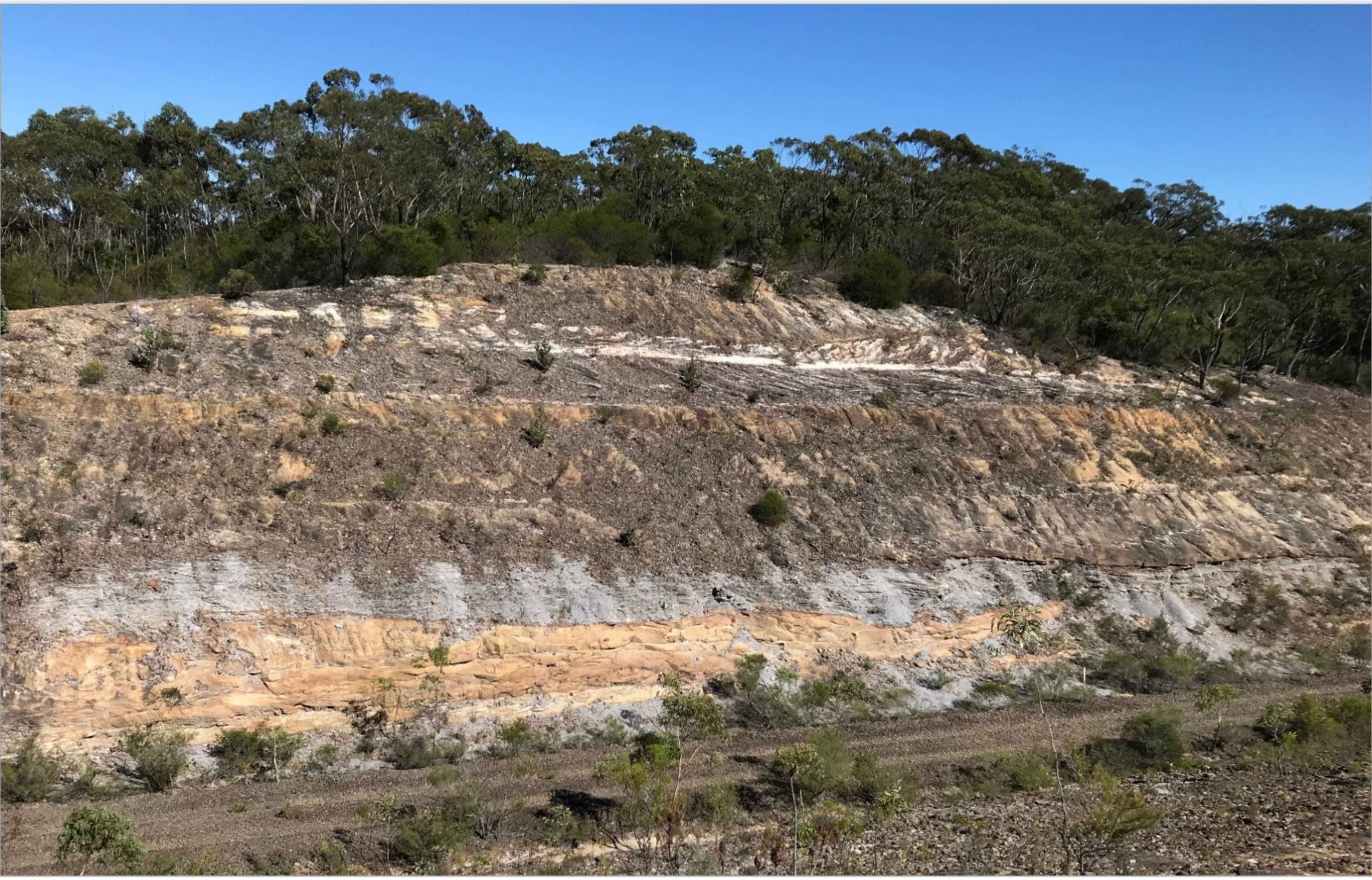
South32 - Illawarra Metallurgical Coal

DENDROBIUM MINE

End of Panel Groundwater Assessment for Longwall 17 (Area 3B)



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EXECUTIVE SUMMARY

This report provides an assessment of the hydrogeological effects of Longwall 17 extraction in Area 3B at Dendrobium Mine, as required under the conditions of mining approval. Extraction of Longwall 17 commenced on 12/12/2020 and was completed on 13/10/2021. Longwall 17 is the ninth panel to be extracted in Area 3B, with an extracted length of 1909 m, a void width of 305 m (including first workings) and a cutting height of up to 3.9 m.

The average daily inflow to Area 3B during Longwall 17 extraction was 5.20 ML/day and total mine inflow was 8.13 ML/day. Compared with the previous longwall, the total mine inflow increased by 23%, mainly as a result of increased inflow to Area 3B (36% increase). Total mine inflow remains below numerical model predictions. From 2016 there is an apparent correlation between large rainfall events and peaks in mine inflow. The amplitude of the rainfall-related peaks accounts for approximately 14% of the inflow in Area 3B. To date, analysis of isotopic tracers tritium and radiocarbon indicate very low components of modern water in Area 3B goaf inflow (≤ 3.1 % modern carbon).

Groundwater salinity (as indicated by Electrical Conductivity – EC) shows a general increase with depth below the surface. Samples collected from two groundwater bores located adjacent to lake Avon (S2314_75m and S2436_35m) show a trend of declining EC over the last 3 longwalls. It is recommended that quarterly sampling and analysis, including for stable isotopes, tritium and ^{14}C be carried out for the next 12 months at those bores.

Mining of Longwall 17 resulted in continued depressurisation of the target coal seam and overlying strata. The observed changes in groundwater levels are in line with (or less than) numerical model predictions, including piezometers installed in the barrier zone between Lake Avon and Area 3B. As expected, the greatest depressurisation is within the Wongawilli Coal Seam, and decreases with height above the seam.

IMC continued its investigation into the height of fracturing above longwalls, with installation of a post-mining hole over Longwall 17. Investigations to date have found that mining-induced fracturing is highly variable but appears to extend to the surface in both Area 3A and 3B. Piezometers installed after longwall extraction indicate significant depressurisation throughout all strata and throughout the Hawkesbury Sandstone (HBSS) in most holes. Drawdown in the HBSS reduces with distance and is typically negligible at distances greater than 1.2 km from the goaf footprint. Holes in Areas 3A and 3B show positive pressure heads (above extracted longwalls) in some sensors in the upper CVSS and BACS and evidence for localised perching and groundwater recovery which continued in 2021. However shallow groundwater levels remain below pre-mining levels.

Investigation of the hydrogeology of the Elouera Fault were largely completed in 2021. Six inclined cored holes have been drilled at two sites along the fault, four of which have intersected the fault plane. Extensive permeability and tracer testing has shown that the fault zone is heterogeneous on a scale of tens of metres and does not form a continuous conduit to groundwater flow. The fault likely forms a weak transverse barrier to groundwater flow due minor lithology offsets.

Permeability testing and groundwater observations at piezometers located in the barrier zone between Lake Avon and extracted longwalls in Area 3B indicate that strata movement following longwall extraction has resulted in increases in permeability in three out of eight locations and localised hydraulic gradients towards the mine. Seepage losses from Lake Avon have been estimated by regional and local scale numerical models to be in the range 0.09 to 0.69 ML/day as at the end of Longwall 17. The estimates are within the tolerable loss limit of 1 ML/day prescribed by Dams Safety NSW and supported by the low levels of tritium and 14C in mine inflow water in Area 3B.

1. INTRODUCTION

Illawarra Metallurgical Coal (IMC) operates the Dendrobium underground coal mine, located approximately 12 km west of Wollongong (NSW) in the Southern Coalfield (Figure 1). IMC is required under the conditions of mining approval to submit regular reviews of the local hydrological data, including groundwater level and quality, and potential seepage losses from stored water.

IMC operates an extensive network of groundwater monitoring sensors (piezometers), groundwater sampling pumps and down-hole geotechnical instruments. Groundwater data from more than 800 active piezometers at >200 monitoring bores is updated monthly via telemetry or collected by IMC field teams.

This End of Panel (EoP) assessment reviews groundwater level and quality monitoring data up to one month after the completion of Longwall 17 (cumulative). Data are assessed against baseline and impact criteria defined in the Trigger Action Response Plan (TARP) which forms part of the Subsidence Management Plan for Area 3B (BHPBilliton, 2015) and the Groundwater management plans contained therein.

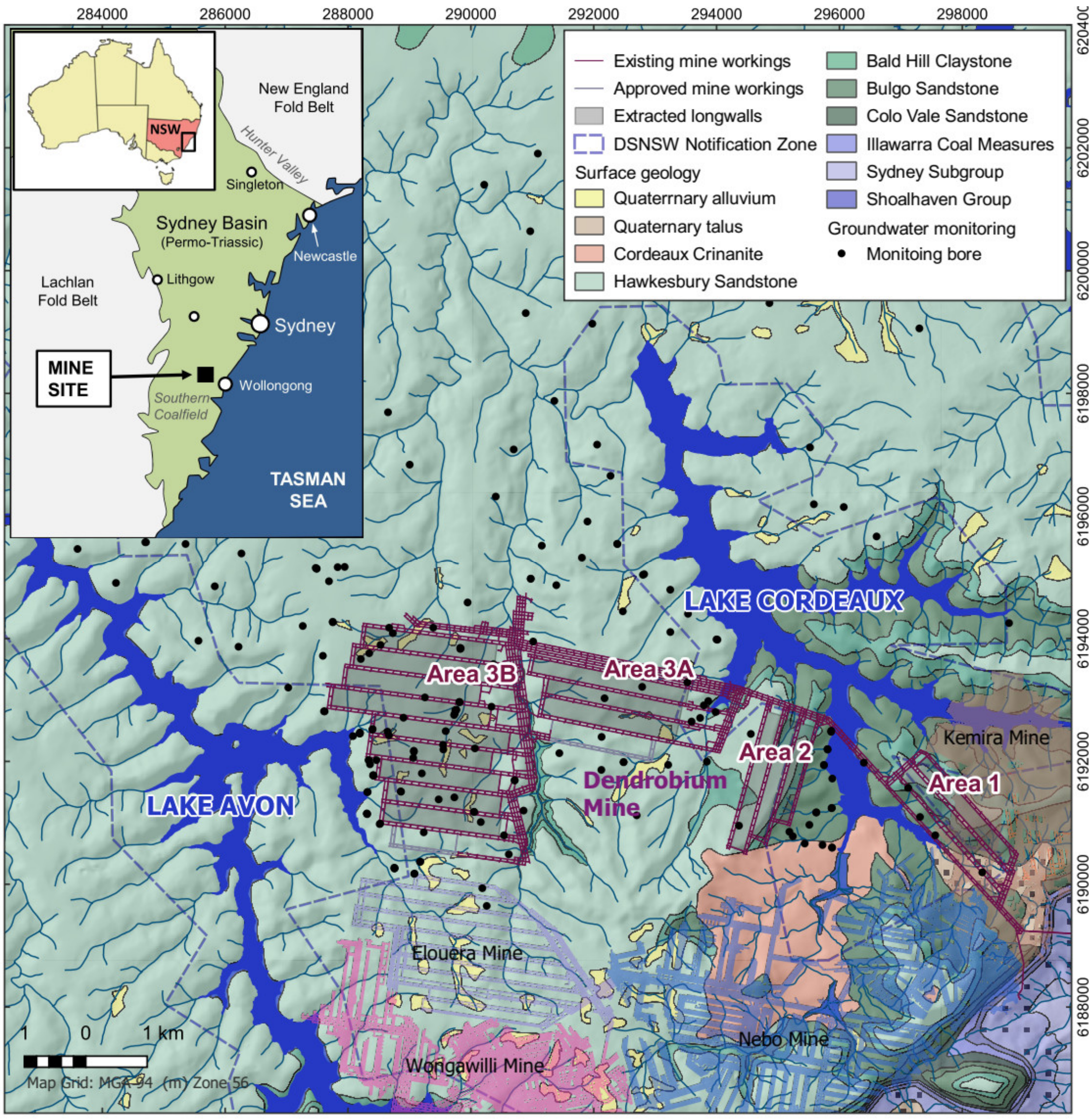

Figure 1. Location of Dendrobium Mine and surface geology

1.1 Longwall 17

Longwall mining at Dendrobium has been carried out in three designated areas: Area 1 (east of Lake Cordeaux), Area 2 (west of Lake Cordeaux), and Areas 3A and 3B (between Lake Cordeaux and Lake Avon). Coal is extracted from the Wongawilli Seam in Areas 1 through 3B. Previous 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.

Extraction of Longwall 17 commenced on 12/12/2020 and was completed on 13/10/2021. Longwall 17 is the ninth panel to be extracted in Area 3B, with an extracted length of 1909 m, a void width of 305 m (including first workings) and a cutting height of up to 3.9 m.

1.2 WaterNSW feedback on previous EOP report

WaterNSW reviewed the Longwall 16 End of Panel reports and provided comments to the NSW Department of Planning Industry and Environment in a letter dated 17/5/2021, with follow-up comments in a letter dated 7/7/2021. Recommendations relate to monitoring and analysis of surface water systems and are addressed in the accompanying surface water assessment (HGEO, 2022). There were no recommendations relating to groundwater reporting.

1.3 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 (HBSS). The HBSS is the dominant outcropping formation across the mine area, but lower stratigraphic units (Bald Hill Claystone (BHCS), Narrabeen Group) are exposed in deeply incised parts of Wongawilli Creek and along the south-eastern shores of Lake Cordeaux.

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

Recharge to the aquifer systems is primarily from rainfall infiltration through outcropping formations, generally the HBSS in the western half of the Dendrobium mine area and the Bulgo Sandstone (BGSS) 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.

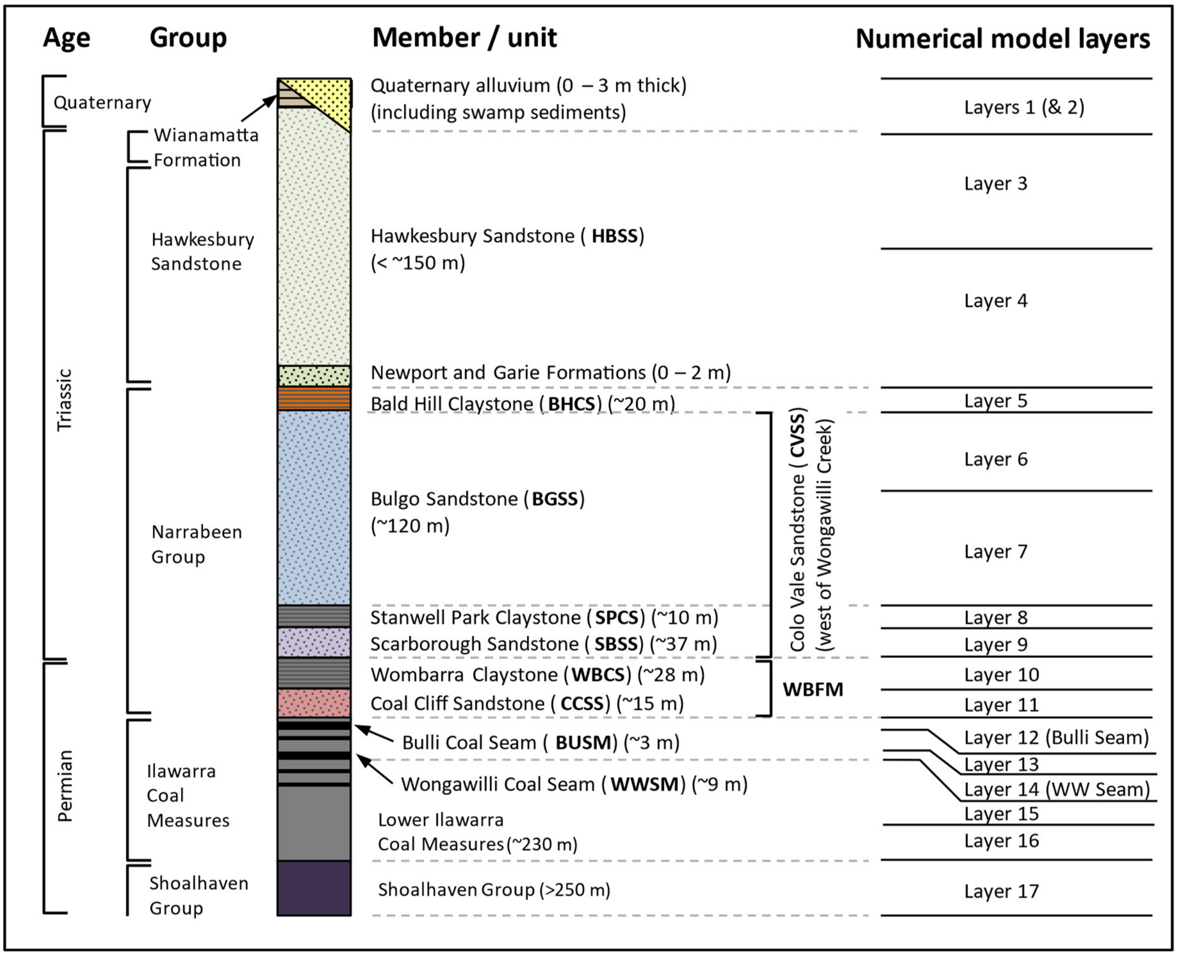

Figure 2. Generalised stratigraphy of the Southern Coalfield

1.4 Effects of mining

Extraction of coal using longwall methods commonly results in ground subsidence and associated deformation and fracturing of overlying strata (Peng and Chiang, 1984; Whittaker and Reddish, 1989). 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 (Advisian, 2016; McNally and Evans, 2007). The height to which vertically connected (and free-draining) fracture networks extend above the mined seam is therefore important in assessing potential impacts 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; for example, Forster 1995; Guo *et al.* 2007; Mills 2011; Tammetta 2013; Ditton & Merrick 2014. These methods have been used at numerous coal mines in NSW to provide guidance on the height of fracturing (or depressurisation) for the development of numerical groundwater impact models. It is important to note that the terms used by the authors are not equivalent; Tammetta refers to the "height of desaturation" (more precisely, complete depressurisation); Ditton and Merrick refer to a "zone of continuous cracking" (Zone A), and Mills refers to a zone of large downward movement (Zone 2).

The Independent Expert Panel for Mining in the Catchment (IEPMC) was established in 2018 to provide advice to government on impacts of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to quantity of water (IEPMC, 2019a, 2019b). In relation to hydrogeological impacts and height of fracturing, the Panel considers that:

"…*changes in ground behaviour and fracturing, permeability and the lateral extent of affected areas occur gradationally rather than as step changes. The so-called 'fractured zone' is a misnomer. Fracturing still develops above this zone and may be connected. Due largely to the different interests and focus of geoscience and engineering disciplines, zones defining mining-induced rock deformation do not necessarily align with zones defining groundwater response to mining.*

Adhikary *et al.* (2020) reviewed strata-caving mechanics and the observations of Tammetta (2013) and developed empirical equations defining upper and lower bound estimates for the height of connected fracturing. The equations are functions of the effective panel width (W') and height of mining (t) only. The authors propose that the upper and lower bounds could be used to define possible ranges of fracturing heights in probabilistic modelling, and that the upper bound should be used as a conservative assumption in deterministic studies[1]. Modelling indicated that subsidence above wide or super-critical[2] panels would be accommodated by fracturing to the surface; however, the authors emphasise that the seam to surface fracturing does not imply seam to surface connection. In addition, rock mass dilation may result in sudden and complete piezometric pressure drops throughout overlying strata that are independent of (and beyond) the connected fracture network. Initial piezometric pressure loss may recover to various degrees depending on the fracture network, recharge rate, and aquitard integrity including the presence of self-healing clay-rich aquitards. Those conclusions are consistent with observations at Dendrobium as summarised in this report.

Since 2018 IMC has carried out targeted investigations into the height of fracturing and groundwater conditions above completed longwalls at Dendrobium Mine. Investigation holes have been drilled above existing Longwalls 12 to 17 in Area 3B and Longwalls 6 and 7 in Area 3A, allowing assessment of effects above longwalls of different width. The main findings of the investigation are summarised in Section 3.2.1.

1.5 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 has been revised and updated several times since 2012 to better represent subsidence fracturing and to allow assessment of shallow groundwater within swamps and baseflow to streams (HydroSimulations, 2016). The current model was developed by Watershed Hydrogeo (2020) using an unstructured grid and

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[1] Note that for Area 3B, the lower and upper bounds of Adhikary *et al.* (2020) are 199 – 387 m. Those values bracket or contain estimates based on Mills 2011 (305 m), Tammetta 2013 (351 – 377 m) and Ditton & Merrick 2014 (216 – 258 m; Geol-A95).

[2] Adhikary *et al.* (2020) define critical and super-critical width, in the absence of site-specific data, as W/d ≥ 1.2 and ≥1.4, where W is the effective panel width and d is the depth of cover (seam top to ground surface). For longwalls in Area 3B W/d ranges from 0.74 to 1.12 (sub-critical).

MODFLOW-USG. The model includes historical mining at Dendrobium and surrounding mines, and proposed developments at Dendrobium Mine Areas 5 to the north of Area 3B.

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

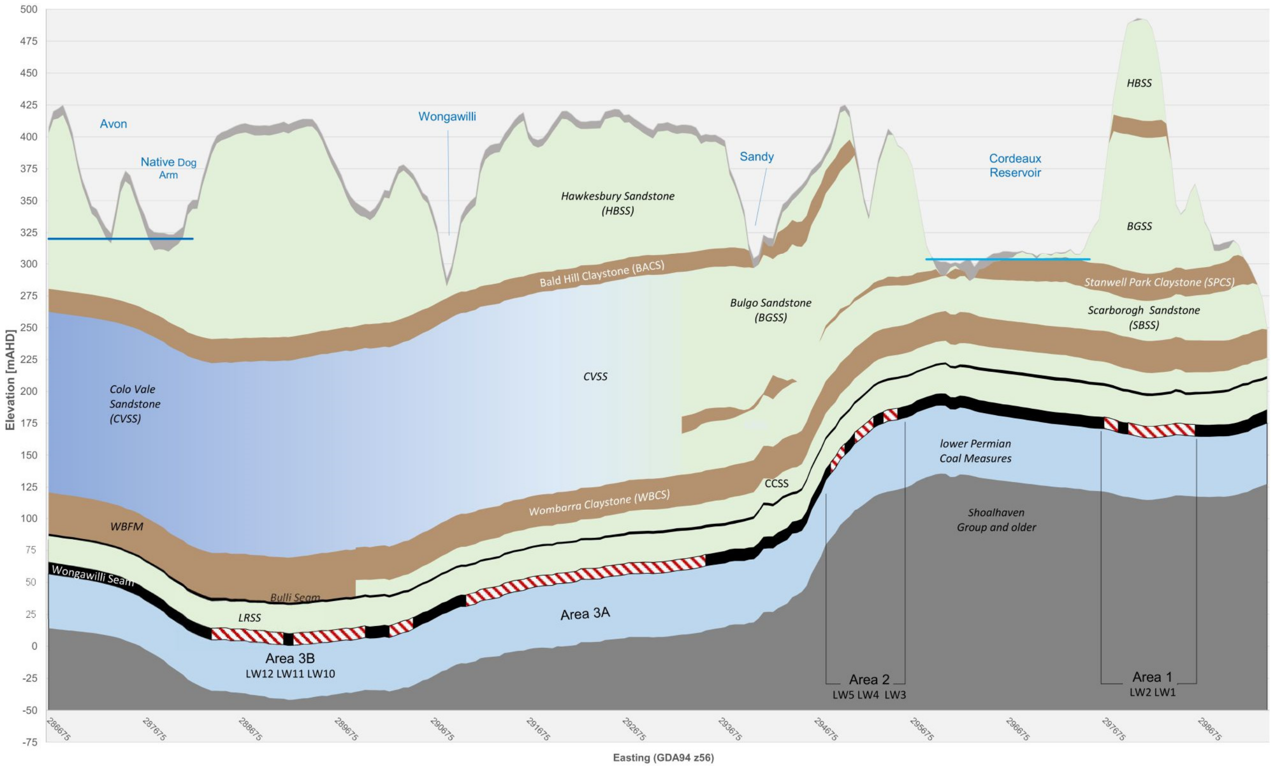

Figure 3. Geological cross-section (east-west) through Dendrobium Mine

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 (BHP Billiton, 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 relevant groundwater-monitoring locations.

2.2 Groundwater monitoring network

The groundwater-monitoring locations for Areas 3B are shown in Figure 4. A list of all monitoring bores installed at Dendrobium is included in Appendix A. There are approximately 204 active monitoring bores located across the Dendrobium mine lease, containing over 810 piezometers, excluding those that are decommissioned or no longer monitored. During 2021, new monitoring bores were installed (and or instrumented) as shown in Table 1:

Table 1. Groundwater monitoring installed in 2021

Bore ID	Location details	MGA mE	MGA mN	Max sensor depth (m)	VWP sensors	TDR cable
S2493B	Longwall 17	289658	6191102	272.0	9	
S2545	Longwall 21	291431	6194210	255.9	8	Yes
S2573	Elouera Fault	289503	6190139	405		

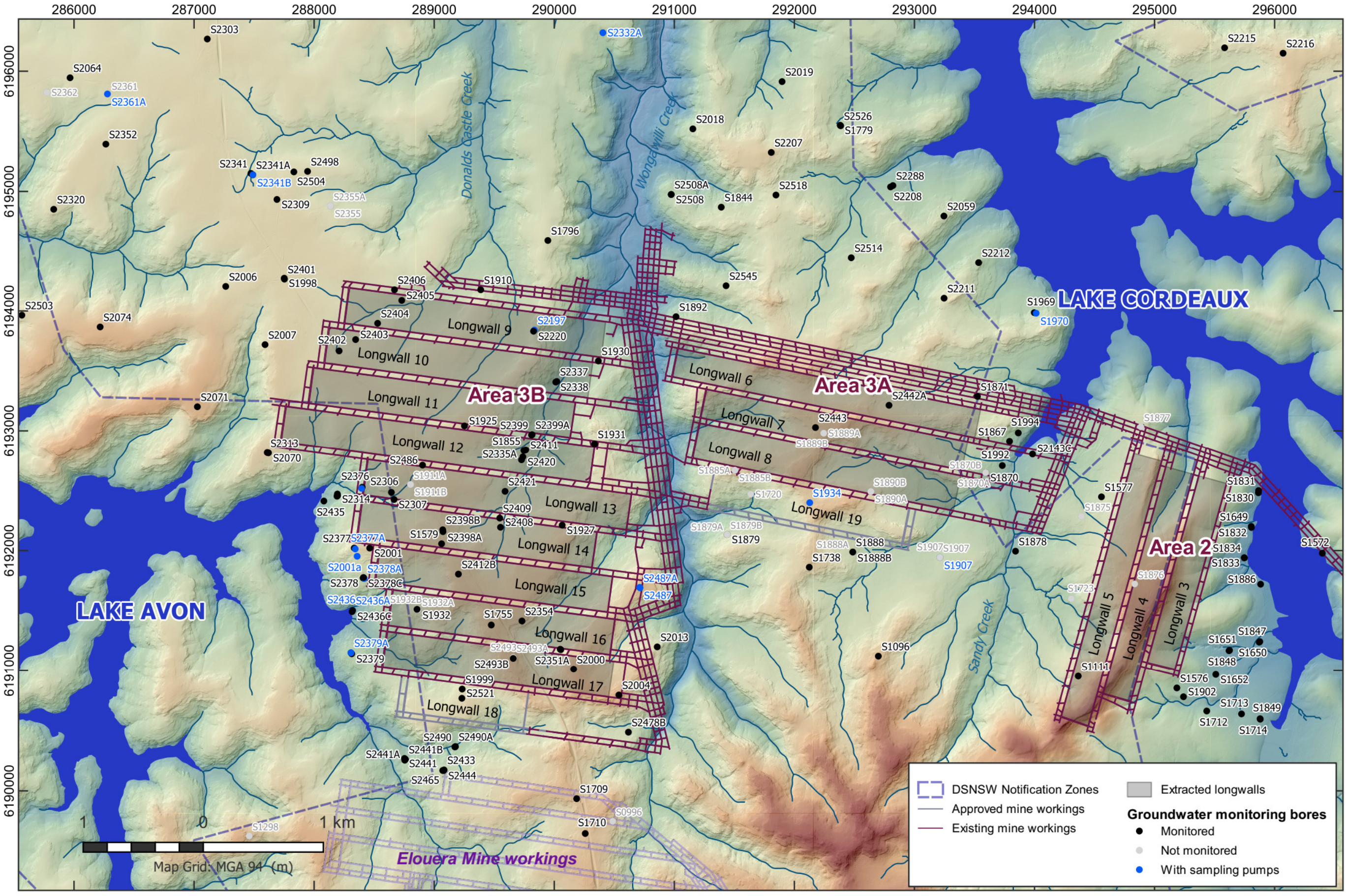

Figure 4. Deep groundwater monitoring network around Areas 2, 3A and 3B

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 (Contreras et al., 2008; Mikkelson and Green, 2003).

Standpipe piezometers, consisting of a slotted open casing, are best suited to monitoring of relatively shallow groundwater systems within moderate to high permeability strata (e.g. swamp sediments and shallow HBSS). 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 ***piezometric head*** (mAHD) and ***pressure head*** (m H_2O). Piezometric 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 depressurisation at the location of the sensor and, given the uncertainty in pressure measurements, may be totally or partially desaturated. Both piezometric and pressure head hydrographs are presented in Appendix B.

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 a reference date and the end of the current reporting period.

In this assessment the groundwater drawdown reference date is November 2009, immediately prior to the start of mining at Area 3A. This date was selected because very few piezometers were operational in Area 3B prior to 2009. The following procedure was used to calculate groundwater drawdown.

- Piezometric head and pressure head data were tabulated from the Dendrobium VWP database. Data were reduced to daily observations using a median of sub-daily data.
- The median head at each operational sensor was obtained for the last 3 months of the recently completed longwall and the last three months of Longwall 5 (ending in November 2009). This approach is used to capture sensors with records that fall slightly short of the end of panel.
- The average head was calculated for each of five subunits: middle HBSS, lower HBSS, upper BGSS, lower BGSS and SBSS. This allows piezometric heads to be compared at bore locations where sensors are set at inconsistent depths. The subunits also correspond to the subunits used in the regional numerical model (HydroSimulations, 2016), allowing direct comparison with model predictions.
- For bores that were installed after 2009, the piezometric head in 2009 was spatially interpolated from sensors within each subunit that were active at that time (using kriging).
- Drawdown was calculated for each subunit as the difference between median heads at the end of the recently completed longwall and the end of Longwall 5 (either observed or interpolated).
- Where one or more of the sensors in the subunit recorded less than 1 m of pressure head (assumed to be near desaturation), the drawdown is recorded as a minimum. Those locations are highlighted on the relevant spatial plots.
- Sensor data for decommissioned or damaged bores are not extrapolated. Locations that have been decommissioned, damaged or for which data are otherwise unavailable at the time of reporting are not included in analysis.

Spatial plots are presented and discussed in Section 3.3.

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 Dams Safety NSW monthly.

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 (blue symbols). Currently there are eight sampling bores in Area 3B containing 20 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 shore of Lake Avon. The SBSS is monitored at two locations: S1886 (Area 2) and S1870 (Area 3C).

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), and isotopes of carbon and hydrogen. 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 Dams Safety NSW. More than 3,400 water samples have been collected and analysed at Dendrobium Mine since 2004 (including > 1100 tritium analyses), providing an extensive database 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 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 3.5.

Samples collected from bores can sometimes be influenced by drilling water, 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.

