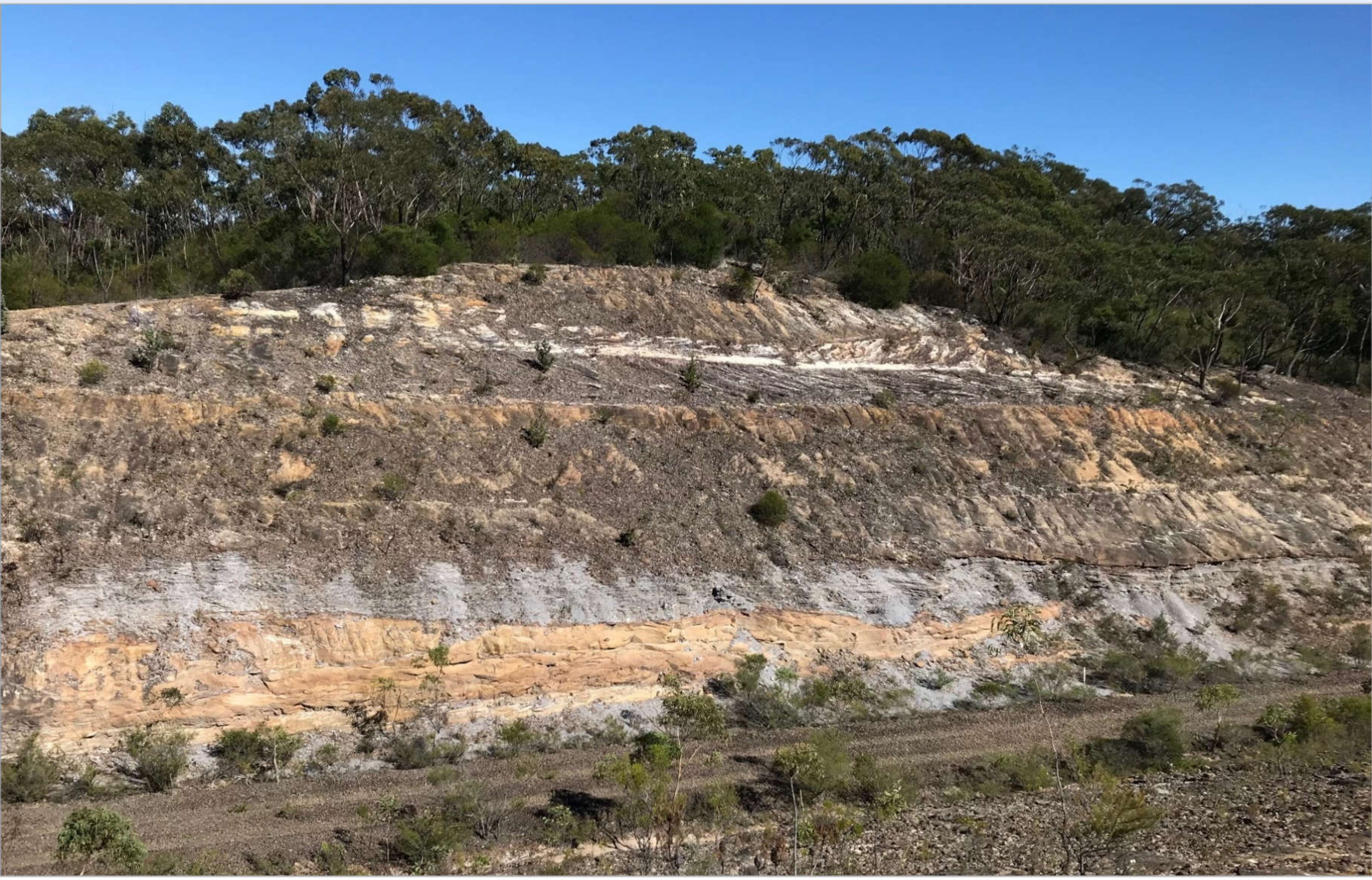
South32 - Illawarra Coal

DENDROBIUM MINE

End of Panel Groundwater Assessment for Longwall 13 (Area 3B)



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EXECUTIVE SUMMARY

This report provides an assessment of the hydrogeological effects of Longwall 13 extraction in Area 3B at Dendrobium Mine, as required under the conditions of mining approval. Extraction of Longwall 13 commenced on 4 March 2017 and was completed on 19 April 2018. Longwall 13 is the fifth panel to be extracted in Area 3B, with an extracted length of 2270 m, a void width of 305 m (including first workings) and a cutting height of between 3.7 and 3.95 m.

The average daily groundwater inflow to Area 3B during Longwall 13 extraction was 4.68 ML/d which represents approximately 62% of total mine inflow for the period. Inflows to Area 3B have generally increased over time in proportion to the total mined area since 2013. From 2016 the increasing trend has slowed and a weak correlation between mine inflow to Area 3B is emerging. The amplitude of the variation due to rainfall accounts for approximately 20% of the total inflow. However, to date, the concentration of tritium (an isotopic indicator of modern water) in Area 3B mine inflow water is not statistically different from deep groundwater.

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.

Mining of Longwall 13 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 13 and extending to S2194, located 1.4 km to the south of Longwall 13. Drawdown in the Hawkesbury Sandstone is greatest above and immediately adjacent to Longwall 13, with some drawdown also evident 435 m to the south of Longwall 13.

Observations at monitoring bores installed above mined longwalls indicate that the Hawkesbury Sandstone undergoes fracturing to the ground surface, accompanied by depressurisation of most shallow strata. There is evidence that drainage of the Hawkesbury Sandstone above goafs is not complete in all areas and some perched groundwater horizons remain.

Starting in 2015, a series of monitoring bores was installed along the barrier zone between Lake Avon reservoir and Area 3B. Observations at those bores indicate depressurisation of the upper Colo Vale Sandstone in response to longwall extraction, but only variable drawdown in the Hawkesbury Sandstone. A hydraulic gradient towards the lake is preserved in the Hawkesbury Sandstone at S2313, whereas at S2314 and S2376 the hydraulic gradient is locally reversed towards the mine, implying movement of groundwater from the lake to the mine. It is estimated that seepage loss between Lake Avon and Longwalls 12 to 16 would be less than 0.28 ML/day (or 0.17 ML/day/km of shoreline adjacent to extracted longwalls). This estimate is consistent with numerical modelling predictions.

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 13, particularly in the critical area between Lake Avon and Area 3B. The model tends 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 13 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 13 extraction in Area 3B at Dendrobium Mine, as required under the conditions of mining approval. Extraction of Longwall 13 commenced on 4 March 2017 and was completed on 19 April 2018. Longwall 13 is the fifth panel to be extracted in Area 3B, with an extracted length of 2270 m, a void width of 305 m (including first workings) and a cutting height of between 3.7 and 3.95 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 and partially overlapping Area 1.

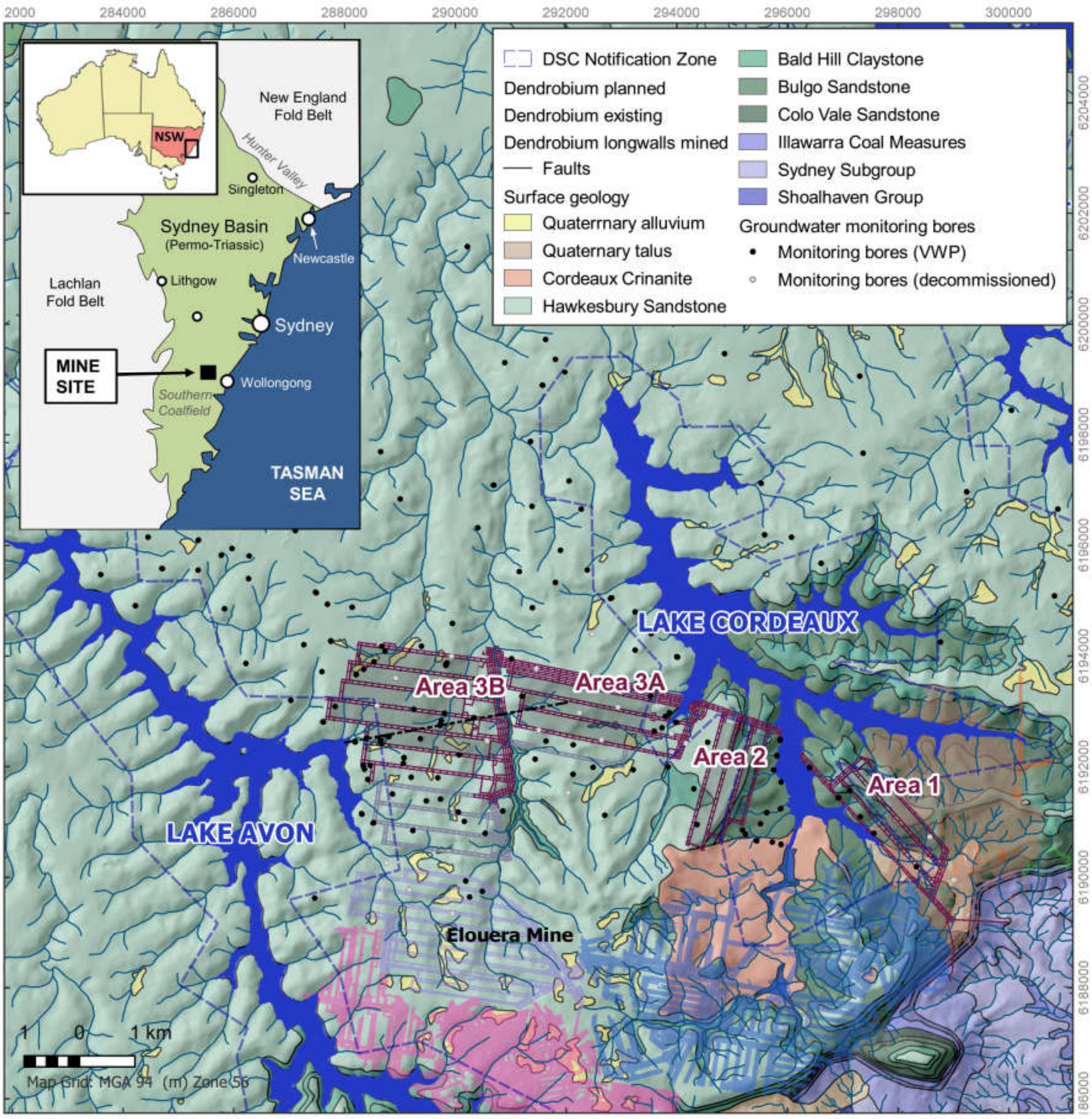

Figure 1. Location of Dendrobium Mine and surface geology

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.

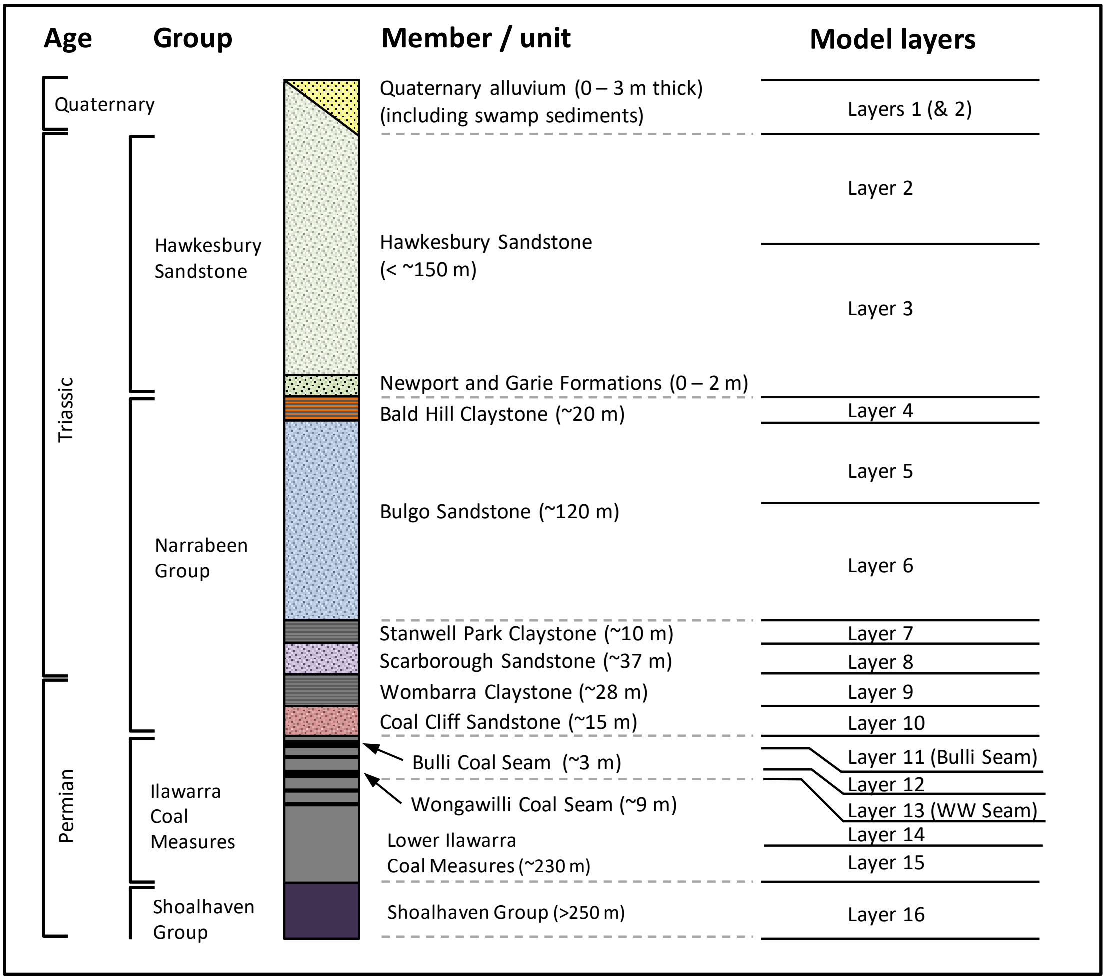

Figure 2. Stratigraphy of the Southern Coalfield

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 and associated deformation and fracturing of overlying strata (Peng & Chiang 1984; Whittaker & Reddish 1989). While authors differ in their terminology, there is general agreement on the overall fracture zonation patterns. Fracturing is most intense and vertically connected immediately above the collapsed longwall (goaf), and grades upwards through zones of less fractured strata (Booth 2002). Fracturing of the overburden can cause significant changes in aquifer characteristics such as permeability and storage, and potentially can provide pathways for vertical groundwater movement between shallow groundwater and surface water systems and underground mines (McNally & Evans 2007; Advisian 2016). The height to which vertically connected (and free-draining) fracture networks extend above the mined seam is therefore important in assessing potential impact of longwall mining on groundwater and surface water systems.

Several authors have developed empirical approaches to estimating the height of connected fracturing or complete groundwater drainage above longwalls (Forster 1995; Guo *et al.* 2007; Mills 2011; Tammetta 2013; e.g. Ditton & Merrick 2014). These methods have been used at numerous coal mines in NSW to provide guidance on the height of fracturing for the development of numerical groundwater impact models. At Dendrobium, the methods of Ditton and Merrick (2014) and Tammetta (2013) yield estimates that are significantly different from each other. A review of longwall subsidence fracturing at Dendrobium was commissioned by the NSW Department of Planning and Environment (DPE). The review by consultants PSM (2017) concluded that such empirical approaches carry significant uncertainty and limitations related to the data on which they were based, and that fracturing above the (305 m wide) panels in Area 3B likely extends to the surface (Galvin 2017; PSM 2017). The latter conclusion is consistent with the predictions of the Tammetta model at Dendrobium Area 3B, and observations presented here.

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 2016). 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.

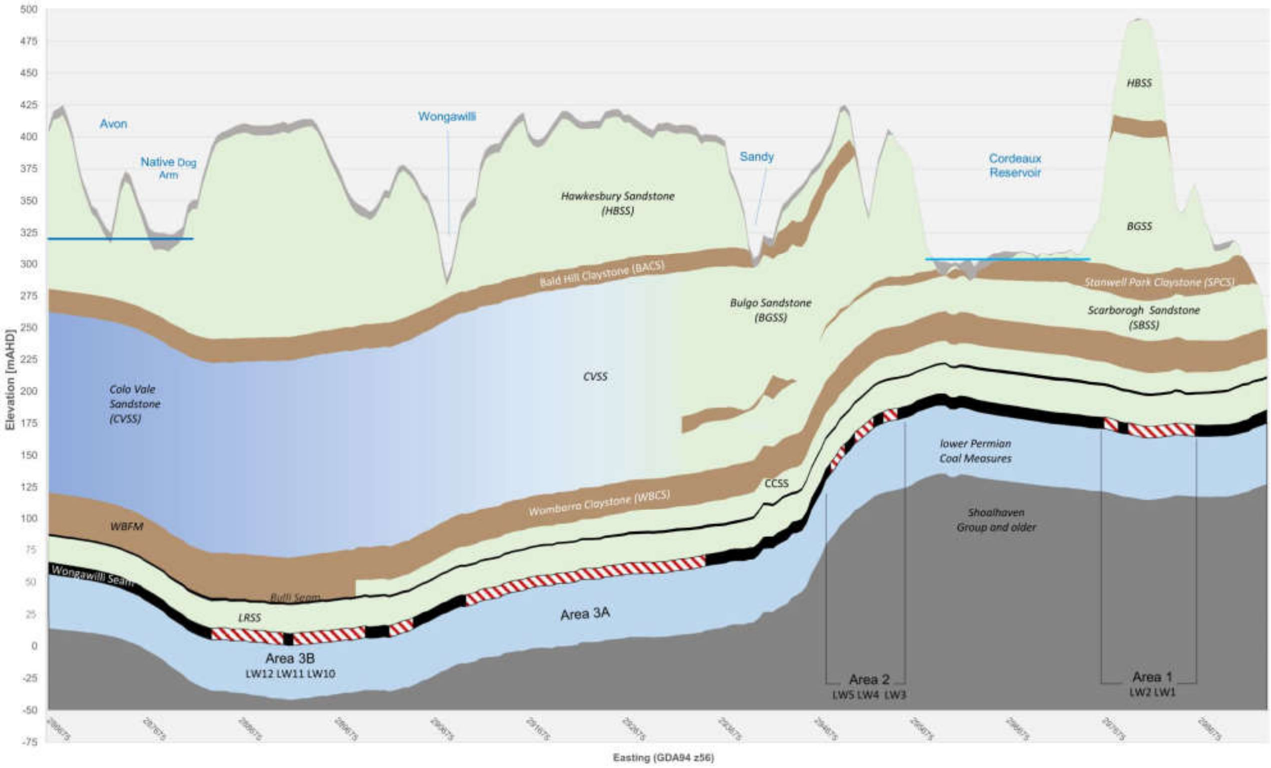

Figure 3. Geological cross-section (east-west) through Dendrobium Mine

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.

2.2 Groundwater monitoring network

The groundwater-monitoring locations for Areas 3B are shown in Figure 4. A list of all piezometers installed in Areas 2 and 3 are listed in Appendix C.

There are approximately 175 monitoring bores located across the Dendrobium mine lease, containing 681 piezometers, excluding those that are decommissioned or no longer monitored. Within the area covered by Figure 4 alone, there are approximately 95 active monitoring bores with 431 sensors.

Since 2015, a number of new monitoring bores have been installed above mined and planned longwalls, and between Lake Avon Reservoir and Area 3B. These new sites provide important new information on groundwater responses to mining, and groundwater conditions within the barrier between the lake and the mine. New sites include:

- WC21 monitoring bores (S2335 – S2338), above Longwalls 10 and 12;
- Swamp 11 monitoring bores (S2306 and S2307), above and at the margin of Longwall 13;
- Avon Dam holes (S2313, S2314, S2376, S2377, S2378, S2379), between Lake Avon and Mine Area 3B;
- Above longwall holes: Longwall 12 (S2399), Longwall 14 (S2398), Longwall 15 (S2412) and Longwall 16 (S2354);
- Swamp 1b rehabilitation study (S2401 – S2406), above Longwalls 9 and 10.

2.3 Deep groundwater levels

Deep groundwater levels are monitored using one or more piezometers installed within monitoring bores. Monitoring bores typically have an index number with an ‘S’ prefix such as S2314, within which piezometers may be installed at multiple depth levels (e.g. S2314_128m). In most cases, the piezometers are vibrating wire piezometers (VWP) that are fully grouted into the bore hole. The sensors contain a sensitive diaphragm that deforms in response to subtle changes in pore pressure that are transmitted through the connected pores of the grout from the adjacent geological strata. VWP sensors are commonly used in deep mining and geotechnical applications where the strata permeability is low and conventional (standpipe) piezometers are impractical (Mikkelson & Green 2003; Contreras *et al.* 2008).

Standpipe piezometers, consisting of a slotted open casing, are used in a small number of locations and are best suited to monitoring of relatively shallow groundwater systems within moderate to high permeability strata (e.g. swamp sediments and shallow Hawkesbury Sandstone). Automated loggers record groundwater pressures each hour (typically). The recorded data are subsequently converted to fluid pressure head (m) and potentiometric head (mAHD).

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 2 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. Both piezometric and pressure head hydrographs are presented in Appendix A.

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.

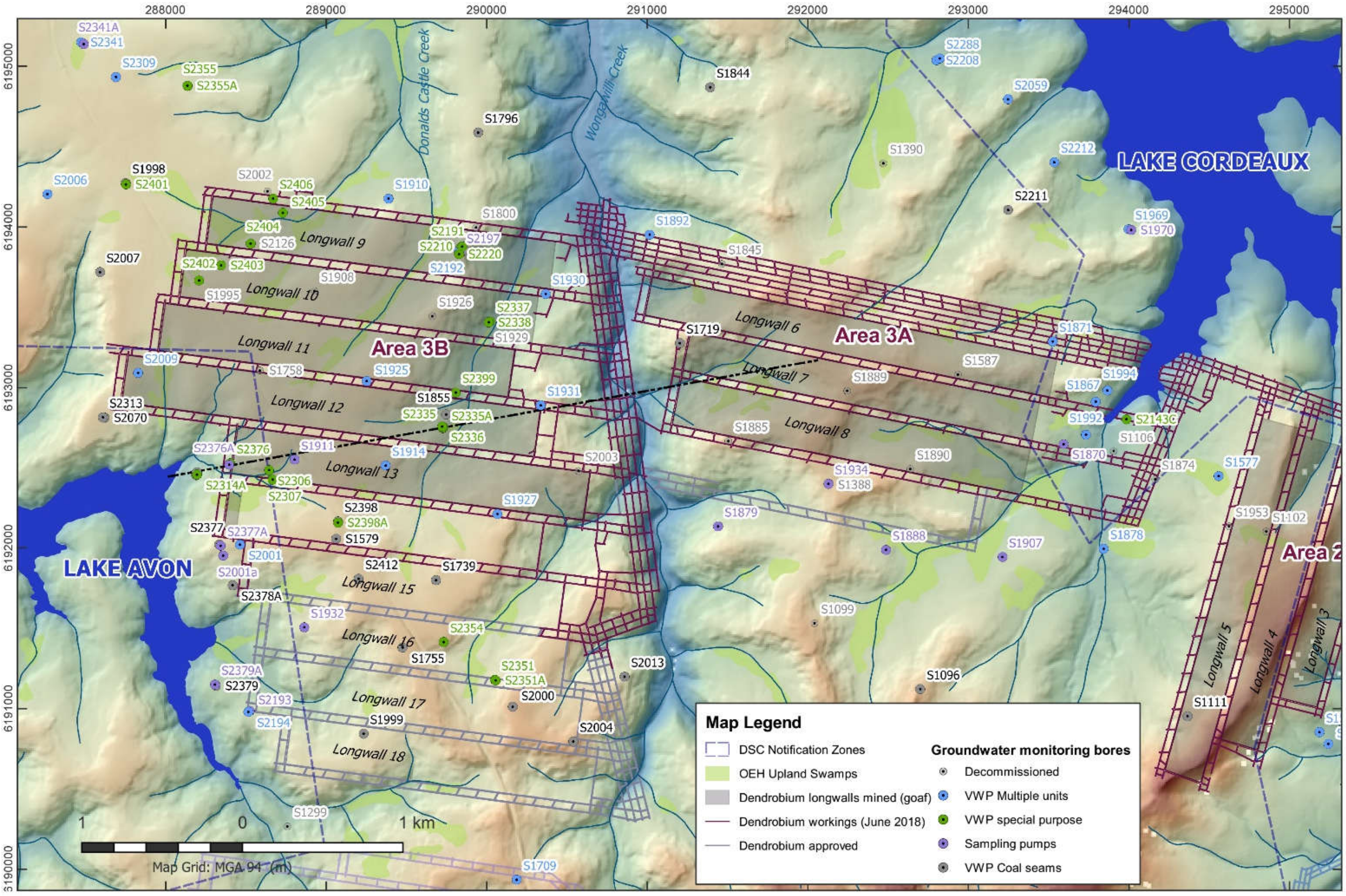

Figure 4. Deep groundwater monitoring network around Areas 2, 3A and 3B

2.4 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.

2.5 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	31/05/2017
S1870	DEN85	3A	2	1		03/10/2017
S1879	DEN92	3A	2	1		21/11/2016
S1885	DEN93	3A	2	1		19/06/2012
S1888	DEN96	3A	2	1		21/11/2016
S1889	DEN97	3A	2	1		13/07/2011
S1890	DEN98	3A	1	1		19/06/2012
S1907	DEN103	3A	2	1		19/12/2013
S1934	DEN115	3A	2			16/04/2014
S1911	DEN106	3B	2	1		26/11/2015
S1929	DEN111	3B	2	1		28/07/2014
S1932	DEN114	3B	3			01/02/2018
S2001a	DEN125A	3B	2	1		04/10/2017
S2197		3B	1	1		12/09/2013
S2313	Avon 1	3B	2	1		12/12/2017
S2314	Avon 2	3B	2	1		30/11/2017
S1970	DEN118A	3C	1	1	1	16/04/2014

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 3000 water samples have been collected and analysed since 2003, providing an excellent baseline for ongoing assessment and a basis for chemically characterising 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 (average EC ~ 170 µS/cm) whereas mine seepage water is distinctly more brackish (average 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.

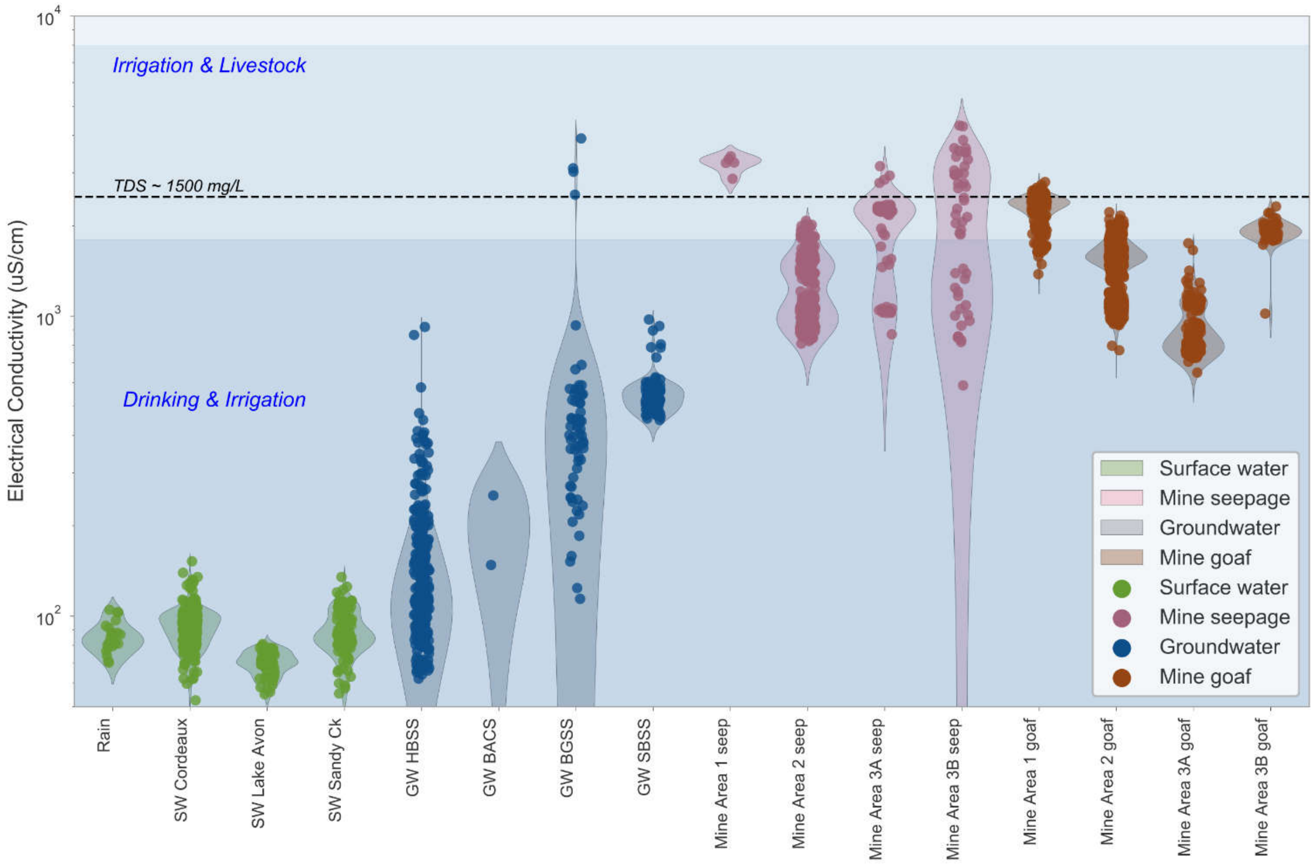

Figure 5. Violin plot showing the range in EC of surface water, groundwater and mine inflow

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 13 was extracted (3 April 2017 to 19 April 2018). The average daily inflow to Area 3B during Longwall 13 extraction was 4.68 ML/d which represents approximately 62% of total mine inflow for the period. The average water balance for Area 3B was similar for Longwall 13 to that during Longwall 12 (4.5 ML/day).

Table 2. Dendrobium Mine Inflow during the Extraction of Longwall 13 (in ML/day)

STATISTIC	AREA 1	AREA 2	AREA 3A	AREA 3B	TOTAL
MEAN	0.33	1.08	1.45	4.68	7.53
STANDARD DEVIATION	0.00	1.11	1.03	1.74	2.09
MINIMUM	0.33	0	0	0	1.89
MAXIMUM	0.35	4.58	6.51	8.00	12.82

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. Note that pumping from Area 3B ceased for approximately 4 weeks after Tailgate 9 (TG9) became flooded and inaccessible in late July 2017. Pumping resumed after a new pump station was established in TG9 in late August.

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 Longwalls 12 and 13, representing a possible departure from the area-inflow relationship, as was seen at Area 3A after Longwall 7. As of Longwall 12 there is an apparent correlation between periods of high inflow to Area 3B and periods of high rainfall with a lag time of between two and three months. Peak inflow rates to Area 3B following high rainfall events is one to two ML/day higher than during low rainfall periods. The inflow peak that followed the high rainfall event of early 2017 accounts for approximately 20% of the total inflow for the 2017 year. The peak component in 2016 was approximately 12%.

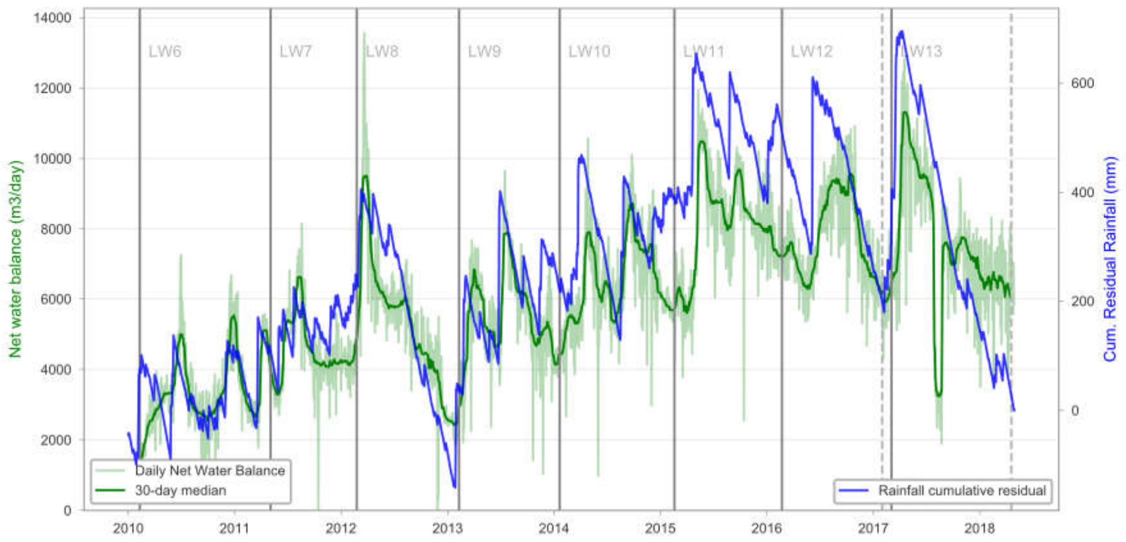

Figure 6. Groundwater inflow from water balance for all mine areas (kL/day)

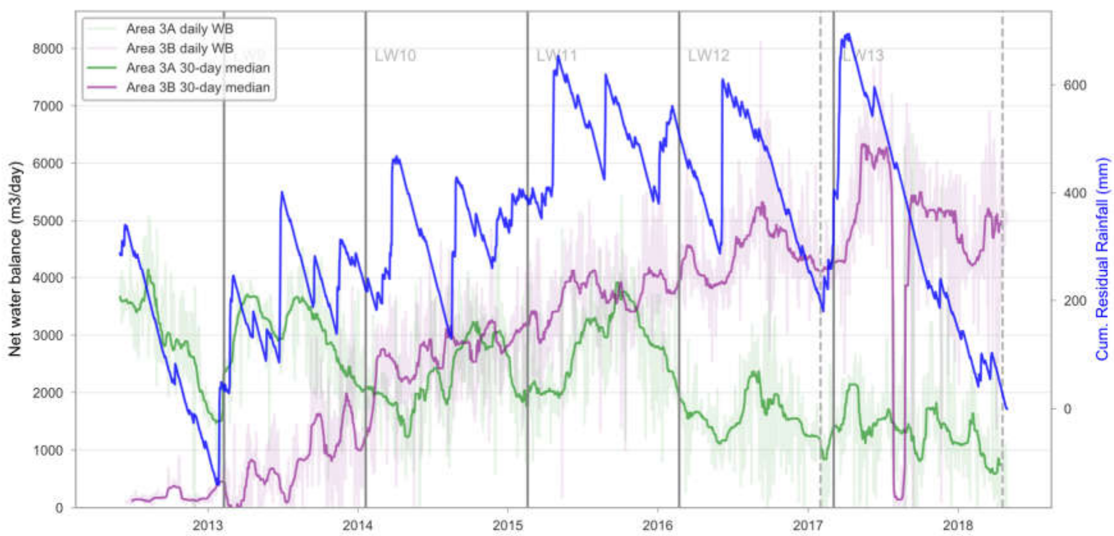

Figure 7. Groundwater inflow to the mine for Areas 3A and 3B (kL/d)

The modern water component in mine inflow is monitored by analysing tritium in samples collected from goaf inflow and development seepage water samples. The results are reported monthly to the DSC. Tritium is an isotope of hydrogen (^3H), generated in the atmosphere through interactions with cosmic rays and through past atmospheric nuclear weapons testing (Clark 2015). Tritium is incorporated into water molecules in rainfall and enters groundwater systems through recharge (rainfall and stream-bed infiltration). Tritium decays exponentially according to its half-life (12.32 years) and is typically only detectable in surface water samples and in groundwater that recharged within 4 to 5 half-lives (50 to 70 years). Detection of tritium above deep groundwater baseline levels in mine inflow samples would indicate a component of modern water in the sample (as it does for samples from Area 2). As of June 2018, tritium in samples from the Area 3B goaf were not statistically different from deep groundwater baseline data (represented by the shaded area below 0.2 TU in Figure 8, from HGEO 2018b). The laboratory processing time for high precision tritium analysis can be more than 6 months and therefore results for some samples collected in the latter part of Longwall 13 are pending.

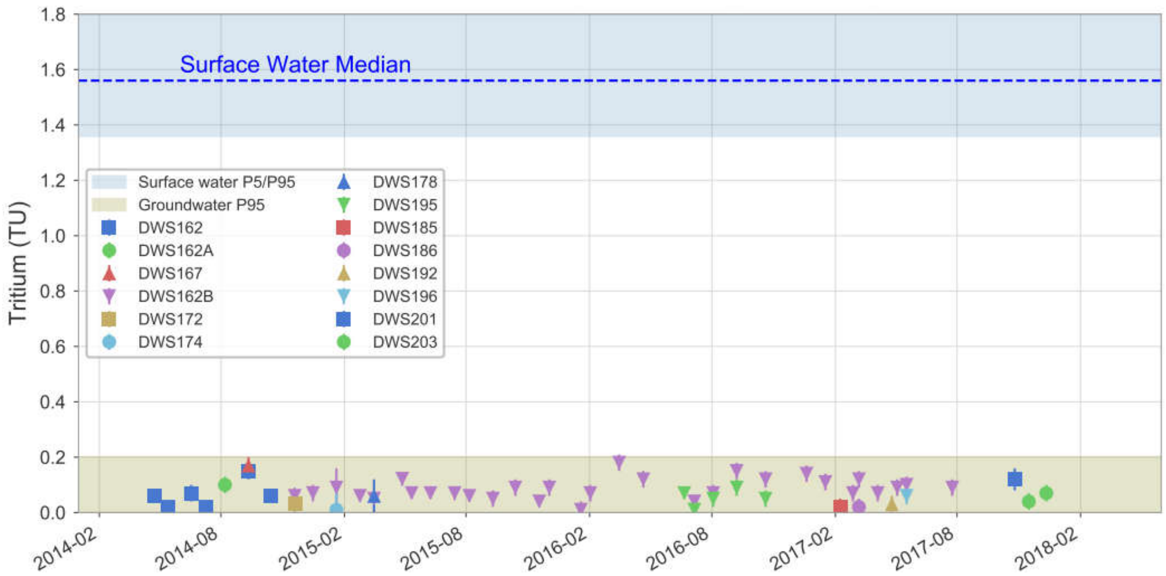

Figure 8. Tritium concentration in water samples from Area 3B (from HGEO, 2018)

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 (Piezometric head and pressure head hydrographs).

3.2.1 Area 3B: Strata above mined longwalls

Piezometer cables in bores located above the footprint of a longwall are usually sheared or the sensors rendered inoperable by ground movements associated with mining and there is rarely a continuous record of groundwater pressures after the longwall has passed the monitoring location. Therefore, it is useful to consider groundwater monitoring data from locations above longwalls in two groups:

1. Baseline monitoring of groundwater levels as the longwall approached the monitoring location (until the cables shear). The most useful locations for this purpose are S1910, S1911, S1914, S1925, S1929, and S2192; and

2. Monitoring established over the goaf following the passage of the longwall. Currently operational locations include: S2220, S2306, S2337/S2338 and S2335A. Piezometers installed over Longwalls 9, 10 (Swamp 1b), 12, 14 and 15 in 2018 are currently being equipped).

The response of groundwater pressures in strata above longwalls was reviewed recently by PSM (2017). However at the time of the review there was only one post-mining monitoring bore located above a mined longwall in Area 3B – S2220 (at the site of the Longwall 9 investigations; Parsons Brinckerhoff, 2014). Since the PSM review, a number of piezometers have been installed above previously mined longwalls since 2017, providing an improved understanding of groundwater responses above longwalls, particularly within the Hawkesbury Sandstone (see Section 2.2).

Prior to being mined under:

Review of hydrographs from piezometers installed above longwalls prior to being mined under show evidence of depressurisation at the coal seams before mining started at Area 3A and years before mining started in Area 3B (Table 3; Appendix A). Depressurisation of most overlying strata is apparent from the start of Mining at Area 3A and the rate of depressurisation increased as mining moved to Area 3B, and with every successive Longwall in Area 3B. Depressurisation is generally greater in the deeper formations. Transient pressure *increases* are also common as the longwall approaches or passes nearby the monitoring site and these reflect compression and relaxation of the strata as the subsidence wave passes (Booth 2002). Piezometer cables typically shear when the longwall passes within 10 m of the location, but at some sites shearing has occurred when the longwall was up to 660 m away (e.g. S1929).

The last observations prior to shearing at S1911 and S1914 (for example) show strong depressurisation throughout the strata, with some horizons in the Colo Vale Sandstone at, or close to, zero pressure head. However, some sensors continue to record positive pressure heads indicating incomplete drainage of some strata or fractured rock domains above the goaf.

After being mined under:

Observations during installation of S2220, S2306, S2335A and S2338, indicate that the Hawkesbury Sandstone undergoes fracturing to the surface, accompanied by depressurisation of most strata (Table 3; Appendix A). Pressure head in all piezometers at S2306 declined to near-zero, whereas positive pressure head is observed in sensors at S2220 and S2338.

These results indicate that fracture networks propagate to shallow depths causing depressurisation of adjacent strata above mined longwalls over much of Area 3B. However, there is evidence that drainage of the Hawkesbury Sandstone above goafs is not complete in all areas and some perched groundwater horizons remain in shallow sandstone strata. In the case of S2220, perched horizons appear to respond to groundwater recharge events. Perching at S2338 is not clear, since piezometers at a similar depth in the immediately adjacent S2337 record near-zero pressure head suggesting full depressurisation of monitored strata (Hawkesbury Sandstone).

Table 3. Observations at piezometers above longwall panels

Bore ID	Location	Date installed	Status	Observations
S2192	LW9	25/3/2013	Inactive from 18/11/2014	Only seven months of data were recorded prior to cable shearing when mined under by LW9. Evidence for depressurisation of Bulgo Sandstone and Stanwell Park Claystone prior to shearing.
S2220	LW9 (post-mining)	10/10/2014	Operational	Installed over LW9 goaf post-mining at LW9 investigation site; records strong downward gradient, but with positive pressure heads, and distinct trends in the three sensors (likely perching); gradual recovery of pore pressures since LW10.
S1908	LW10	16/5/2008	Inactive from 1/5/2014	Gradual depressurisation of deeper sandstone strata (lower BGSS and SBSS) during Area 3A mining; rapid depressurisation in all strata as LW9 passed; cable sheared as LW10 mined under the bore.
S1926	LW10	27/8/2008	Inactive from 8/8/2014	Gradual depressurisation of deeper sandstone strata (lower BGSS and SBSS) but pressure increase in HBSS during Area 3A mining; transient compression effect as LW9 passed, then rapid depressurisation and cable sheared as LW10 mined under the bore.
S1929	LW10	27/8/2008	Inactive from 8/8/2014	Gradual depressurisation in all units since the start of LW6. Transient compression effects towards the end of LW9. Cables sheared on 8/8/2014 as LW10

Bore ID	Location	Date installed	Status	Observations
				approached at a distance of 660m. Mined under by LW10 on 5/11/2014.
S2009	LW12	10/8/2009	Inactive from 24/3/2016	Large gap in data between 2010 and late-2014. Moderate depressurisation in all units during LW11, before shearing as LW12 mined under the location.
S1911	LW13	22/1/2008	Inactive from 5/5/2017	Partial depressurisation in all units when LW12 passed on 9/7/2016. Mined under by LW13 on 12/5/2017 causing depressurisation in all units and cable shear.
S1914	LW13	28/4/2008	Inactive from 10/8/2017	Partial depressurisation in all units when LW12 passed on 24/9/2016. Mined under by LW13 on 18/8/2017 causing depressurisation in all units and cable shear.
S2306	LW13 (Swamp 11) (post-mining)	9/9/2015	Operational	Pressure increase as LW12 passed in July 2016; sharp depressurisation at all levels in HBSS when undermined by LW13 on 14/4/2017.
S2335 / S2336	LW12 (WC21)	19/10/2016	Operational as of 20/7/2017	Depressurisation of HBSS when mined under by LW12; piezometers record near-zero pressure head, but responsive to flood events in adjacent WC21.
S2337 / S2338	LW10 (post-mining)	25/11/2016	Operational	Piezometers in S2337 show close to zero pressure head (fully depressurised) whereas sensors in S2338 record possible perching and response to flooding in WC21 in early 2017.

3.2.2 Area 3B: Strata outside mined longwalls

In this section, data from piezometers located outside the mined longwall footprint of Area 3B are presented and discussed (excluding the Avon monitoring bores discussed below). These include bores S2006 (to the west of Longwall 9), S2001, S1910, S1932 and S2194 (see Table 4).

Piezometers located to the north and west of the longwall footprint (S1910 and S2006) show a gradual decline in groundwater pressures in most strata with the rate of decline increasing with depth and proximity to the longwall. Those observations are consistent with the gradual expansion of a drawdown cone away from the mine and are in line with numerical modelling predictions.

Piezometers located to the south of the active longwalls in Area 3B (in bores S1932, S2001, S2194) show more pronounced depressurisation in the mid- to deep stratigraphic levels with some strata pressures dropping to zero well in advance of the longwall. It is likely that those piezometers are affected by depressurisation from the Elouera mine to the south, as well as drawdown from Dendrobium, an effect that is predicted from numerical groundwater modelling. The additional depressurisation from the Elouera Mine will likely result in lower (or plateauing) rates of groundwater inflow to Area 3B as mining progresses to the south.

Two monitoring bores located south of active mining (S1932 and S2001) show an unusual response of increasing hydraulic pressure in the Scarborough Sandstone (SBSS) following an initial decline. The apparent recovery in pressures affects only three sensors in each bore and occurs at different times in each bore (S2001: LW10; S1932: LW7-8). Given that the bores are only 650 m apart and at broadly similar distances from LW7 to LW10, it is difficult to reconcile the responses to a longwall event or strata compression effect, and it is possible that they reflect sensor malfunction.

Table 4. Observations at piezometers outside longwall panels

Bore ID	Location	Date installed	Status	Observations
S2006	1020 m west of LW9		Operational	Gradual decline in Narrabeen Group sandstones and Coal Measures since 2010, totalling ~ 25 m or ~3.5 m per year, starting to plateau. Minor drawdown in lower HBSS (total 9 m or 1.3 m/y), GW levels in mid-HBSS have increased since 2010 (by 8.9 m).
S1910	130 m north of LW9		Two sensors operational	Gradual decline in groundwater pressures in most strata prior to LW9 (~1.5 m/y in BGSS); sharp depressurisation and cables sheared when LW9 passed by in 2013. Upper two HBSS sensors remain active indicating groundwater recovery at 125 m depth (5.7 m since 2015, or 2.5 m/y).
S2001	LW15 (435 m south of LW13)		Operational	Unusual response: Initial depressurisation in SBSS and BGSS during LW6 and LW7 (Area 3A), but then apparent recovery in SBSS during mining of LW10. Increasing decline in pressures in lower HBSS, upper-BGSS and lower-SBSS; desaturation (zero head) in those units in 2018.
S1932	LW16 (890 m south of LW13)	31/8/2008	Operational	Unusual response: Initial depressurisation in SBSS and CCSS during LW6 and LW7 (Area 3A), but then apparent recovery in SBSS during mining LW8-LW10. Depressurisation started in most strata from LW11 and increased during LW13. Slight drawdown in lower HBSS.
S2194	LW17 (1460 m south of LW13)		Operational	Steady depressurisation of lower BGSS and SBSS strata since installation in 2013 (55 – 67 m; or 10m/y), and to a lesser extent in upper BGSS (~6.5 m; or 1.5 m/y). Lower BGSS and SBSS now at or approaching zero head, likely due to combined Elouera Mine and Dendrobium effects. Decline in groundwater level of ~3 m in mid-HBSS and ~ 9 m in lower HBSS since 2014.

3.2.3 Avon reservoir bores

Starting in 2015, a series of monitoring bores were installed along the barrier zone between Lake Avon reservoir and Area 3B. The objectives of the bores are to characterise the strata permeability before and/or after mining of adjacent longwall panels and to provide ongoing groundwater monitoring. Those observations provide critical information to allow more accurate calculation and modelling of potential seepage losses from the reservoir(s) to the mine. Monitoring bores that are installed and operational at the end of Longwall 13 are listed in Table 5.

Table 5. Observations at piezometers between Lake Avon and Area 3B

Bore ID	Location	Date installed	Status	Observations
S2313	140m from the western corner of LW12	31/10/2015	Operational	Pre- and post-mining holes reported in SCT (2015, 2016) and in HGEO (2018a). Depressurisation in the lower HBSS and upper BGSS (Colo Vale SS at this location) in the months following the start of LW12. Drawdown stabilises during LW13 with heads below Lake Avon FSL. Upper HBSS shows no drawdown and head (371 m AHD) remains above the Lake Avon FSL (320.18 m AHD).
S2314	210 m from the western end of LW13	13/11/2015	Operational	Pre- and post-mining holes reported in HGEO (2017). Piezometers show depressurisation in HBSS and BGSS, with all showing heads below the Lake Avon FSL. Drawdown appears to be stabilising in the BGSS (Colo Vale SS).
S2376	10 m from the western end of LW13	6/10/2017	Operational	Post-mining hole only, reported in HGEO (2018a). Piezometers record depressurisation in the upper BGSS (Colo Vale SS) during late 2018; Levels in the lower HBSS stable at ~283 m AHD, below Lake Avon FSL (320.18 m AHD); upper HBSS sensor recording zero head.
S2377	100 m from LW14 and 200 m from LW15		Not yet operational	No data as of June 2018
S2378	95 m from the western end of LW15		Not yet operational	No data as of June 2018
S2379	265 m from the western end of LW17		Not yet operational	No data as of June 2018

Piezometers at S2313, located 140 m from the western corner of Longwall 12 recorded depressurisation in the lower Hawkesbury Sandstone and in the upper Bulgo Sandstone (designated as part of the Colo Vale Sandstone at this location) in the months following the start of Longwall 12. As of the end of Longwall 13, piezometric head in those strata are below Lake Avon FSL (320.18 m AHD), although it is likely that piezometric heads in the upper Bulgo Sandstone were below Lake Avon FSL prior to mining at Area 3B (e.g. S1929). A sensor at 49 m depth shows that piezometric levels in the upper Hawkesbury Sandstone have not been drawn-down as a result of Longwall 12 extraction and have in fact increased over the last two years. The piezometric head in the Hawkesbury Sandstone remains above the Lake Avon FSL, implying a hydraulic gradient towards the lake at this location.

Monitoring bores S2313 and S2376 are depicted on the hydrogeological cross section in Figure 9, which shows a profile extending west to east from Lake Avon to bore S1911 in the centre of Longwall 13 (updated from HGEO 2018a). S2314 is located 210 from Longwall 13 and S2376 is located just 10 m from the Longwall 13 goaf foot print. S1911 became inactive after being mined under by Longwall 13 in April 2017. Piezometers in both bores show a strong downward hydraulic gradient and depressurisation in the upper Colo Vale Sandstone. At S2314, the shallowest sensor shows that groundwater levels in the upper Hawkesbury Sandstone have declined to below the Lake Avon FSL and below the current lake level. The shallowest sensors in the Hawkesbury Sandstone, at both

S2314 and S2376, were at zero or near-zero pressure head meaning that the host strata were desaturated, and the water table was below those sensors. All four piezometers at S2306, directly above Longwall 13, show desaturation of the Hawkesbury Sandstone to a depth of at least 70 m.

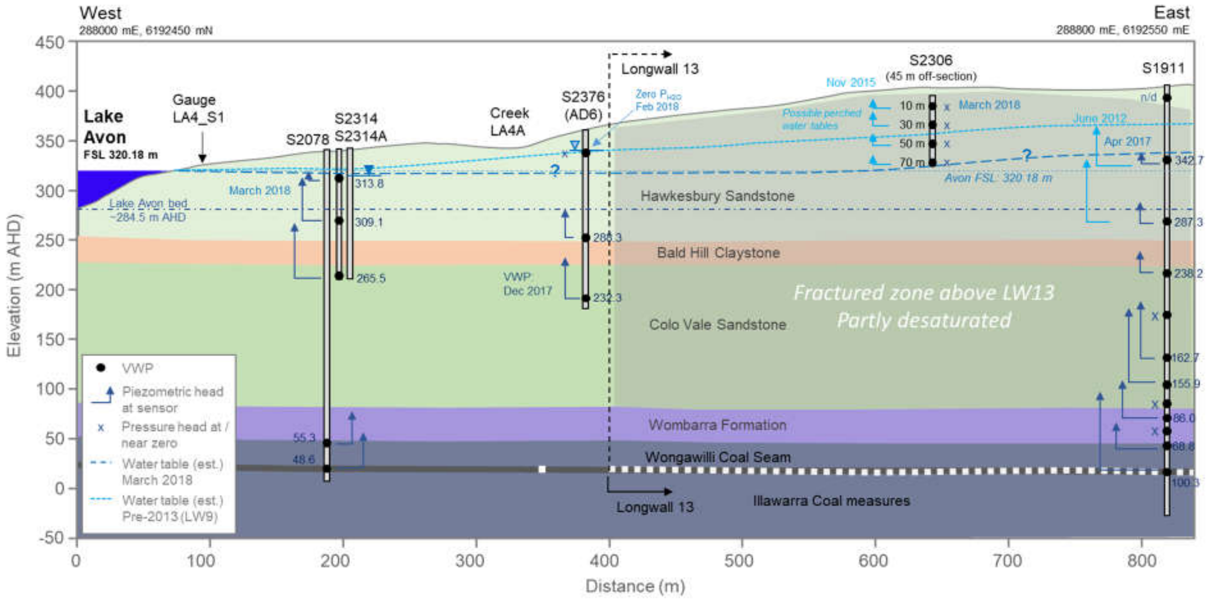

Figure 9. Hydrogeological cross section between Lake Avon and bore S1911.

Observations to date indicate variable conditions in the barrier zone between Lake Avon and mined longwalls of Area 3B. While depressurisation of the upper Colo Vale Sandstone in response to longwall extraction is widespread, response in the Hawkesbury Sandstone is variable. A hydraulic gradient towards the lake is preserved in the Hawkesbury Sandstone at S2313, whereas at S2314 and S2376 the hydraulic gradient is locally reversed towards the mine, implying movement of groundwater from the lake to the mine. The rate of seepage loss from the reservoir depends on both the hydraulic gradient and the permeability of the strata in the barrier zone (i.e. Darcy's Law; Darcy 1856). An estimate of potential seepage loss was calculated based on measured post-mining strata permeability and conservative assumptions regarding hydraulic gradient by HGEO (2018a). It was concluded that seepage loss between Lake Avon and Longwalls 12 to 16 would be no greater than 0.28 ML/day (or 0.17 ML/day/km of shoreline adjacent to extracted longwalls). This estimate is of a similar magnitude to that obtained from numerical modelling (see Section 3.5.3) and within the tolerable loss limit of 1 ML/day prescribed by the DSC (DSC 2014).

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. 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. Piezometric heads were relatively stable in all monitored strata during Longwall13.

S1934 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, and the shallowest sensor (38 m) shows increasing groundwater level in the Hawkesbury Sandstone since Longwall 11.

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 13 (Figure 13 to Figure 17), and
2. The change (drawdown) in average piezometric head between the end of Longwall 11 and the end of Longwall 13 (Figure 18 to Figure 22).

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 13 through Figure 17). This provides an overview of groundwater conditions across Areas 3A and 3B as of the end of Longwall 13.

The Wongawilli Coal Seam becomes depressurised well in advance of mining (Figure 13). 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 14). 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 15) is depressurised in the vicinity of the mined areas and to the south of Longwall 13. 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. The average piezometric head in the Hawkesbury Sandstone is above the adjacent reservoir at most bores that are located between mined longwalls and reservoirs, with the exception of S2314 (as described in Section 3.2.3).

3.3.2 Groundwater drawdown during Longwall 13

Changes in piezometric head between the end of Longwall 12 and the end of Longwall 13 are shown for the Wongawilli Coal Seam, Bulli Coal Seam, Scarborough Sandstone, Bulgo Sandstone and Hawkesbury Sandstone in Figure 18 through Figure 22.

Drawdown in the Wongawilli and Bulli Coal seams has extended south of the active mining areas. However, the incremental drawdown for Longwall 13 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 13 and extending to S2194, located 1.4 km to the south of Longwall 13. Drawdown in the Hawkesbury Sandstone is generally less than that observed in the underlying units and is most noticeable above and immediately adjacent to Longwall 13, with some drawdown also evident at S2001, located 435 m to the south. Elsewhere drawdown is negligible or negative (an increase in groundwater level).

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 6. As with previous reviews, the groundwater salinity tends to increase with depth.

A notable change is seen in the most recent sampling round from S1886 (DEN94) where samples from all three depths (at 22 m, 30 m, and 38 m) show EC field measurements that are up to 200µS/cm higher than last sampling round (highlighted in Table 6). Laboratory measured EC for all three samples are within the historical range suggesting that the field EC measurements are in error.

The average EC for all samples collected are: 163 µS/cm for the Hawkesbury Sandstone (n = 298), 579 µS/cm for the Bulgo Sandstone (n = 75) and 559 µS/cm for the Scarborough Sandstone (n = 112). 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 6. Summary of EC measurements at monitoring bores

Bore ID	Alt ID	Depth (m)	Unit	Samples		Mean EC (µS/cm)	
				LW12	LW13	LW12	LW13
S1870	DEN85A	10	Hawkesbury Sandstone	1	1	70	91
S1870	DEN85A	16.5	Hawkesbury Sandstone	1	1	77	105
S1879	DEN92	10	Hawkesbury Sandstone	2		66	
S1879	DEN92	58	Hawkesbury Sandstone	2		179	
S1888	DEN96	7.3	Hawkesbury Sandstone	2		83	
S1932	DEN114	10	Hawkesbury Sandstone		2		124
S1932	DEN114	98	Hawkesbury Sandstone		2		210
S1934	DEN115	55	Hawkesbury Sandstone				
S2001	DEN125A	106	Hawkesbury Sandstone	0	1		289
S2001	DEN125A	63	Hawkesbury Sandstone	0	1		226
S2313	S2313	138	Hawkesbury Sandstone	1	2	174	138
S2313	S2313	54	Hawkesbury Sandstone	1	2	116	115
S2314	S2314	30	Hawkesbury Sandstone	3	2	169	215
S2314	S2314	75	Hawkesbury Sandstone	3	2	174	191
S1888	DEN96	200	Bulgo / Colo Vale Sandstone	4		581	
S2313	S2313	194	Bulgo / Colo Vale Sandstone	1	2	*	375
S2314	S2314	128	Bulgo / Colo Vale Sandstone	3	2	*	445
S1886	DEN94	22	Scarborough Sandstone	1	1	511	530
S1886	DEN94	30	Scarborough Sandstone	1	1	510	565
S1886	DEN94	38	Scarborough Sandstone	1	1	515	538

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 13 from the original model output files (provided to HGEO 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 10 is a plot of the modelled and observed heads as of the end of Longwall 13. 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.

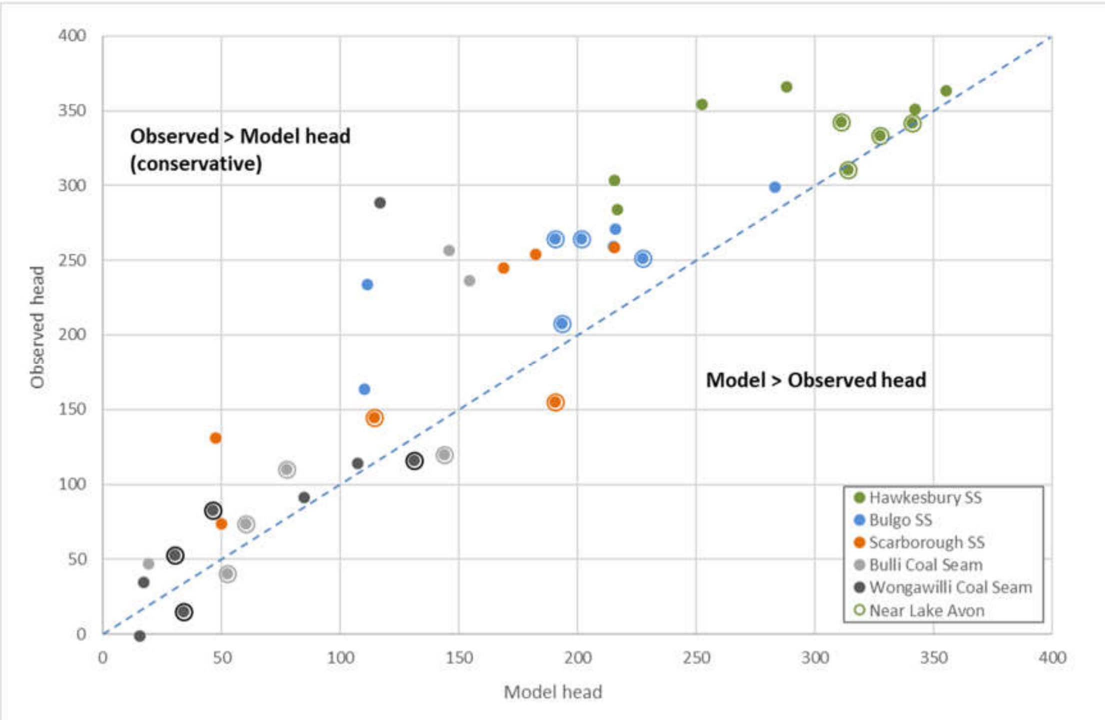

Figure 10. Observed versus model predicted heads at the end of Longwall 13

The following are concluded from the comparison in Figure 10:

- 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 and Hawkesbury Sandstones.

- 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 11 is a plot of the modelled and observed groundwater inflow to Area 3B during the extraction of Longwall 13. 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.

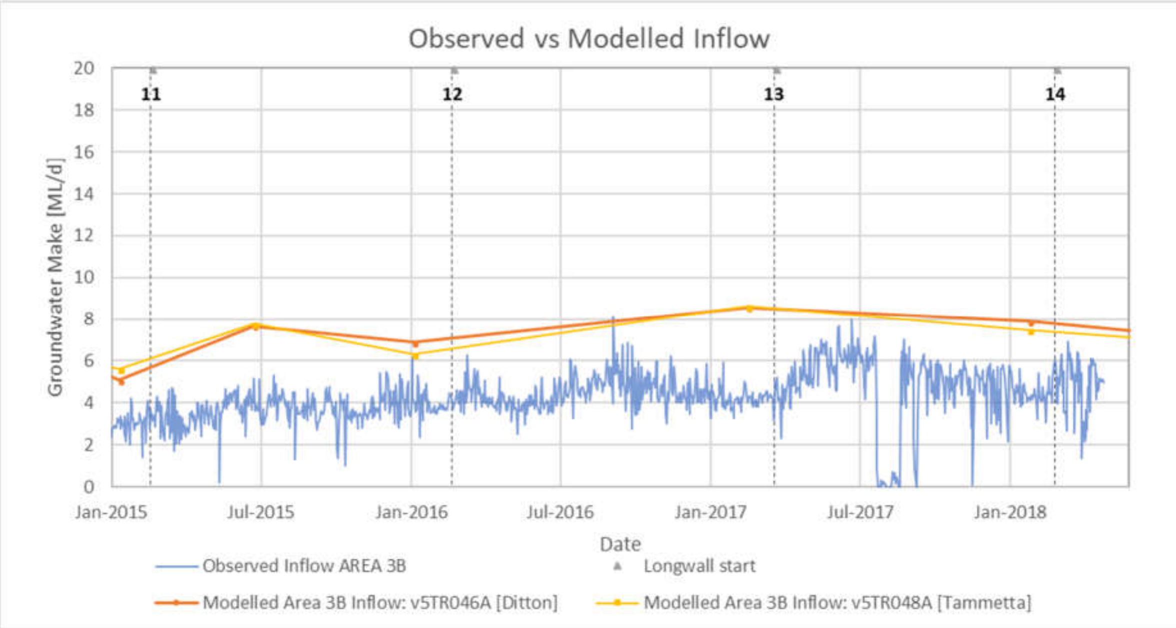

Figure 11. Observed versus model predicted mine groundwater inflow to mine Area 3B

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 13 are shown in Figure 12. 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 13 is less than 0.4 ML/d and therefore within the tolerable loss limit of 1 ML/day prescribed by the DSC (DSC 2014).

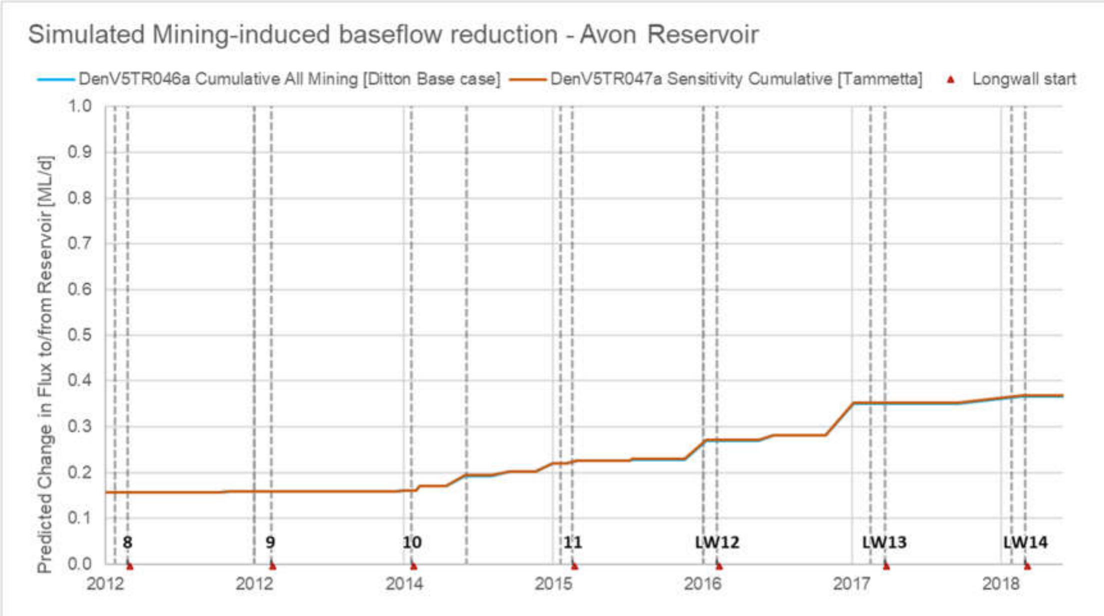

Figure 12. Model estimates of mine-induced reduction of baseflow to Lake Avon

4. CONCLUSION

The following conclusions are made with respect to the assessment of groundwater conditions following the completion of Longwall 13:

- Mining of Longwall 13 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 13 and extending to S2194, located 1.4 km to the south of Longwall 13.
- Drawdown in the Hawkesbury Sandstone is greatest above and immediately adjacent to Longwall 13, with some drawdown also evident at S2001, located 435 m to the south. Elsewhere drawdown is negligible or negative (an increase in groundwater level).
- Observations at monitoring bores installed above mined longwalls indicate that the Hawkesbury Sandstone undergoes fracturing to the ground surface, accompanied by depressurisation of most strata. There is evidence that drainage of the Hawkesbury Sandstone above goafs is not complete in all areas and some perched groundwater horizons remain.
- Starting in 2015, a series of monitoring bores was installed along the barrier zone between Lake Avon reservoir and Area 3B. Observations at those bores indicate depressurisation of the upper Colo Vale Sandstone in response to longwall extraction, but variable drawdown in the Hawkesbury Sandstone. A hydraulic gradient towards the lake is preserved in the Hawkesbury Sandstone at S2313, whereas at S2314 and S2376 the hydraulic gradient is locally reversed towards the mine, implying movement of groundwater from the lake to the mine. It is estimated that seepage loss between Lake Avon and Longwalls 12 to 16 would be less than 0.28 ML/day (or 0.17 ML/day/km of shoreline adjacent to extracted longwalls). This estimate is consistent with numerical modelling predictions.
- The average daily groundwater inflow to Area 3B during Longwall 12 extraction was 4.68 ML/d which represents approximately 62% of total mine inflow for the period. Inflows to Area 3B have generally increased over time in proportion to the total mined area since 2013. From 2016, the increasing trend has slowed and a weak correlation between rainfall and mine inflow to Area 3B is emerging.
- There is an apparent lag of two to three months between high rainfall events and the peak high inflow to Area 3B. The amplitude of the variation due to rainfall accounts for approximately 20% of the total inflow. To date, the concentration of tritium (an isotopic indicator of modern water) in Area 3B mine inflow water is not statistically different from deep groundwater.
- 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 13. 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 13 is less than 0.4 ML/d and within the tolerable loss limit of 1 ML/day prescribed by the DSC.

