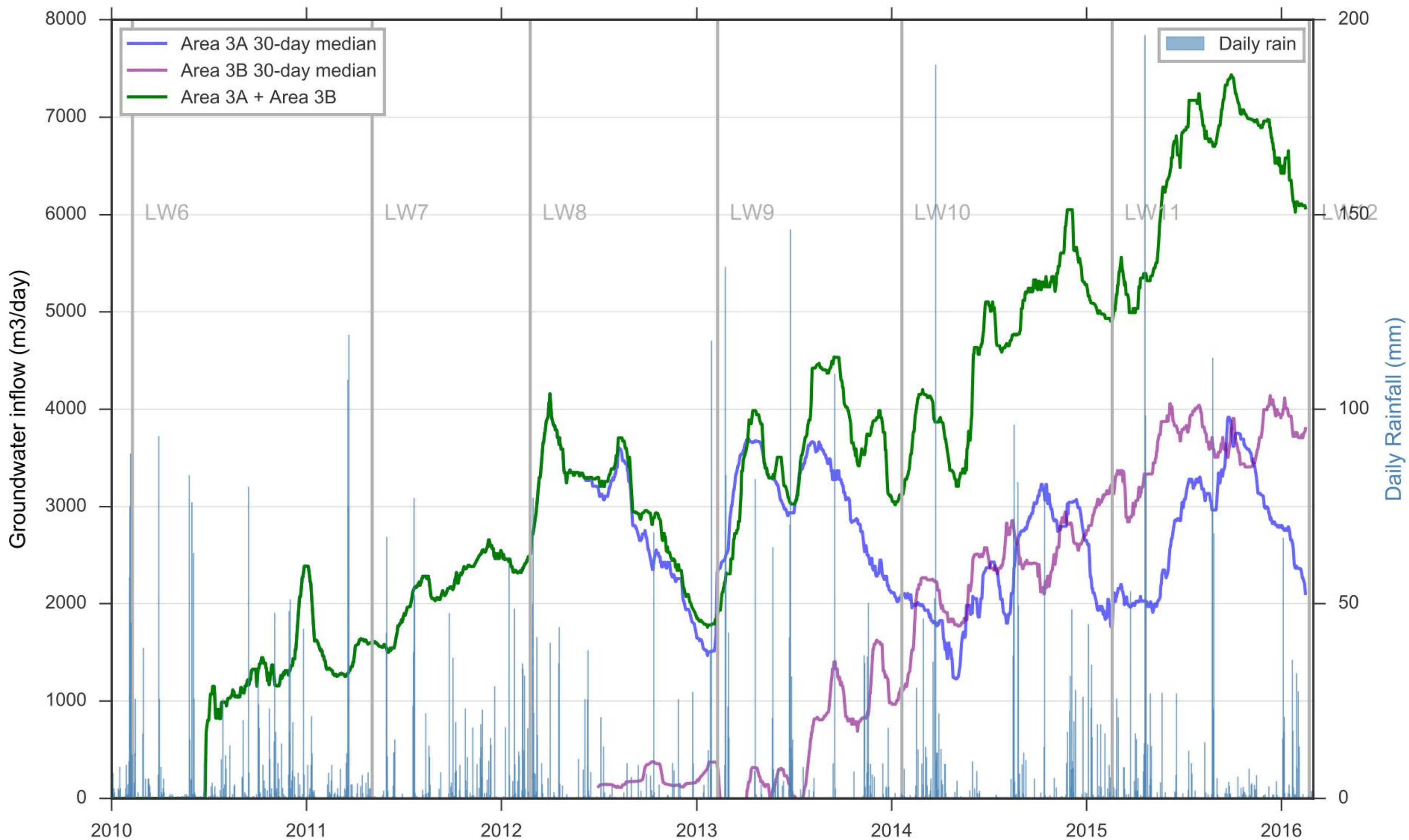


Figure 2.31 Running average (31 day) mine inflow for Dendrobium Areas 3A and 3B from the commencement of Longwall 6 [ML/d]