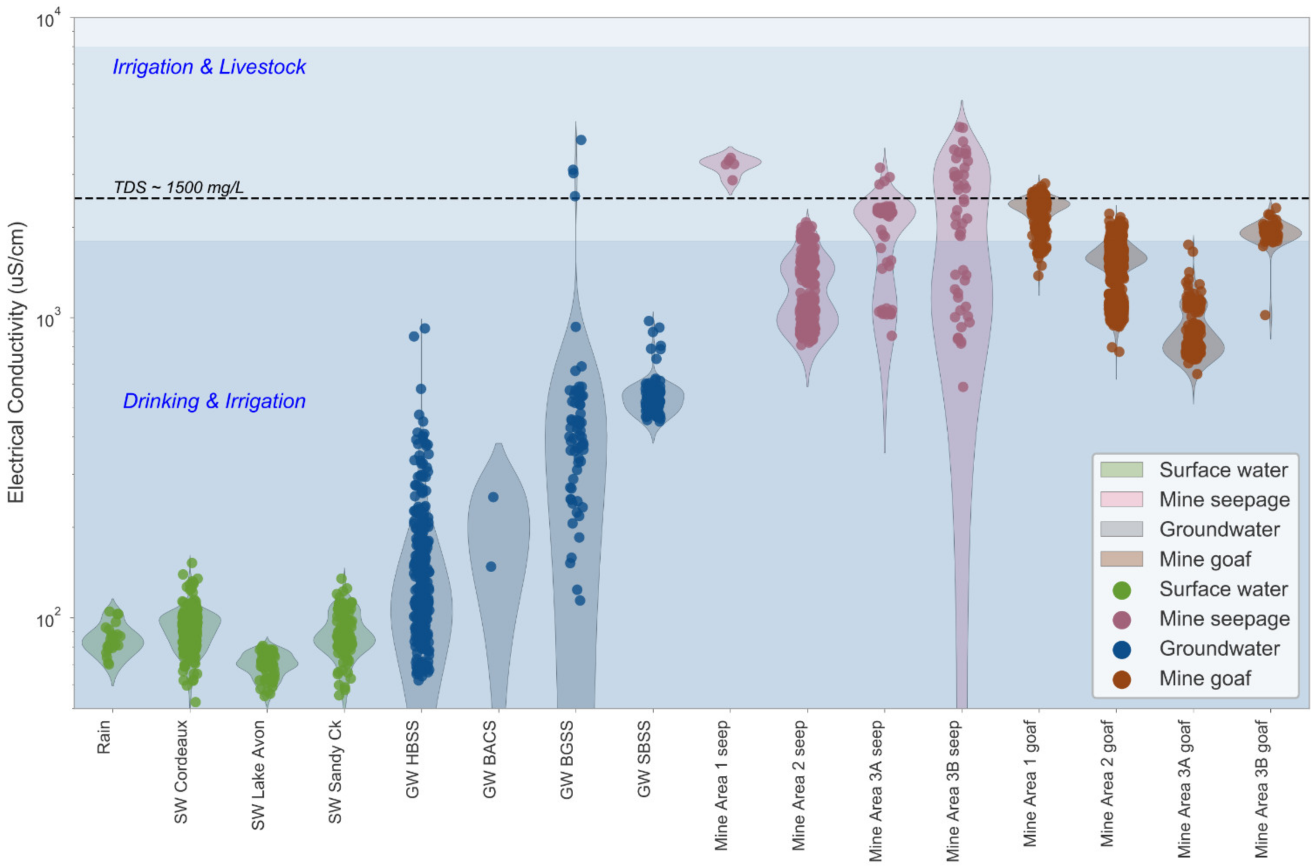

Figure 5. Violin plot showing the range in EC of surface water, groundwater and mine inflow

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 17 was extracted (12/12/2020 to 13/10/2021). The average daily inflow to Area 3B during Longwall 17 extraction was 5.2 ML/day which represents 64% of total mine inflow for the period (a similar proportion to Longwall 16). Compared with the previous longwall, the total mine inflow increased by 23% and the inflow in Area 3B increased by 36%. The increase in total mine inflow is mainly due to an increase of inflow in Area 3B (Table 2).

Table 2. Dendrobium Mine Inflow during the Extraction of Longwall 17 (in ML/day)

STATISTIC	AREA 1	AREA 2	AREA 3A	AREA 3B	TOTAL
Longwall 17 (mean)	0.75	1.31	0.87	5.20	8.13
Longwall 17 (maximum)	*2.05*	*6.83*	*5.44*	*8.42*	*14.51*
Longwall 16 (mean)	0.33	1.59	0.85	3.82	6.59
Longwall 15 (mean)	0.33	0.72	0.68	4.03	5.75
Longwall 14 (mean)	0.33	0.28	1.03	4.21	5.84

Time-series plot of total groundwater inflow to Dendrobium Mine (all mine areas) 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 total mine water balance has increased steadily from 2010 as mining progressed with peak mine inflows correlating closely with periods of high rainfall.

The mine water balances for Areas 3A and 3B are shown in Figure 7. Groundwater ingress to Area 3B increased steadily since the start of mining in that area (2013), initially correlating with the total area mined. However, the rate of increase declined (flattened) during the mining of Longwall 12 and Longwall 13 and the water balance decreased during the extraction of Longwall 14 and Longwall 15. This overall trend reflects a declining groundwater inflow per unit area mined due to progressive depressurisation of the surrounding strata by previous mining (a decline in driving head), and also the unusually dry conditions during 2018-2019. Since the start of 2020, the water balance for Area 3B has trended higher, correlating with the higher-than-average rainfall over the last two years. As of Longwall 12, peaks in inflow to Area 3B appear to correlate with periods of high rainfall with a lag time of between two and three months. Prior to Longwall 12, the influence of rainfall on the water balance was less distinct.

Groundwater ingress to Area 3A has declined by more than 50% as mining has progressed in Area 3B. The correlation of inflow peaks to major rainfall events in Area 3A has become less distinct since the end of Longwall 12.

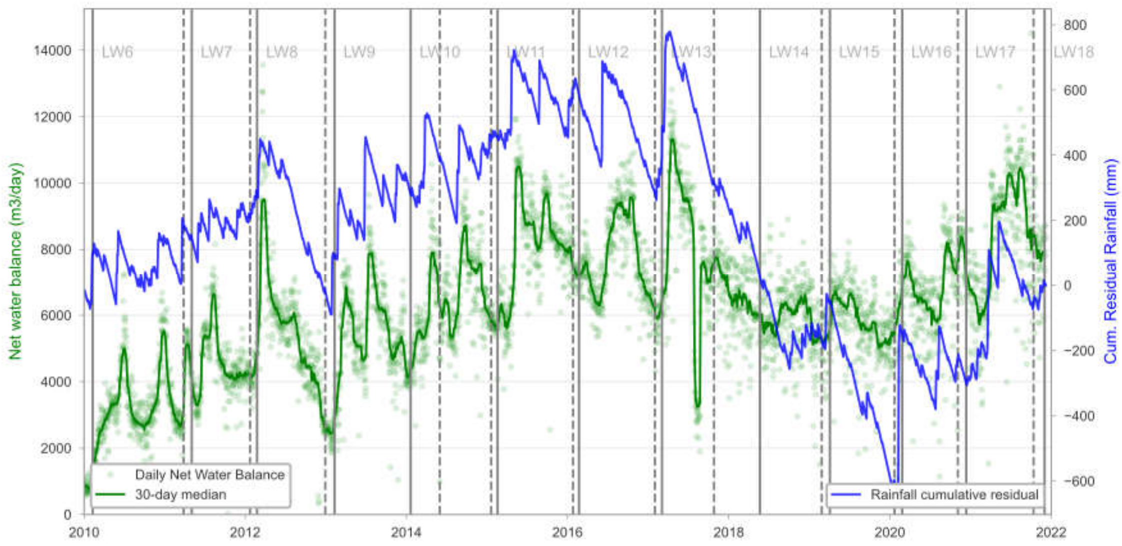

Figure 6. Groundwater inflow from water balance for all mine areas (kL/day)

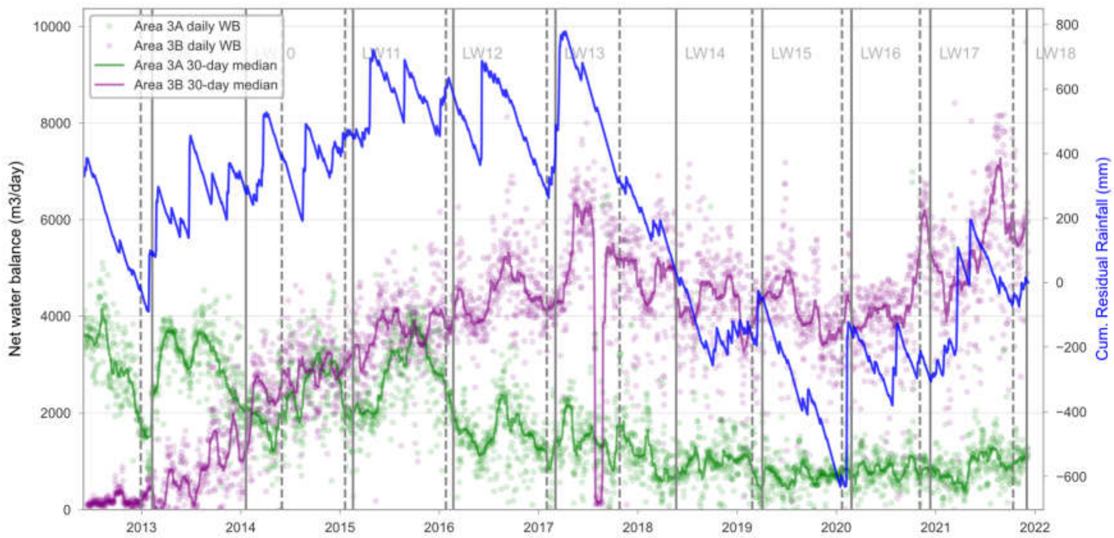

Figure 7. Groundwater inflow to the mine for Areas 3A and 3B (kL/d)

3.1.1 Estimates of the surface water component of mine inflow

The correlation of inflow peaks with periods of high rainfall at Area 3B implies that there is a rainfall (or surface water) induced component to mine inflow. Two approaches are used to assess the proportion of mine inflow at Area 3B that may be attributed to rainfall or surface water:

1. Baseflow separation approach, whereby the volume related to the inflow peaks is estimated as a fraction of the total inflow for a given period. Baseflow is a concept from stream flow hydrology whereby the baseflow represents the groundwater discharge component of low, as opposed to the 'quick flow' component of rainfall runoff represented by the hydrograph peaks (in this case peaks in mine inflow following rain events).

2. Isotopic tracer approach, whereby tracers of modern water (tritium and radiocarbon) are used to detect and estimate the proportion of rainfall or surface water in mine inflow samples.

The two approaches assess surface water input in different ways and will not necessarily yield similar results. The baseflow separation approach estimates the inflow component related to high rainfall events. Those events result in a rise in groundwater levels or piezometric head (within porous rock and fracture networks) which drive transient increases in mine inflow. However, the water itself may be largely or entirely derived from the release of (old) groundwater storage[3] unless there are direct and rapid pathways between the surface and the goaf. This appears to be the case for Area 3B inflows and contrasts with observations at Area 2, as evidenced below.

A base-flow separation analysis of Area 3B water balance data is shown in Figure 8. The daily water balance data (grey circles) is highly variable due to the nature of pumping cycles in the underground mine and the trend is best represented as a 30-day moving average (the blue line). The moving average clearly defines peaks in net mine inflow following large rainfall events, with a two to three-month delay. Since the end of Longwall 16 there have been two major peaks in water balance at Area 3B, reflecting the higher-than-average rainfall during 2020 and 2021.

Applying digital stream baseflow separation filters to the water balance data is problematic due to the high variability of the data (including negative values). Therefore, the baseflow component has been approximated by interpolating between troughs in the 30-day moving average water balance. The potential rainfall-induced inflow component is defined by the difference between the two curves (blue shading). Using this method, the rainfall-induced component of inflow during Longwall 17 was 14%, compared with 12% during Longwall 16, and 13% during Longwall 15.

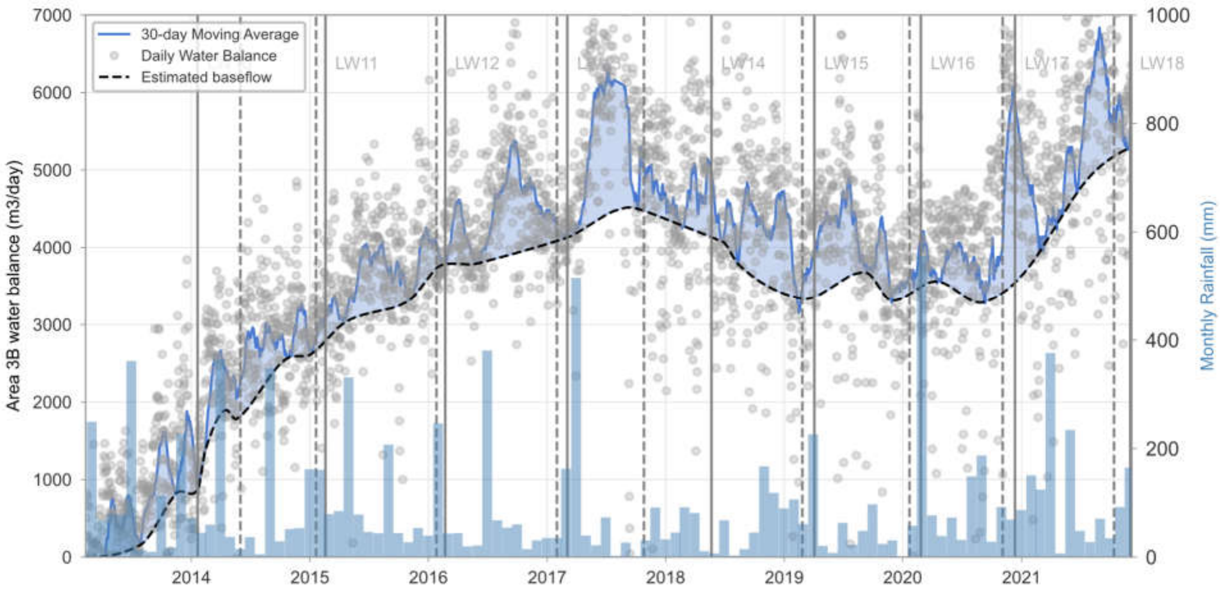

Figure 8. Estimate of potential surface water component to Area 3B water balance

3.1.2 Tritium in mine inflow

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 Dams

[3] Note that the volume of groundwater storage above the longwall footprint alone is significant. Unconfined or drainable groundwater storage would be in the order of 7 GL per longwall (assuming an average longwall goaf area of 610,000 m2, a Specific Yield of 3% averaged over all strata and an average saturated thickness of 370 m in Area 3B). Confined or elastic storage would be small in comparison; in the order of 20 ML (assuming a Specific Storage coefficient of around 10^{-6} m^{-1}; David *et al.* 2017). At the average mine inflow rate per longwall, complete drainage of the column (ignoring lateral groundwater flow) would take in the order of 20 years. Old groundwater storage release is likely to dominate mine inflow for many years.

Safety NSW. 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).

Tritium is widely assumed to be a conservative tracer in that it is not significantly sorbed or otherwise retarded during groundwater transport (e.g. Cendón et al., 2014; Štamberg et al., 2014). However, a recent review by ANSTO (2018), commissioned by South32, concluded that tritium may undergo diffusive exchange with (and therefore loss to) zones of older groundwater. While the effect has not been quantified in terms of typical groundwater pathways at Dendrobium, it is important to consider when assessing tritium results. Despite possible diffusive losses, tritium remains an important and unambiguous indicator of modern water when tritium is detected above baseline levels.

A timeseries plot of tritium in groundwater samples from Area 3B goaf (at the outflow point) is shown in Figure 9. Tritium in samples collected from Area 3B goaf outflow is typically within or close to baseline concentrations in deep groundwater (represented by the shaded area below 0.2 TU in Figure 9, from (HGEO, 2021a), implying that the component of modern water in mine inflow to Area 3B is very low - likely less than 9% which is the 90th percentile estimate based on binary mixing calculations. Samples are collected approximately monthly; however, analysis and reporting of results from ANSTO can take 6 to 12 months. The most recent analysis is from a sample collected on 22/2/2021, during the initial stages of Longwall 17.

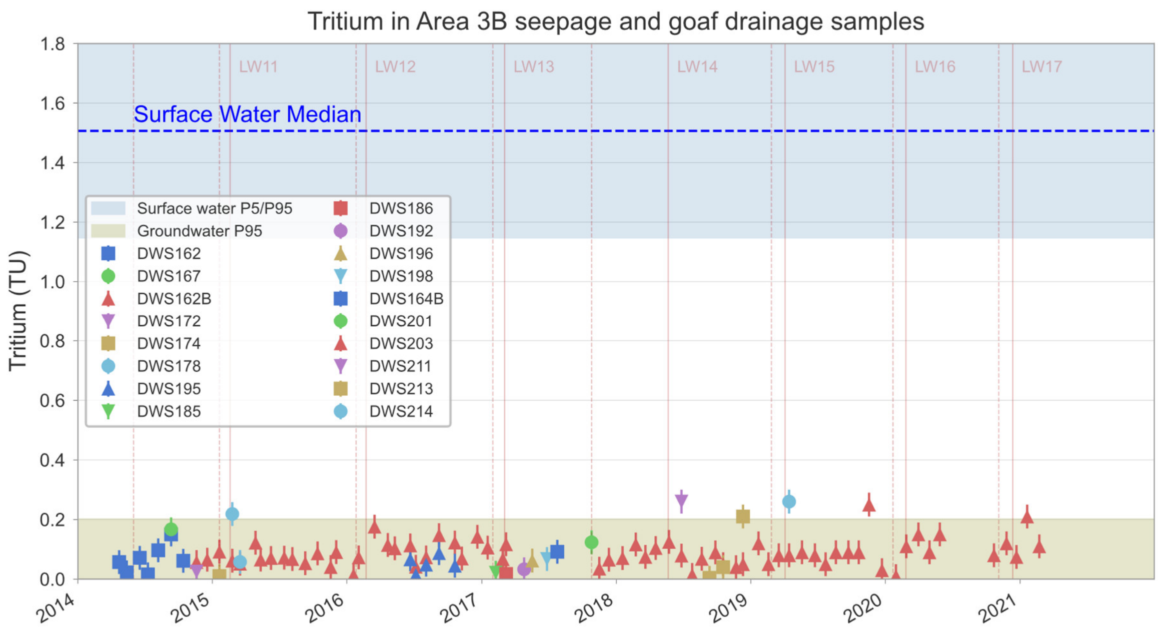

Figure 9. Tritium concentration in water samples from Area 3B (from HGEO, 2021)

3.1.3 Radiocarbon (14C) in mine inflow

Carbon-14 (14C) has been analysed in mine water, groundwater and surface water samples since 2020 as an additional indicator of modern water. 14C is a radioactive isotope of carbon with a half-life of 5,730 years. It is a widely used tracer for groundwater movement up to 30,000 years old. 14C is produced in the atmosphere and becomes part of the carbon cycle through uptake of plants and respiration and oxidation of the soil zone. Surface water and rainfall infiltrating into the ground contain small amounts of carbon dioxide extracted from the air. Leaving the atmosphere, the water comes in contact with the soil air, where the partial pressure of vegetation (root-respiration) generated carbon dioxide is much higher. The 14C content of these sources is the so-called “modern” level and is used for the reference in calculating the percentage modern carbon (pMC) and groundwater age.

Three sample results have been received from Area 3B goaf inflow since 2020. Results are presented in Table 3 with corresponding results for tritium analysis. More recent samples have been submitted to ANSTO for analysis and results are pending. All samples collected from the goaf outflow tank (DWS203) have low pMC (≤ 3.1%) which, together with low corresponding tritium concentrations, implies that inflow to Area 3B is mostly from old, deep groundwater sources with only a very small proportion of modern water.

Table 3. Radiocarbon and tritium in Area 3B goaf water samples

Date	Sample location	EC (µs/cm)	Tritium (TU)	pMC (14C)	Conventional 14C age (years BP)
22/10/2020	Area 3B goaf (DWS203)	1740	0.08	2.25 %	30,490
25/11/2020	Area 3B goaf (DWS203)	1780	0.12	3.10 %	27,920
22/12/2020	Area 3B goaf (DWS203)	1720	0.07	2.14 %	30,890

3.2 Deep groundwater levels – time-series hydrographs

Representative hydrographs from VWP arrays are presented and discussed below. Hydrograph plots are presented in Appendix B (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, S2412, 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. Since 2018, a number of new piezometer arrays were installed over previously mined longwalls 6 and 7 in Area 3A and Longwalls 12 to 17 in Area 3B.

Prior to being mined beneath:

Review of hydrographs from piezometers installed above longwalls prior to being mined beneath show evidence of depressurisation at the coal seams before mining started at Area 3A and years before mining started in Area 3B (Appendix B). 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). Recent examples are S2436 immediately after the start of Longwall 16 and S2478B towards the end of Longwall 17. 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 CVSS 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 beneath:

Since 2018 IMC has carried out investigation drilling above extracted Longwalls 6 and 7 (Area 3A) and Longwalls 12 to 17 (Area 3B) to characterise the height of fracturing and assess groundwater conditions in strata above the longwall goaf (HGEO, 2021b, 2020a, 2020b). Eleven sites were drilled as part of the investigation, adding to five sites drilled as part of previous investigations above extracted longwalls (Longwall 9, Swamp 1b and WC21). A pre-longwall hole has been drilled near the midline of planned Longwall 18 (hole S2521), which will be re-drilled and tested following longwall extraction. These investigations now provide a good understanding of fracturing and depressurisation above extracted longwalls at Dendrobium. The height of fracturing investigation report was reviewed by Professor Bruce Hebblewhite (2020). The main findings are summarised below:

- In both Areas 3A and 3B, mining-induced fracturing, including high-angle fracturing is highly variable but appears to extend to the surface. The density of fracturing generally decreases with height above the goaf, with anomalous fracturing within the Bald Hill Claystone and below 120 m above the goaf. On average, the density of fracturing above the 249 m wide longwalls is less than that above the 305 m wide longwalls (although the profiles are variable).
- In most over-goaf holes, fractures display a weak preferred orientation parallel to the longwall face within 100 to 200 m above the goaf, transitioning upward to lower-angle or bedding plane fractures above that height. One hole drilled above a longwall pillar shows a weak preferred orientation parallel to the longwall (length), again transitioning upward into lower-angle structures above 100-200 m.
- All holes drilled above extracted longwalls show a significant increase in horizontal permeability throughout the profile. Packer tests indicate an increase in permeability of 2 to 3 orders of magnitude relative to pre-mining conditions. At the centreline of Longwall 12 (S2420) there is an anomalous zone of apparently unaffected (near median) permeability in the upper CVSS and Bald Hill Claystone (BACS). Above the pillar zone between Longwall 11 and Longwall 12, packer tests indicate distinctly lower post-longwall permeability than the centreline holes throughout all strata.
- Changes in vertical permeability cannot be measured directly from packer testing. The decrease in high-angled fractures with height above the goaf implies that, while vertical permeability is likely enhanced throughout all strata, the ratio of vertical to horizontal permeability decreases with height above the goaf.
- VWPs installed after longwall extraction indicate significant depressurisation throughout all strata, with near-zero pressure heads recorded in most piezometers. Complete depressurisation is recorded throughout the HBSS in most holes drilled above goaf. However, holes in both areas show positive and increasing pressure heads in some sensors in the upper CVSS and BACS, indicating localised perching and recovery of groundwater levels within those strata.

In the context of previous models for fracturing above extracted longwalls, it is interpreted that the height of connected fracturing (and depressurisation) extends to the surface in Areas 3A and 3B and likely also in Areas 1 and 2. However, observations of localised perching and recovery above extracted longwalls suggests the height of connected fracturing is variable across the site.

3.2.2 Area 3B: Strata outside mined longwalls

In this section, data from piezometers located outside the current mined longwall footprint are discussed (excluding the Avon monitoring bores which are discussed below). These include bores installed within planned mining Areas 5 and 6. Refer to hydrographs in Appendix B.

Piezometers located to the north and west, and within 1 km of the longwall footprint (S1910, S1892, S1998 / S2401, S2006 and S2007) 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. The most strongly affected strata are within 500 m of extracted longwalls (S1910, S1892). At S2006 (1 km west of Longwall 9) piezometric head deceased to their lowest level in most strata towards the end of Longwall 14 and have shown recovery in within the HBSS and upper BGSS since Longwall 14.

Monitoring bores installed in Area 5 show that drawdown is minor at distances greater than 1.2 to 1.5 km from Area 3B. At S2341 (1.2 km), there is some evidence for depressurisation in the deeper sandstone strata; however, all sensors show piezometric head at an elevation corresponding to the HBSS. Similar piezometric levels are observed at S2352 (2.3 km), S2342 (2.6 km), S2345 (3.5 km) and S2340 (4.7 km). At those relatively distant locations, piezometric head within the HBSS is typically above 320 m AHD (and above the level of Lake Avon), whereas levels within the BGSS and SBSS have heads < 300 m AHD and display broadly hydrostatic profiles. This condition has not significantly changed during the extraction of Longwall 17.

3.2.3 Avon reservoir bores

A series of monitoring bores was installed along the barrier zone between Lake Avon reservoir and Area 3B to characterise the strata permeability before and/or after mining of adjacent longwall panels and to provide ongoing groundwater monitoring. Holes are typically re-drilled and tested following extraction of the adjacent longwall(s). Those observations provide critical information to allow more accurate calculation and modelling of potential seepage losses from the reservoir(s) to the mine. Results of drilling, permeability testing and monitoring have been reported as the investigation has expanded, and hole re-drilling has been completed. A review of data was reported by HGEO (2021c) after the re-drilling of hole S2379 at site AD5 following the extraction of Longwall 17. Monitoring bores that are installed and operational at the end of Longwall 17 are listed in Table 4 with a summary of recent observations.

Table 4. Observations at piezometers between Lake Avon and Area 3B

Site	Hole	Monitoring	Comments
AD1	S2313	VWP: 49 m, 131 m, 182 m TDR Installed 31/10/2015	Groundwater levels in all sensors declined following extraction of Longwall 12 adjacent to the site. Piezometric head in the two deepest sensors have remained below the level of Lake Avon since the start of monitoring. The shallowest piezometer (49 m) has declined slightly since 2017 but remains above Lake Avon FSL, possibly representing a perched water table.
AD2	S2314	VWP: 29 m, 75 m, 128 m TDR	Groundwater levels in all sensors declined following extraction of Longwall 12. The deepest sensor (128 m) shows

Site	Hole	Monitoring	Comments
		Installed 13/11/2015	depressurisation responses to Longwalls 12 to 15 and gradual recovery after Longwall 15. The piezometric head in all three sensors is below Lake Avon FSL and there is a correlation between variations in groundwater level and lake level in the shallowest sensors (29 and 75 m depth)..
AD3	S2377	VWP: 27 m, 112 m, 187 m Pumps: 34 m, 115 m, 200 m TDR Installed 21/5/2018	Piezometric levels in the deeper two sensors are below Lake Avon FSL and showed little additional response to Longwall 17. The shallowest sensor (27.1 m) likely records a perched water table within the HBSS. It shows a decline in head over time and is approaching zero pressure head.
AD4	S2378	VWP: 30 m, 90 m, 164 m Pumps: 29 m, 70 m, 164 m TDR Installed 14/11/2017	The deeper two sensors (90 m and 164 m) show strong compression and depressurisation responses to Longwalls 13 to 16. Piezometric levels at the base of the HBSS have declined from near the Lake Avon FSL to >20 m below the FSL since Longwall 13. The sensor at 112 m is registering zero pressure head.
AD5	S2379	VWP: 30 m, 50 m, 108 m TDR Installed 22/2/2018	Site AD5 is adjacent to Longwall 17. The deepest two sensors (50 m and 108 m) record increasing piezometric head in the HBSS and BGSS since 2018. As of mid-2021 groundwater levels are significantly above the level of Lake Avon. The uppermost sensor (30m) has recorded near-zero pressure head since 2018 and may be in unsaturated strata.
AD6	S2376	VWP: 29 m, 107 m, 169 m Pumps: 29 m, 107 m, 169 m Installed 6/10/2017	Site AD6 is located within 10 m of Longwall 13 footprint. Piezometric levels in the deeper two sensors are below Lake Avon FSL. Groundwater levels show responses to heavy rainfall events and slight recovery during 2020-21. The shallowest sensor (29 m) has recorded near-zero pressure head since 2018 and likely represents desaturation of the strata.
AD7	S2435	VWP: 25 m, 60 m, 100 m Pumps: 29 m, 64 m, 116 m Installed 12/11/2018	Site AD7 is located within 40 m of the lake shore. The piezometric head in all three sensors is below the Lake Avon FSL and current lake level. There was a rise of several metres in all sensors following heavy rainfall events during 2020 and 2021. Variations in groundwater level in the shallowest piezometer are similar to the variation in the Lake Avon water level.
AD8	S2436	VWP: 25 m, 65 m, 93 m, 35.1 m, 45.9 m Pumps: 35 m, 90 m Installed 19/11/2018	Site AD8 is located within metres of the lake edge at FSL. Groundwater levels at the base of the HBSS have declined to below the FSL and current lake level. Most sensors show a strong pore pressure response to subsidence movements associated with Longwalls 15 to 17 (compression and pore-pressure increase). Strong transient depressurisation is seen in the deepest sensor at 93 m depth and groundwater levels in the upper CVSS are below the FSL.

In summary, piezometers in the Lake Avon barrier zone show widespread depressurisation of all strata in response to mining in Area 3B, as predicted in numerical groundwater models (Watershed Hydrogeo, 2020). Groundwater levels at the base of the HBSS were likely near or just above the lake level prior to mining and have declined to be below the lake level. There is evidence for recovery in groundwater pressures in the CVSS at AD2, AD7, and to a lesser extent, at AD6.

The observed levels imply hydraulic gradients away from the lake and towards the mine adjacent to extracted longwalls; however, gradients remain towards the lake beyond the influence of the extracted longwalls. Perched aquifers are apparent in upper parts of the HBSS which can persist after mining.

A plot of model predicted piezometric head versus observed head at piezometers adjacent to lake Avon as of the end of Longwall 17 is shown in Figure 10. The plot shows that for most piezometers, observed head is similar to, or higher than, the numerical model prediction. Therefore, the model predictions are generally accurate as of Longwall 17 or tend to over-estimate groundwater drawdown. A notable exception is S2376_107 m (AD6) which is within 10 m of Longwall 13 goaf footprint.

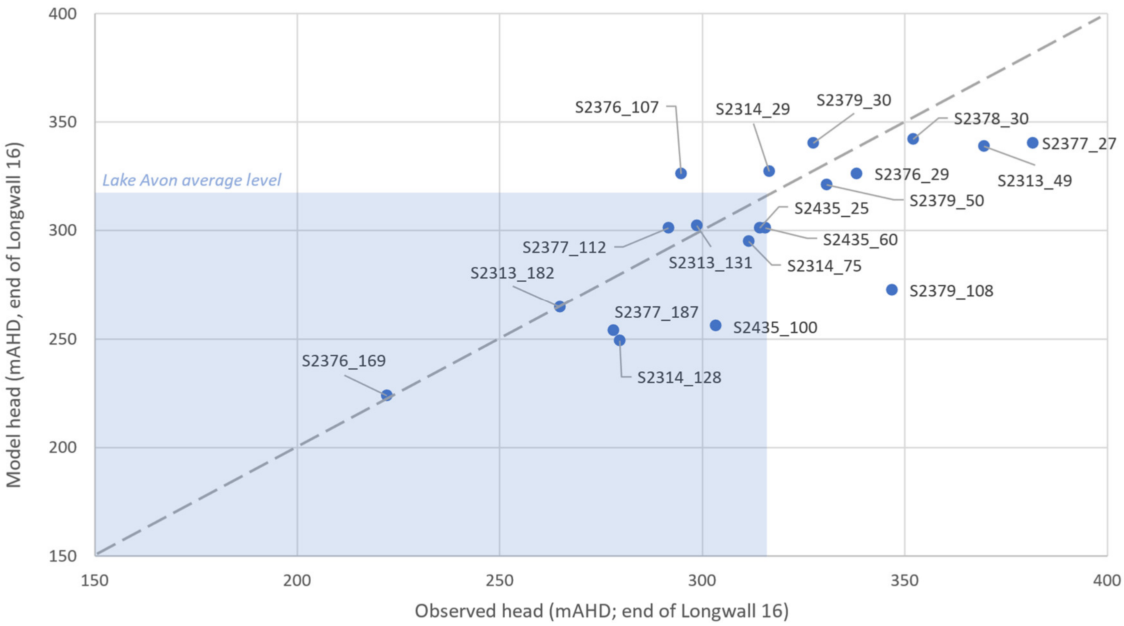

Figure 10. Modelled versus observed piezometric head for Avon Dam monitoring sites

Hydraulic gradients away from the lake imply groundwater flow from the lake to the mine and seepage loss from the lake. The rate of seepage loss is governed by the hydraulic gradient and permeability (measured and expressed as hydraulic conductivity) of the intervening strata which has been tested prior to mining (at most sites) and following extraction of longwalls. Estimates of seepage loss have been calculated using several approaches, including regional and local scale numerical models (see Section 3.4.3, below)

Figure 11 is a summary of hydraulic conductivity in the HBSS in the elevation range between the top and base of Lake Avon at each site, updated to reflect the results of the post-Longwall 17 testing at site AD5. At six of the eight sites, testing was carried out both before and after the adjacent longwall was extracted (AD1 to AD5 and AD8), and at a further two sites the tests were carried out only after the adjacent longwalls were extracted (AD6 and AD7). Measurements of hydraulic conductivity from packer testing are shown with a logarithmic scale (y-axis) versus radial distance from the nearest longwall (x-axis). The grey band represents the 10 to 90 percentile range for numerous packer tests carried out in HBSS prior to mining. The plot shows that at three locations (AD2, AD7 and AD8), the mean post-mining strata permeability is one to two orders of magnitude higher than pre-mining conditions as a result of bedding plane movements and strata stress relief beyond the goaf footprint. However, at five locations (AD1, AD3, AD4, AD5 and AD6), testing after mining shows strata permeability that remains largely within the P10-P90 range for non-mining affected HBSS.