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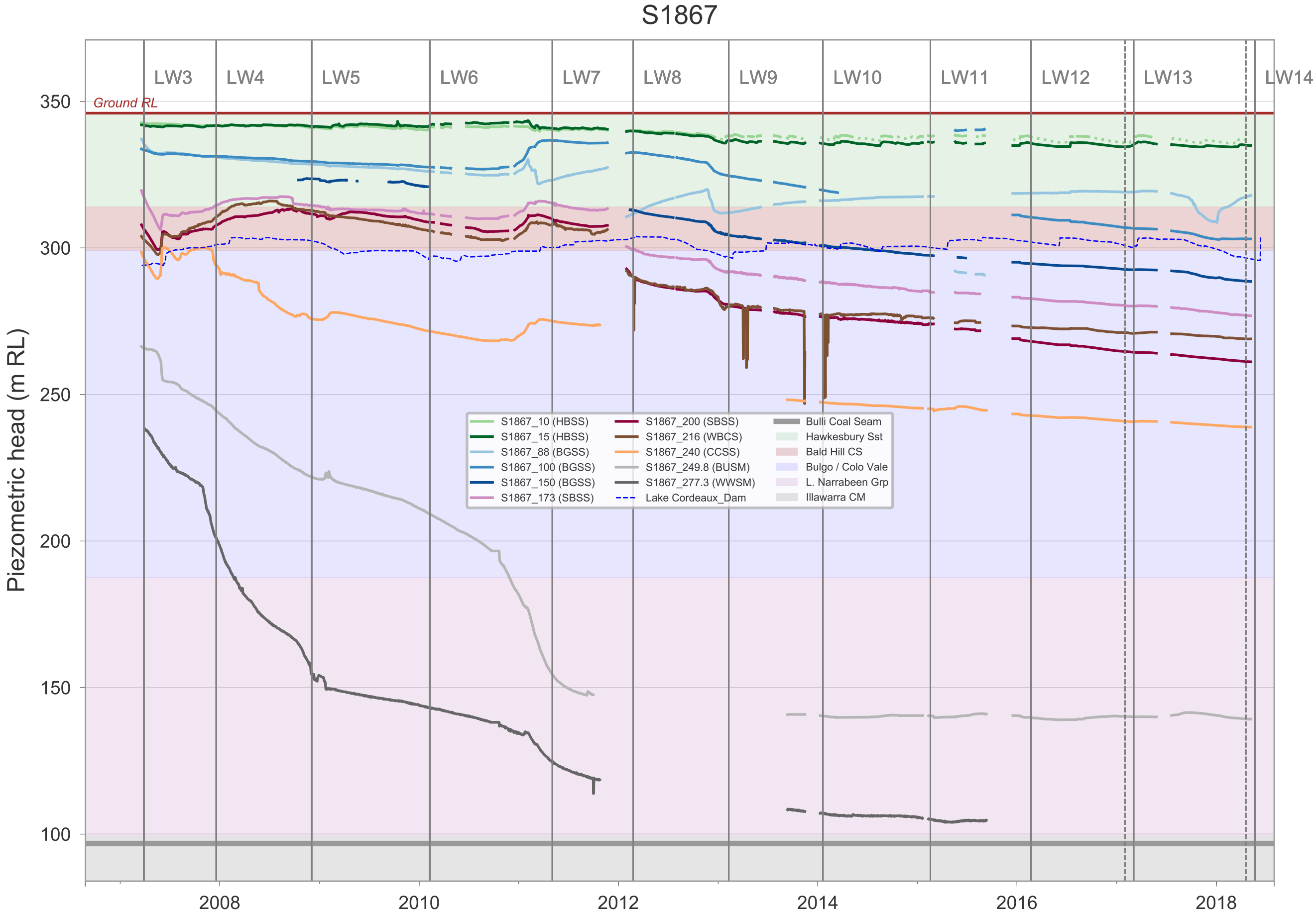
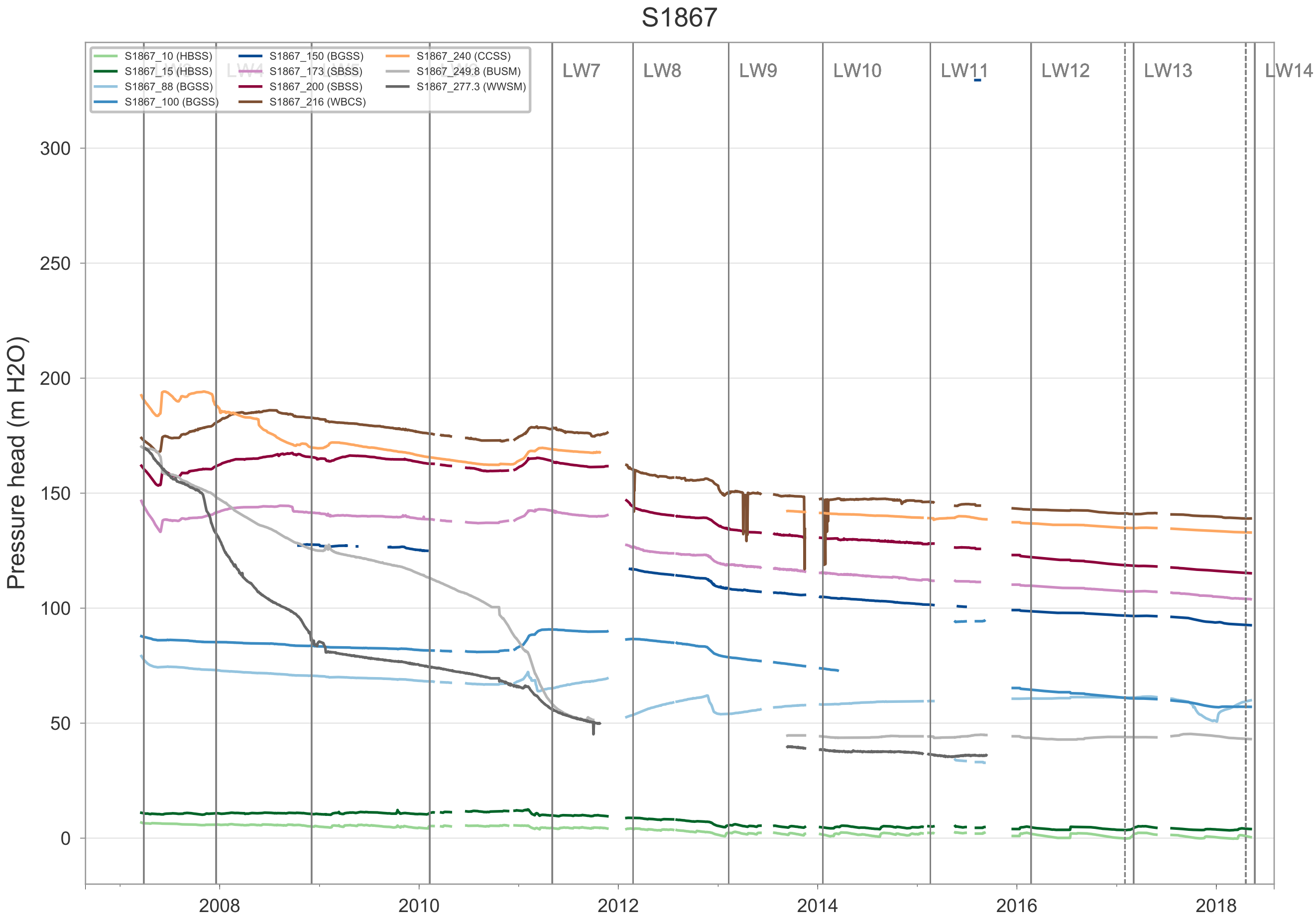
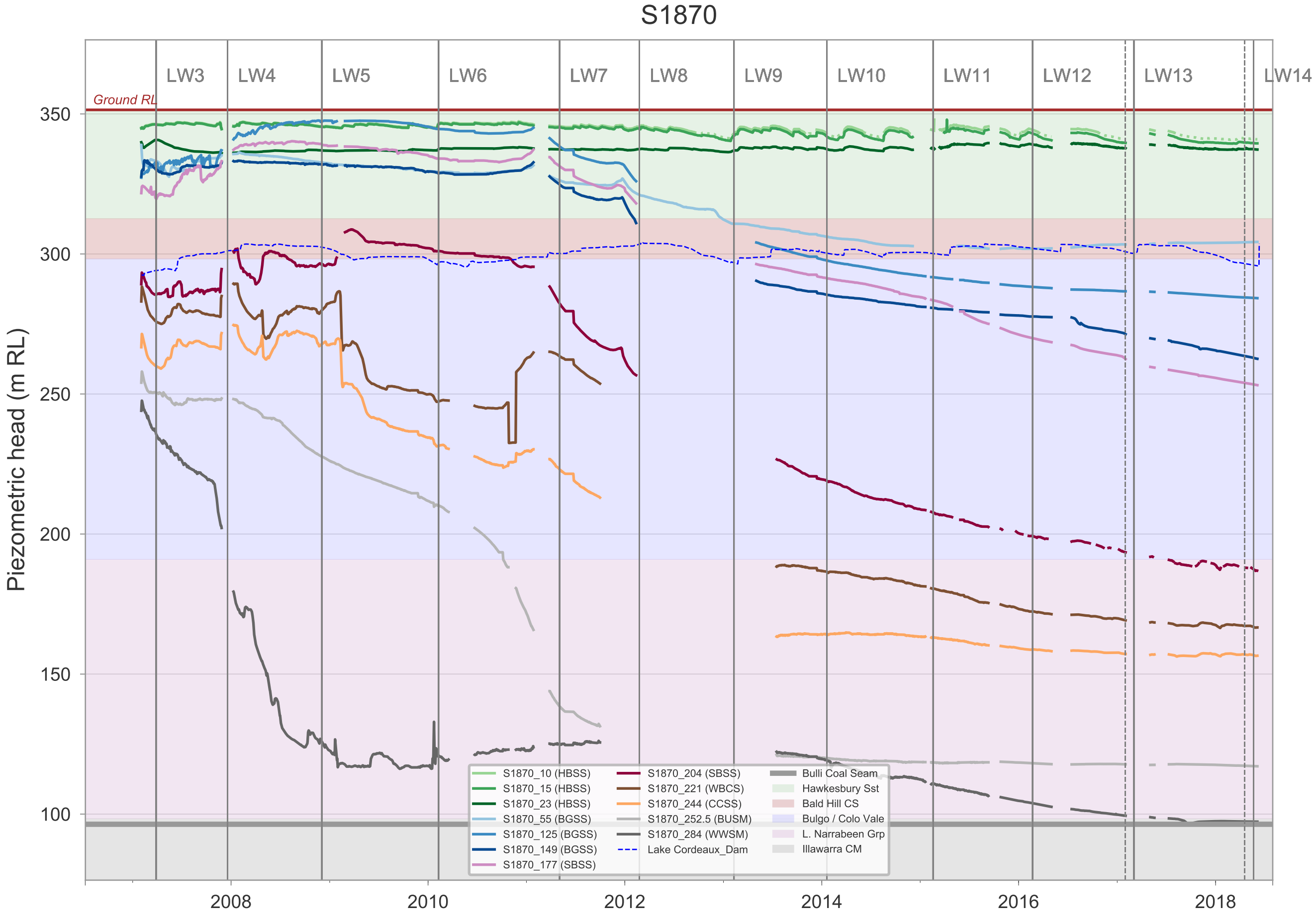
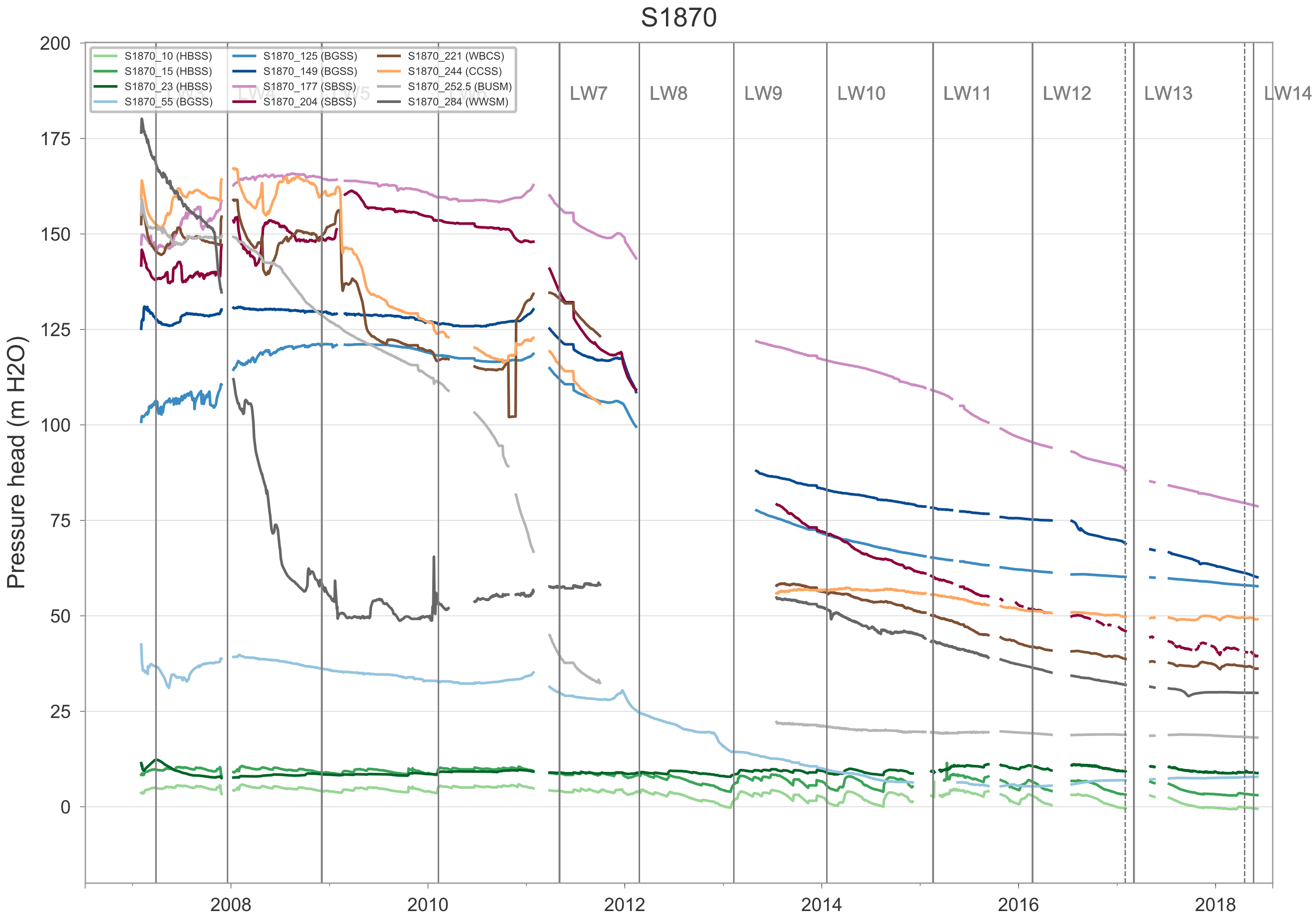
APPENDIX A: BORE HYDROGRAPHS

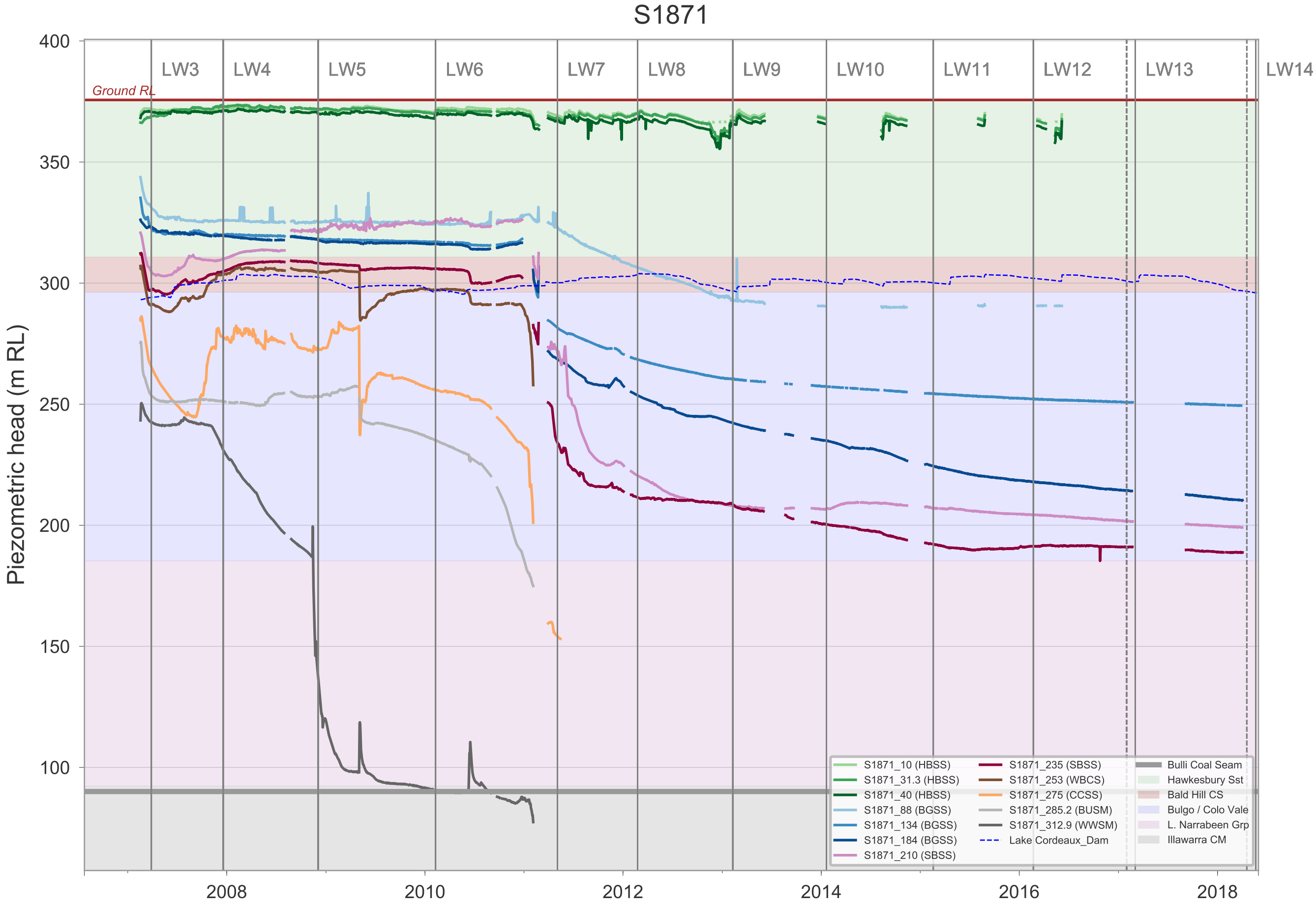

S1867
LW3
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground RL
Piezometric head (m RL)
350
300
250
200
150
100
2008
2010
2012
2014
2016
2018
S1867_10 (HBSS)
S1867_15 (HBSS)
S1867_88 (BGSS)
S1867_100 (BGSS)
S1867_150 (BGSS)
S1867_173 (SBSS)
S1867_200 (SBSS)
S1867_216 (WBCS)
S1867_240 (CCSS)
S1867_249.8 (BUSM)
S1867_277.3 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM

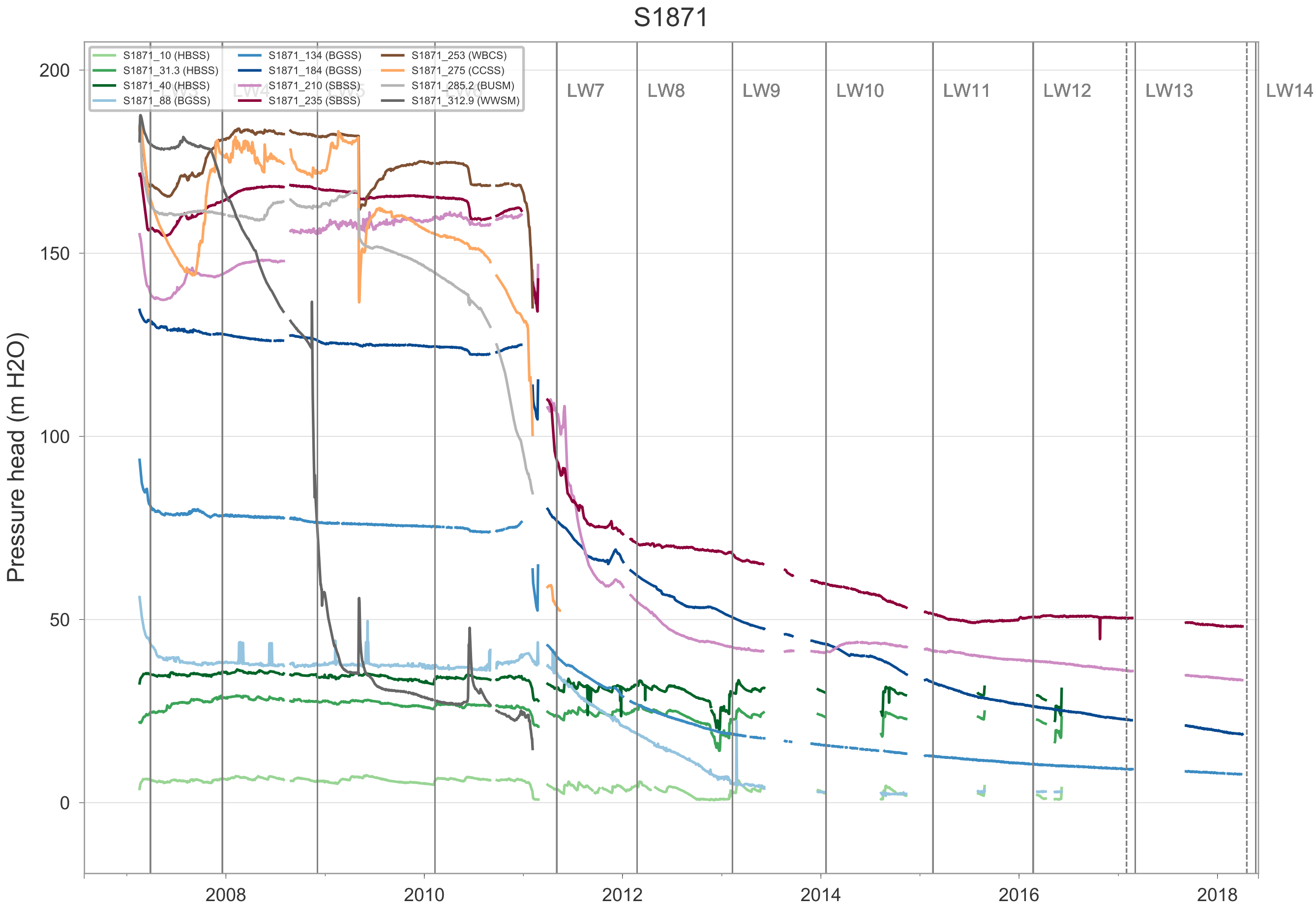

S1867
S1867_10 (HBSS)
S1867_15 (HBSS)
S1867_88 (BGSS)
S1867_100 (BGSS)
S1867_150 (BGSS)
S1867_173 (SBSS)
S1867_200 (SBSS)
S1867_216 (WBCS)
S1867_240 (CCSS)
S1867_249.8 (BUSM)
S1867_277.3 (WWSM)
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Pressure head (m H2O)
300
250
200
150
100
50
0
2008
2010
2012
2014
2016
2018

Groundwater hydrographs

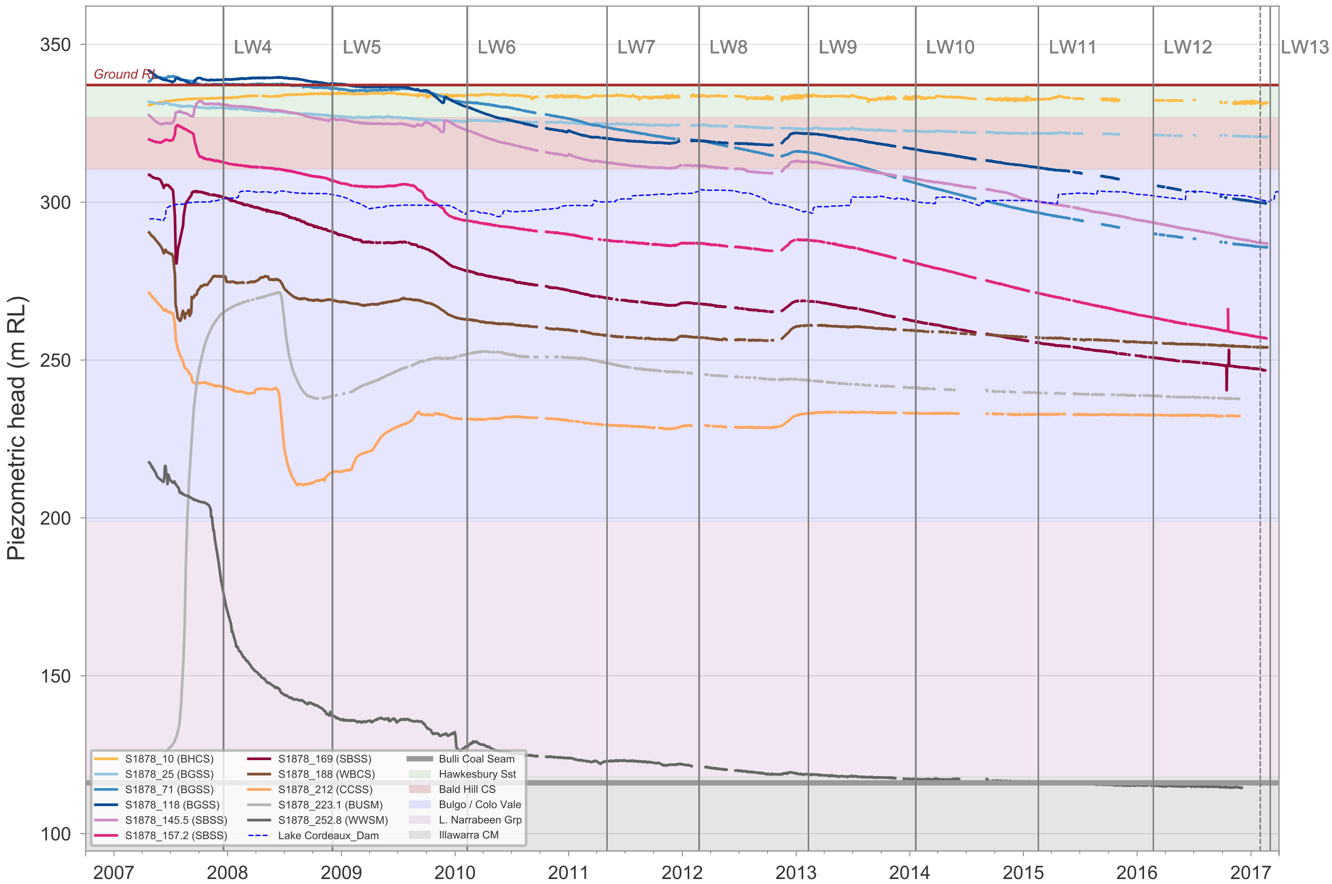





S1871
400
350
300
250
200
150
100
Piezometric head (m RL)
LW3
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground RL
2008
2010
2012
2014
2016
2018
S1871_10 (HBSS)
S1871_31.3 (HBSS)
S1871_40 (HBSS)
S1871_88 (BGSS)
S1871_134 (BGSS)
S1871_184 (BGSS)
S1871_210 (SBSS)
S1871_235 (SBSS)
S1871_253 (WBCS)
S1871_275 (CCSS)
S1871_285.2 (BUSM)
S1871_312.9 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM

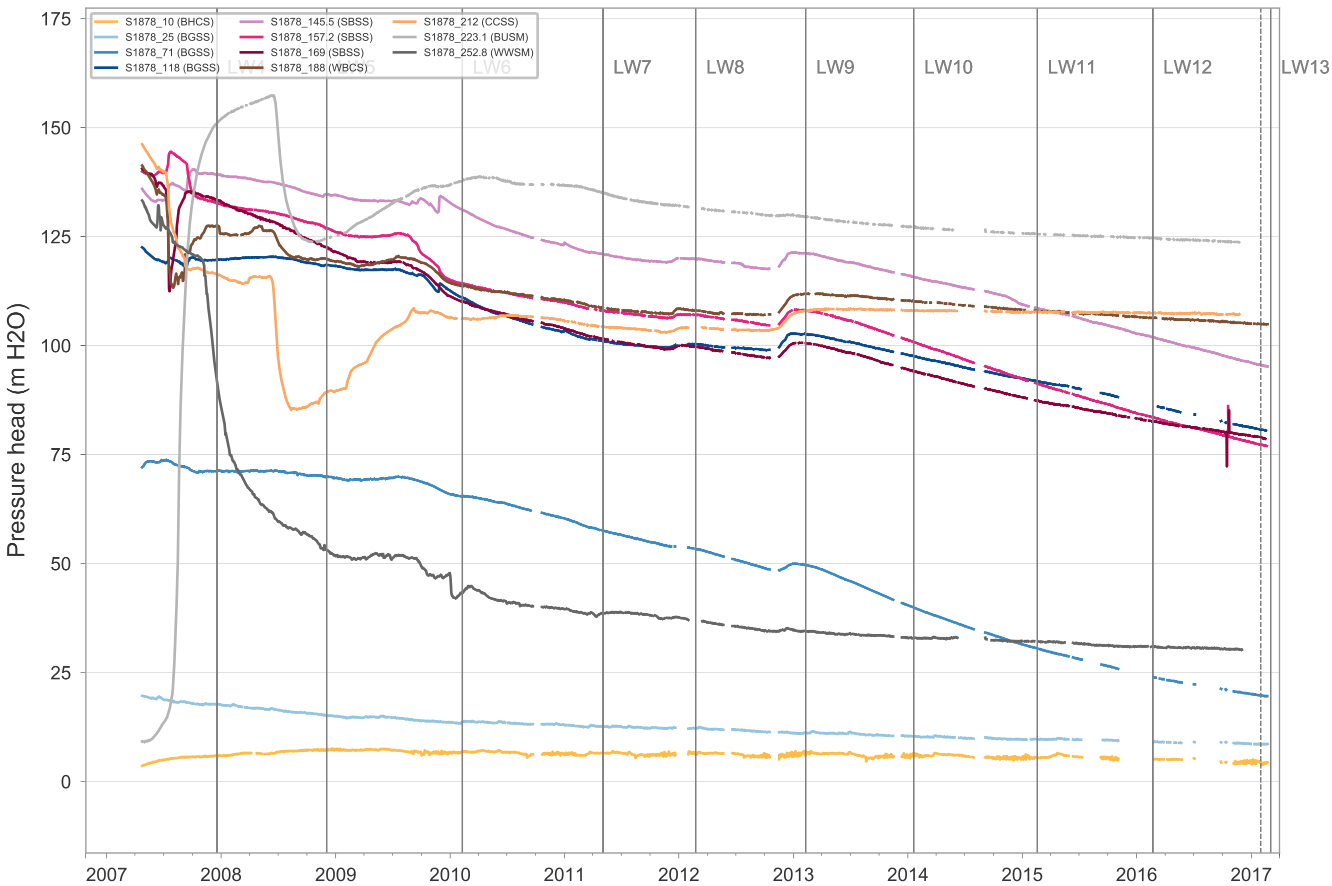

S1871
200
150
100
50
0
Pressure head (m H2O)
S1871_10 (HBSS)
S1871_31.3 (HBSS)
S1871_40 (HBSS)
S1871_88 (BGSS)
S1871_134 (BGSS)
S1871_184 (BGSS)
S1871_210 (SBSS)
S1871_235 (SBSS)
S1871_253 (WBCS)
S1871_275 (CCSS)
S1871_285.2 (BUSM)
S1871_312.9 (WWSM)
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
2008
2010
2012
2014
2016
2018

S1878

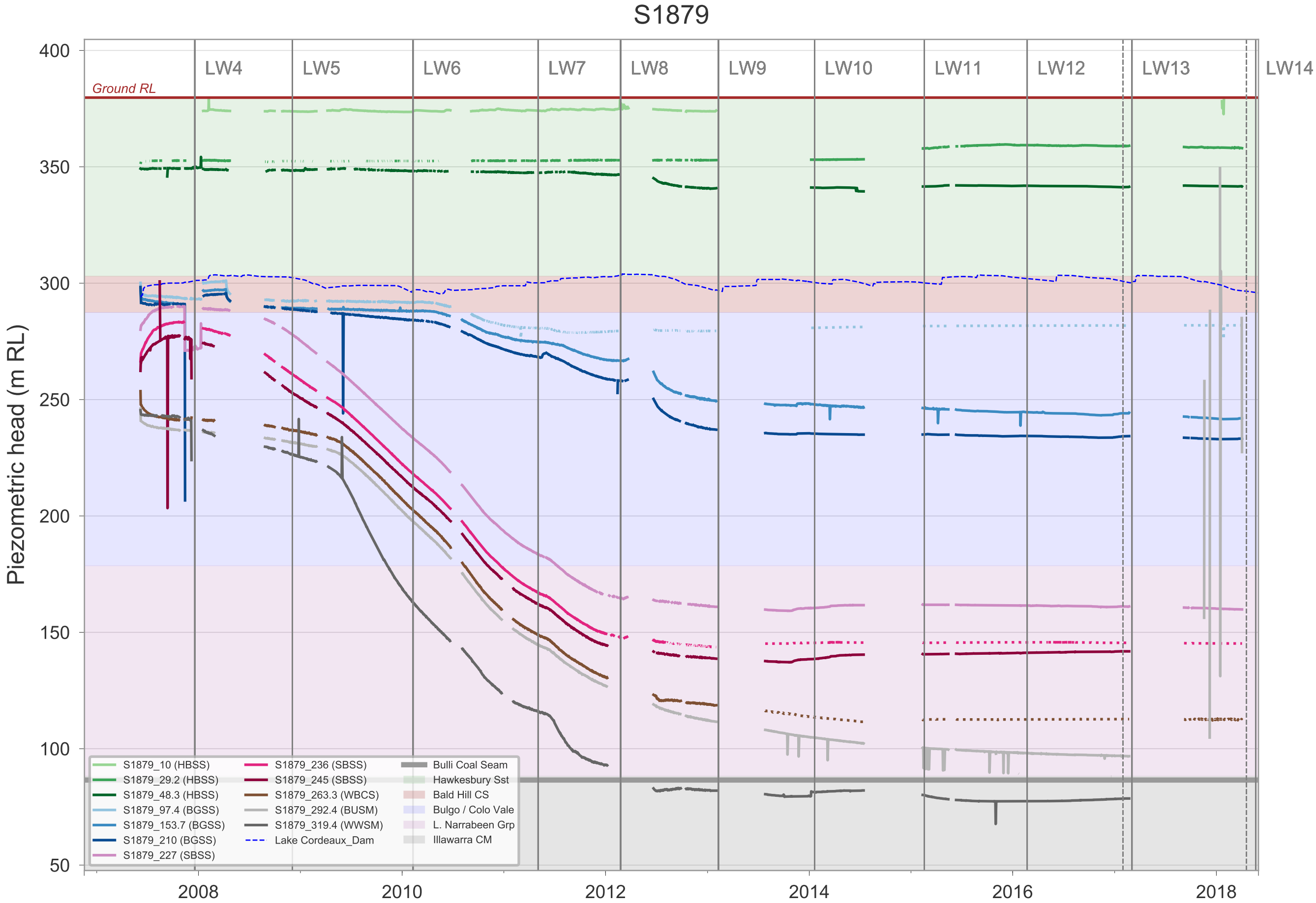


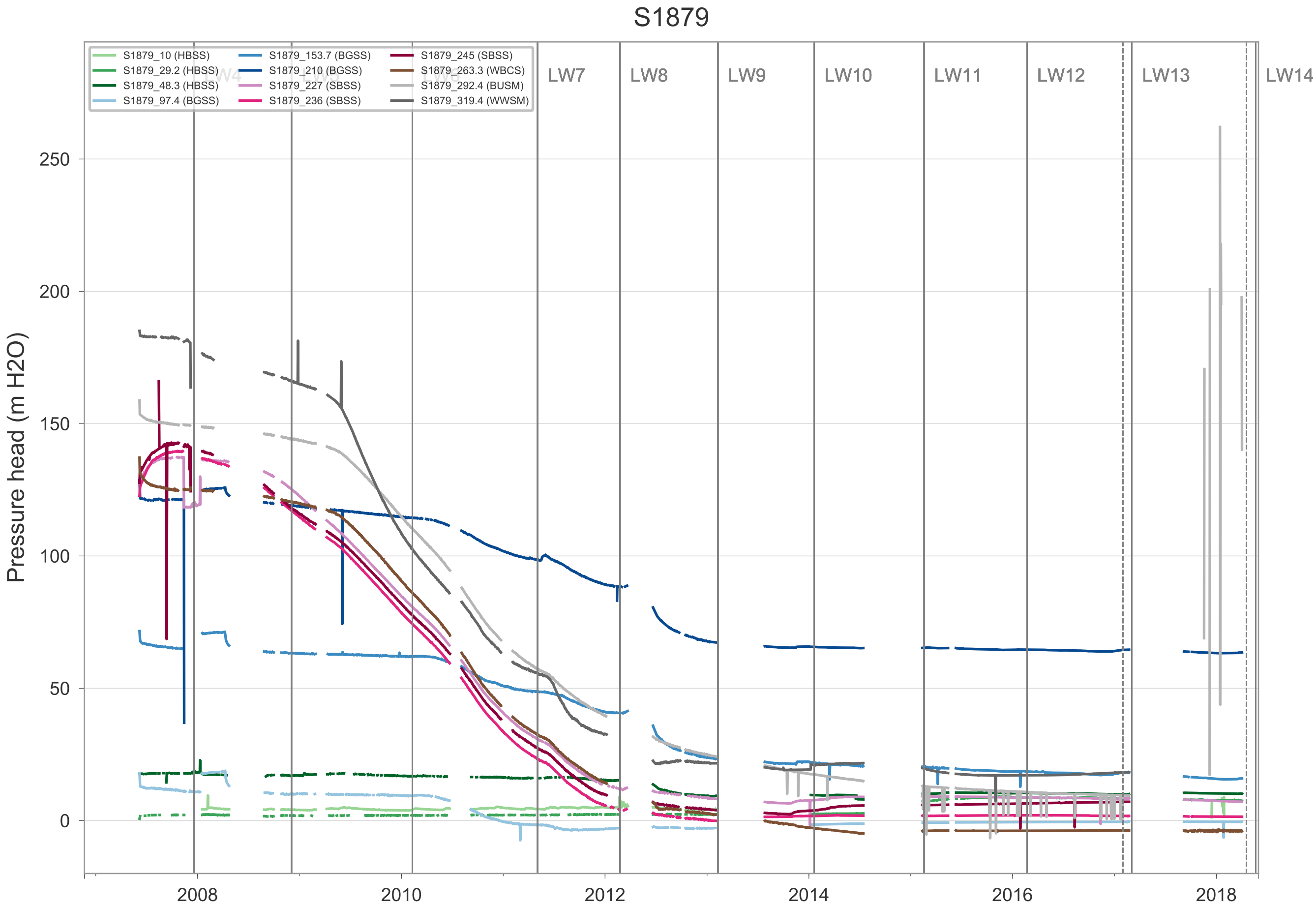
Piezometric head (m RL)
350
300
250
200
150
100
Ground RL
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
S1878_10 (BHCS)
S1878_25 (BGSS)
S1878_71 (BGSS)
S1878_118 (BGSS)
S1878_145.5 (SBSS)
S1878_157.2 (SBSS)
S1878_169 (SBSS)
S1878_188 (WBCS)
S1878_212 (CCSS)
S1878_223.1 (BUSM)
S1878_252.8 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

S1878

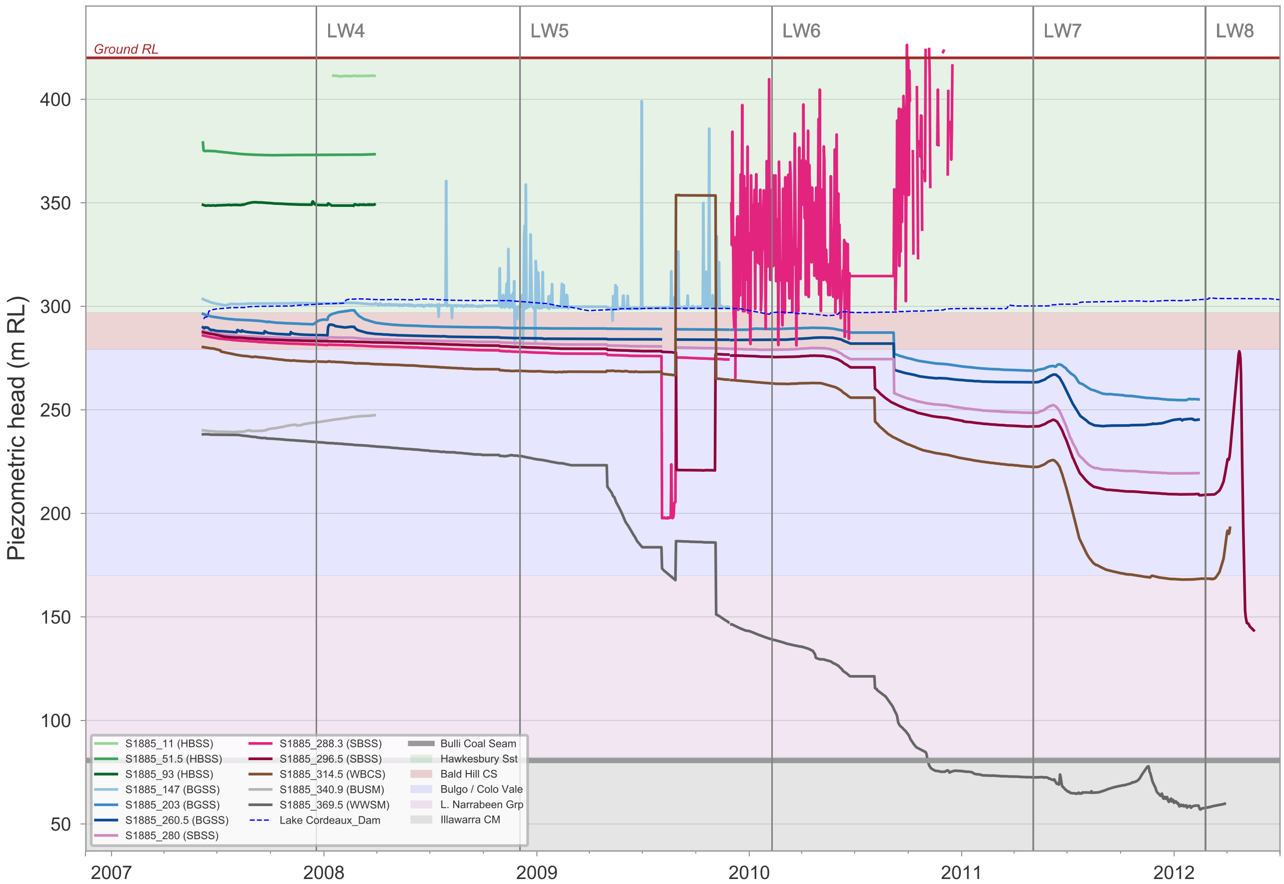


Pressure head (m H2O)
175
150
125
100
75
50
25
0
S1878_10 (BHCS)
S1878_25 (BGSS)
S1878_71 (BGSS)
S1878_118 (BGSS)
S1878_145.5 (SBSS)
S1878_157.2 (SBSS)
S1878_169 (SBSS)
S1878_188 (WBCS)
S1878_212 (CCSS)
S1878_223.1 (BUSM)
S1878_252.8 (WWSM)
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

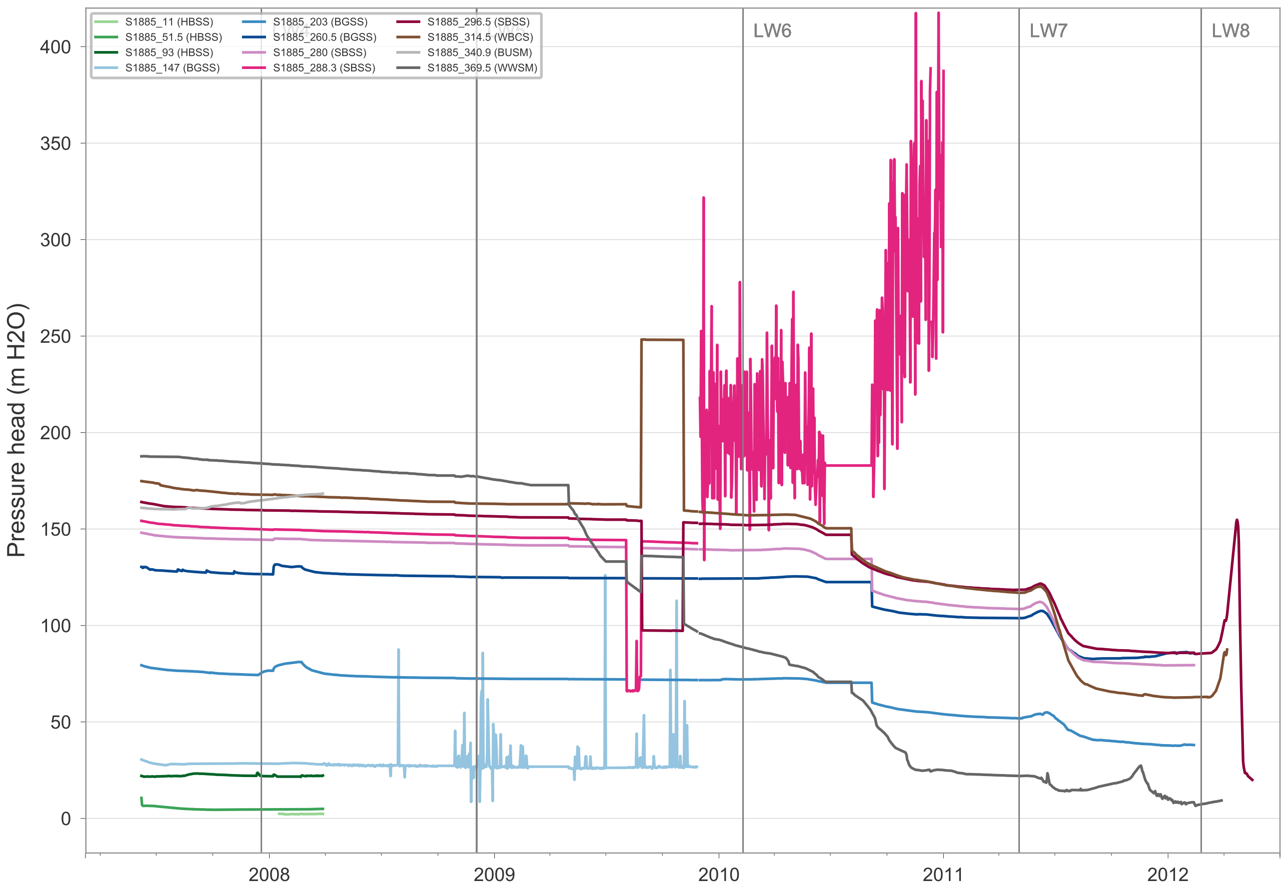

S1879
Piezometric head (m RL)
400
350
300
250
200
150
100
50
2008
2010
2012
2014
2016
2018
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground RL
S1879_10 (HBSS)
S1879_29.2 (HBSS)
S1879_48.3 (HBSS)
S1879_97.4 (BGSS)
S1879_153.7 (BGSS)
S1879_210 (BGSS)
S1879_227 (SBSS)
S1879_236 (SBSS)
S1879_245 (SBSS)
S1879_263.3 (WBCS)
S1879_292.4 (BUSM)
S1879_319.4 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM


S1879
Pressure head (m H2O)
250
200
150
100
50
0
2008
2010
2012
2014
2016
2018
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
S1879_10 (HBSS)
S1879_29.2 (HBSS)
S1879_48.3 (HBSS)
S1879_97.4 (BGSS)
S1879_153.7 (BGSS)
S1879_210 (BGSS)
S1879_227 (SBSS)
S1879_236 (SBSS)
S1879_245 (SBSS)
S1879_263.3 (WBCS)
S1879_292.4 (BUSM)
S1879_319.4 (WWSM)

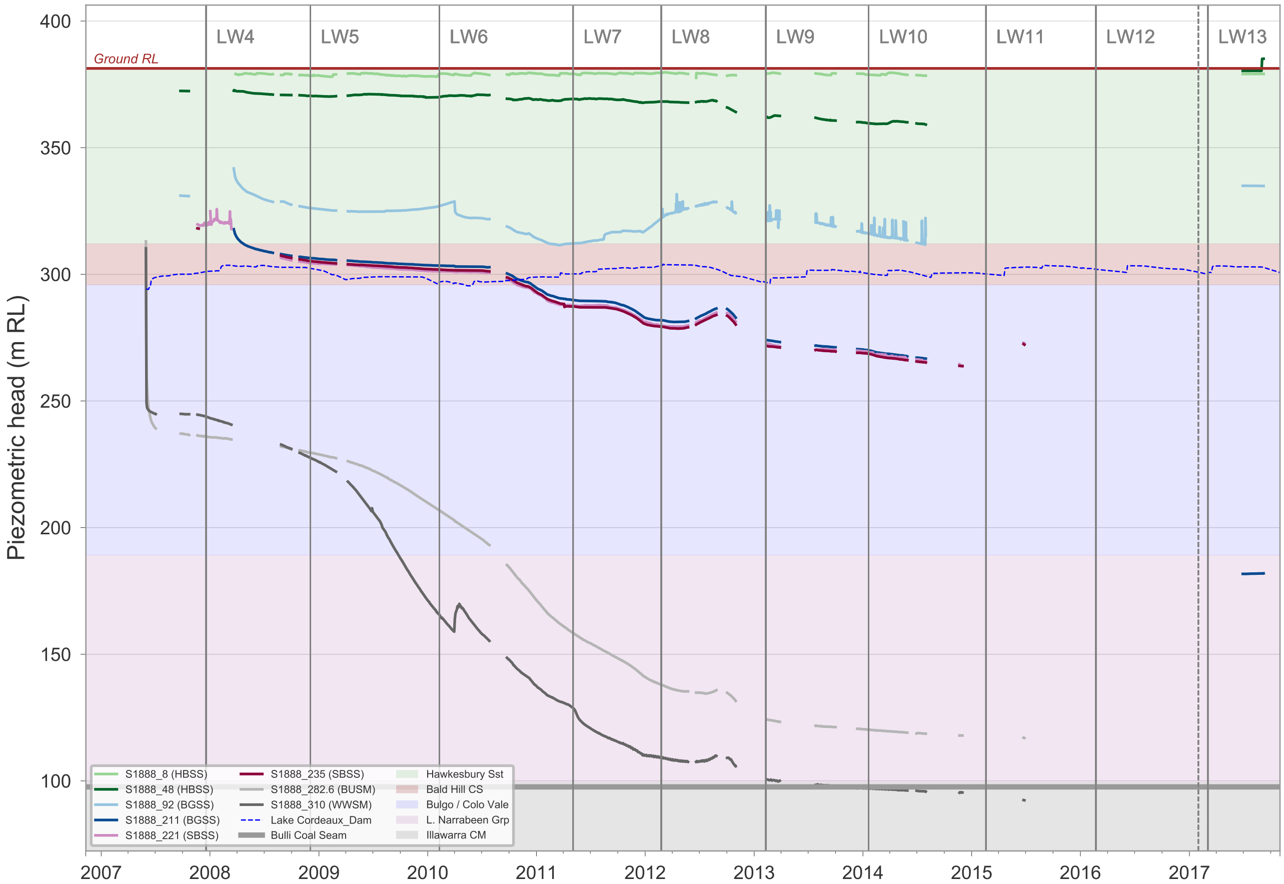
S1885


LW4
LW5
LW6
LW7
LW8
Ground RL
Piezometric head (m RL)
400
350
300
250
200
150
100
50
2007
2008
2009
2010
2011
2012
S1885_11 (HBSS)
S1885_51.5 (HBSS)
S1885_93 (HBSS)
S1885_147 (BGSS)
S1885_203 (BGSS)
S1885_260.5 (BGSS)
S1885_280 (SBSS)
S1885_288.3 (SBSS)
S1885_296.5 (SBSS)
S1885_314.5 (WBCS)
S1885_340.9 (BUSM)
S1885_369.5 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM

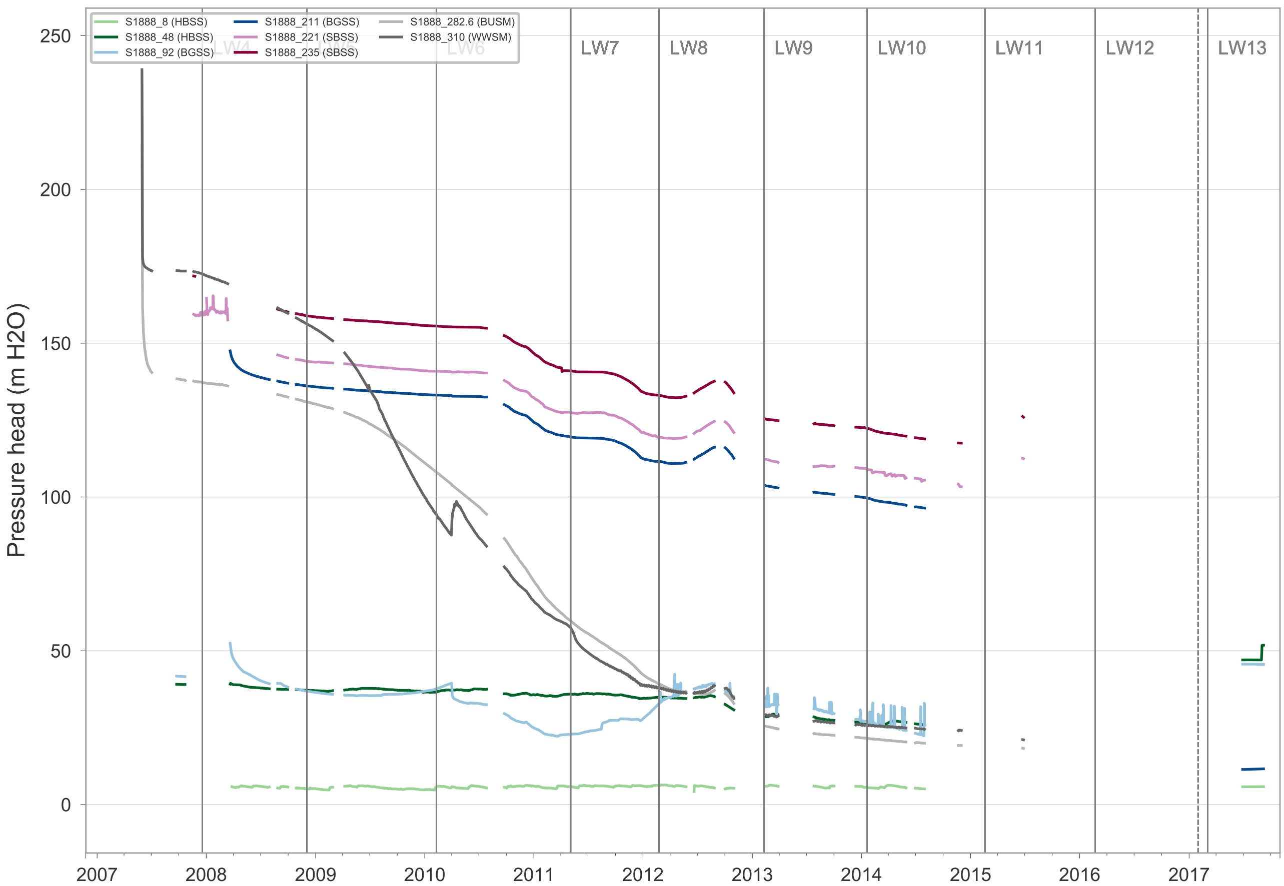
S1885

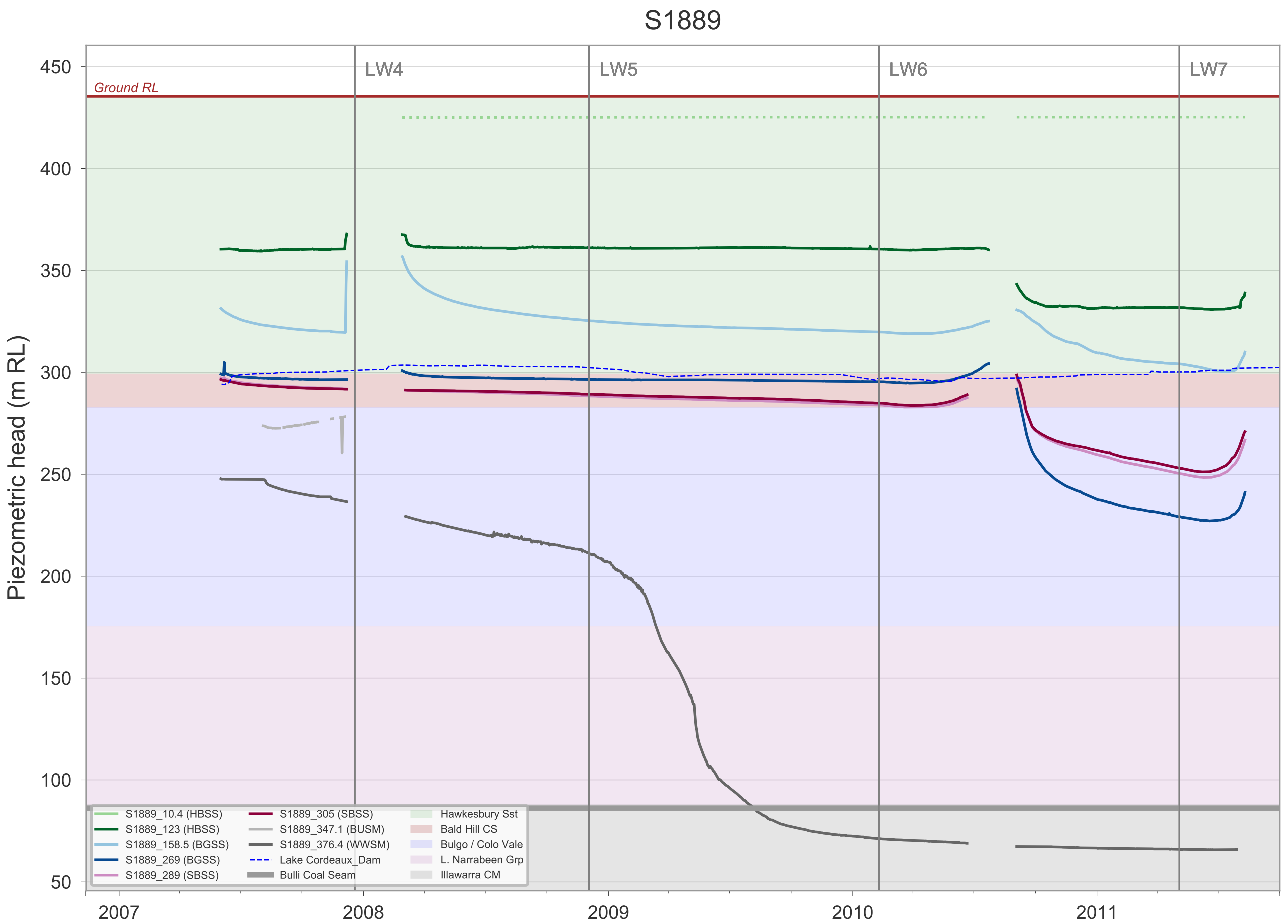

LW6
LW7
LW8
Pressure head (m H2O)
400
350
300
250
200
150
100
50
0
2008
2009
2010
2011
2012
S1885_11 (HBSS)
S1885_51.5 (HBSS)
S1885_93 (HBSS)
S1885_147 (BGSS)
S1885_203 (BGSS)
S1885_260.5 (BGSS)
S1885_280 (SBSS)
S1885_288.3 (SBSS)
S1885_296.5 (SBSS)
S1885_314.5 (WBCS)
S1885_340.9 (BUSM)
S1885_369.5 (WWSM)

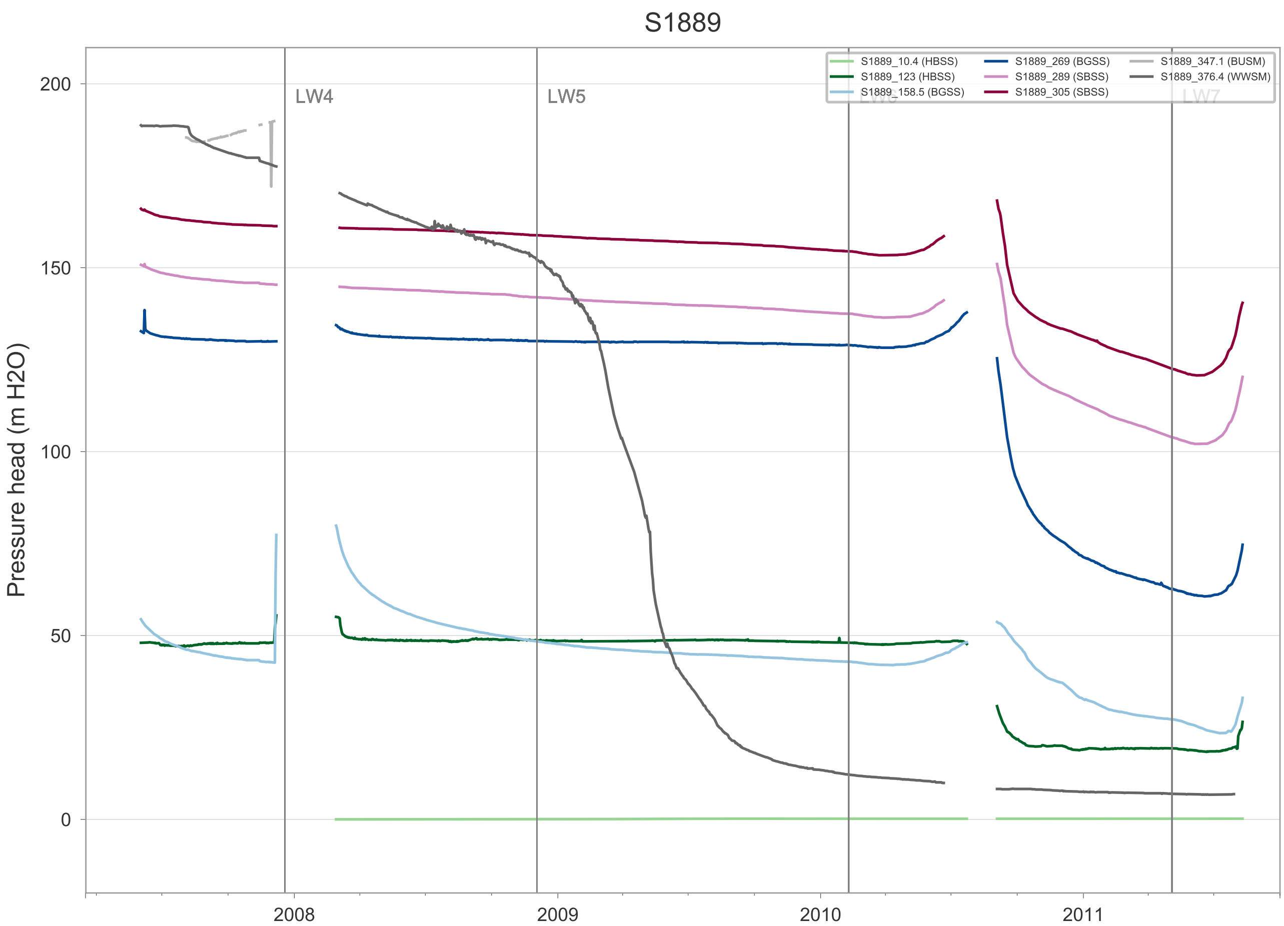
S1888

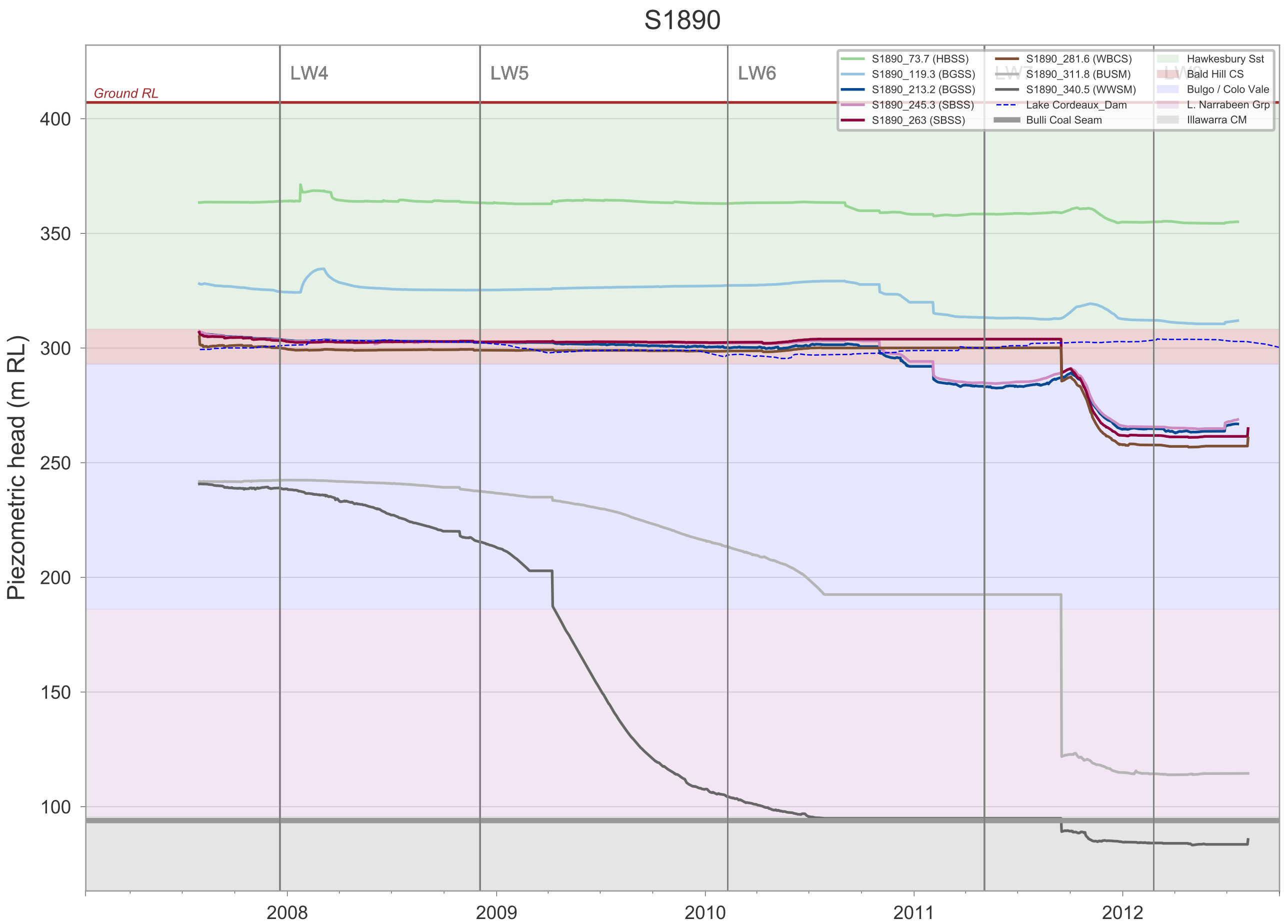

Piezometric head (m RL)
Ground RL
LW4
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
S1888_8 (HBSS)
S1888_48 (HBSS)
S1888_92 (BGSS)
S1888_211 (BGSS)
S1888_221 (SBSS)
S1888_235 (SBSS)
S1888_282.6 (BUSM)
S1888_310 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
400
350
300
250
200
150
100
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

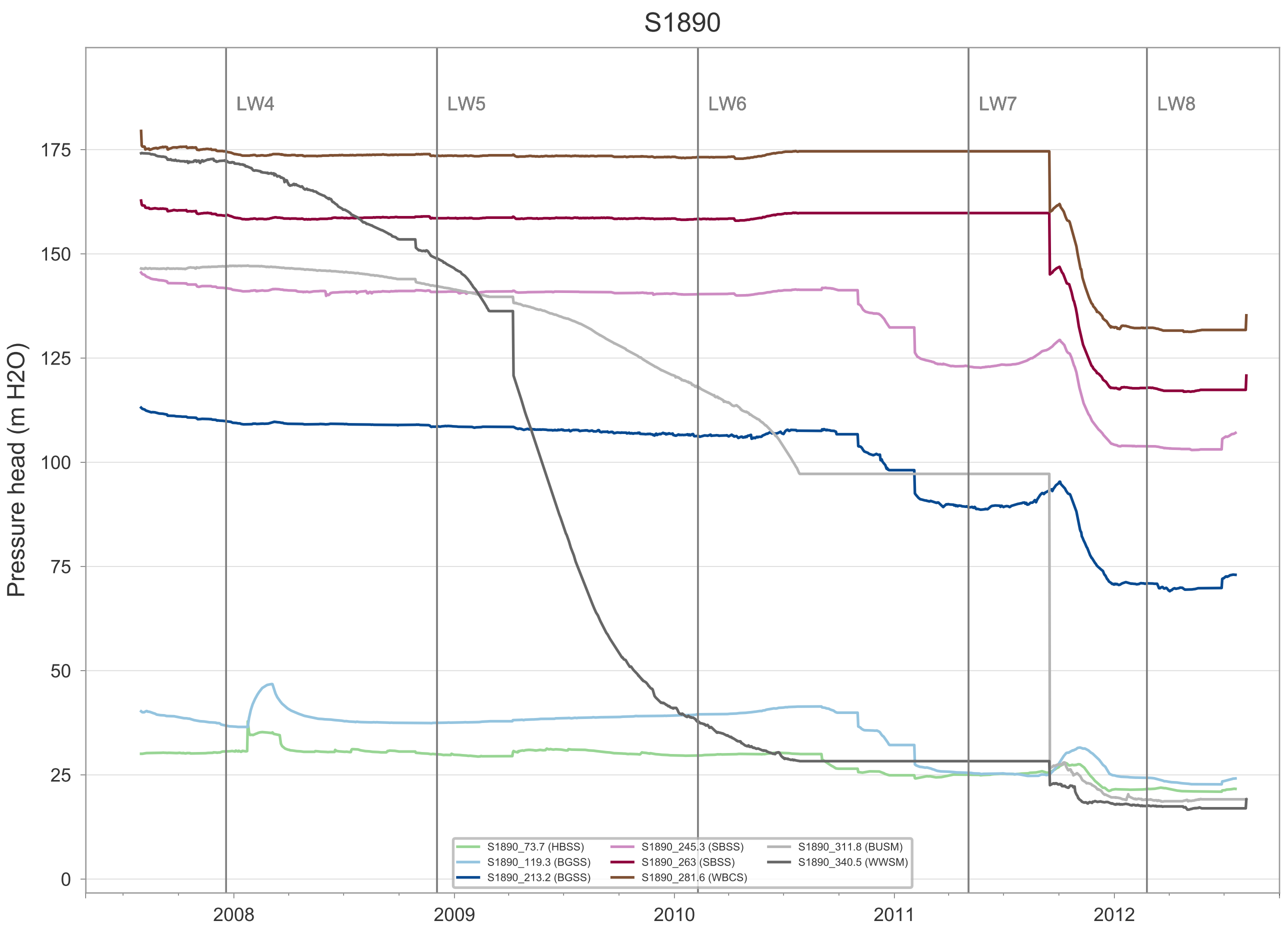
S1888

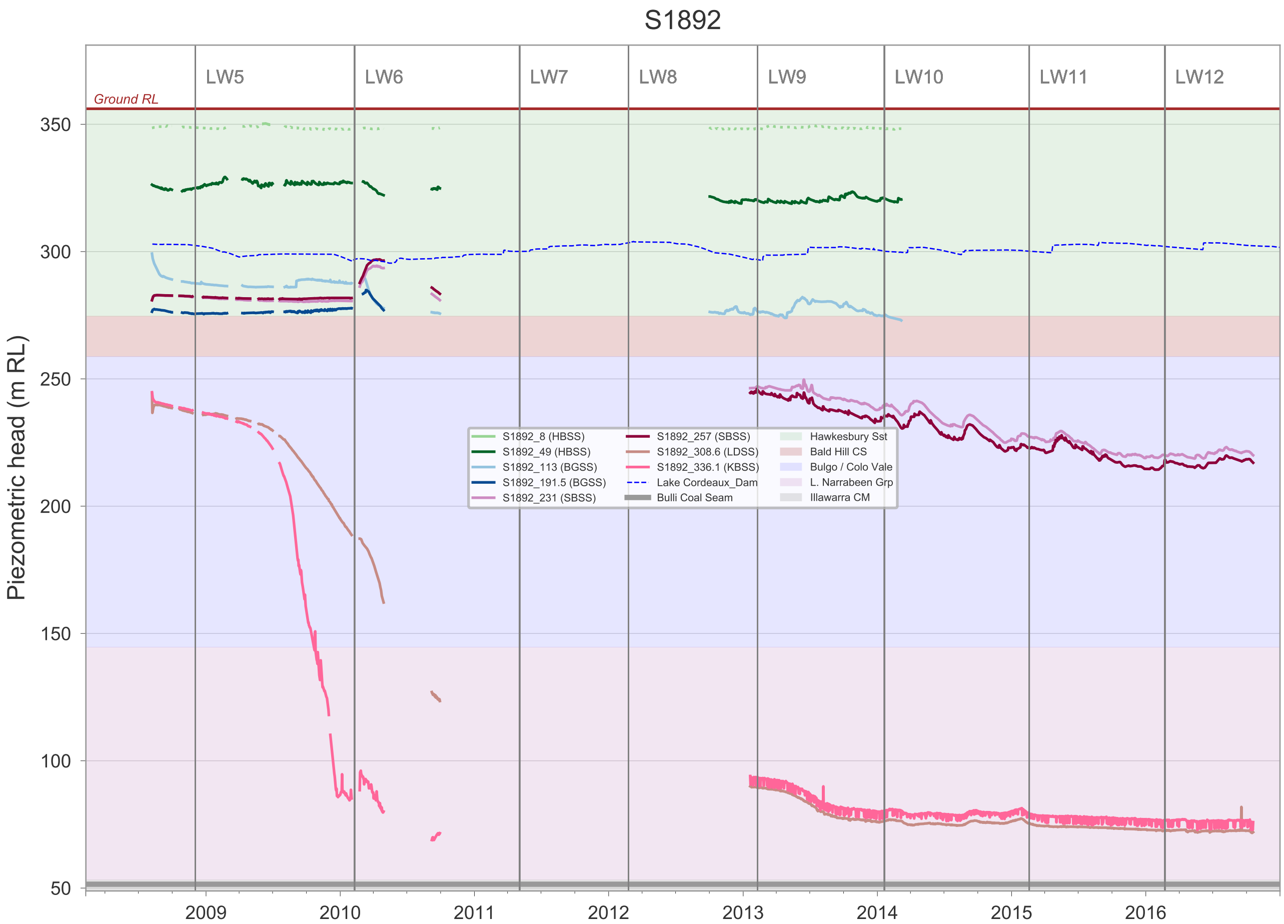

Pressure head (m H2O)
S1888_8 (HBSS)
S1888_48 (HBSS)
S1888_92 (BGSS)
S1888_211 (BGSS)
S1888_221 (SBSS)
S1888_235 (SBSS)
S1888_282.6 (BUSM)
S1888_310 (WWSM)
LW7
LW8
LW9
LW10
LW11
LW12
LW13
250
200
150
100
50
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