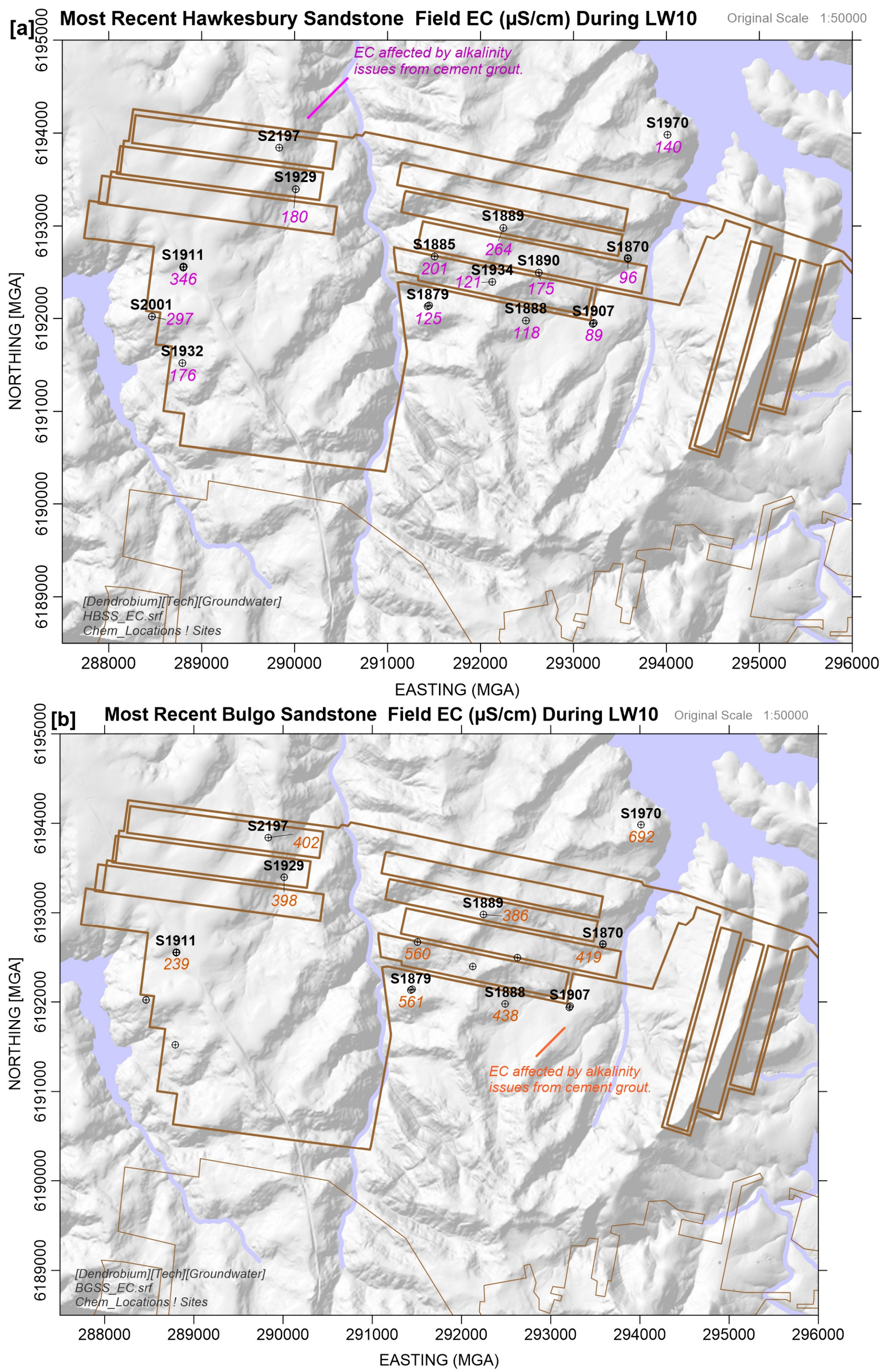


Figure 2.32 Average field electrical conductivity [EC] measurements [µS/cm] in Area 3 for [a] Hawkesbury Sandstone and [b] Bulgo Sandstone groundwater