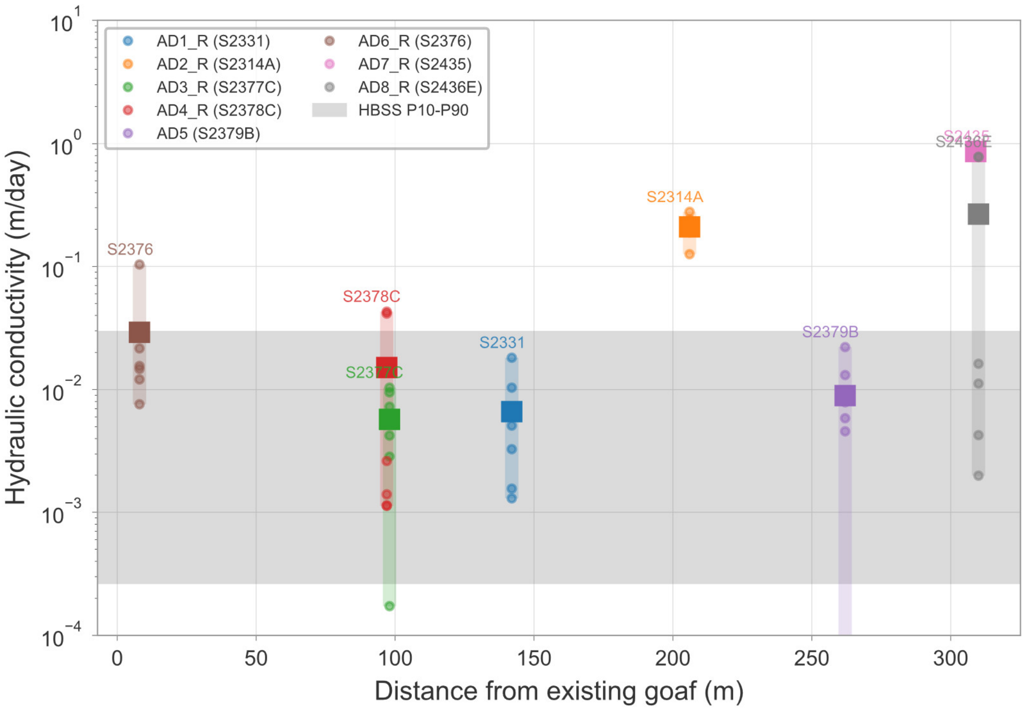

Figure 11. Permeability tests in Avon Dam bores.

There is no correlation between permeability increase and proximity to goaf, implying that strata fracturing (including bedding plane shear) and strata stress changes is influenced by other factors such as topography and associated phenomena (valley closure) as was suggested by SCT (2015).

3.2.4 Potentially transmissive geological structures

Geological structures such as faults and fracture zones have the potential to form conduits for groundwater flow to the mine and transmit drawdown to receptors distant from the mine. The permeability structure of faults is related to the internal structure, rock type, the prevailing stress regime and post-movement mineralisation of the fault zone (Bense et al., 2013). Such factors can lead to a range of possible permeability structures, including a barrier to flow; a conduit to flow; or a complex conduit-barrier system whereby a fine-grained core may impede transverse flow and the damaged (outer) zone may promote enhanced flow along the fault. Complex barrier-window scenarios can arise where strata of varying permeability and thickness are variably off-set along the fault and fine-grained material from claystone units may be smeared along the core zone (Yielding et al., 1997).

A geological assessment, including mapped and potential structures was carried out prior to mining in Area 3B (BHP Billiton, 2013). The geology between Avon Reservoir and Area 3B mine workings was further assessed by South32 (2018) and the geology associated with proposed Longwall 18 by South32 (2020). A combination of exploration techniques including; surface exploration boreholes, aeromagnetic and seismic surveys, surface mapping, underground in-seam drilling and underground mapping have been used to build the geological model in the area.

SRK (2020) assessed faults and surface lineaments above and around Dendrobium Mine . The assessment included analysis of mine subsidence data (LiDAR) to determine if surface subsidence is controlled by or reactivates mapped surface lineaments. The study identified several very minor linear anomalies directly above mined longwall panels in Area 3B, with none identified in Areas 2 or 3A. The study concluded that the potential for reactivation of lineaments extending outside the planned mining areas was assessed as low.

In a separate study, HGEO (2020c) assessed of the spatial relationship between piezometric response in vibrating wire piezometers (anomalous drawdown compared with predictions) and proximity to known or inferred geological structures. The study concluded that anomalous drawdown responses are not correlated with mapped structural features. Rather, they are randomly distributed amongst active monitoring bores and with respect to mapped structural features. This is consistent with the observations in the underground mine that large inflows of groundwater are typically not associated with mapped linear features such as igneous dykes and faults.

Doyle (2007) and Tonkin and Timms (2015) concluded that virtually all faults encountered in first workings near supply reservoirs in the Southern Coalfield produce no, or very minor inflows. The low transmissivity of faults is attributed to the discontinuous nature of most faults, infill by impermeable clay minerals, and high regional horizontal stress. Historical high inflow events (e.g. the Blue Panel, Wongawilli Colliery) have been associated with mining cover depths of less than 100 m leading to insufficient lateral offset from the reservoir because this offset was based on angle of draw and not a minimum offset distance.

Notwithstanding the above, the potential for reactivation of fault zones during mine subsidence and subsequent connection with surface water bodies should not be discounted. The Elouera Fault located immediately south of Area 3B is of particular interest with respect to the development of planned Longwall 18. Results of an ongoing investigation into the hydrogeology of the Elouera Fault are summarised below.

Elouera Fault (Native Dog Creek Tributary 1)

The northern tributary to Native Dog Creek (NDT1) runs broadly parallel to, and north of, the mapped trace of the Elouera Fault (at seam level). The Elouera Fault zone is a complex fault comprising three distinct but (structurally) connected fault zones and several splay structures. The main fault plane dips to the south at between 53 and 63° (based on recent drilling) and offsets the Wongawilli Seam by up to 40 m (downfaulted to the south). The fault trace is projected to intersect the surface on the northern slopes of the NDT1 valley. Recent drilling has identified the fault within the CVSS and drilling at Swamp 35 intersected a fault zone likely associated with Elouera Fault within the lower part of the HBSS. As yet, no surface trace of the fault has been identified in outcrop.

A hydrogeological investigation of the Elouera fault was carried out by IMC to assess the structural and hydrogeological characteristics of the Elouera Fault zone, and its potential to provide a connection between Lake Avon and the proposed longwalls. Six inclined cored holes have been drilled at two sites along the fault, four of which intersect the fault plane. Preliminary results of the investigation were reported by HGEO (2020d) and reporting of cross-hole tracer testing is currently underway (WSP, in progress). Initial findings of the investigation are as follows:

- Elouera Fault is characterised by multiple fault cores within a broad fractured (damaged) zone that ranges between 8 m and 31 m thick (true thickness). The fault cores are planar features comprising infill of clay or pulverized rock (fault gauge or fault breccia) measuring between centimetres and several tens of centimetres thick. The fault damage zones are characterised by elevated fracture frequency compared with holes drilled outside the influence of faulting and mine subsidence.
- Narrow-spaced packer testing across the Elouera Fault shows a highly variable permeability structure (and overall average permeability) between drill sites and between closely adjacent holes at the same site. The data indicate that permeable zones are discontinuous on a scale of

tens of metres and the fault does not form a continuous conduit to groundwater flow. The highest average permeability was observed at the shallowest fault intersection (upper CVSS).

- The BACS, a regionally important aquitard, is not completely offset and maintains continuity across the fault. The major stratigraphic units (Hawkesbury Sandstone [HBSS] and CVSS) are largely continuous across the fault with minor displacement relative to their thickness. Analysis of the effects of offsetting minor lithologies across the fault indicates that the fault likely represents a weak barrier to transverse (north-south) groundwater flow (a decrease in permeability of ~0.3 to ~0.5 orders of magnitude).
- Groundwater levels observed in open holes at Site 2 and piezometers at Site 3 are above the level of Lake Avon within the HBSS and ~215 m above the water level in the adjacent Elouera Mine workings. Given that the Elouera Fault is intersected by most of the investigation holes, and is intersected by the Elouera Mine workings, these observations imply that 1) groundwater gradients within the HBSS are towards Lake Avon; 2) depressurisation of deeper strata due to previous mining at Elouera to the south and current mining in Area 3B to the north has not resulted in depressurisation of the HBSS via the fault; and 3) the fault zone is not a significant conduit to flow.

The investigation holes are to be equipped with piezometer arrays and TDR cables to assess progressive depressurisation across the fault and to detect ground movement related to mining.

3.3 Deep groundwater levels – spatial patterns

The spatial distribution of piezometric heads and drawdown in piezometric head due to mining is shown in the following figures:

1. Bores where there are one or more sensors within the HBSS that record near-zero pressure head (assumed to be desaturated; Figure 12);
2. The change (drawdown) in average piezometric head between the end of Longwall 5 (November 2009) and the end of Longwall 17 (Figure 13 to Figure 17); and
3. The piezometric head in the lower HBSS relative to the Lake Avon FSL and recent lake levels as of the end of Longwall 17 (Figure 14).

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. Piezometers that have been inactive for 2 years or more are excluded from the analysis. It should be noted that calculations of drawdown since 2009 are subject to uncertainty because of the inconsistency in the depths of sensors within each geological unit between monitoring bores.

3.3.1 Spatial distribution in groundwater drawdown

Maps of observed and estimated drawdown are shown for subunits within the HBSS, BGSS (and stratigraphic equivalent within the CVSS), and the SBSS. Analysis concentrates on the Triassic sandstone formations since those units are most relevant to connected surface water processes; drawdown in the Wongawilli and Bulli coal seams is shown in time series plots (hydrographs). The coal seams, being typically more permeable than the host coal measures and overlying Narrabeen Group, depressurise well in advance of mining, defining a broad zone of drawdown around current mining areas that coalesces with residual drawdown from neighbouring historic mines.

Analysis of drawdown in the HBSS focusses on the lower 70 m of the formation (lower HBSS). Comparison of drawdown in the upper and middle parts of the formation is problematic and potentially misleading (an underestimate) because of the number of sensors within desaturated strata. The number of sensors that record zero or near-zero (< 2 m H_2O pressure head) is shown in Figure 12. It is common for bores located above extracted longwalls to show near-zero pressure head conditions in multiple sensors implying drawdown of head below those sensors. The typical depth to water on the plateau areas prior to mining was in the order of 25 to 30 m. Therefore, sensors that are at less than 15 m depth are plotted separately (as green symbols) since it is more likely that those sensors would be desaturated under natural conditions.

Within the lower HBSS, maximum drawdown in the order of 40 to 50 m is observed in piezometer arrays above and immediately surrounding extracted longwalls. However, review of individual hydrographs (Appendix A) indicates that most strata above extracted longwalls are depressurised with evidence for perched aquifers forming above low-permeability horizons. Therefore, drawdown values above extracted longwalls should be considered as minima. Drawdown in the HBSS reduces rapidly away from the mined longwalls. Note that in some monitoring bores (e.g. S1879, S1934) pressure head values suggest there are multiple perched aquifers and therefore calculated head and drawdown values for a geological unit would be averages of those perched heads. Bores at which a groundwater increase is recorded relative to 2009 (“negative drawdown”) are shown as zero. A number of piezometers recorded groundwater recovery relative to the baseline in 2021 due to the high rainfall.

Piezometric head in the lower HBSS compared with the water level in Lake Avon is shown in Figure 14. It is apparent that most bores located between extracted longwalls in Area 3B and Lake Avon record piezometric heads that are below the current lake level, consistent with a gradient away from the reservoir as described previously. It should be noted that some bores contain sensors at higher stratigraphic levels that record piezometric head above the lake level (e.g. S2313_49 m) and therefore the hydraulic gradient within the barrier zone varies with both location and elevation. In addition, there is evidence for minor perched water tables persisting in some sensors. Bores at which no colour symbols are shown are those for which recent data were unavailable at the time of reporting (< 90 days before the end of the Longwall).

Observations of piezometric head in the BGSS are mainly restricted to near the extracted and planned longwalls (Figure 15 and Figure 16). Drawdown exceeding 70 m and exceeding 130 m is estimated at several bores (e.g. S2486, S2510). Drawdown decreases away from the mined areas such that less than 30 m of drawdown is estimated at distances of 1.2 km or more north of Area 3B (S2341, S2006). Significant depressurisation is expected in the BGSS (and units below) due to subsidence-related fracturing extending upwards from the goaf into these units.

The SBSS (Figure 17) is depressurised in the vicinity of the mined areas. As with the BGSS, estimated drawdown decreases to the northwest with distance from Area 3B; however, depressurisation of ~78 m is observed to the northeast (S2059) due to residual drawdown from neighbouring mines.

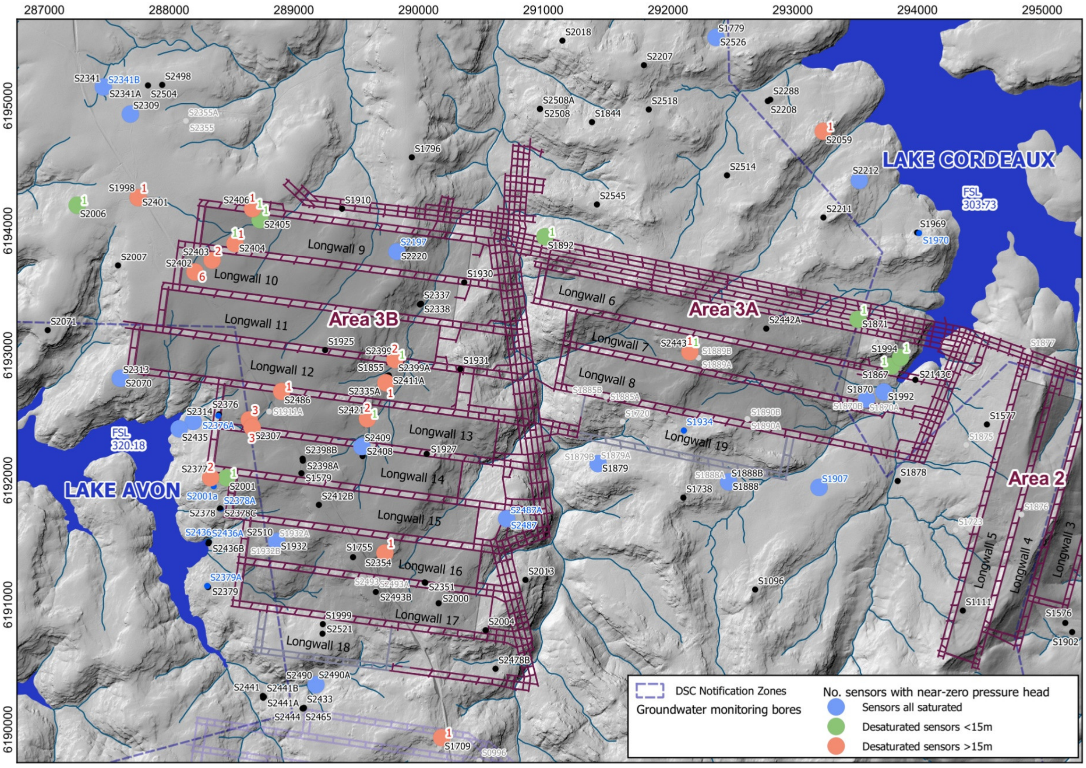

Figure 12. Sensors recording desaturated conditions in the Hawkesbury Sandstone (2021)

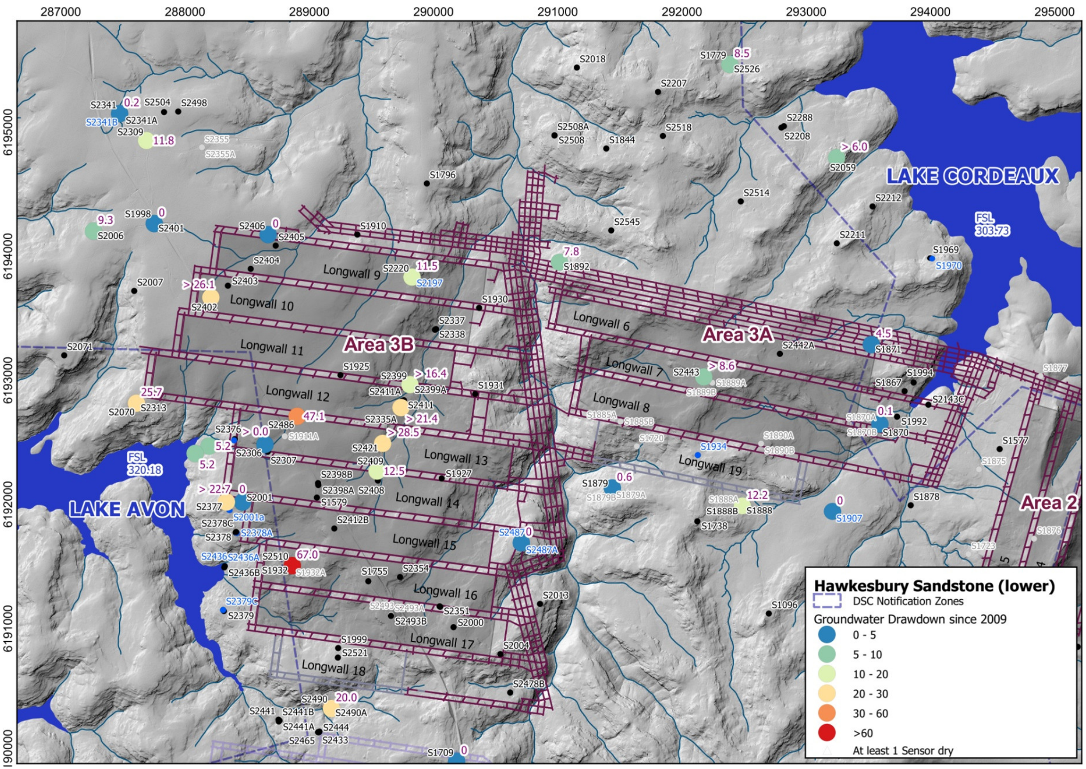

Figure 13. Drawdown in piezometric head in the lower Hawkesbury Sandstone (2009-2021)

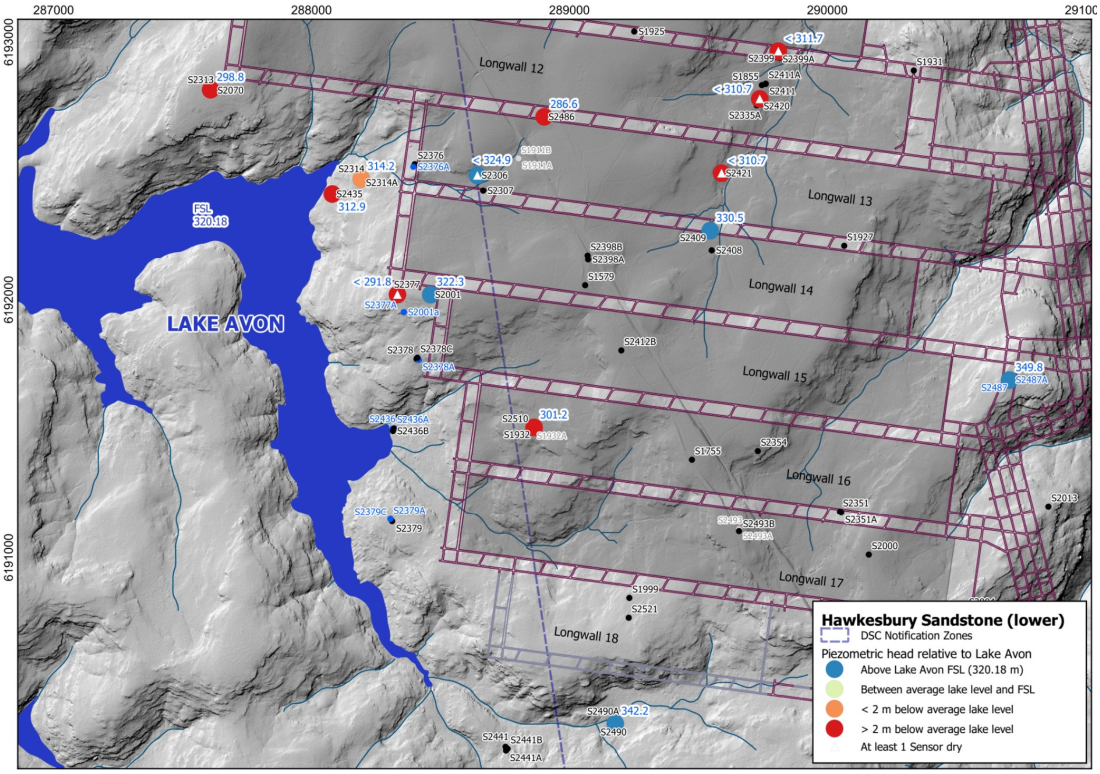

Figure 14. Piezometric head in the lower Hawkesbury Sandstone relative to Lake Avon (2021)

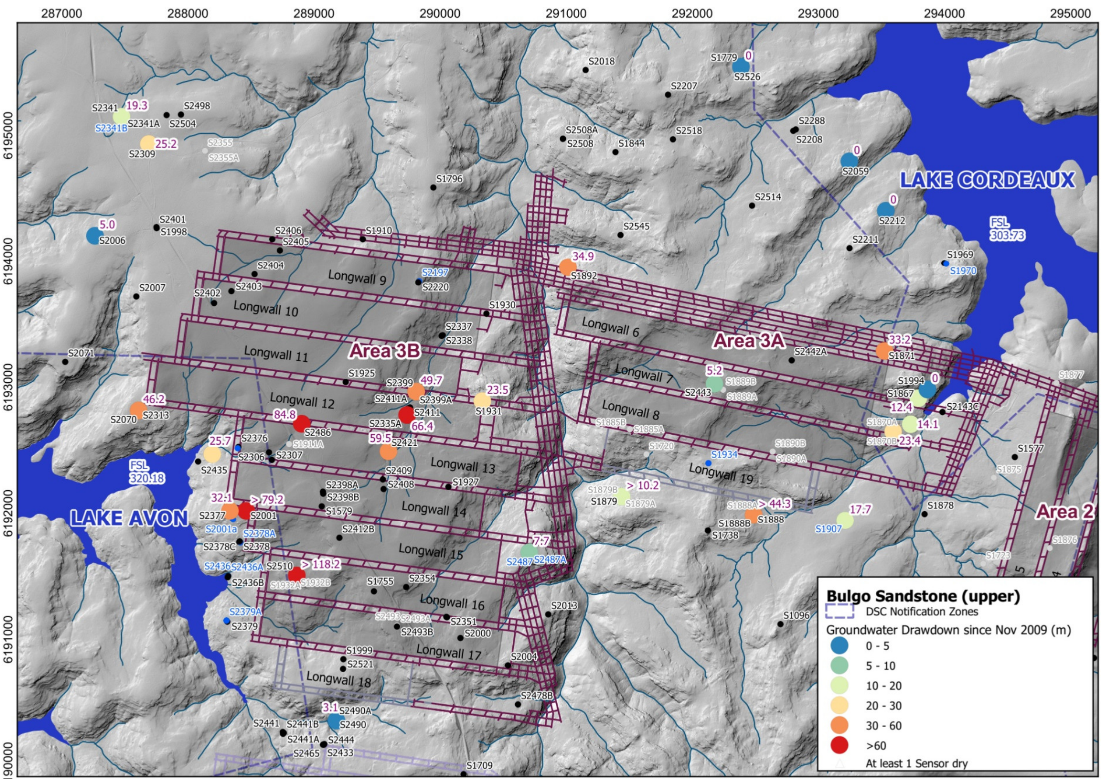

Figure 15. Drawdown in piezometric head in the upper Bulgo Sandstone (2009-2021)

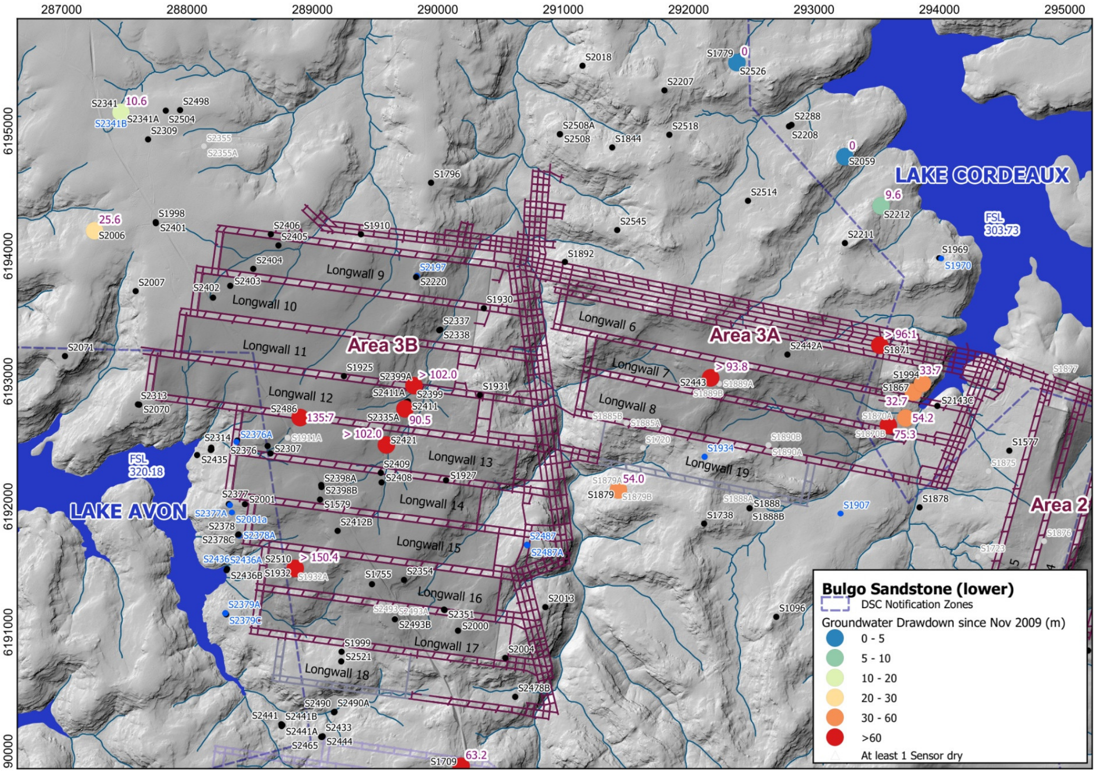

Figure 16. Drawdown in piezometric head in the lower Bulgo Sandstone (2009-2021)

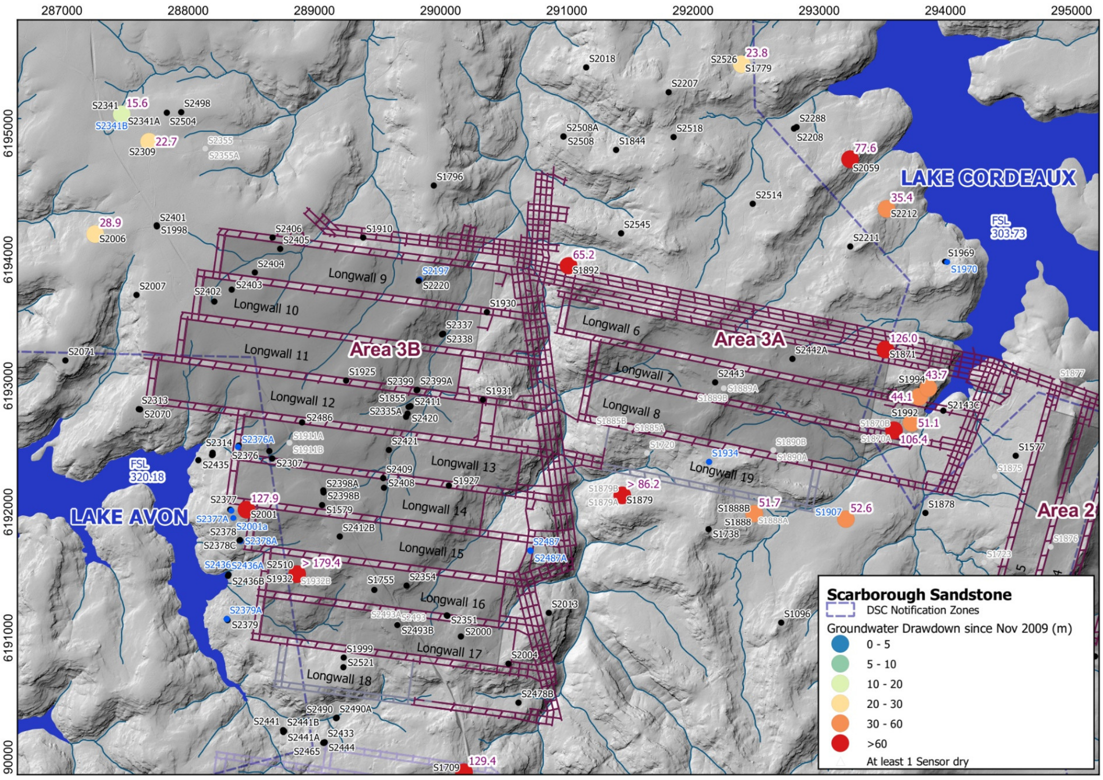

Figure 17. Drawdown in piezometric head in the Scarborough Sandstone (2009-2021)

3.4 Comparison with model predictions

3.4.1 Deep groundwater levels

In this section observed deep groundwater levels are compared with those predicted in the most recent groundwater impact model for Dendrobium Mine (Watershed Hydrogeo, 2020). The comparison was carried out by extracting the predicted heads at representative sensors as of the end of Longwall 17 from the original model output files (provided to HGEO by Watershed Hydrogeo), and plotting those heads against the observed heads (as presented in Section 3.3). It is therefore an independent assessment of the ongoing accuracy of the groundwater model predictions.

Figure 18 is a plot of the modelled and observed heads as of the end of Longwall 17. The data are coloured according to the formation, and bores that are located adjacent to Lake Avon are highlighted with concentric circles (holes, S2313, S2314, S2376, S2377, S2378, S2379, S2435, S2436, and holes S2001, S2194). Data from an accurate and well-calibrated model should cluster along the diagonal 1:1 line. Points plotting below the line indicate that observed heads are higher than predicted (i.e. the model over-predicts drawdown and is conservative), while points that plot above the line indicate that the model under-predicts drawdown at those locations.

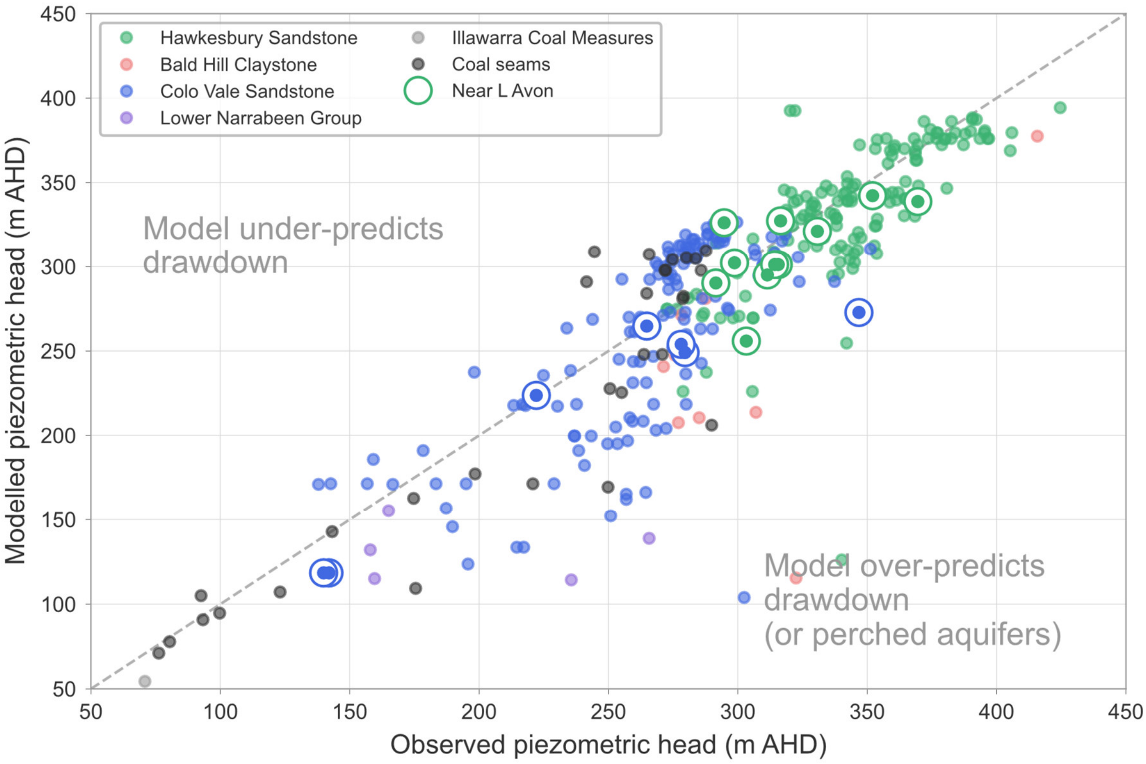

Figure 18. Observed versus model predicted heads at the end of Longwall 17

The following are concluded from the comparison in Figure 18:

- 61% of the observed-modelled piezometric head pairs plot below the 1:1 line indicating that the model is mostly conservative with respect to predicted groundwater drawdown impacts.
- Model predictions for piezometers in the HBSS plot close to the 1:1 line, particularly those in the range 280 to 350 m head, corresponding to the elevation range for watercourses in Area 3B.