S1889
Ground RL
LW4
LW5
LW6
LW7
Piezometric head (m RL)
450
400
350
300
250
200
150
100
50
2007
2008
2009
2010
2011
S1889_10.4 (HBSS)
S1889_123 (HBSS)
S1889_158.5 (BGSS)
S1889_269 (BGSS)
S1889_289 (SBSS)
S1889_305 (SBSS)
S1889_347.1 (BUSM)
S1889_376.4 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM


S1889
LW4
LW5
Pressure head (m H2O)
200
150
100
50
0
2008
2009
2010
2011
S1889_10.4 (HBSS)
S1889_123 (HBSS)
S1889_158.5 (BGSS)
S1889_269 (BGSS)
S1889_289 (SBSS)
S1889_305 (SBSS)
S1889_347.1 (BUSM)
S1889_376.4 (WWSM)


S1890
Piezometric head (m RL)
Ground RL
LW4
LW5
LW6
S1890_73.7 (HBSS)
S1890_119.3 (BGSS)
S1890_213.2 (BGSS)
S1890_245.3 (SBSS)
S1890_263 (SBSS)
S1890_281.6 (WBCS)
S1890_311.8 (BUSM)
S1890_340.5 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
400
350
300
250
200
150
100
2008
2009
2010
2011
2012


S1890
Pressure head (m H2O)
LW4
LW5
LW6
LW7
LW8
S1890_73.7 (HBSS)
S1890_119.3 (BGSS)
S1890_213.2 (BGSS)
S1890_245.3 (SBSS)
S1890_263 (SBSS)
S1890_281.6 (WBCS)
S1890_311.8 (BUSM)
S1890_340.5 (WWSM)
175
150
125
100
75
50
25
0
2008
2009
2010
2011
2012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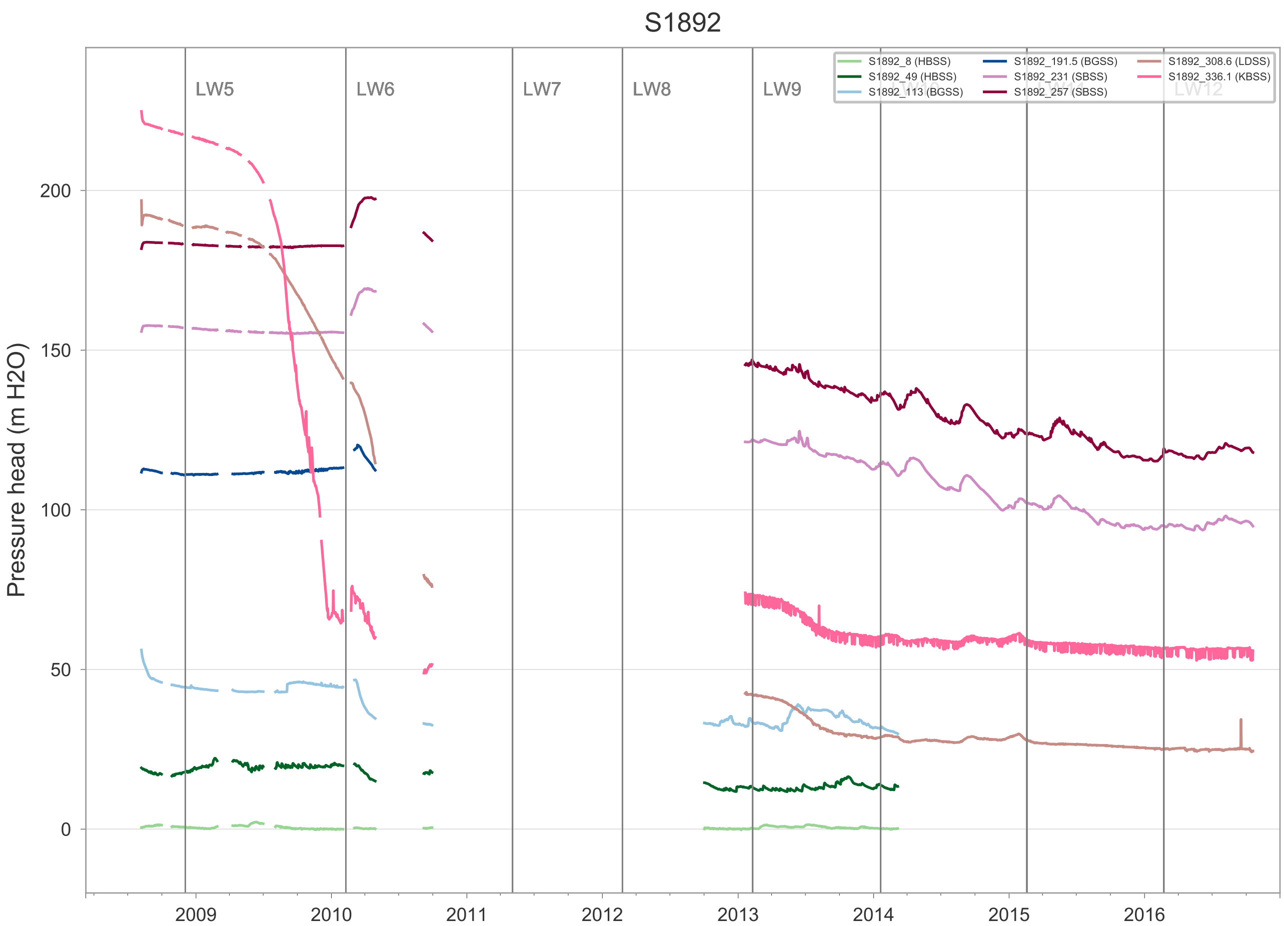
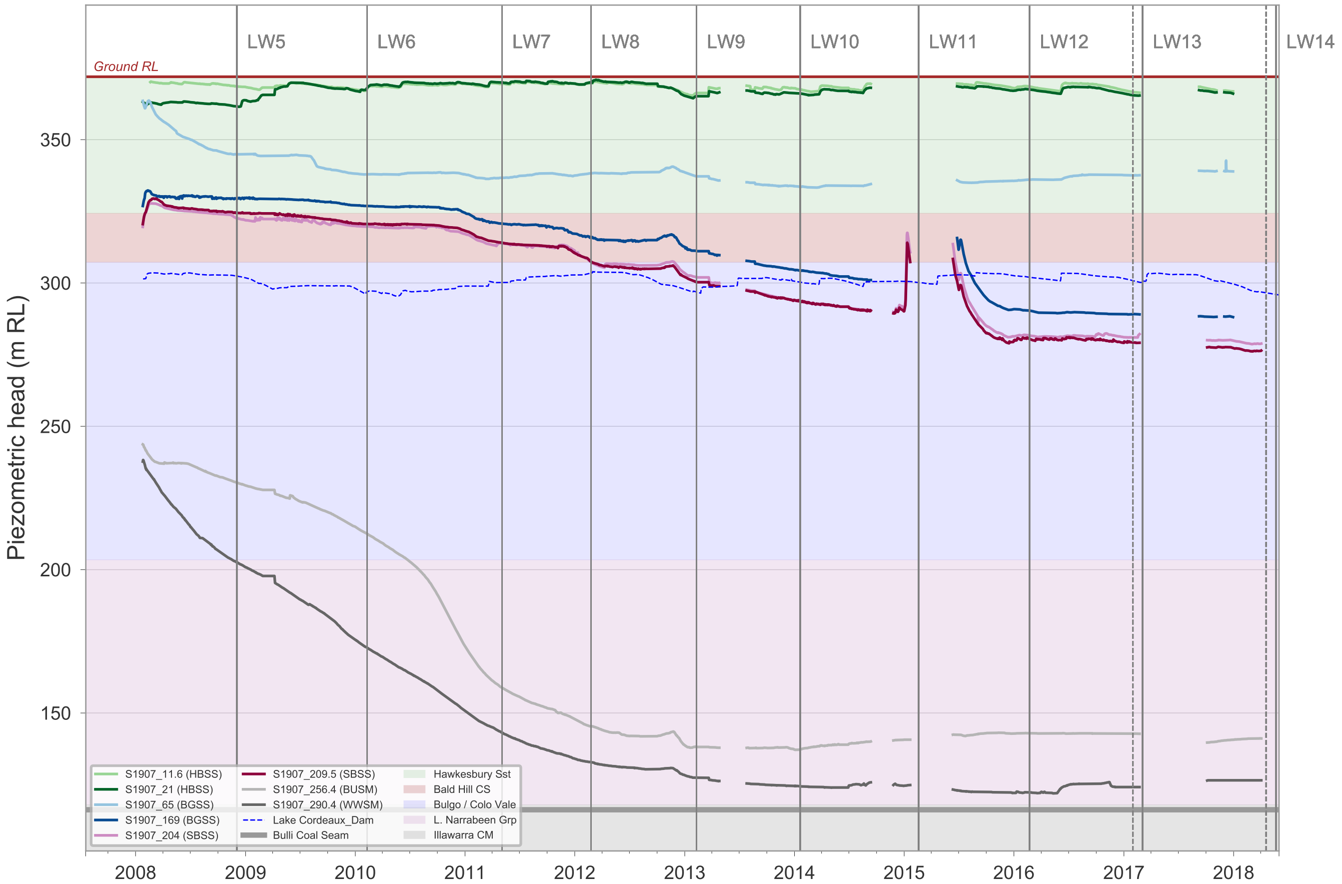
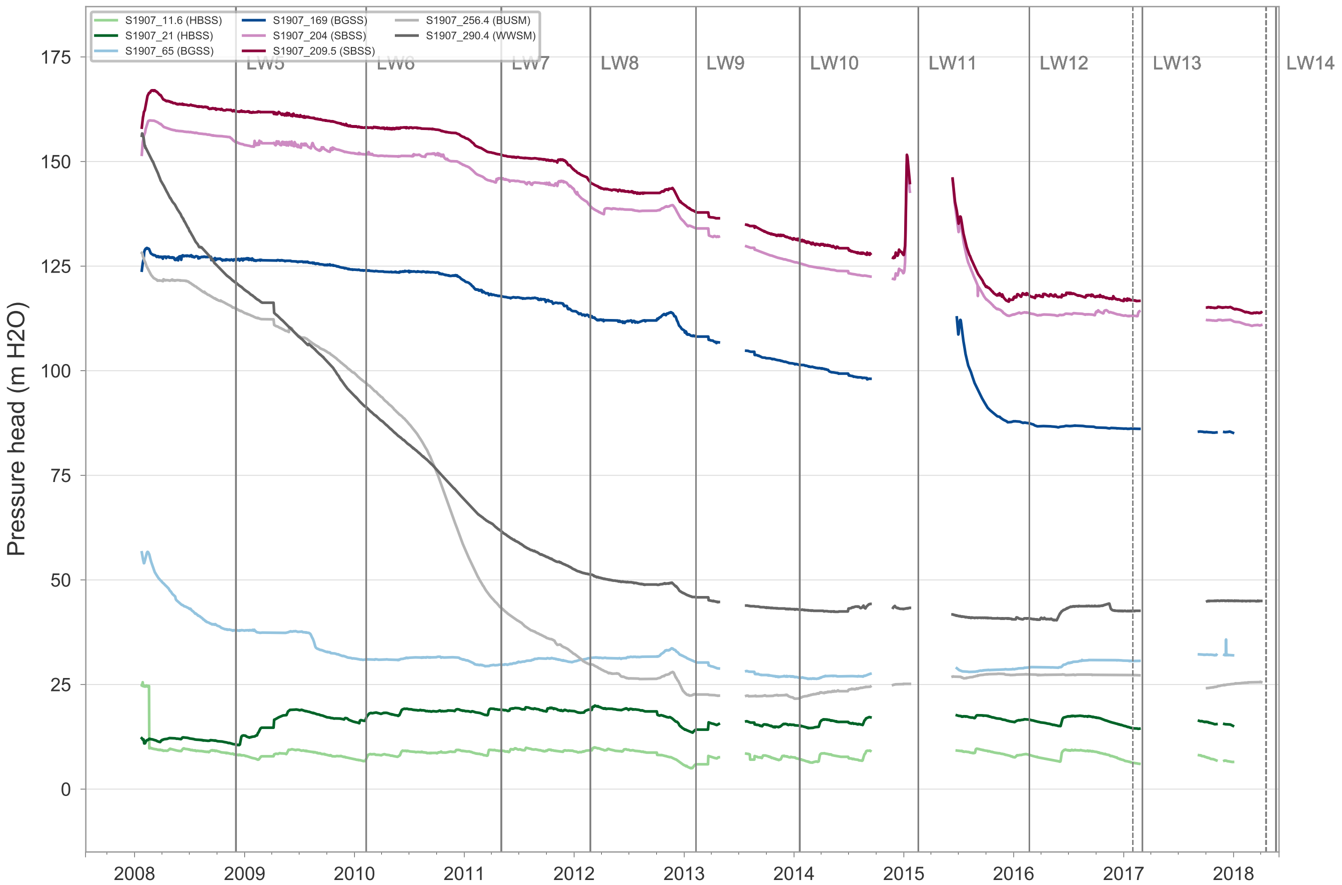
Piezometric head (m RL)
Ground RL
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
S1892_8 (HBSS)
S1892_49 (HBSS)
S1892_113 (BGSS)
S1892_191.5 (BGSS)
S1892_231 (SBSS)
S1892_257 (SBSS)
S1892_308.6 (LDSS)
S1892_336.1 (KBSS)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
350
300
250
200
150
100
50
2009
2010
2011
2012
2013
2014
2015
2016


S1892
Pressure head (m H2O)
LW5
LW6
LW7
LW8
LW9
LW12
S1892_8 (HBSS)
S1892_49 (HBSS)
S1892_113 (BGSS)
S1892_191.5 (BGSS)
S1892_231 (SBSS)
S1892_257 (SBSS)
S1892_308.6 (LDSS)
S1892_336.1 (KBSS)
200
150
100
50
0
2009
2010
2011
2012
2013
2014
2015
2016

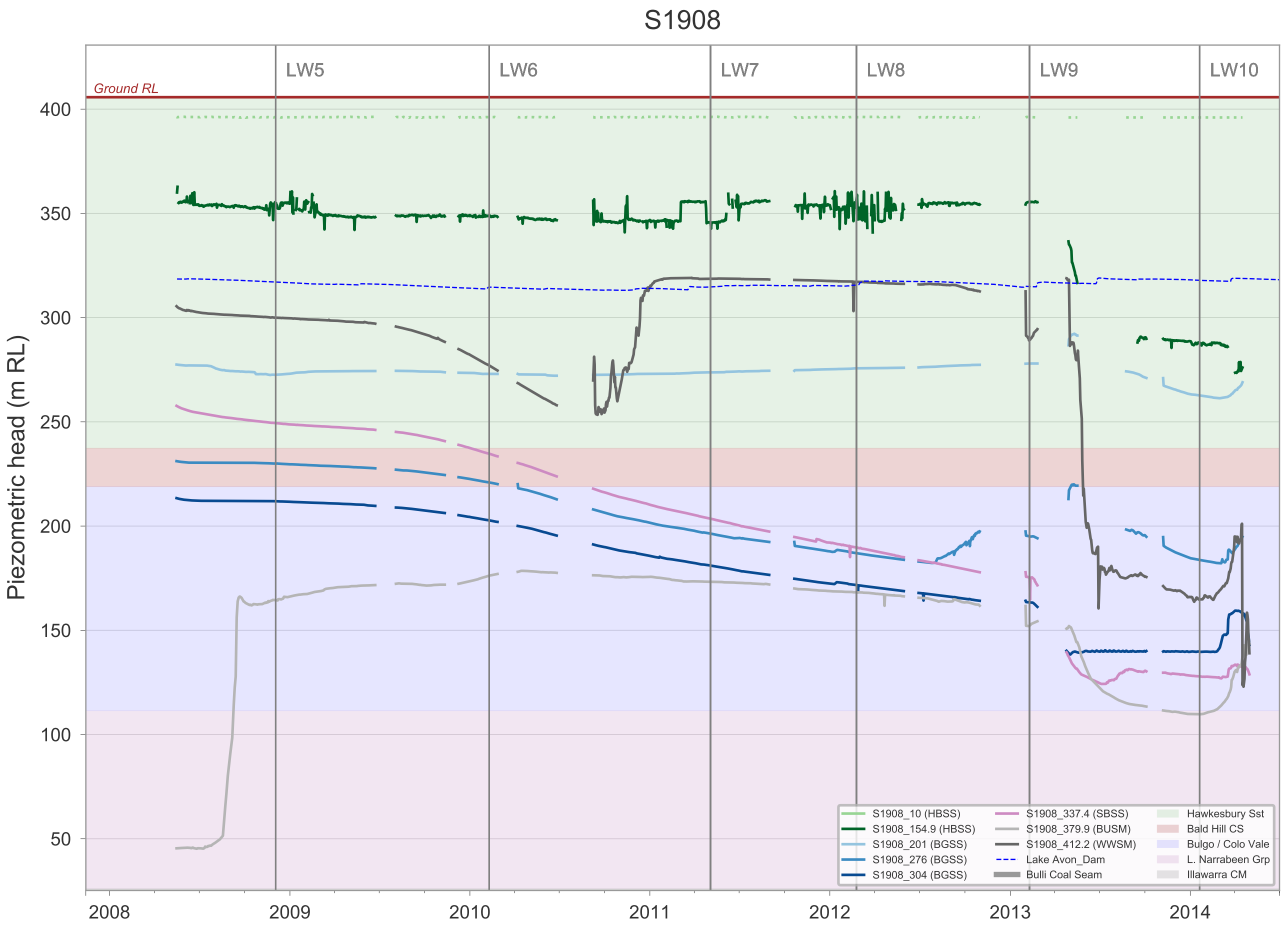
S1907

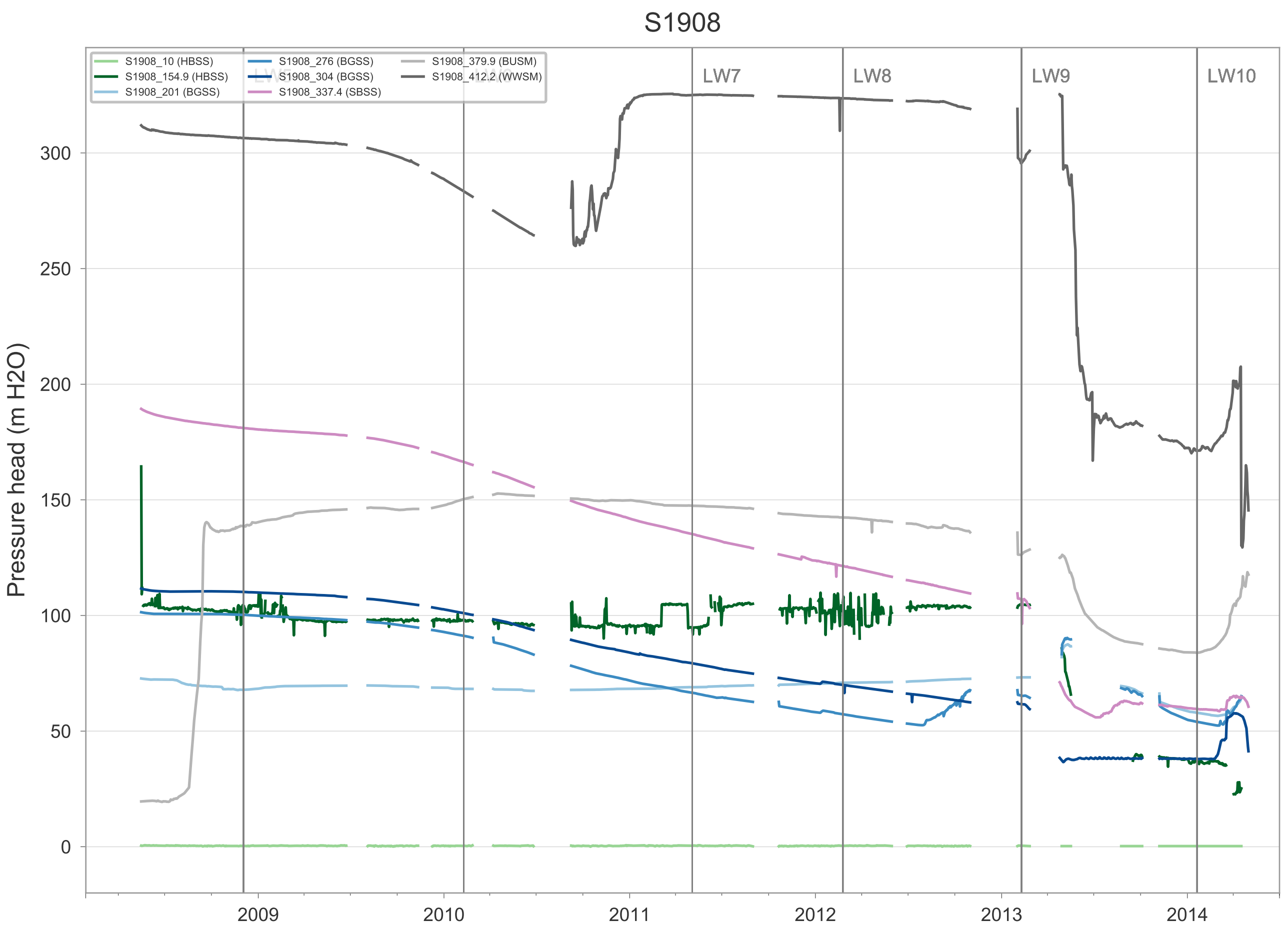

Piezometric head (m RL)
Ground RL
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
S1907_11.6 (HBSS)
S1907_21 (HBSS)
S1907_65 (BGSS)
S1907_169 (BGSS)
S1907_204 (SBSS)
S1907_209.5 (SBSS)
S1907_256.4 (BUSM)
S1907_290.4 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
350
300
250
200
150
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

S1907

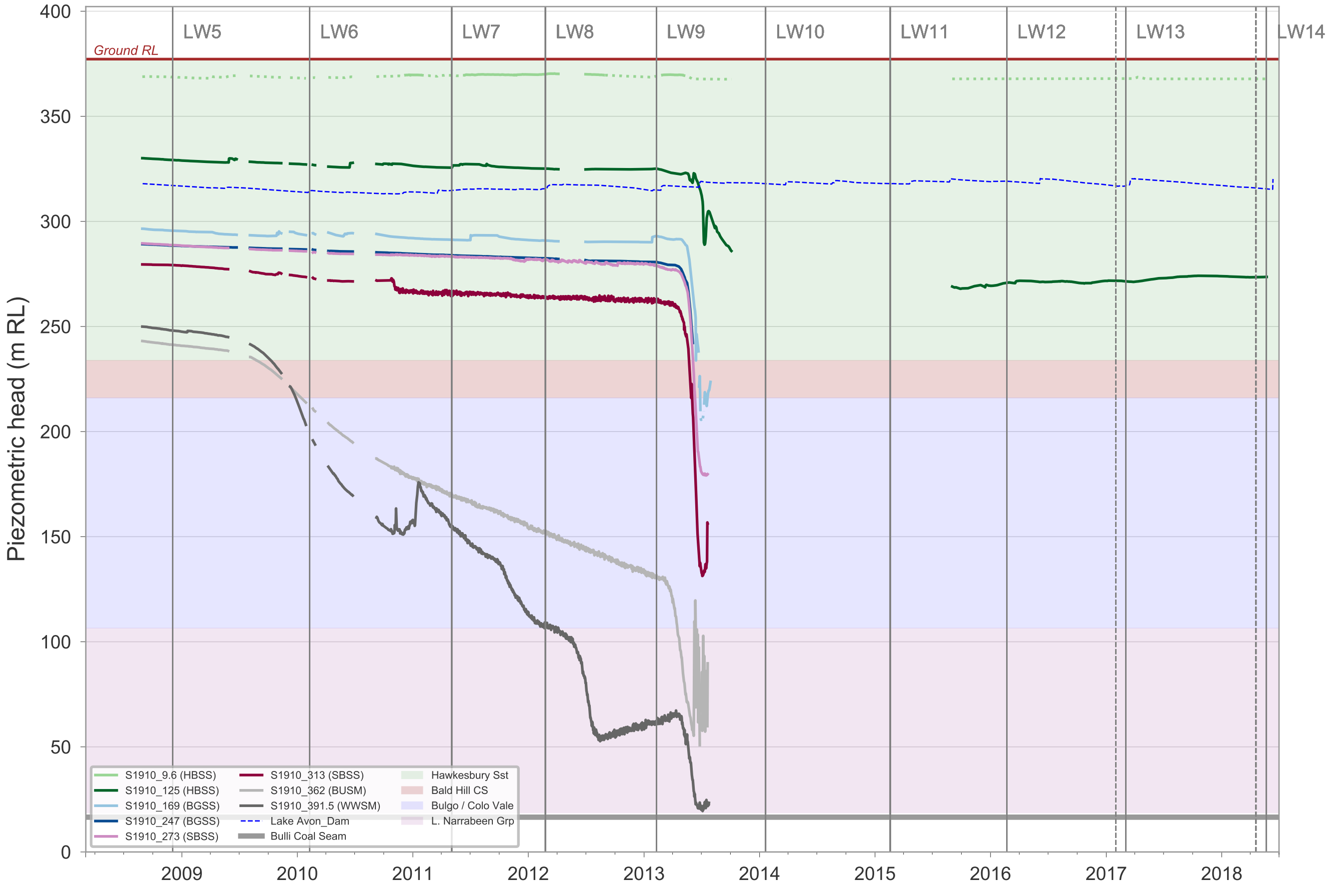

Pressure head (m H2O)
S1907_11.6 (HBSS)
S1907_21 (HBSS)
S1907_65 (BGSS)
S1907_169 (BGSS)
S1907_204 (SBSS)
S1907_209.5 (SBSS)
S1907_256.4 (BUSM)
S1907_290.4 (WWSM)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
175
150
125
100
75
50
25
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

Groundwater hydrographs



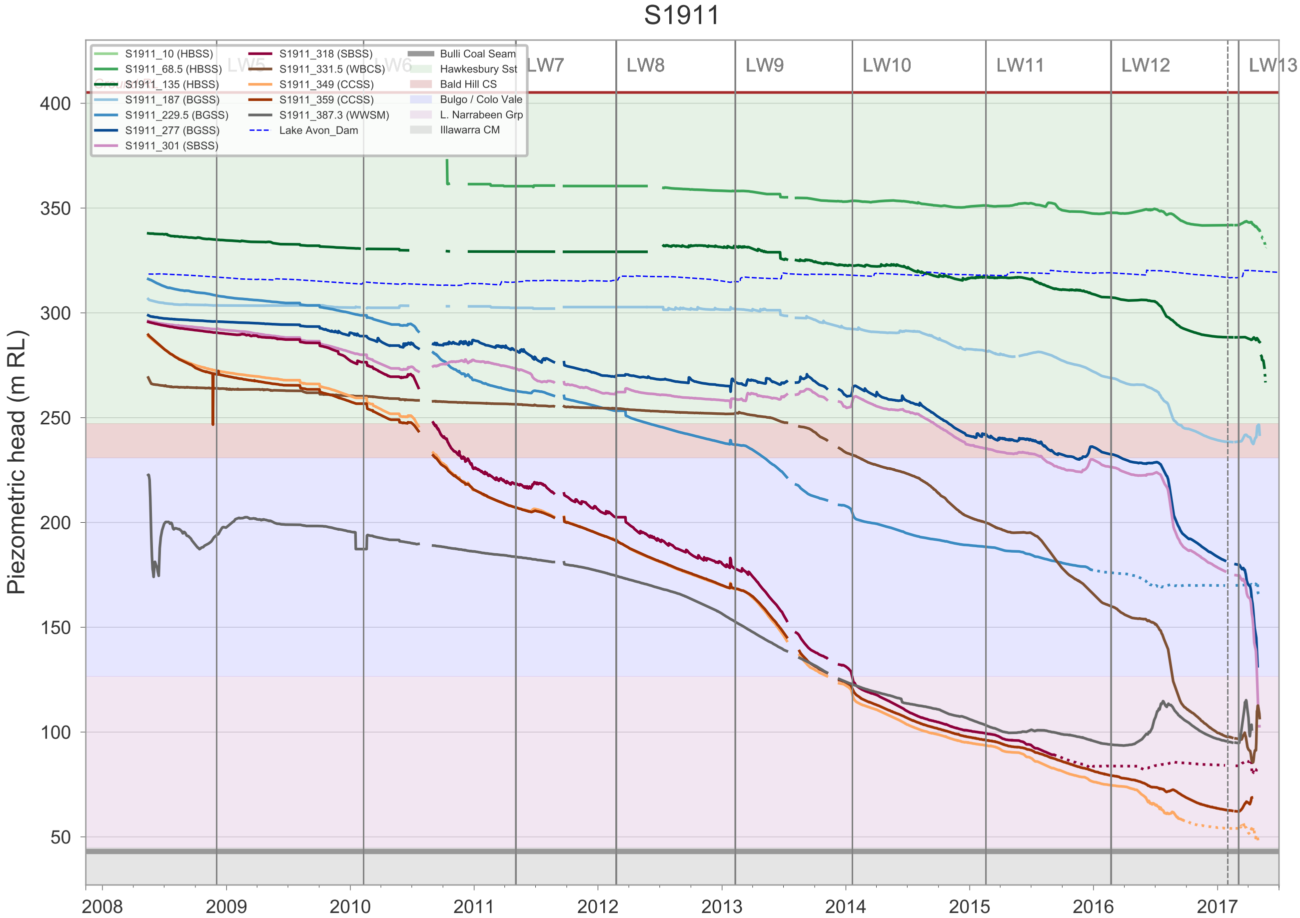


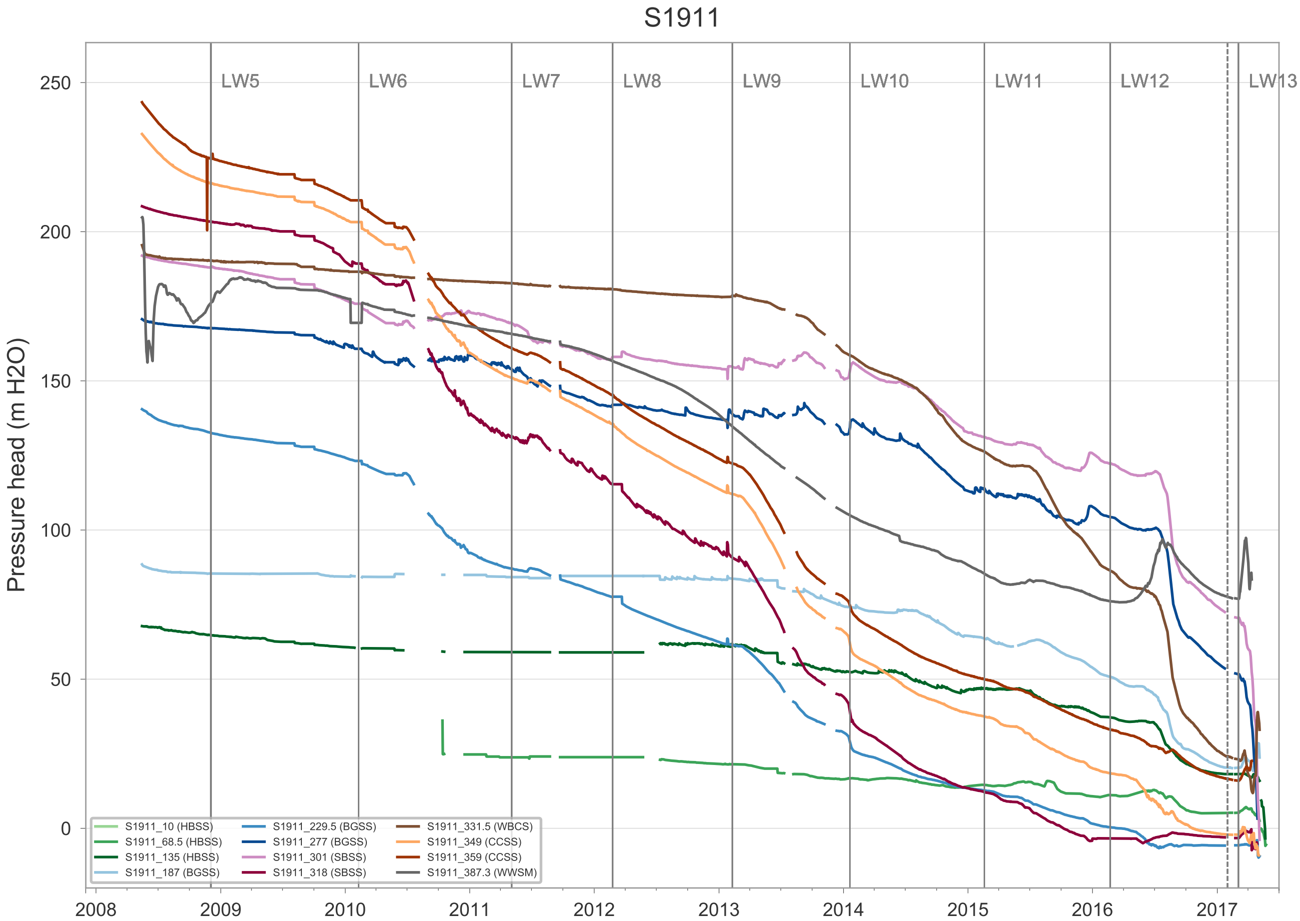
S1910

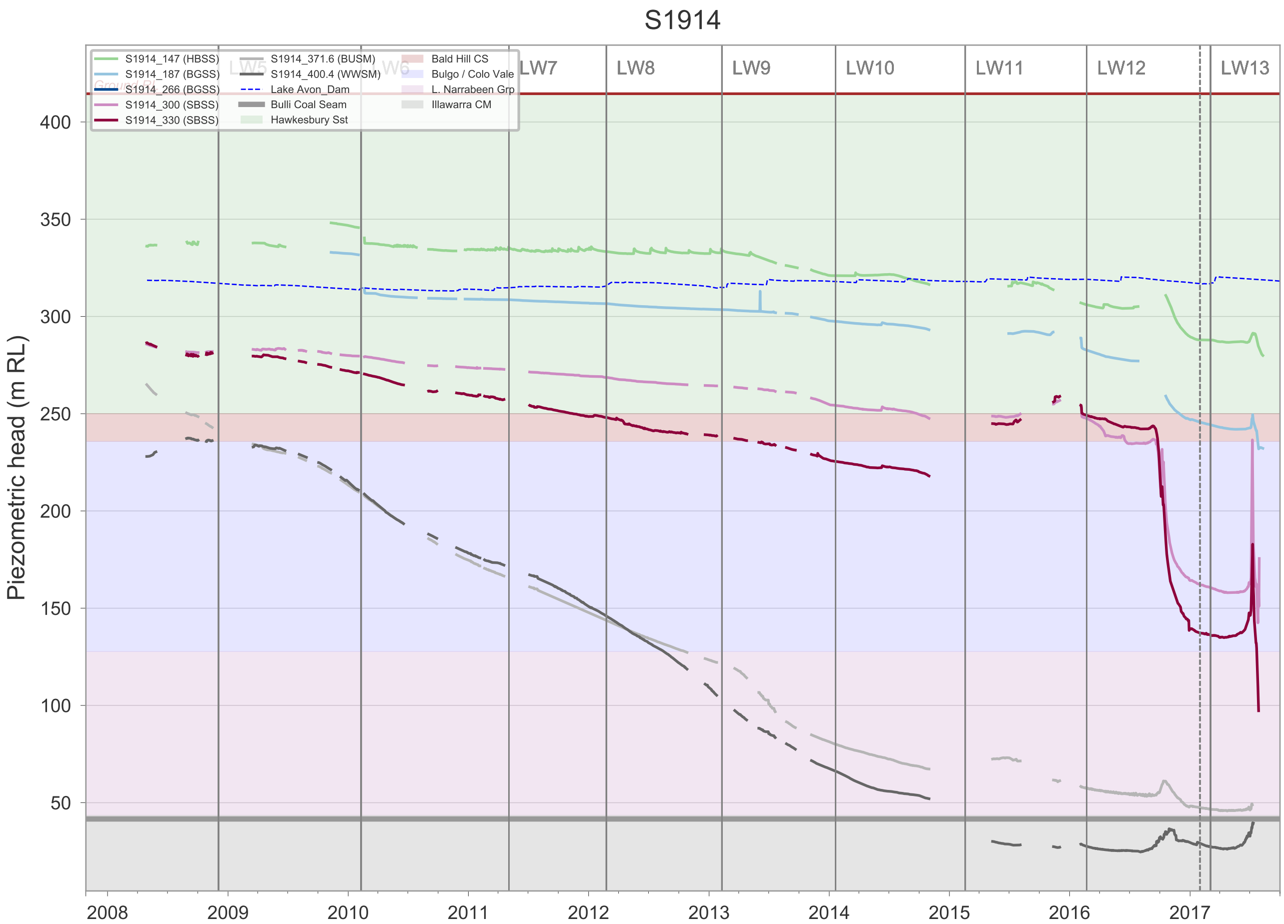

Piezometric head (m RL)
Ground RL
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
S1910_9.6 (HBSS)
S1910_125 (HBSS)
S1910_169 (BGSS)
S1910_247 (BGSS)
S1910_273 (SBSS)
S1910_313 (SBSS)
S1910_362 (BUSM)
S1910_391.5 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp

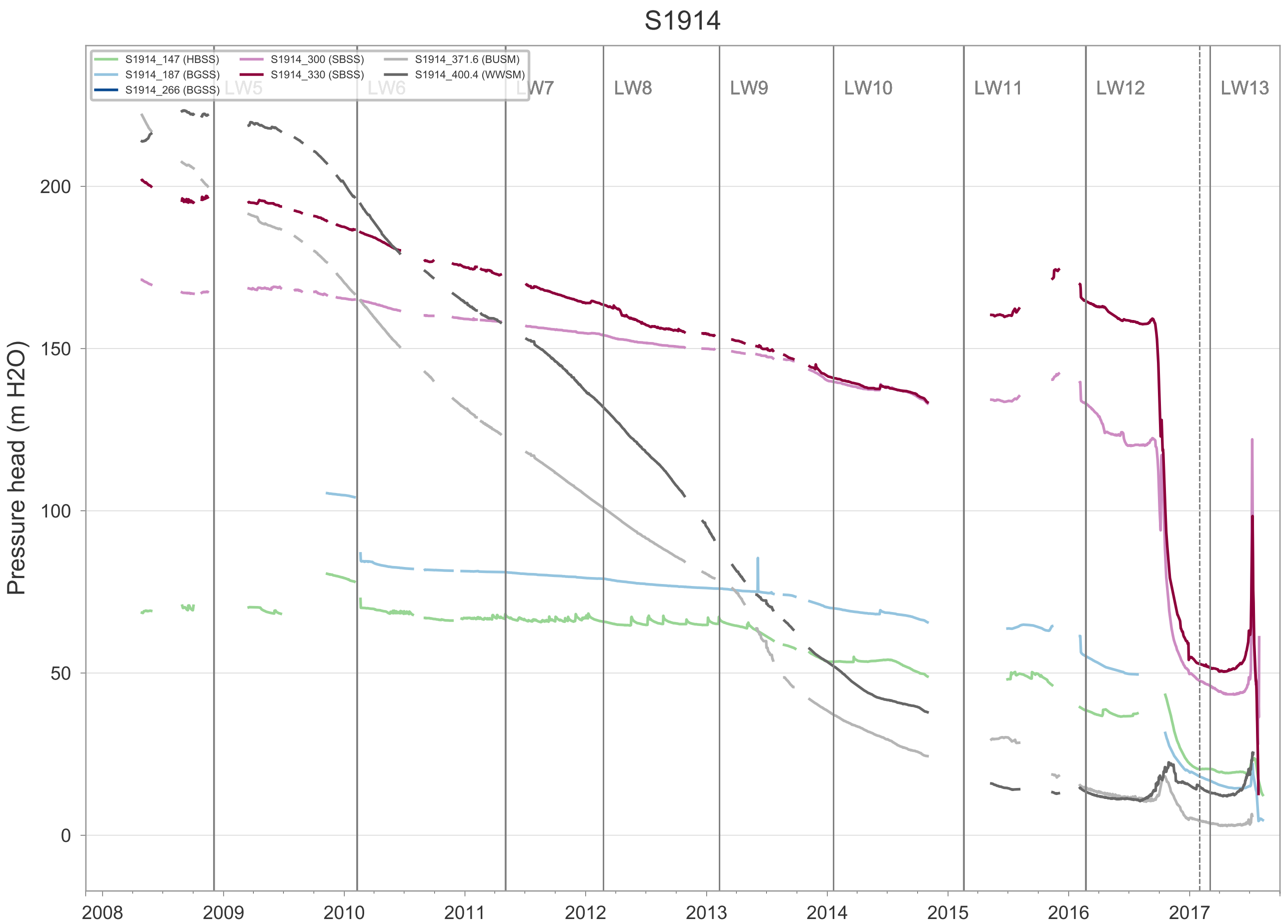
S1910

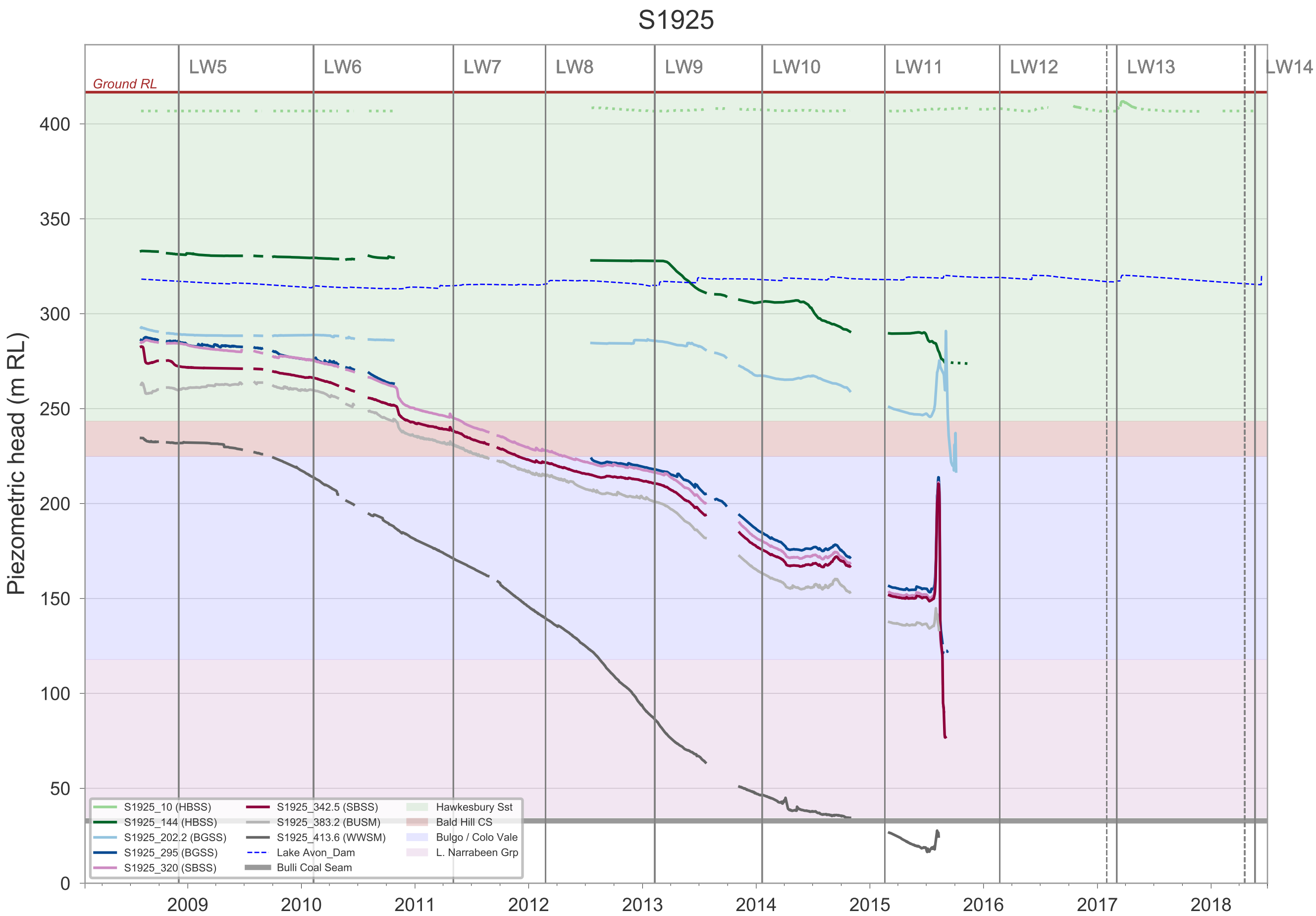

Pressure head (m H2O)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
S1910_9.6 (HBSS)
S1910_125 (HBSS)
S1910_169 (BGSS)
S1910_247 (BGSS)
S1910_273 (SBSS)
S1910_313 (SBSS)
S1910_362 (BUSM)
S1910_391.5 (WWSM)

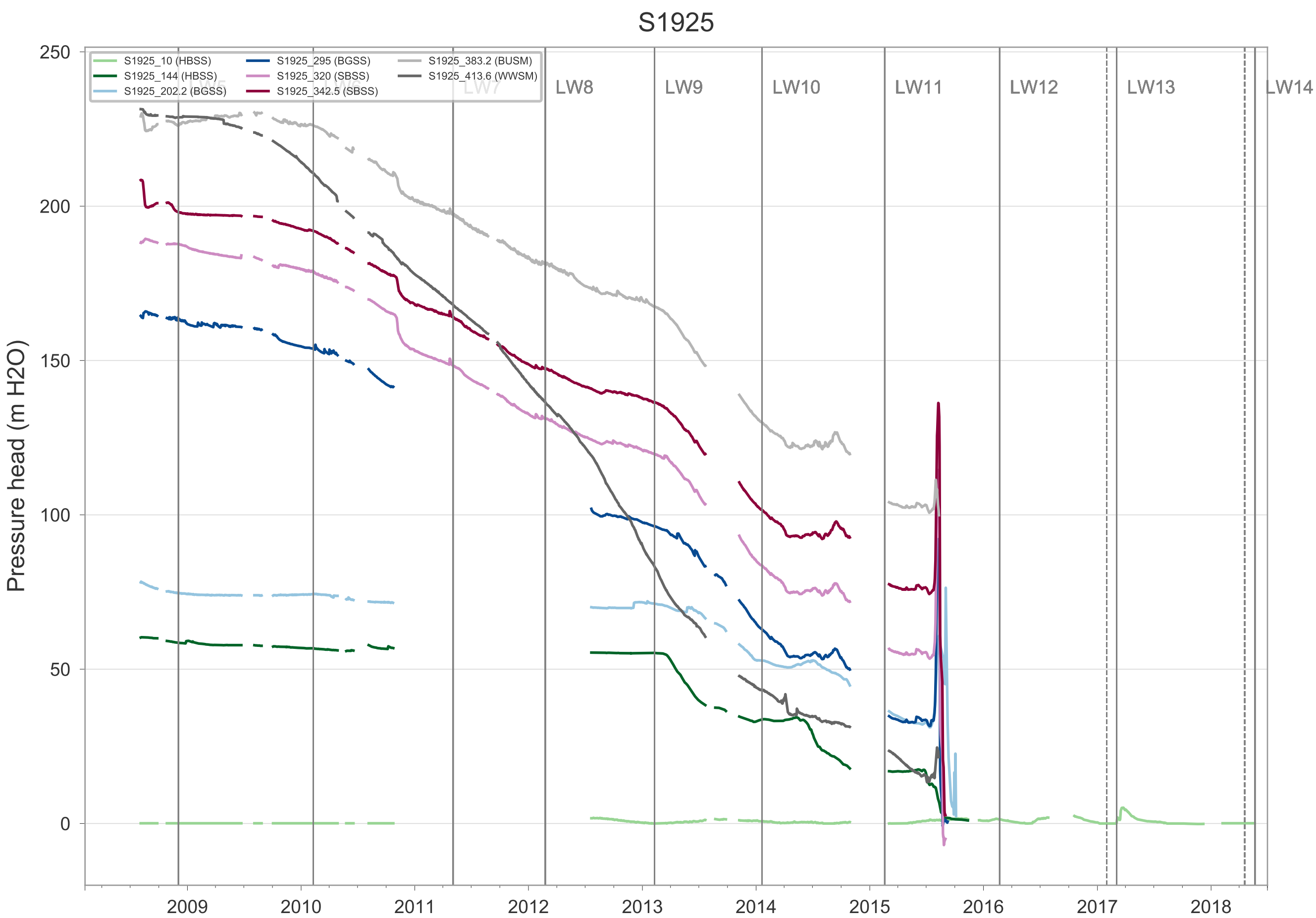

S1911
Piezometric head (m RL)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
S1911_10 (HBSS)
S1911_68.5 (HBSS)
S1911_135 (HBSS)
S1911_187 (BGSS)
S1911_229.5 (BGSS)
S1911_277 (BGSS)
S1911_301 (SBSS)
S1911_318 (SBSS)
S1911_331.5 (WBCS)
S1911_349 (CCSS)
S1911_359 (CCSS)
S1911_387.3 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
400
350
300
250
200
150
100
50
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


S1911
Pressure head (m H2O)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
S1911_10 (HBSS)
S1911_68.5 (HBSS)
S1911_135 (HBSS)
S1911_187 (BGSS)
S1911_229.5 (BGSS)
S1911_277 (BGSS)
S1911_301 (SBSS)
S1911_318 (SBSS)
S1911_331.5 (WBCS)
S1911_349 (CCSS)
S1911_359 (CCSS)
S1911_387.3 (WWSM)
250
200
150
100
50
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

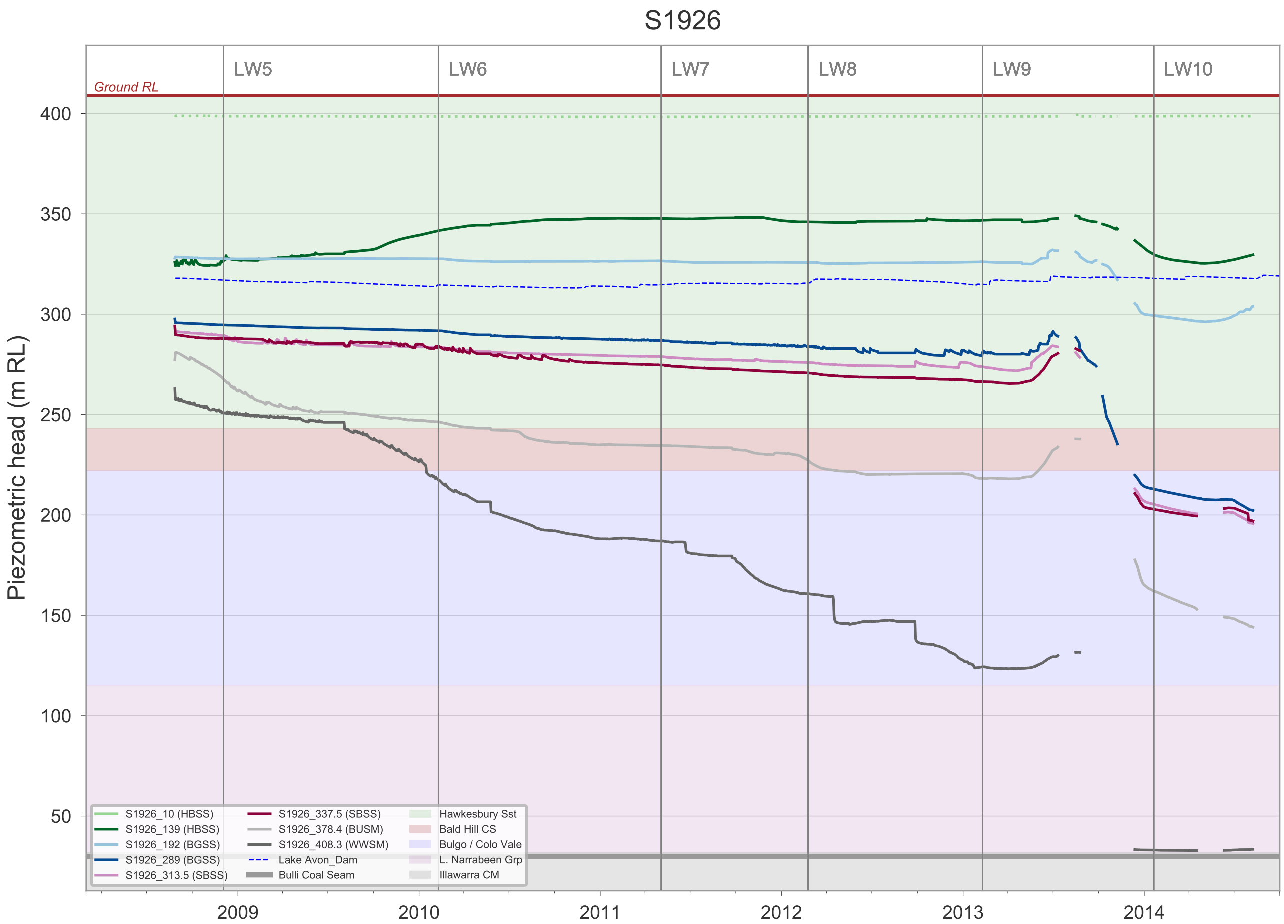

S1914
S1914_147 (HBSS)
S1914_187 (BGSS)
S1914_266 (BGSS)
S1914_300 (SBSS)
S1914_330 (SBSS)
S1914_371.6 (BUSM)
S1914_400.4 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
Piezometric head (m RL)
400
350
300
250
200
150
100
50
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

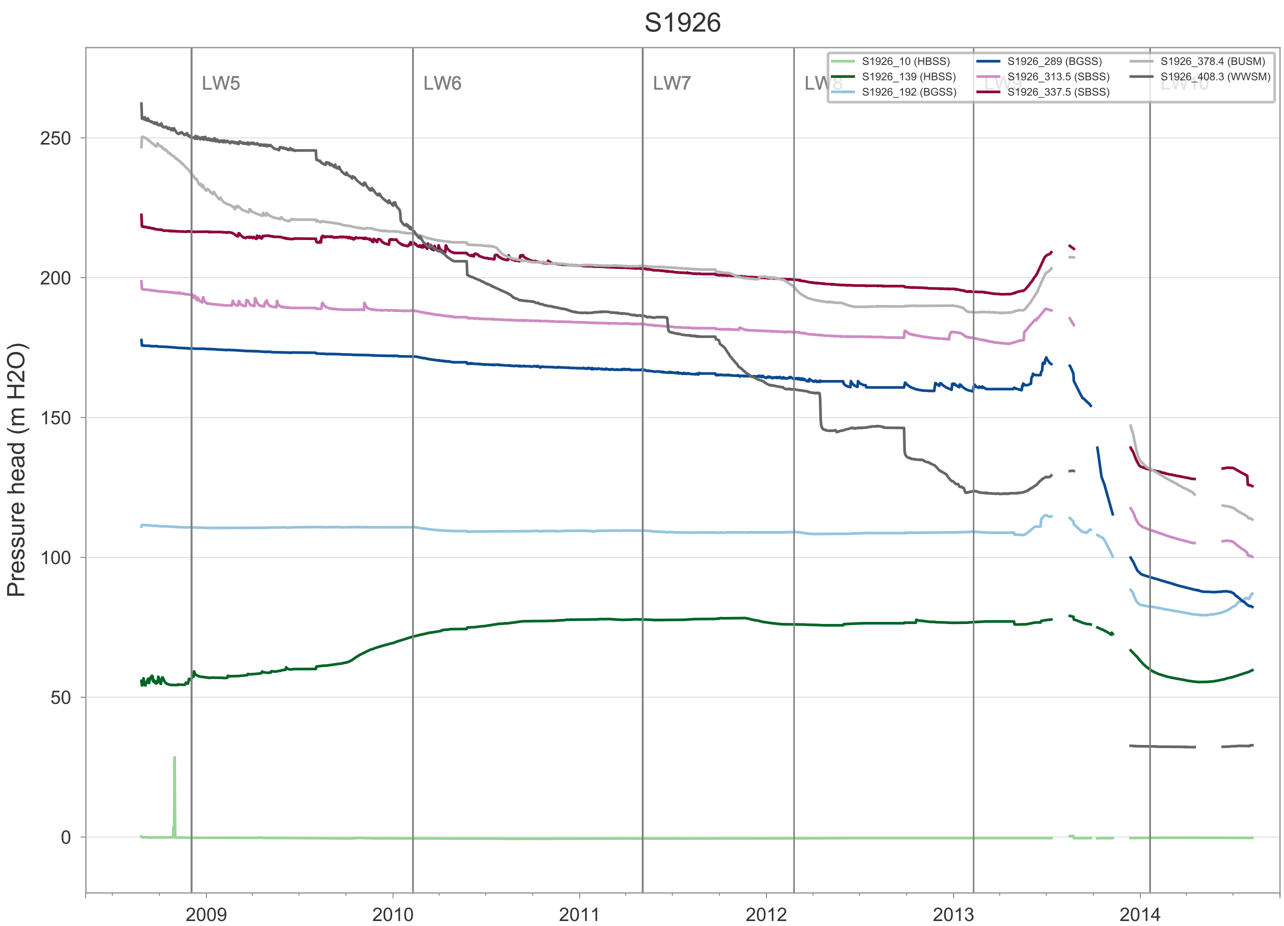

S1914
S1914_147 (HBSS)
S1914_187 (BGSS)
S1914_266 (BGSS)
S1914_300 (SBSS)
S1914_330 (SBSS)
S1914_371.6 (BUSM)
S1914_400.4 (WWSM)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
Pressure head (m H2O)
200
150
100
50
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


S1925
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Ground RL
Piezometric head (m RL)
400
350
300
250
200
150
100
50
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
S1925_10 (HBSS)
S1925_144 (HBSS)
S1925_202.2 (BGSS)
S1925_295 (BGSS)
S1925_320 (SBSS)
S1925_342.5 (SBSS)
S1925_383.2 (BUSM)
S1925_413.6 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp

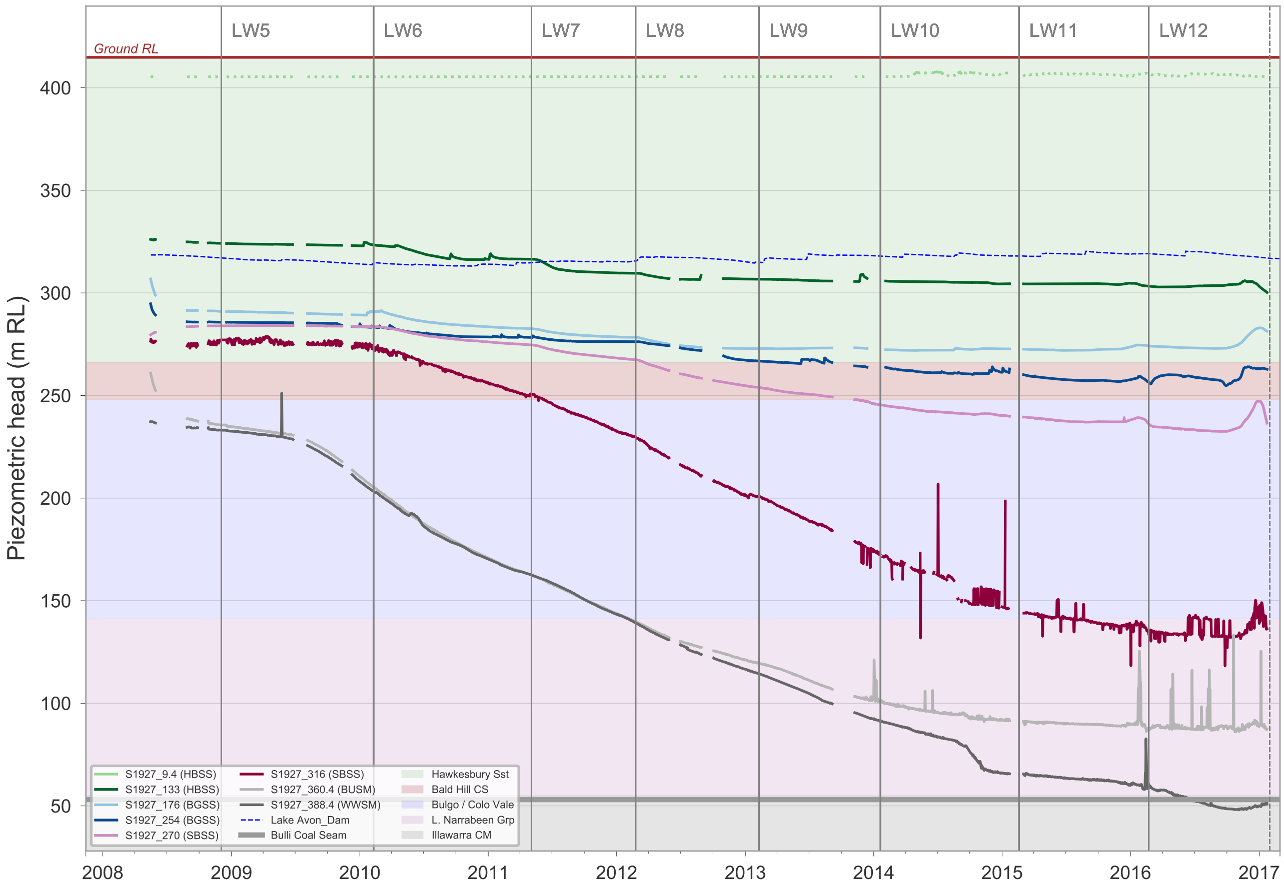

S1925
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Pressure head (m H2O)
250
200
150
100
50
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
S1925_10 (HBSS)
S1925_144 (HBSS)
S1925_202.2 (BGSS)
S1925_295 (BGSS)
S1925_320 (SBSS)
S1925_342.5 (SBSS)
S1925_383.2 (BUSM)
S1925_413.6 (WWSM)

Groundwater hydrographs

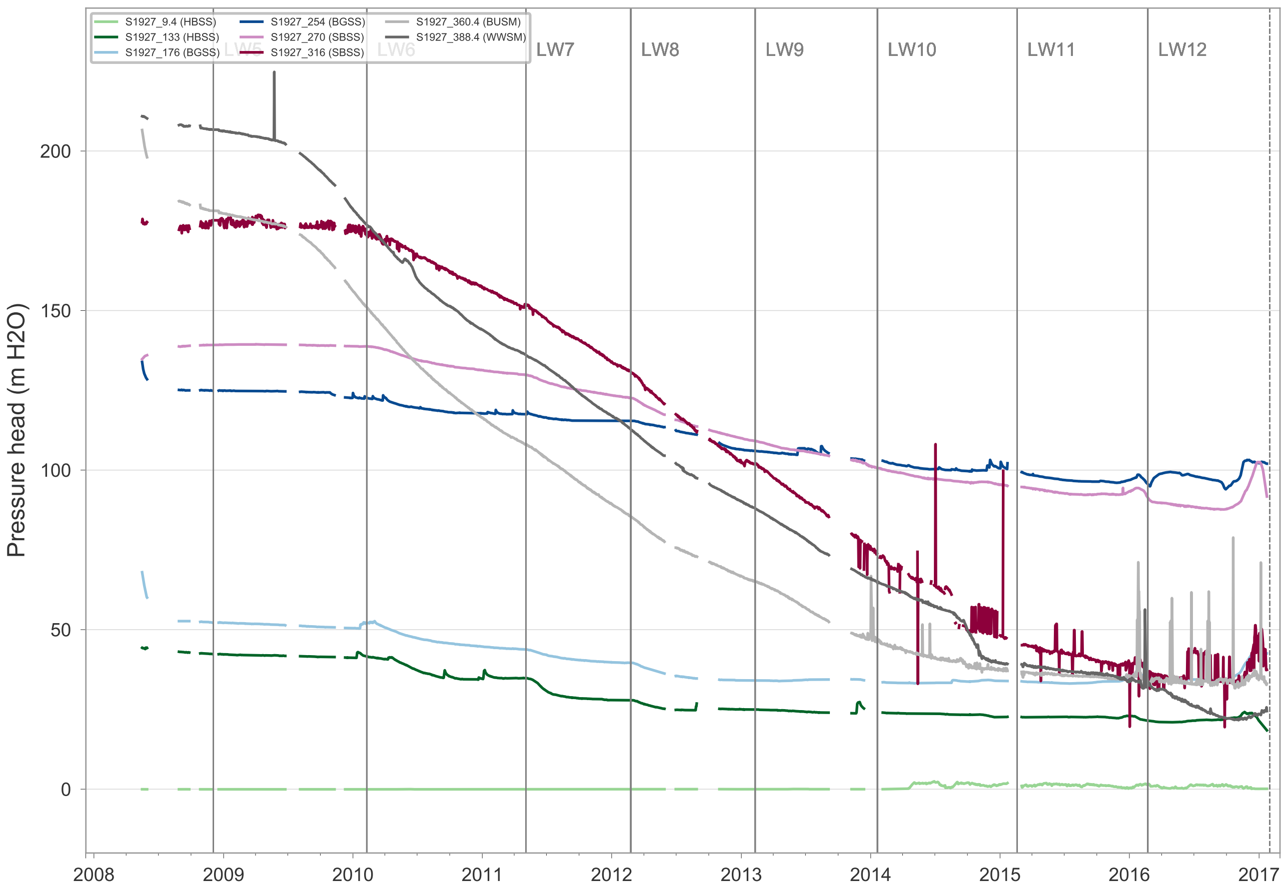


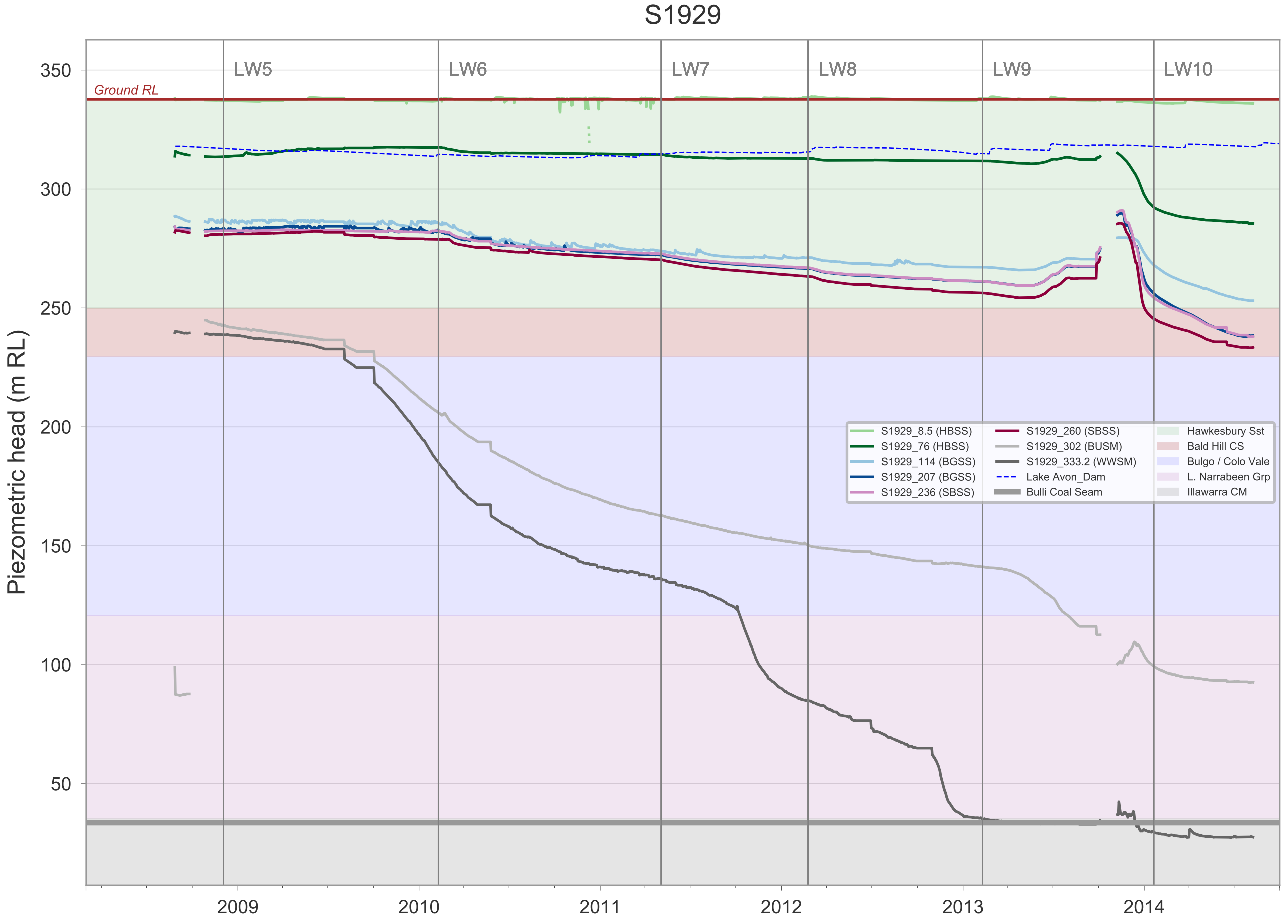


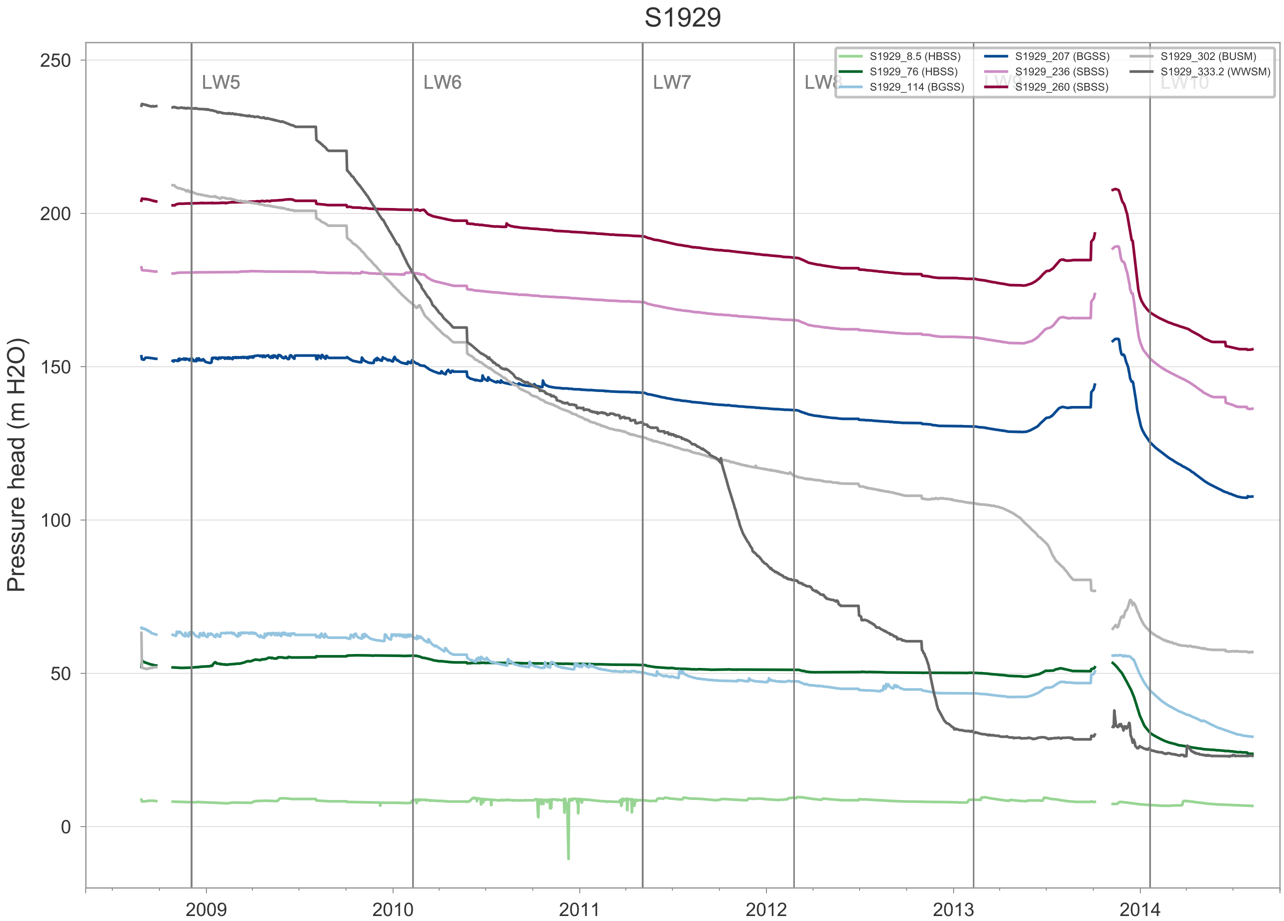
S1927


LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
Ground RL
Piezometric head (m RL)
400
350
300
250
200
150
100
50
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
S1927_9.4 (HBSS)
S1927_133 (HBSS)
S1927_176 (BGSS)
S1927_254 (BGSS)
S1927_270 (SBSS)
S1927_316 (SBSS)
S1927_360.4 (BUSM)
S1927_388.4 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM