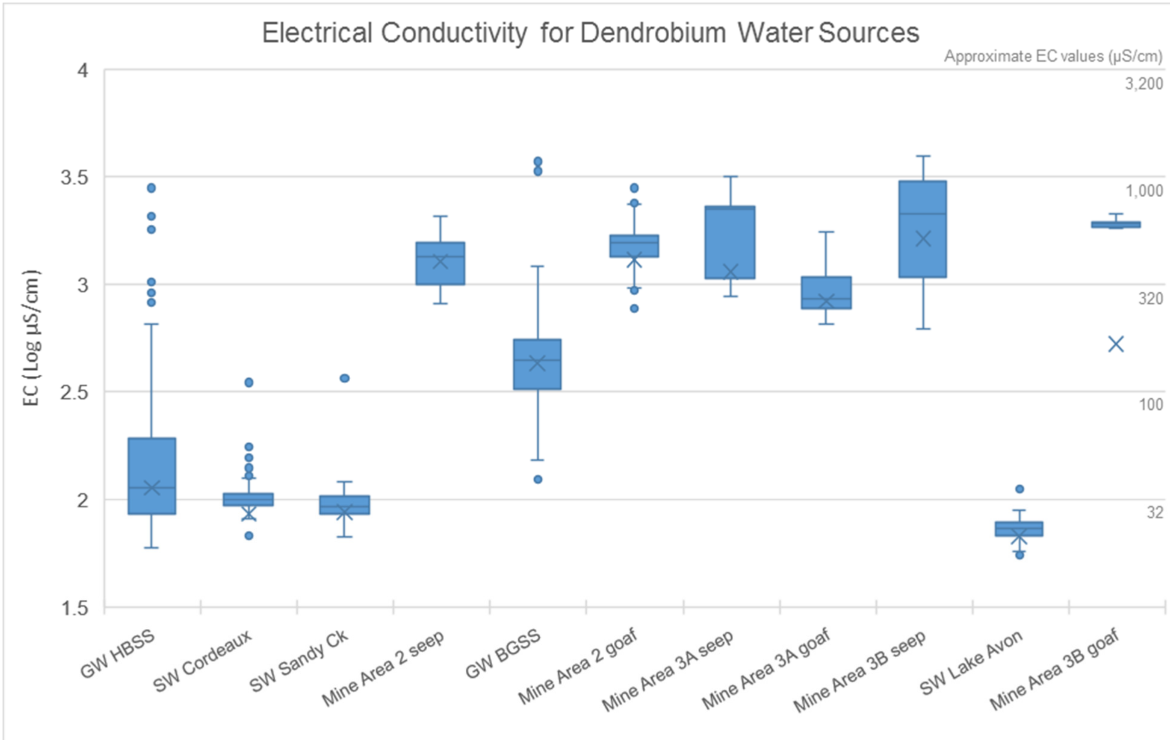


Figure 2.33 Ranges in field measured electrical conductivity [EC] for various water sources [log μS/cm]