- Model and observed heads for piezometers within the HBSS adjacent to Lake Avon plot close to the 1:1 line. Observed heads within this barrier zone are therefore generally in line with model predictions.

3.4.2 Mine water balance

Figure 19 is a plot of the modelled and observed groundwater inflow to Area 3B during the extraction of Longwalls 9 to 17. The numerical model is set up with stress periods corresponding to the originally planned longwall start and end dates (approximately yearly). The plot shows that the numerical model simulates groundwater inflow to Area 3B accurately up to Longwall 13 (mid-2017). From approximately mid-2017, the model simulated groundwater inflow continues to increase in line with the cumulative area mined, whereas the mine water balance records a decline in groundwater inflow to Area 3B to 2020. From 2020, the observed mine inflow resumes an upward trend parallel to, but below, the predicted onflow. The departure of observed mine inflow from the predicted inflow corresponds with severe drought conditions from 2017 to 2019 and is likely related to the reduced groundwater levels during that period (i.e. a decline in hydraulic head which drives mine inflow). As noted in Section 3.1, there is no clear evidence from isotopic tracers of an increase in the proportion of modern water in mine inflow from 2020.

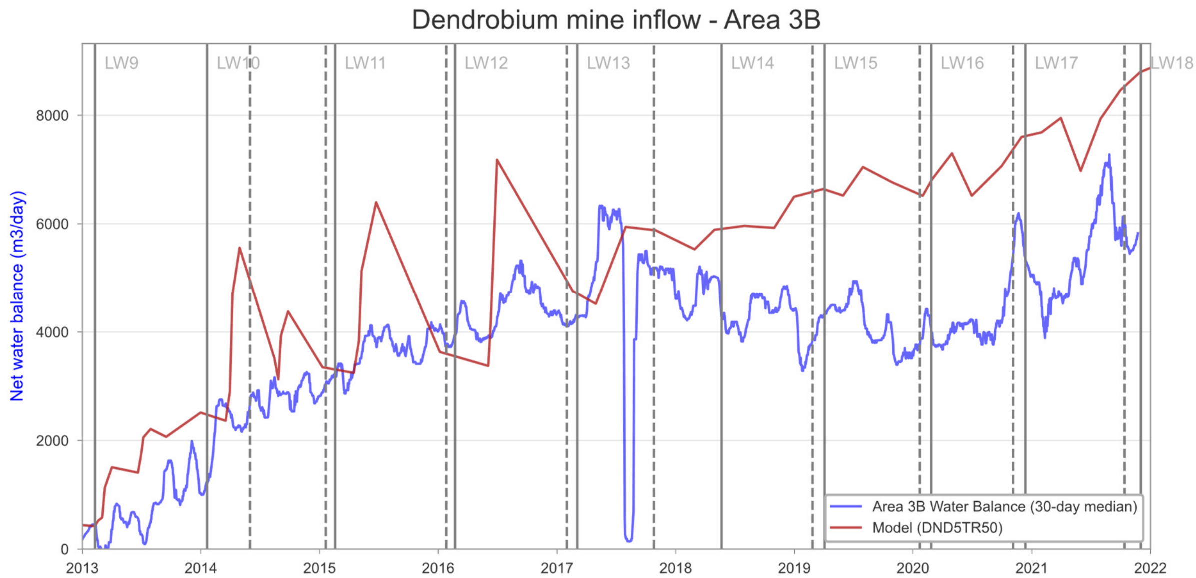

Figure 19. Observed versus model predicted mine groundwater inflow to mine Area 3B

3.4.3 Seepage loss from Lake Avon

The actual rate of seepage loss from Lake Avon cannot be measured directly and can only be estimated by calculation (using for example, Darcy's Law) or by numerical modelling. All estimates rely on assumptions relating to the permeability and hydraulic head distribution within the sandstone barrier zone between the lake and the mine.

Forecast estimates of the net loss (seepage) from Lake Avon to of the end of Longwall 18, based on the regional groundwater model range between **0.09 and 0.45 ML/day** (Watershed Hydrogeo, 2020). This loss comprises induced leakage from, and reduced seepage to, the Lake, relative to pre-mining conditions. The estimated range is within the tolerable loss limit of 1 ML/day prescribed by Dams Safety NSW (DSC, 2014).

A local-scale numerical model was developed by HGEO (2018) to assess the effect of the observed strata permeability changes (and variability) on estimates of seepage from Lake Avon. The model was developed using MODFLOW-USG and comprised 10 layers. The hydraulic conductivity (K) of each layer was defined by interpolating the measured (post-mine) permeability from packer tests at each test bore site (Figure 20). An average post-mining hydraulic gradient was applied to produce an estimate of seepage loss per km length of lake shoreline.

The model was revised in August 2021 to include the most recent testing of strata permeability at location AD8 (S2379) following part extraction of Longwall 17 (HGEO, 2021c) (Section 3.2.3). The revised model estimates a seepage loss of 0.36 ML/day/km of shoreline. This equates to a seepage loss of ~0.69 ML/day adjacent to Longwalls 12 to 17 (0.89 ML/day from Longwall 12 to Native Dog Creek). The slightly higher estimate from the local-scale model reflects the conservative assumptions used, such as uniform steady state flow towards the mine and complete desaturation above the longwall goaf.

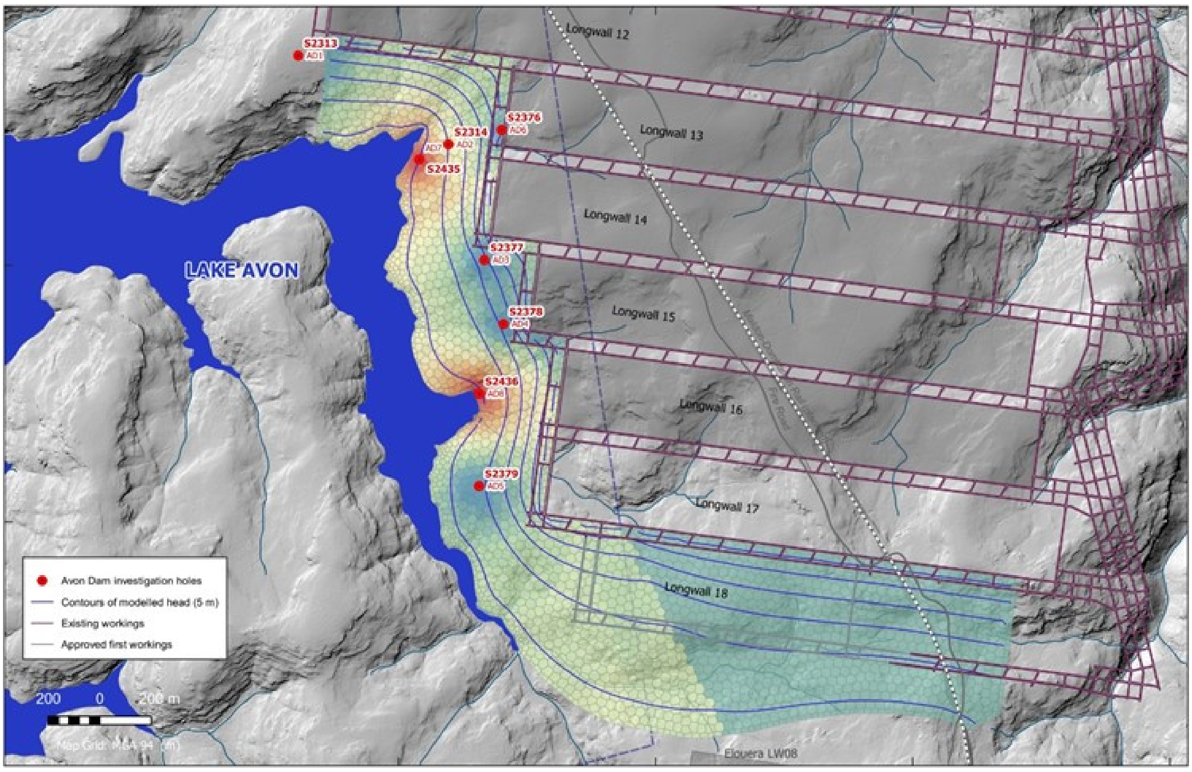

Figure 20. Map showing the layout of the local-scale numerical model (colour shading represents variation in hydraulic conductivity)

3.5 Groundwater chemistry

Previous reviews have shown that there is no clear spatial pattern in the distribution of groundwater quality in HBSS and BGSS bores. Groundwater salinity measured using electrical conductivity (EC) for all samples collected from monitoring bores in Areas 2, 3A, 3B and 5 are summarised in Table 5. As with previous reviews, the groundwater salinity tends to increase with depth. Due to frequent catchment closures not all bores were accessed for sampling during Longwall 17. However, of the samples collected most are within 20% of the previous groundwater sample.

The average EC from two sampling pumps is >20% lower in the most recent sampling round than the previous (within the last three longwalls; blue shading in Table 5):

- **2314_75m**, located between Lake Avon and Area 3B within the Hawkesbury Sandstone (Avon Dam hole AD2), shows declining EC during each successive longwall since Longwall

14. The most recent tritium analysis for samples from that pump is 0.04 (3/10/2018), which is just above detection level and consistent with negligible contribution from modern water (Lake Avon has a tritium content of ~1.5 TU; n = 78 samples). Results from more recent samples are pending due to significant delays at ANSTO due to Covid-19.

- **S2436_35 m**, located immediately adjacent to Lake Avon within the Bulgo Sandstone (Avon dam hole AD8). Samples from this pump also show declining EC during successive longwalls since Longwall 15. To date, no tritium analysis results are available for samples from this pump.

Given the location of these bores adjacent to Lake Avon and the apparent freshening trend, it is recommended that quarterly sampling be carried out at these bores for the next 12 months, if not already scheduled. Samples should be analysed for chemistry (IMC standard suite), stable and radiogenic isotopes (stable isotopes, ^{2}H, ^{18}O, ^{13}C; tritium and ^{14}C).

Table 5. Summary of EC measurements at monitoring bores

Bore ID	Depth (m)	Unit	Area	Mean EC (µS/cm)			
				LW14	LW15	LW16	LW17
S1870	10	HBSS	Den 3A		80		67
S1870	16.5	HBSS	Den 3A		87		74
S1879	10	HBSS	Den 3A		75		
S1879	58	HBSS	Den 3A		233		
S1888	10	HBSS	Den 3A		102		
S1907	10	HBSS	Den 3A			74	
S1907	23.5	HBSS	Den 3A			77	
S1934	55	HBSS	Den 3A		115		
S1970	43	HBSS	Den 3C				86
S2001	63	HBSS	Den 3B			183	
S2313	54	HBSS	Den 3B	76			66
S2313	138	HBSS	Den 3B	122			100
S2314	30	HBSS	Den 3B	184			128
S2314	75	HBSS	Den 3B	193	158	144	126
S2321	68	HBSS	Den 5				278
S2321	137	HBSS	Den 5				149
S2340	65	HBSS	Den 5		386		342
S2340	113	HBSS	Den 5				432
S2340	137	HBSS	Den 5		2020		
S2341	149	HBSS	Den 5				200
S2341A	98	HBSS	Den 3C	189			
S2341A	149	HBSS	Den 3C	247			
S2361	70	HBSS	Den 3C	272			1830
S2365	68	HBSS	Den 3C	329			
S2365	70	HBSS	Den 3C				292
S2376	30	HBSS	Den 3B		123		
S2376	102	HBSS	Den 3B		193		
S2377	34	HBSS	Den 3B	101		88	79
S2377	113	HBSS	Den 3B	126	88	94	84
S2378	29	HBSS	Den 3B	132			
S2378	89	HBSS	Den 3B	172	149	155	150
S2379	47	HBSS	Den 3B	82	86		77
S1879	200	BGSS	Den 3A		639		
S1907	167	BGSS	Den 3A			868	
S1970	109	BGSS	Den 3C				309
S2313	194	BGSS	Den 3B	524			512
S2314	128	BGSS	Den 3B	409	380	381	346
S2321	198	BGSS	Den 5				667
S2340	215	BGSS	Den 5		129		587
S2341	228	BGSS	Den 5				746
S2341A	228	BGSS	Den 3C	1400			
S2376	169	BGSS	Den 3B		396		
S2378	164	BGSS	Den 3B	153			
S2379	128	BGSS	Den 3B	291	484		443
S2436	35	BGSS	Den 3B		222	188	147
S2436	90	BGSS	Den 3B		4910*	480	461
S1870	160	SBSS	Den 3A		319		264
S1886	22	SBSS	Den 2	410	486	596	497
S1886	30	SBSS	Den 2	416	524	696	571
S1886	38	SBSS	Den 2	530	621	719	585

Note: * Results affected by bentonite pack near pump intake. Blue shading = Average EC ≥20% lower than previous.

4. CONCLUSION

The following conclusions are made with respect to the assessment of groundwater conditions following the completion of Longwall 17:

- The average daily inflow to Area 3B during Longwall 17 extraction was 5.2 ML/day which represents 64% of total mine inflow for the period (a similar proportion to Longwall 16). Compared with the previous longwall, the total mine inflow increased by 23% and the inflow in Area 3B increased by 36%. The increase in total mine inflow is mainly due to an increase of inflow in Area 3B. Total mine inflow remains below numerical model predictions.
- There is an apparent lag of two to three months between high rainfall events and peak inflow to Area 3B. The amplitude of the variation due to rainfall accounts for approximately 14% of the total inflow during Longwall 17. Isotopic tracers of modern water (tritium and 14C) indicate negligible or minor components of modern water in water pumped from Area 3B.
- Groundwater salinity (as indicated by Electrical Conductivity – EC) shows a general increase with depth below the surface. Samples collected from two groundwater bores located adjacent to Lake Avon (S2314_75m and S2436_35m) show a trend of declining EC over the last 3 longwalls. It is recommended that quarterly sampling and analysis, including for stable isotopes, tritium and ^{14}C be carried out for the next 12 months.
- Mining of Longwall 17 resulted in continued depressurisation of the target coal seam and overlying strata. The observed changes in groundwater levels are generally in line with numerical model predictions that support mining approvals. Importantly, for piezometers installed in the barrier zone between Lake Avon and Area 3B, observed head is similar to, or higher than, the numerical model prediction. Therefore, the model predictions are generally accurate as of Longwall 17 or tend to over-estimate groundwater drawdown.
- IMC continued its investigation into the height of fracturing above longwalls, with installation of a post-mining hole over Longwall 17. Investigations to date have found that mining-induced fracturing is highly variable but appears to extend to the surface in both Area 3A and 3B. Piezometers installed after longwall extraction indicate significant depressurisation throughout all strata and throughout the Hawkesbury Sandstone (HBSS) in most holes. Drawdown in the HBSS reduces with distance and is typically negligible at distances greater than 1.2 km from the goaf footprint.
- Holes in both areas show positive pressure heads in some sensors in the upper CVSS and BACS and evidence for localised perching and groundwater recovery above the goaf which continued in 2021. However shallow groundwater levels remain below pre-mining levels.
- Piezometers installed along the barrier zone between Lake Avon and extracted longwalls in Area 3B show declines in piezometric heads to levels below contemporaneous water levels in Lake Avon. The observed levels imply hydraulic gradients away from the lake and towards the mine adjacent to extracted longwalls. Testing of strata permeability before and after mining of adjacent longwalls indicates that permeability increases by at least an order of magnitude at some locations as a result of strata movement, with minor, or no change in strata permeability at other locations.
- Seepage losses from Lake Avon have been estimated by regional and local scale numerical models to be in the range 0.09 to 0.69 ML/day as at the end of Longwall 17. The estimates are within the tolerable loss limit of 1 ML/day prescribed by Dams Safety NSW and supported by the low levels of tritium and 14C in mine inflow water in Area 3B.

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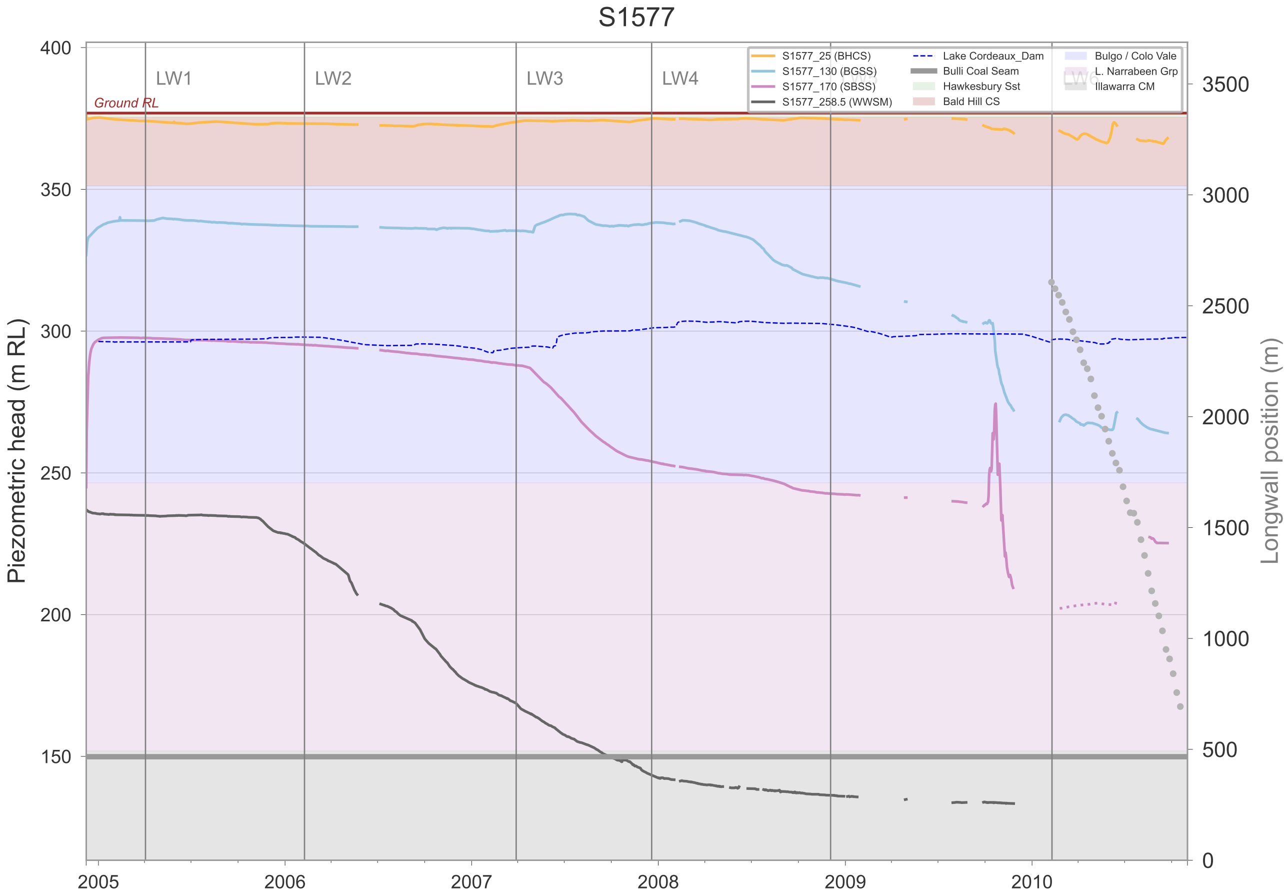
APPENDIX A: List of monitoring bores

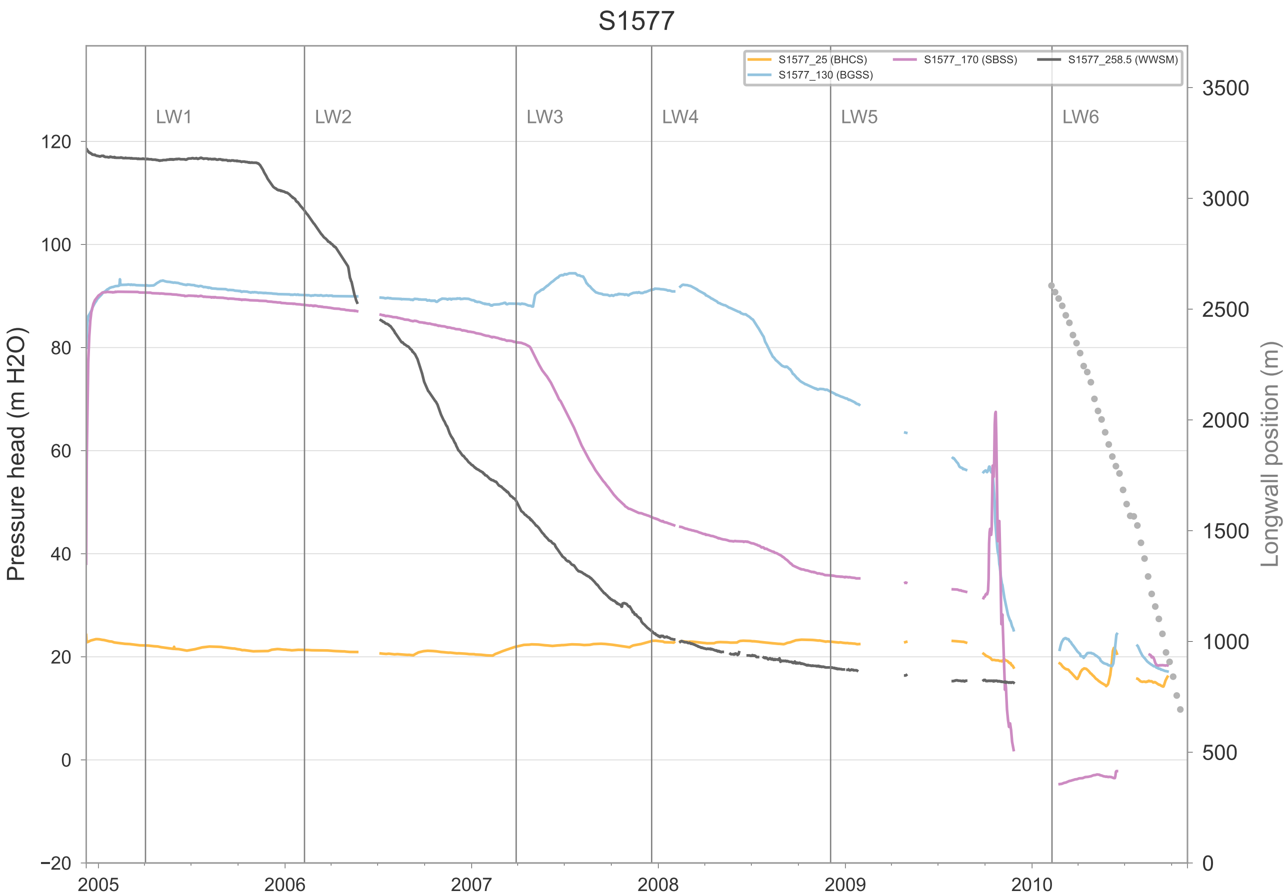
Bore ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_Area	Sensors	First_record	Last_record	Years	%with_data
S1577	Dendrobium DDH 38	294558.0	6192446.6	376.9	Den 2	4	8/12/2004	23/09/2010	5.8	81.3
S1709	DC Elouera DDH 8	290186.4	6189934.4	434.3	Den Other	8	28/02/2005	1/12/2021	16.8	83.8
S1710	DC Elouera DDH 9	290258.0	6189645.7	432.5	Den Other	3	19/05/2005	1/12/2021	16.5	89.4
S1719	DC Dendrobium DDH 56	291202.0	6193277.0	413.6	Den 3A	1	16/06/2005	18/02/2010	4.7	91.9
S1739	DC Dendrobium DDH 62	289683.6	6191798.7	423.7	Den 3B	1	2/09/2005	19/01/2019	13.4	71.3
S1755	DC Dendrobium DDH64	289475.4	6191380.2	433.3	Den 3B	2	10/01/2006	24/04/2020	14.3	73.8
S1758	Dendrobium DDH 65	288586.6	6193106.9	408.8	Den 3B	2	26/01/2006	10/06/2014	8.4	72.1
S1796	Dendrobium DDH 69	289946.6	6194587.4	398.6	Den 3B	1	5/04/2006	10/06/2021	15.2	57.1
S1800	Dendrobium DDH 70	289933.4	6193996.5	392.5	Den 3B	2	25/04/2006	31/08/2011	5.4	90.4
S1844	Dendrobium DDH 76	291391.1	6194868.8	375.6	Den 3C	2	22/08/2006	29/11/2021	15.3	68.5
S1845	Dendrobium DDH 77	291464.0	6193770.0	399.7	Den 3A	2	29/11/2006	4/01/2010	3.1	90.6
S1855	Dendrobium DDH 82	289746.5	6192833.2	366.6	Den 3B	2	11/12/2006	27/07/2016	9.6	88.8
S1867	ED Dendrobium DDH 84	293792.6	6192912.5	346.0	Den 3A	11	20/03/2007	30/11/2021	14.7	93.6
S1870	ED Dendrobium DDH 85	293593.2	6192648.2	351.5	Den 3A	12	2/02/2007	22/07/2021	14.5	91.2
S1871	ED Dendrobium DDH 86	293525.0	6193287.1	375.6	Den 3A	12	17/02/2007	30/11/2021	14.8	91
S1878	ED Dendrobium DDH 91	293842.3	6191994.3	337.1	Den 3A	11	24/04/2007	7/02/2020	12.8	95.2
S1879	ED Dendrobium DDH 92	291440.3	6192133.4	379.7	Den 3A	12	7/06/2007	30/11/2021	14.5	81.9
S1885	ED Dendrobium DDH 93	291504.4	6192667.9	420.0	Den 3A	12	7/06/2007	17/05/2012	4.9	91
S1886	ED Dendrobium PDH 94	295883.8	6191719.6	307.5	Den 2	1	23/03/2007	9/06/2021	14.2	88.7
S1888	ED Dendrobium DDH 96	292486.5	6191987.4	381.3	Den 3A	8	31/05/2007	30/11/2021	14.5	73
S1889	ED Dendrobium DDH 97	292244.8	6192980.4	435.4	Den 3A	8	2/06/2007	10/08/2011	4.2	92
S1890	ED Dendrobium DDH 98	292637.3	6192490.5	407.1	Den 3A	8	31/07/2007	7/08/2012	5	100
S1892	ED Dendrobium DDH 99	291014.1	6193952.0	356.1	Den 3A	8	7/08/2008	30/11/2021	13.3	46
S1902	ED Dendrobium DDH 100	295241.3	6190779.8	343.1	Den 2	4	4/10/2007	10/06/2021	13.7	86.2
S1907	ED Dendrobium DDH 103	293212.2	6191943.1	371.9	Den 3A	8	25/01/2008	29/11/2021	13.8	88.7
S1908	ED Dendrobium DDH 104	288925.9	6193601.4	405.7	Den 3B	8	16/05/2008	1/05/2014	6	79.7
S1910	EDEN105	289387.4	6194176.3	377.2	Den 3B	8	29/08/2008	5/03/2019	10.5	76.5
S1911	EDEN106	288802.8	6192549.4	405.2	Den 3B	12	15/05/2008	24/05/2017	9	96.7
S1914	EDEN107	289370.0	6192511.9	414.5	Den 3B	7	29/04/2008	10/08/2017	9.3	79.4
S1925	ED Dendrobium DDH 108	289251.6	6193041.1	416.7	Den 3B	8	4/08/2008	10/06/2021	12.9	87.5
S1926	ED Dendrobium DDH 109	289660.4	6193444.9	409.0	Den 3B	8	27/08/2008	8/08/2014	5.9	96.3
S1927	ED Dendrobium DDH 110	290066.0	6192211.0	414.8	Den 3B	8	16/05/2008	23/01/2017	8.7	88.9
S1929	ED Dendrobium DDH 111	290010.6	6193398.1	337.7	Den 3B	8	27/08/2008	8/08/2014	5.9	97
S1930	ED Dendrobium DDH 112	290367.3	6193582.9	353.1	Den 3B	12	27/05/2008	10/06/2021	13	83
S1931	ED Dendrobium DDH 113	290335.6	6192889.9	396.4	Den 3B	9	11/08/2008	29/07/2021	13	77.7
S1932	ED Dendrobium DDH 114	288863.3	6191505.4	396.1	Den 3B	11	31/08/2008	10/03/2020	11.5	89.8
S1934	ED Dendrobium DDH 115	292128.0	6192398.0	427.5	Den 3A	4	5/12/2009	17/03/2020	10.3	56.7
S1969	EDEN118	293998.1	6193985.7	368.5	Den 3C	11	12/08/2009	5/05/2021	11.7	59.2
S1992	EDEN119	293732.1	6192706.8	339.1	Den 3A	8	10/05/2009	30/11/2021	12.6	97.2
S1994	EDEN120	293865.2	6192982.4	345.5	Den 3A	8	13/01/2009	31/10/2021	12.8	65
S1995	EDEN121	288212.4	6193662.3	404.5	Den 3B	2	12/06/2009	28/01/2014	4.6	65.6
S1998	EDEN122	287750.6	6194273.1	410.5	Den 3B	2	11/06/2009	15/01/2020	10.6	63.5
S1999	EDEN123	289232.8	6190843.7	406.4	Den 3B	2	10/07/2009	20/04/2021	11.8	83.9
S2000	EDEN124	290161.4	6191011.2	442.0	Den 3B	2	10/07/2009	9/06/2021	11.9	74.4
S2001	EDEN125	288462.6	6192020.0	413.9	Den 3B	10	6/08/2009	1/11/2021	12.2	96.2
S2002	EDEN126	288633.4	6194222.1	400.0	Den 3B	2	21/07/2009	19/02/2012	2.6	85.3
S2003	EDEN127	290571.1	6192478.0	409.4	Den 3B	2	4/08/2009	1/03/2014	4.6	10.8
S2004	EDEN128	290538.5	6190794.8	443.5	Den 3B	2	14/10/2010	22/07/2021	10.8	0
S2006	EDEN129	287263.2	6194204.3	409.1	Den 3B	10	24/07/2009	31/10/2021	12.3	74.1
S2007	EDEN130	287590.8	6193718.9	405.8	Den 3B	2	17/06/2009	14/06/2021	12	69.8
S2009	EDEN131	287828.2	6193092.0	402.5	Den 3B	10	10/08/2009	24/03/2016	6.6	24.1
S2013	EDEN134	290857.7	6191198.2	399.7	Den 3B	2	22/07/2009	1/12/2021	12.4	67.6
S2059	EDEN148	293245.7	6194795.1	380.8	Den 3C	11	16/08/2011	31/10/2021	10.2	59
S2070	EDEN150	287619.3	6192813.2	414.7	Den 3B	2	15/05/2013	9/06/2021	8.1	77.5
S2078	EDEN154	288190.0	6192451.9	342.0	Den 3B	2	20/06/2010	13/03/2017	6.7	96.7
S2192	S2192	289826.7	6193848.7	389.3	Den 3B	6	25/03/2013	18/11/2014	1.7	34.8
S2194	S2194	288514.9	6190978.8	371.1	Den 3B	11	13/04/2013	1/04/2018	5	98.8
S2208	S2208	292801.1	6195037.3	344.0	Den 3C	8	19/12/2014	31/10/2020	5.9	99.8
S2211	S2211	293247.0	6194106.0	397.7	Den 3C	2	2/10/2013	1/11/2021	8.1	93.5
S2212	S2212	293534.8	6194402.9	369.2	Den 3C	10	11/10/2013	31/10/2021	8.1	98.4
S2220	S2220 (AQ5)	289827.2	6193830.7	388.1	Den 3B	3	12/11/2014	31/10/2021	7	99.9
S2306	Swamp Bore 3 (adjacent)	288643.3	6192483.7	395.5	Den 3B	4	16/09/2015	31/10/2021	6.1	94.6
S2307	Swamp Bore 4	288665.9	6192424.6	394.5	Den 3B	4	16/09/2015	1/11/2021	6.1	95.1
S2309	Dendrobium S2309_R	287689.9	6194933.2	412.0	Den 3D	10	15/07/2015	31/10/2021	6.3	96.9
S2312	Dendrobium S2312	284450.1	6196150.7	409.4	Den 3D	10	12/08/2015	31/10/2021	6.2	82.4
S2313	Avon 1	287609.0	6192815.5	415.3	Den 3B	3	31/10/2015	31/10/2021	6	92.7
S2314	Avon 2	288193.5	6192470.3	342.4	Den 3B	3	13/11/2015	31/10/2021	6	95.5