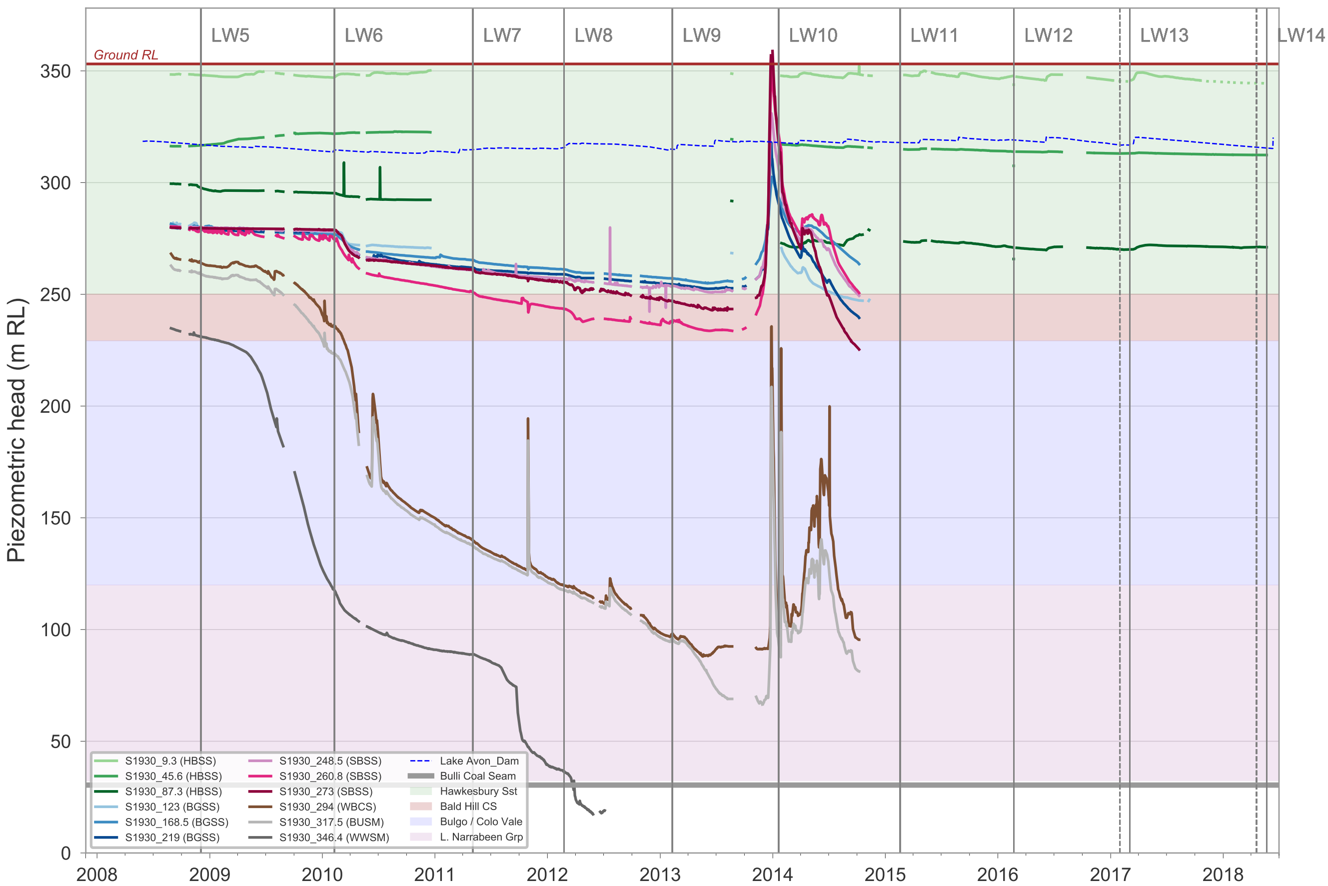
S1927


S1927_9.4 (HBSS)
S1927_133 (HBSS)
S1927_176 (BGSS)
S1927_254 (BGSS)
S1927_270 (SBSS)
S1927_316 (SBSS)
S1927_360.4 (BUSM)
S1927_388.4 (WWSM)
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
Pressure head (m H2O)
200
150
100
50
0
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

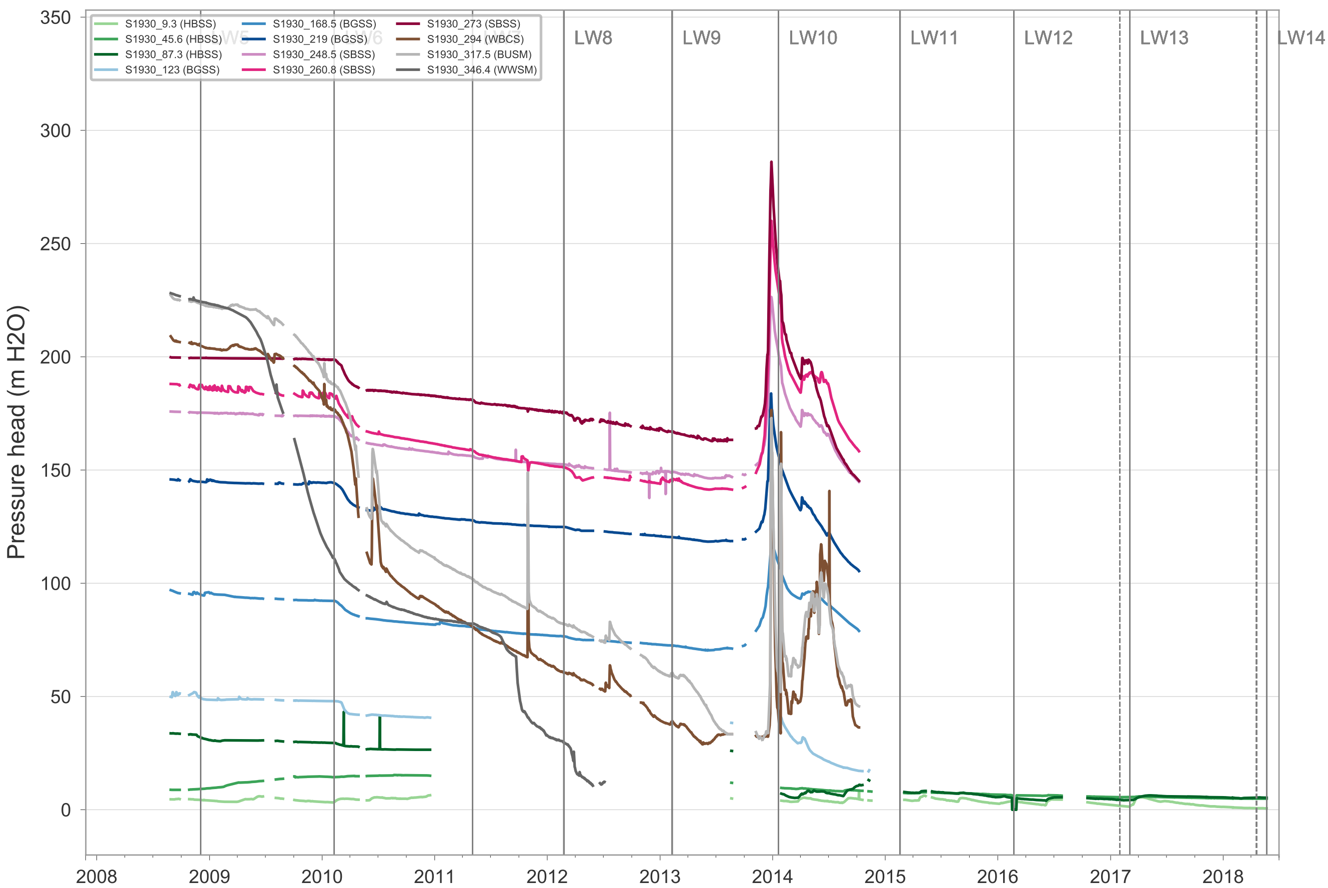

S1929
Piezometric head (m RL)
Ground RL
LW5
LW6
LW7
LW8
LW9
LW10
350
300
250
200
150
100
50
2009
2010
2011
2012
2013
2014
S1929_8.5 (HBSS)
S1929_76 (HBSS)
S1929_114 (BGSS)
S1929_207 (BGSS)
S1929_236 (SBSS)
S1929_260 (SBSS)
S1929_302 (BUSM)
S1929_333.2 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM


S1929
Pressure head (m H2O)
LW5
LW6
LW7
LW8
LW9
LW10
250
200
150
100
50
0
2009
2010
2011
2012
2013
2014
S1929_8.5 (HBSS)
S1929_76 (HBSS)
S1929_114 (BGSS)
S1929_207 (BGSS)
S1929_236 (SBSS)
S1929_260 (SBSS)
S1929_302 (BUSM)
S1929_333.2 (WWSM)

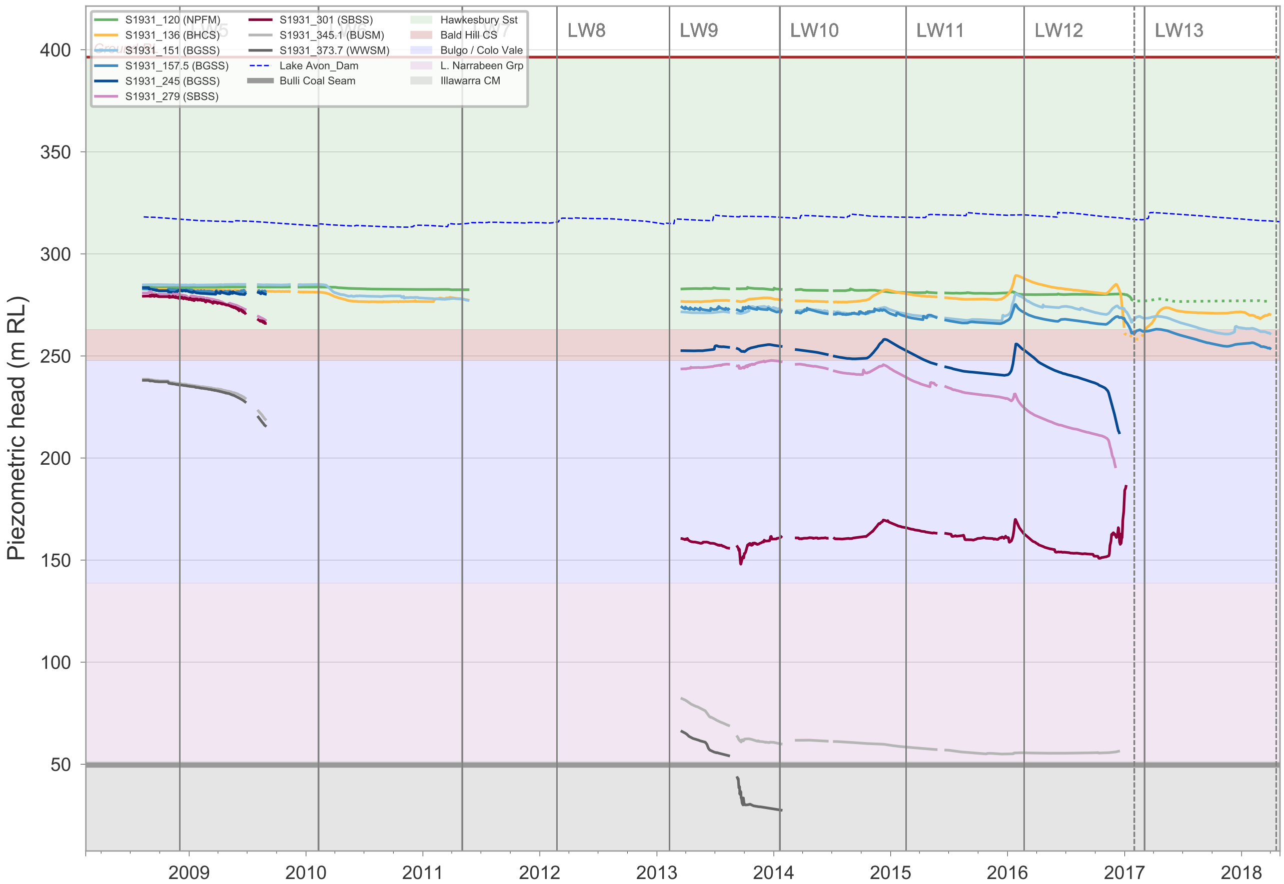
S1930


Ground RL
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Piezometric head (m RL)
S1930_9.3 (HBSS)
S1930_45.6 (HBSS)
S1930_87.3 (HBSS)
S1930_123 (BGSS)
S1930_168.5 (BGSS)
S1930_219 (BGSS)
S1930_248.5 (SBSS)
S1930_260.8 (SBSS)
S1930_273 (SBSS)
S1930_294 (WBCS)
S1930_317.5 (BUSM)
S1930_346.4 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
0
50
100
150
200
250
300
350
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

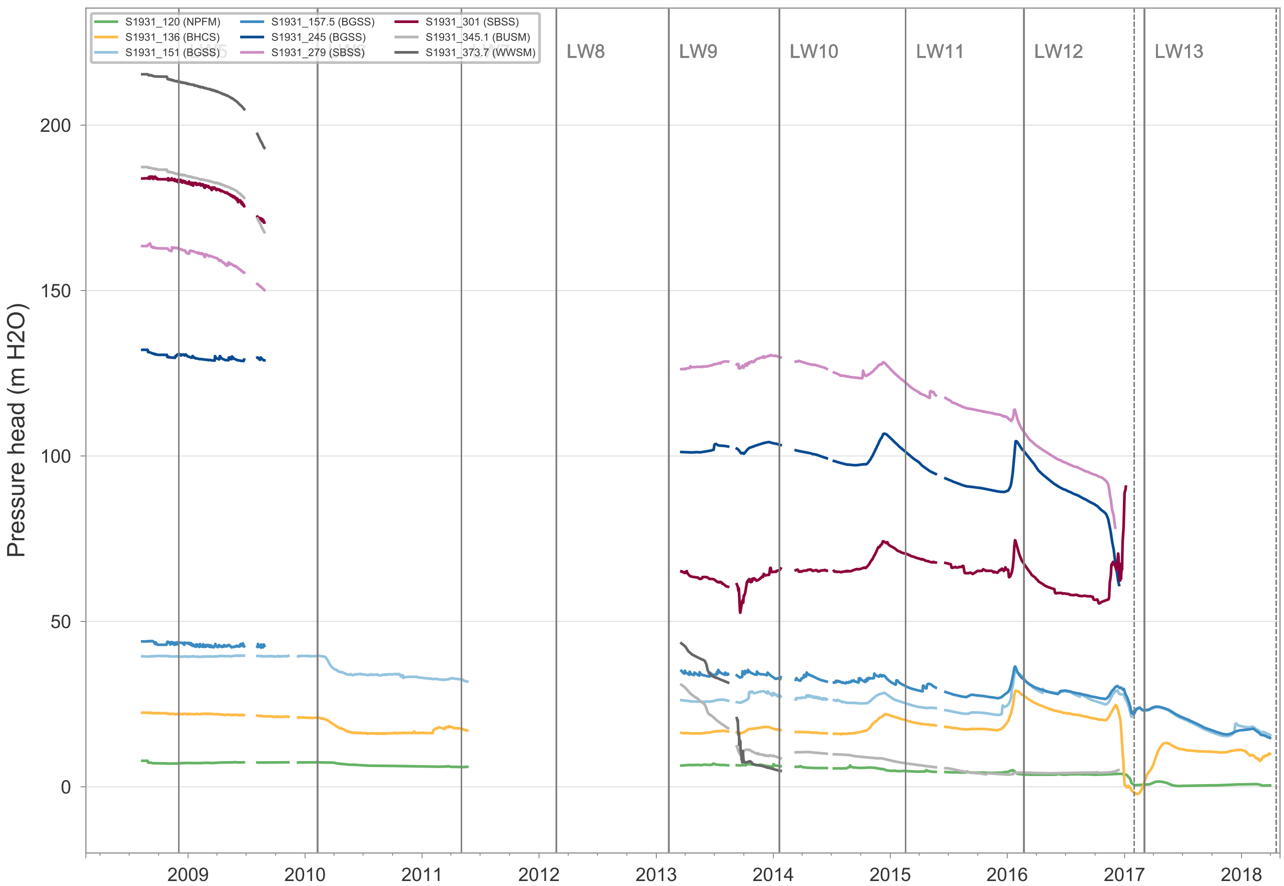
S1930

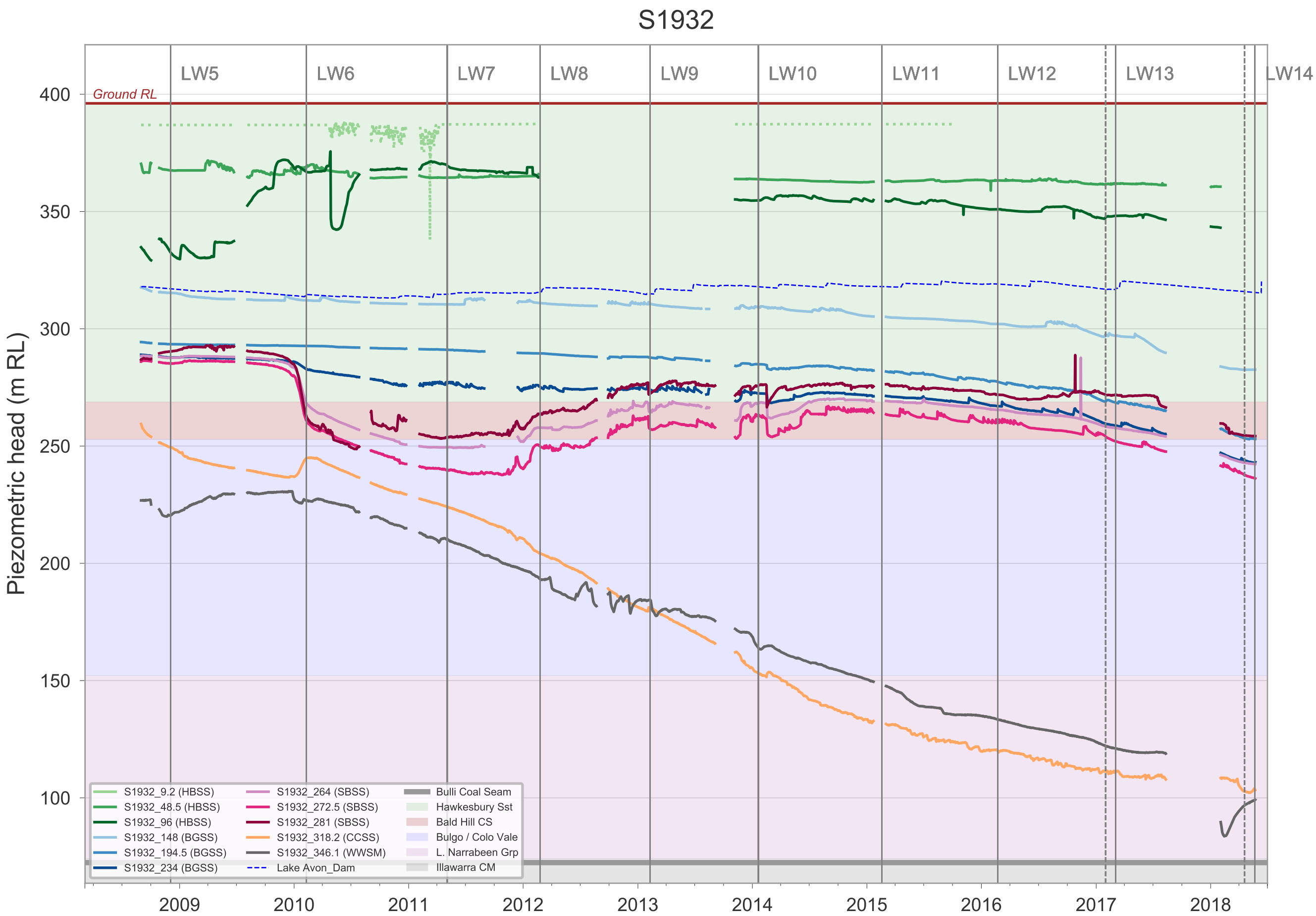

S1930_9.3 (HBSS)
S1930_45.6 (HBSS)
S1930_87.3 (HBSS)
S1930_123 (BGSS)
S1930_168.5 (BGSS)
S1930_219 (BGSS)
S1930_248.5 (SBSS)
S1930_260.8 (SBSS)
S1930_273 (SBSS)
S1930_294 (WBCS)
S1930_317.5 (BUSM)
S1930_346.4 (WWSM)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Pressure head (m H2O)
0
50
100
150
200
250
300
350
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

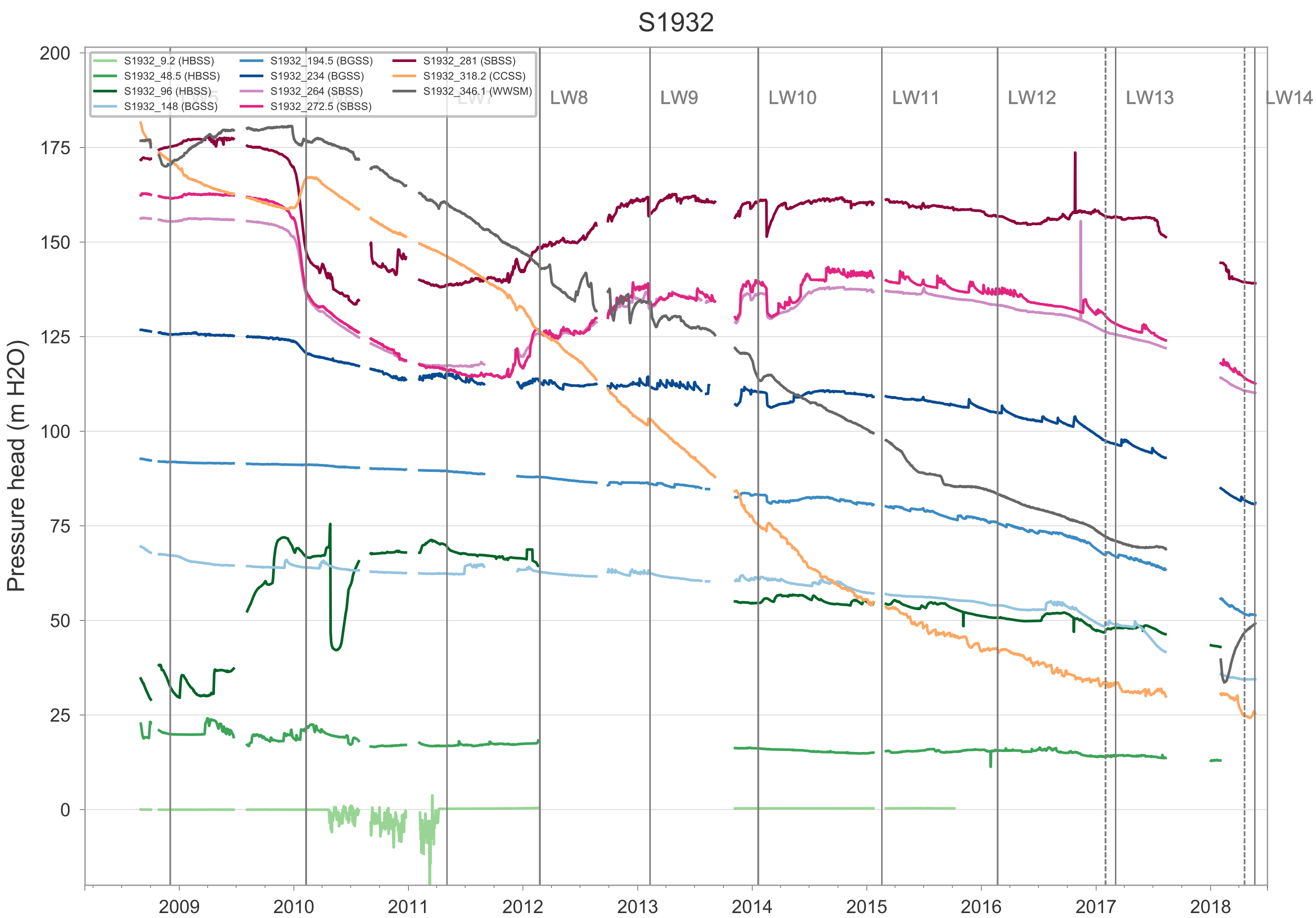
S1931


S1931_120 (NPFM)
S1931_136 (BHCS)
S1931_151 (BGSS)
S1931_157.5 (BGSS)
S1931_245 (BGSS)
S1931_279 (SBSS)
S1931_301 (SBSS)
S1931_345.1 (BUSM)
S1931_373.7 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW8
LW9
LW10
LW11
LW12
LW13
Piezometric head (m RL)
400
350
300
250
200
150
100
50
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

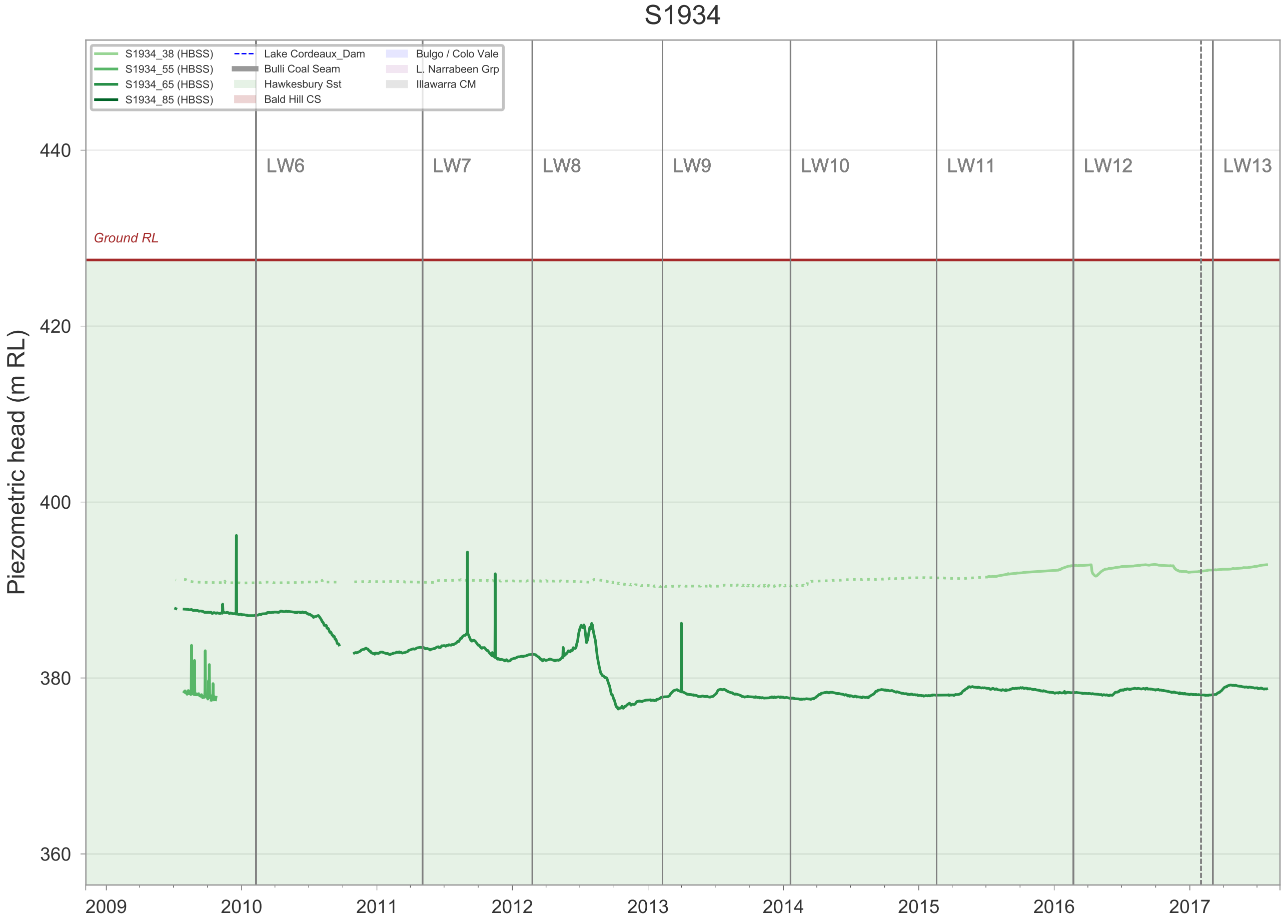
S1931

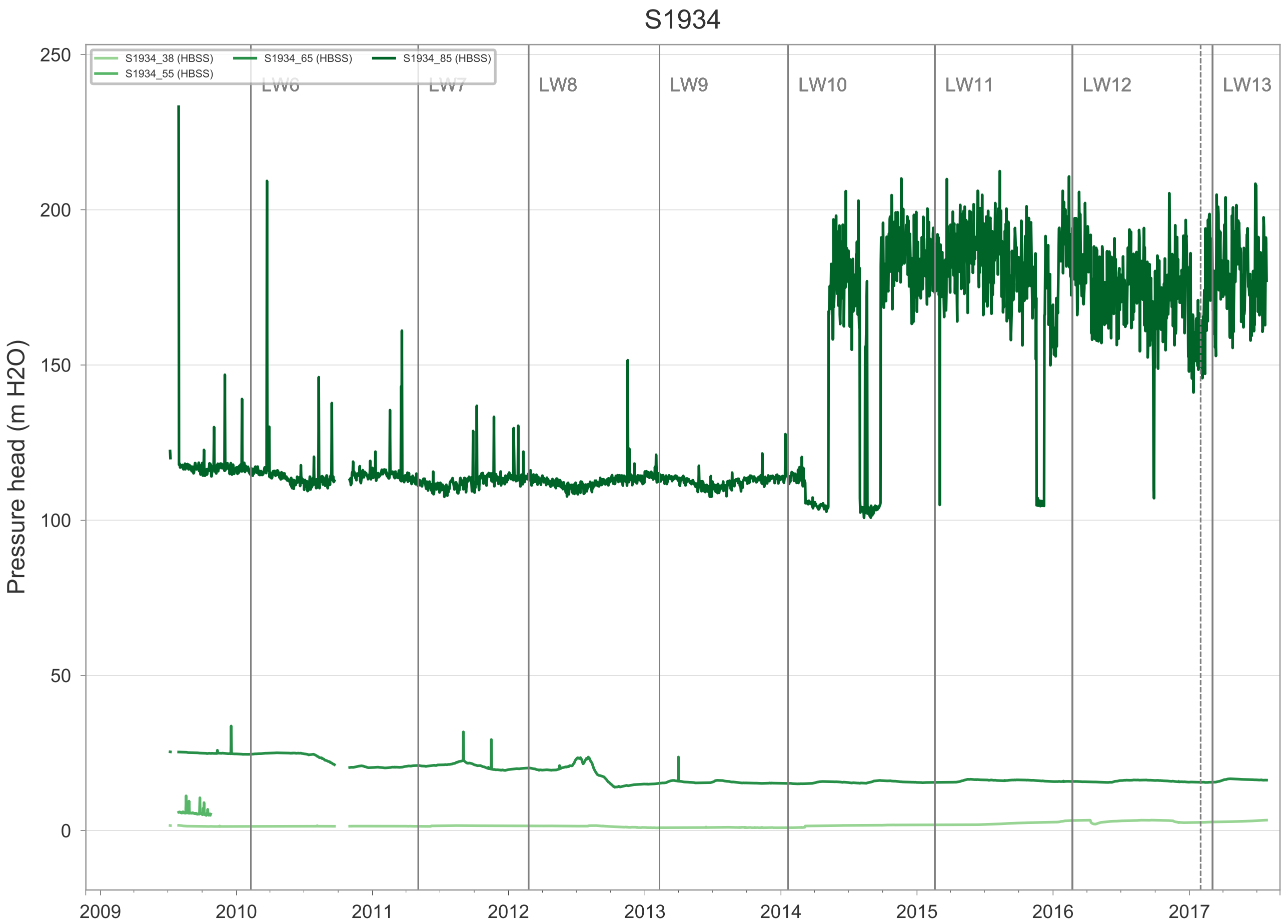

S1931_120 (NPFM)
S1931_136 (BHCS)
S1931_151 (BGSS)
S1931_157.5 (BGSS)
S1931_245 (BGSS)
S1931_279 (SBSS)
S1931_301 (SBSS)
S1931_345.1 (BUSM)
S1931_373.7 (WWSM)
LW8
LW9
LW10
LW11
LW12
LW13
Pressure head (m H2O)
200
150
100
50
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018


S1932
Piezometric head (m RL)
Ground RL
LW5
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
400
350
300
250
200
150
100
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
S1932_9.2 (HBSS)
S1932_48.5 (HBSS)
S1932_96 (HBSS)
S1932_148 (BGSS)
S1932_194.5 (BGSS)
S1932_234 (BGSS)
S1932_264 (SBSS)
S1932_272.5 (SBSS)
S1932_281 (SBSS)
S1932_318.2 (CCSS)
S1932_346.1 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM

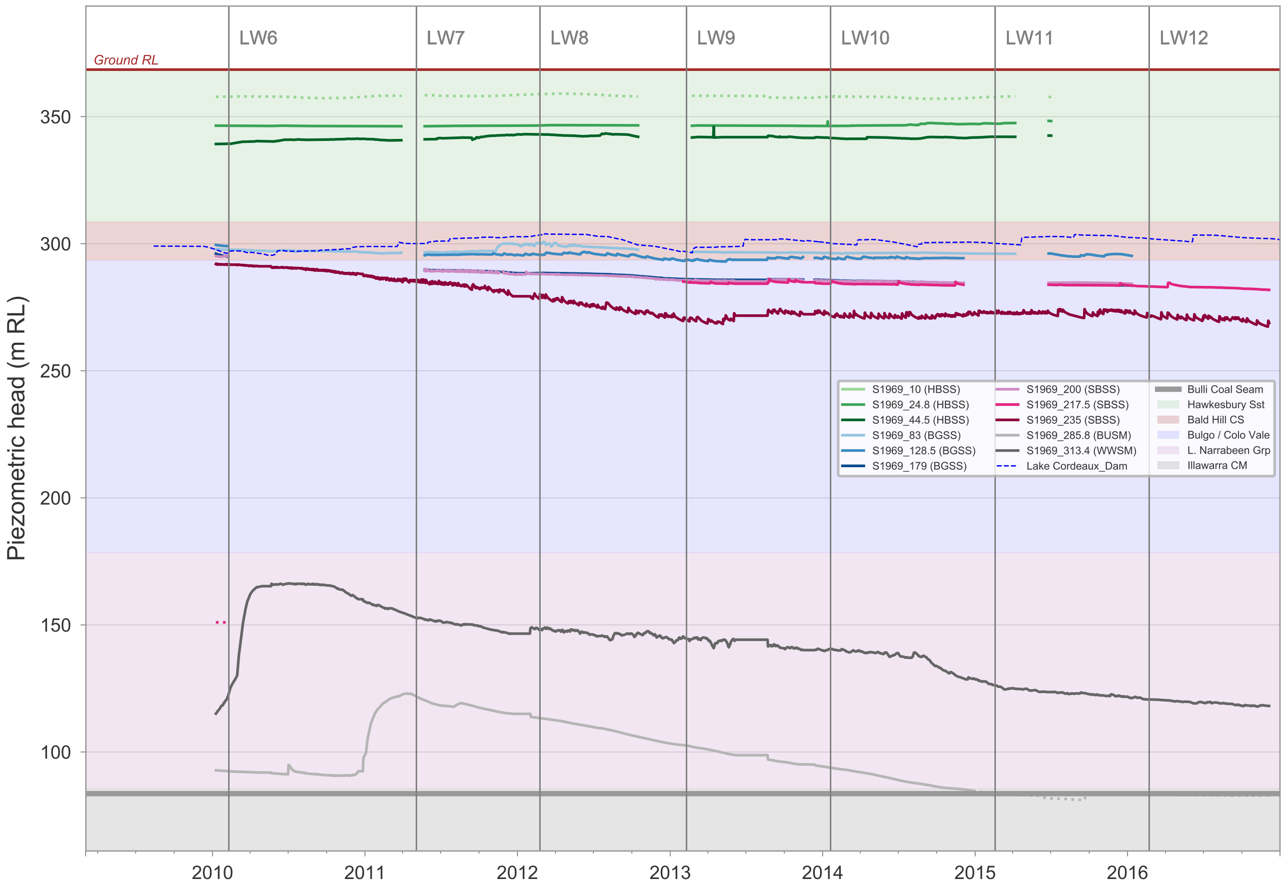

S1932
Pressure head (m H2O)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
200
175
150
125
100
75
50
25
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
S1932_9.2 (HBSS)
S1932_48.5 (HBSS)
S1932_96 (HBSS)
S1932_148 (BGSS)
S1932_194.5 (BGSS)
S1932_234 (BGSS)
S1932_264 (SBSS)
S1932_272.5 (SBSS)
S1932_281 (SBSS)
S1932_318.2 (CCSS)
S1932_346.1 (WWSM)

Groundwater hydrographs

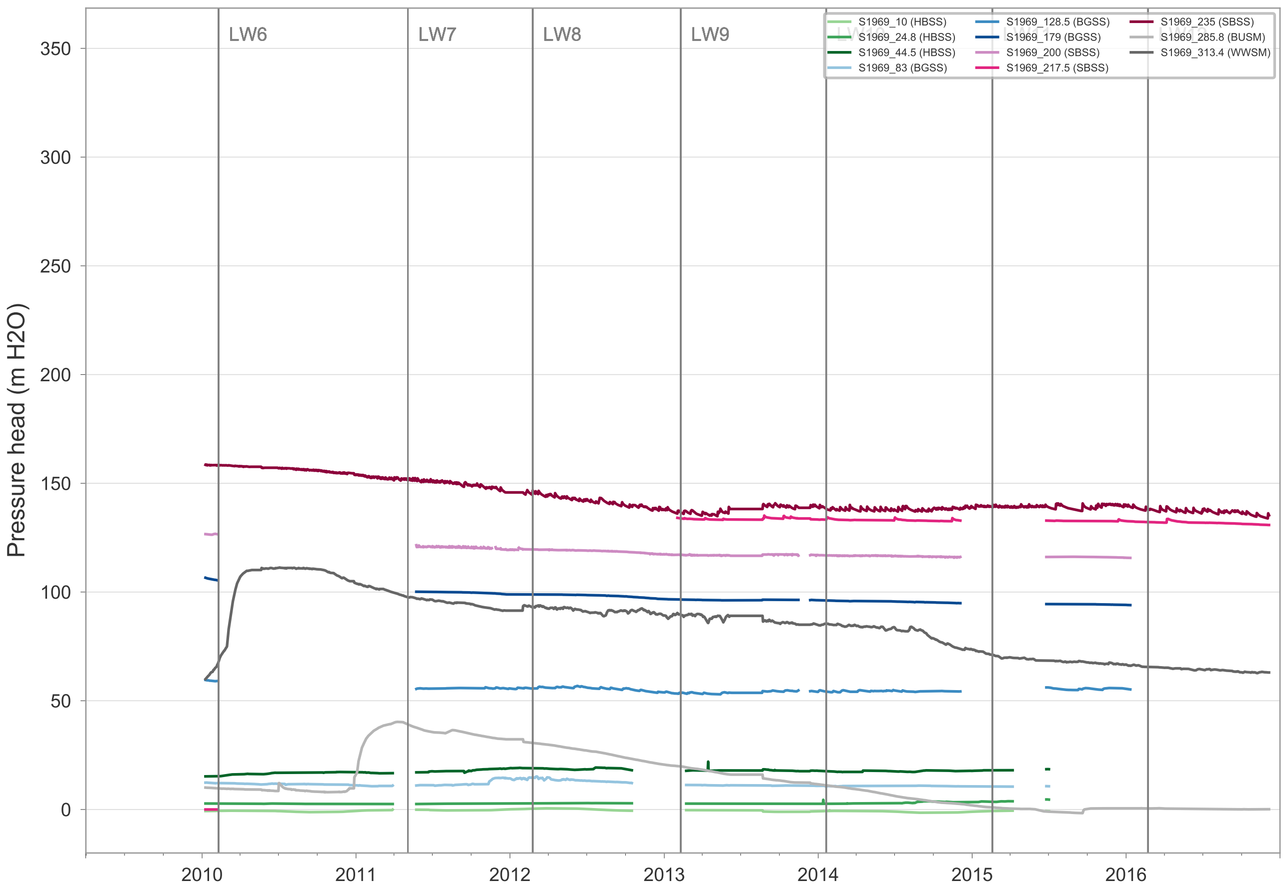




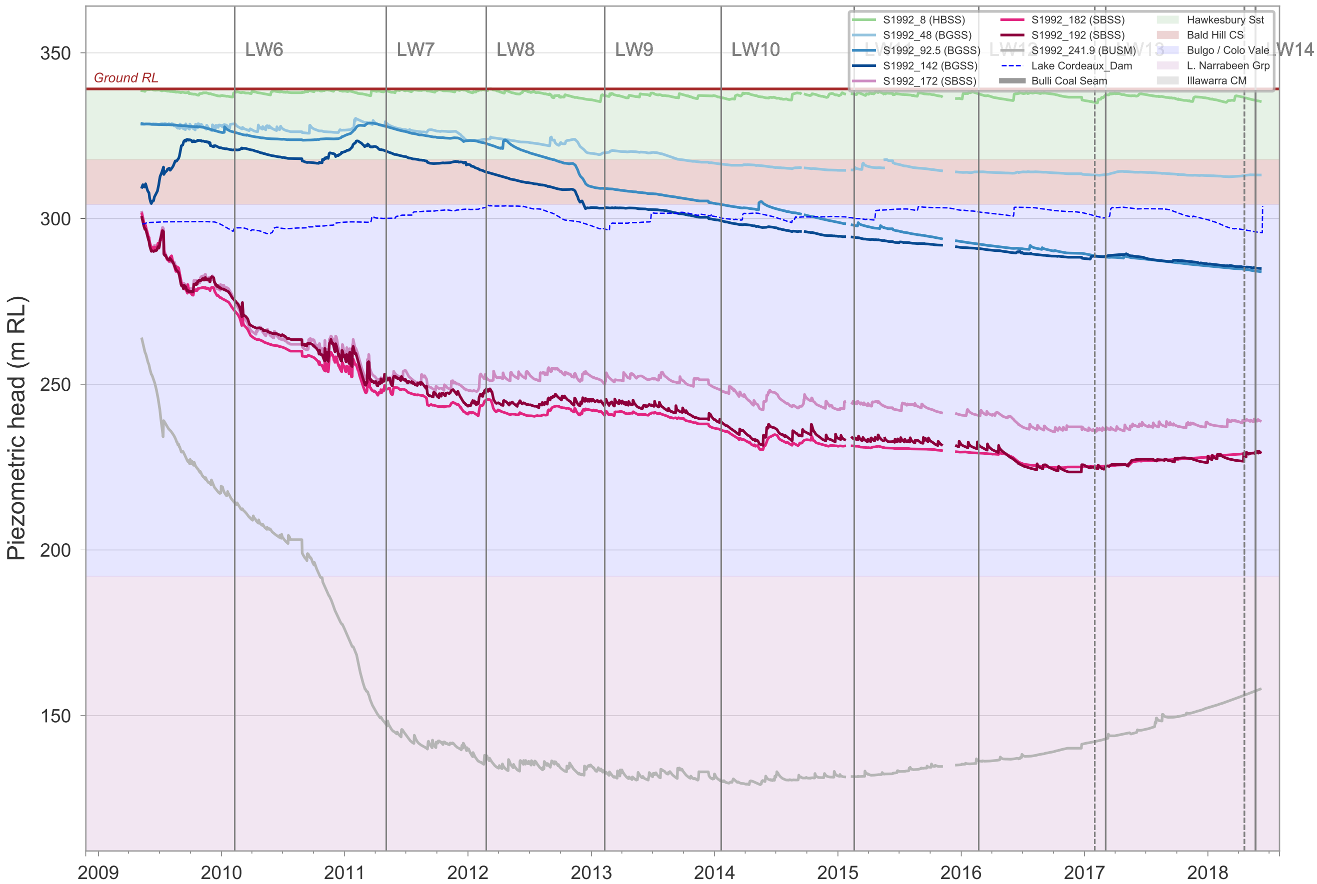
S1969


LW6
LW7
LW8
LW9
LW10
LW11
LW12
Ground RL
Piezometric head (m RL)
350
300
250
200
150
100
2010
2011
2012
2013
2014
2015
2016
S1969_10 (HBSS)
S1969_24.8 (HBSS)
S1969_44.5 (HBSS)
S1969_83 (BGSS)
S1969_128.5 (BGSS)
S1969_179 (BGSS)
S1969_200 (SBSS)
S1969_217.5 (SBSS)
S1969_235 (SBSS)
S1969_285.8 (BUSM)
S1969_313.4 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM

S1969

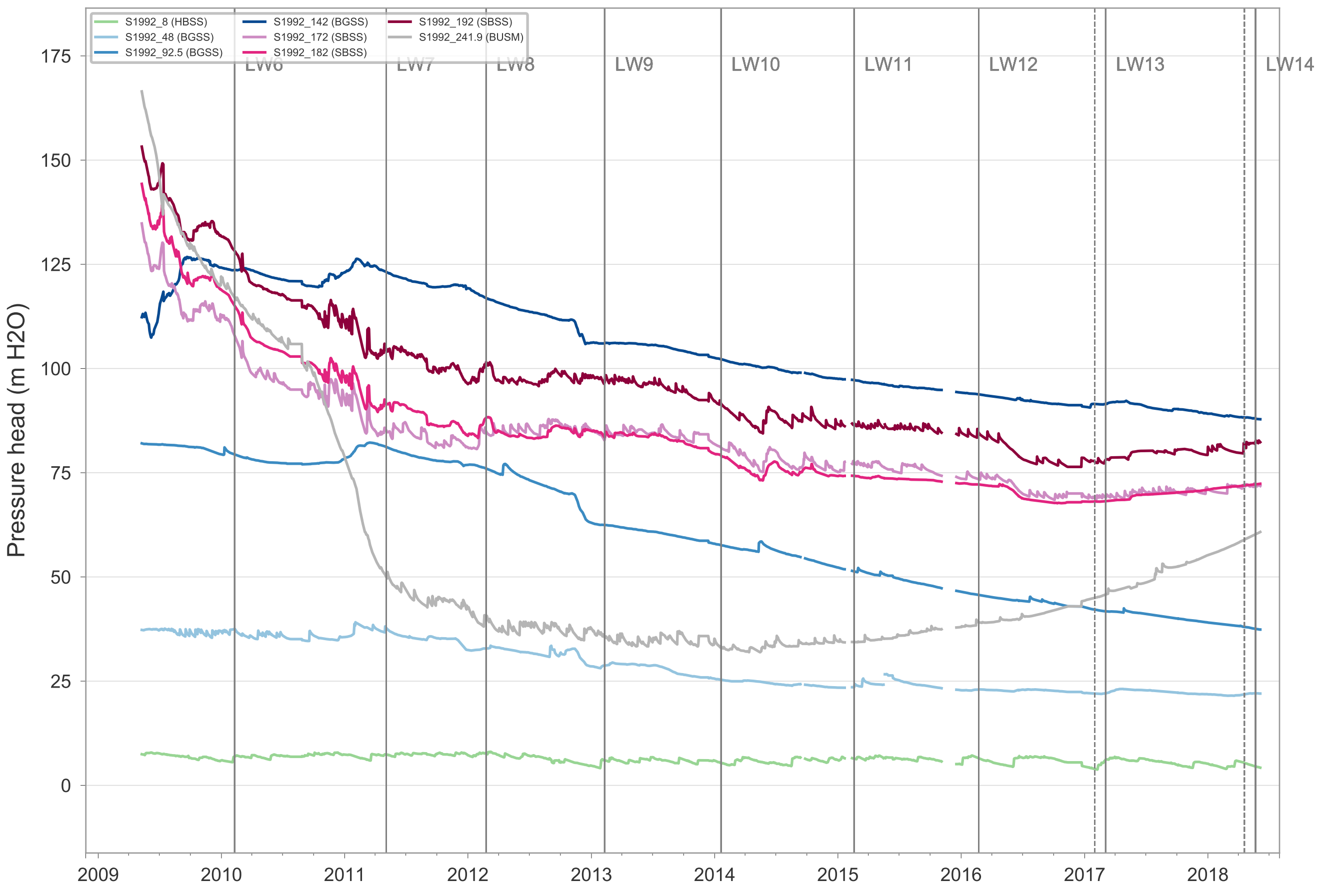

LW6
LW7
LW8
LW9
Pressure head (m H2O)
350
300
250
200
150
100
50
0
2010
2011
2012
2013
2014
2015
2016
S1969_10 (HBSS)
S1969_24.8 (HBSS)
S1969_44.5 (HBSS)
S1969_83 (BGSS)
S1969_128.5 (BGSS)
S1969_179 (BGSS)
S1969_200 (SBSS)
S1969_217.5 (SBSS)
S1969_235 (SBSS)
S1969_285.8 (BUSM)
S1969_313.4 (WWSM)

S1992



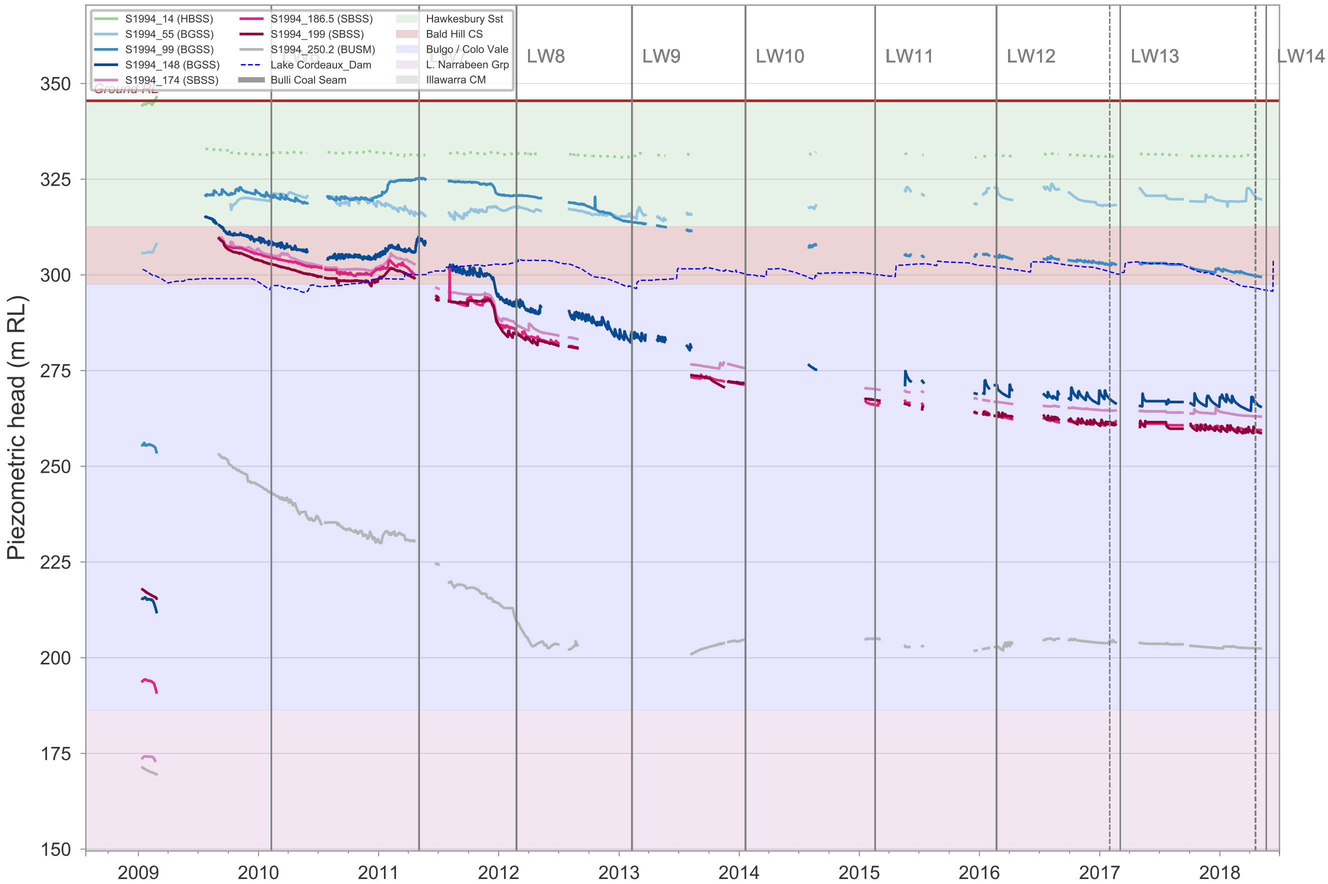
Piezometric head (m RL)
350
300
250
200
150
Ground RL
LW6
LW7
LW8
LW9
LW10
LW14
S1992_8 (HBSS)
S1992_48 (BGSS)
S1992_92.5 (BGSS)
S1992_142 (BGSS)
S1992_172 (SBSS)
S1992_182 (SBSS)
S1992_192 (SBSS)
S1992_241.9 (BUSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

S1992

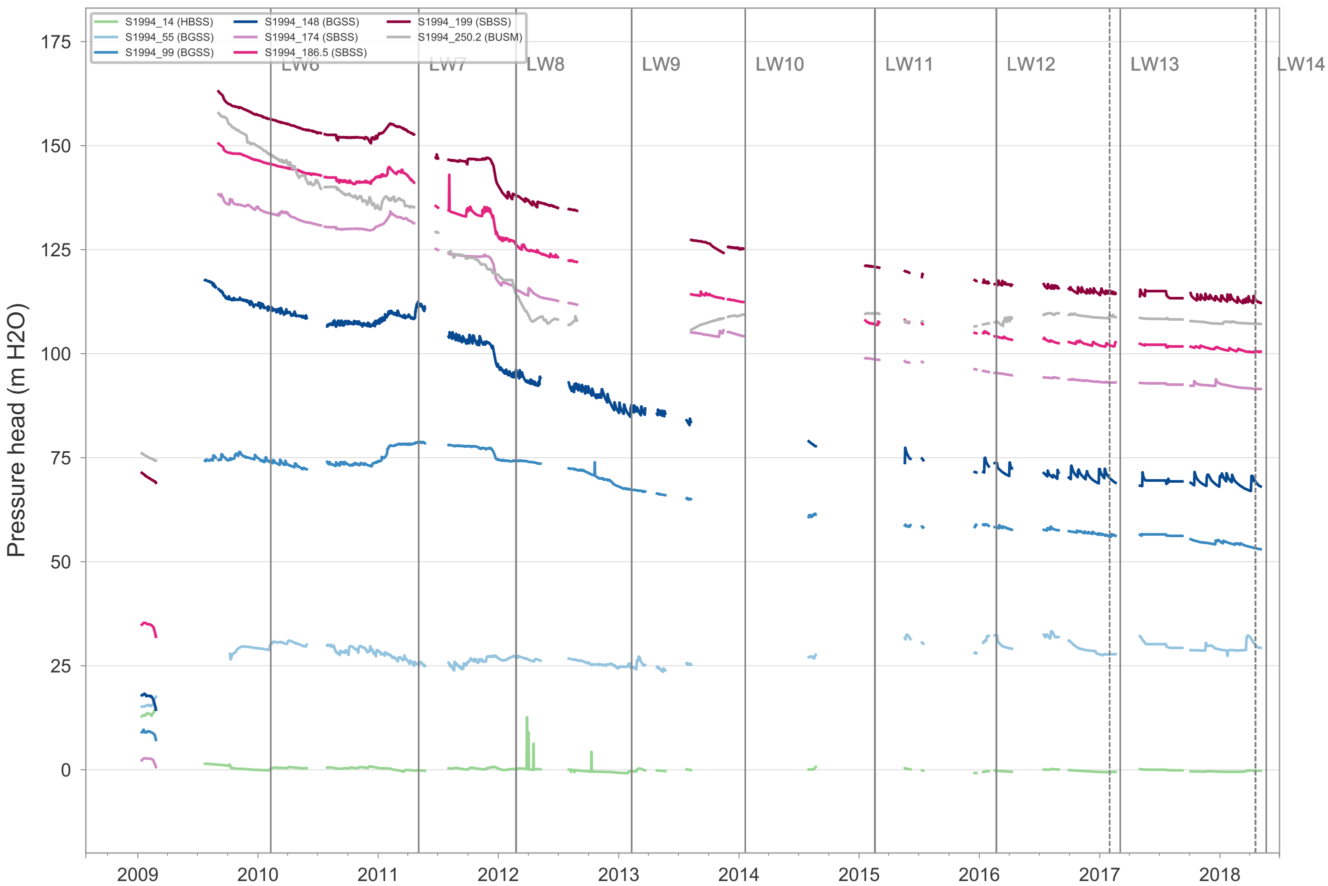


Pressure head (m H2O)
175
150
125
100
75
50
25
0
S1992_8 (HBSS)
S1992_48 (BGSS)
S1992_92.5 (BGSS)
S1992_142 (BGSS)
S1992_172 (SBSS)
S1992_182 (SBSS)
S1992_192 (SBSS)
S1992_241.9 (BUSM)
LW9
LW10
LW11
LW12
LW13
LW14
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

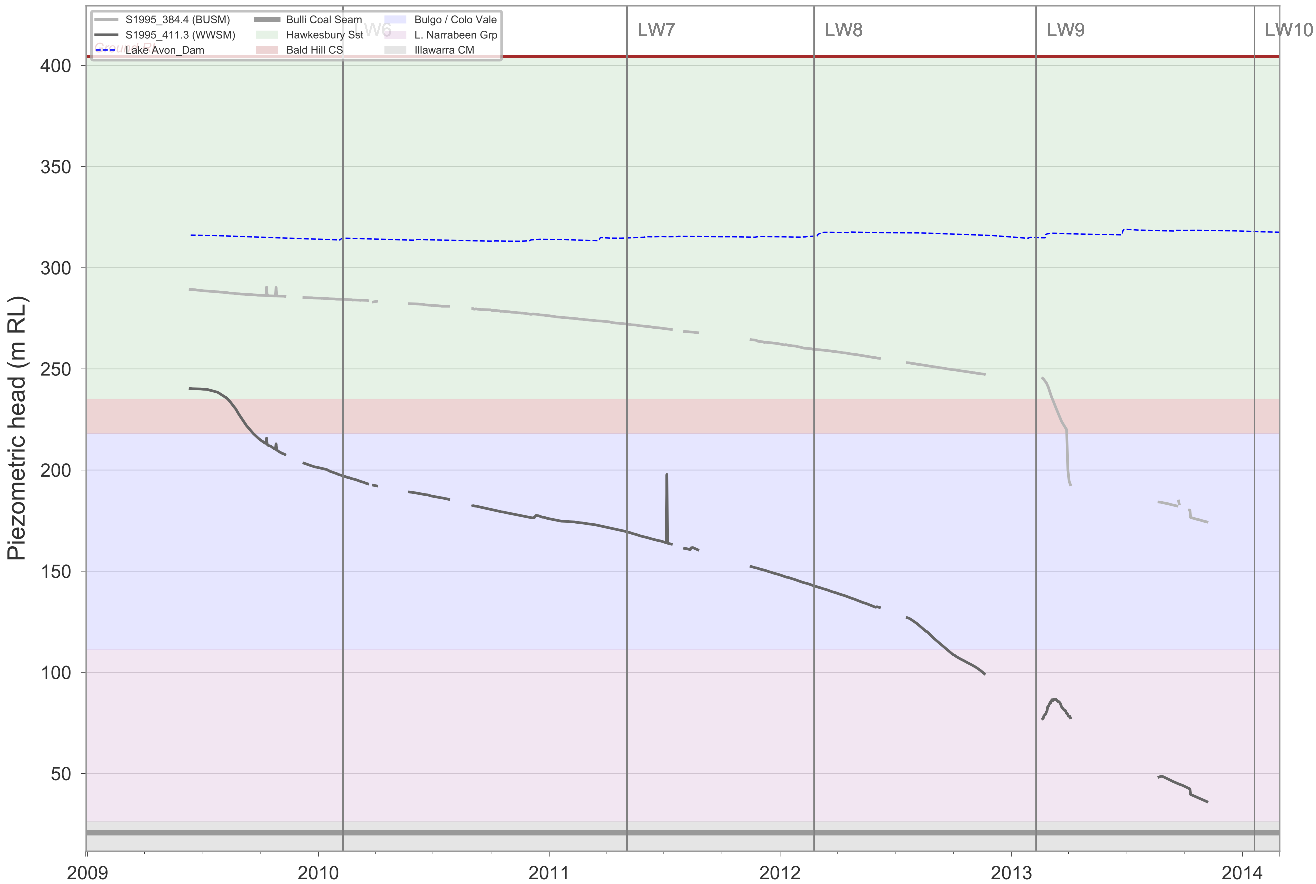
S1994


S1994_14 (HBSS)
S1994_55 (BGSS)
S1994_99 (BGSS)
S1994_148 (BGSS)
S1994_174 (SBSS)
S1994_186.5 (SBSS)
S1994_199 (SBSS)
S1994_250.2 (BUSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Ground RL
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Piezometric head (m RL)
350
325
300
275
250
225
200
175
150
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

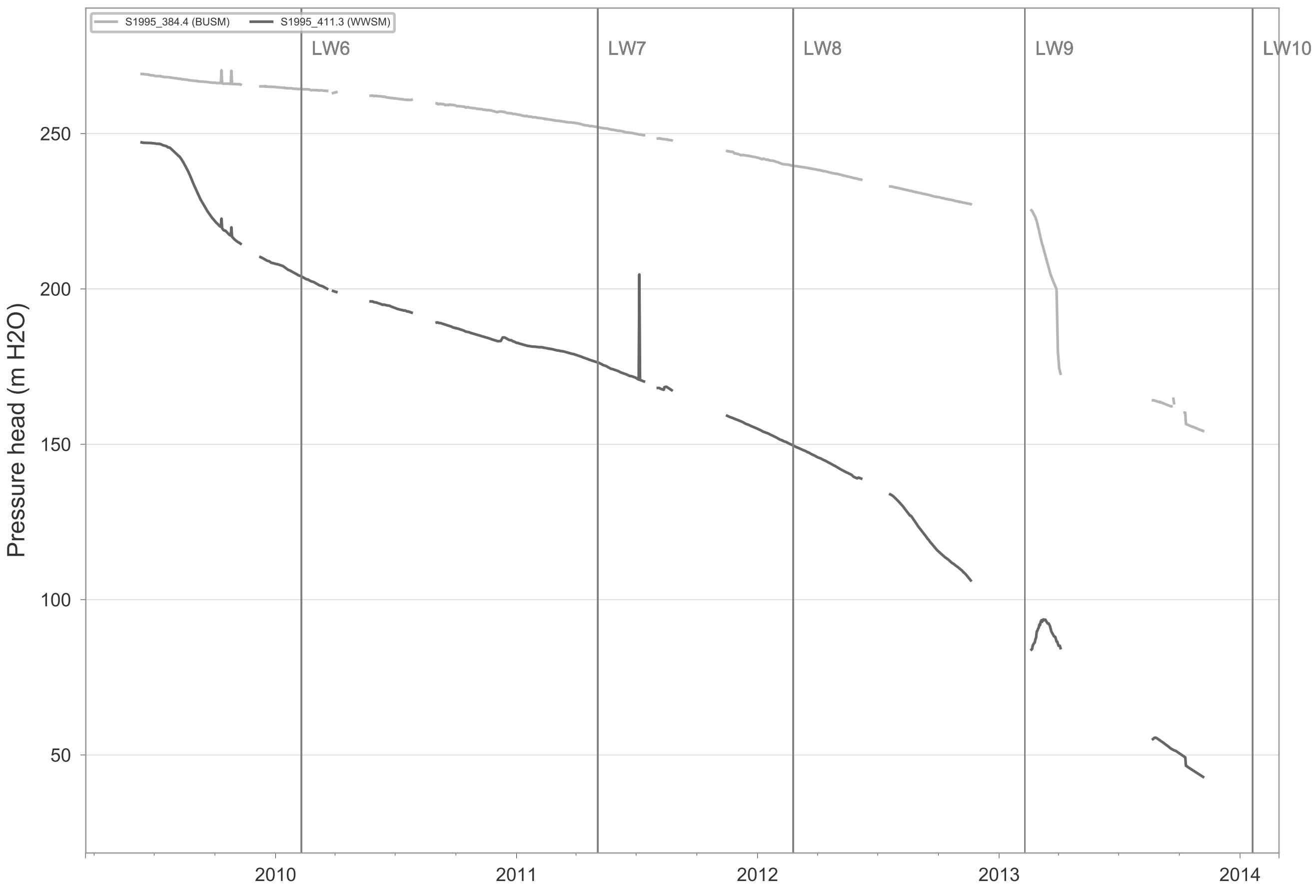
S1994


S1994_14 (HBSS)
S1994_55 (BGSS)
S1994_99 (BGSS)
S1994_148 (BGSS)
S1994_174 (SBSS)
S1994_186.5 (SBSS)
S1994_199 (SBSS)
S1994_250.2 (BUSM)
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Pressure head (m H2O)
175
150
125
100
75
50
25
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018