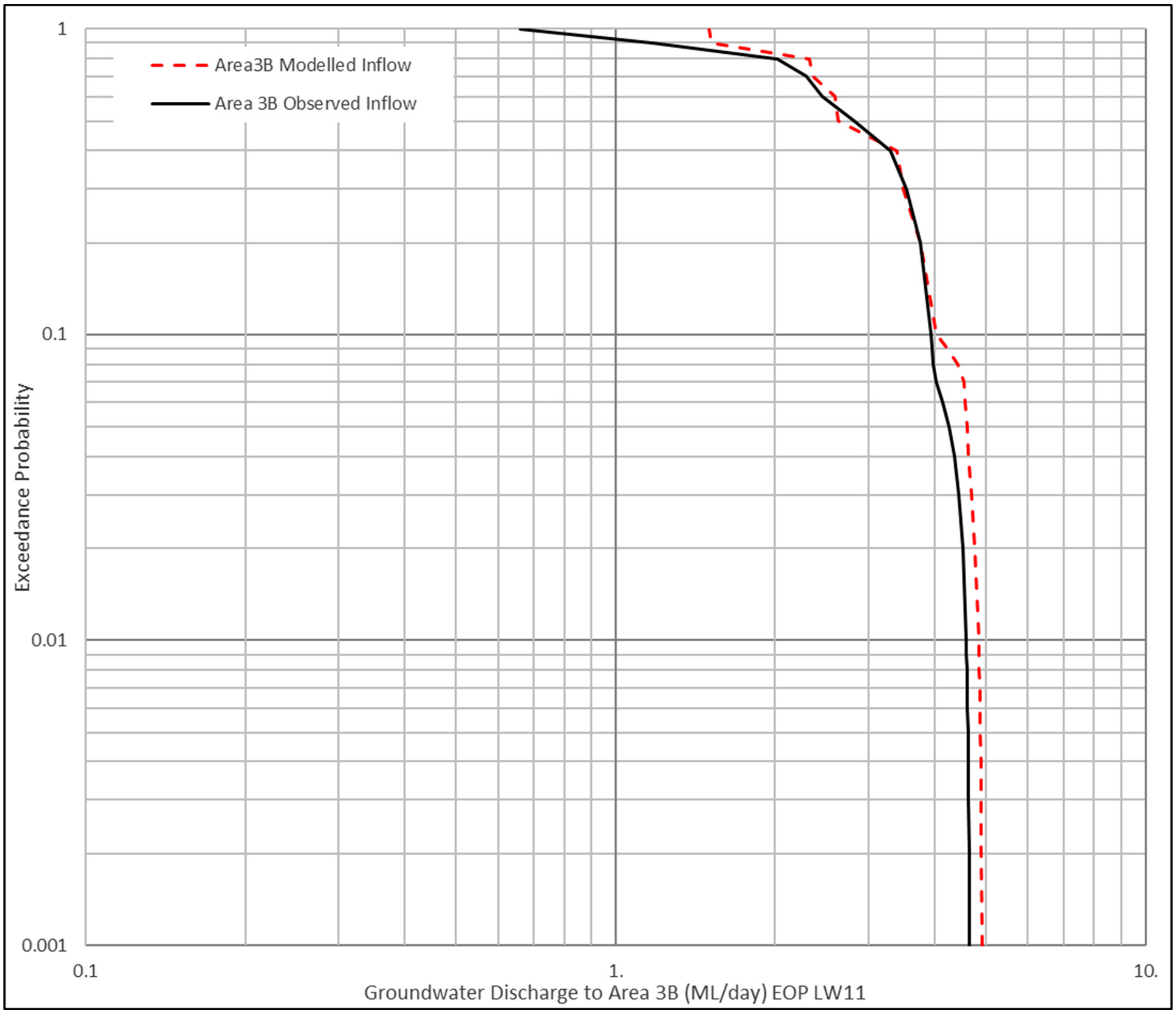


Figure 3.1 Probability distributions for measured and modelled mine inflow to Area 3B [ML/day]