Bore ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_Area	Sensors	First_record	Last_record	Years	%with_data
S2321	Dend S2321	284710.0	6195575.5	411.0	Den 3D	2	12/08/2016	31/10/2021	5.2	98.3
S2325	Dend S2325	283596.2	6195466.7	433.5	Den 3D	8	6/09/2016	31/10/2021	5.2	95.4
S2333	Dend s2333 (D-A3C-14-12)	290697.1	6197087.4	310.9	Den 3C	10	8/10/2016	31/10/2021	5.1	96.8
S2335	WC21Project Hole1Site 2	289725.4	6192748.7	372.6	Den 3B	5	19/10/2016	12/11/2016	0.1	96
S2336	WC21Hole2,Site2	289721.9	6192758.1	372.4	Den 3B	2	21/10/2016	20/07/2017	0.7	81.3
S2337	WC21Project Hole1Site 5	290021.0	6193411.9	336.1	Den 3B	3	25/11/2016	21/06/2021	4.6	91.9
S2338	WC21Hole2,Site5	290012.2	6193406.7	336.1	Den 3B	3	24/11/2016	21/06/2021	4.6	91.9
S2340	D-A5-25	285468.1	6197978.9	396.9	Den 3D	9	7/12/2016	31/10/2021	4.9	91.3
S2341	D-A5-28	287473.5	6195149.8	401.6	Den 3D	10	7/12/2016	31/10/2021	4.9	99.9
S2341A	D-A5-28A	287489.0	6195138.2	402.6	Den 3C	4	21/12/2016	31/10/2021	4.9	95.3
S2342	D-A5-12	287953.2	6196755.8	403.2	Den 3D	10	23/12/2016	31/10/2021	4.9	98.1
S2345	D-A5-19	285356.8	6196094.9	402.0	Den 3D	12	29/04/2017	13/09/2021	4.4	97.7
S2348	D-A5-17	286450.5	6196461.9	396.3	Den 3D	13	11/08/2017	31/10/2021	4.2	61.5
S2351	S14-04	290049.6	6191178.2	402.8	Den 3B	2	1/09/2017	30/06/2021	3.8	87.9
S2352	D-A5-6	286264.6	6195393.3	408.8	Den 3C	10	27/04/2017	31/10/2021	4.5	75.7
S2354	S14_05	289730.9	6191413.7	424.6	Den 3B	1	7/09/2017	31/10/2021	4.2	94.5
S2355	A5_S85_DBH	288136.2	6194877.8	396.6	Den 3C	5	5/08/2017	18/06/2021	3.9	100
S2357	A5-S100_DBH	286809.6	6196991.8	394.0	Den 3C	4	29/07/2017	13/03/2021	3.6	89.7
S2359	D-A5-5	285354.6	6195547.7	403.6	Den 3C	10	11/08/2017	1/12/2021	4.3	67.7
S2361	A5_S109_DBH	286277.9	6195810.7	402.4	Den 3C	4	24/06/2017	6/12/2021	4.5	78.7
S2362	A5_S110_DBH	285772.9	6195823.0	399.9	Den 3C	4	23/06/2017	18/06/2021	4	83.9
S2364	A5_S103_DBH	285982.8	6196782.1	395.0	Den 3C	4	14/11/2017	18/06/2021	3.6	68.4
S2365	A5_101/102_DBH	286042.3	6196448.9	399.2	Den 3C	5	4/09/2017	18/06/2021	3.8	100
S2366	A6_S113_DBH	291865.1	6200199.1	358.6	Den 3D	4	23/05/2018	16/07/2021	3.2	100
S2367	A6_S117_DBH	291630.7	6199726.5	356.1	Den 3D	4	23/05/2018	16/07/2021	3.2	100
S2370	D-A5-2	285554.8	6196642.7	375.6	Den 3C	10	12/05/2018	18/09/2020	2.4	61.2
S2371	A6_S116_DBH	291977.5	6199135.2	351.2	Den 3C	4	23/05/2018	16/07/2021	3.2	100
S2372	A6_S115_DBH	291576.9	6198891.4	373.5	Den 3C	4	23/05/2018	16/07/2021	3.2	100
S2373	A6_S112_DBH	292043.2	6200899.2	359.0	Den 3C	4	7/10/2017	16/07/2021	3.8	100
S2374	A6_S83_DBH	291114.8	6201461.1	324.4	Den 3C	4	24/05/2018	16/07/2021	3.1	100
S2376	Avon 6	288400.4	6192527.0	367.8	Den 3B	3	6/10/2017	15/06/2021	3.7	100
S2377	Avon 3	288333.4	6192020.4	408.2	Den 3B	3	2/06/2018	31/10/2021	3.4	97.5
S2378	Avon 4	288407.4	6191770.9	379.3	Den 3B	4	15/11/2017	15/06/2021	3.6	76.9
S2379	Avon 5	288312.9	6191140.5	356.6	Den 3B	3	17/07/2018	7/12/2021	3.4	46.5
S2398	LW14_1	289073.2	6192164.3	420.2	Den 3B	8	11/05/2018	15/08/2018	0.3	100
S2398B	LW14-1 post extraction Redrill	289070.9	6192172.6	418.0	Den 3B	8	8/03/2019	31/07/2021	2.4	99.2
S2399	LW12_1	289810.5	6192965.1	355.1	Den 3B	8	3/05/2018	30/09/2021	3.4	60.7
S2401	Den01b_R1	287752.2	6194264.9	411.1	Den 3B	6	16/11/2018	1/12/2021	3	76.5
S2402	Den01b_R2	288207.8	6193666.6	403.4	Den 3B	6	6/07/2018	1/12/2021	3.4	76.9
S2403	Den01b_R3	288345.1	6193761.1	400.7	Den 3B	6	16/11/2018	1/12/2021	3	79
S2404	Den01b_R4	288528.6	6193896.8	396.2	Den 3B	6	22/11/2018	1/12/2021	3	79
S2405	Den01b_R5	288729.5	6194087.6	386.1	Den 3B	6	17/11/2018	1/12/2021	3	79.1
S2406	Den01b_R6	288669.1	6194176.5	396.6	Den 3B	6	17/11/2018	1/12/2021	3	79.2
S2408	GW14-2	289552.1	6192193.4	398.1	Den 3B	7	3/10/2018	21/06/2021	2.7	98.2
S2409	GW14-3	289546.1	6192269.7	394.6	Den 3B	6	3/10/2018	31/10/2021	3.1	91.4
S2411	LW12_2	289761.1	6192837.7	364.0	Den 3B	8	5/07/2018	21/06/2021	3	99.2
S2412	LW15-1	289201.1	6191807.4	427.3	Den 3B	8	12/05/2018	17/06/2019	1.1	97
S2412B	GW15-1	289201.6	6191803.7	425.2	Den 3B	8	18/12/2019	31/10/2021	1.9	98.8
S2420	LW12-3	289738.4	6192780.0	367.8	Den 3B	8	3/10/2018	31/10/2021	3.1	87.7
S2421	LW13-1	289590.4	6192492.2	381.8	Den 3B	8	8/02/2019	31/10/2021	2.7	76.2
S2435	AD7	288080.8	6192411.6	328.2	Den 3B	3	21/11/2018	31/10/2021	2.9	100
S2436	AD8	288313.8	6191499.7	320.3	Den 3B	5	4/12/2018	9/06/2021	2.5	96.4
S2438		287944.9	6197535.1	399.3	Den 3C	9	23/11/2018	31/10/2021	2.9	100
S2442A	S2442A-SandyCreek	292788.5	6193213.2	407.6	Den 3A	6	14/03/2019	31/10/2021	2.6	100
S2443	Sandy Creek series	292176.0	6193027.4	426.7	Den 3A	6	3/08/2019	25/10/2021	2.2	85.4
S2478B	Waterfall 54 A3B-03	290617.6	6190486.1	380.1	Den 3B	4	4/06/2020	31/10/2021	1.4	100
S2486	GW-12-4	288902.8	6192710.7	412.1	Den 3B	7	18/12/2019	31/10/2021	1.9	99.7
S2487	GW15-2	290707.0	6191689.0	435.3	Den 3B	5	28/11/2019	1/11/2021	1.9	68.5
S2490	Swamp 35B	289178.0	6190358.0	347.6	Den 3B	4	31/01/2020	1/12/2021	1.8	88.4
S2493	LW17_1	289659.3	6191107.3	434.8	Den 3B	9	2/04/2020	9/04/2021	1	100
S2510	L/W 16 Goaf Hole	288863.3	6191505.4	396.1	Den 3B	8	25/10/2020	28/10/2021	1	69.1
S2526	D-A3-S17-21	292385.9	6195546.0	368.9	Den 3C	10	15/07/2021	30/10/2021	0.3	64.8