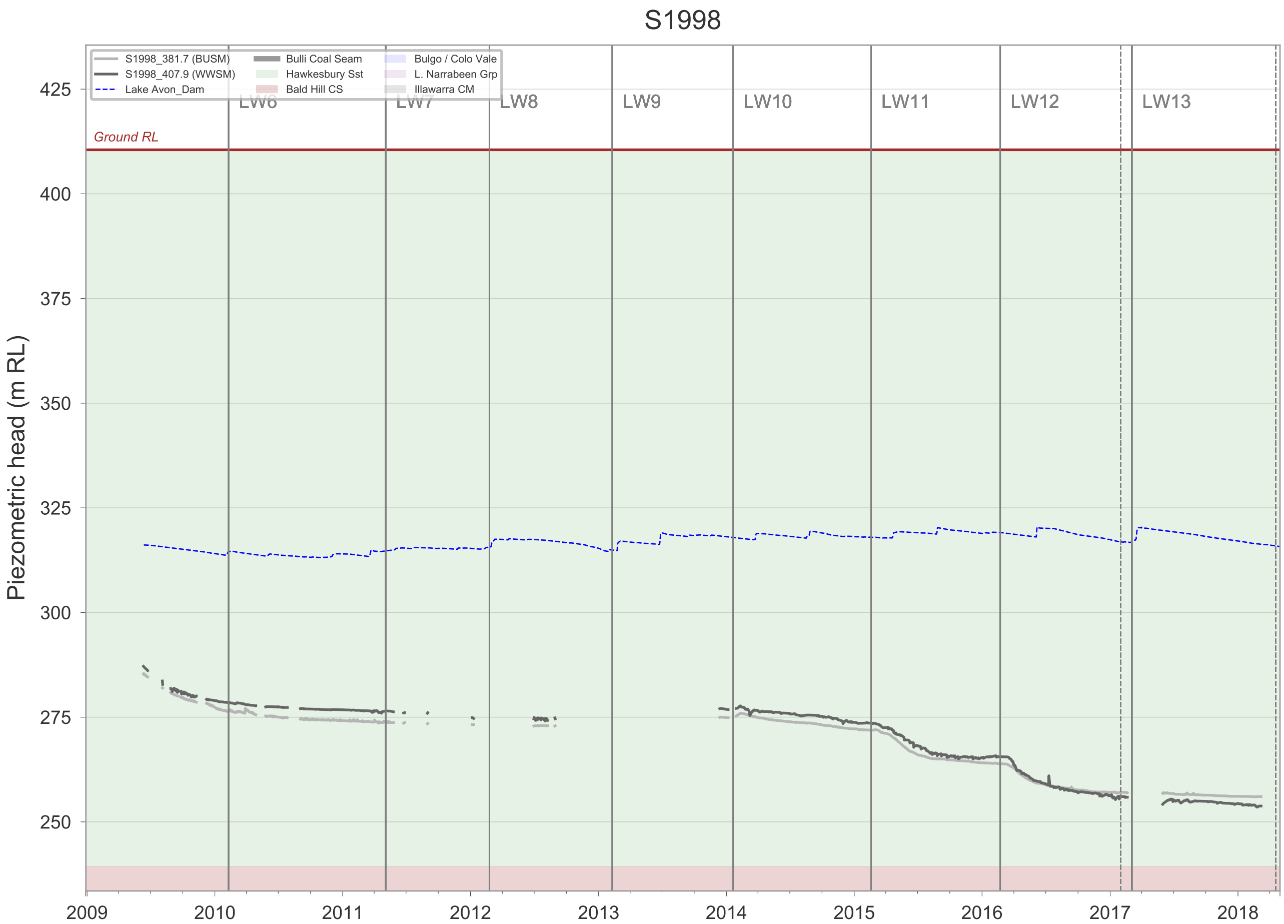
S1995

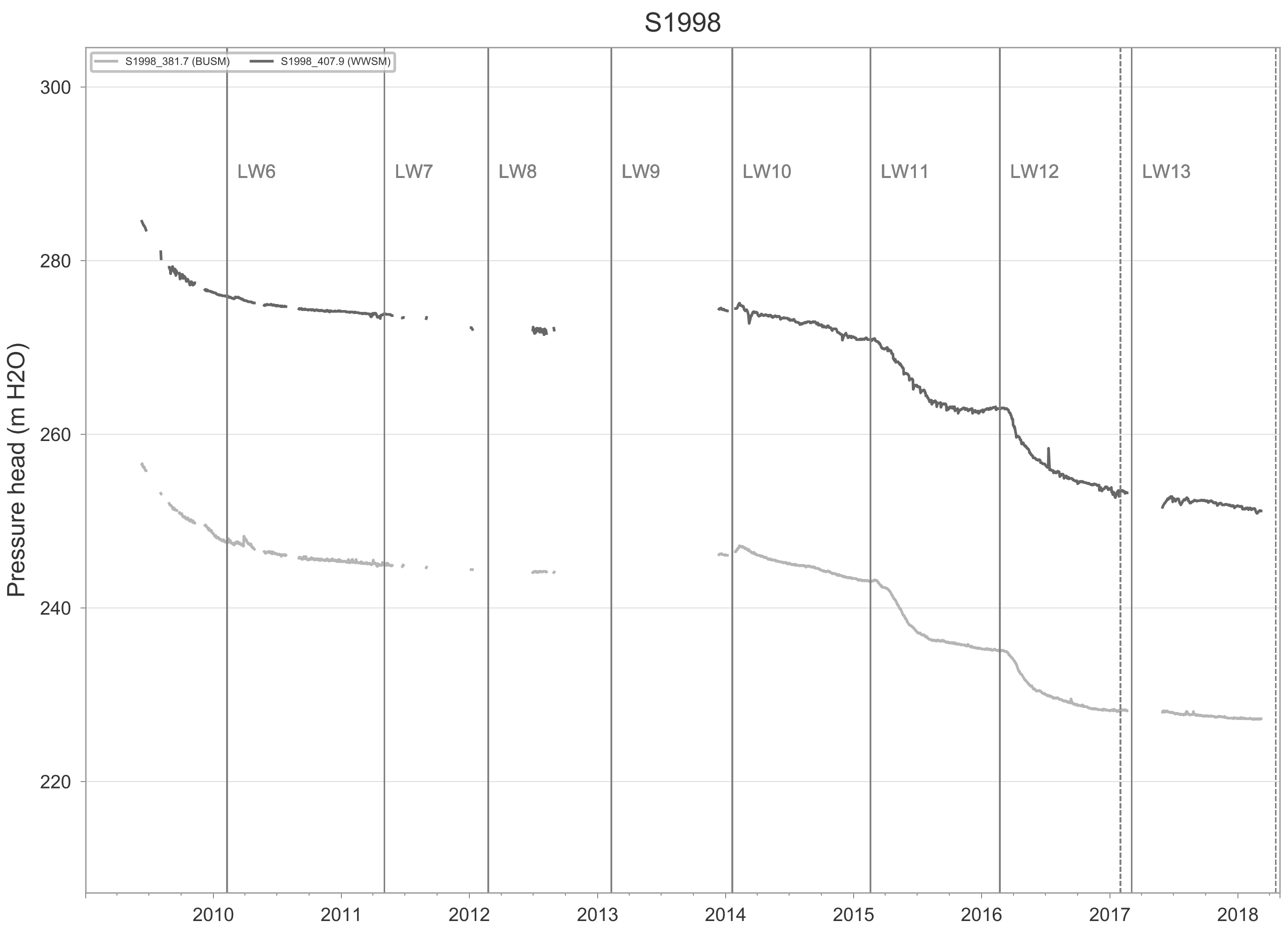

S1995_384.4 (BUSM)
S1995_411.3 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW7
LW8
LW9
LW10
Piezometric head (m RL)
400
350
300
250
200
150
100
50
2009
2010
2011
2012
2013
2014

S1995

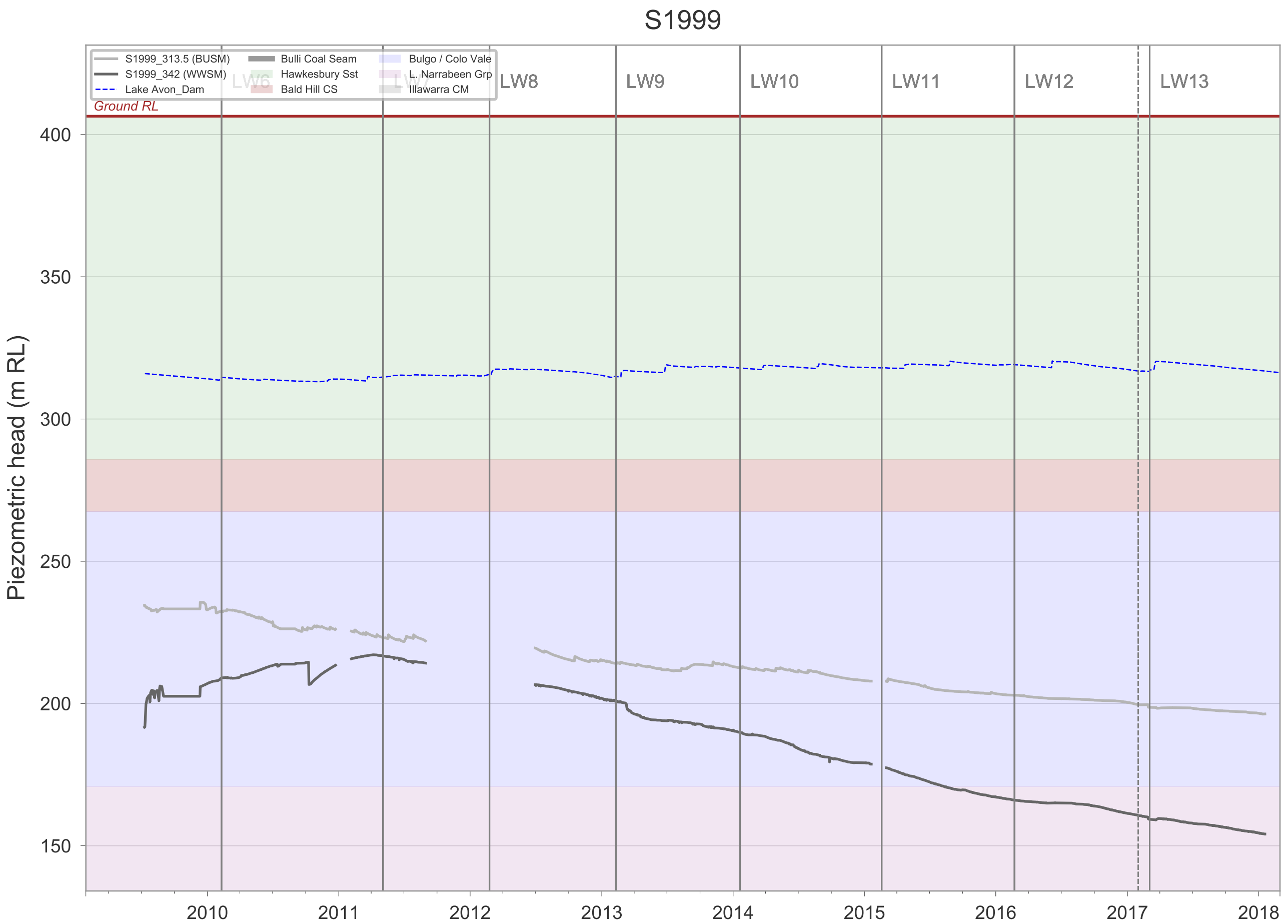

S1995_384.4 (BUSM)
S1995_411.3 (WWSM)
LW6
LW7
LW8
LW9
LW10
Pressure head (m H2O)
250
200
150
100
50
2010
2011
2012
2013
2014

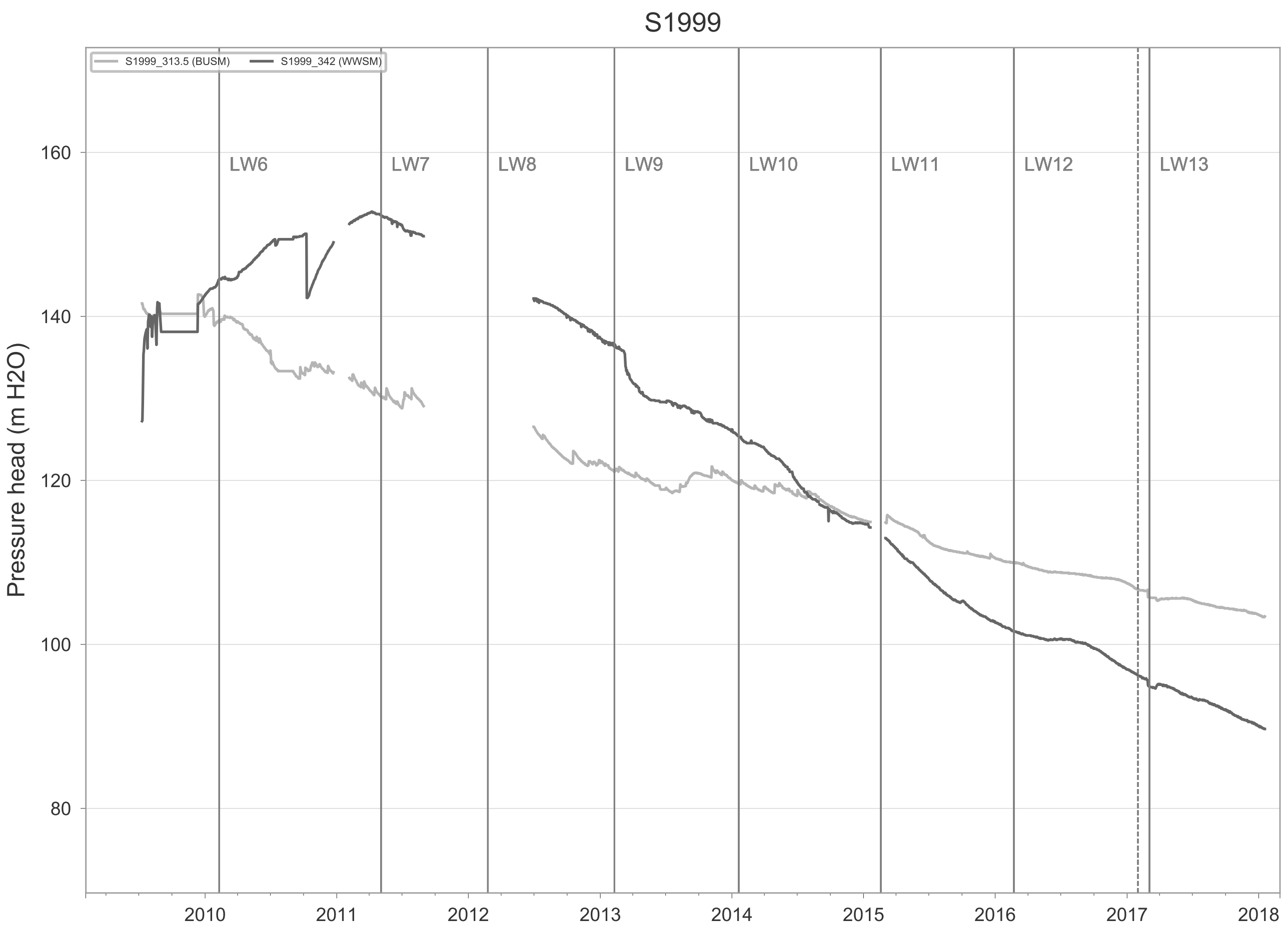
Groundwater hydrographs



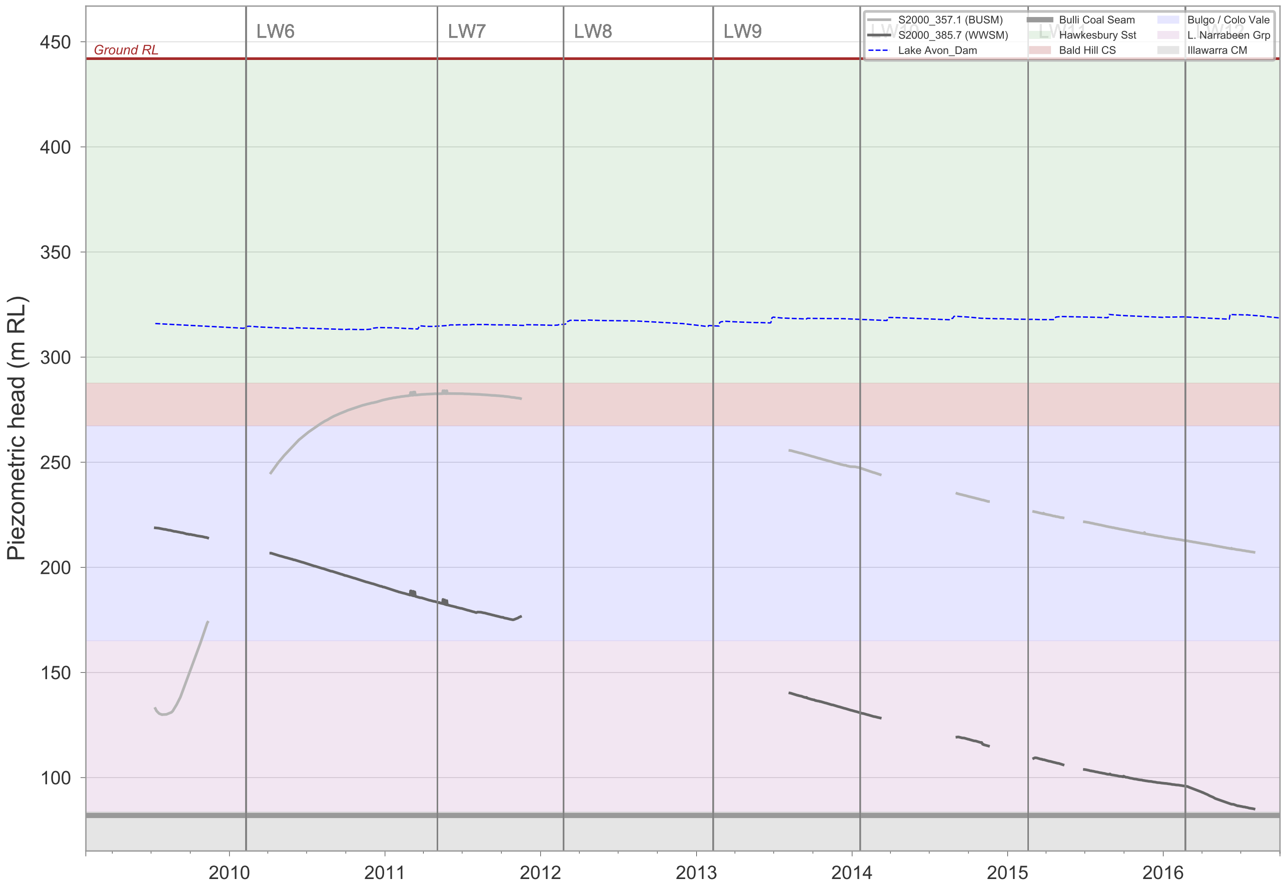


Groundwater hydrographs

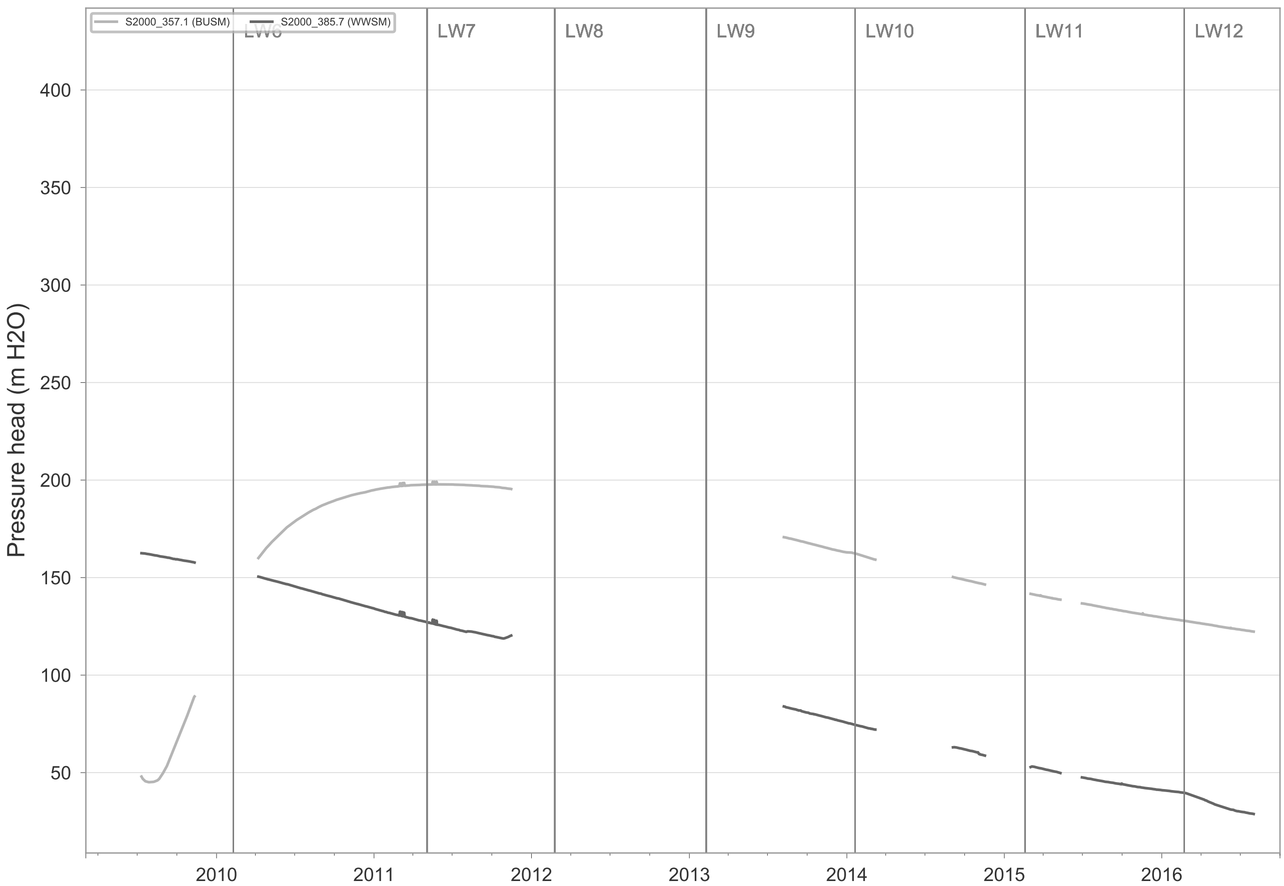




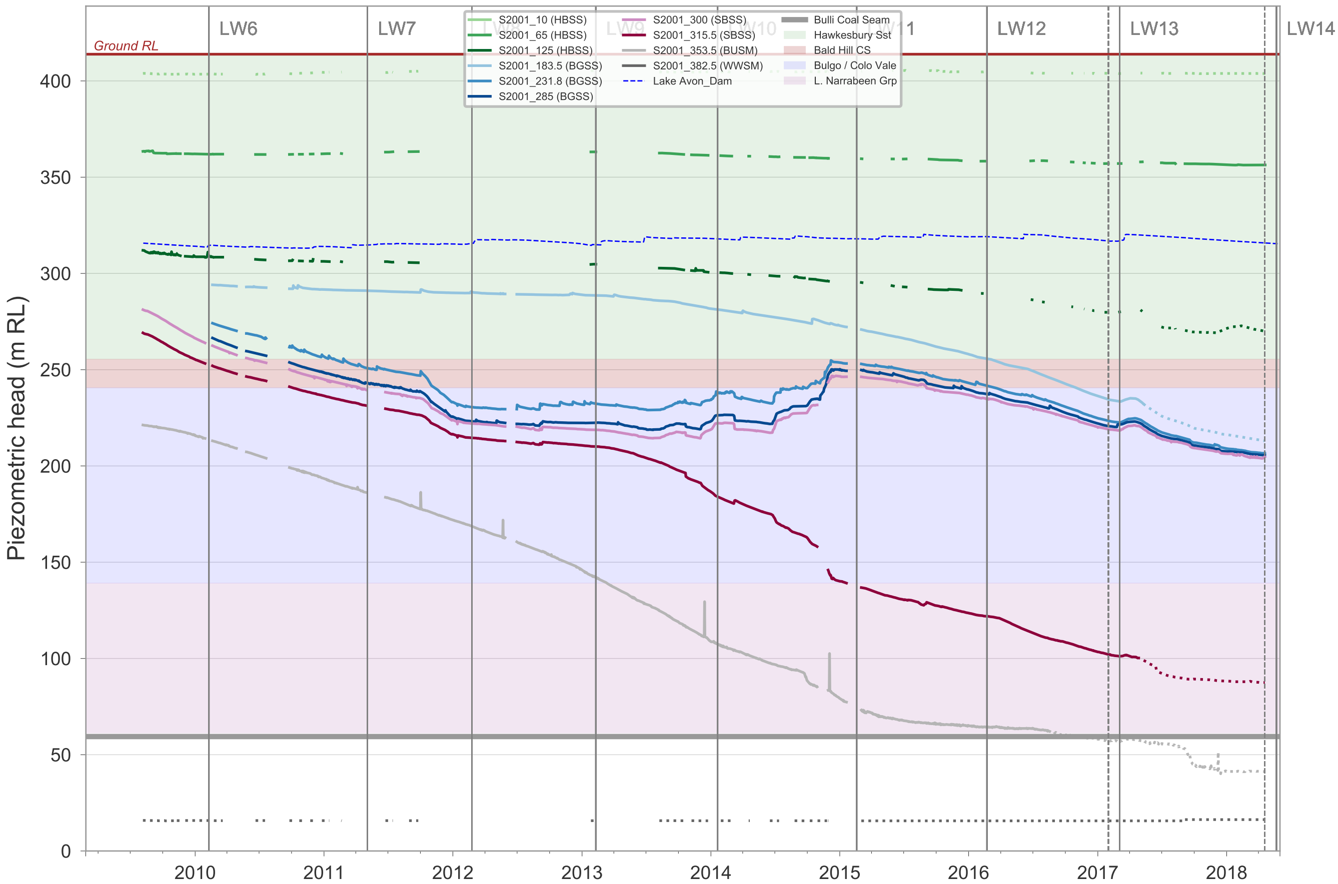
S2000


LW6
LW7
LW8
LW9
S2000_357.1 (BUSM)
S2000_385.7 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Ground RL
Piezometric head (m RL)
450
400
350
300
250
200
150
100
2010
2011
2012
2013
2014
2015
2016

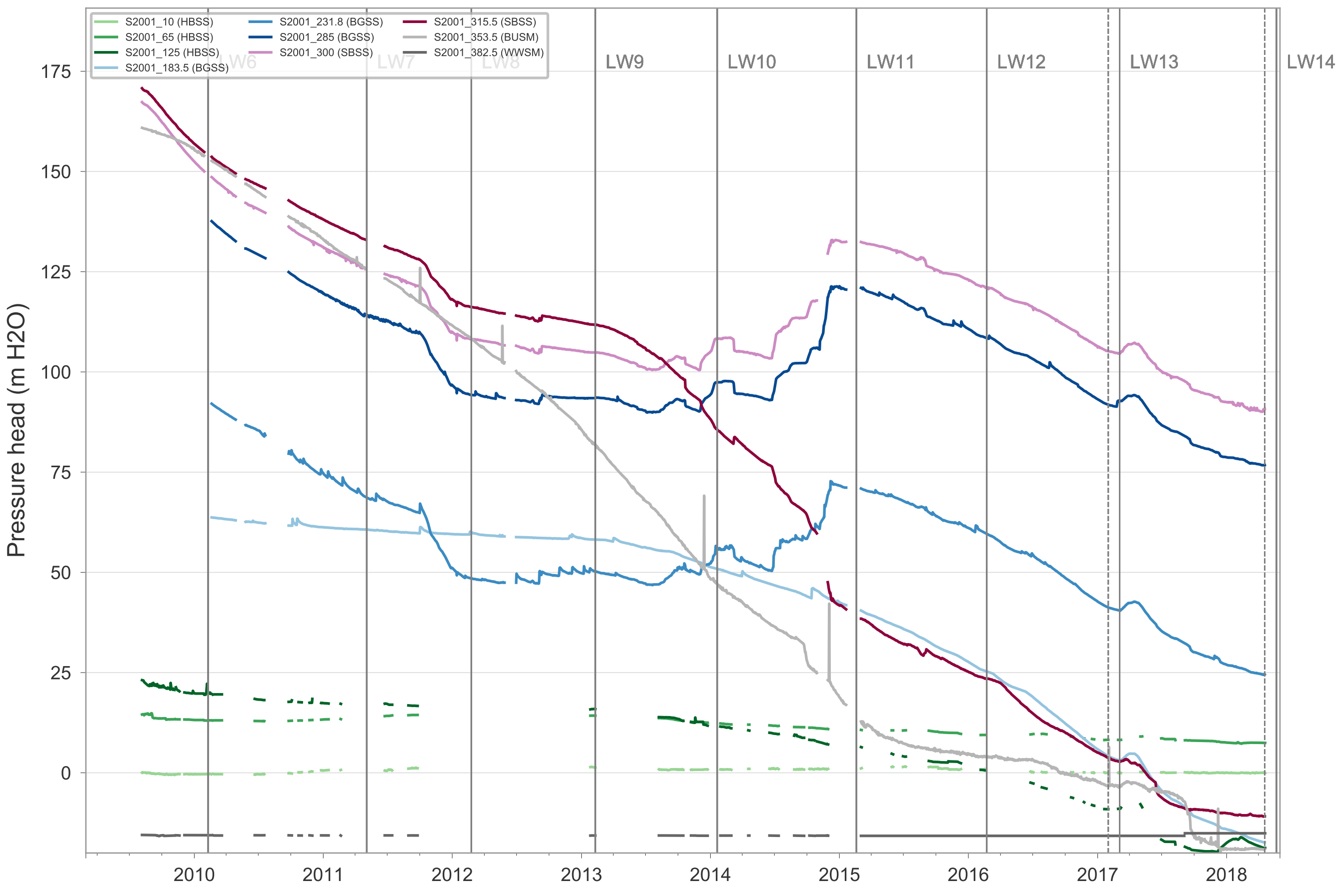
S2000

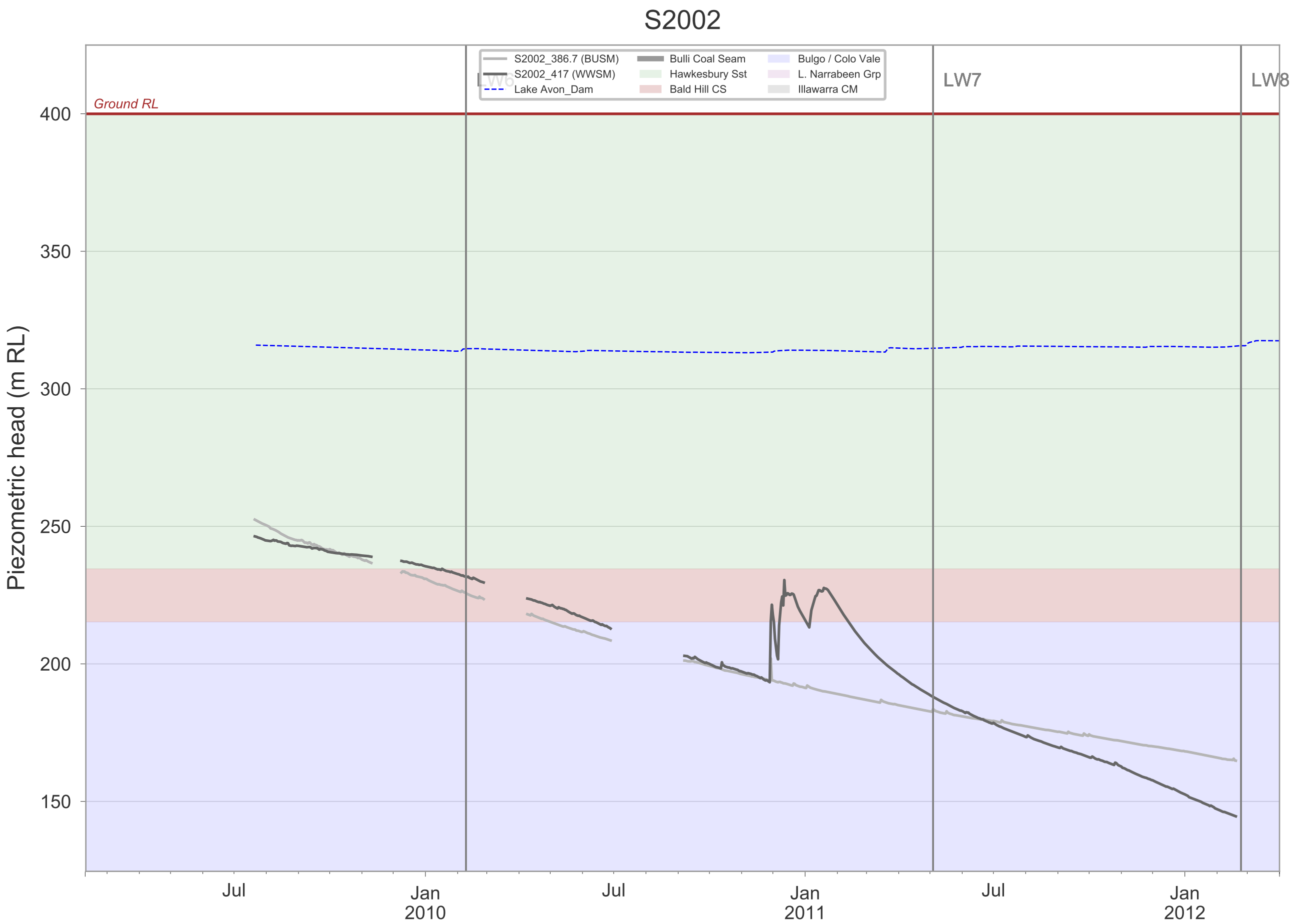

S2000_357.1 (BUSM)
S2000_385.7 (WWSM)
LW7
LW8
LW9
LW10
LW11
LW12
Pressure head (m H2O)
400
350
300
250
200
150
100
50
2010
2011
2012
2013
2014
2015
2016

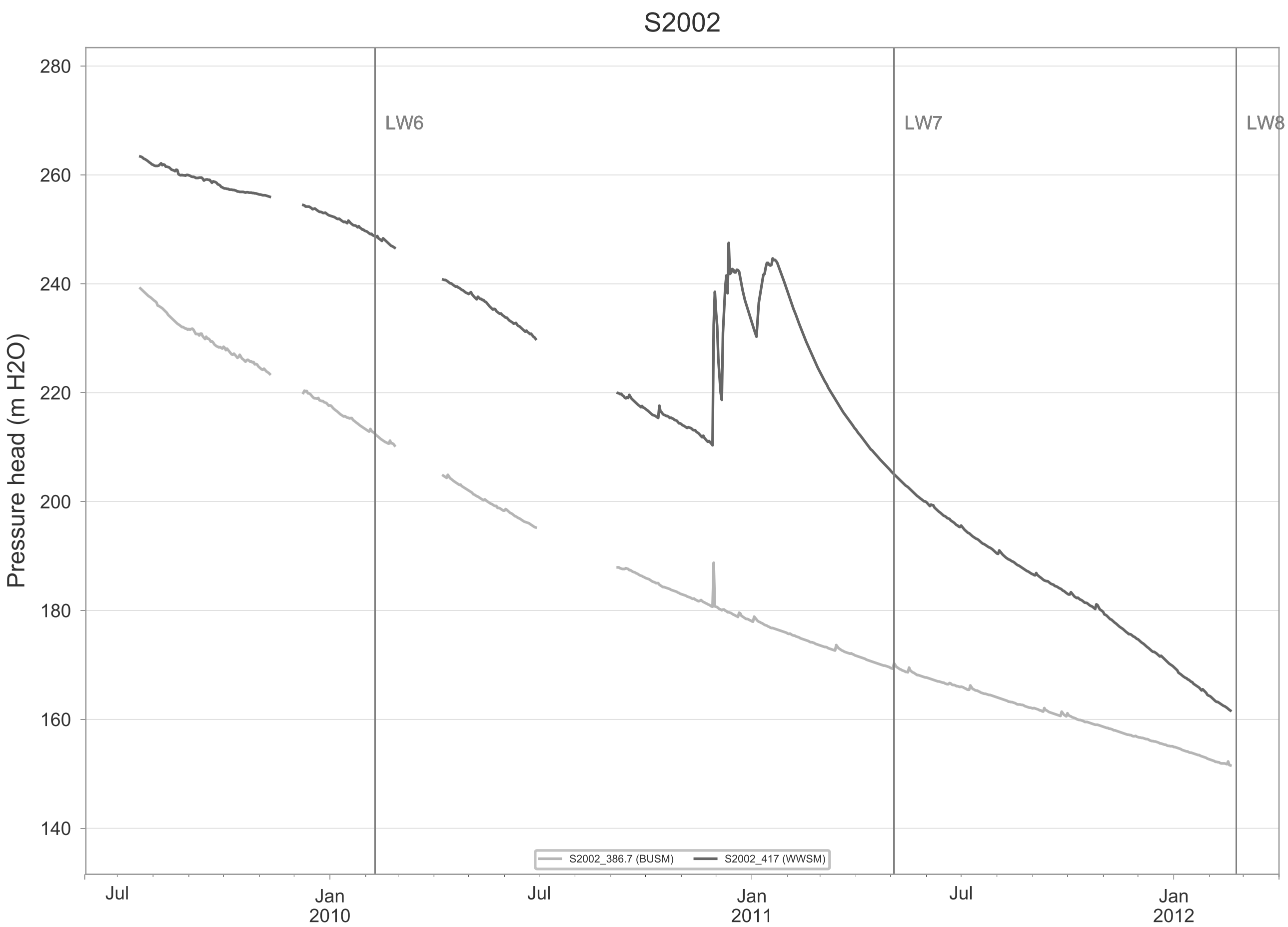
S2001


Ground RL
LW6
LW7
LW12
LW13
LW14
S2001_10 (HBSS)
S2001_65 (HBSS)
S2001_125 (HBSS)
S2001_183.5 (BGSS)
S2001_231.8 (BGSS)
S2001_285 (BGSS)
S2001_300 (SBSS)
S2001_315.5 (SBSS)
S2001_353.5 (BUSM)
S2001_382.5 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Piezometric head (m RL)
0
50
100
150
200
250
300
350
400
2010
2011
2012
2013
2014
2015
2016
2017
2018

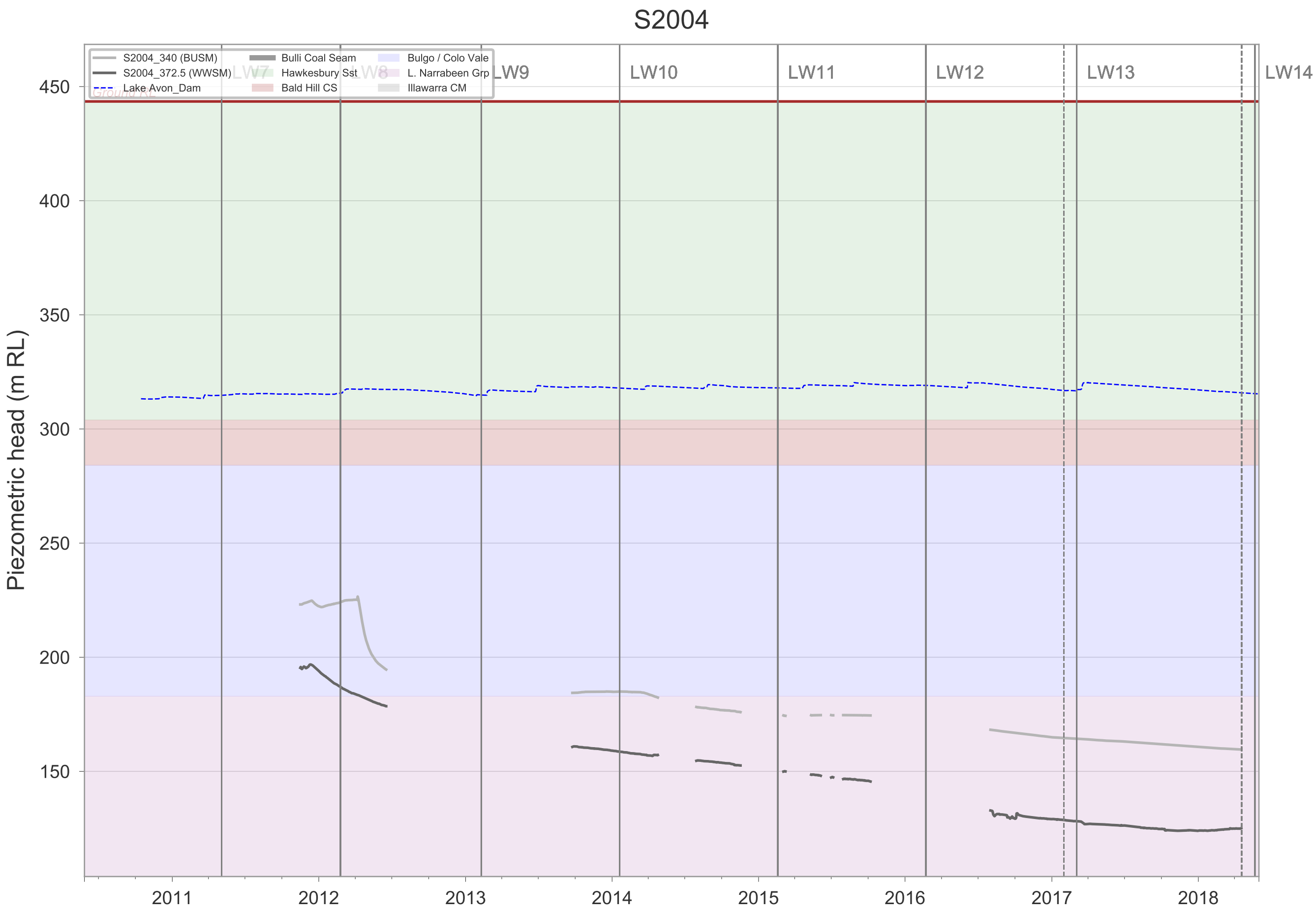
S2001

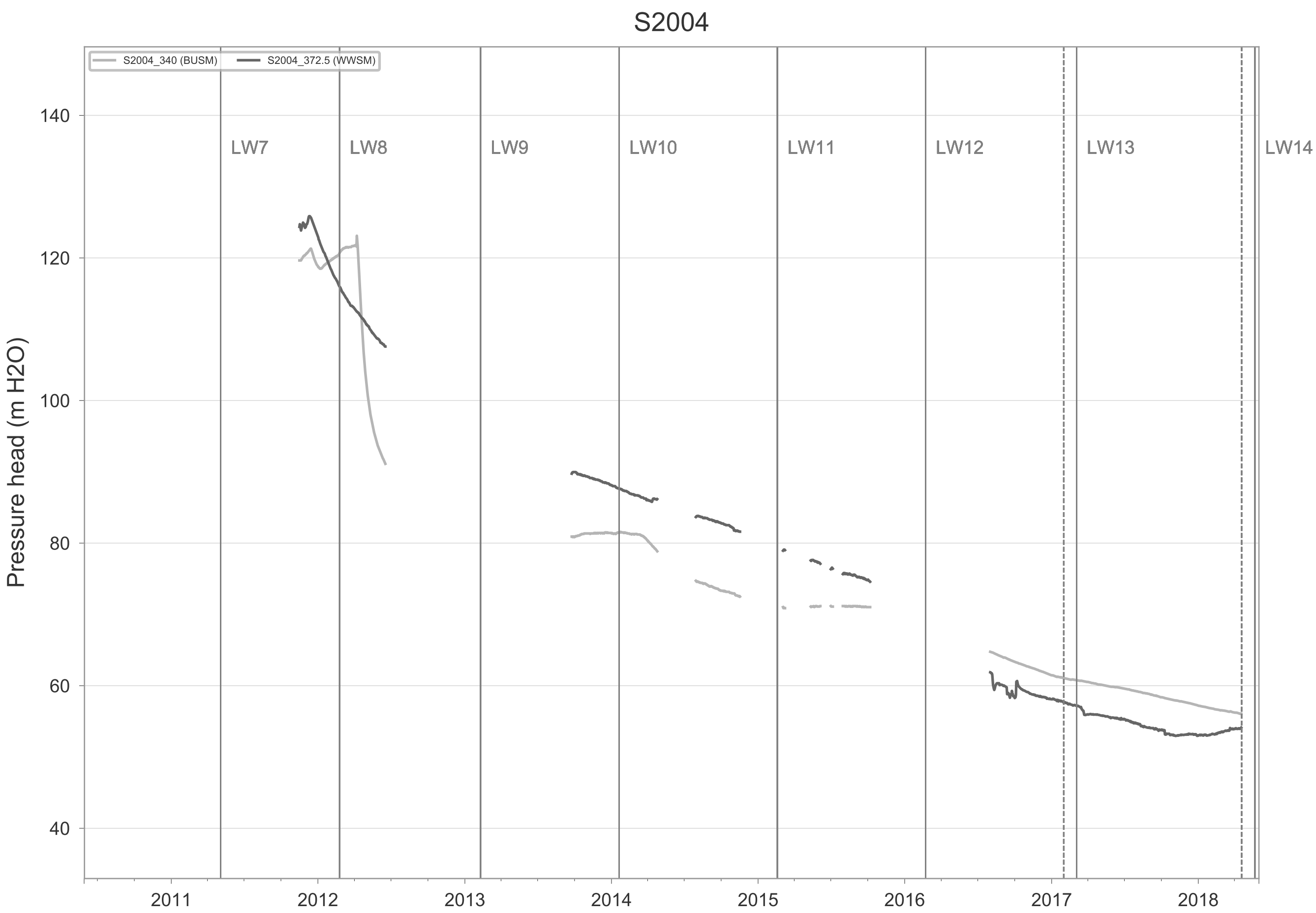

S2001_10 (HBSS)
S2001_65 (HBSS)
S2001_125 (HBSS)
S2001_183.5 (BGSS)
S2001_231.8 (BGSS)
S2001_285 (BGSS)
S2001_300 (SBSS)
S2001_315.5 (SBSS)
S2001_353.5 (BUSM)
S2001_382.5 (WWSM)
LW9
LW10
LW11
LW12
LW13
LW14
Pressure head (m H2O)
0
25
50
75
100
125
150
175
2010
2011
2012
2013
2014
2015
2016
2017
2018

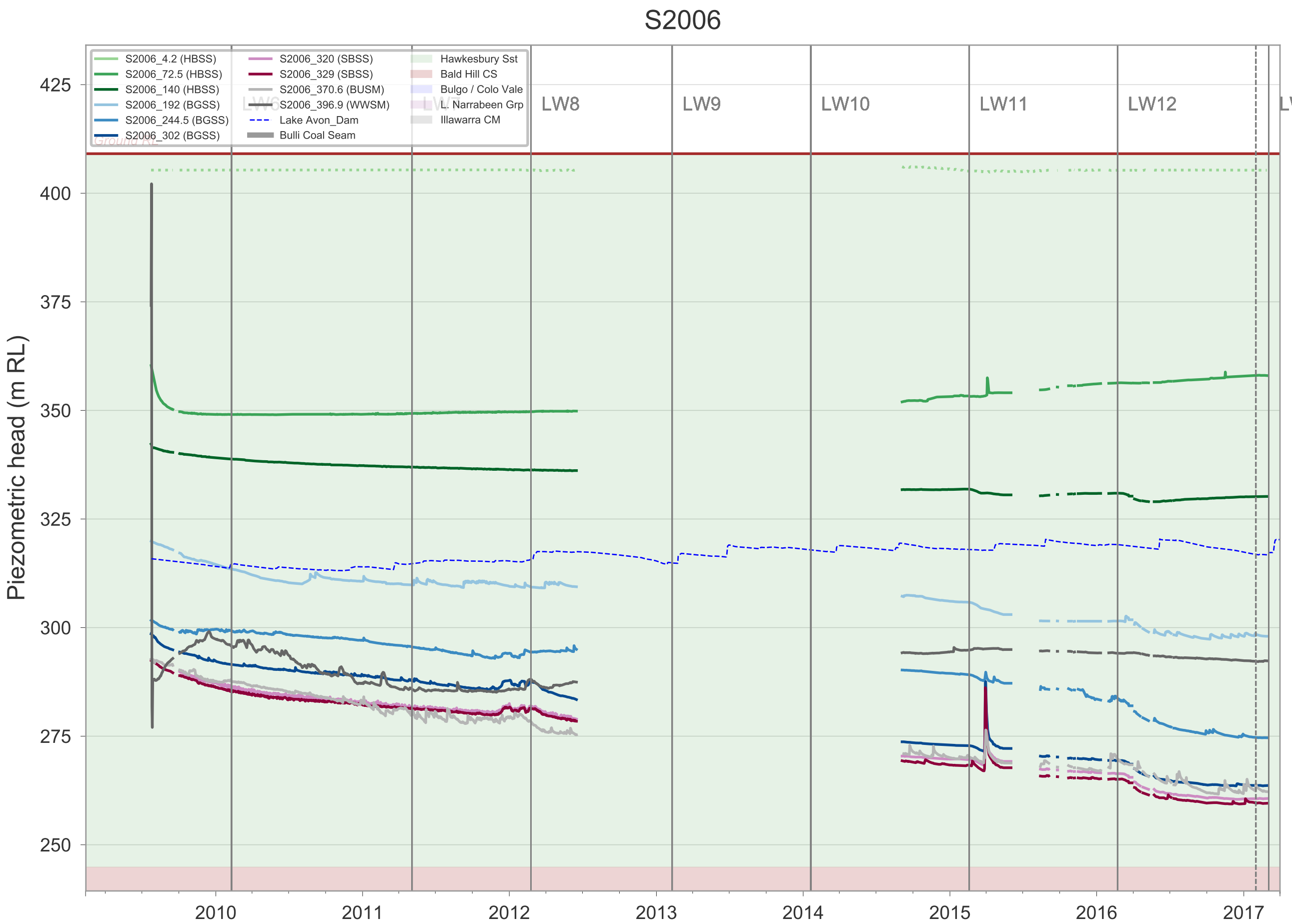

S2002
S2002_386.7 (BUSM)
S2002_417 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Ground RL
LW6
LW7
LW8
Piezometric head (m RL)
400
350
300
250
200
150
Jul
Jan 2010
Jul
Jan 2011
Jul
Jan 2012

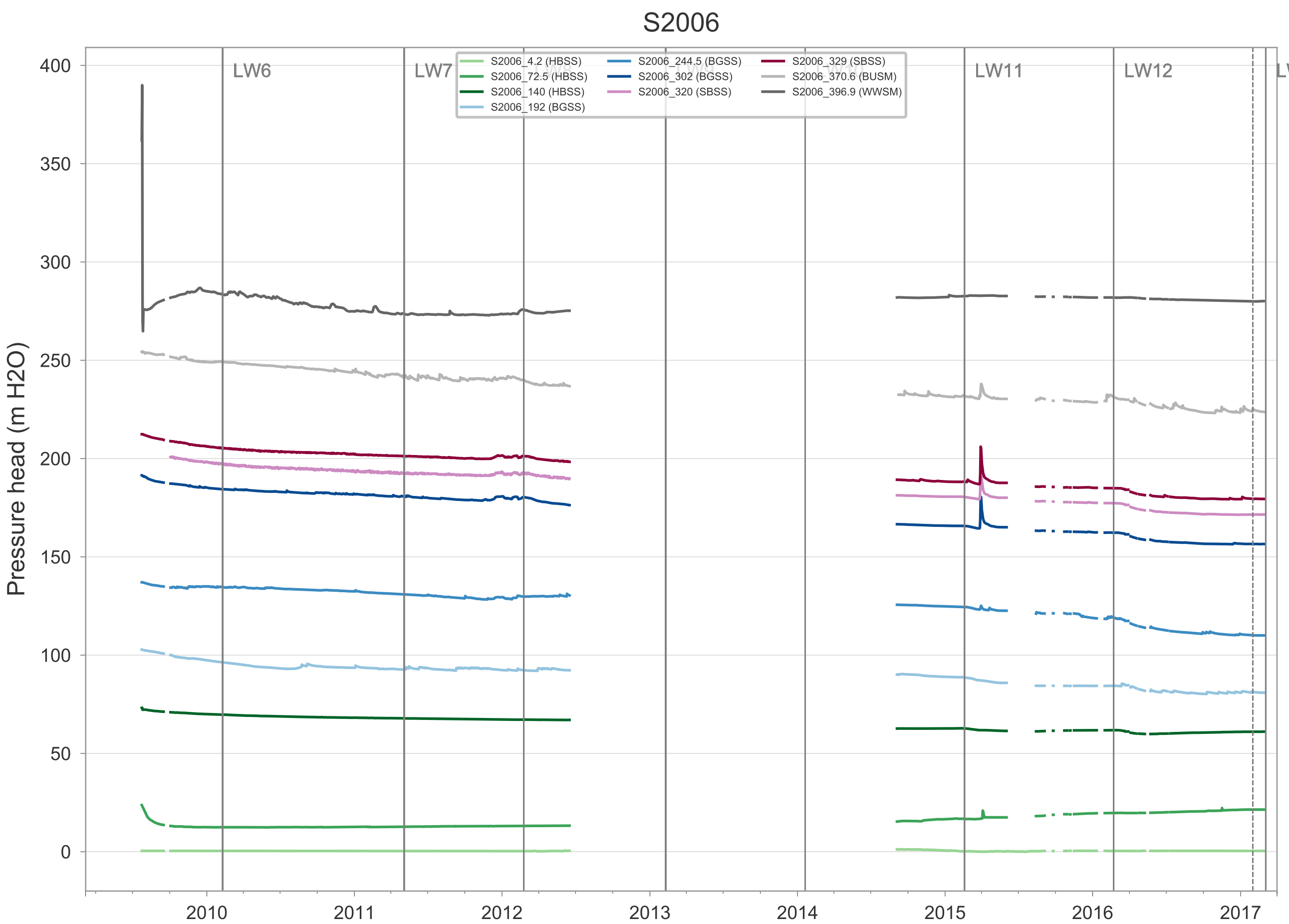

S2002
LW6
LW7
LW8
Pressure head (m H2O)
280
260
240
220
200
180
160
140
S2002_386.7 (BUSM)
S2002_417 (WWSM)
Jul
Jan 2010
Jul
Jan 2011
Jul
Jan 2012

Groundwater hydrographs

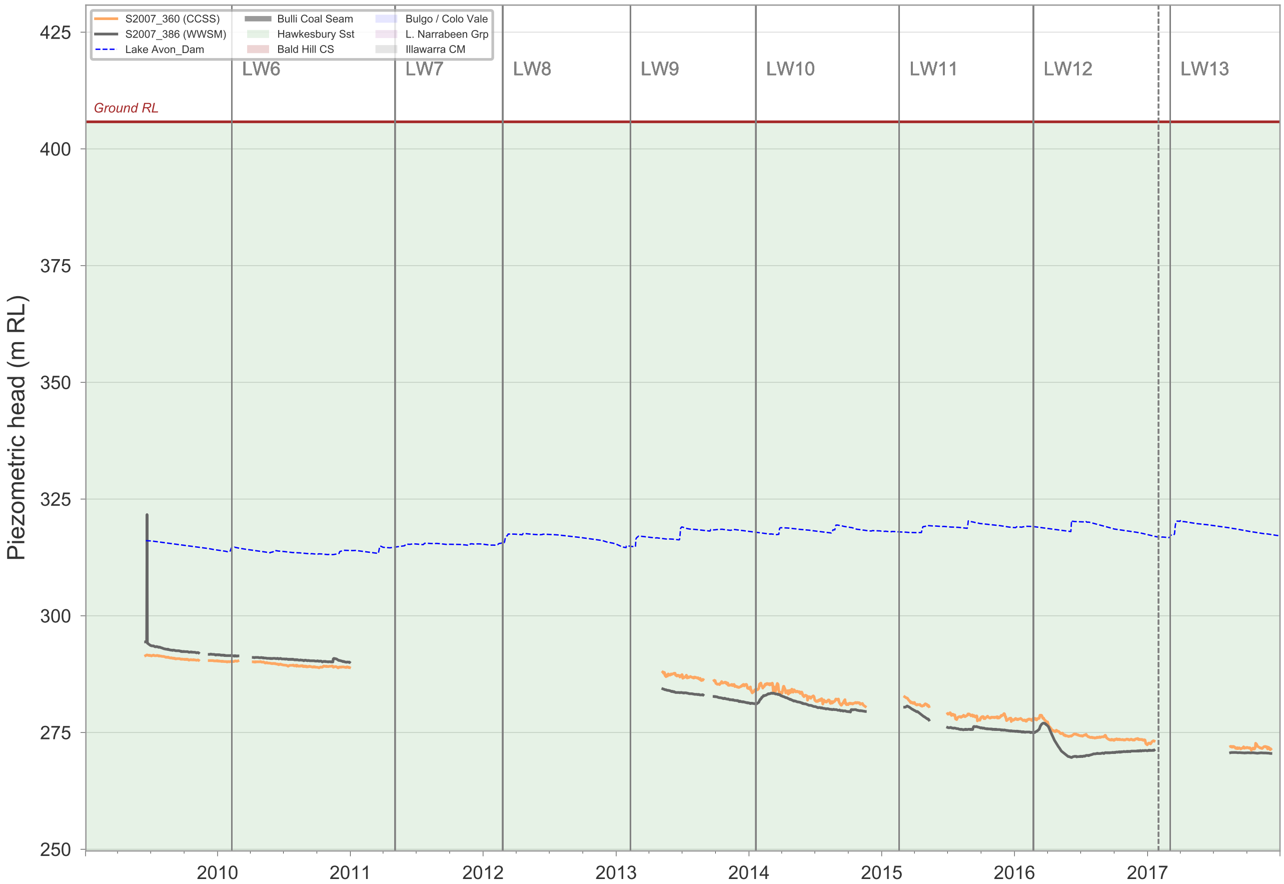




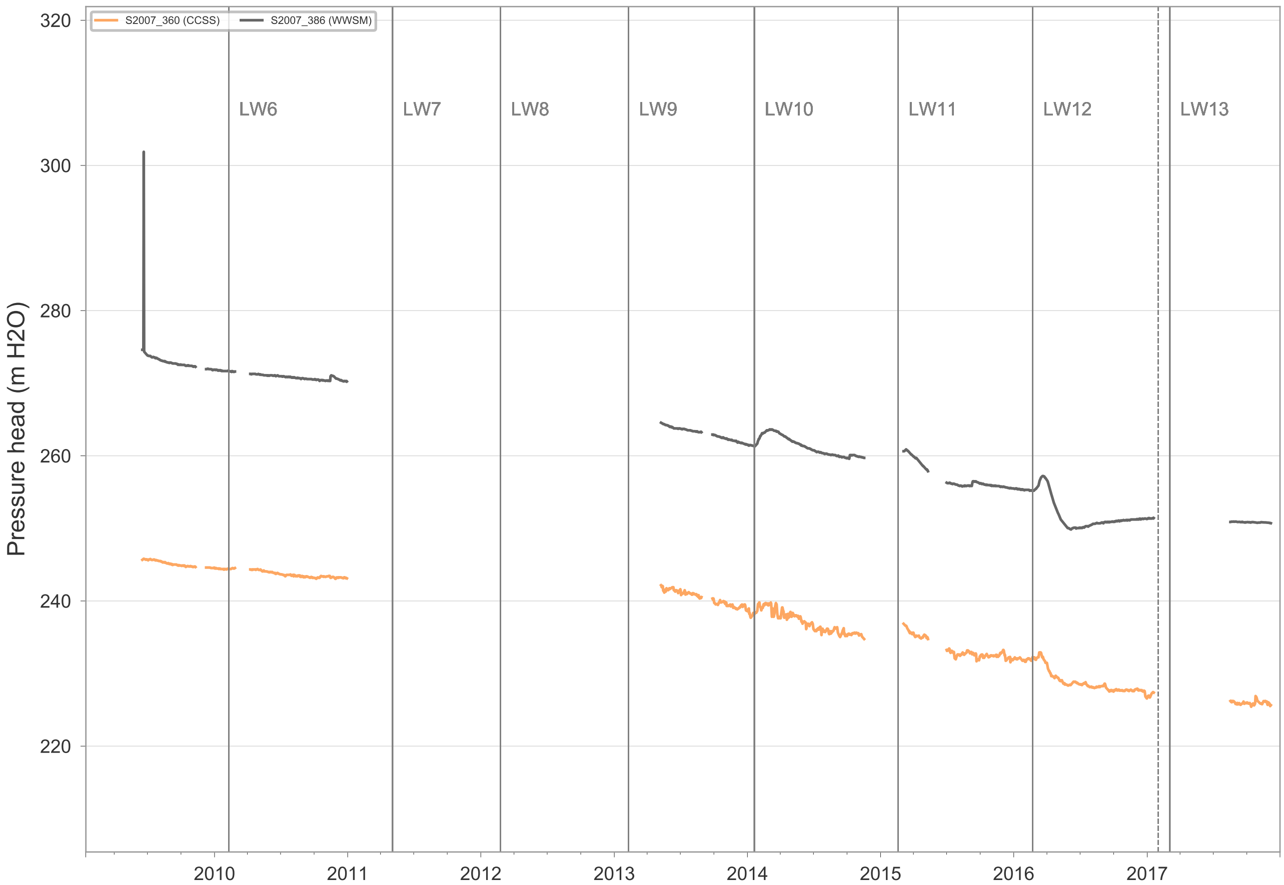

S2006
S2006_4.2 (HBSS)
S2006_72.5 (HBSS)
S2006_140 (HBSS)
S2006_192 (BGSS)
S2006_244.5 (BGSS)
S2006_302 (BGSS)
S2006_320 (SBSS)
S2006_329 (SBSS)
S2006_370.6 (BUSM)
S2006_396.9 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW8
LW9
LW10
LW11
LW12
LW13
Piezometric head (m RL)
425
400
375
350
325
300
275
250
2010
2011
2012
2013
2014
2015
2016
2017

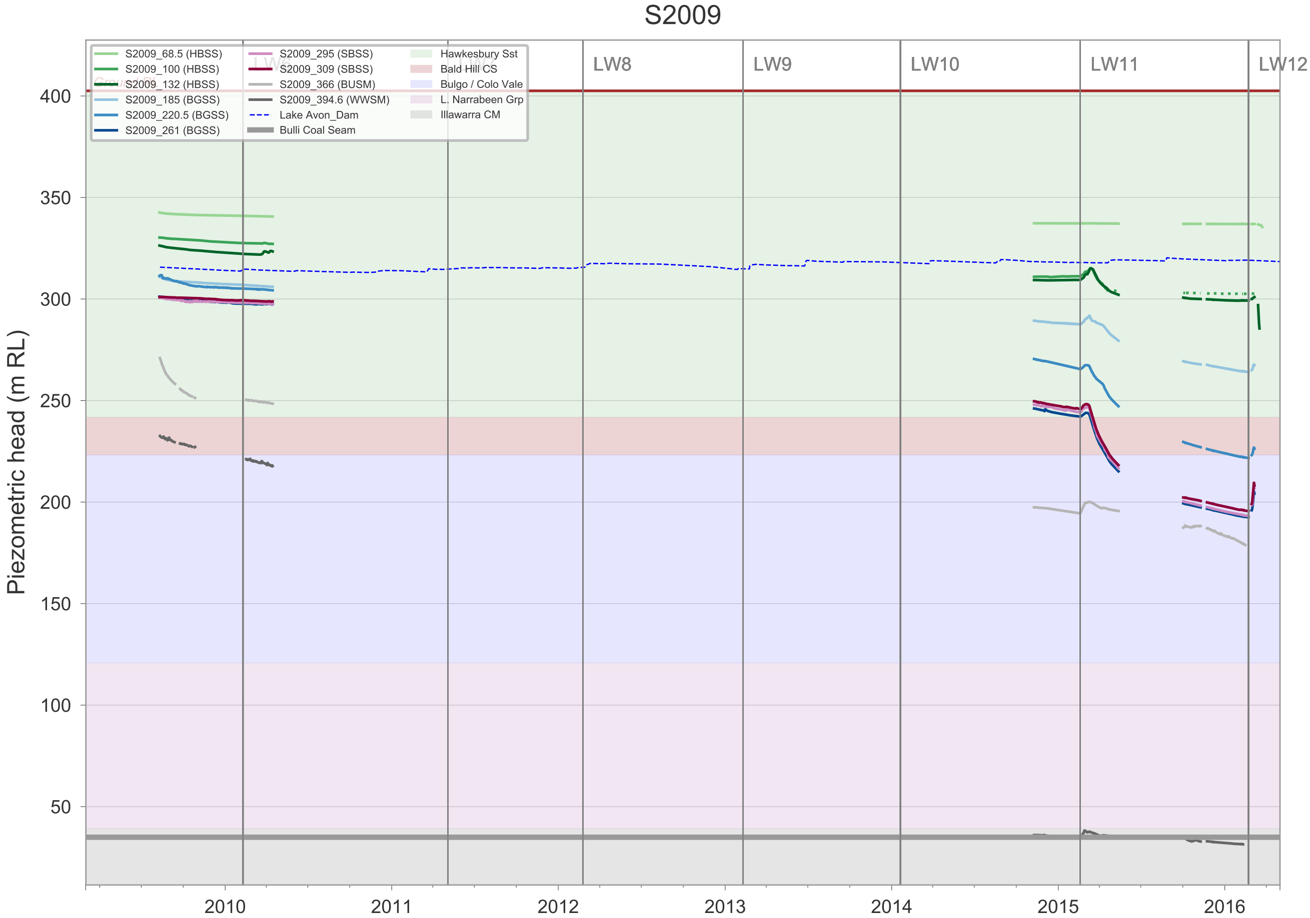

S2006
LW6
LW7
LW11
LW12
LW13
S2006_4.2 (HBSS)
S2006_72.5 (HBSS)
S2006_140 (HBSS)
S2006_192 (BGSS)
S2006_244.5 (BGSS)
S2006_302 (BGSS)
S2006_320 (SBSS)
S2006_329 (SBSS)
S2006_370.6 (BUSM)
S2006_396.9 (WWSM)
Pressure head (m H2O)
400
350
300
250
200
150
100
50
0
2010
2011
2012
2013
2014
2015
2016
2017

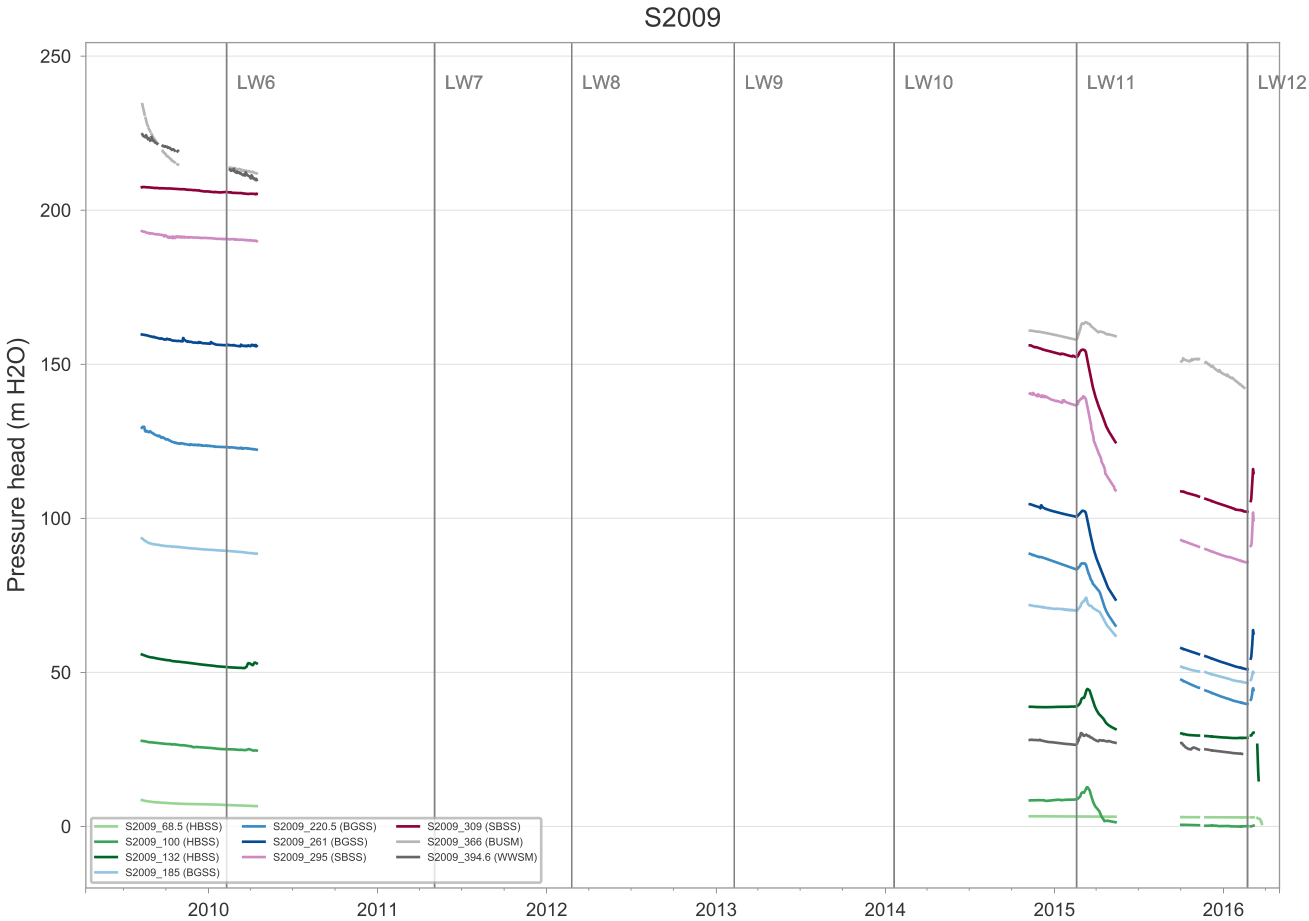
S2007

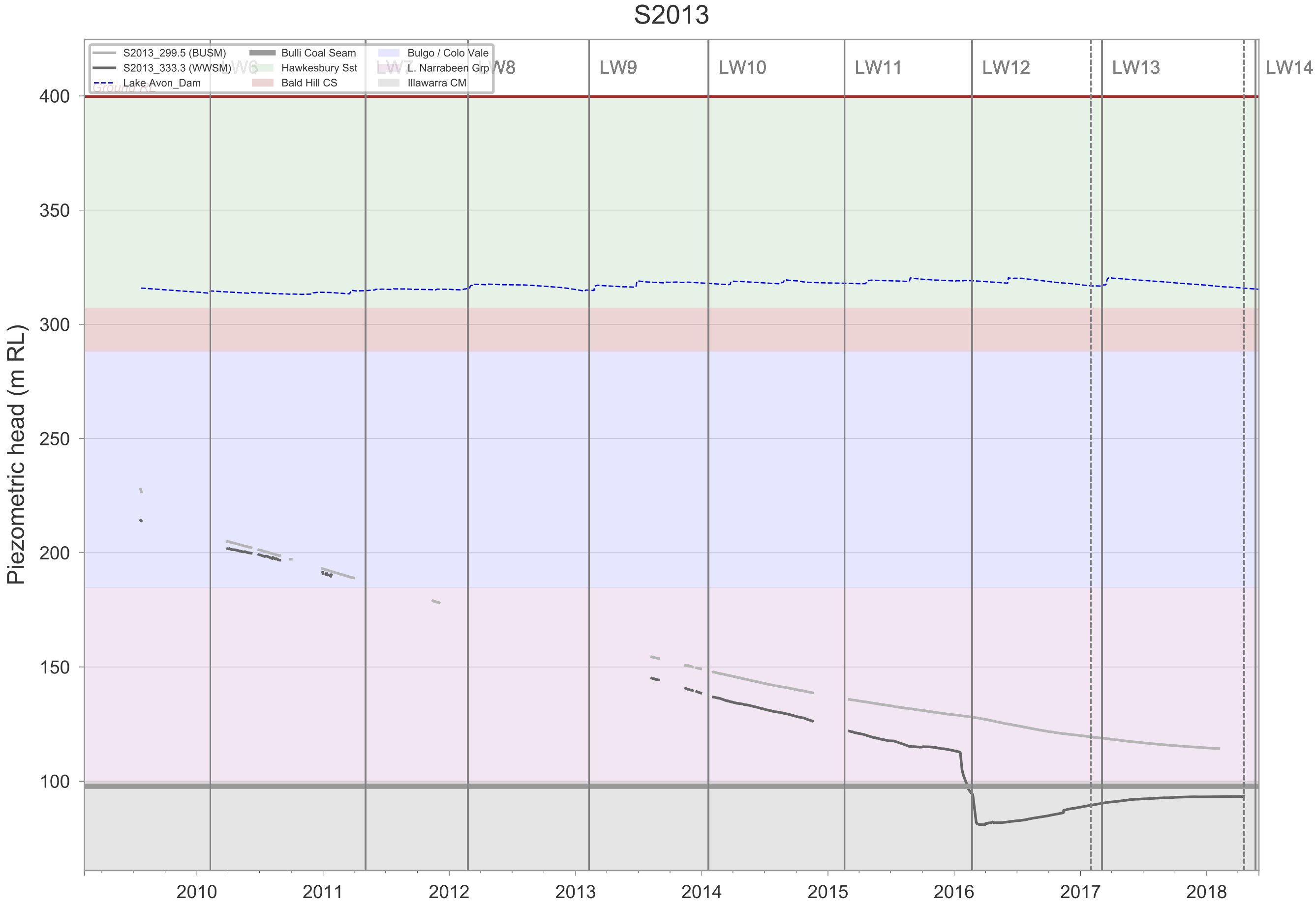

S2007_360 (CCSS)
S2007_386 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Ground RL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
Piezometric head (m RL)
425
400
375
350
325
300
275
250
2010
2011
2012
2013
2014
2015
2016
2017