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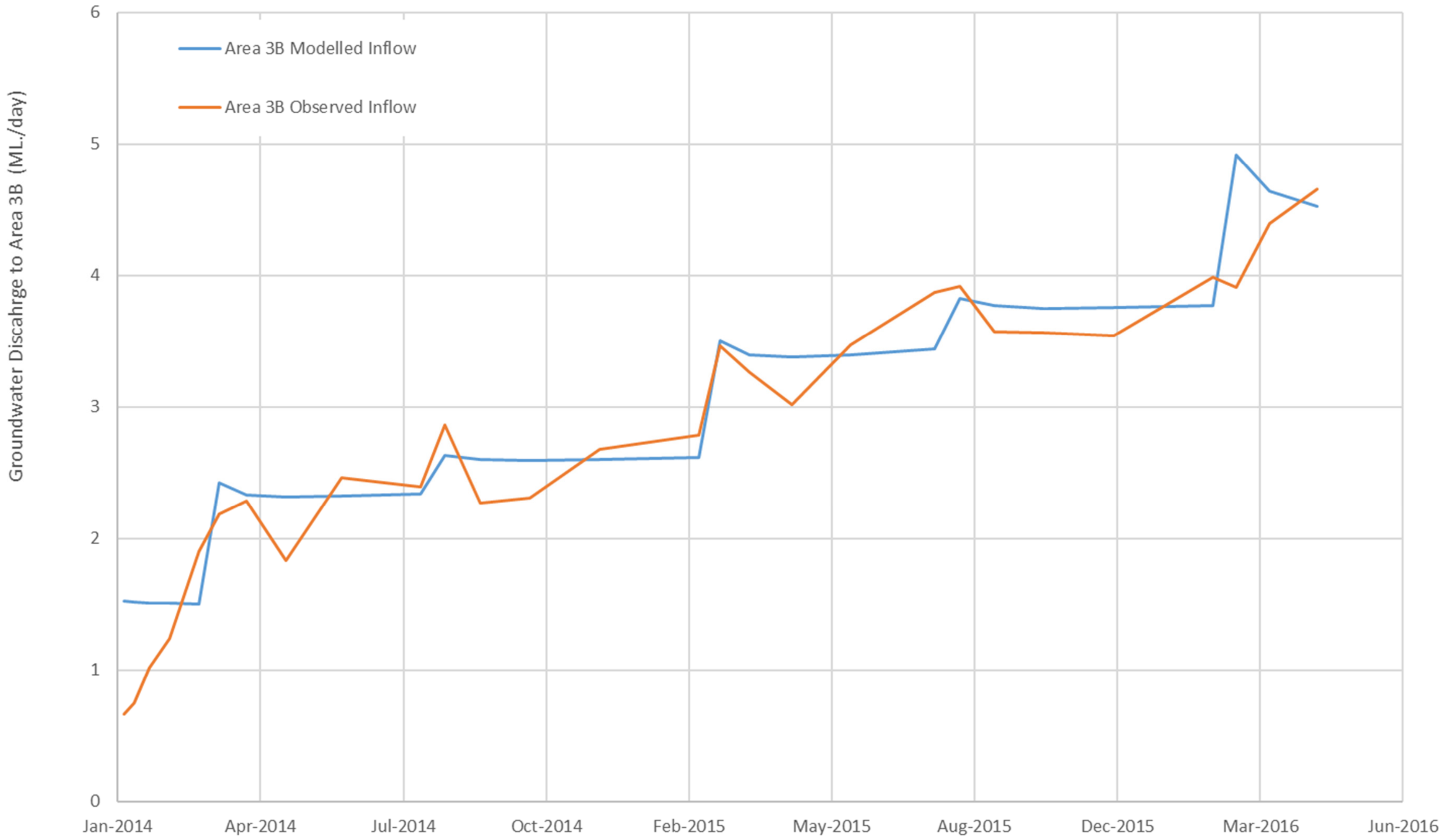

Figure 3.2 Measured and modelled groundwater discharge to Area 3B during Longwall 11 extraction [ML/day]