APPENDIX B: Groundwater hydrographs

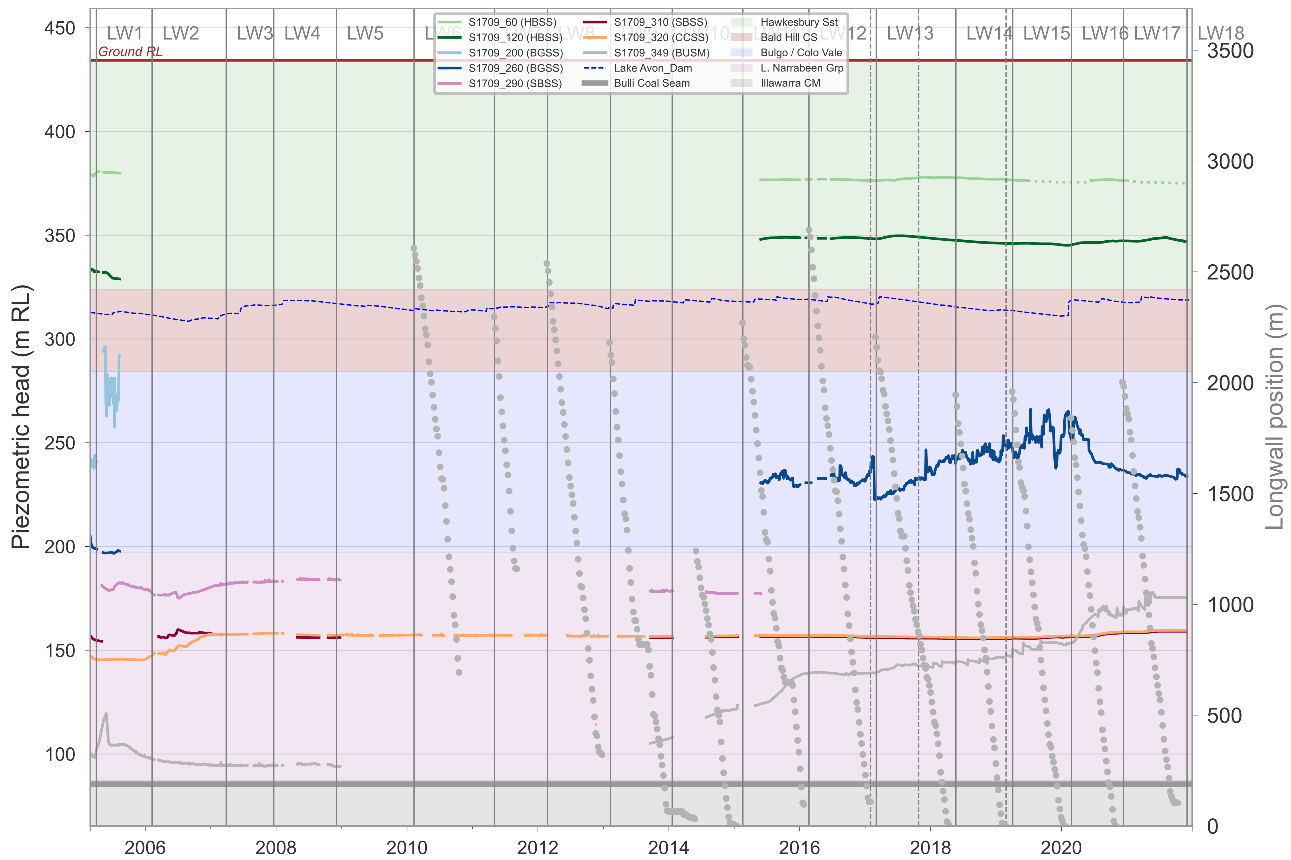
Groundwater hydrographs



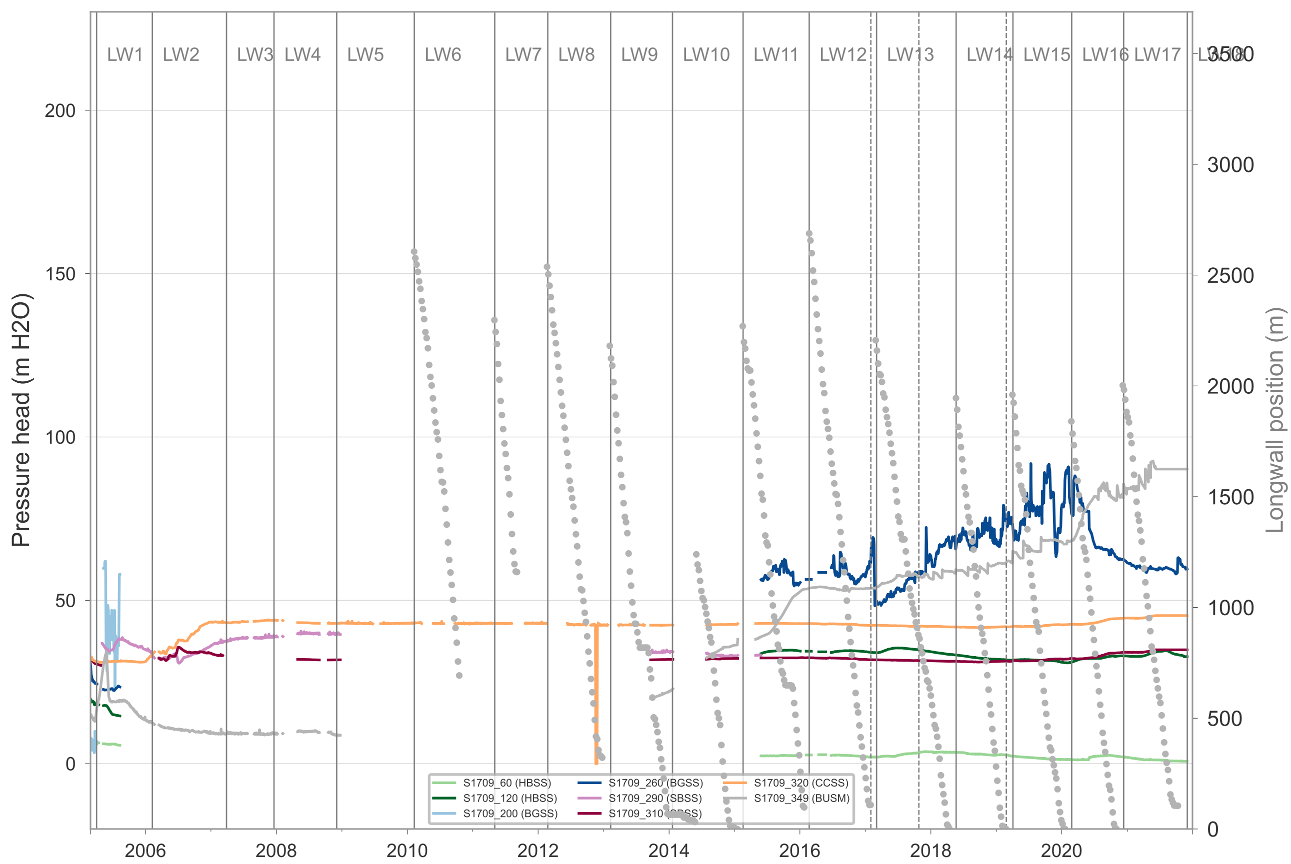


Groundwater hydrographs

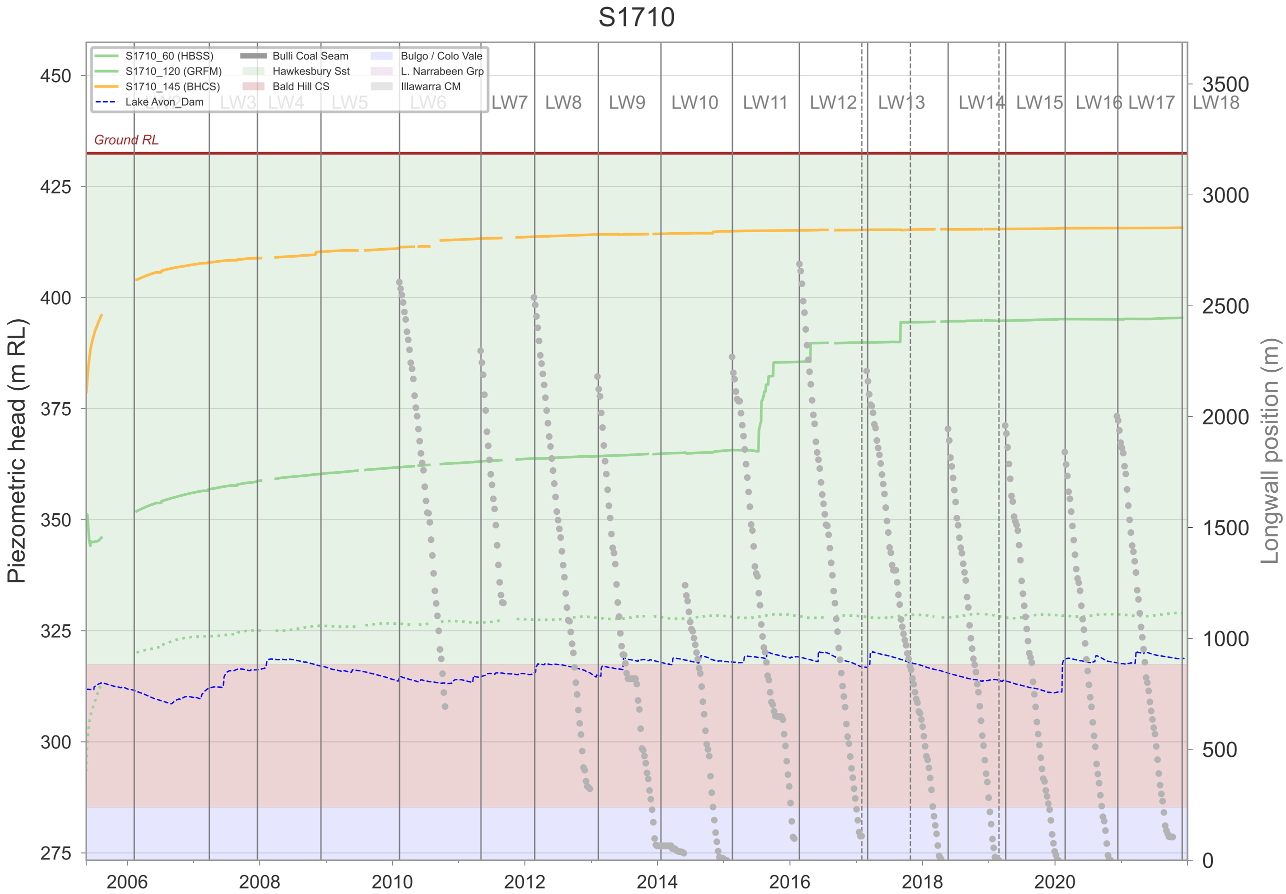
S1709

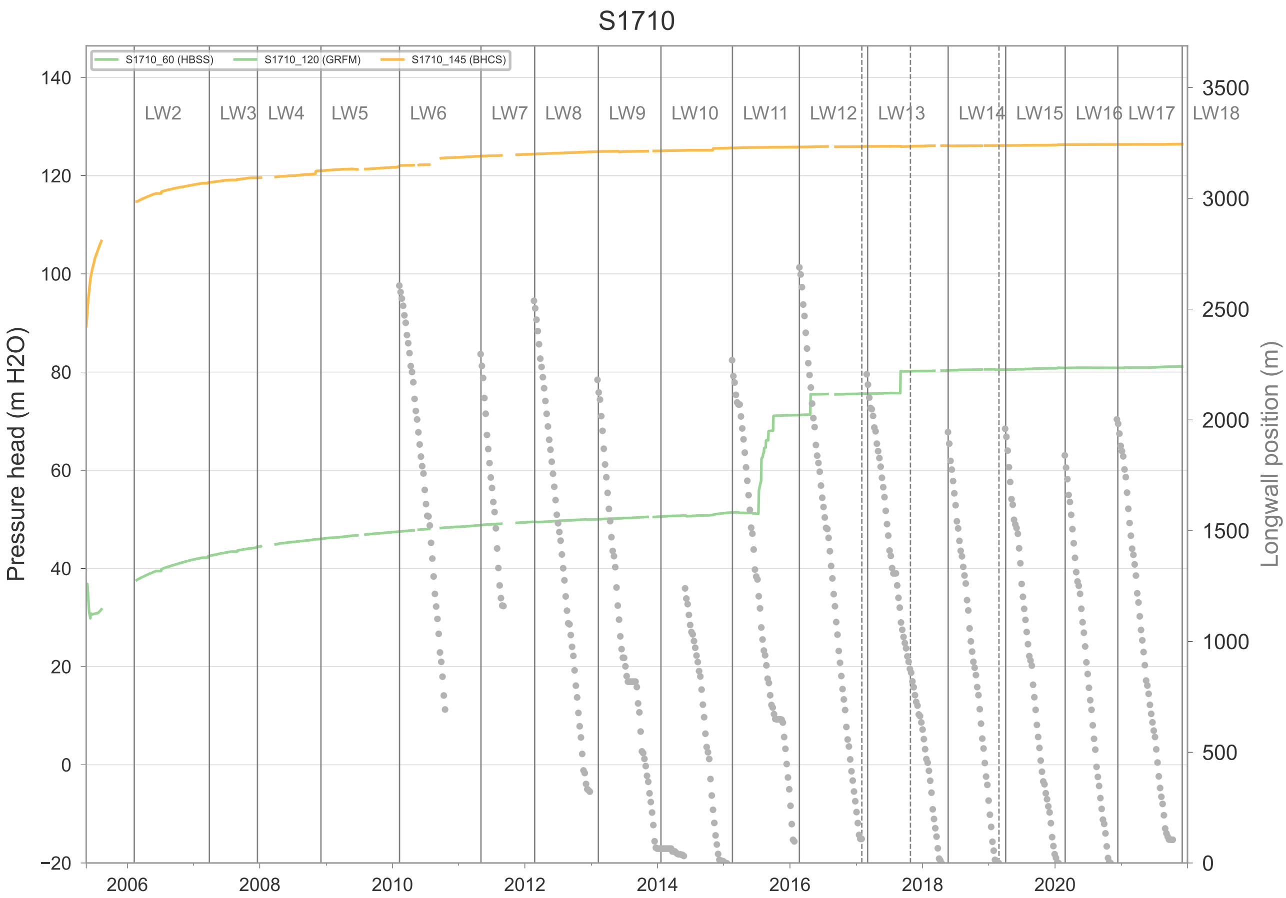


S1709

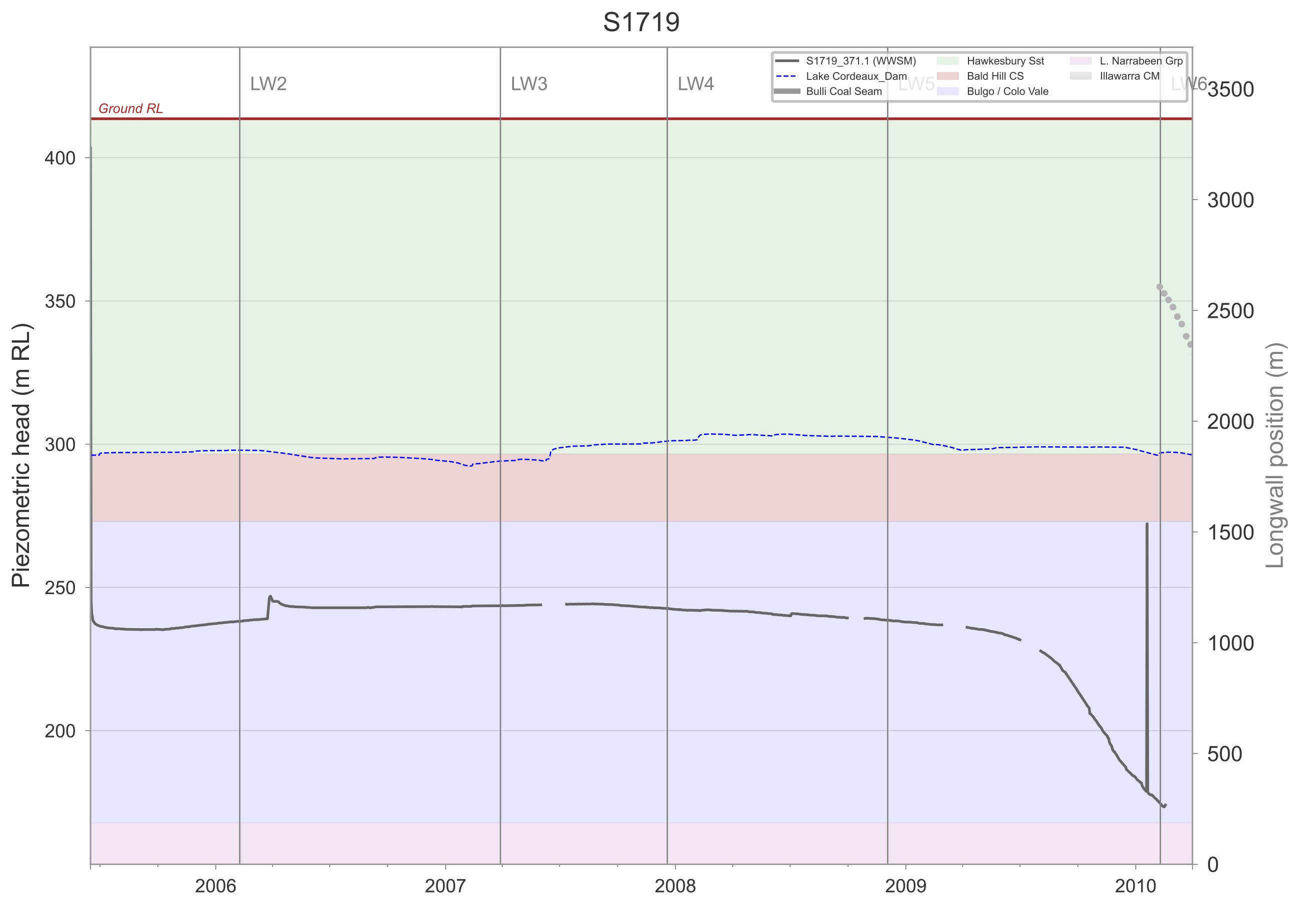


Groundwater hydrographs

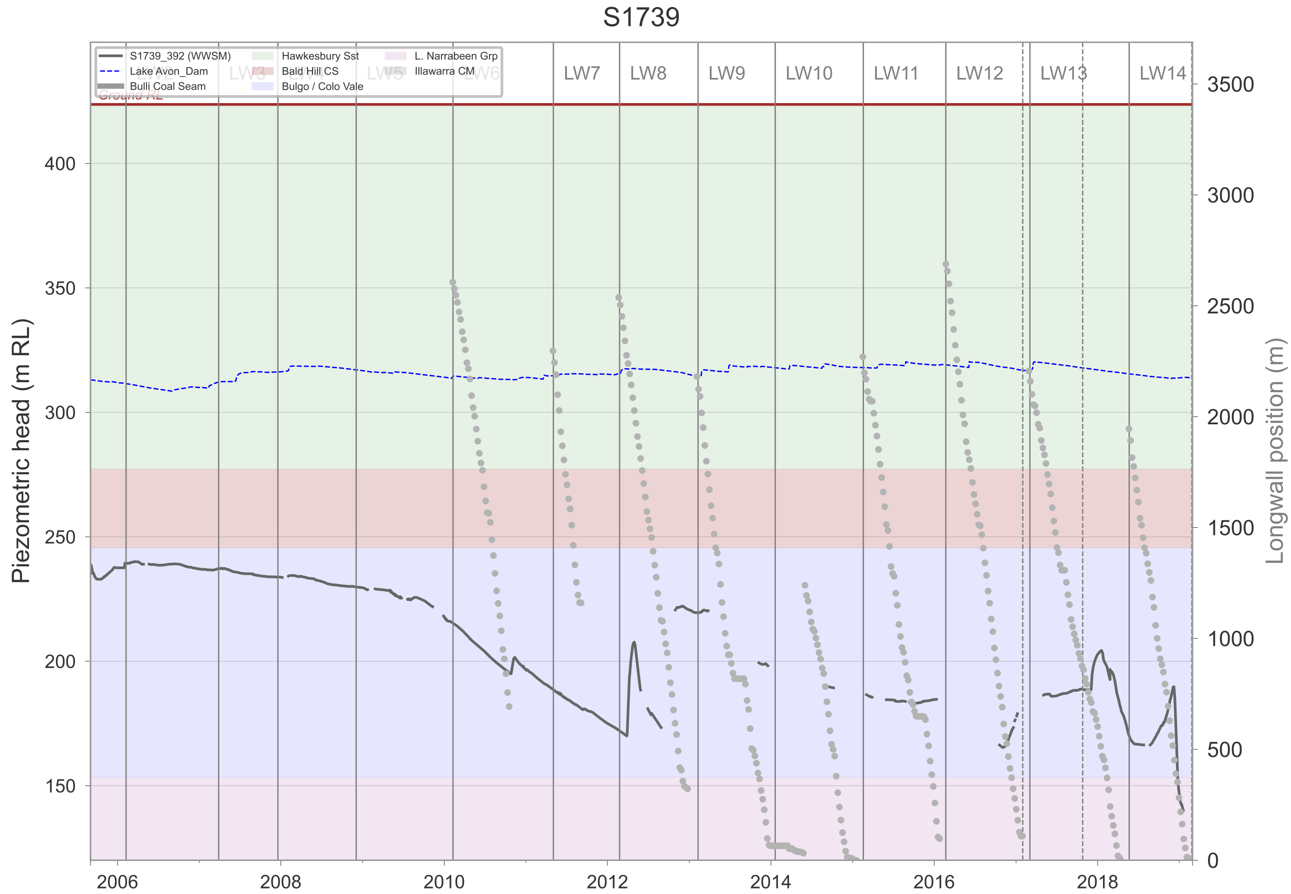


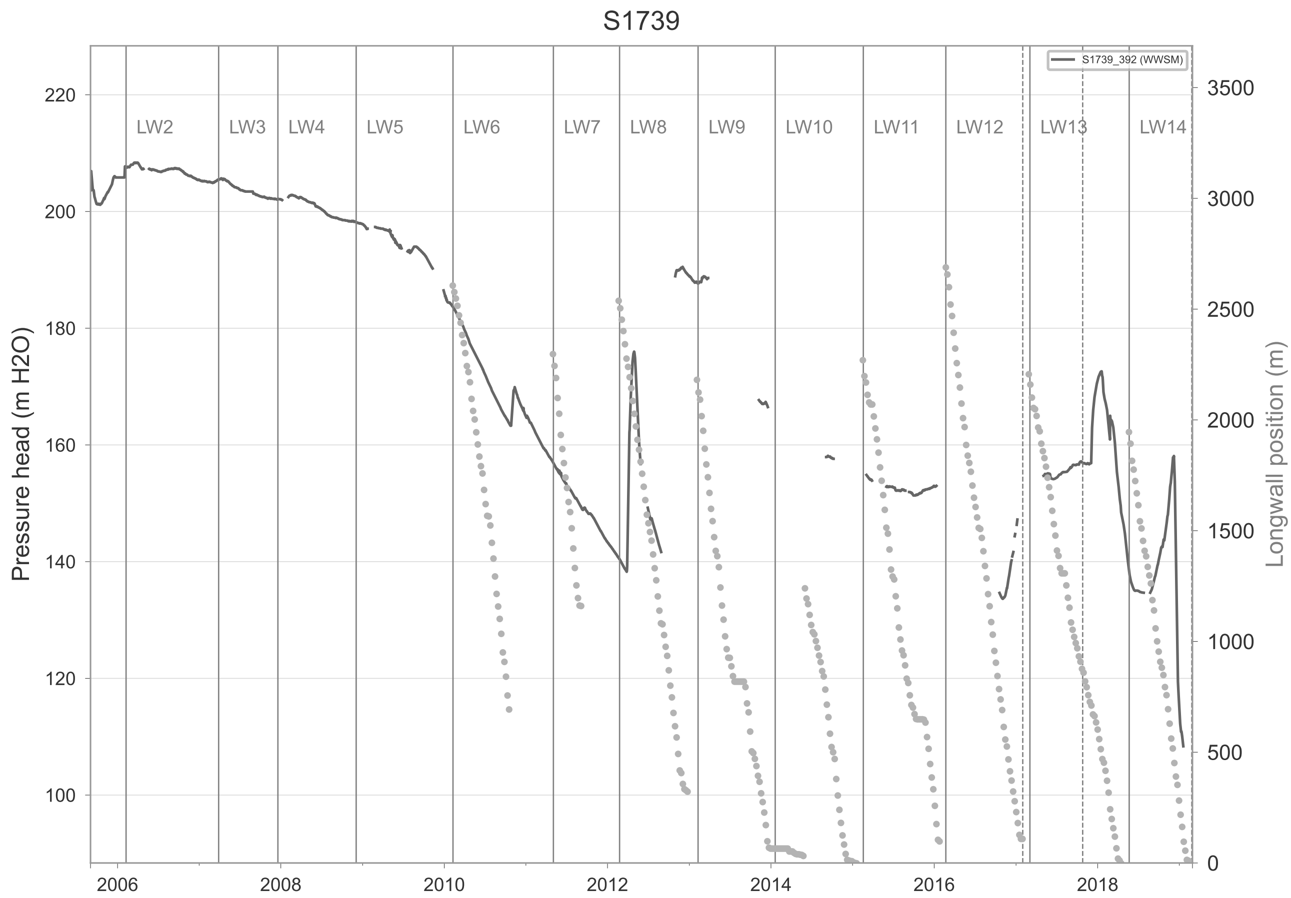


Groundwater hydrographs

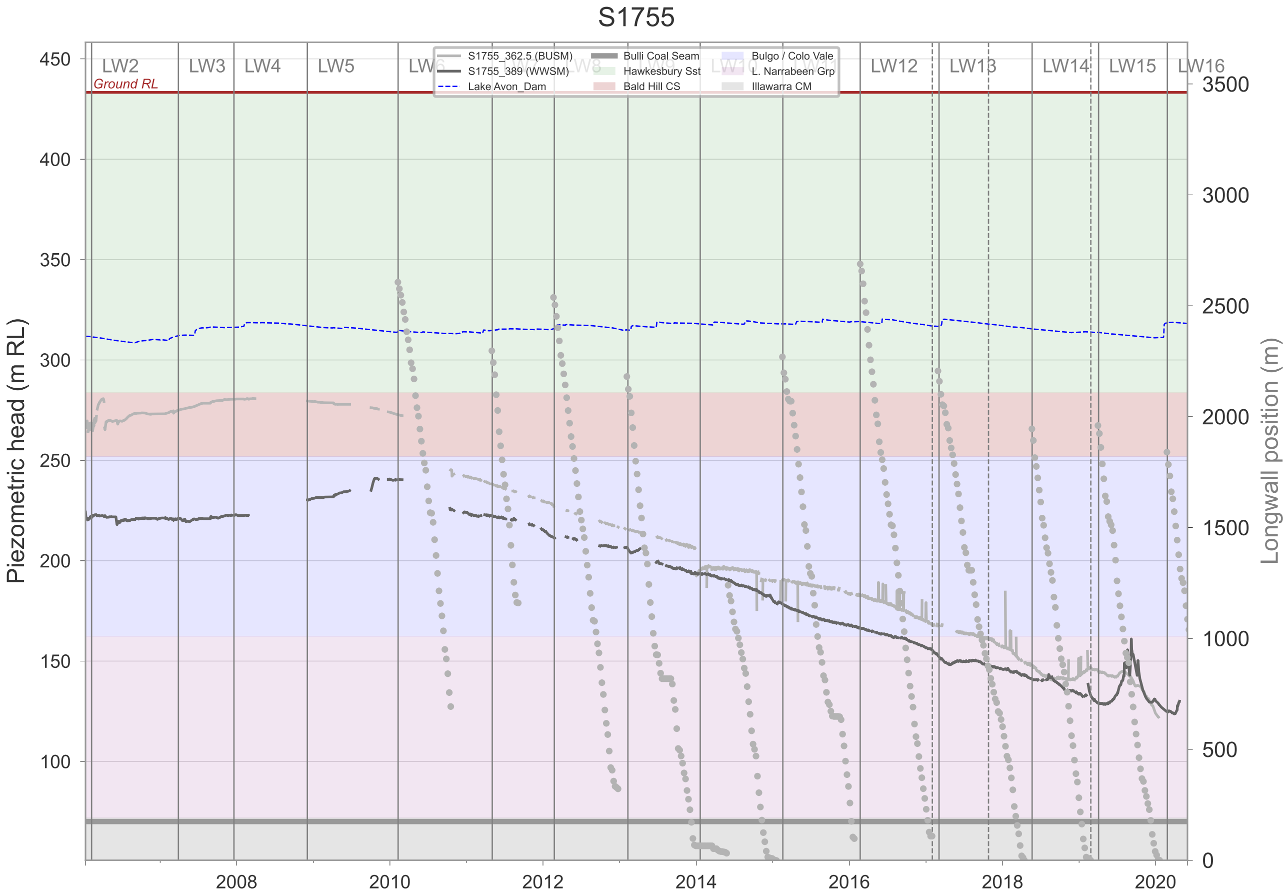


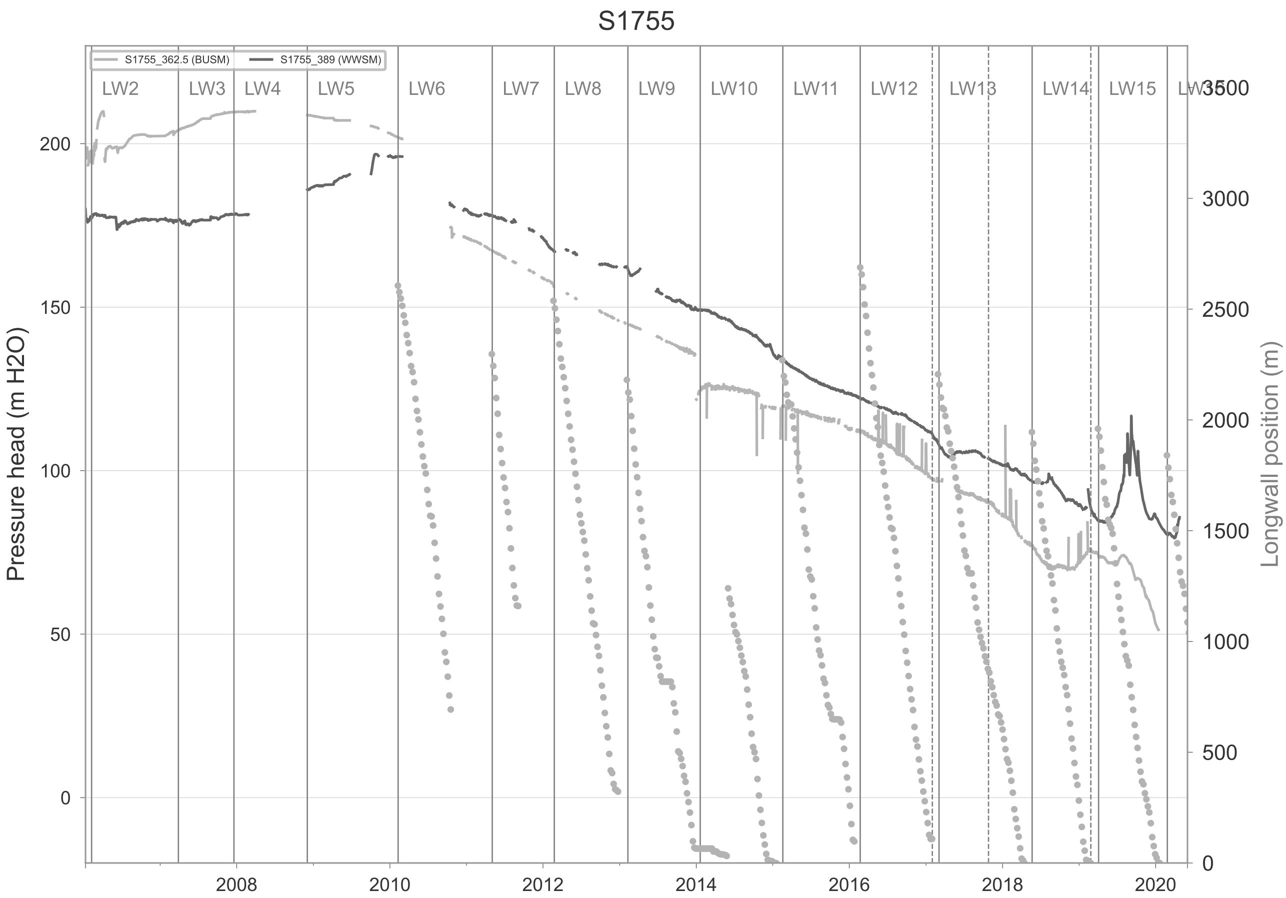
Groundwater hydrographs



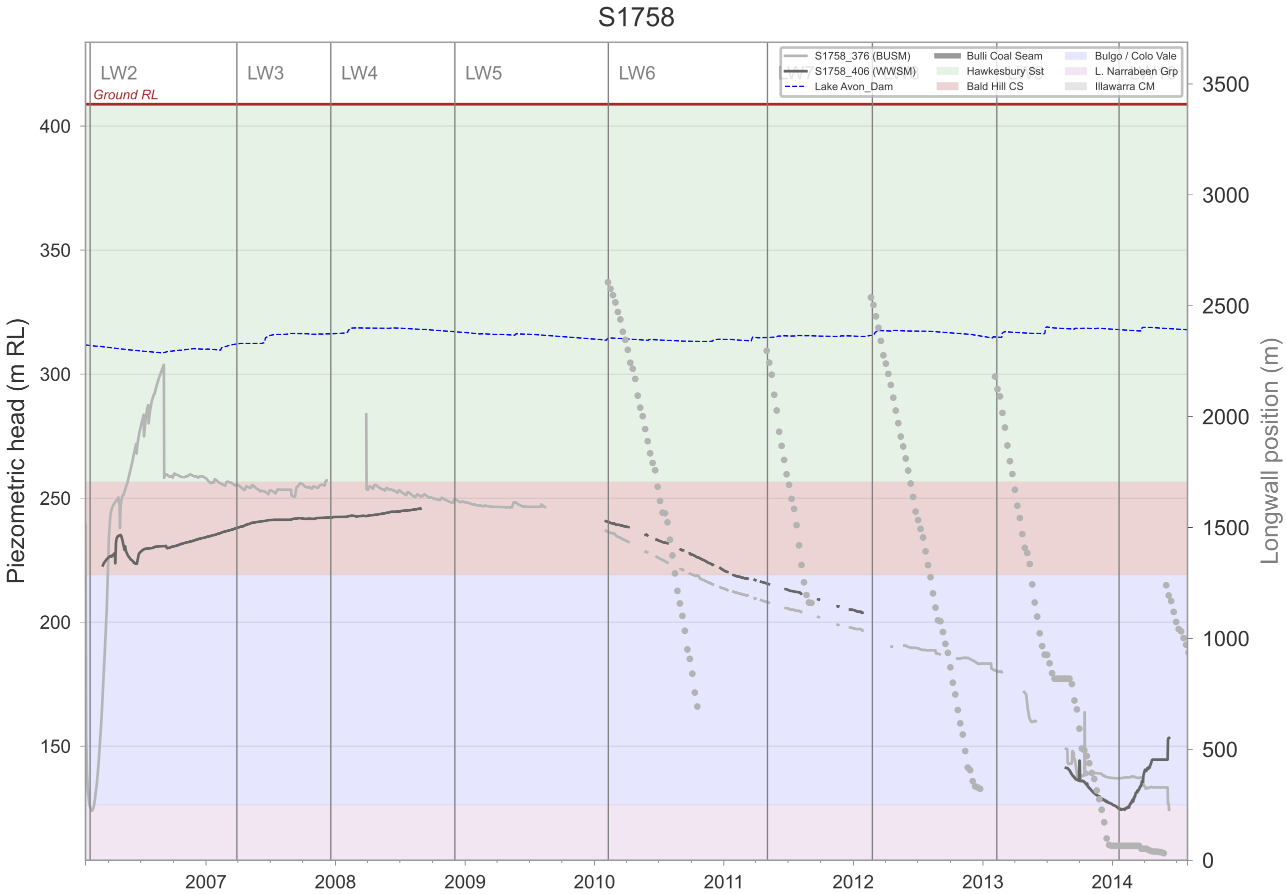


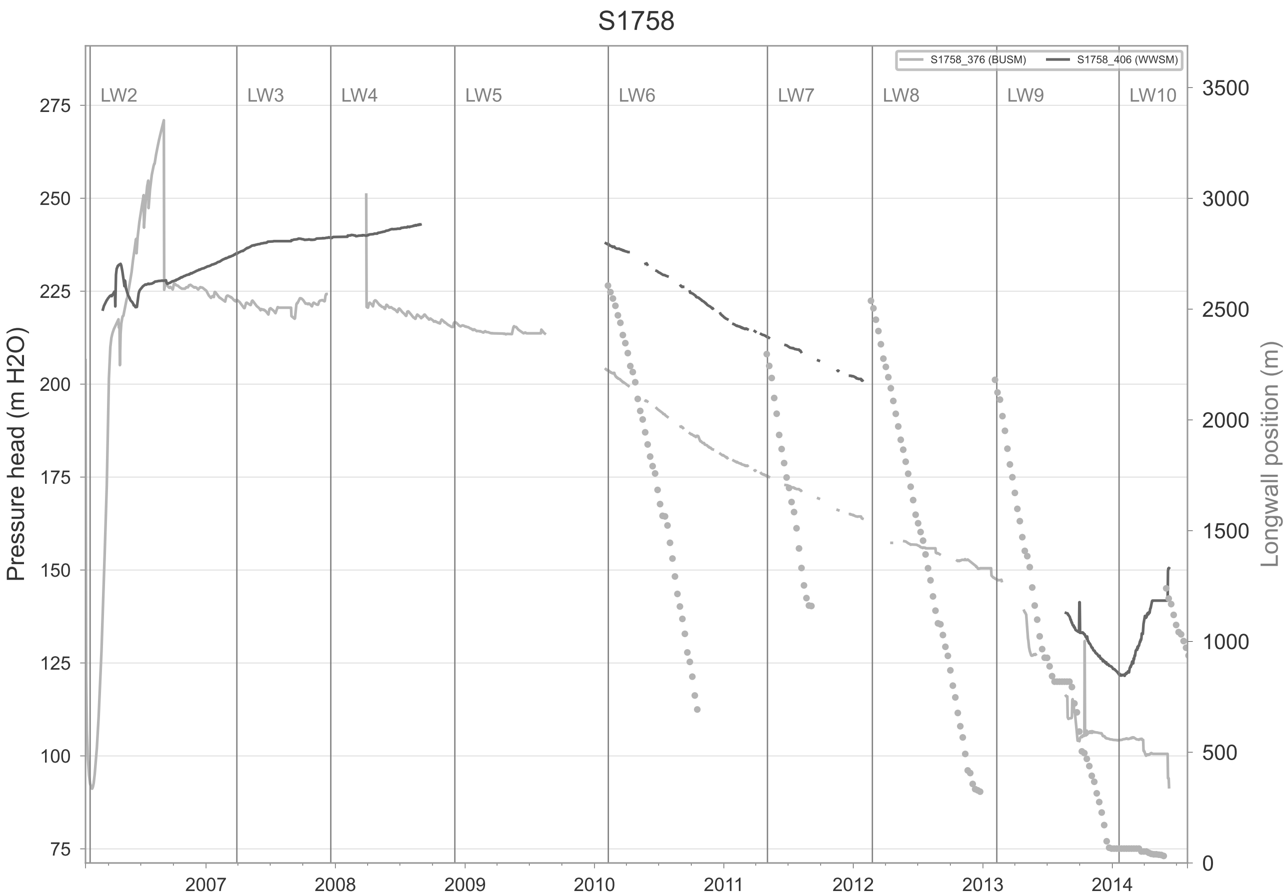
Groundwater hydrographs



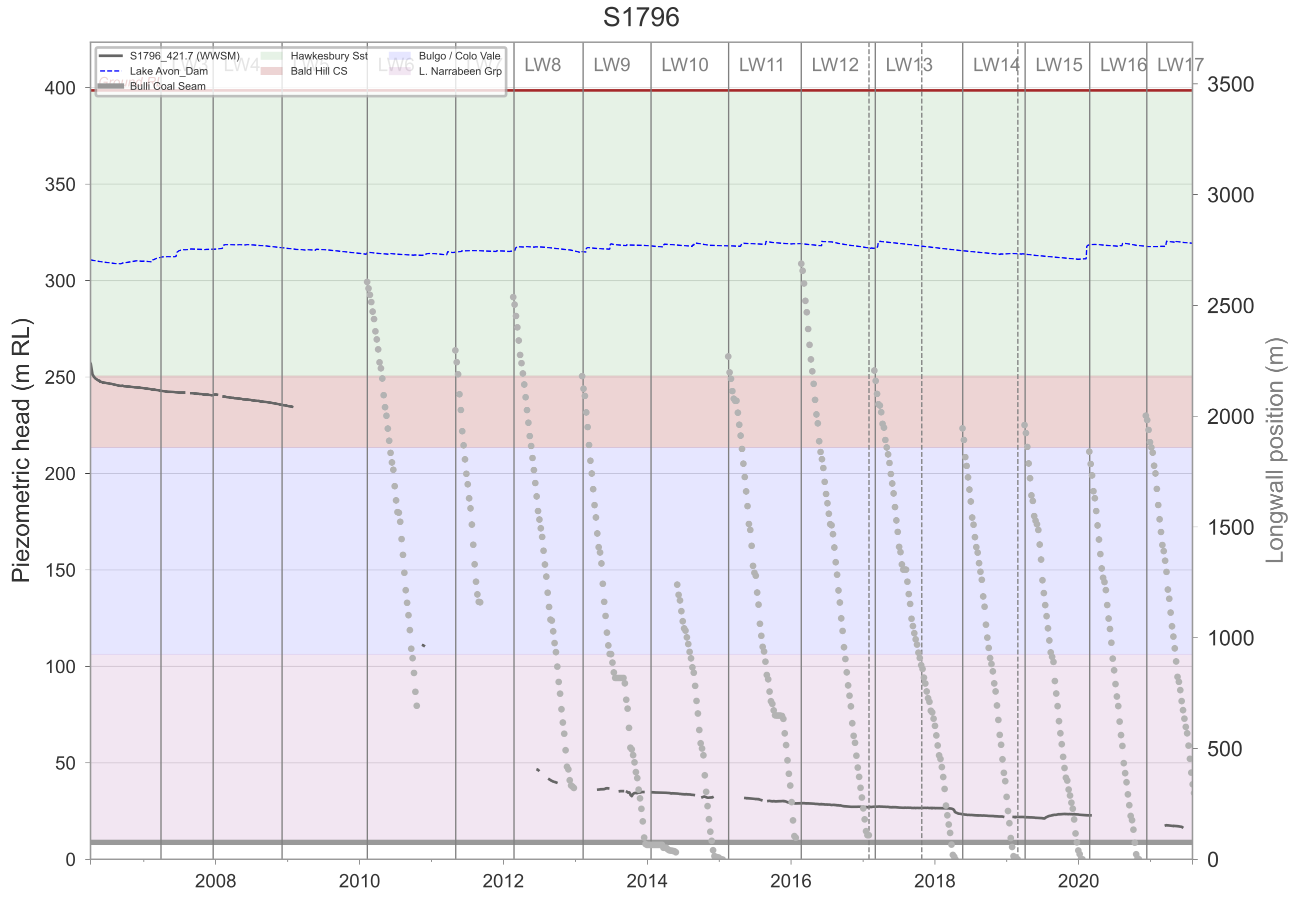


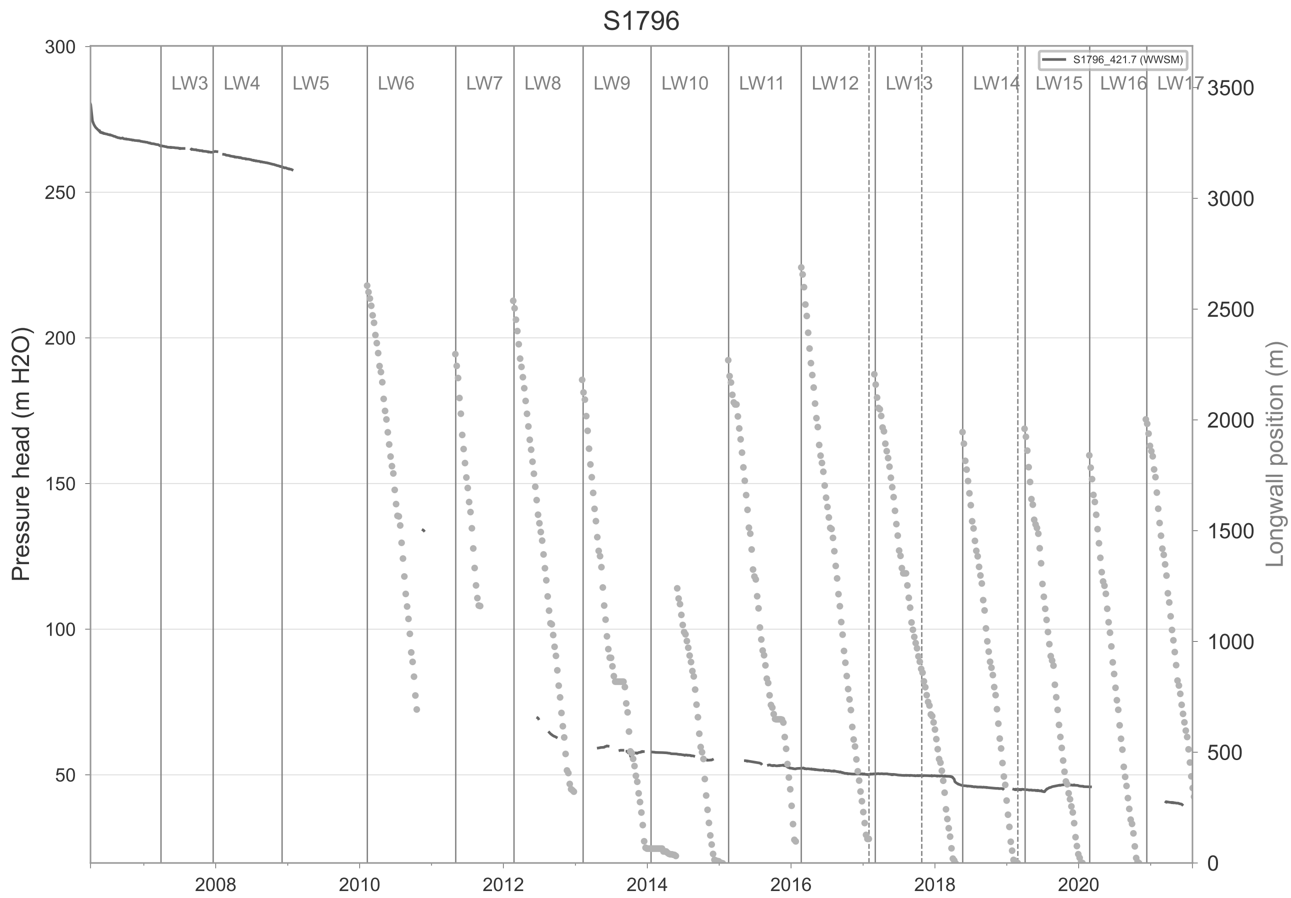