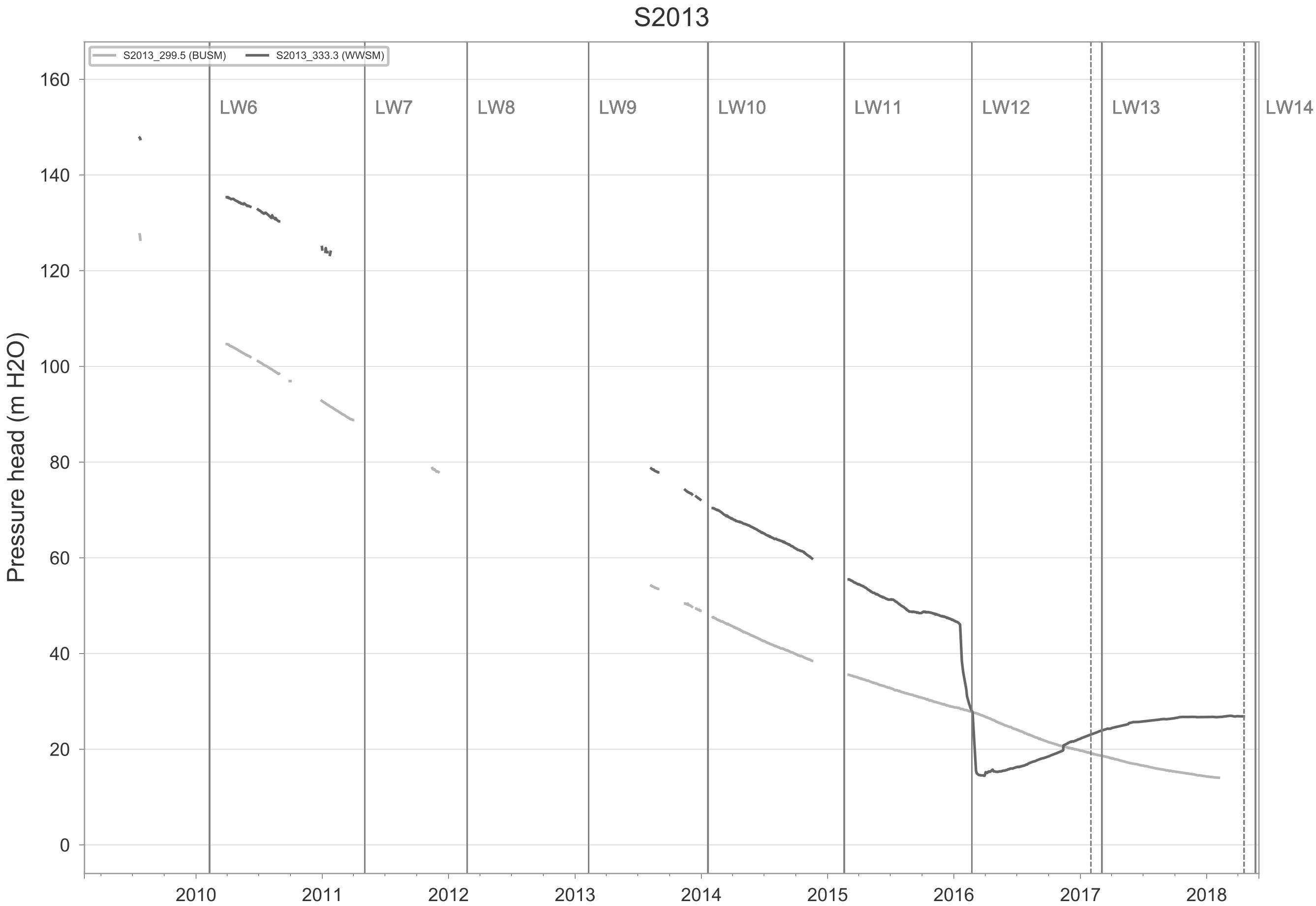
S2007


S2007_360 (CCSS)
S2007_386 (WWSM)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
Pressure head (m H2O)
320
300
280
260
240
220
2010
2011
2012
2013
2014
2015
2016
2017

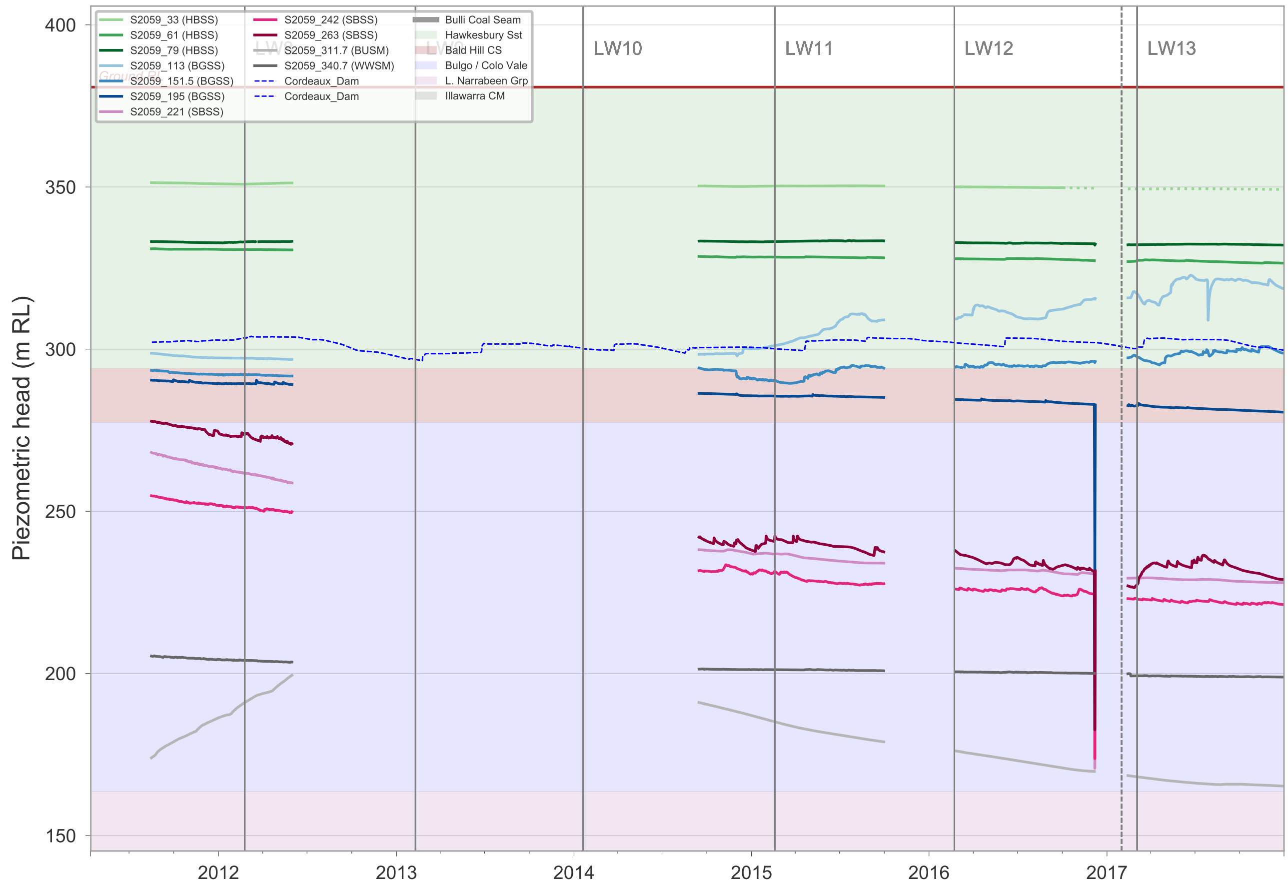

S2009
Piezometric head (m RL)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
Ground RL
400
350
300
250
200
150
100
50
2010
2011
2012
2013
2014
2015
2016
S2009_68.5 (HBSS)
S2009_100 (HBSS)
S2009_132 (HBSS)
S2009_185 (BGSS)
S2009_220.5 (BGSS)
S2009_261 (BGSS)
S2009_295 (SBSS)
S2009_309 (SBSS)
S2009_366 (BUSM)
S2009_394.6 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM


S2009
Pressure head (m H2O)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
250
200
150
100
50
0
2010
2011
2012
2013
2014
2015
2016
S2009_68.5 (HBSS)
S2009_100 (HBSS)
S2009_132 (HBSS)
S2009_185 (BGSS)
S2009_220.5 (BGSS)
S2009_261 (BGSS)
S2009_295 (SBSS)
S2009_309 (SBSS)
S2009_366 (BUSM)
S2009_394.6 (WWSM)

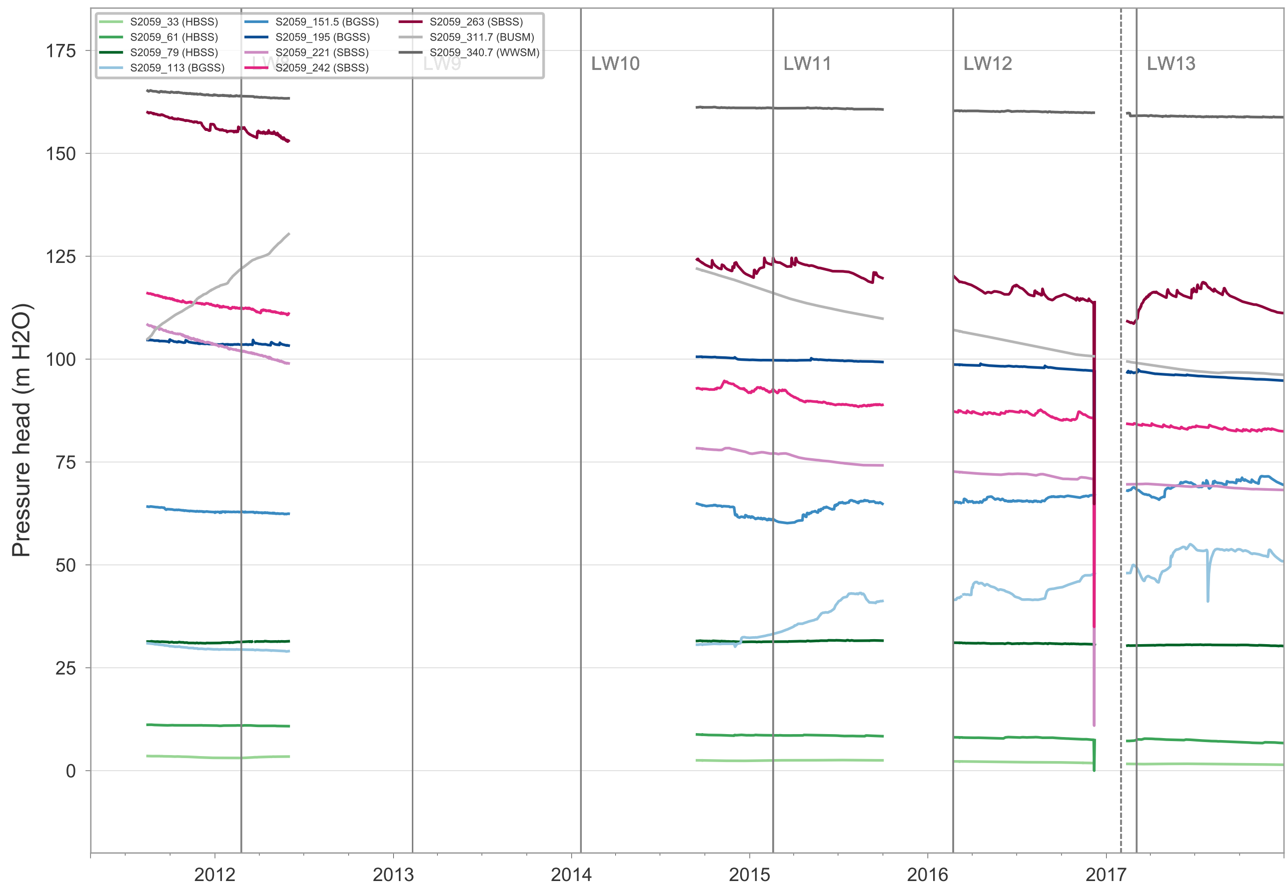

S2013
S2013_299.5 (BUSM)
S2013_333.3 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Ground RL
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Piezometric head (m RL)
400
350
300
250
200
150
100
2010
2011
2012
2013
2014
2015
2016
2017
2018

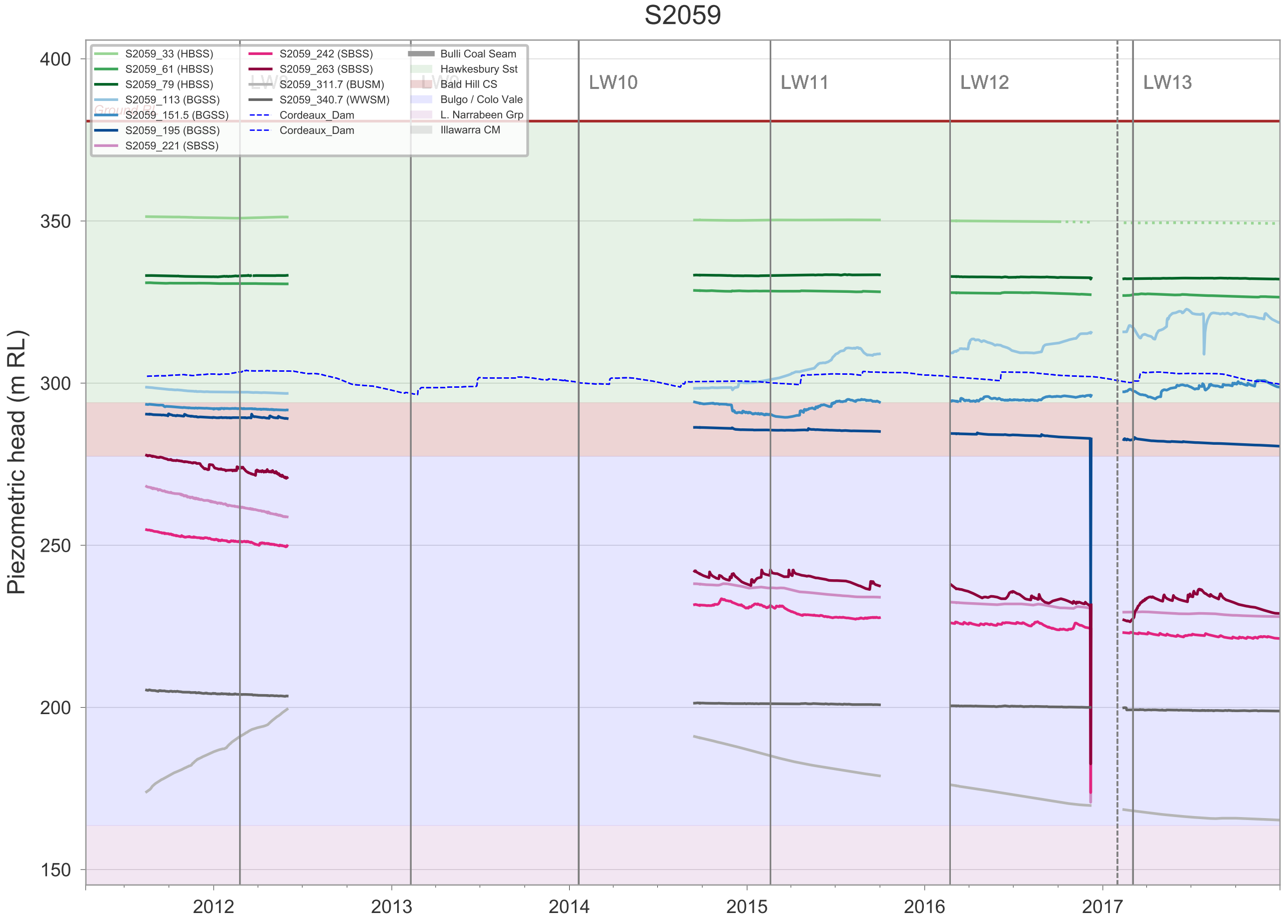

S2013
S2013_299.5 (BUSM)
S2013_333.3 (WWSM)
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
Pressure head (m H2O)
160
140
120
100
80
60
40
20
0
2010
2011
2012
2013
2014
2015
2016
2017
2018

S2059


S2059_33 (HBSS)
S2059_61 (HBSS)
S2059_79 (HBSS)
S2059_113 (BGSS)
S2059_151.5 (BGSS)
S2059_195 (BGSS)
S2059_221 (SBSS)
S2059_242 (SBSS)
S2059_263 (SBSS)
S2059_311.7 (BUSM)
S2059_340.7 (WWSM)
Cordeaux_Dam
Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW10
LW11
LW12
LW13
Piezometric head (m RL)
400
350
300
250
200
150
2012
2013
2014
2015
2016
2017

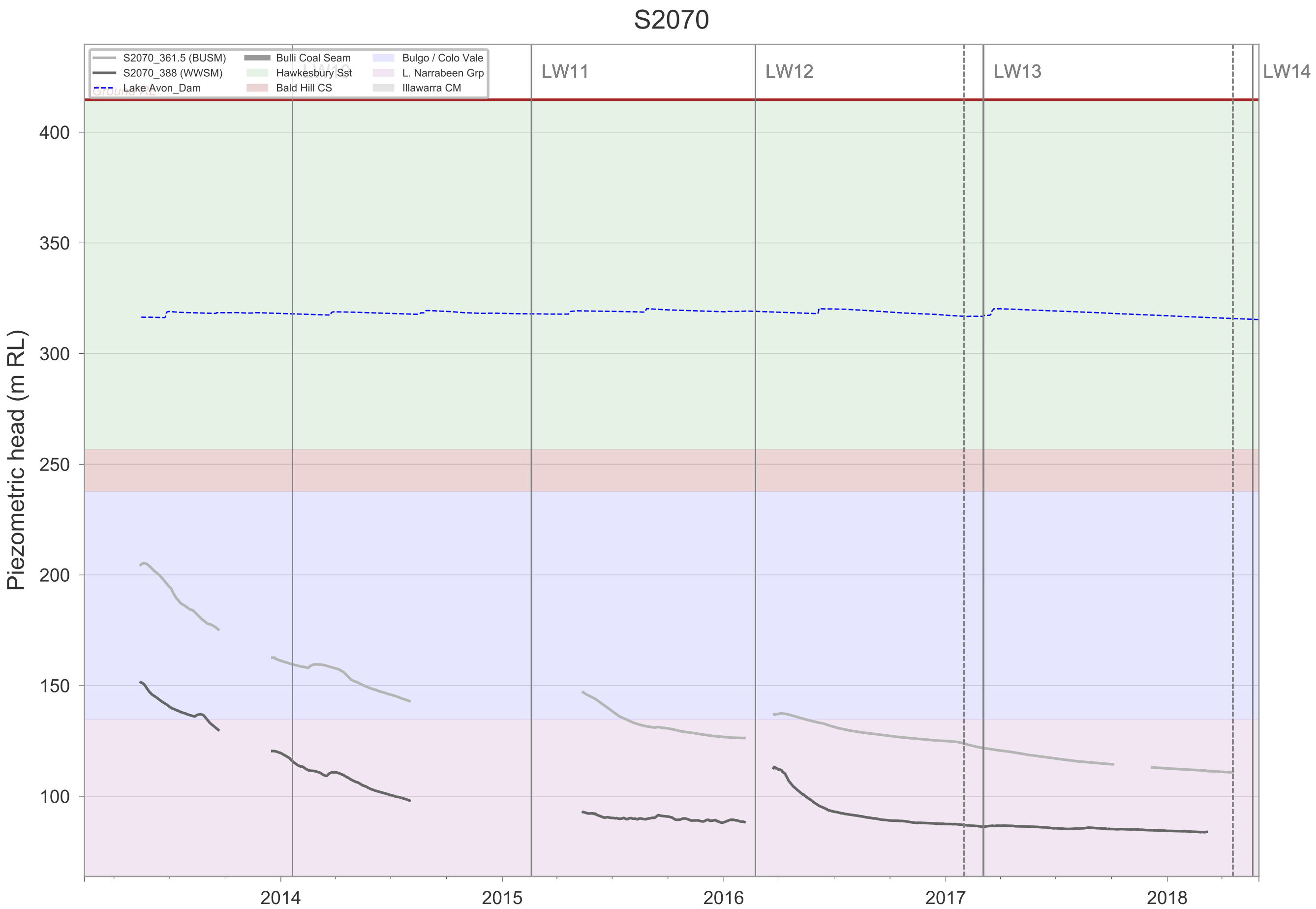
S2059

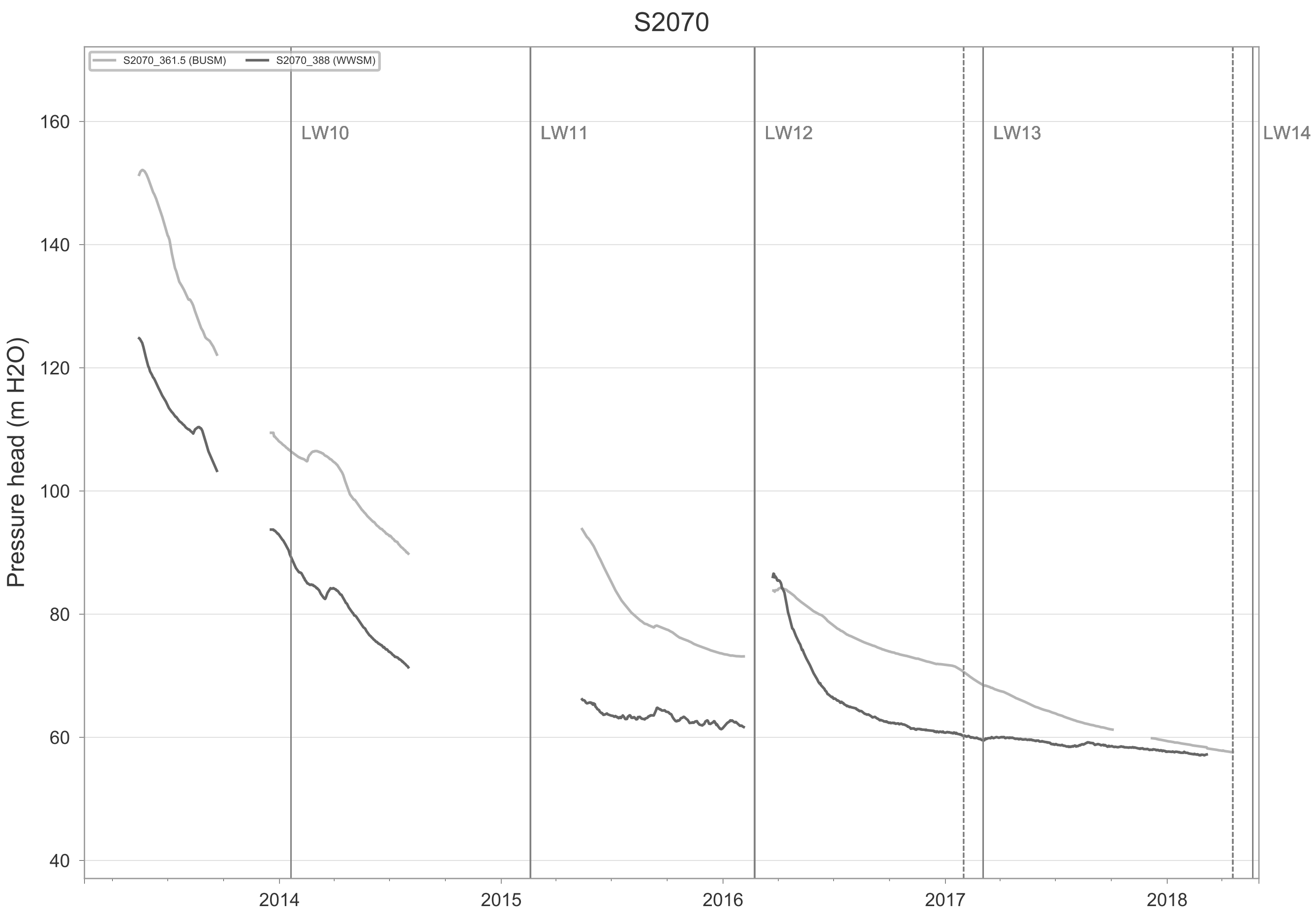

S2059_33 (HBSS)
S2059_61 (HBSS)
S2059_79 (HBSS)
S2059_113 (BGSS)
S2059_151.5 (BGSS)
S2059_195 (BGSS)
S2059_221 (SBSS)
S2059_242 (SBSS)
S2059_263 (SBSS)
S2059_311.7 (BUSM)
S2059_340.7 (WWSM)
LW10
LW11
LW12
LW13
Pressure head (m H2O)
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017


S2059
S2059_33 (HBSS)
S2059_61 (HBSS)
S2059_79 (HBSS)
S2059_113 (BGSS)
S2059_151.5 (BGSS)
S2059_195 (BGSS)
S2059_221 (SBSS)
S2059_242 (SBSS)
S2059_263 (SBSS)
S2059_311.7 (BUSM)
S2059_340.7 (WWSM)
Cordeaux_Dam
Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW10
LW11
LW12
LW13
Piezometric head (m RL)
400
350
300
250
200
150
2012
2013
2014
2015
2016
2017

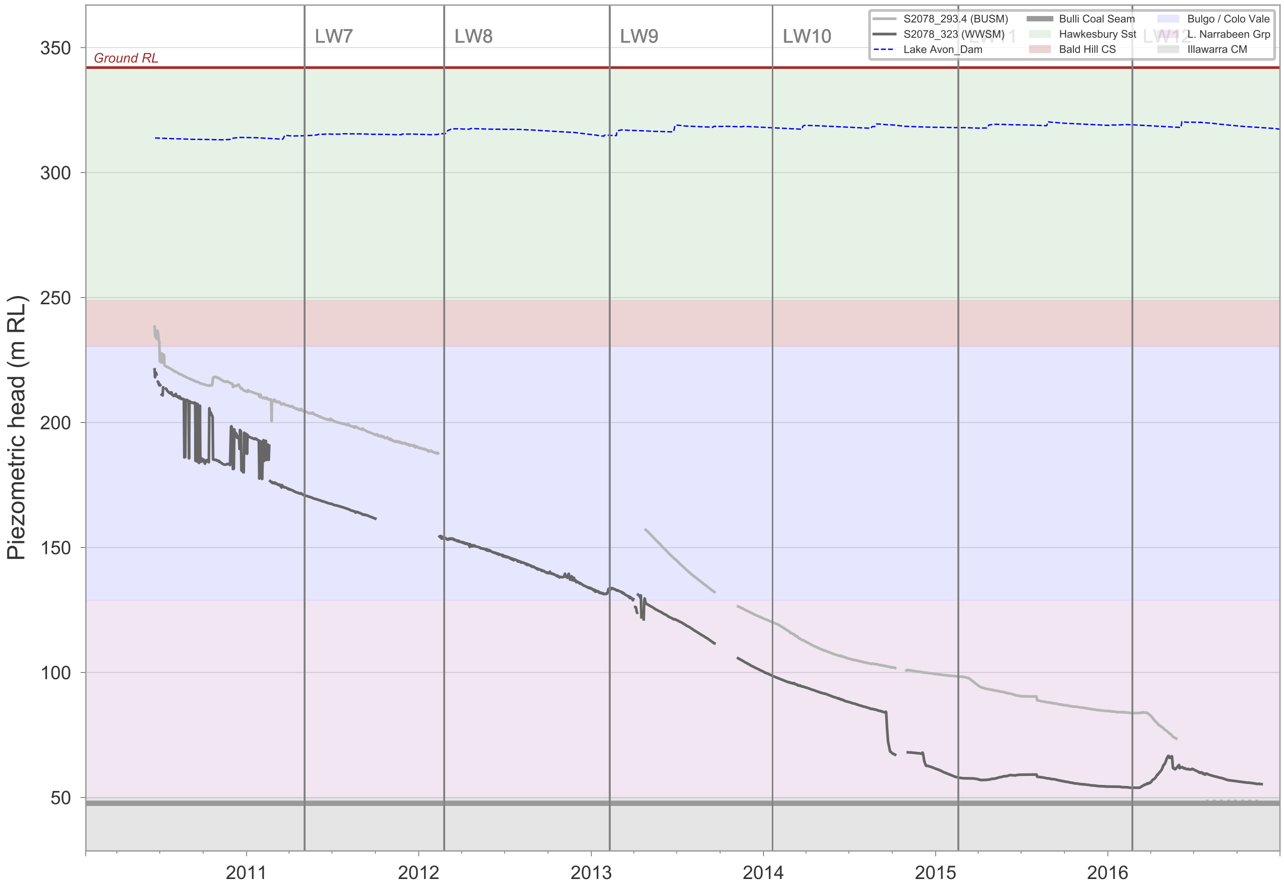

S2059
S2059_33 (HBSS)
S2059_61 (HBSS)
S2059_79 (HBSS)
S2059_113 (BGSS)
S2059_151.5 (BGSS)
S2059_195 (BGSS)
S2059_221 (SBSS)
S2059_242 (SBSS)
S2059_263 (SBSS)
S2059_311.7 (BUSM)
S2059_340.7 (WWSM)
LW10
LW11
LW12
LW13
Pressure head (m H2O)
175
150
125
100
75
50
25
0
2012
2013
2014
2015
2016
2017

Groundwater hydrographs



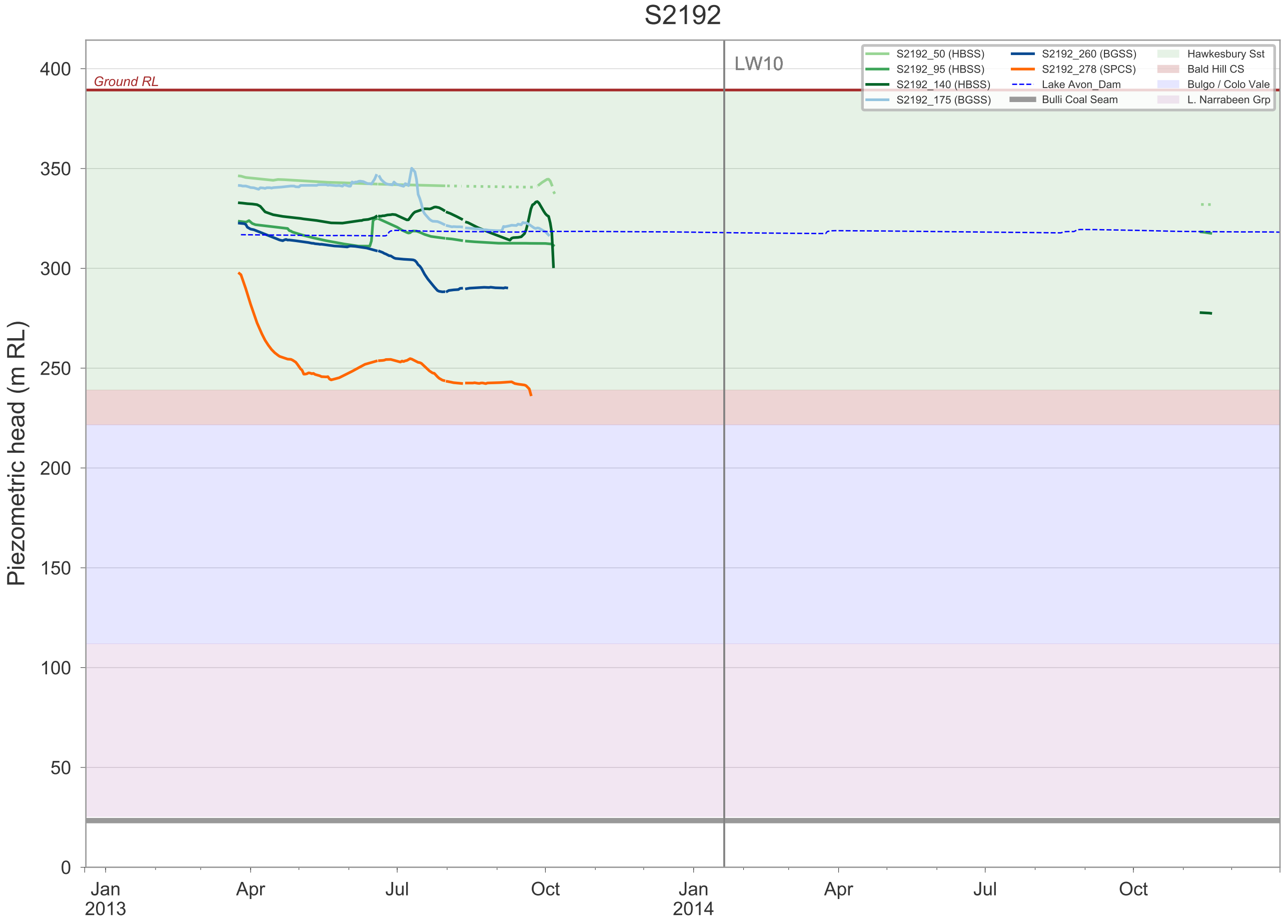


S2078

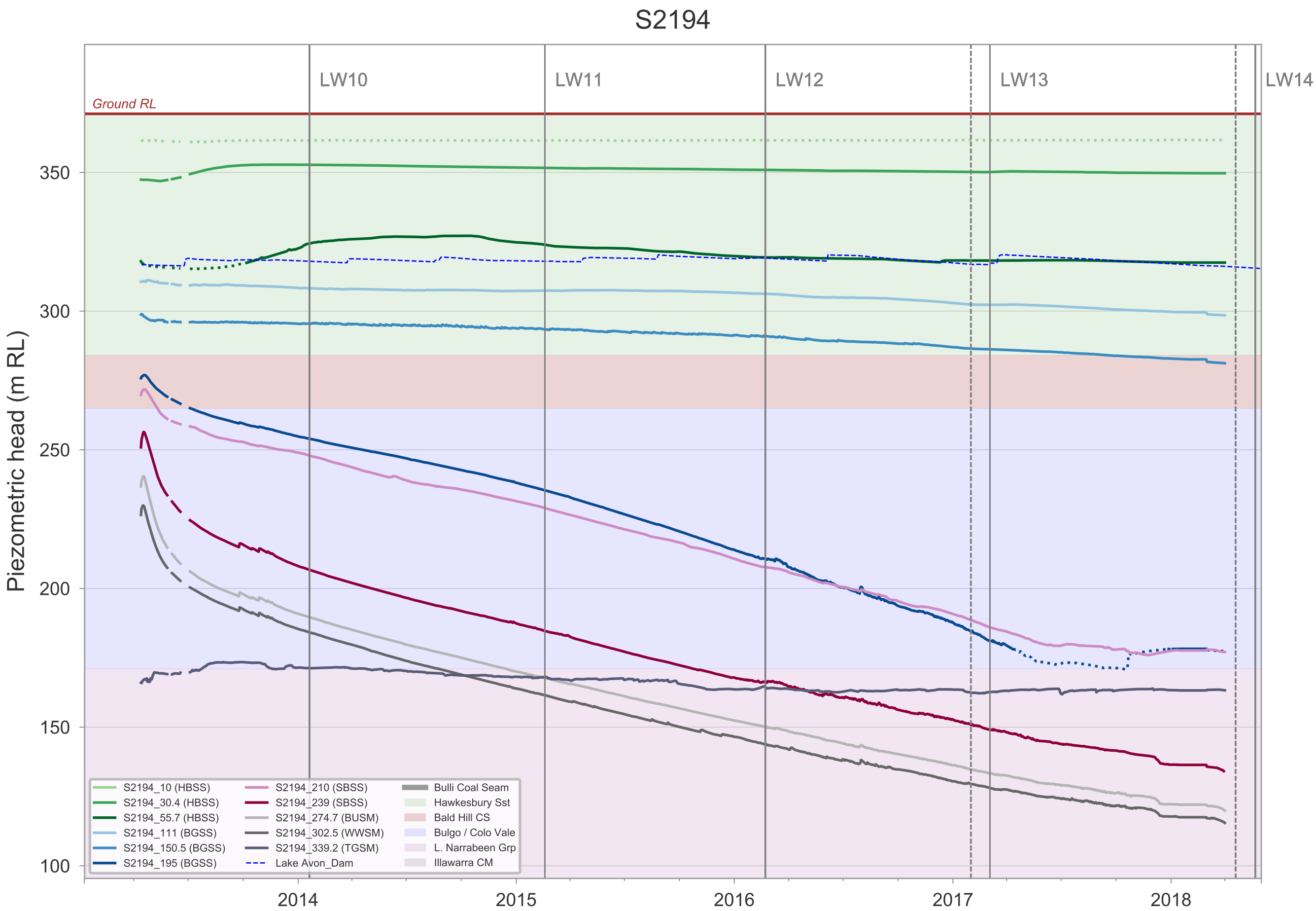

Piezometric head (m RL)
350
300
250
200
150
100
50
Ground RL
LW7
LW8
LW9
LW10
LW11
LW12
S2078_293.4 (BUSM)
S2078_323 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
2011
2012
2013
2014
2015
2016

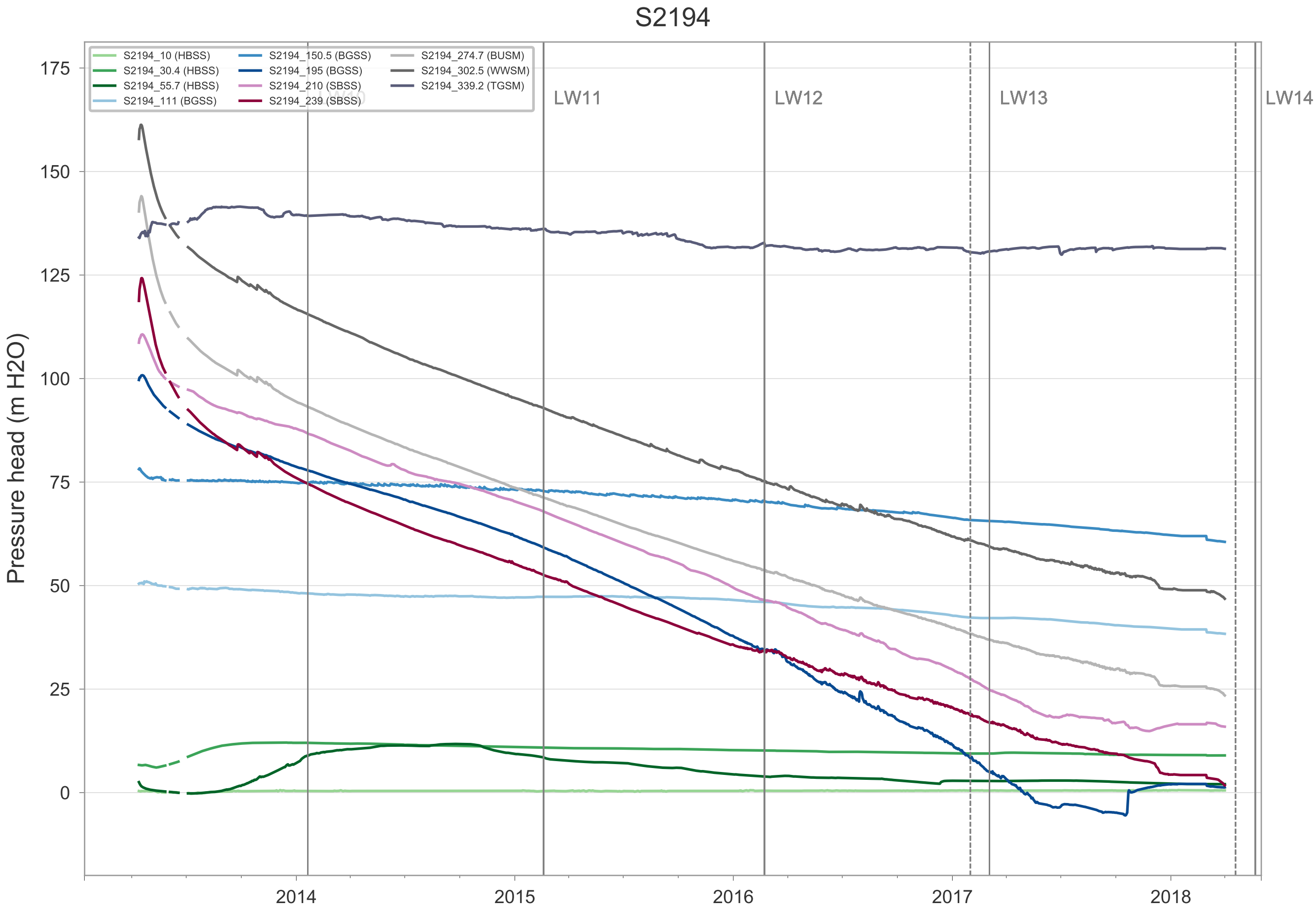
S2078


Pressure head (m H2O)
300
250
200
150
100
50
0
LW7
LW8
LW9
LW10
LW11
LW12
S2078_293.4 (BUSM)
S2078_323 (WWSM)
2011
2012
2013
2014
2015
2016

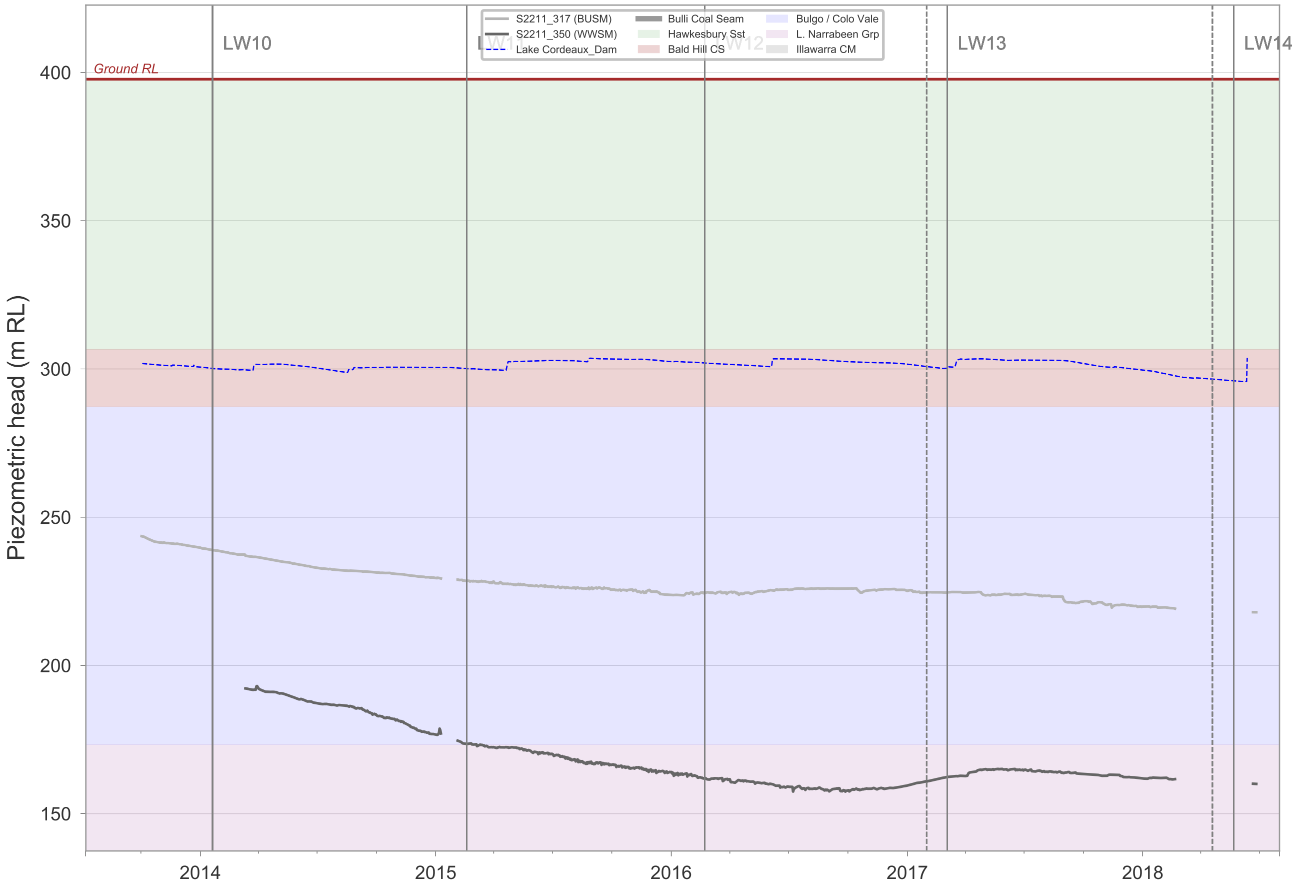

S2192
Ground RL
LW10
S2192_50 (HBSS)
S2192_95 (HBSS)
S2192_140 (HBSS)
S2192_175 (BGSS)
S2192_260 (BGSS)
S2192_278 (SPCS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Piezometric head (m RL)
0
50
100
150
200
250
300
350
400
Jan 2013
Apr
Jul
Oct
Jan 2014
Apr
Jul
Oct


S2192
LW10
S2192_50 (HBSS)
S2192_95 (HBSS)
S2192_140 (HBSS)
S2192_175 (BGSS)
S2192_260 (BGSS)
S2192_278 (SPCS)
Pressure head (m H2O)
0
50
100
150
200
250
300
350
Apr
Jul
Oct
Jan 2014
Apr
Jul
Oct

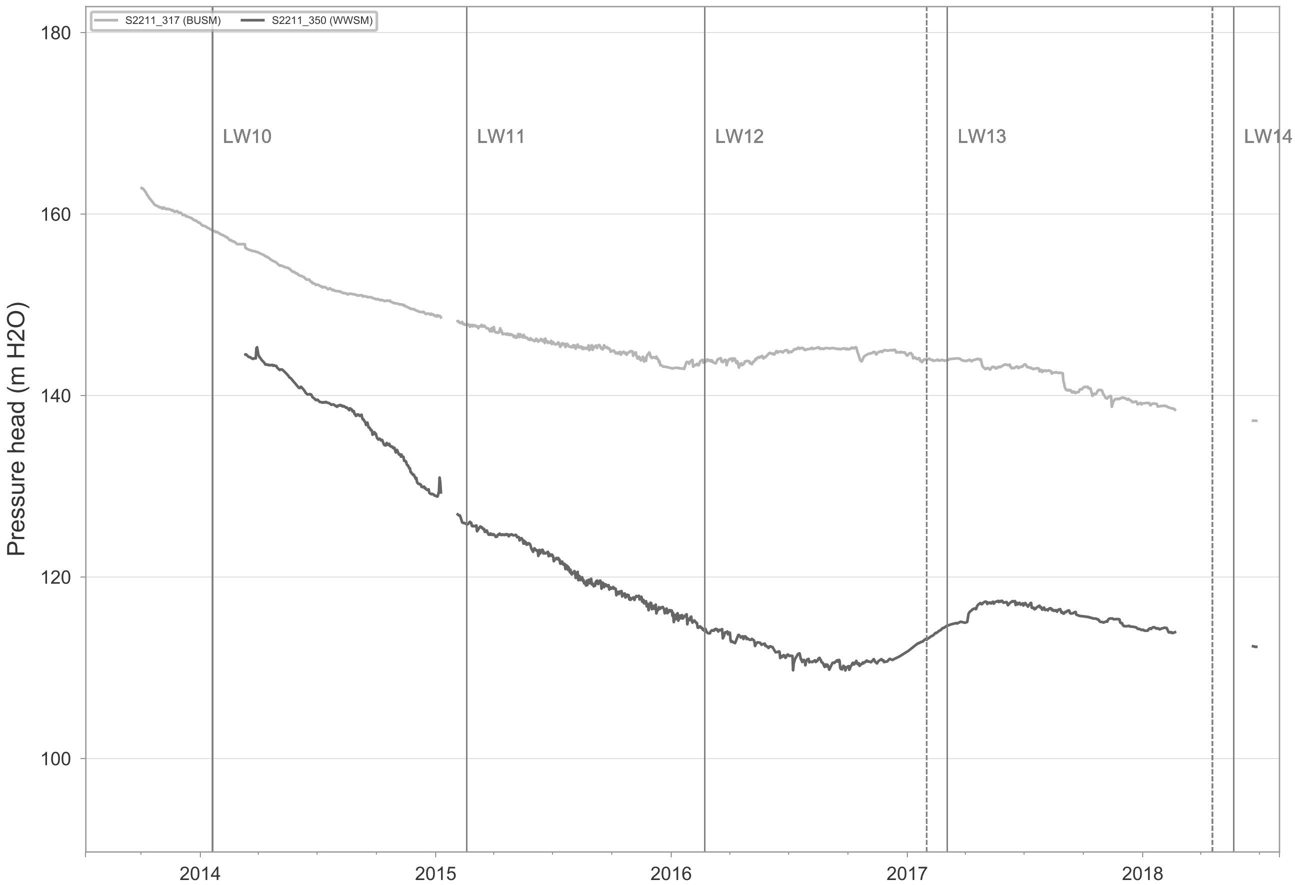

S2194
LW10
LW11
LW12
LW13
LW14
Ground RL
Piezometric head (m RL)
350
300
250
200
150
100
2014
2015
2016
2017
2018
S2194_10 (HBSS)
S2194_30.4 (HBSS)
S2194_55.7 (HBSS)
S2194_111 (BGSS)
S2194_150.5 (BGSS)
S2194_195 (BGSS)
S2194_210 (SBSS)
S2194_239 (SBSS)
S2194_274.7 (BUSM)
S2194_302.5 (WWSM)
S2194_339.2 (TGSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM

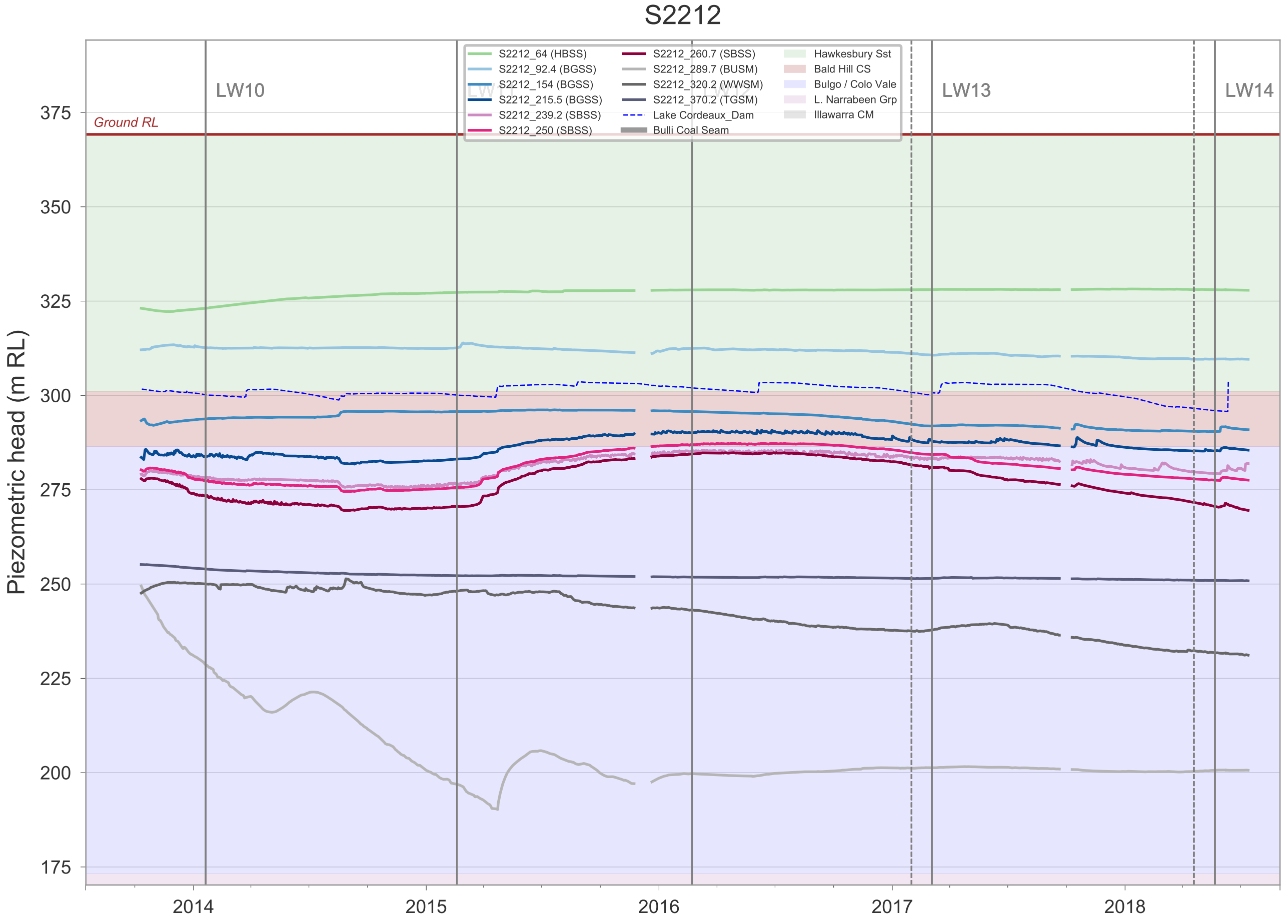

S2194
LW11
LW12
LW13
LW14
Pressure head (m H2O)
175
150
125
100
75
50
25
0
2014
2015
2016
2017
2018
S2194_10 (HBSS)
S2194_30.4 (HBSS)
S2194_55.7 (HBSS)
S2194_111 (BGSS)
S2194_150.5 (BGSS)
S2194_195 (BGSS)
S2194_210 (SBSS)
S2194_239 (SBSS)
S2194_274.7 (BUSM)
S2194_302.5 (WWSM)
S2194_339.2 (TGSM)

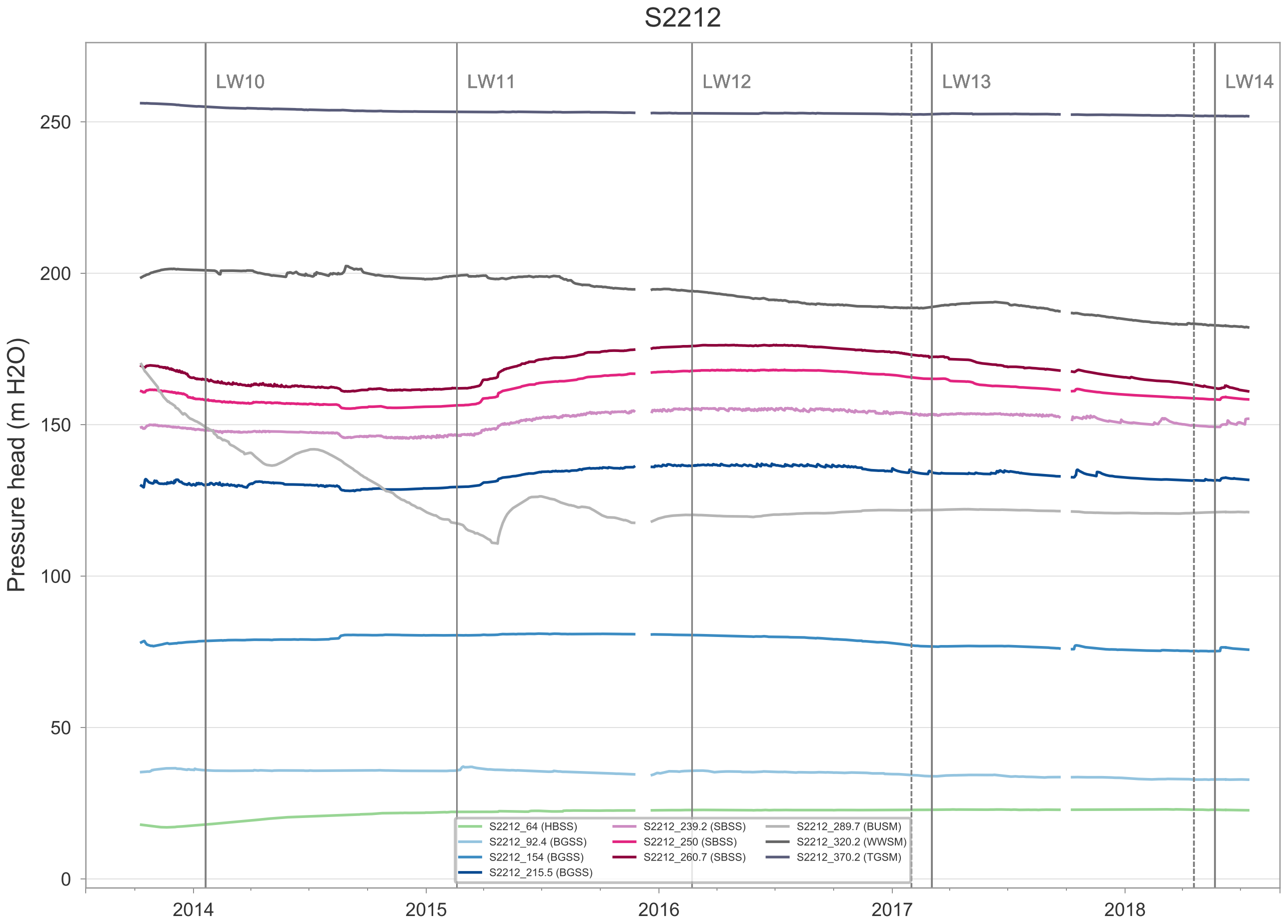
S2211

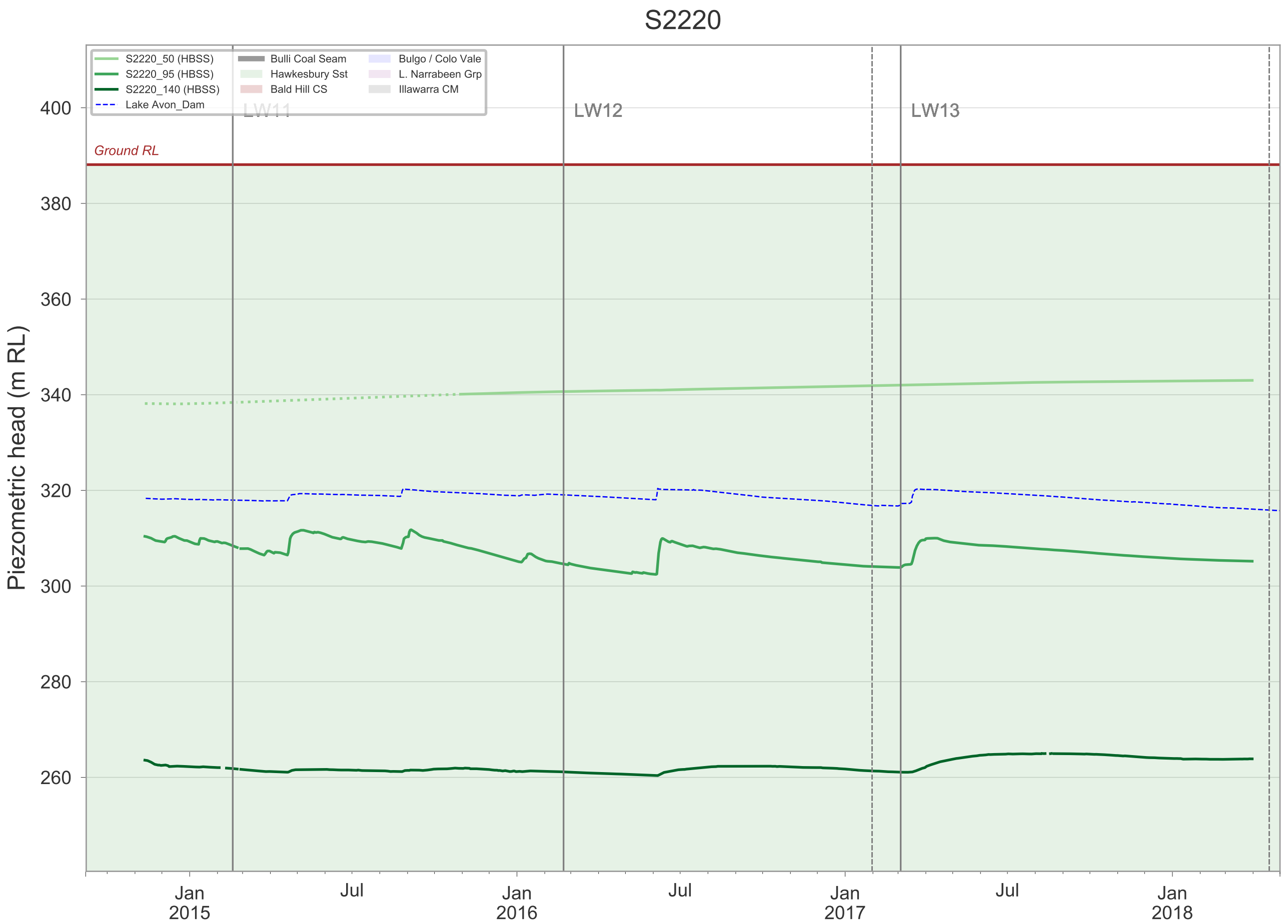

S2211_317 (BUSM)
S2211_350 (WWSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW10
LW11
LW12
LW13
LW14
Ground RL
Piezometric head (m RL)
400
350
300
250
200
150
2014
2015
2016
2017
2018

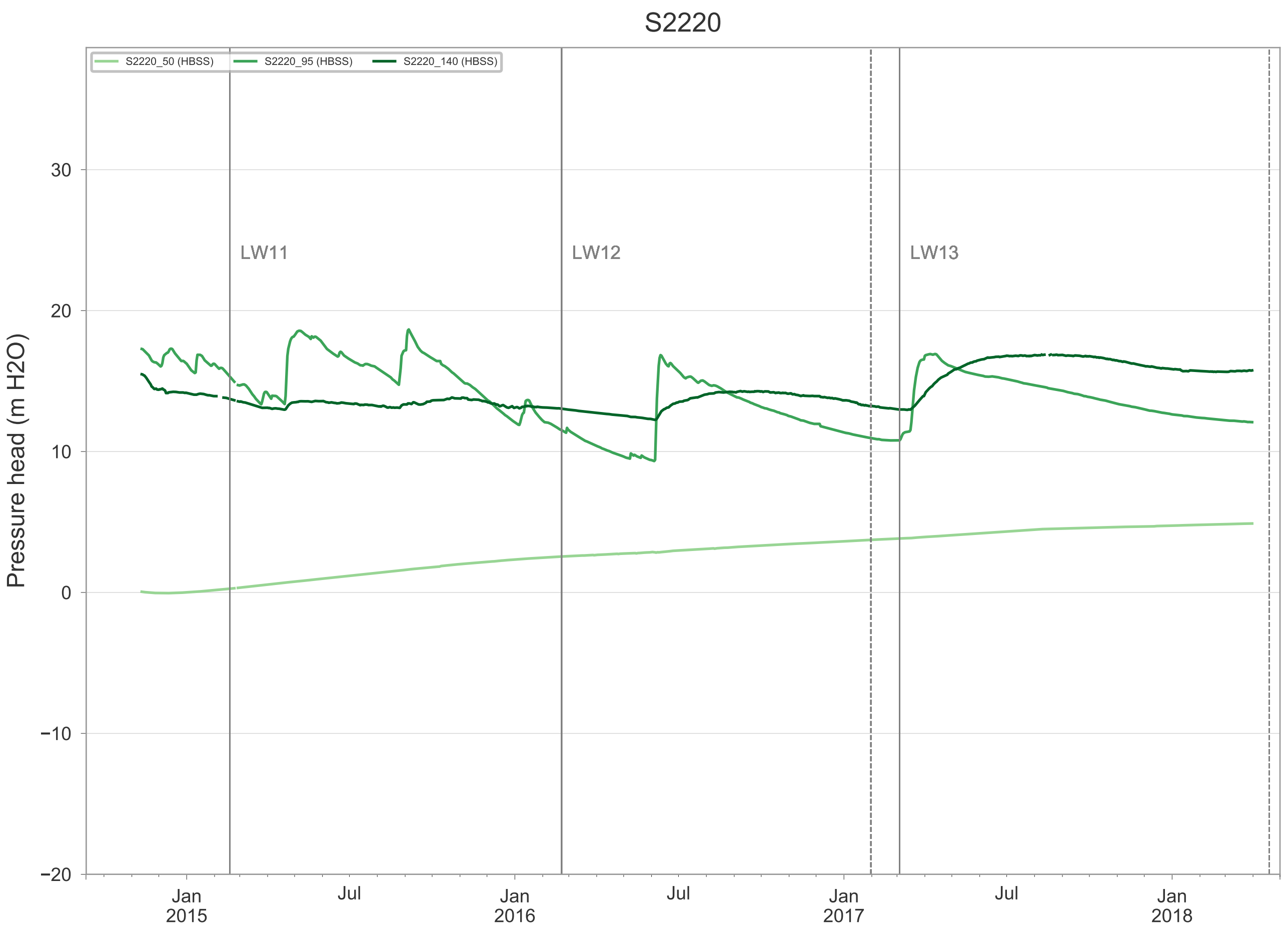
S2211


S2211_317 (BUSM)
S2211_350 (WWSM)
LW10
LW11
LW12
LW13
LW14
Pressure head (m H2O)
180
160
140
120
100
2014
2015
2016
2017
2018

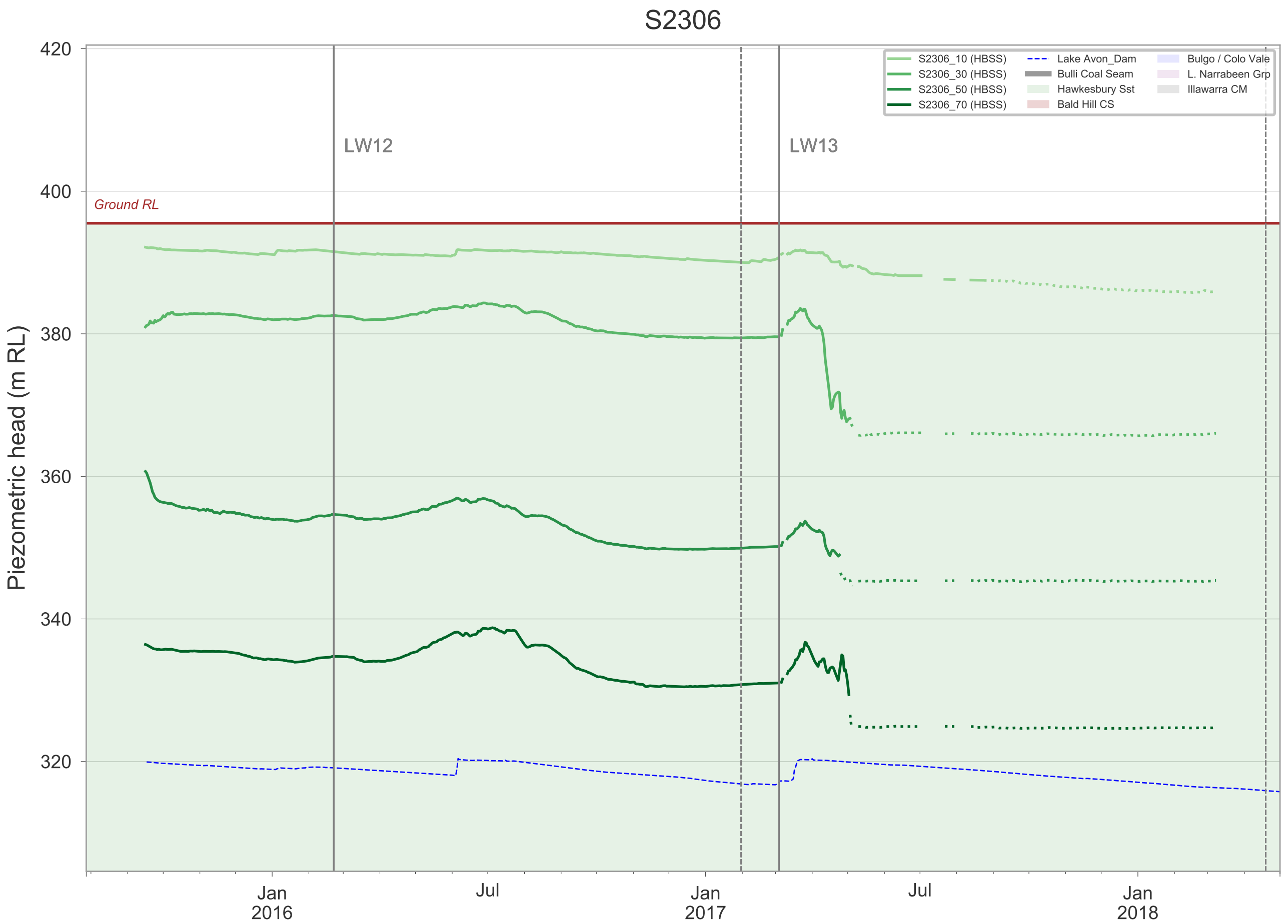

S2212
Piezometric head (m RL)
Ground RL
LW10
LW13
LW14
S2212_64 (HBSS)
S2212_92.4 (BGSS)
S2212_154 (BGSS)
S2212_215.5 (BGSS)
S2212_239.2 (SBSS)
S2212_250 (SBSS)
S2212_260.7 (SBSS)
S2212_289.7 (BUSM)
S2212_320.2 (WWSM)
S2212_370.2 (TGSM)
Lake Cordeaux_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
375
350
325
300
275
250
225
200
175
2014
2015
2016
2017
2018