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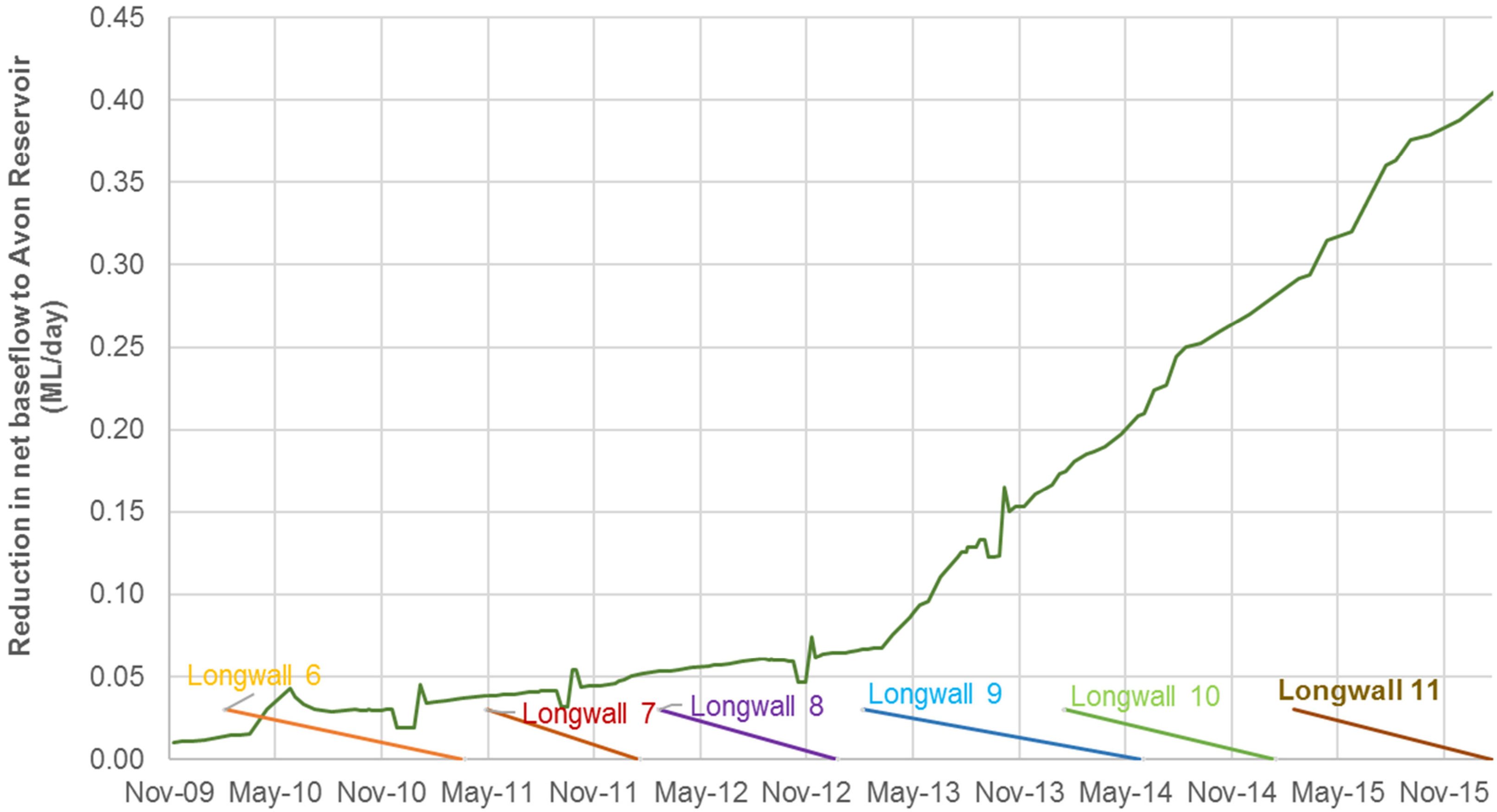

Figure 3.3 **Predicted changes in net baseflow to the Avon Reservoir due to Area 3A and Area 3B longwall extraction [ML/day]**