Groundwater hydrographs





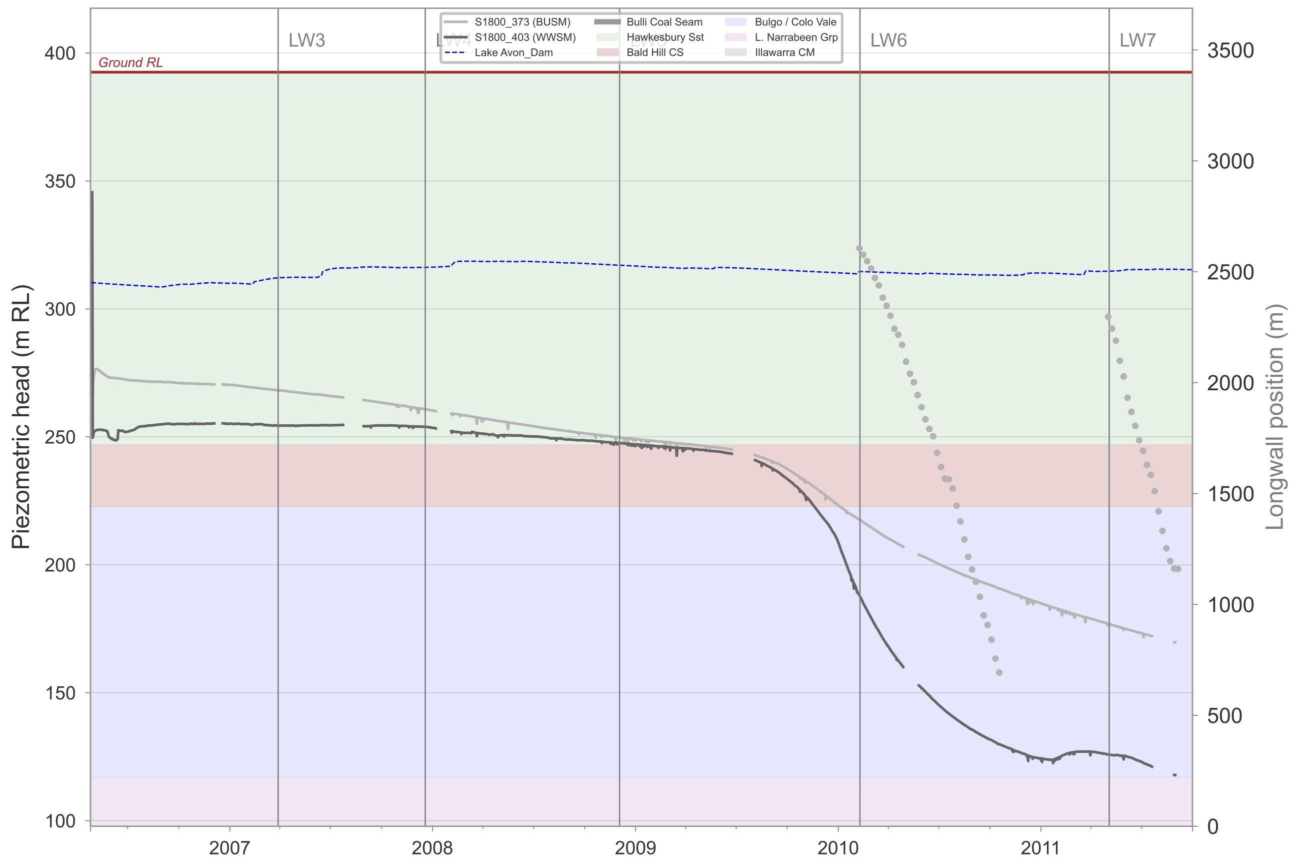
Groundwater hydrographs



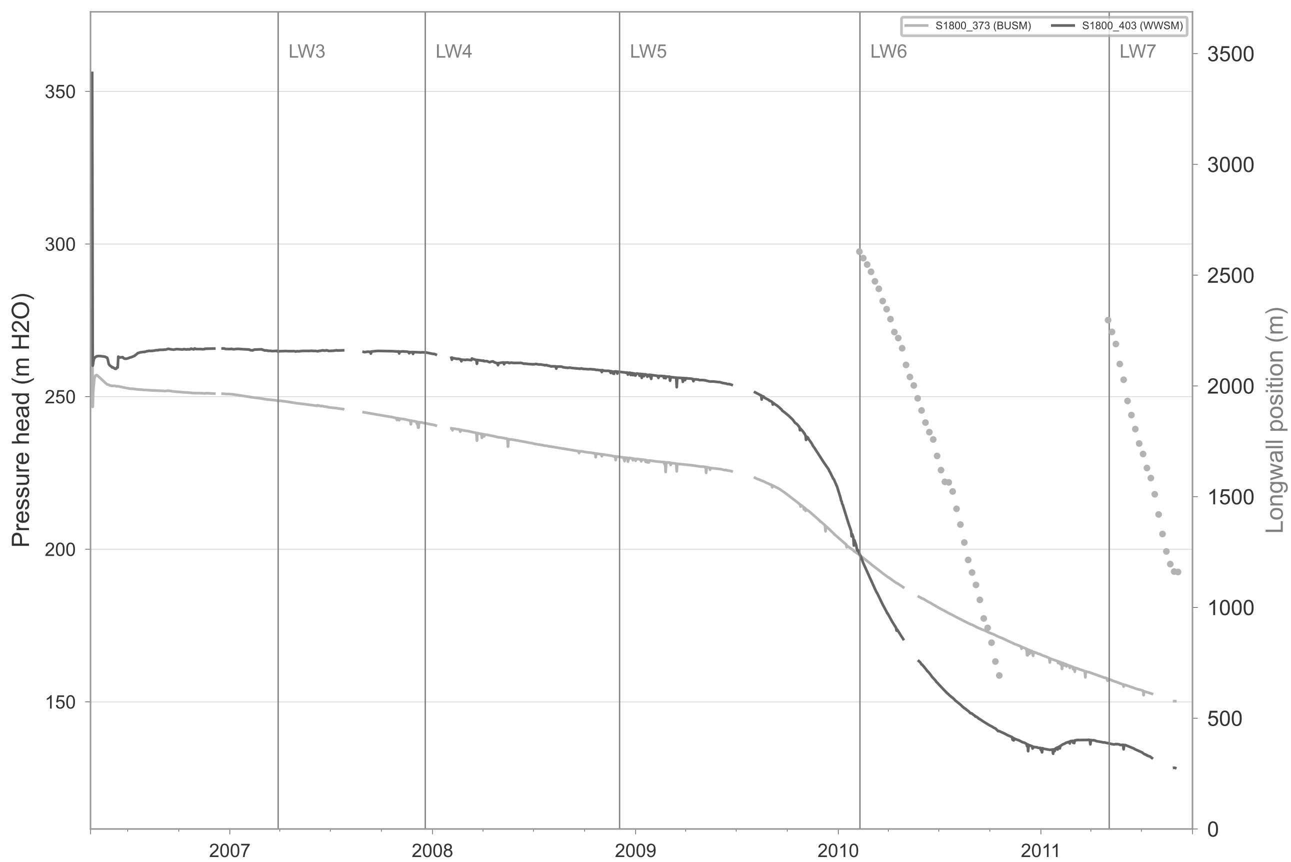


Groundwater hydrographs

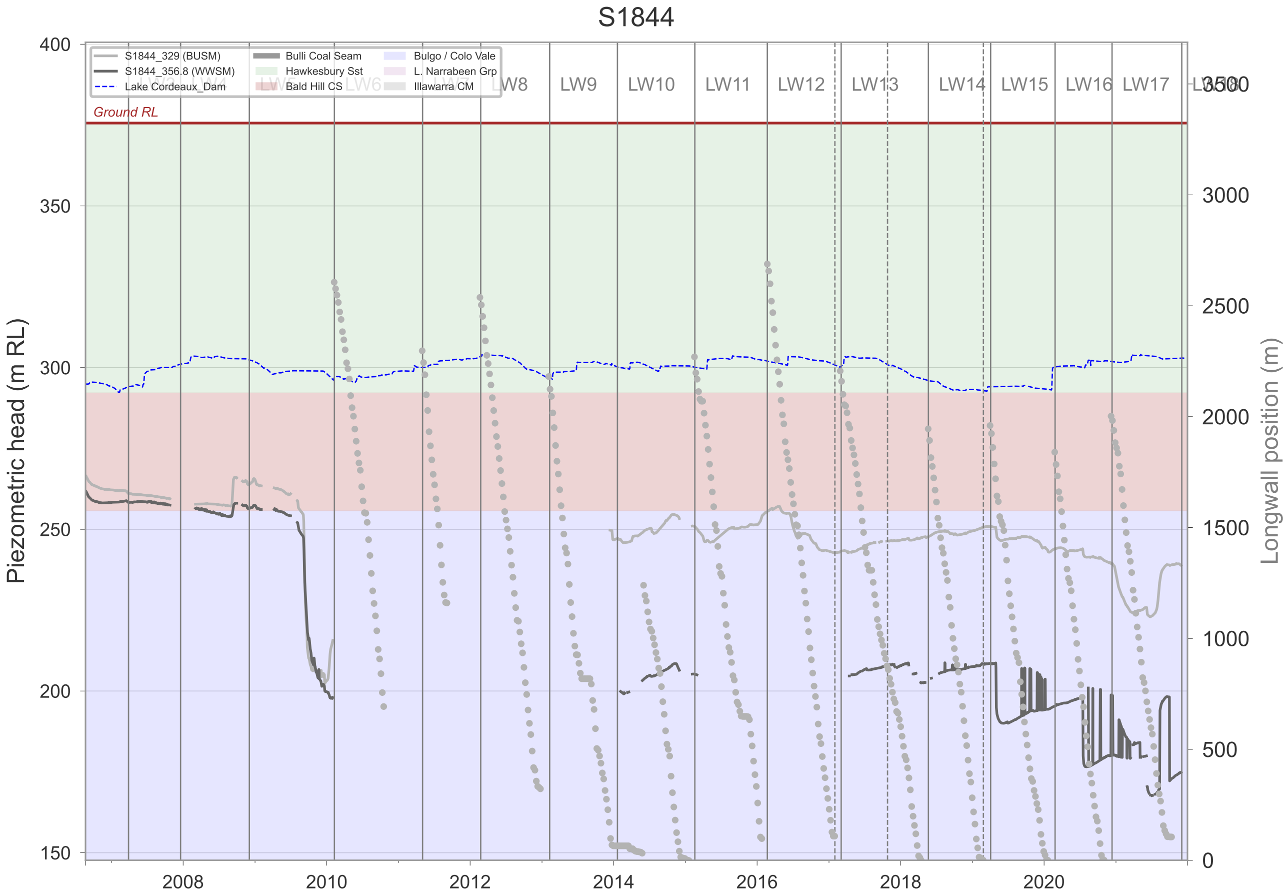
S1800

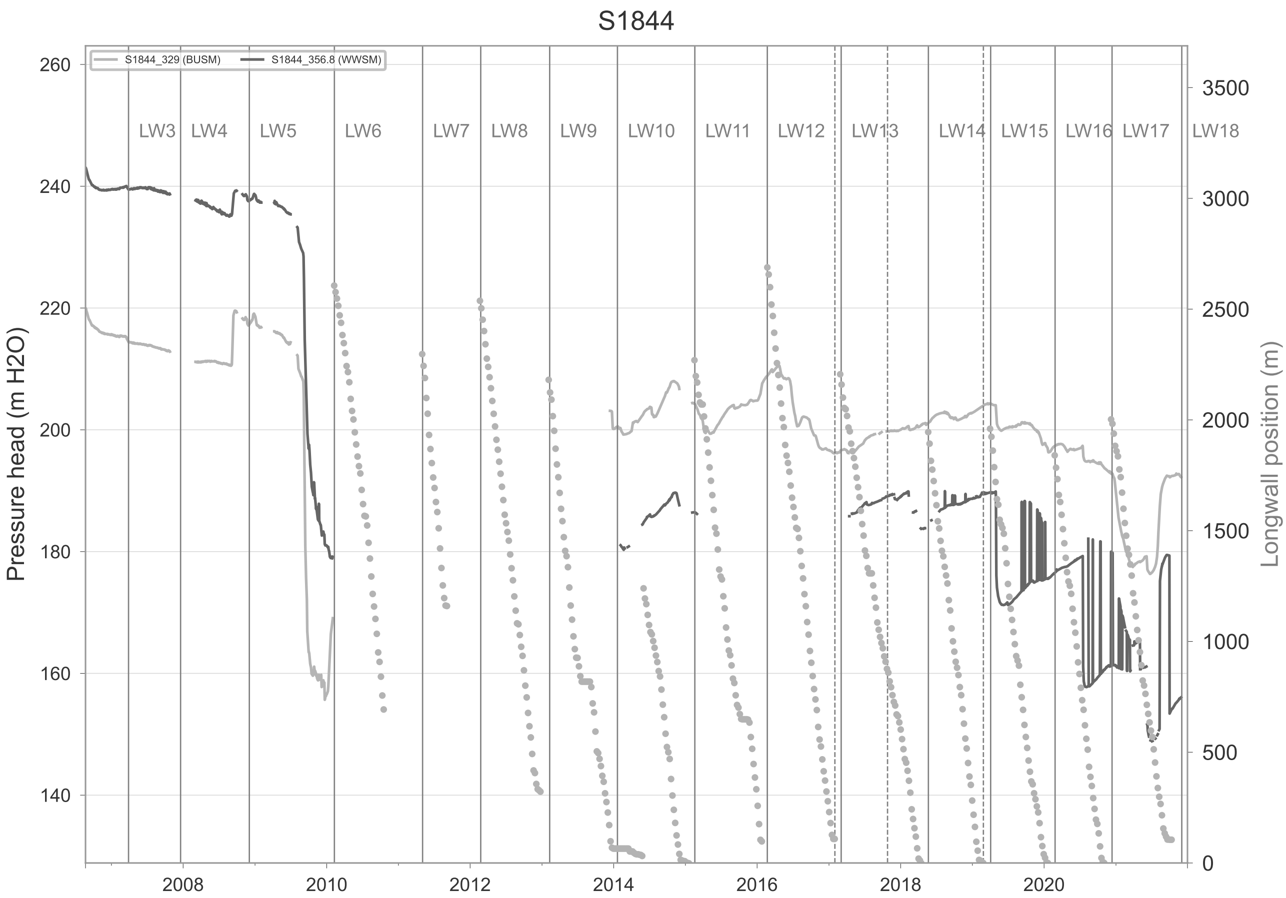


S1800

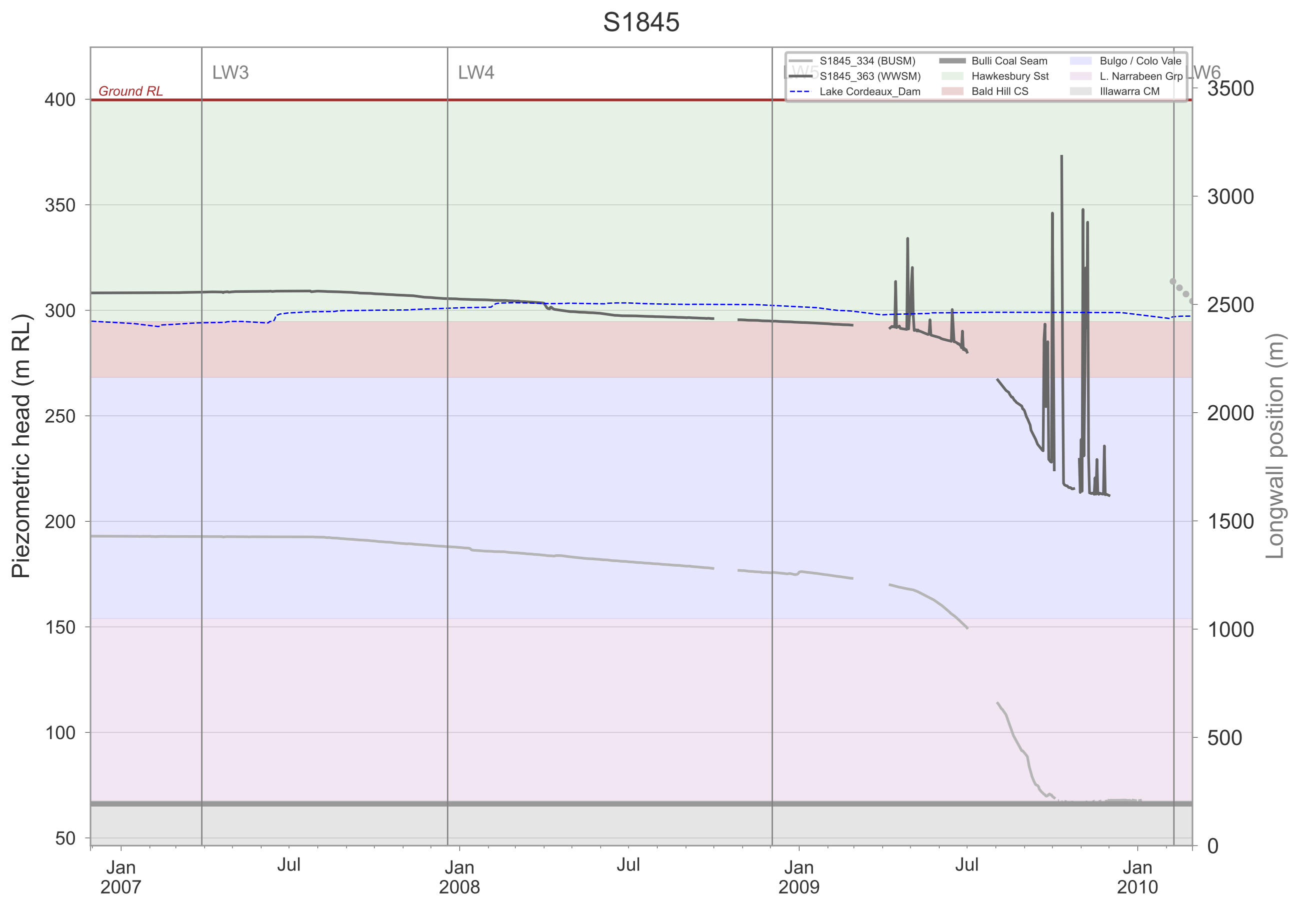


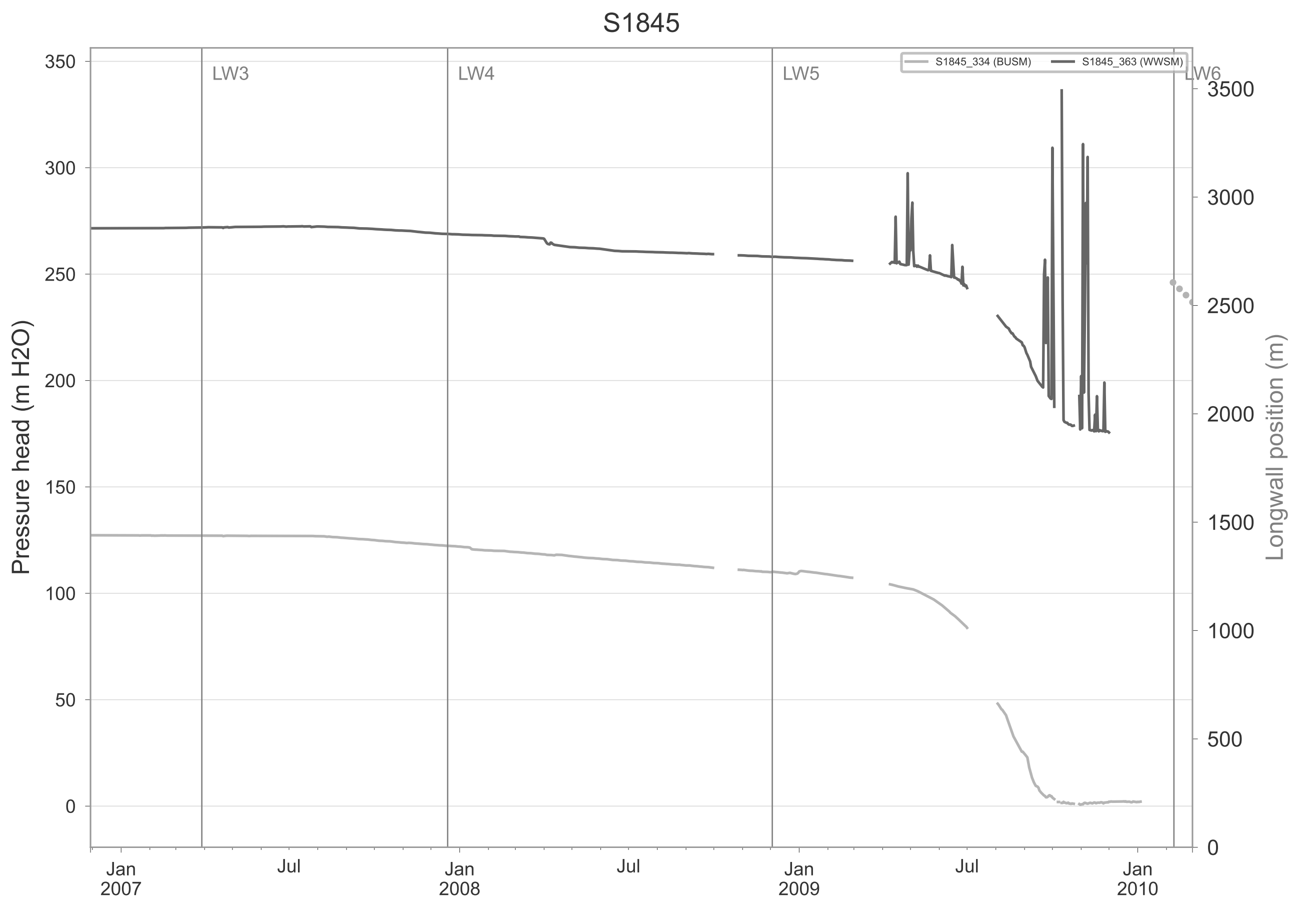
Groundwater hydrographs



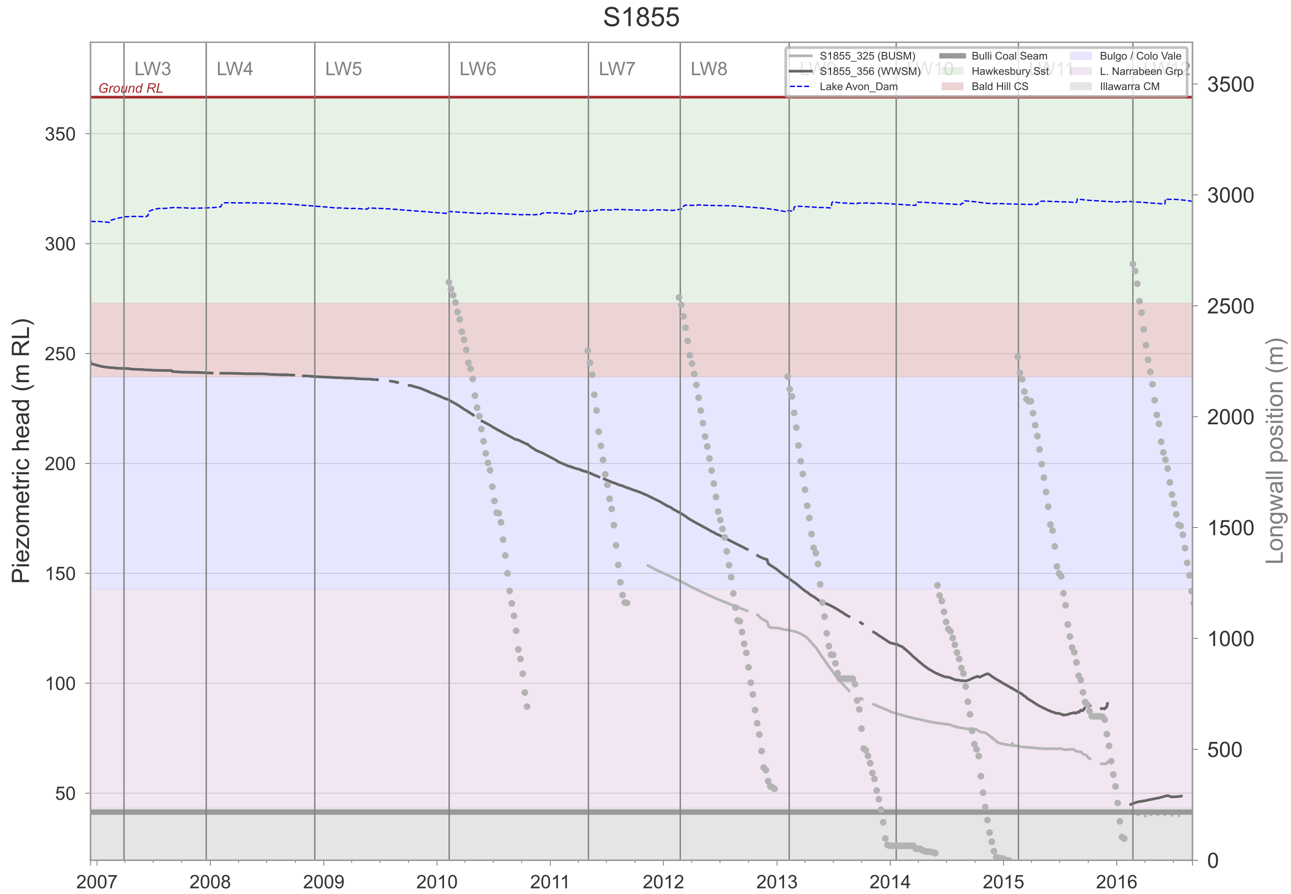


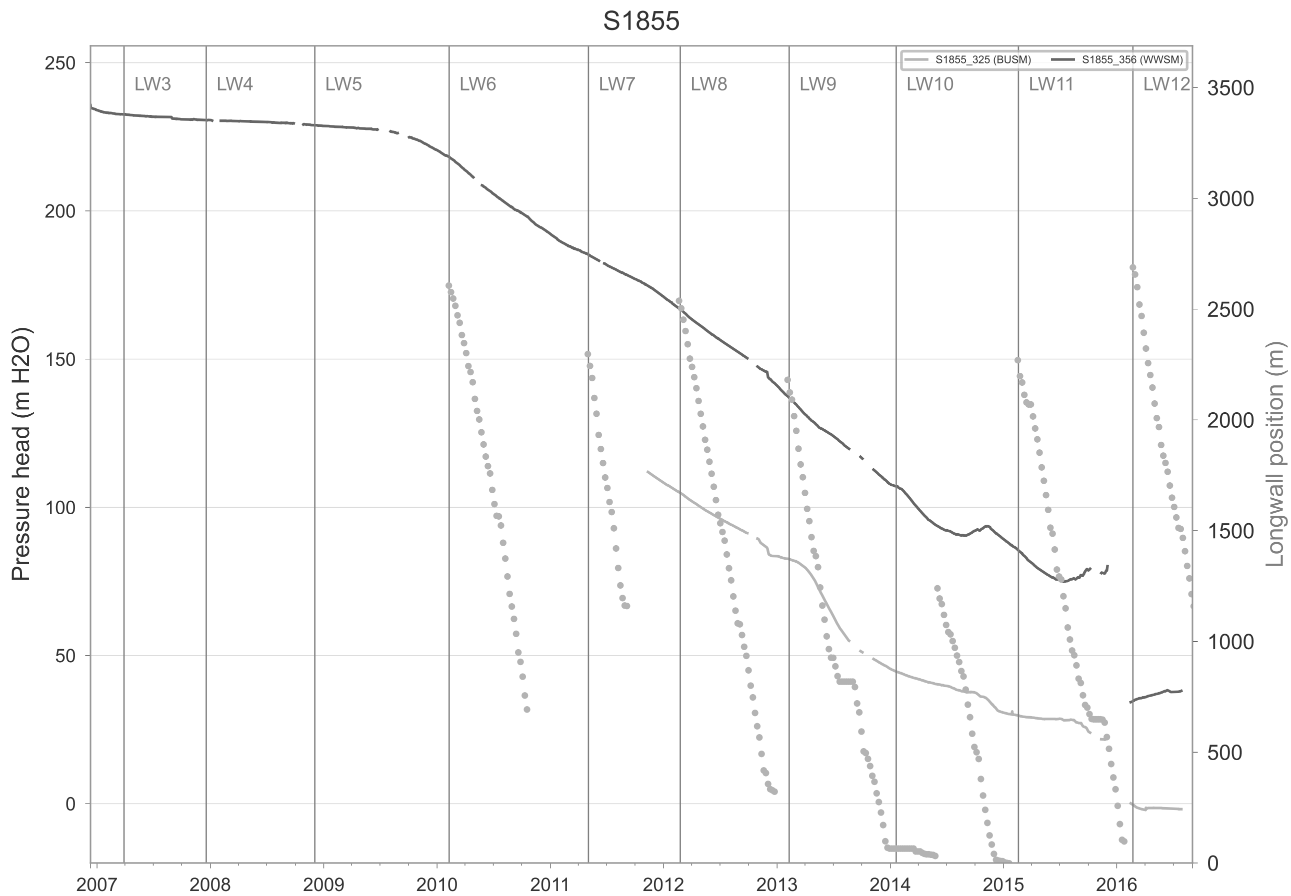
Groundwater hydrographs





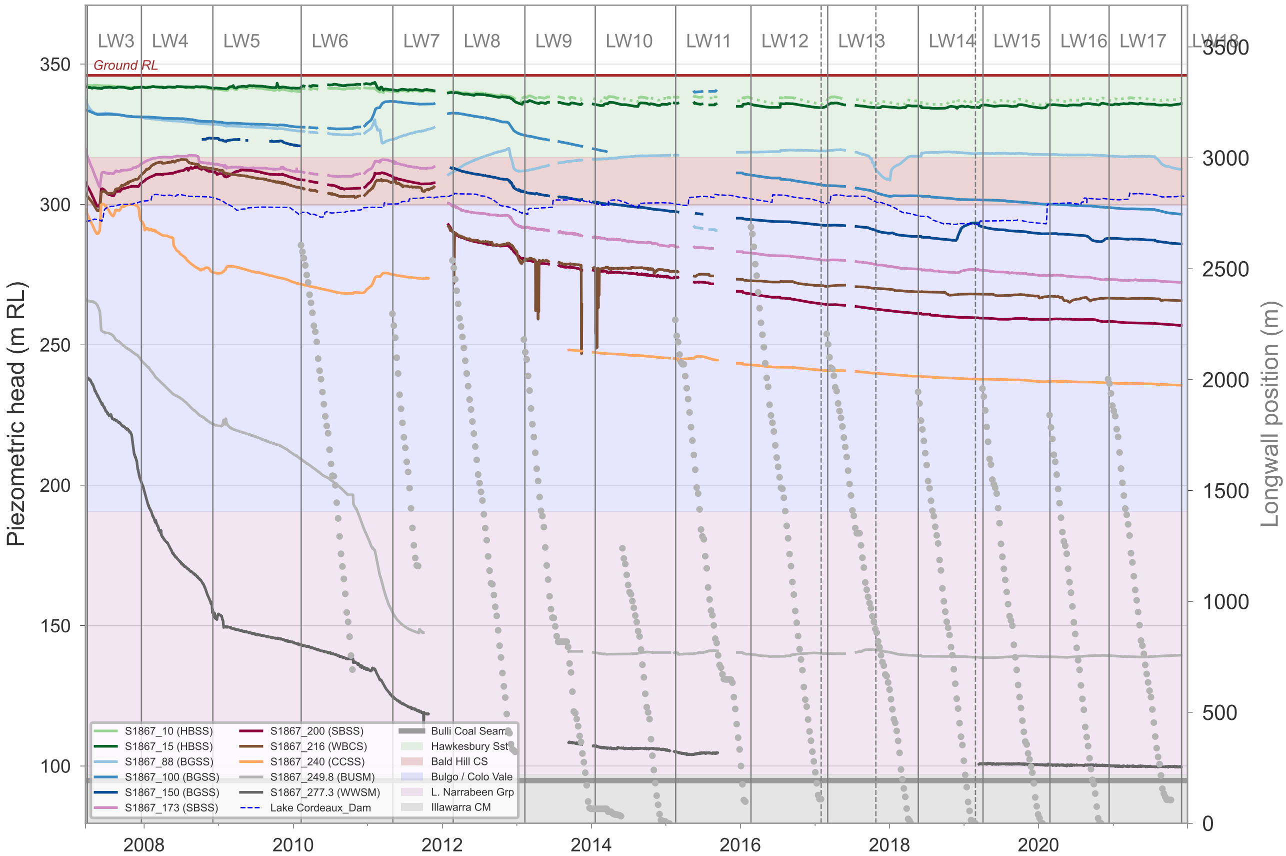
Groundwater hydrographs





Groundwater hydrographs

S1867



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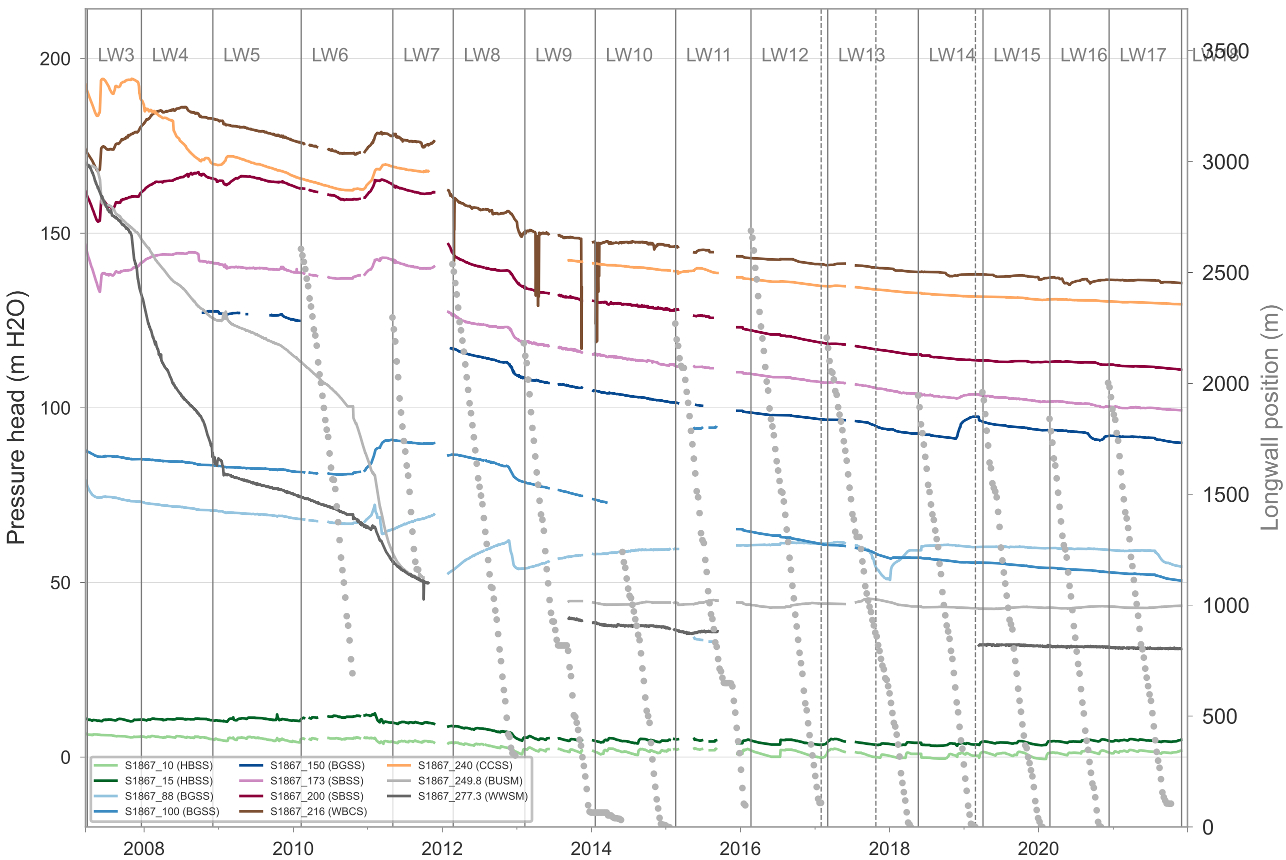

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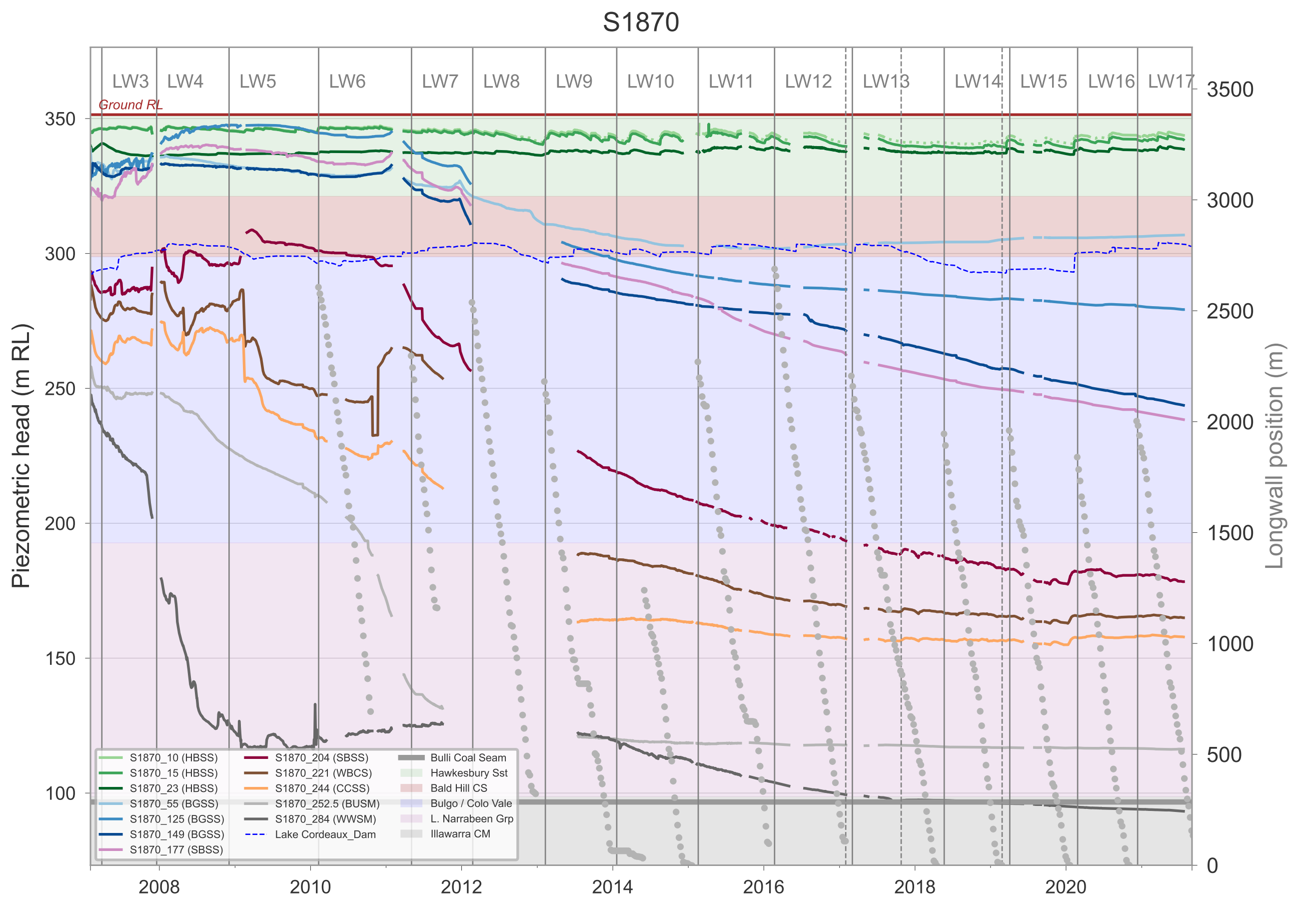