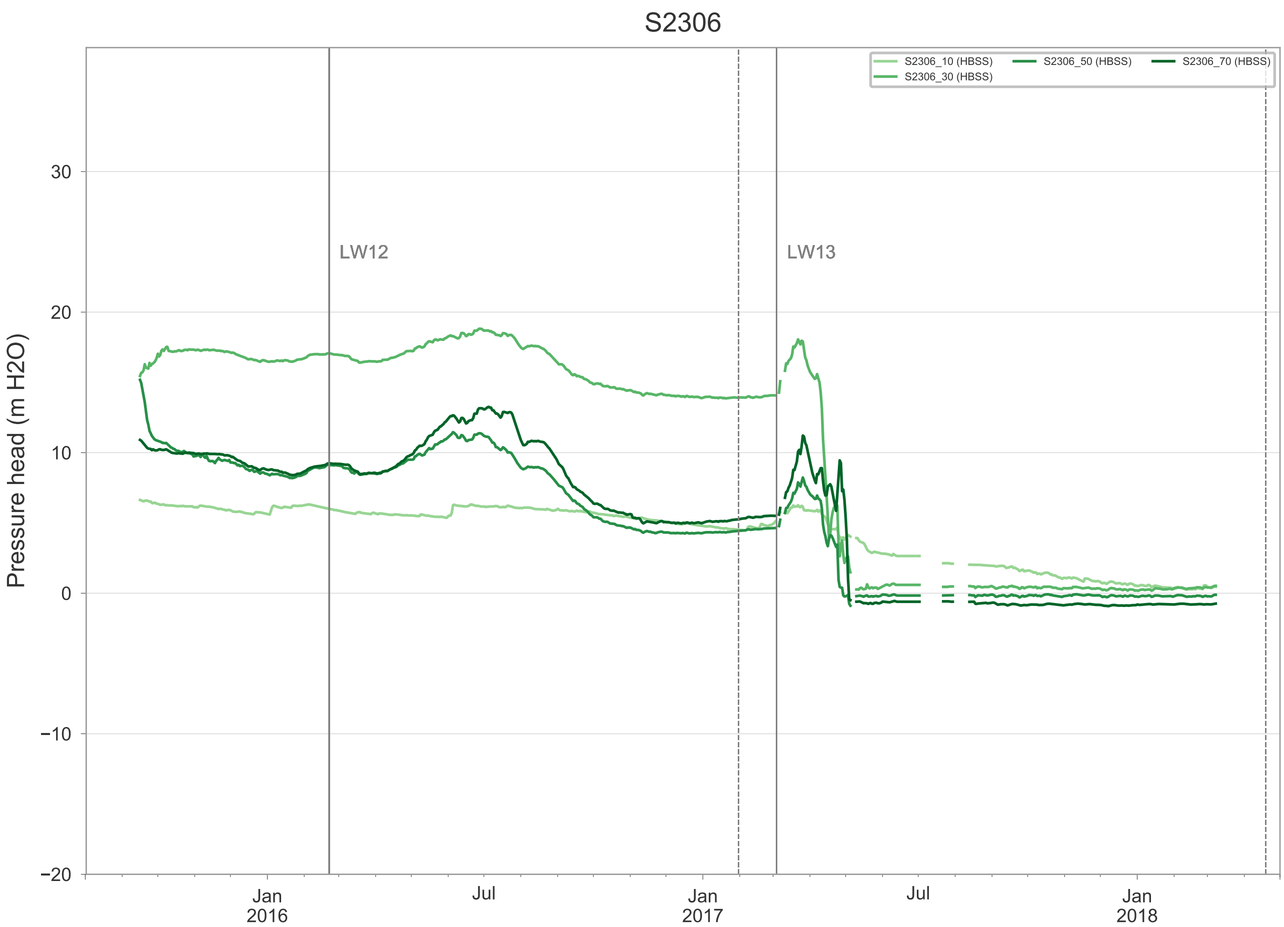

S2212
Pressure head (m H2O)
LW10
LW11
LW12
LW13
LW14
S2212_64 (HBSS)
S2212_92.4 (BGSS)
S2212_154 (BGSS)
S2212_215.5 (BGSS)
S2212_239.2 (SBSS)
S2212_250 (SBSS)
S2212_260.7 (SBSS)
S2212_289.7 (BUSM)
S2212_320.2 (WWSM)
S2212_370.2 (TGSM)
250
200
150
100
50
0
2014
2015
2016
2017
2018

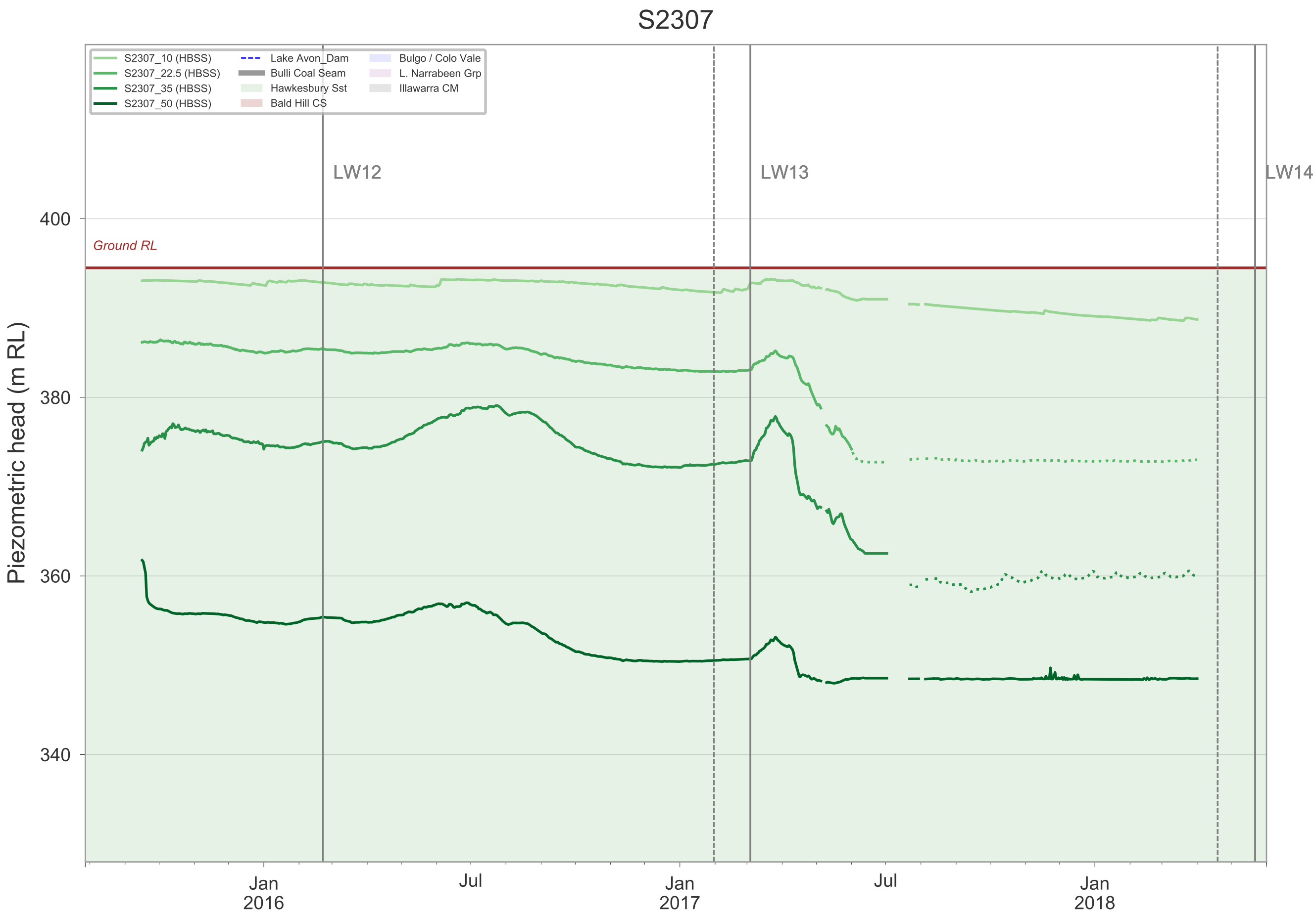

S2220
S2220_50 (HBSS)
S2220_95 (HBSS)
S2220_140 (HBSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW11
LW12
LW13
Ground RL
Piezometric head (m RL)
400
380
360
340
320
300
280
260
Jan 2015
Jul
Jan 2016
Jul
Jan 2017
Jul
Jan 2018

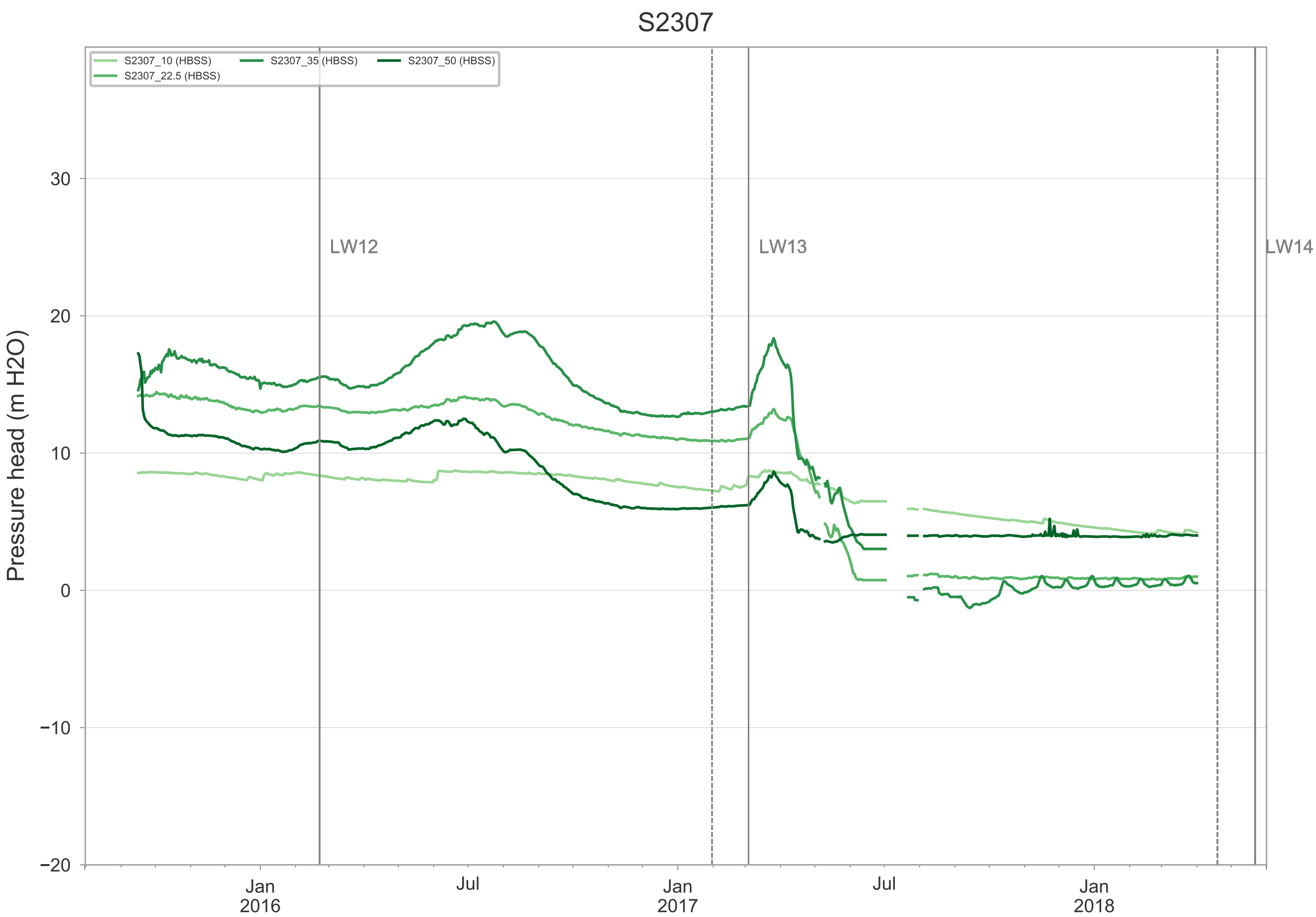

S2220
S2220_50 (HBSS)
S2220_95 (HBSS)
S2220_140 (HBSS)
LW11
LW12
LW13
Pressure head (m H2O)
30
20
10
0
−10
−20
Jan 2015
Jul
Jan 2016
Jul
Jan 2017
Jul
Jan 2018

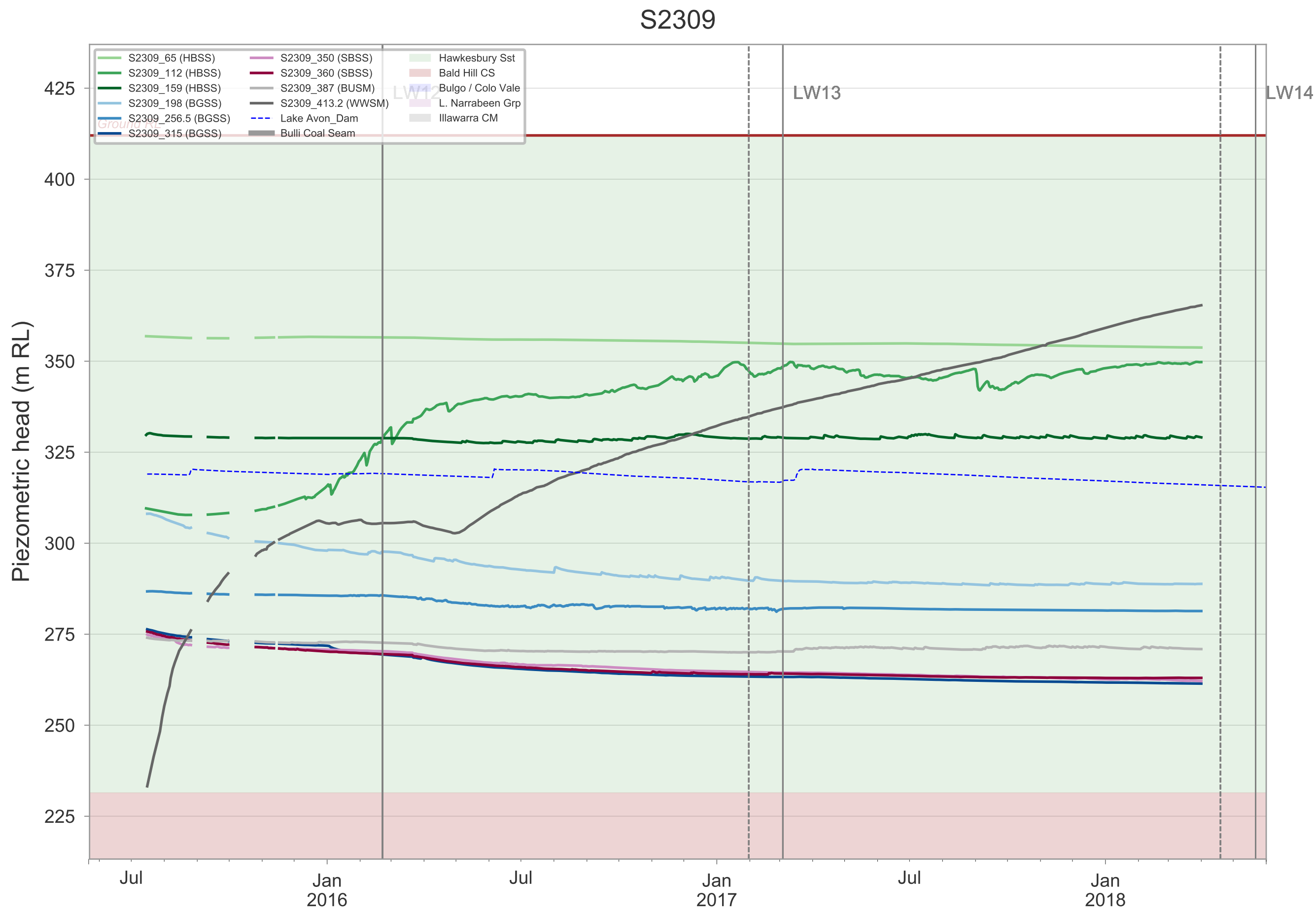
Groundwater hydrographs

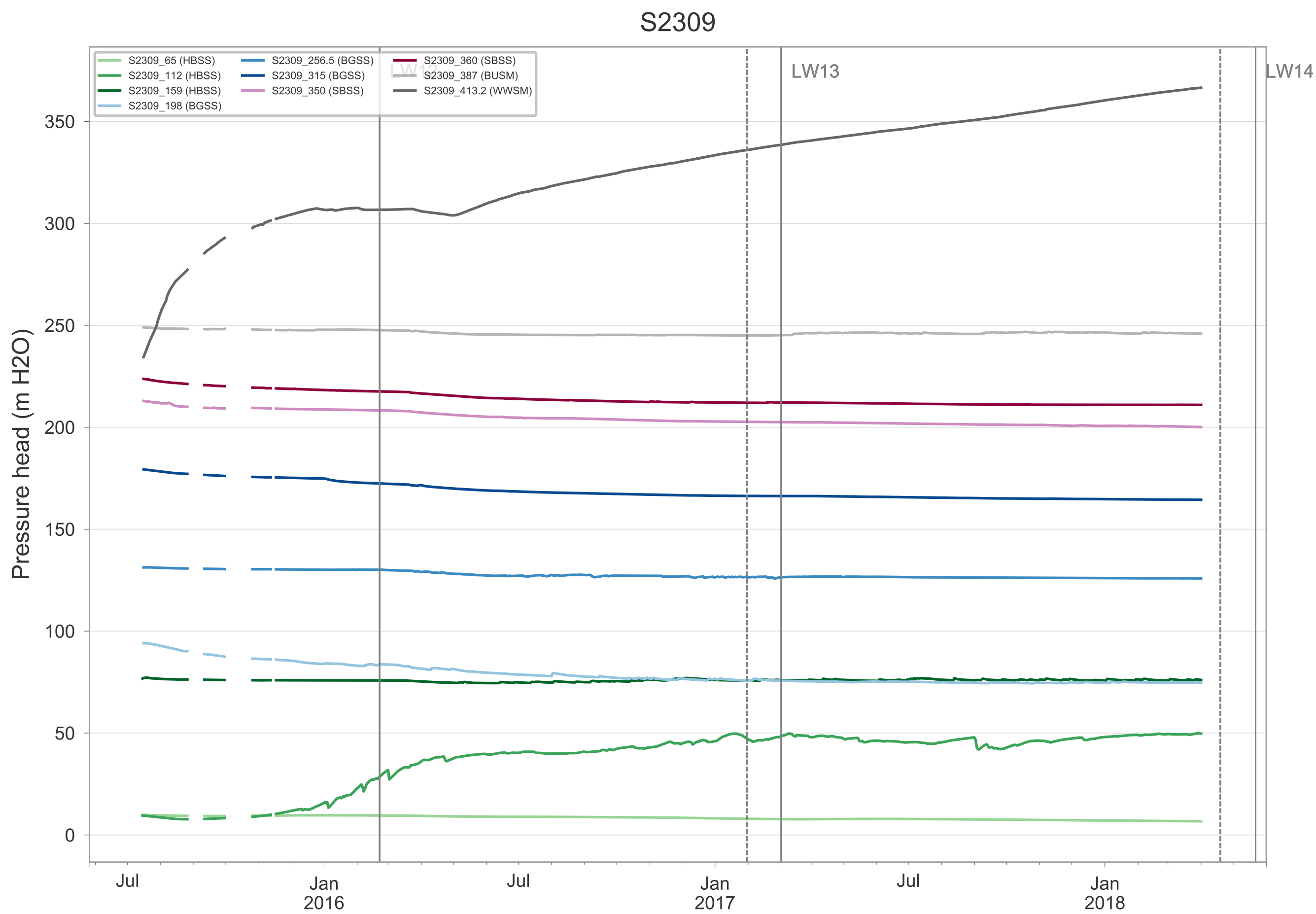


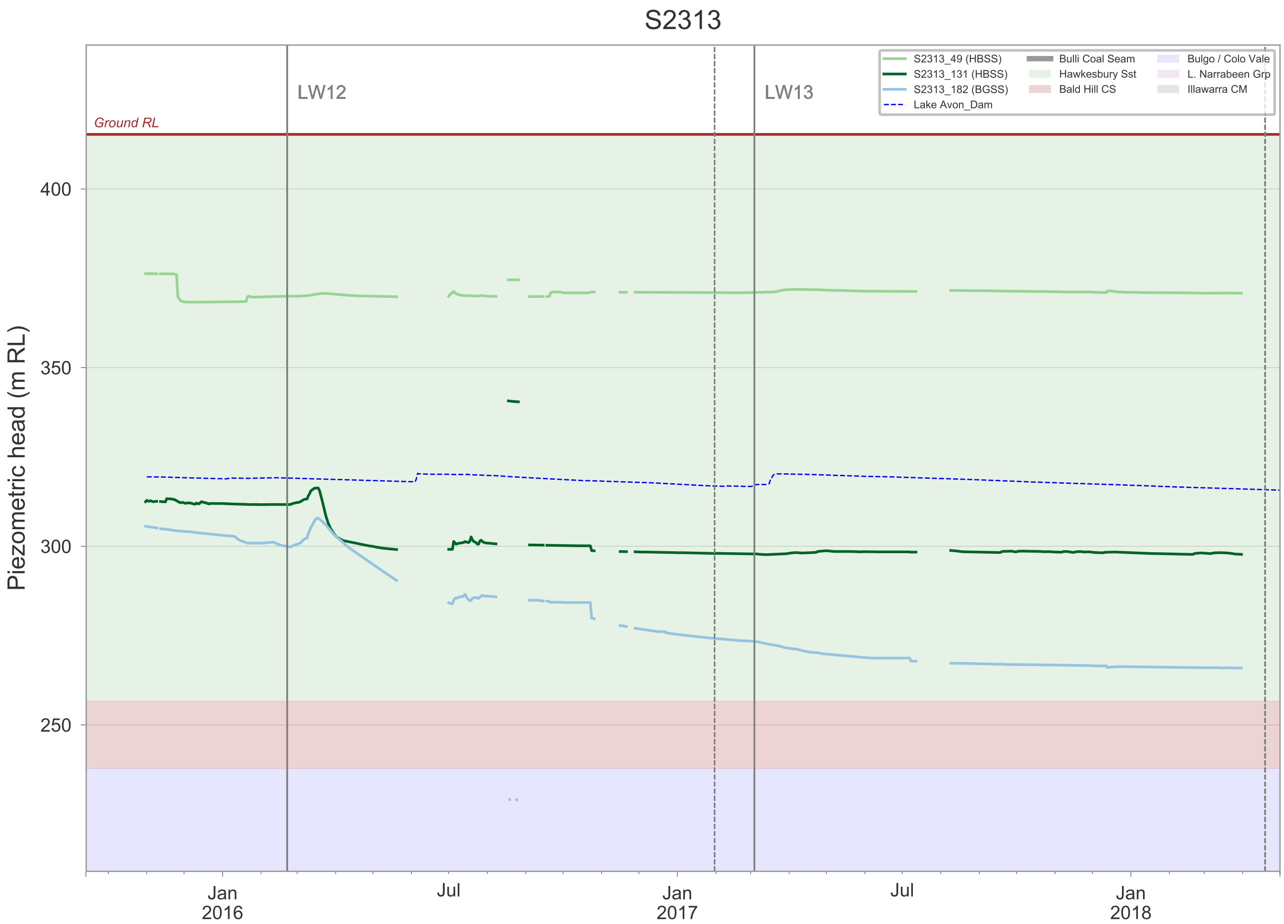


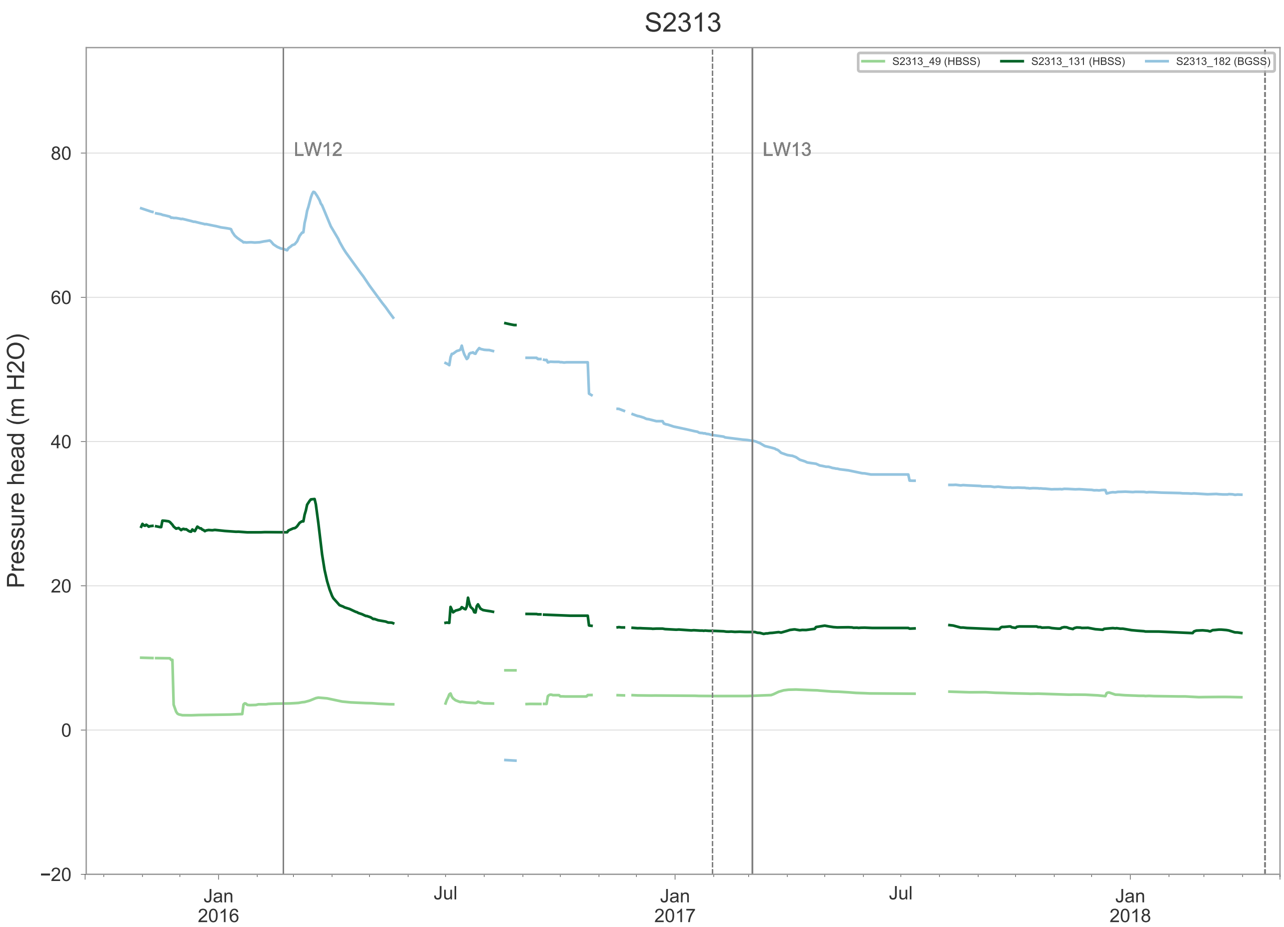

S2307
S2307_10 (HBSS)
S2307_22.5 (HBSS)
S2307_35 (HBSS)
S2307_50 (HBSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW12
LW13
LW14
Ground RL
Piezometric head (m RL)
400
380
360
340
Jan 2016
Jul
Jan 2017
Jul
Jan 2018


S2307
S2307_10 (HBSS)
S2307_22.5 (HBSS)
S2307_35 (HBSS)
S2307_50 (HBSS)
LW12
LW13
LW14
Pressure head (m H2O)
30
20
10
0
−10
−20
Jan 2016
Jul
Jan 2017
Jul
Jan 2018

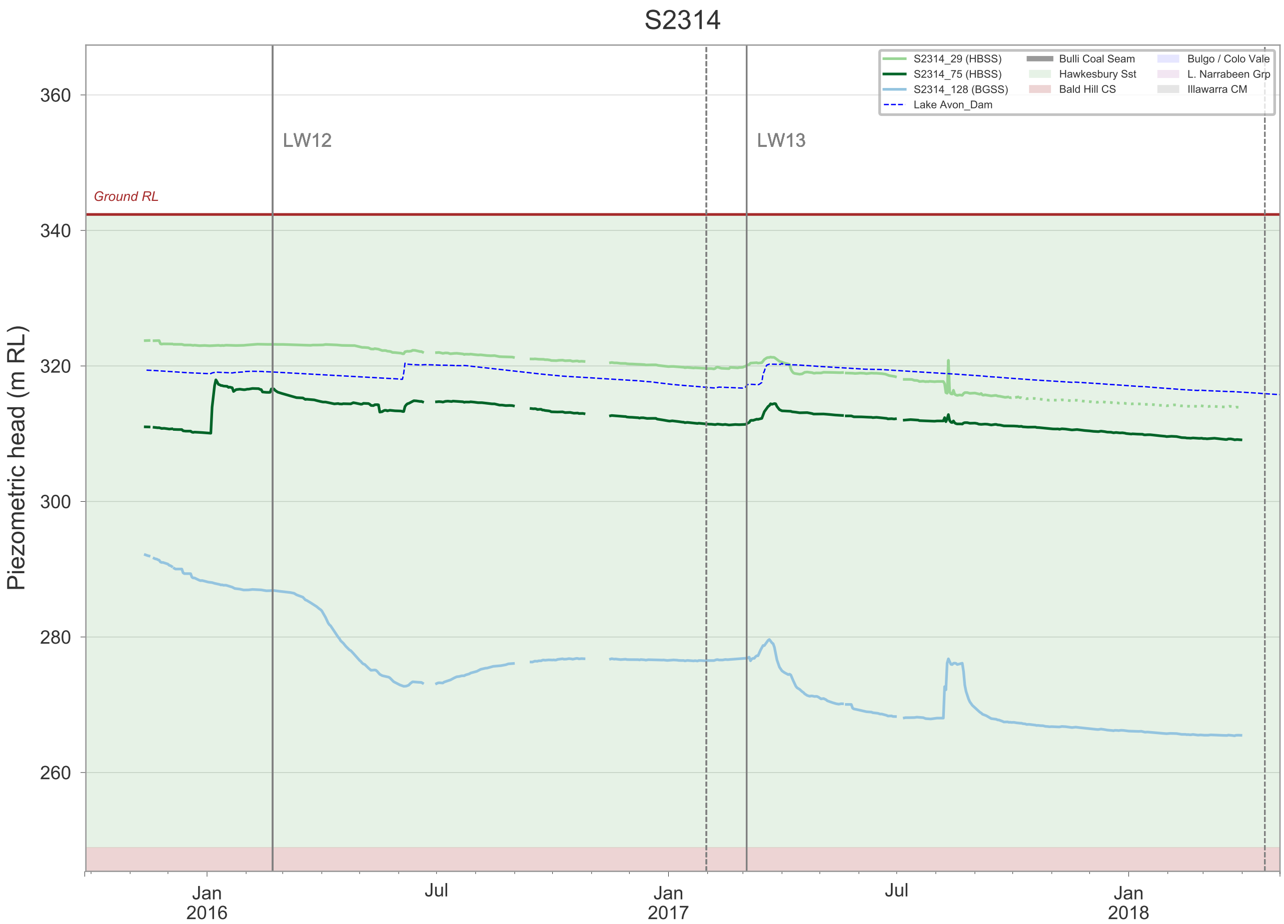

S2309
Piezometric head (m RL)
S2309_65 (HBSS)
S2309_112 (HBSS)
S2309_159 (HBSS)
S2309_198 (BGSS)
S2309_256.5 (BGSS)
S2309_315 (BGSS)
S2309_350 (SBSS)
S2309_360 (SBSS)
S2309_387 (BUSM)
S2309_413.2 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW12
LW13
LW14
425
400
375
350
325
300
275
250
225
Jul
Jan 2016
Jul
Jan 2017
Jul
Jan 2018

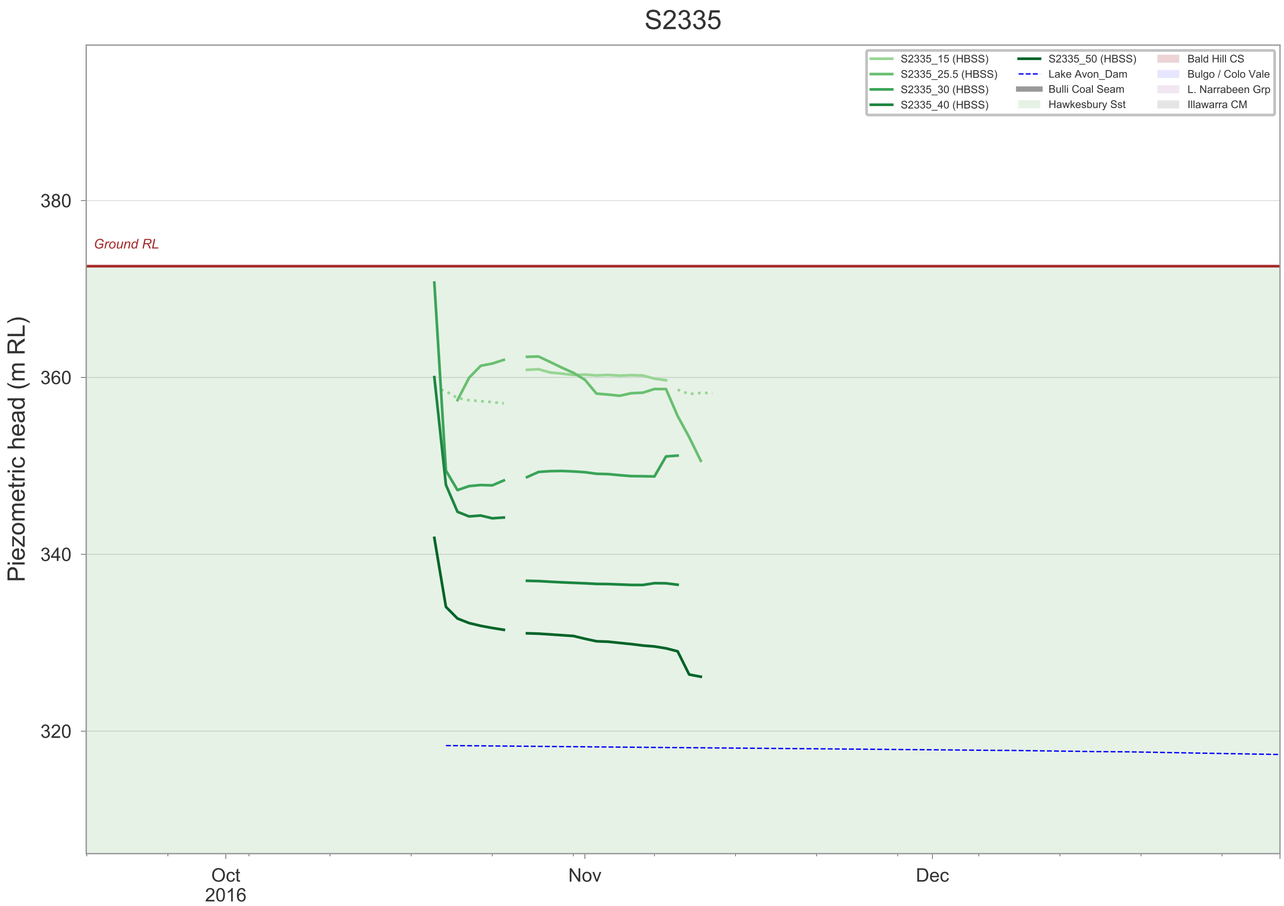

S2309
Pressure head (m H2O)
S2309_65 (HBSS)
S2309_112 (HBSS)
S2309_159 (HBSS)
S2309_198 (BGSS)
S2309_256.5 (BGSS)
S2309_315 (BGSS)
S2309_350 (SBSS)
S2309_360 (SBSS)
S2309_387 (BUSM)
S2309_413.2 (WWSM)
LW13
LW14
350
300
250
200
150
100
50
0
Jul
Jan 2016
Jul
Jan 2017
Jul
Jan 2018

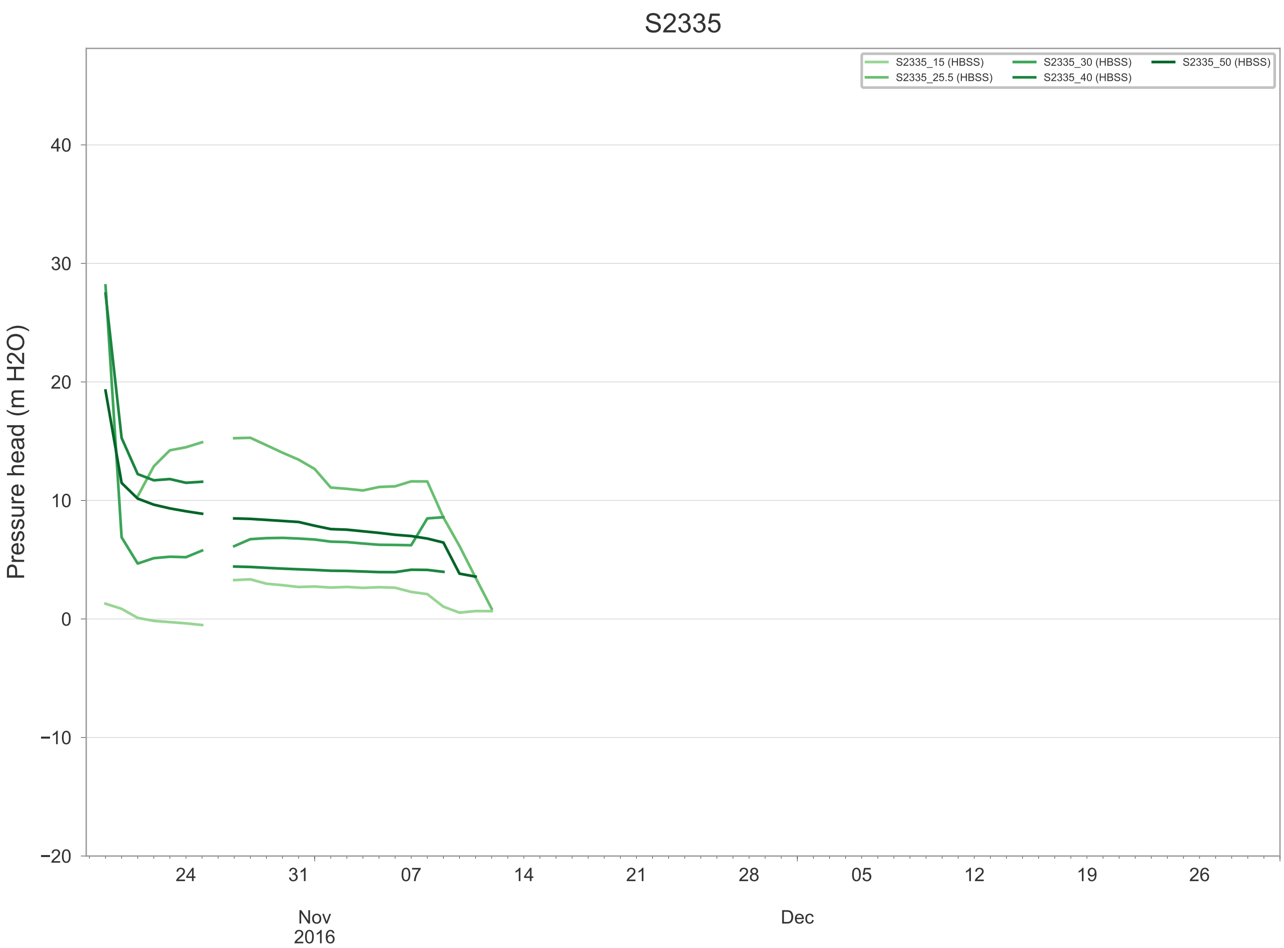

S2313
S2313_49 (HBSS)
S2313_131 (HBSS)
S2313_182 (BGSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW12
LW13
Ground RL
Piezometric head (m RL)
400
350
300
250
Jan 2016
Jul
Jan 2017
Jul
Jan 2018

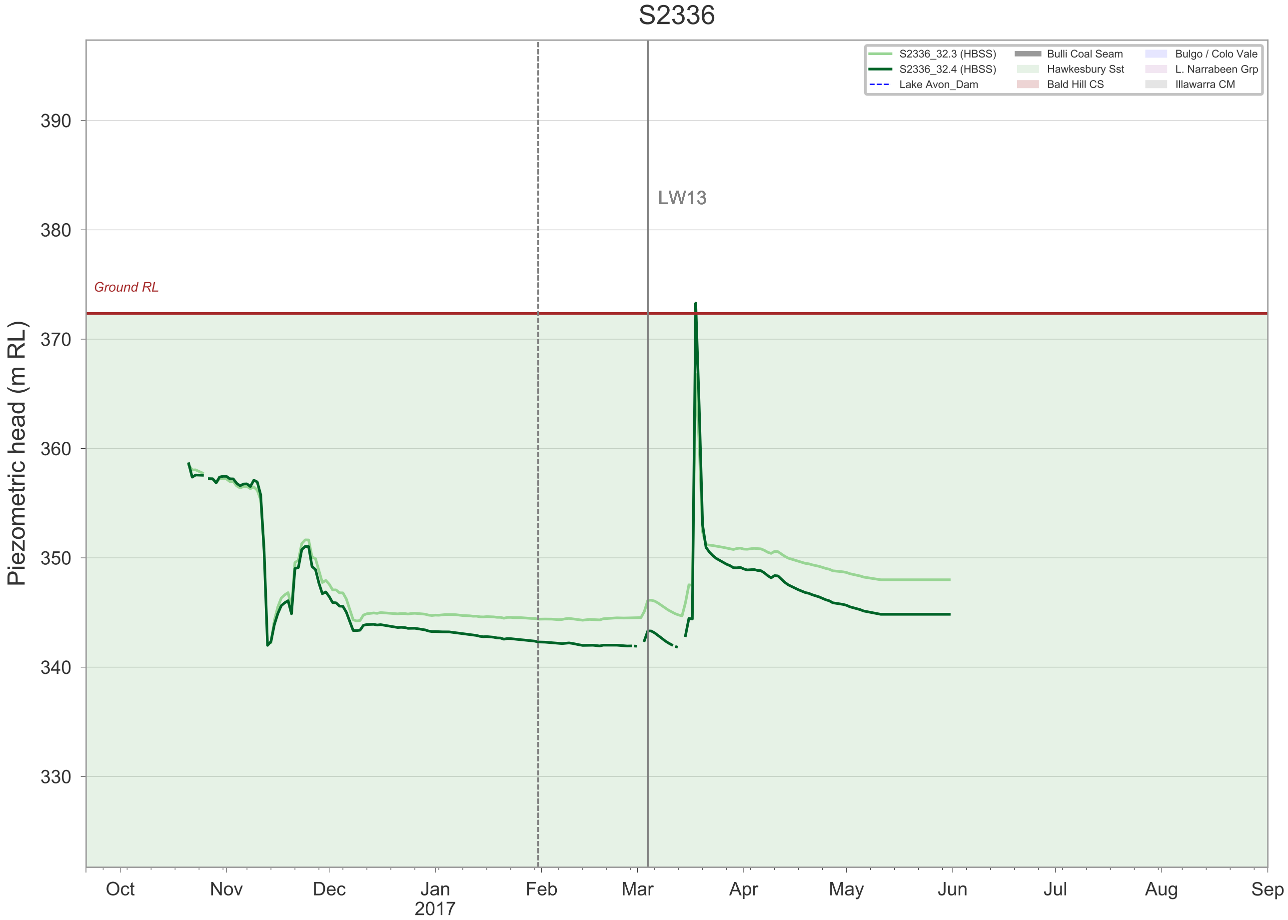

S2313
S2313_49 (HBSS)
S2313_131 (HBSS)
S2313_182 (BGSS)
LW12
LW13
Pressure head (m H2O)
80
60
40
20
0
−20
Jan 2016
Jul
Jan 2017
Jul
Jan 2018

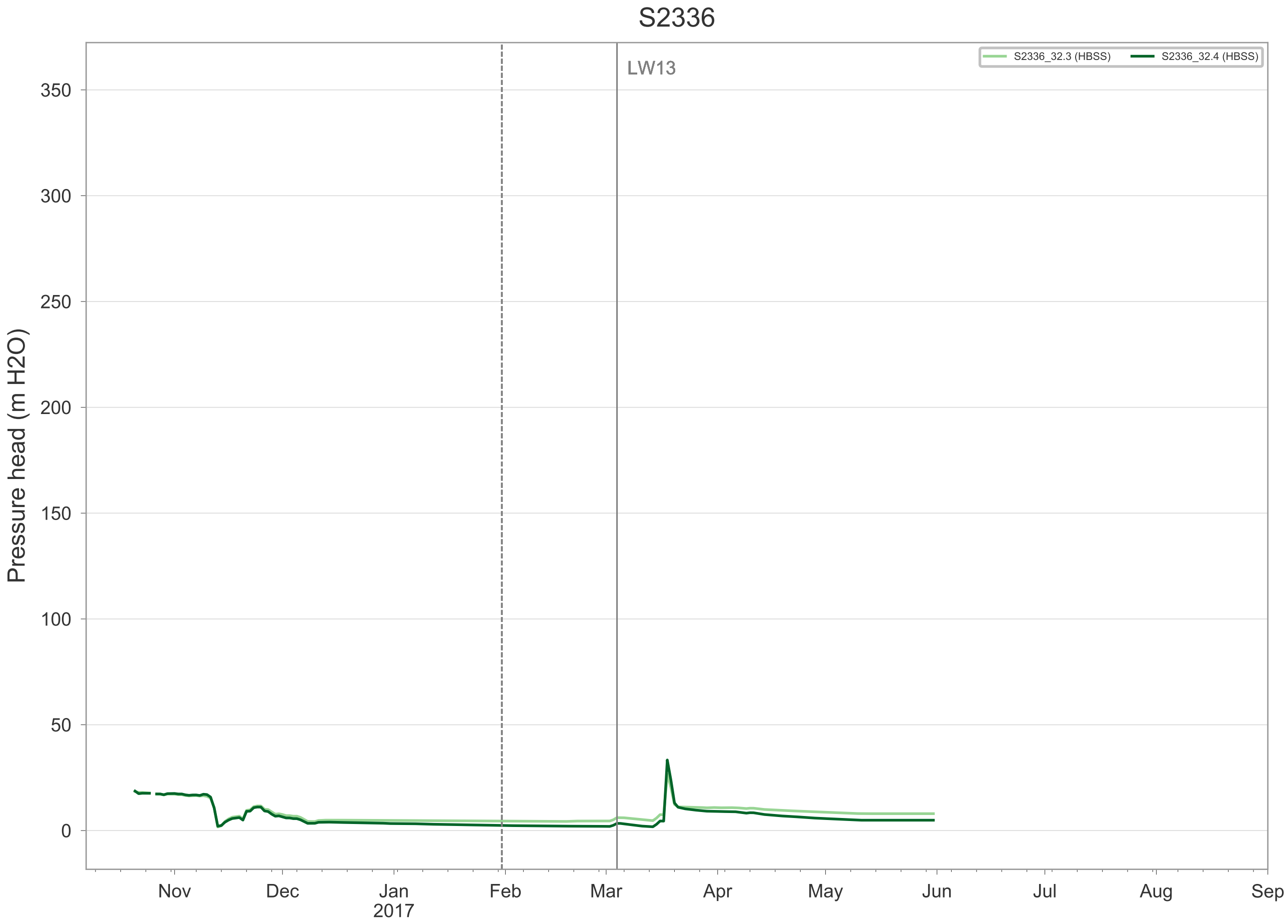
Groundwater hydrographs



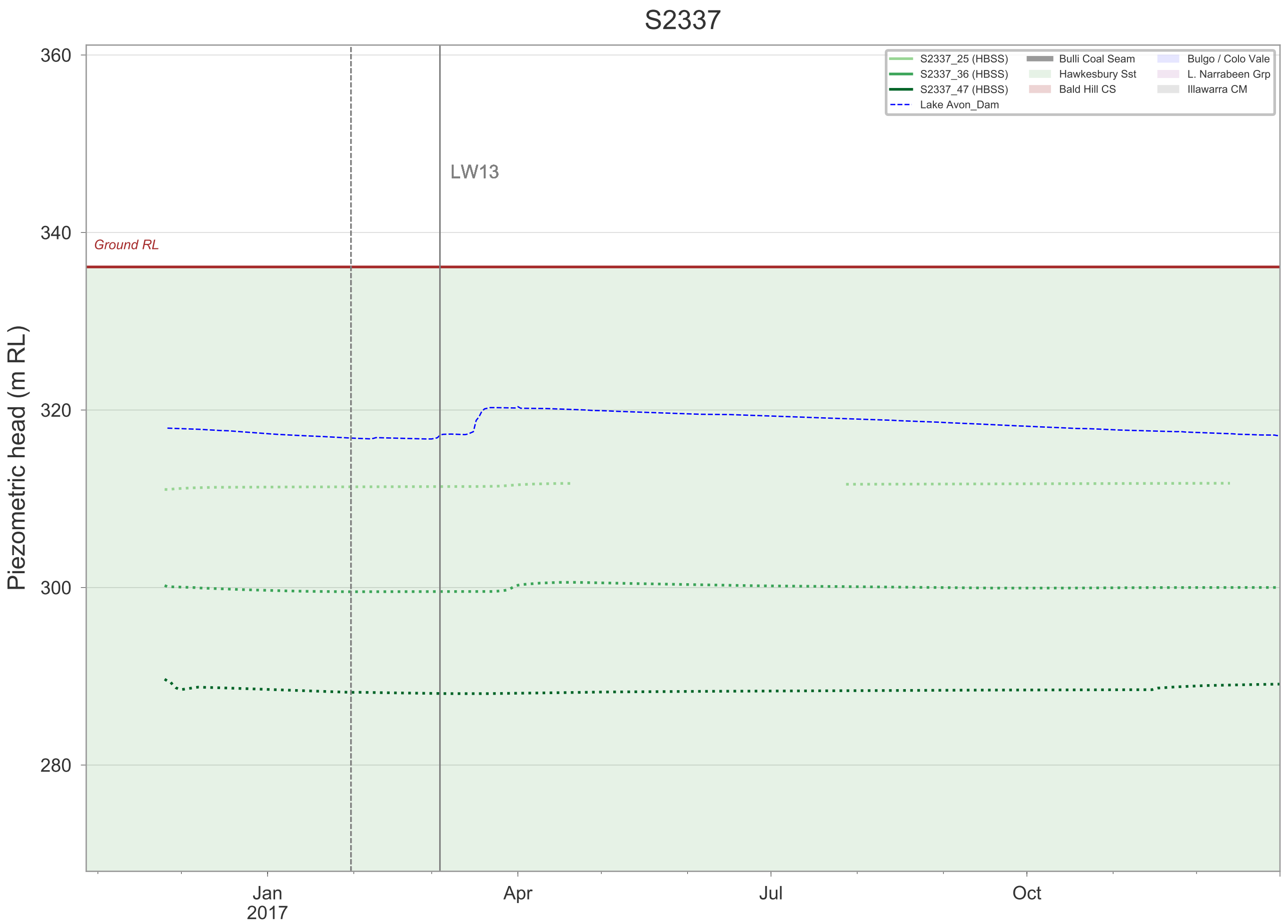

S2335
S2335_15 (HBSS)
S2335_25.5 (HBSS)
S2335_30 (HBSS)
S2335_40 (HBSS)
S2335_50 (HBSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Ground RL
Piezometric head (m RL)
380
360
340
320
Oct
2016
Nov
Dec

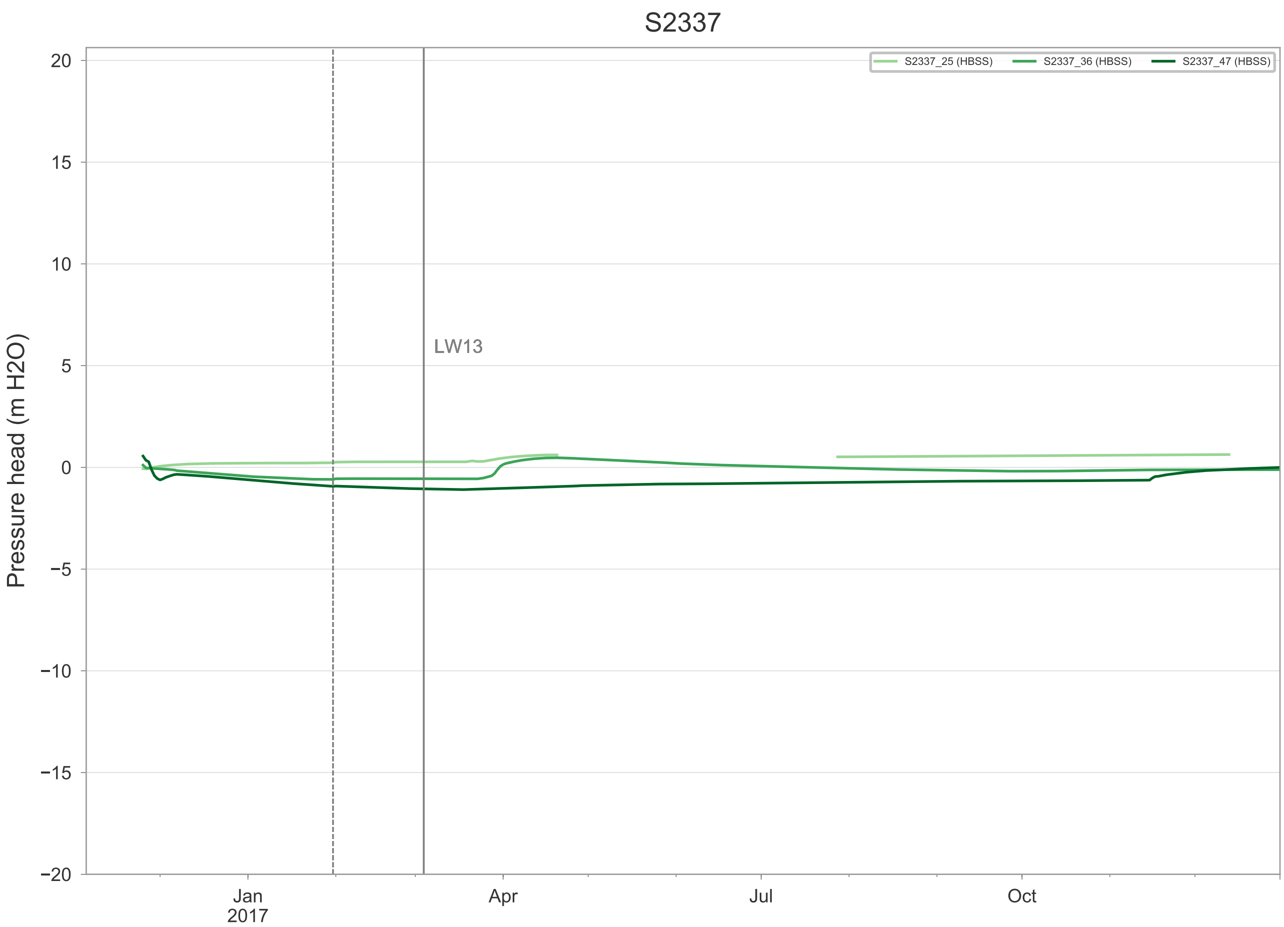

S2335
S2335_15 (HBSS)
S2335_25.5 (HBSS)
S2335_30 (HBSS)
S2335_40 (HBSS)
S2335_50 (HBSS)
Pressure head (m H2O)
40
30
20
10
0
−10
−20
24
31
07
14
21
28
05
12
19
26
Nov
2016
Dec

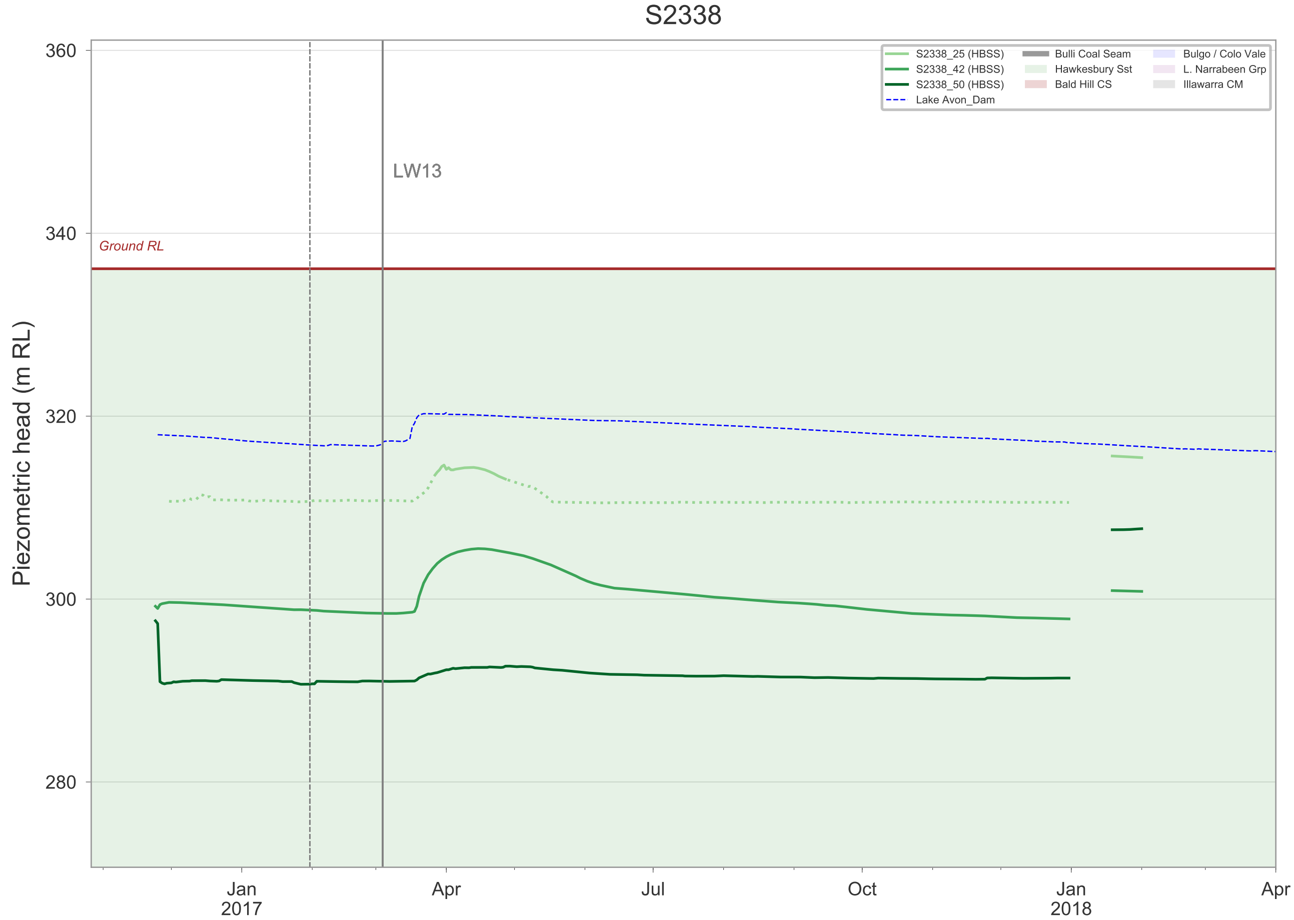

S2336
S2336_32.3 (HBSS)
S2336_32.4 (HBSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW13
Ground RL
Piezometric head (m RL)
390
380
370
360
350
340
330
Oct
Nov
Dec
Jan
2017
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

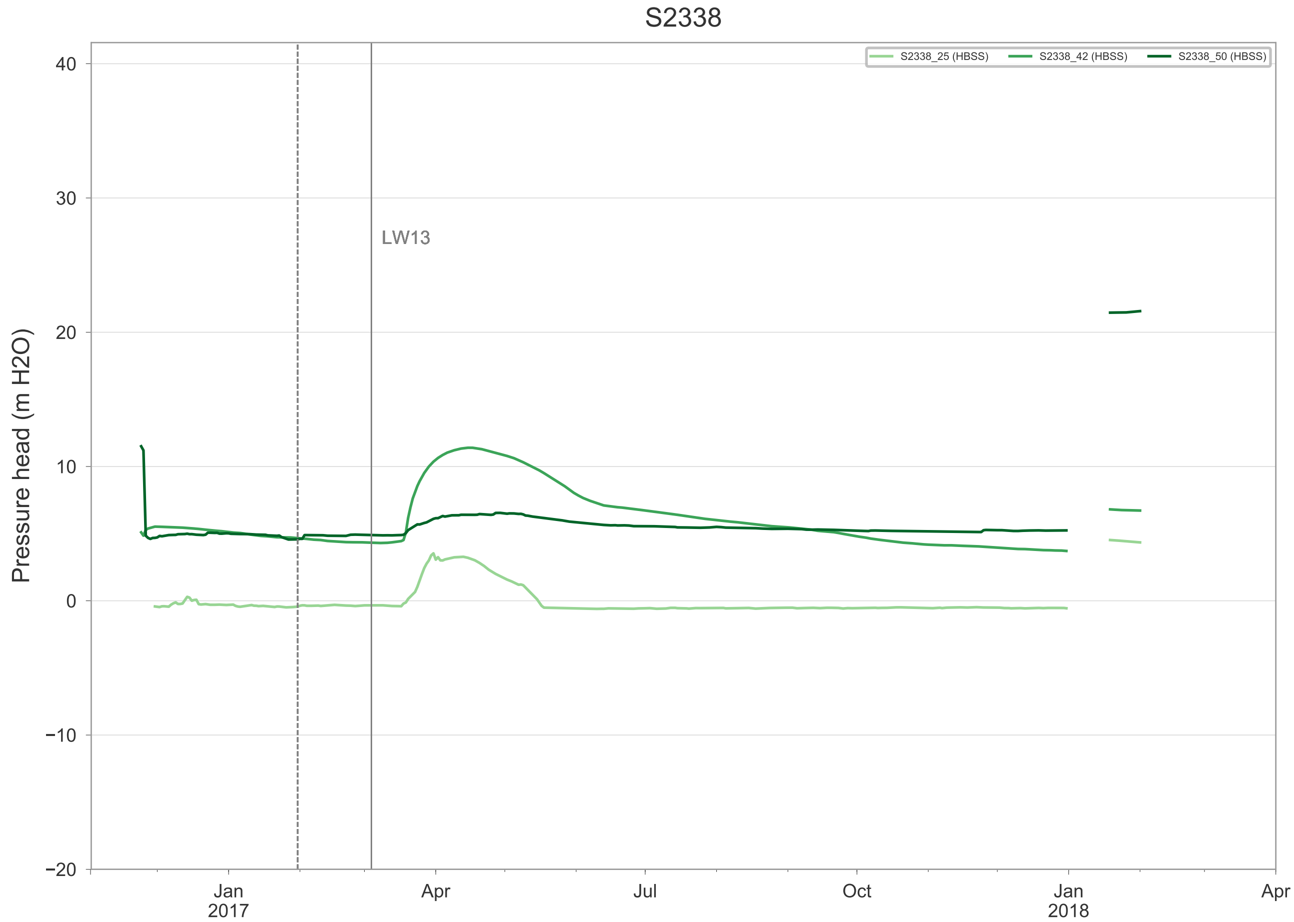

S2336
S2336_32.3 (HBSS)
S2336_32.4 (HBSS)
LW13
Pressure head (m H2O)
350
300
250
200
150
100
50
0
Nov
Dec
Jan
2017
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

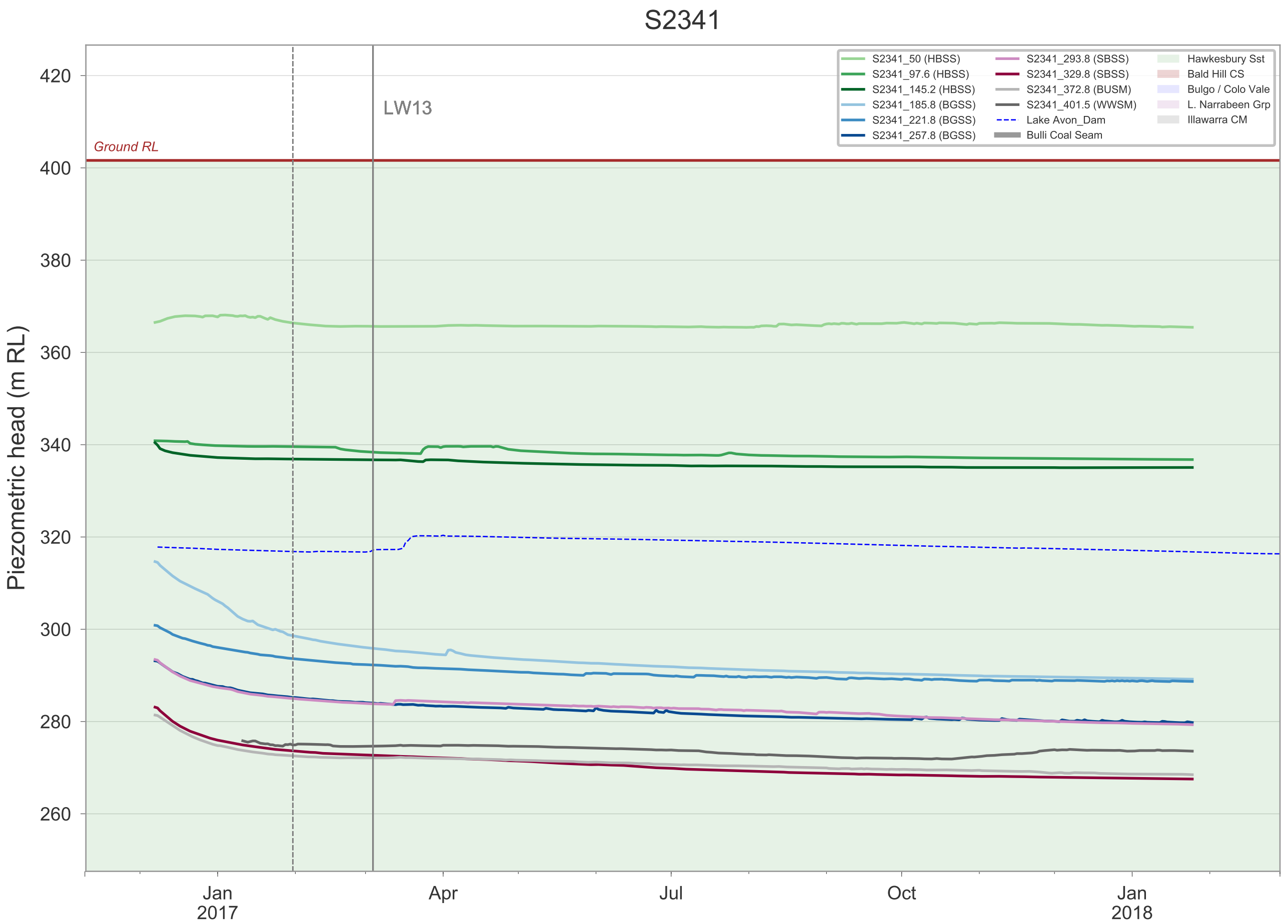
Groundwater hydrographs

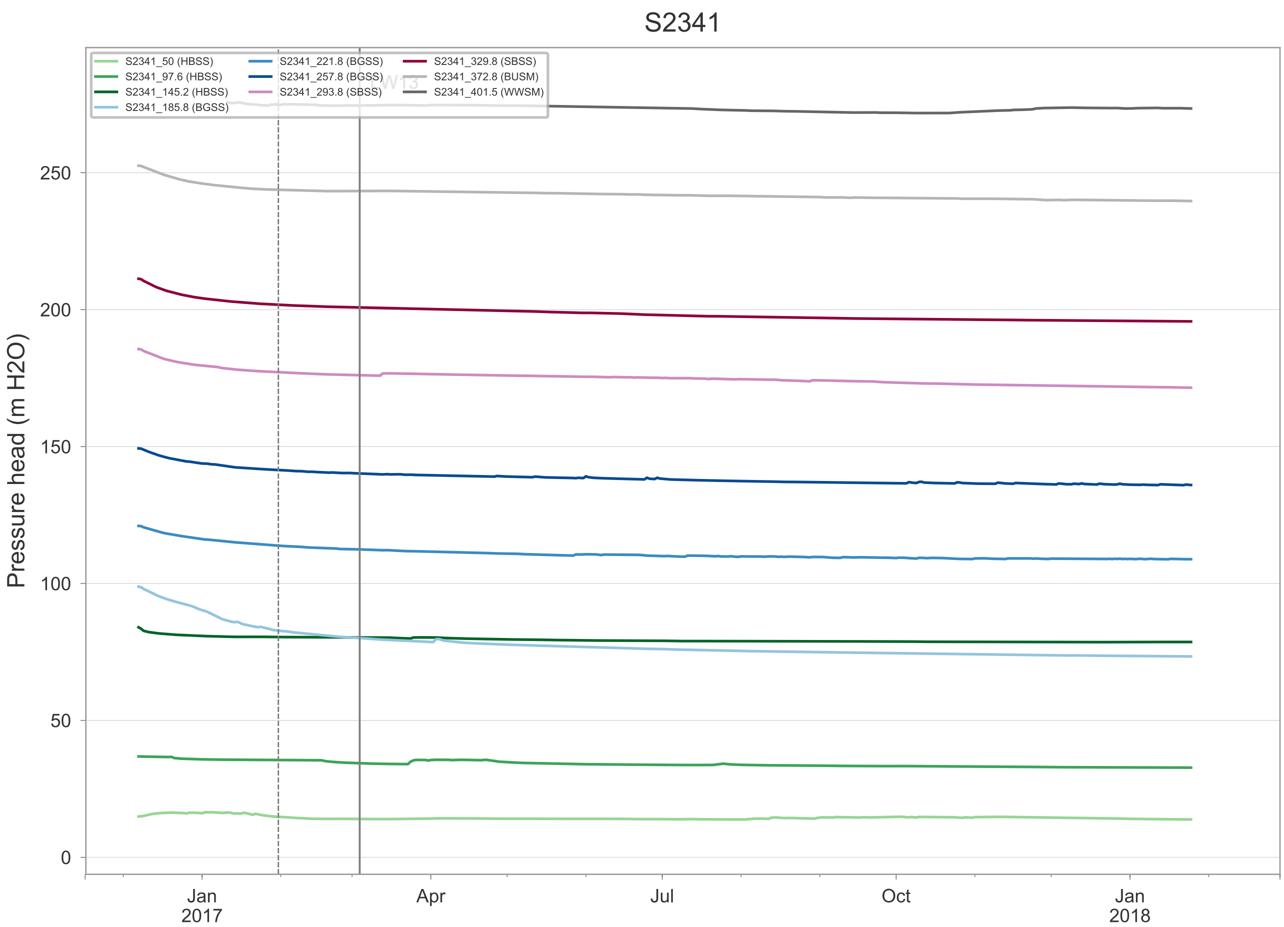


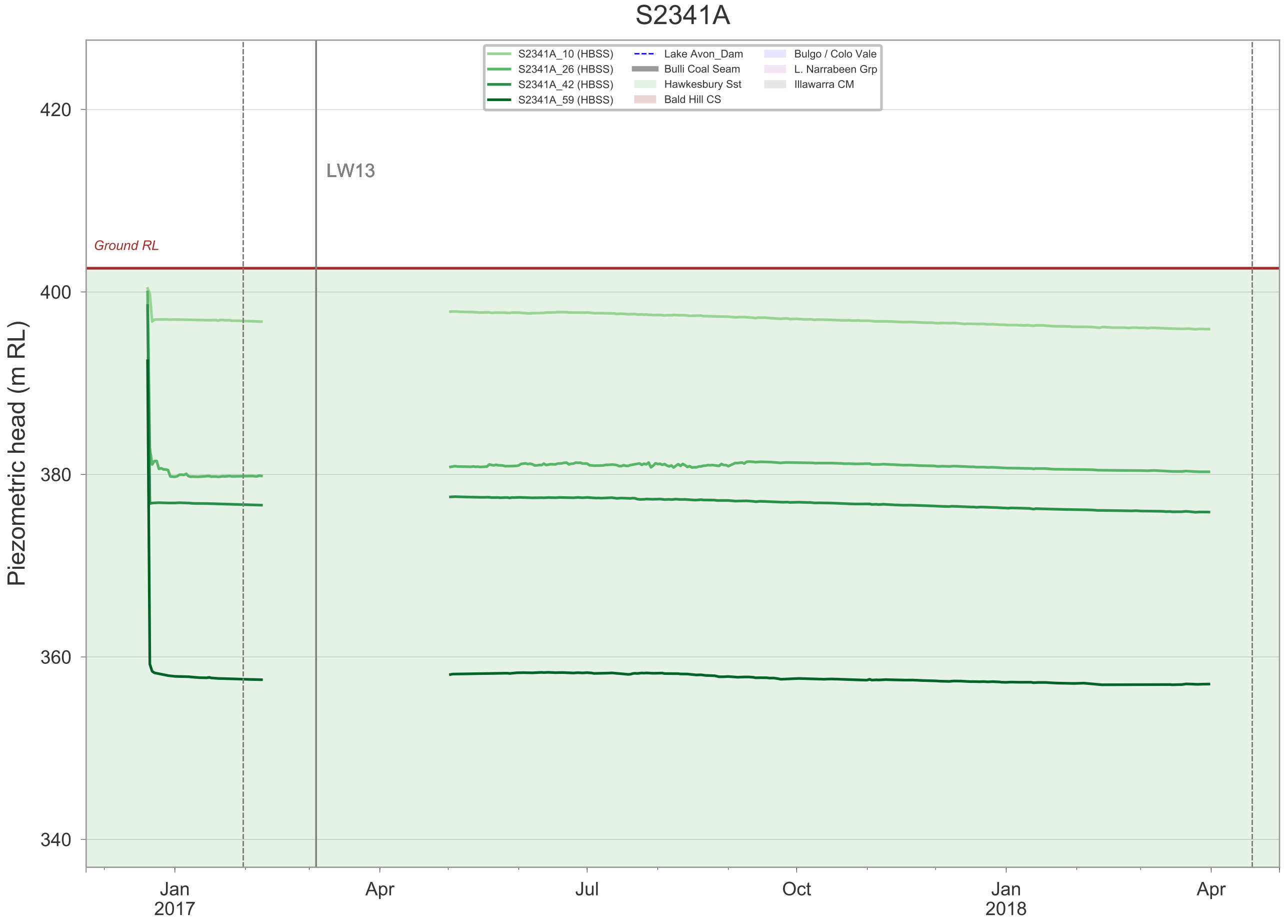



S2338
S2338_25 (HBSS)
S2338_42 (HBSS)
S2338_50 (HBSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW13
Ground RL
Piezometric head (m RL)
360
340
320
300
280
Jan
2017
Apr
Jul
Oct
Jan
2018
Apr