Source: x:\HydroSim\Dendrobium\Dendrobium\BHP002\GWModel\DenV3TR\Processing\Calibration\Zonebudget\DenV3TR57_52_Reservoir_Inflow_Impacts.xlsx

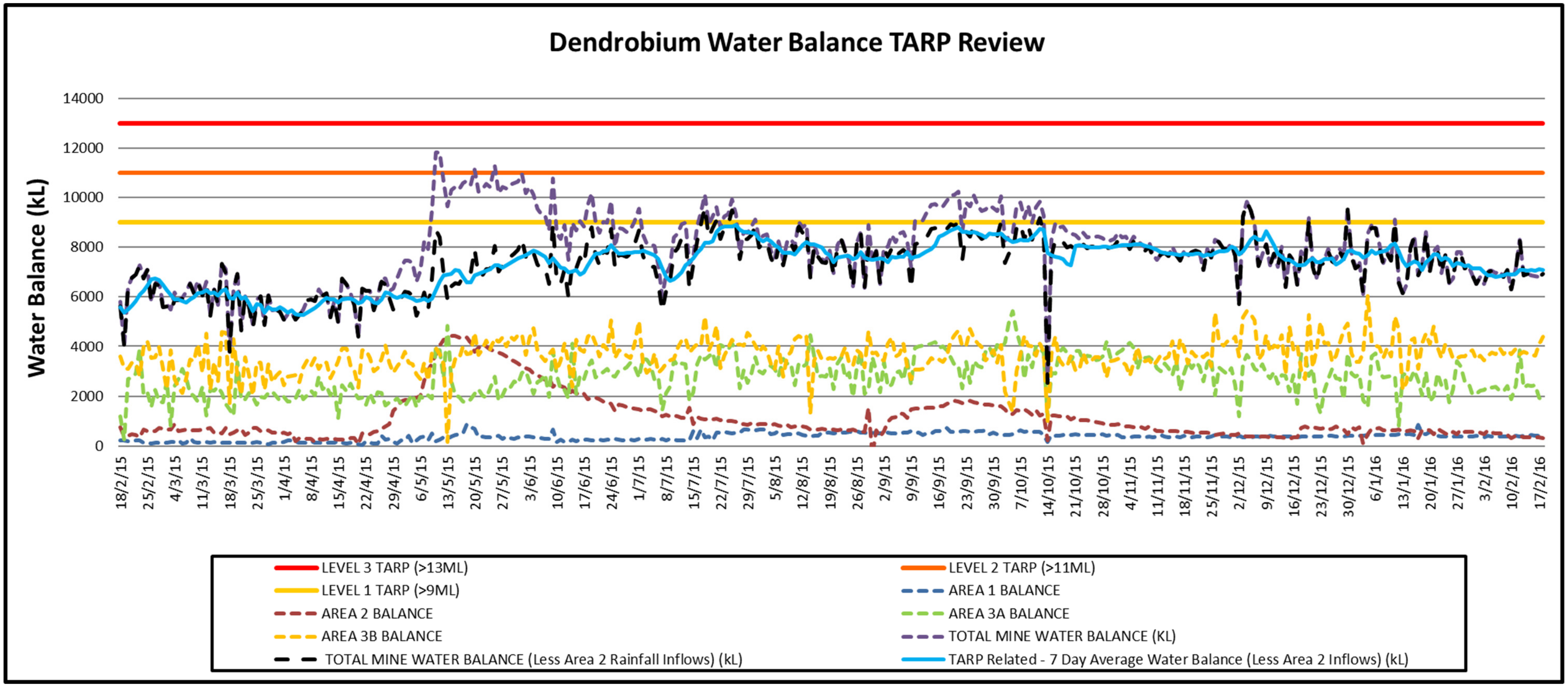

Figure 3.4 Dendrobium Water Balance for TARP review during Longwall 11 extraction.