S2338
S2338_25 (HBSS)
S2338_42 (HBSS)
S2338_50 (HBSS)
LW13
Pressure head (m H2O)
40
30
20
10
0
−10
−20
Jan
2017
Apr
Jul
Oct
Jan
2018
Apr


S2341
Piezometric head (m RL)
Ground RL
LW13
S2341_50 (HBSS)
S2341_97.6 (HBSS)
S2341_145.2 (HBSS)
S2341_185.8 (BGSS)
S2341_221.8 (BGSS)
S2341_257.8 (BGSS)
S2341_293.8 (SBSS)
S2341_329.8 (SBSS)
S2341_372.8 (BUSM)
S2341_401.5 (WWSM)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Jan 2017
Apr
Jul
Oct
Jan 2018


S2341
Pressure head (m H2O)
S2341_50 (HBSS)
S2341_97.6 (HBSS)
S2341_145.2 (HBSS)
S2341_185.8 (BGSS)
S2341_221.8 (BGSS)
S2341_257.8 (BGSS)
S2341_293.8 (SBSS)
S2341_329.8 (SBSS)
S2341_372.8 (BUSM)
S2341_401.5 (WWSM)
Jan 2017
Apr
Jul
Oct
Jan 2018

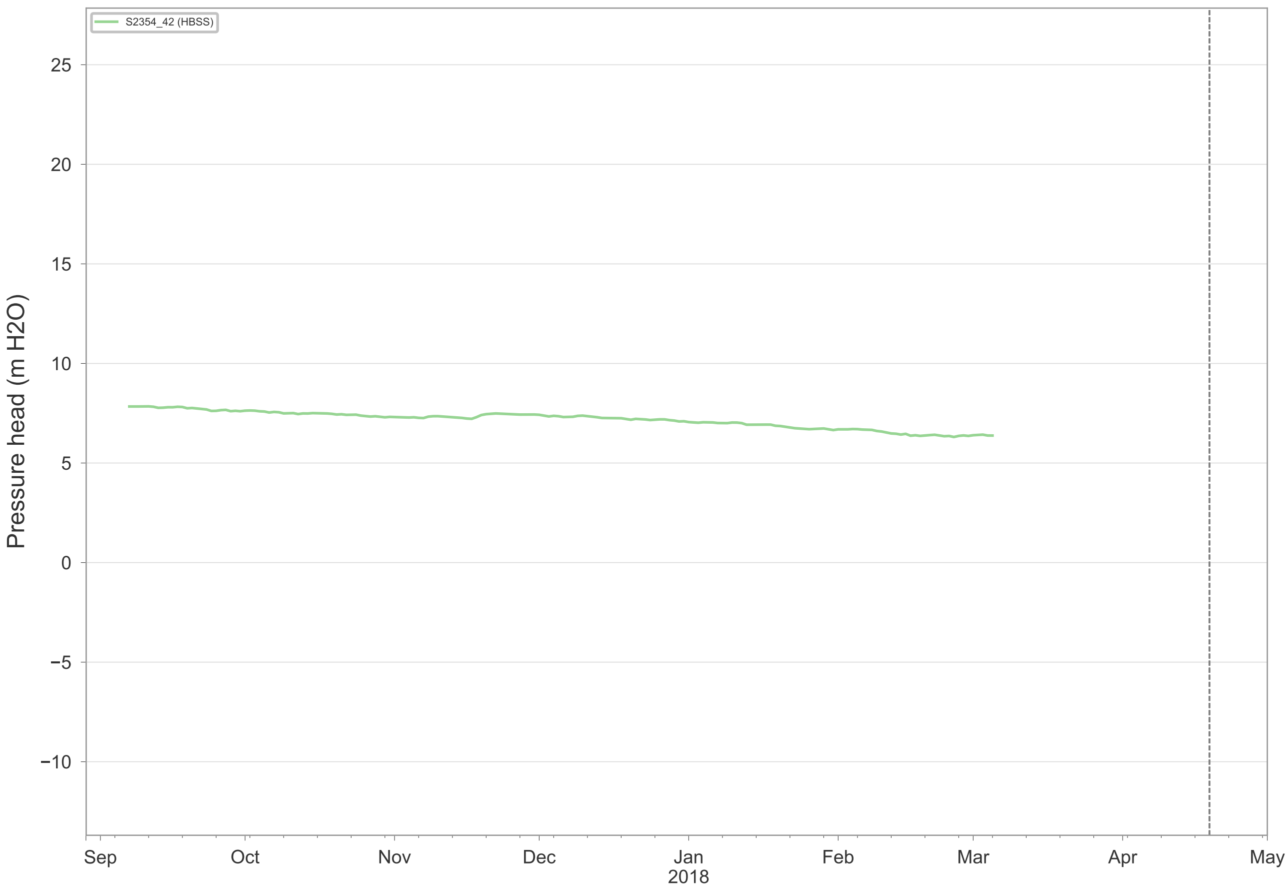

S2341A
S2341A_10 (HBSS)
S2341A_26 (HBSS)
S2341A_42 (HBSS)
S2341A_59 (HBSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
LW13
Ground RL
Piezometric head (m RL)
420
400
380
360
340
Jan 2017
Apr
Jul
Oct
Jan 2018
Apr

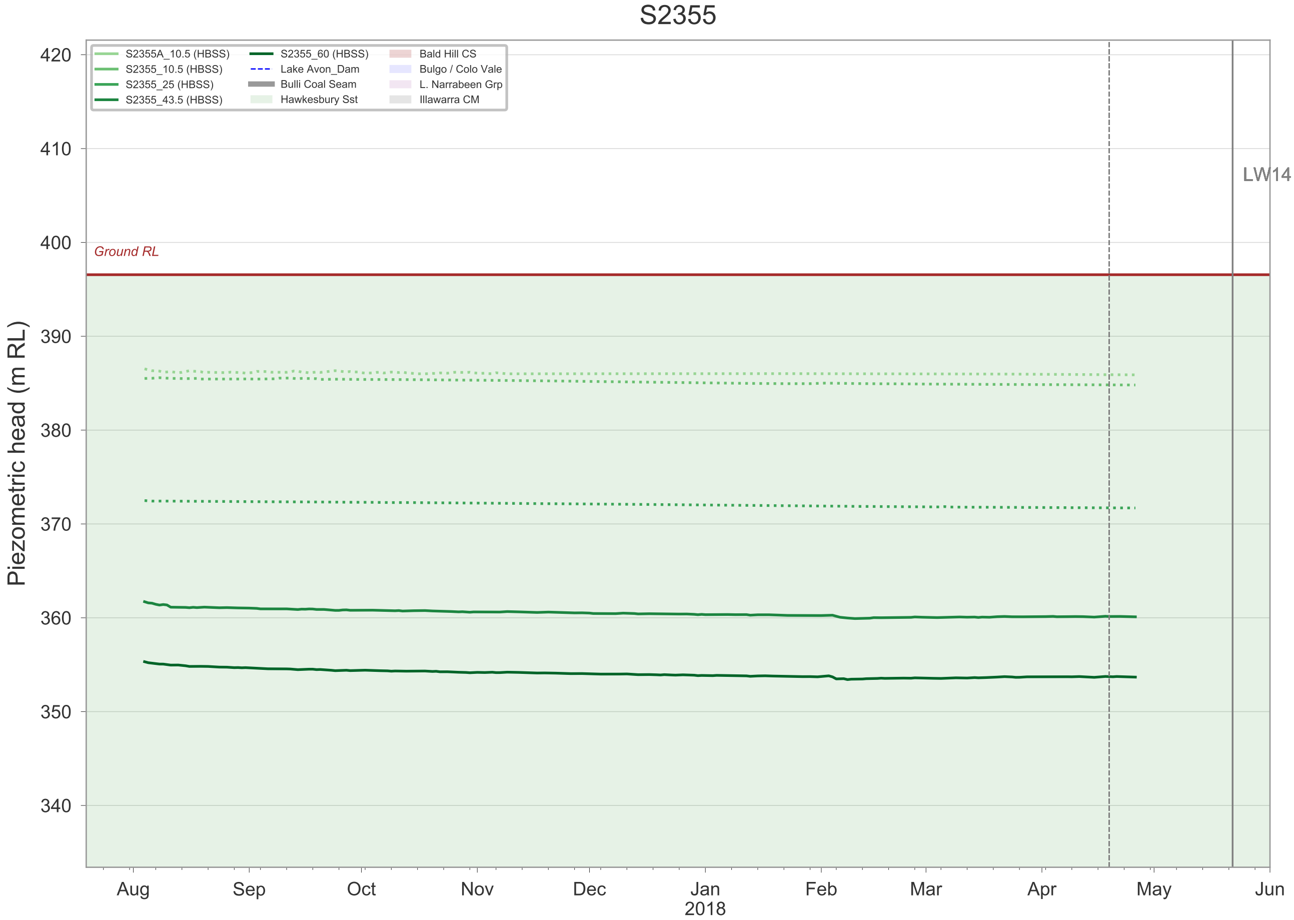

S2341A
LW13
Pressure head (m H2O)
60
50
40
30
20
10
0
−10
S2341A_10 (HBSS)
S2341A_26 (HBSS)
S2341A_42 (HBSS)
S2341A_59 (HBSS)
Jan 2017
Apr
Jul
Oct
Jan 2018
Apr

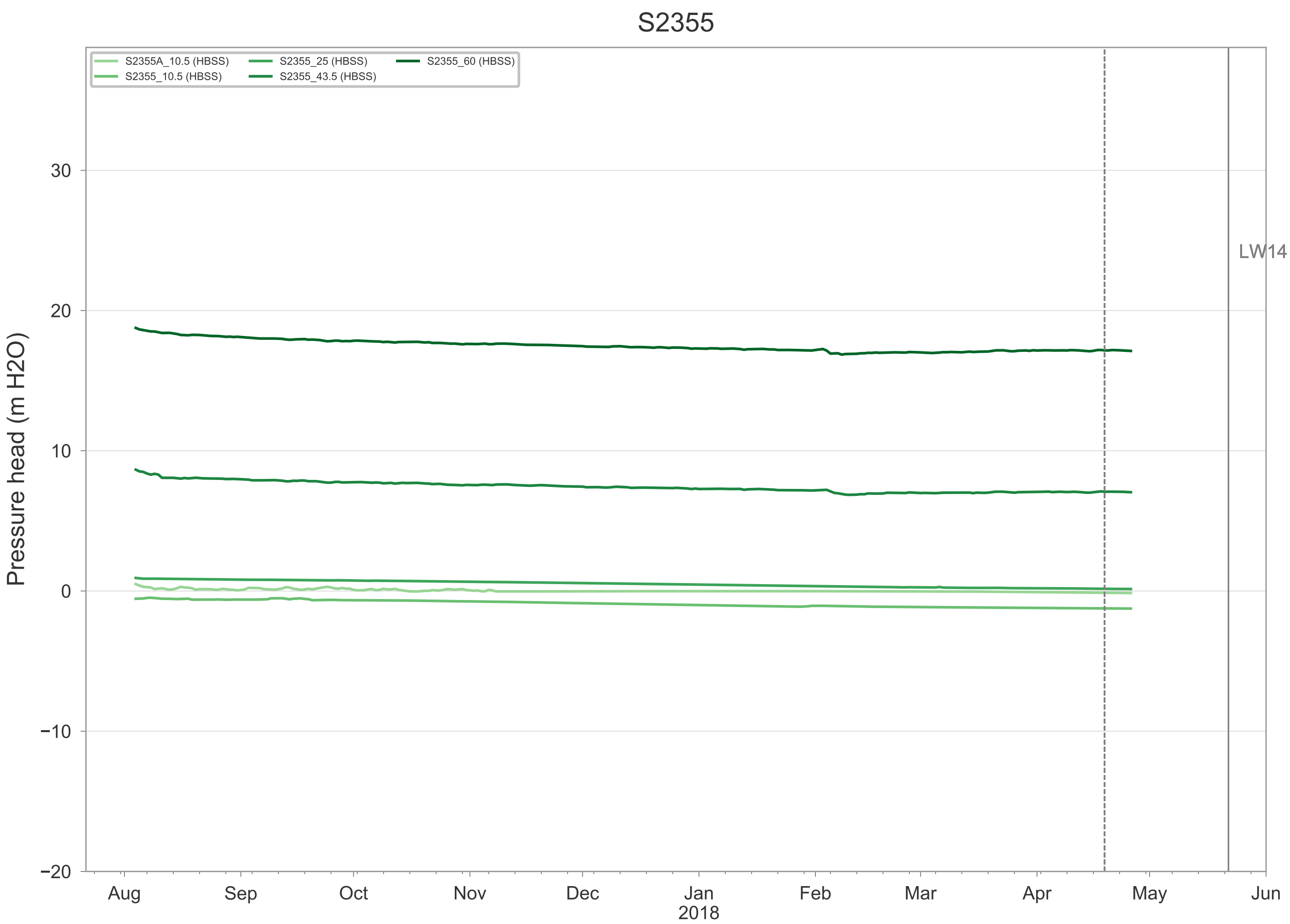
Groundwater hydrographs

S2354

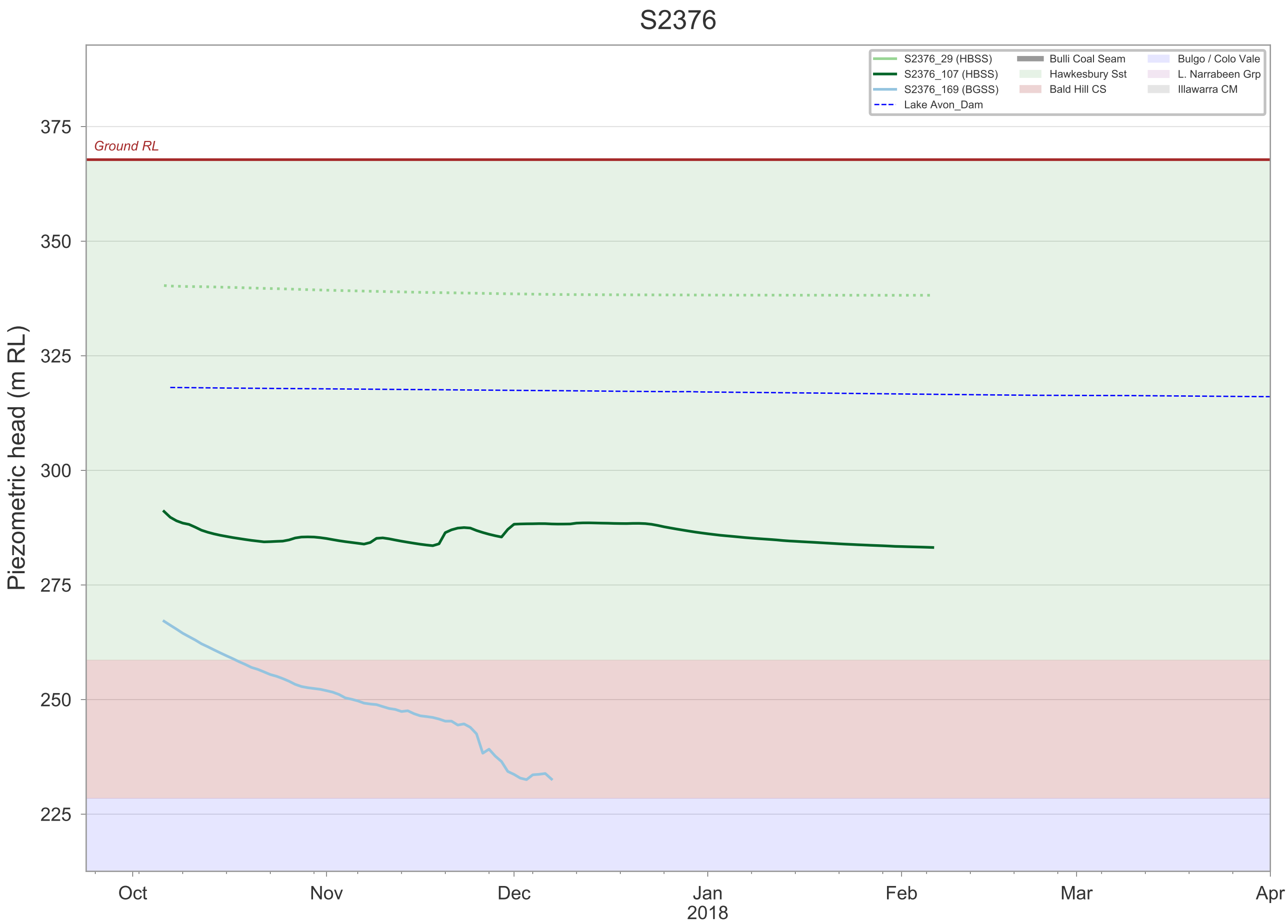
S2354

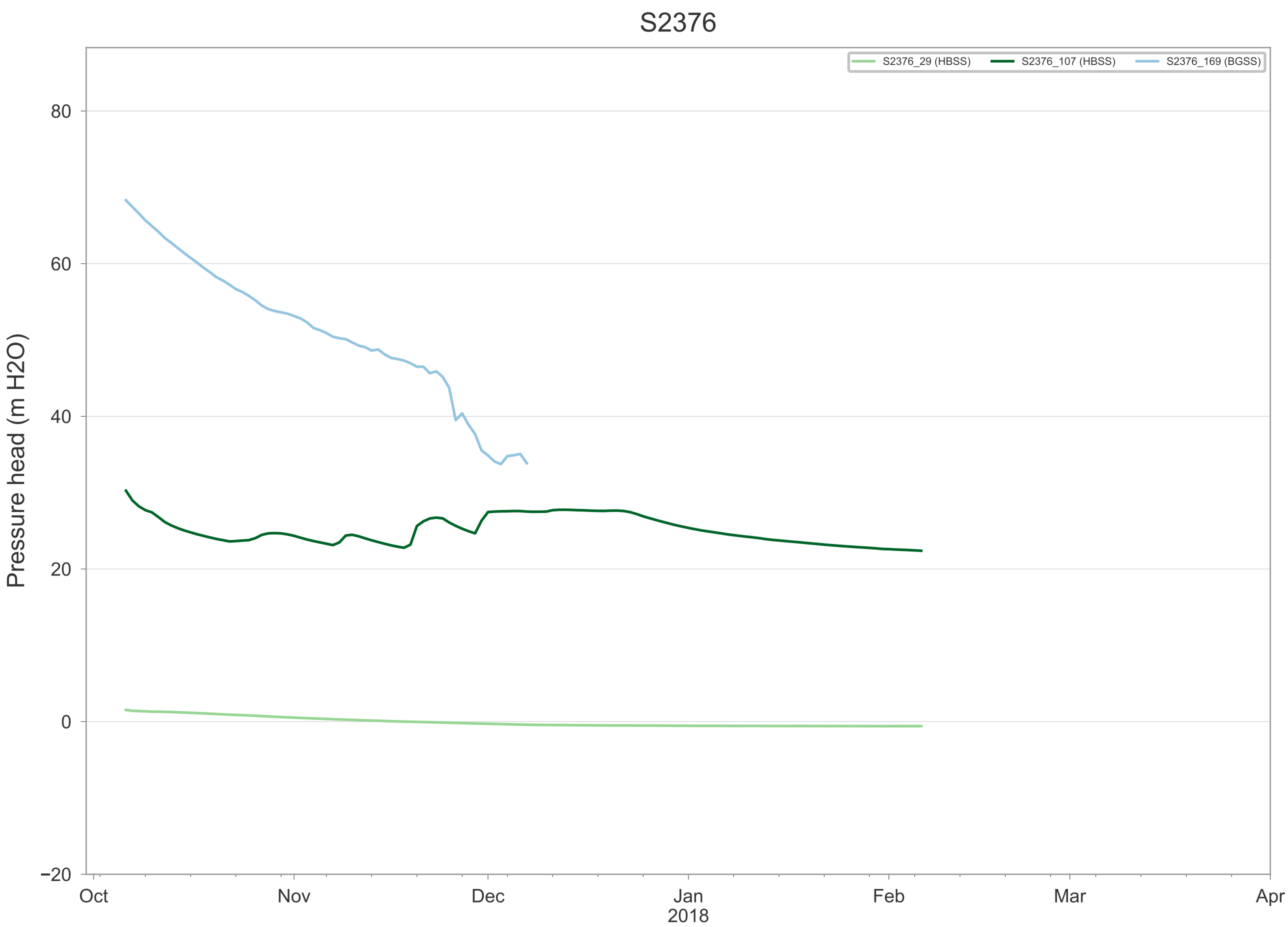



S2355
Piezometric head (m RL)
420
410
400
390
380
370
360
350
340
S2355A_10.5 (HBSS)
S2355_10.5 (HBSS)
S2355_25 (HBSS)
S2355_43.5 (HBSS)
S2355_60 (HBSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Ground RL
LW14
Aug
Sep
Oct
Nov
Dec
Jan
2018
Feb
Mar
Apr
May
Jun

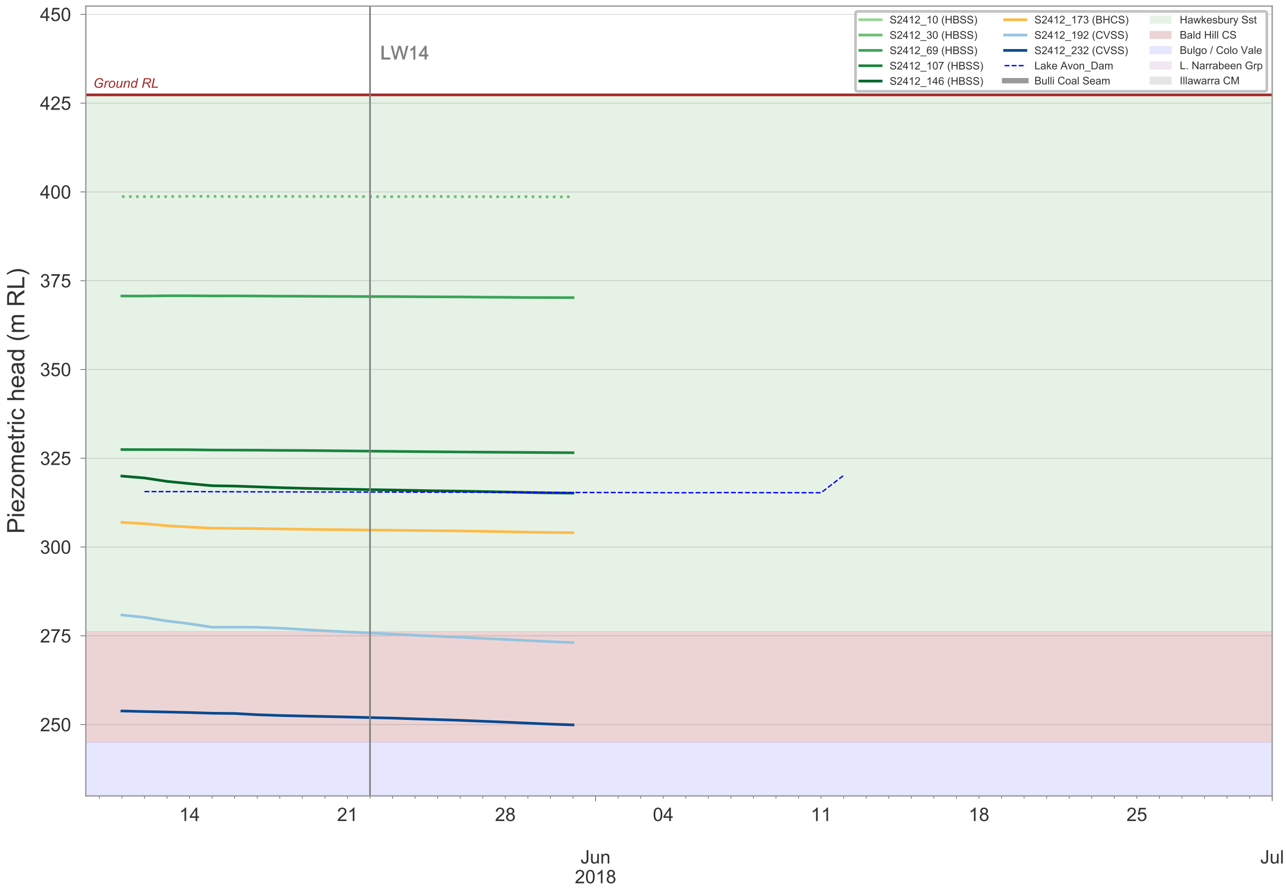

S2355
Pressure head (m H2O)
30
20
10
0
−10
−20
S2355A_10.5 (HBSS)
S2355_10.5 (HBSS)
S2355_25 (HBSS)
S2355_43.5 (HBSS)
S2355_60 (HBSS)
LW14
Aug
Sep
Oct
Nov
Dec
Jan
2018
Feb
Mar
Apr
May
Jun

Groundwater hydrographs

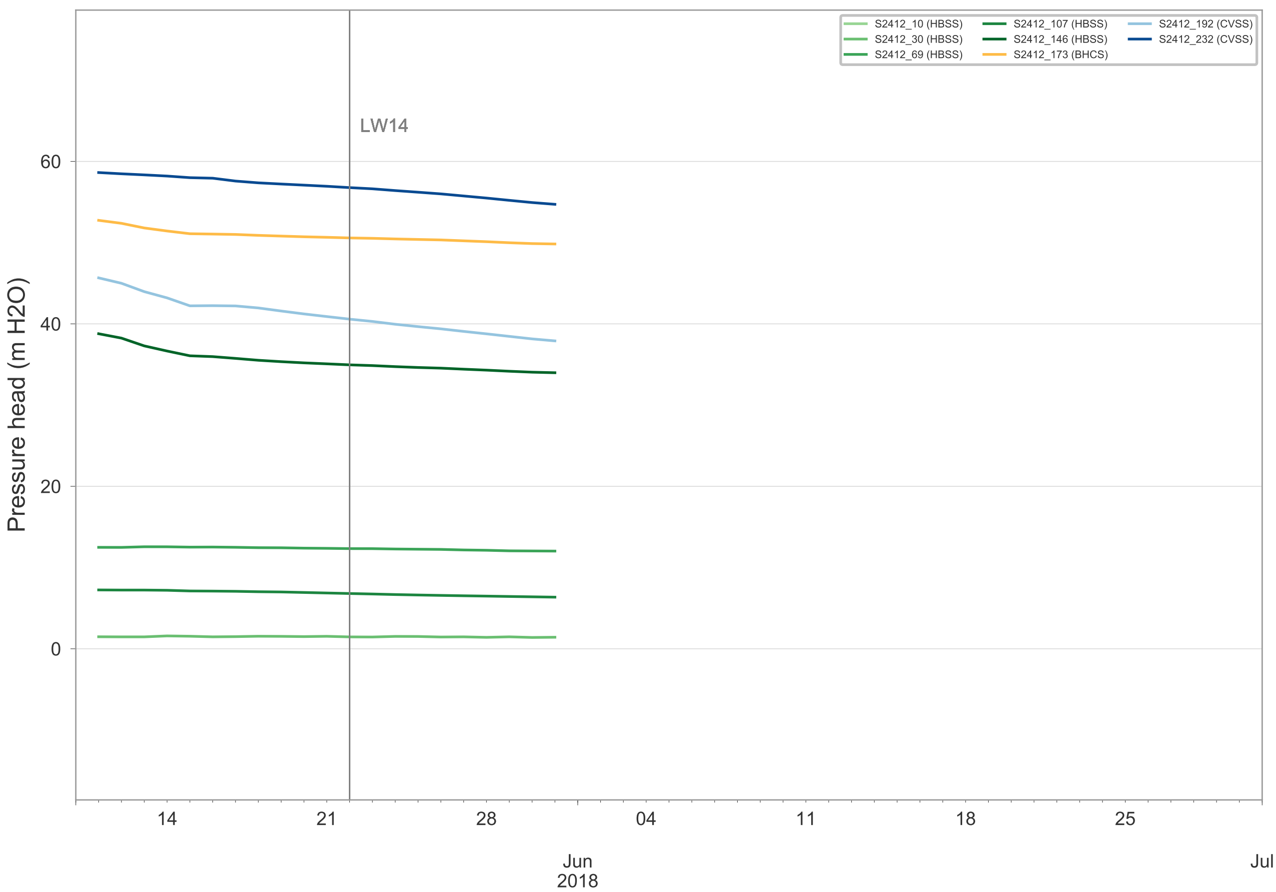




S2412


LW14
Ground RL
S2412_10 (HBSS)
S2412_30 (HBSS)
S2412_69 (HBSS)
S2412_107 (HBSS)
S2412_146 (HBSS)
S2412_173 (BHCS)
S2412_192 (CVSS)
S2412_232 (CVSS)
Lake Avon_Dam
Bulli Coal Seam
Hawkesbury Sst
Bald Hill CS
Bulgo / Colo Vale
L. Narrabeen Grp
Illawarra CM
Piezometric head (m RL)
450
425
400
375
350
325
300
275
250
14
21
28
04
11
18
25
Jun
2018
Jul

S2412


LW14
S2412_10 (HBSS)
S2412_30 (HBSS)
S2412_69 (HBSS)
S2412_107 (HBSS)
S2412_146 (HBSS)
S2412_173 (BHCS)
S2412_192 (CVSS)
S2412_232 (CVSS)
Pressure head (m H2O)
60
40
20
0
14
21
28
04
11
18
25
Jun
2018
Jul

APPENDIX B: SPATIAL PLOTS

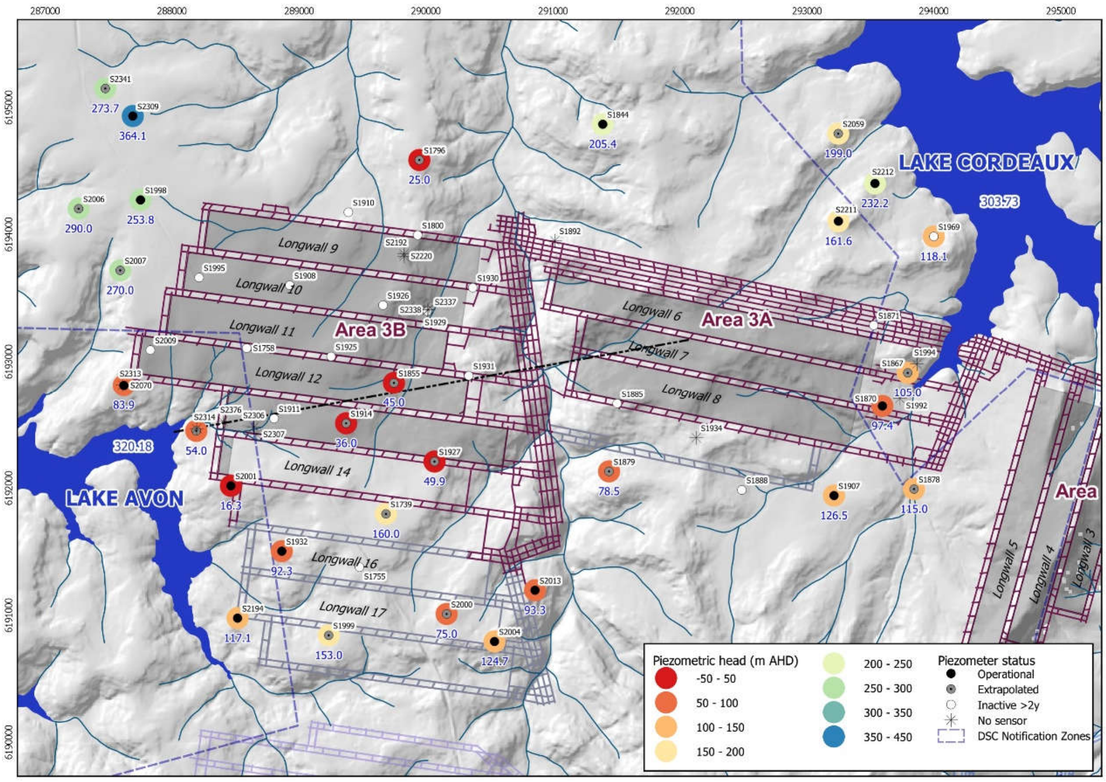


Figure 13. Average piezometric head in the Wongawilli Coal Seam at the end of LW13

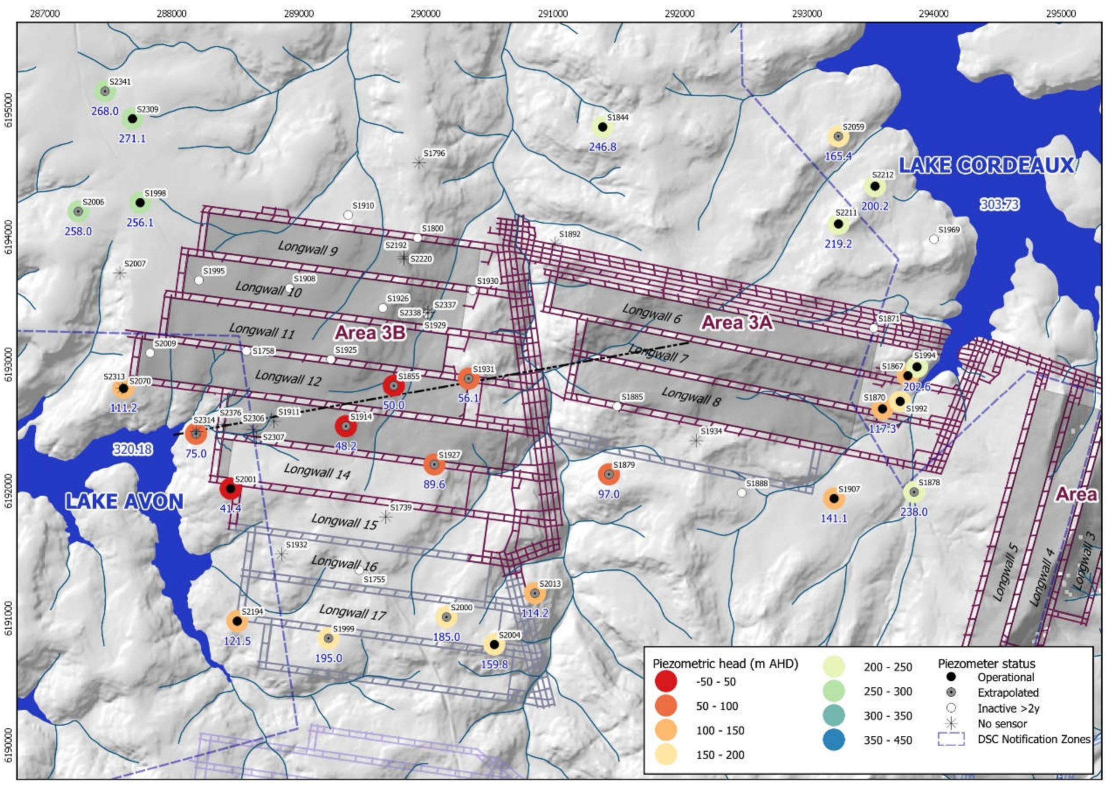


Figure 14. Average piezometric head in the Bulli Coal Seam at the end of LW13

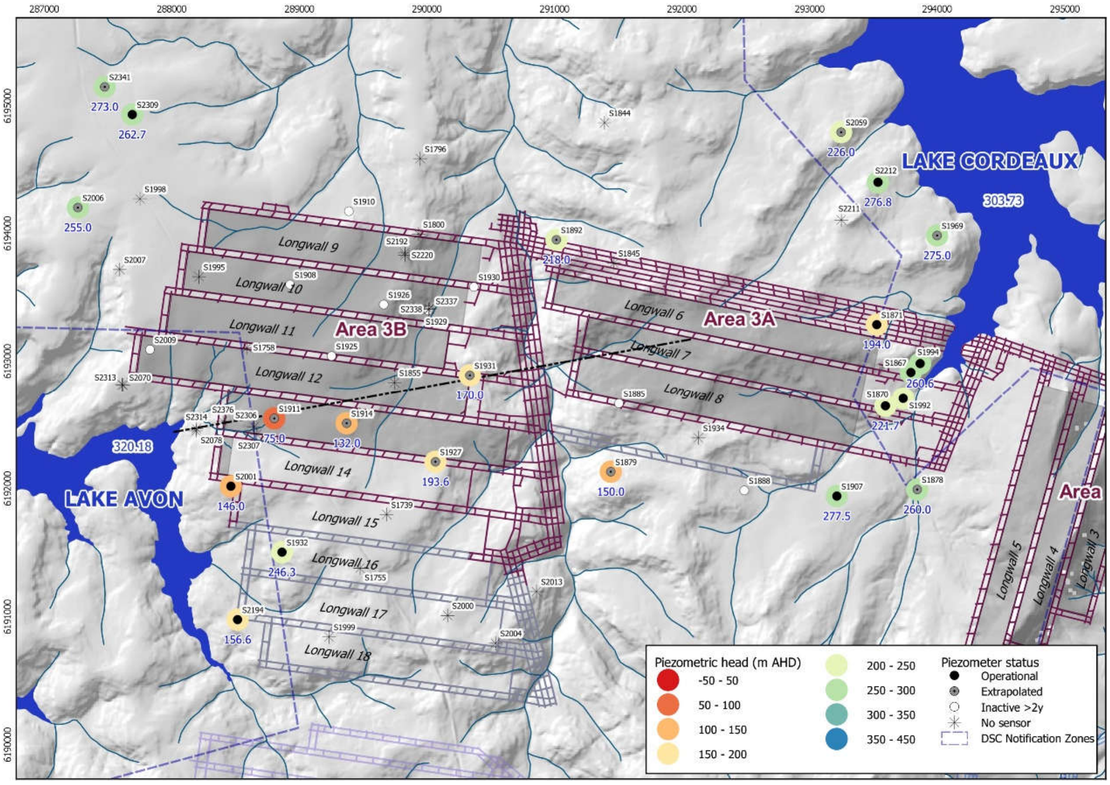


Figure 15. Average piezometric head in the Scarborough Sandstone at the end of LW13

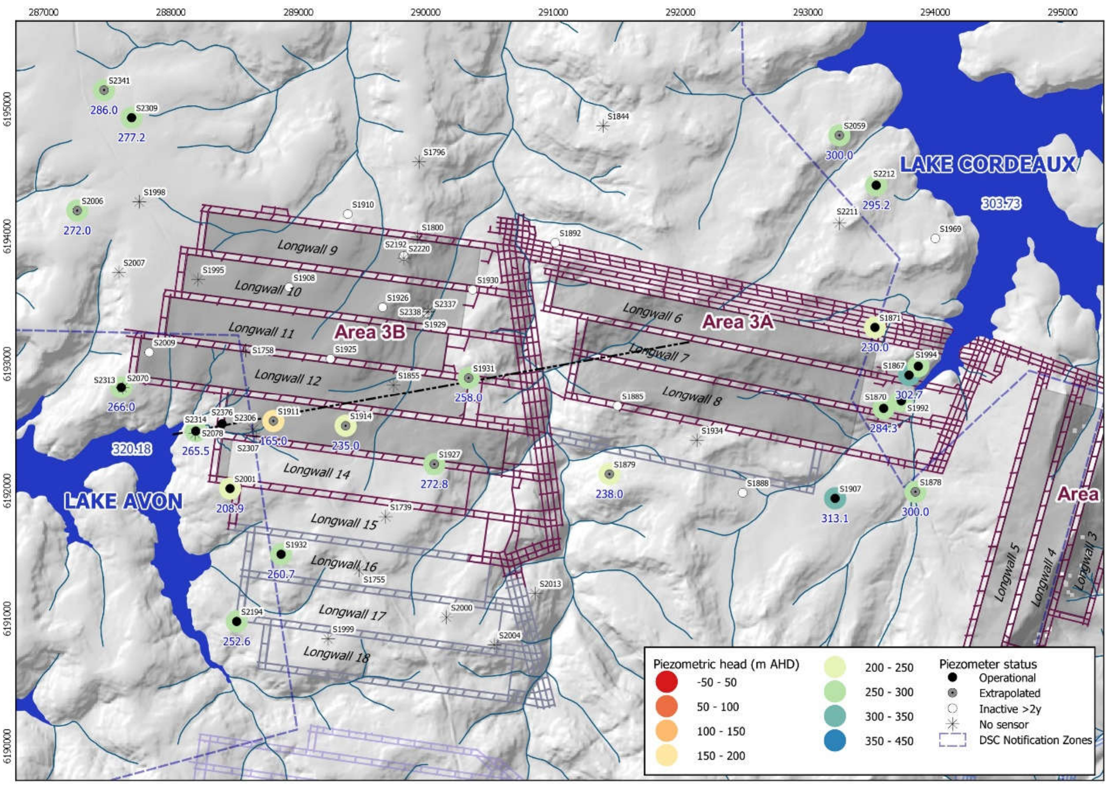


Figure 16. Average piezometric head in the Bulgo Sandstone at the end of LW13

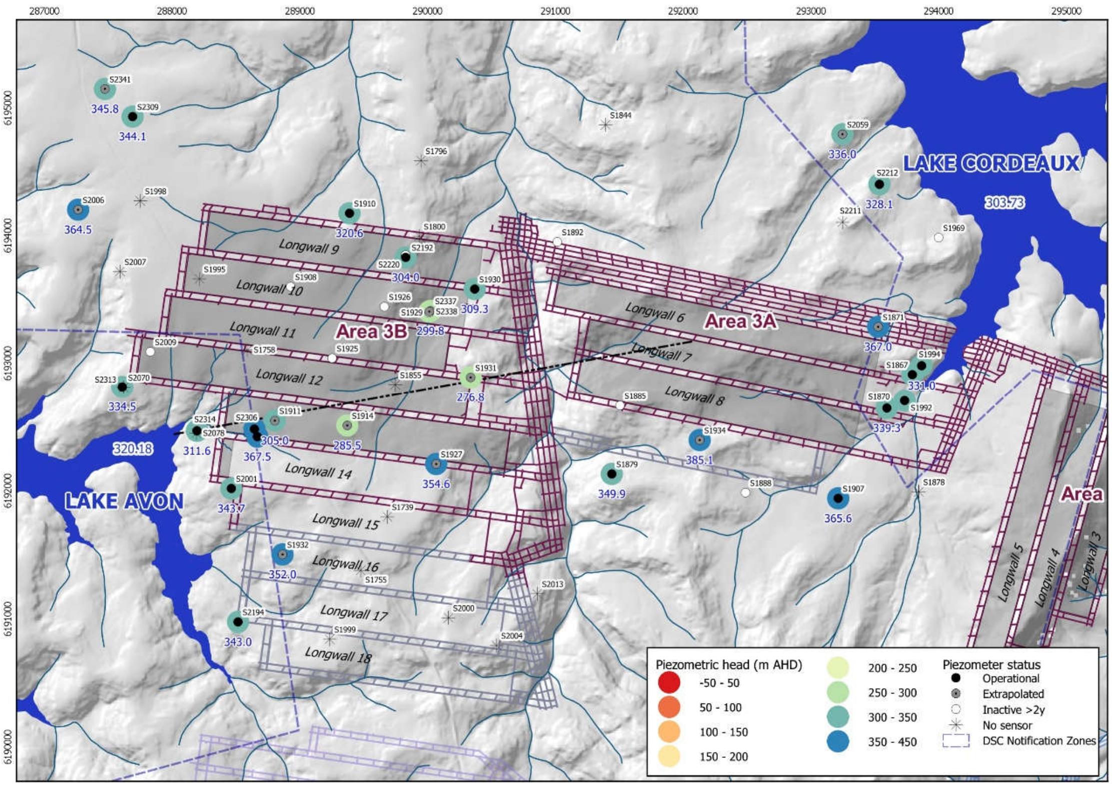


Figure 17. Average piezometric head in the Hawkesbury Sandstone at the end of LW13

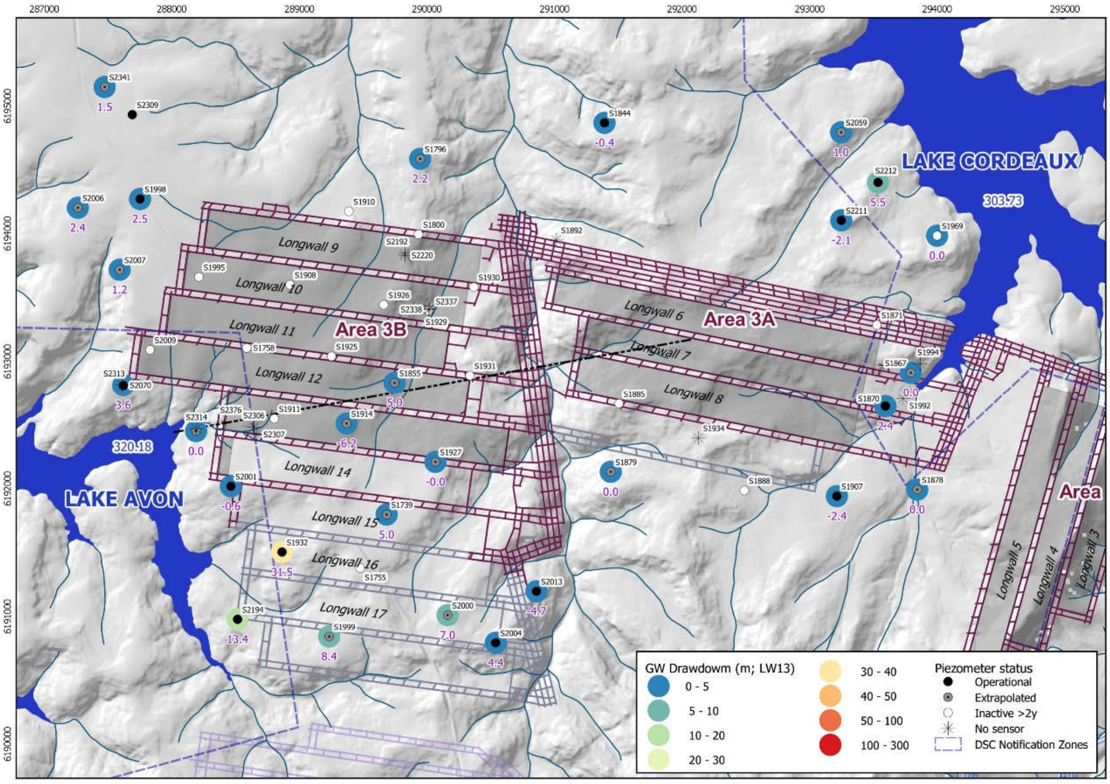


Figure 18. Drawdown in piezometric head in the Wongawilli Coal Seam during LW13

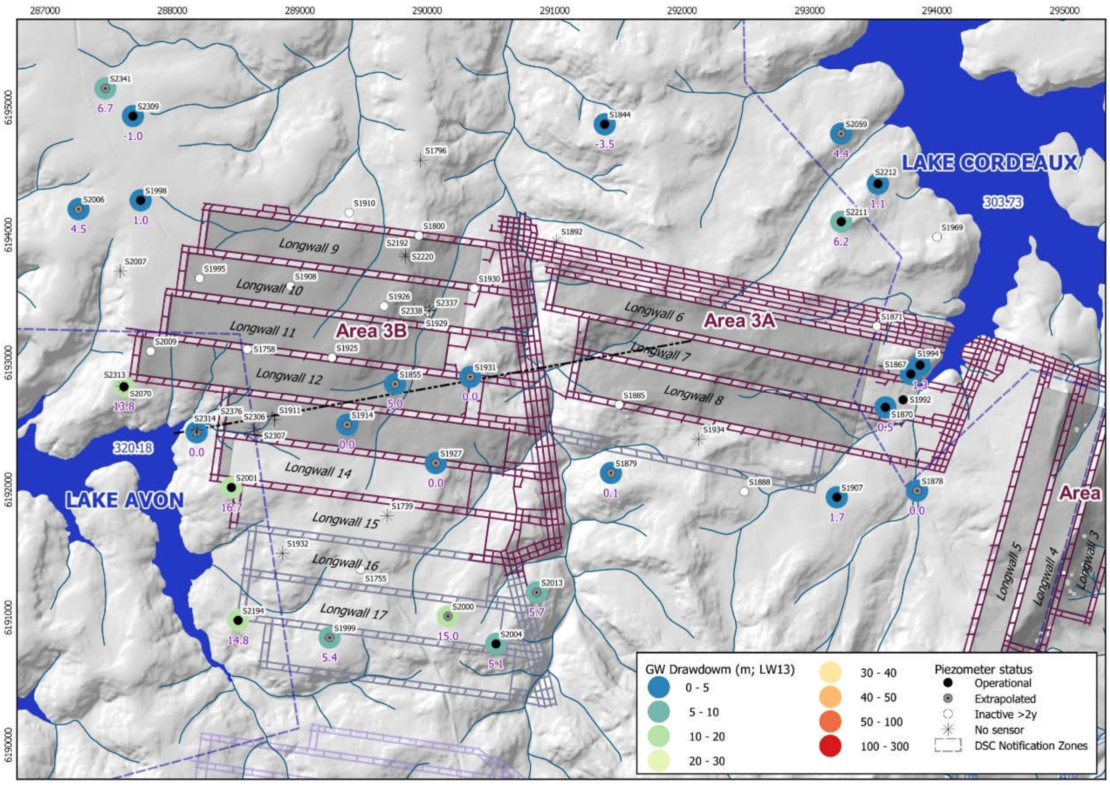


Figure 19. Drawdown in piezometric head in the Bulli Coal Seam during LW13

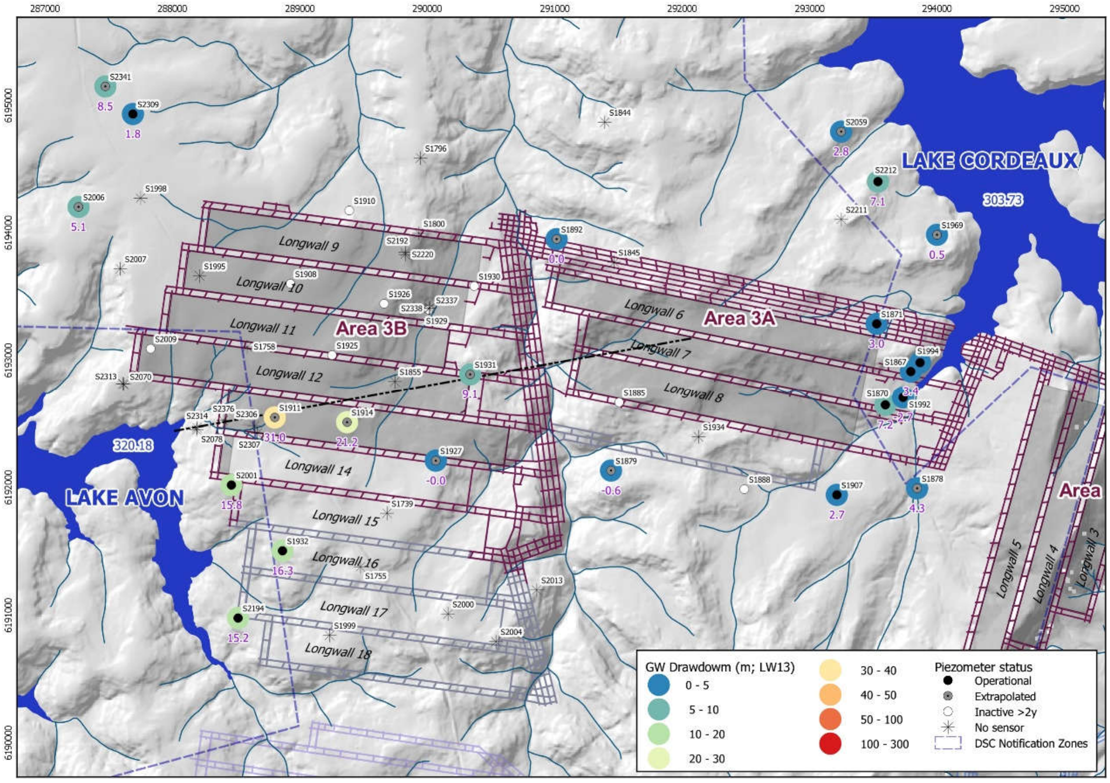


Figure 20. Drawdown in piezometric head in the Scarborough Sandstone during LW13

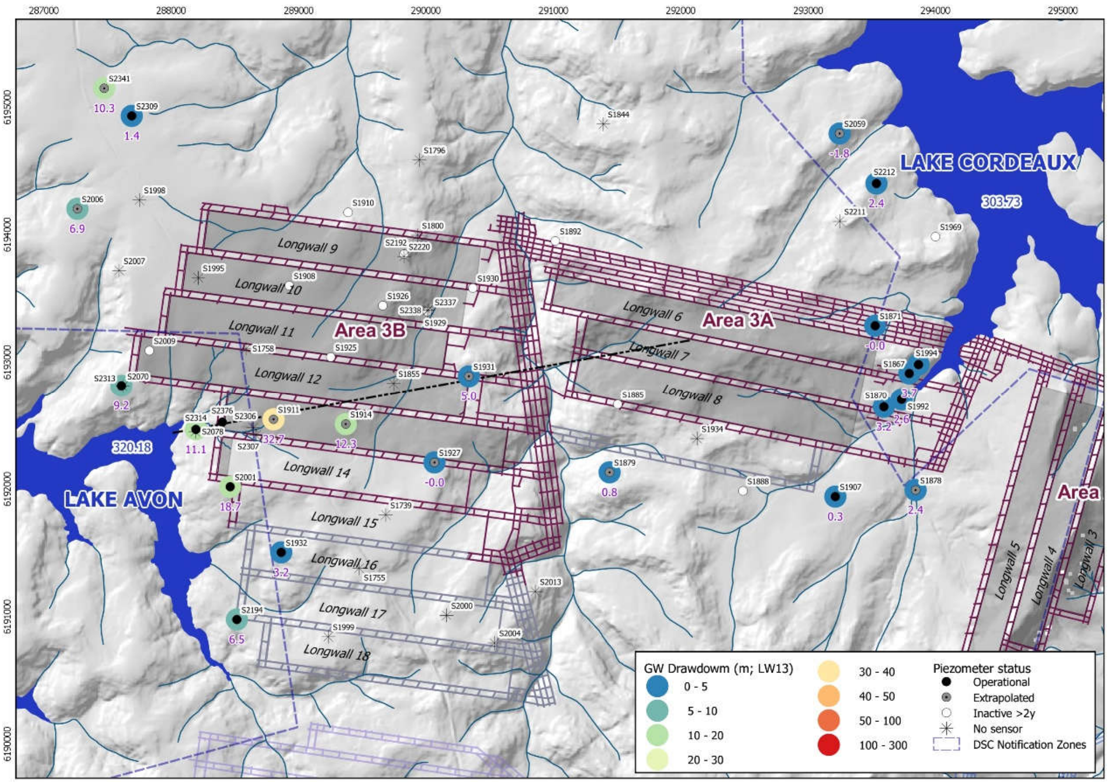


Figure 21. Drawdown in piezometric head in the Bulgo Sandstone during LW13

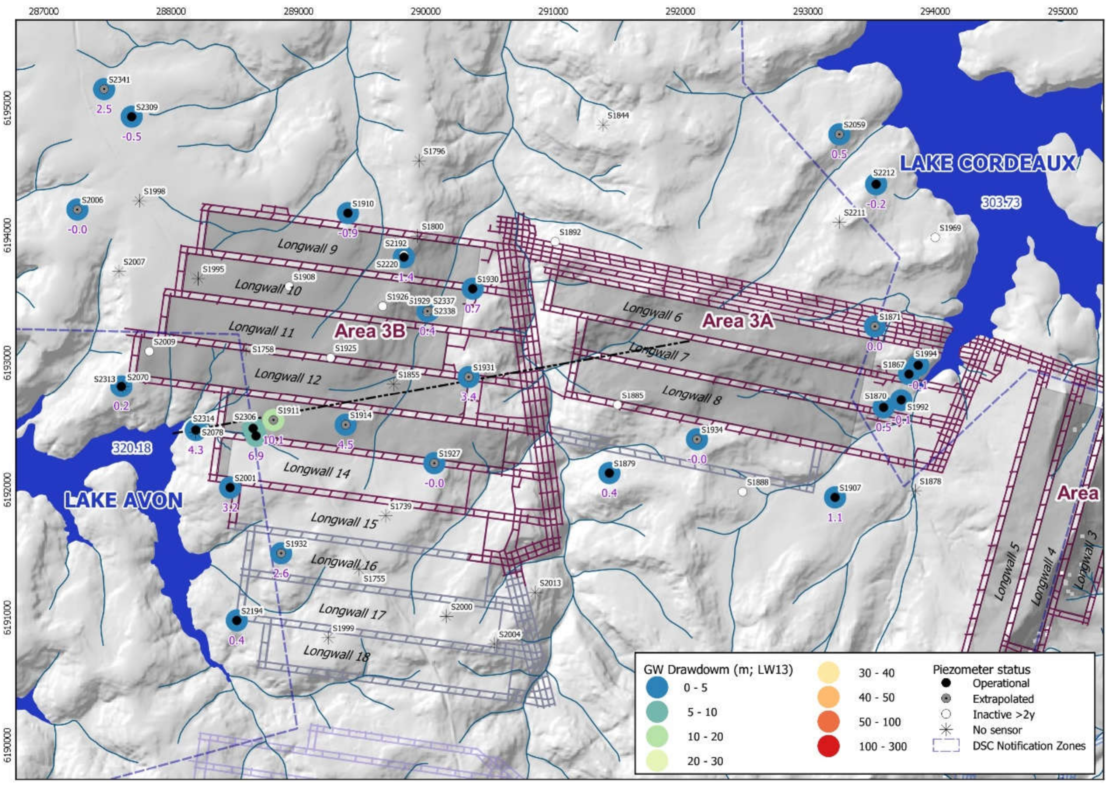


Figure 22. Drawdown in piezometric head in the Hawkesbury Sandstone during LW13

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	Kemira19	292700	6191121	435.1	Den 3A	1	22/11/2007	24/02/2010	2.3
S1099	Kemira22	292041	6191531	429.9	Den 3A	1	06/12/2006	28/01/2010	3.1
S1388	DEN29	292129	6192393	427.6	Den 3A	1	04/04/2006	22/01/2010	3.8
S1577	DEN38	294558	6192447	376.9	Den 2	4	08/12/2004	23/09/2010	5.8
S1710	Elouera09	290258	6189646	432.5	Den Other	4	19/05/2005	21/05/2018	13
S1719	DEN56	291202	6193277	413.6	Den 3A	1	16/06/2005	18/02/2010	4.7
S1739	DEN62	289684	6191799	423.7	Den 3B	1	02/09/2005	19/01/2017	11.4
S1755	DEN64	289475	6191380	433.3	Den 3B	2	10/01/2006	03/02/2016	10.1
S1758	DEN65	288587	6193107	408.8	Den 3B	2	26/01/2006	10/06/2014	8.4
S1796	DEN69	289947	6194587	398.6	Den 3B	1	05/04/2006	18/01/2018	11.8
S1800	DEN70	289933	6193997	392.5	Den 3B	2	25/04/2006	31/08/2011	5.4
S1844	DEN76	291391	6194869	375.6	Den 3C	2	22/08/2006	30/03/2018	11.6
S1845	DEN77	291464	6193770	399.7	Den 3A	2	29/11/2006	04/01/2010	3.1
S1855	DEN82	289747	6192833	366.6	Den 3B	2	11/12/2006	27/07/2016	9.6
S1867	DEN84	293793	6192912	346.0	Den 3A	11	20/03/2007	06/06/2018	11.2
S1870	DEN85	293593	6192648	351.5	Den 3A	12	02/02/2007	05/06/2018	11.3
S1871	DEN86	293525	6193287	375.6	Den 3A	12	17/02/2007	03/04/2018	11.1
S1878	DEN91	293842	6191994	337.1	Den 3A	11	24/04/2007	22/02/2017	9.8
S1879	DEN92	291440	6192133	379.7	Den 3A	12	07/06/2007	03/04/2018	10.8
S1885	DEN93	291504	6192668	420.0	Den 3A	12	07/06/2007	17/05/2012	4.9
S1888	DEN96	292487	6191987	381.3	Den 3A	8	31/05/2007	07/09/2017	10.3
S1889	DEN97	292245	6192980	435.4	Den 3A	8	02/06/2007	10/08/2011	4.2
S1890	DEN98	292637	6192491	407.1	Den 3A	8	31/07/2007	07/08/2012	5
S1892	DEN99	291014	6193952	356.1	Den 3A	8	07/08/2008	19/10/2016	8.2
S1902	DEN100	295241	6190780	343.1	Den 2	4	04/10/2007	31/05/2017	9.7
S1907	DEN103	293212	6191943	371.9	Den 3A	8	25/01/2008	03/04/2018	10.2
S1908	DEN104	288926	6193601	405.7	Den 3B	8	16/05/2008	01/05/2014	6
S1910	DEN105	289387	6194176	377.2	Den 3B	8	29/08/2008	23/05/2018	9.7
S1911	DEN106	288803	6192549	405.2	Den 3B	12	15/05/2008	24/05/2017	9
S1914	DEN107	289370	6192512	414.5	Den 3B	7	29/04/2008	10/08/2017	9.3
S1925	DEN108	289252	6193041	416.7	Den 3B	8	04/08/2008	21/05/2018	9.8
S1926	DEN109	289660	6193445	409.0	Den 3B	8	27/08/2008	08/08/2014	5.9
S1927	DEN110	290066	6192211	414.8	Den 3B	8	16/05/2008	23/01/2017	8.7
S1929	DEN111	290011	6193398	337.7	Den 3B	8	27/08/2008	08/08/2014	5.9
S1930	DEN112	290367	6193583	353.1	Den 3B	12	27/05/2008	22/05/2018	10

Bore_ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_ Area	Sensors	First_record	Last_record	Years
S1931	DEN113	290336	6192890	396.4	Den 3B	9	11/08/2008	31/03/2018	9.6
S1932	DEN114	288863	6191505	396.1	Den 3B	11	31/08/2008	23/05/2018	9.7
S1934	DEN115	292128	6192398	427.5	Den 3A	4	23/04/2009	27/07/2017	8.3
S1969	DEN118	293998	6193986	368.5	Den 3C	11	12/08/2009	05/12/2016	7.3
S1992	DEN119	293732	6192707	339.1	Den 3A	8	10/05/2009	05/06/2018	9.1
S1994	DEN120	293865	6192982	345.5	Den 3A	8	13/01/2009	05/05/2018	9.3
S1995	DEN121	288212	6193662	404.5	Den 3B	2	12/06/2009	28/01/2014	4.6
S1998	DEN122	287751	6194273	410.5	Den 3B	2	11/06/2009	08/03/2018	8.7
S1999	DEN123	289233	6190844	406.4	Den 3B	2	10/07/2009	18/01/2018	8.5
S2000	DEN124	290161	6191011	442.0	Den 3B	2	10/07/2009	01/08/2016	7.1
S2001	DEN125	288463	6192020	413.9	Den 3B	10	06/08/2009	20/04/2018	8.7
S2002	DEN126	288633	6194222	400.0	Den 3B	2	21/07/2009	19/02/2012	2.6
S2003	DEN127	290571	6192478	409.4	Den 3B	2	04/08/2009	01/03/2014	4.6
S2004	DEN128	290538	6190795	443.5	Den 3B	2	14/10/2010	18/04/2018	7.5
S2006	DEN129	287263	6194204	409.1	Den 3B	10	24/07/2009	27/02/2017	7.6
S2007	DEN130	287591	6193719	405.8	Den 3B	2	17/06/2009	06/12/2017	8.5
S2009	DEN131	287828	6193092	402.5	Den 3B	10	10/08/2009	24/03/2016	6.6
S2013	DEN134	290858	6191198	399.7	Den 3B	2	22/07/2009	18/04/2018	8.7
S2059	DEN148	293246	6194795	380.8	Den 3C	11	16/08/2011	31/12/2017	6.4
S2070	DEN150	287619	6192813	414.7	Den 3B	2	15/05/2013	19/04/2018	4.9
S2078	DEN154	288190	6192452	342.0	Den 3B	2	20/06/2010	22/11/2016	6.4
S2192	AQ3	289827	6193849	389.3	Den 3B	6	25/03/2013	18/11/2014	1.7
S2194		288515	6190979	371.1	Den 3B	11	13/04/2013	01/04/2018	5
S2211		293247	6194106	397.7	Den 3C	2	02/10/2013	26/06/2018	4.7
S2212		293535	6194403	369.2	Den 3C	10	11/10/2013	13/07/2018	4.8
S2220	AQ5	289827	6193831	388.1	Den 3B	3	12/11/2014	31/03/2018	3.4
S2306	Swamp11_3	288643	6192484	395.5	Den 3B	4	16/09/2015	08/03/2018	2.5
S2307	Swamp11_4	288666	6192425	394.5	Den 3B	4	16/09/2015	01/04/2018	2.5
S2309		287690	6194933	412.0	Den 3D	10	15/07/2015	01/04/2018	2.7
S2313	Avon01	287609	6192816	415.3	Den 3B	3	31/10/2015	31/03/2018	2.4
S2314	Avon02	288194	6192470	342.4	Den 3B	3	13/11/2015	31/03/2018	2.4
S2335	WC21_S2_ H1	289725	6192749	372.6	Den 3B	5	19/10/2016	12/11/2016	0.1
S2336	WC21_S2_ H2	289722	6192758	372.4	Den 3B	2	21/10/2016	20/07/2017	0.7
S2337	WC21_S5_ H1	290021	6193412	336.1	Den 3B	3	25/11/2016	31/12/2017	1.1
S2338	WC21_S5_ H2	290012	6193407	336.1	Den 3B	3	24/11/2016	01/02/2018	1.2
S2354	S14_05	289731	6191414	424.6	Den 3B	1	07/09/2017	05/03/2018	0.5

Bore_ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_ Area	Sensors	First_record	Last_record	Years
S2376	Avon06	288400	6192527	367.8	Den 3B	3	06/10/2017	06/02/2018	0.3
S2401	Swamp1b_01	287752	6194265	411.1	Den 3B	6			0
S2402	Swamp1b_02	288208	6193667	403.4	Den 3B	6			0
S2403	Swamp1b_03	288345	6193761	400.7	Den 3B	6			0
S2404	Swamp1b_04	288529	6193897	396.2	Den 3B	6			0
S2405	Swamp1b_05	288730	6194088	386.1	Den 3B	6			0
S2406	Swamp1b_06	288669	6194176	396.6	Den 3B	6			0
S2412	LW15-1	289201	6191807	427.3	Den 3B	8	11/05/2018	31/05/2018	0.1