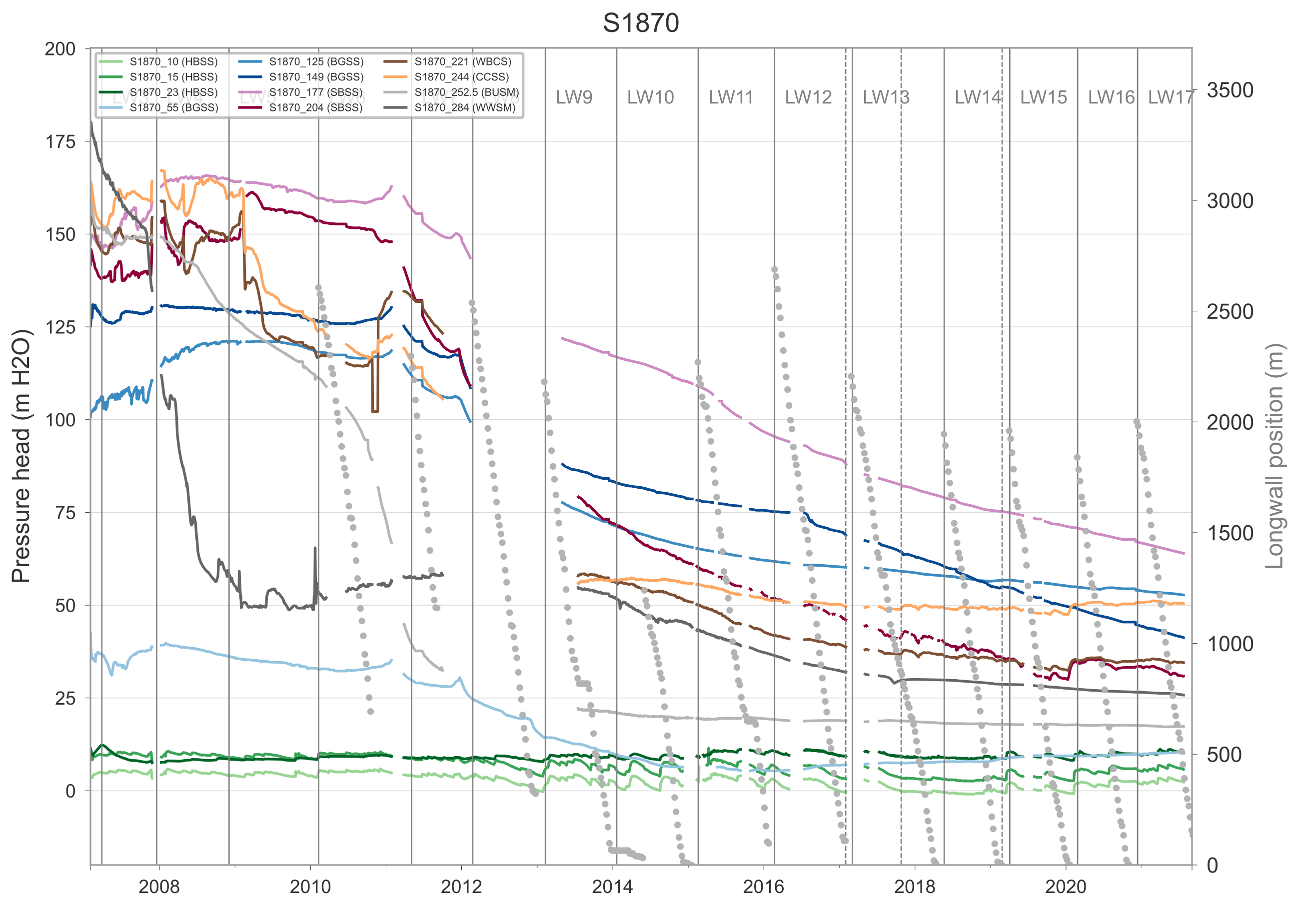

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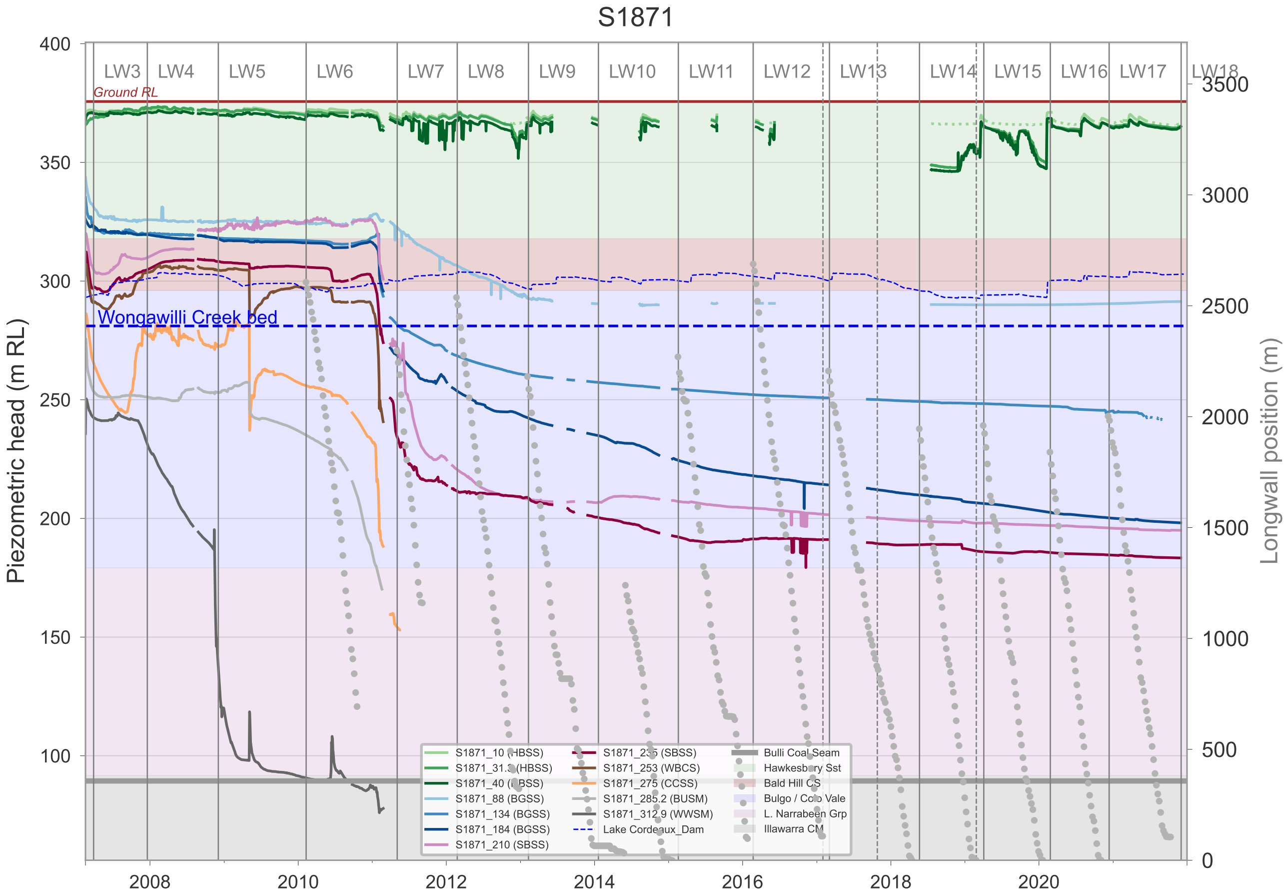
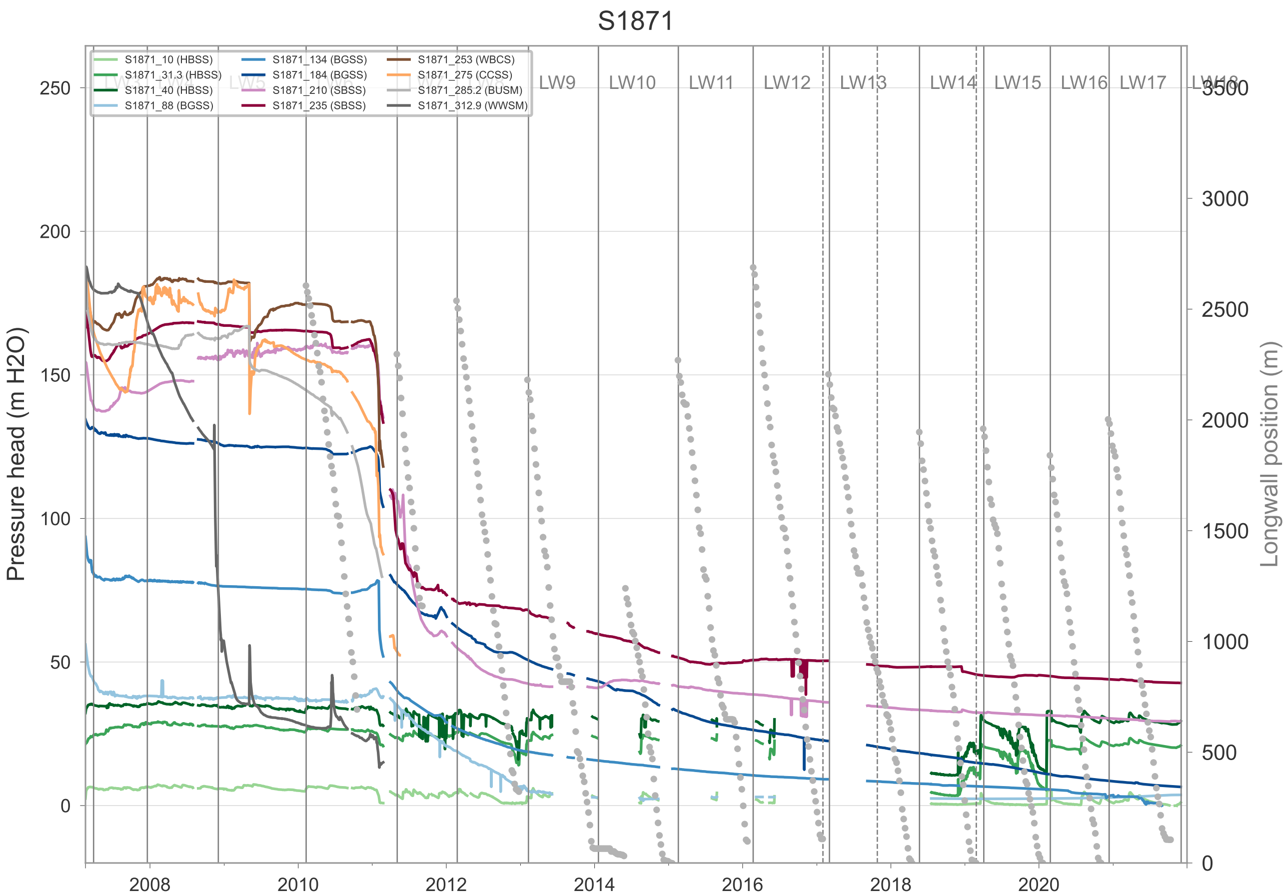
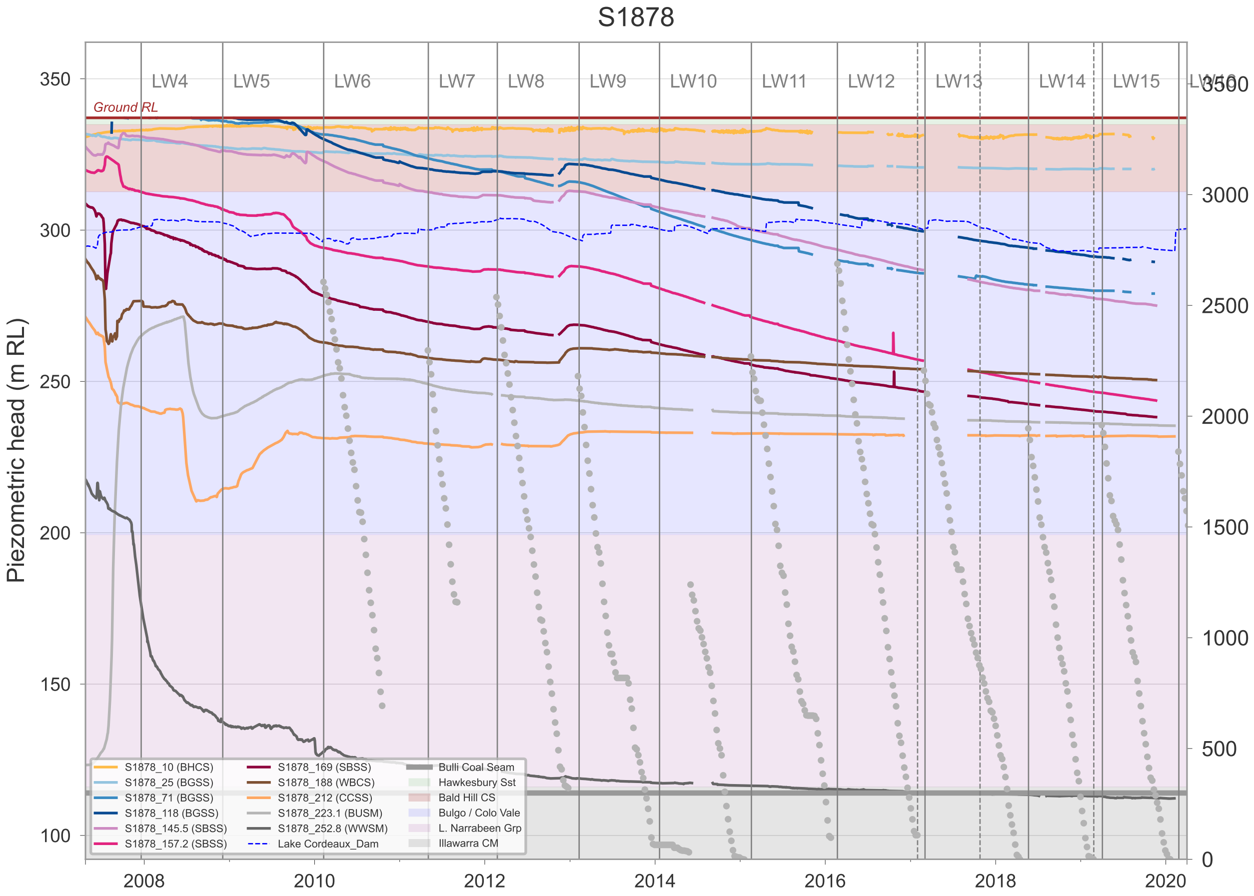
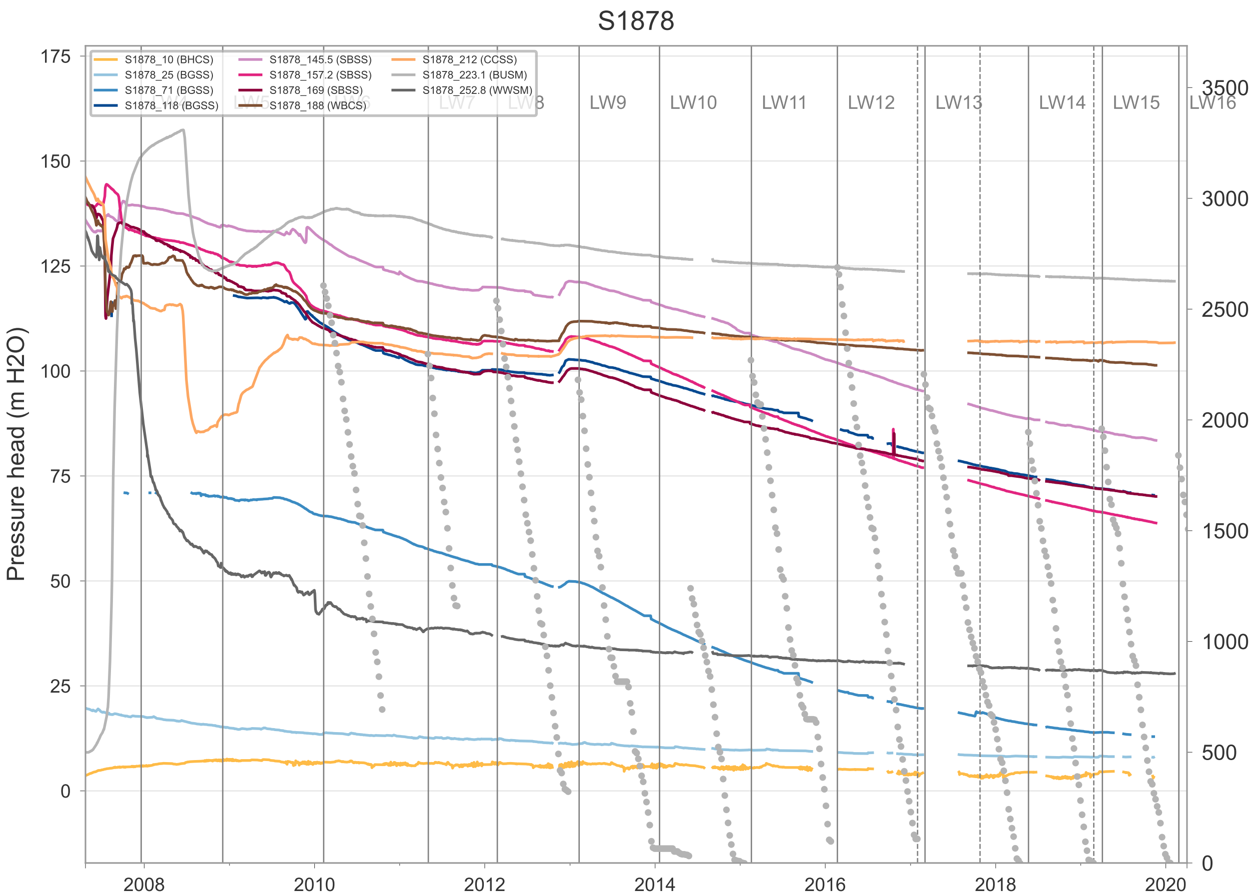




Groundwater hydrographs





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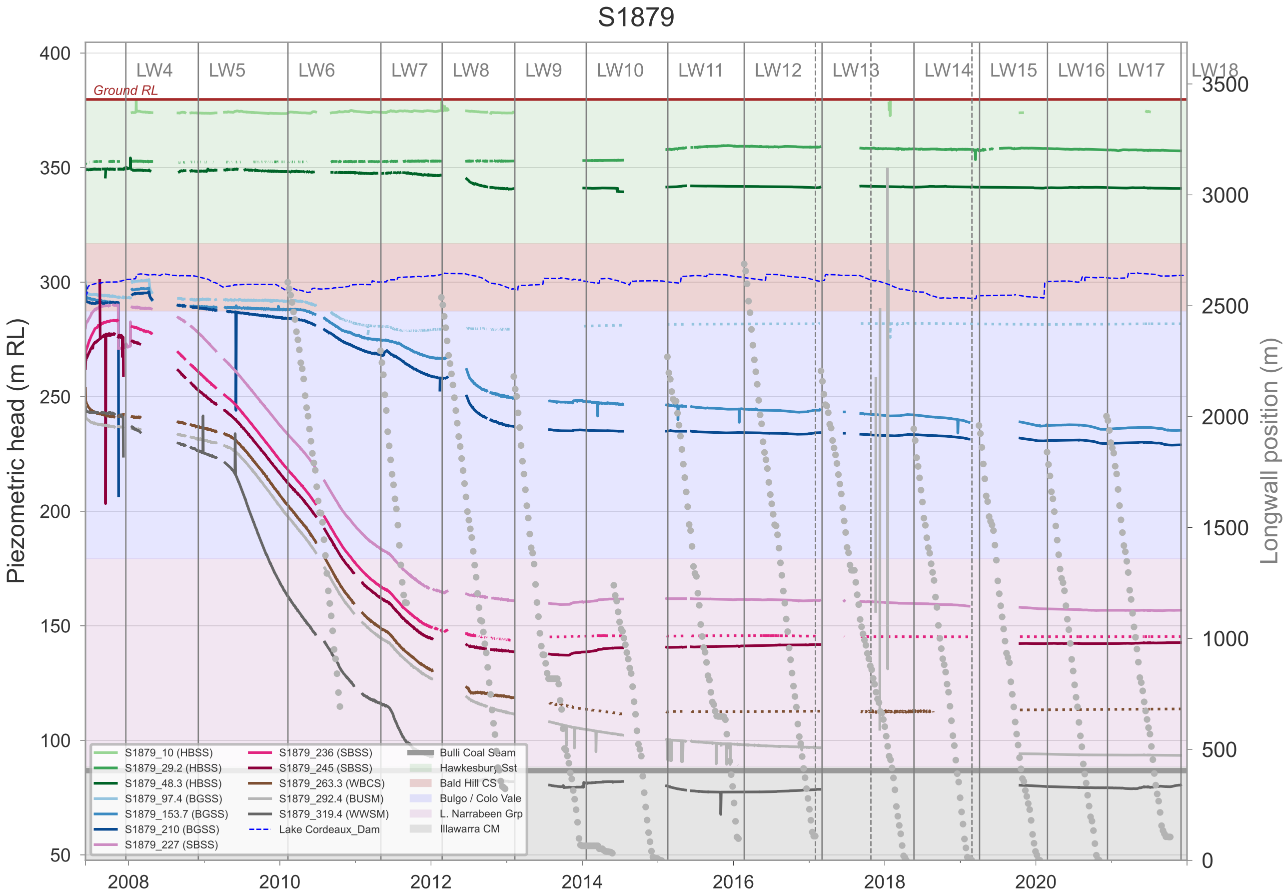

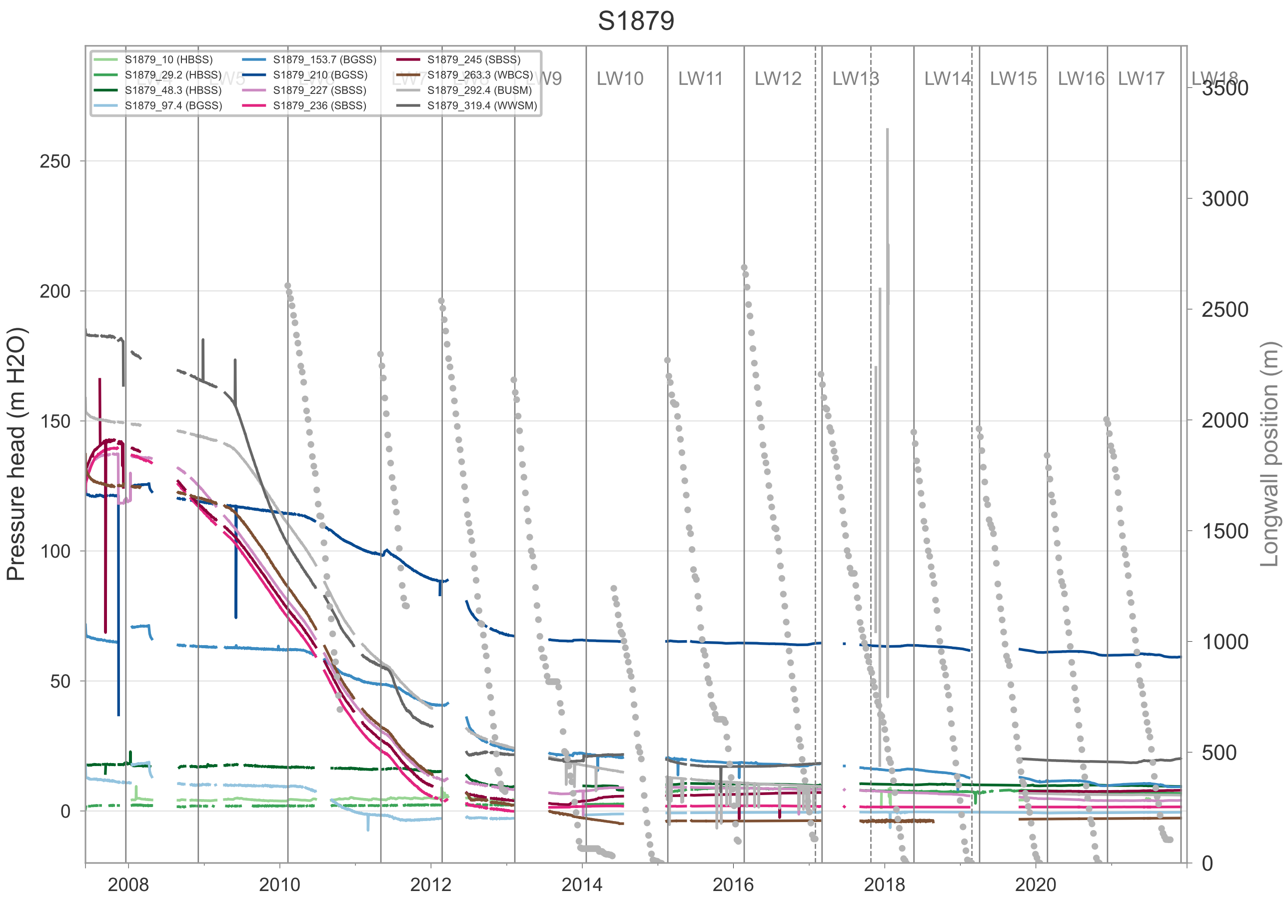

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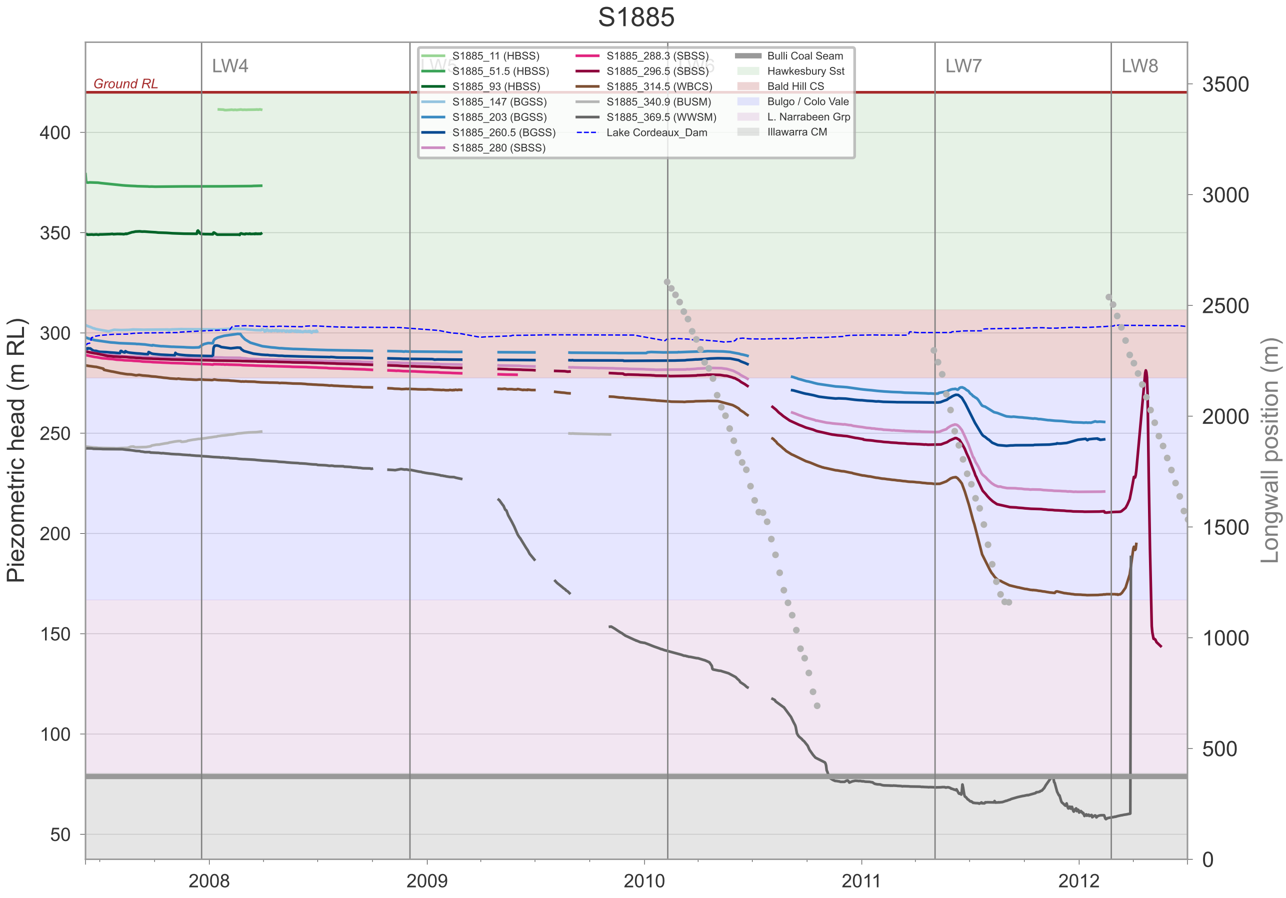

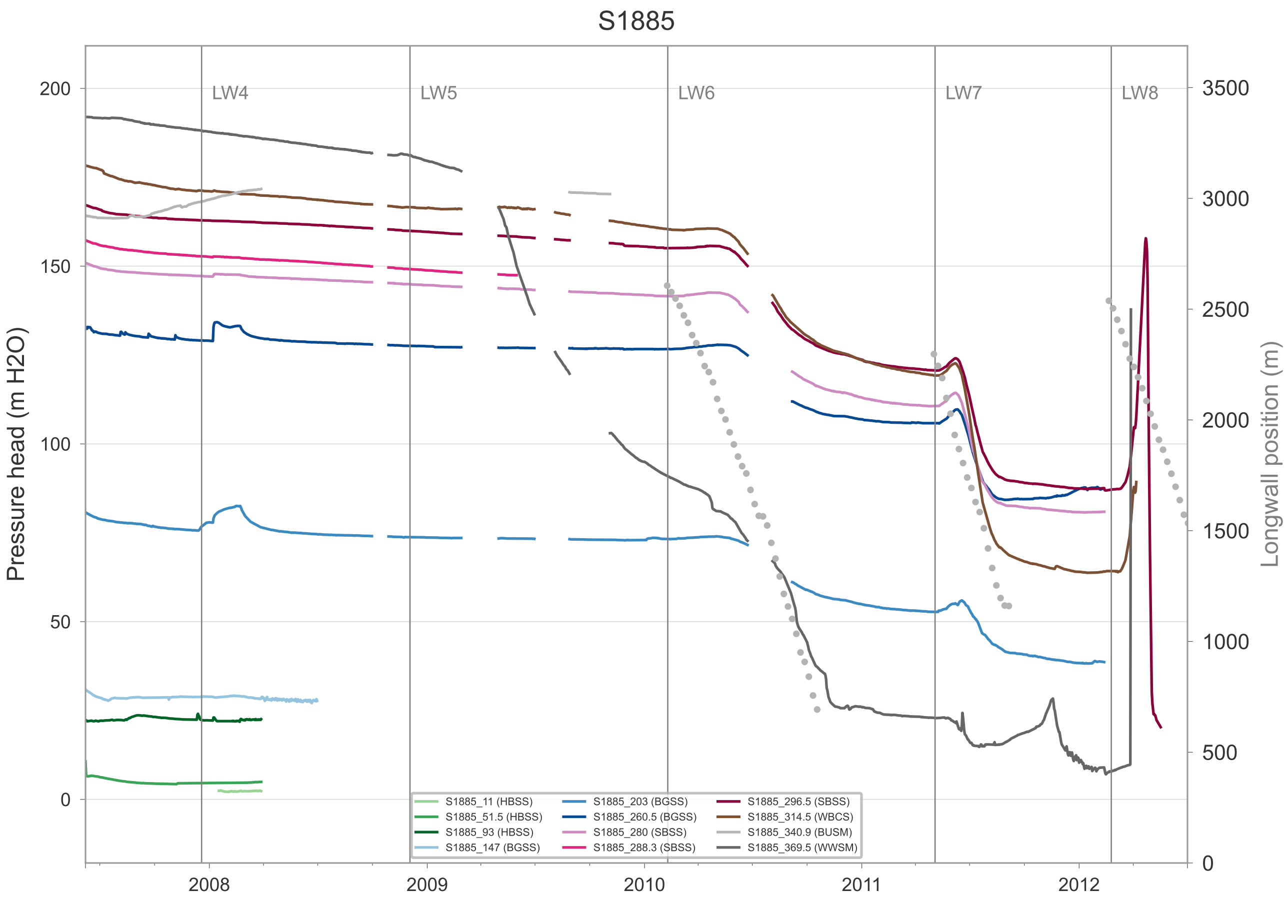

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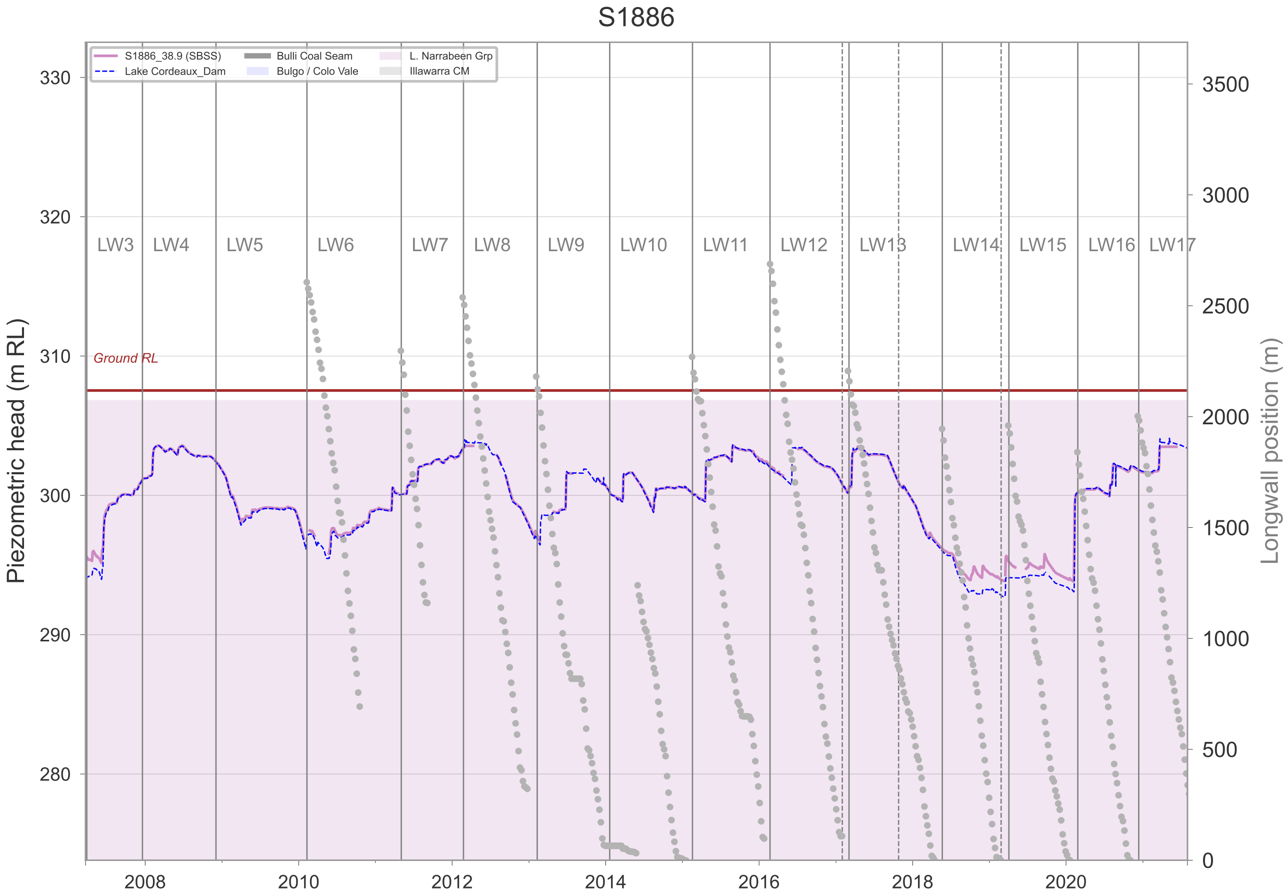

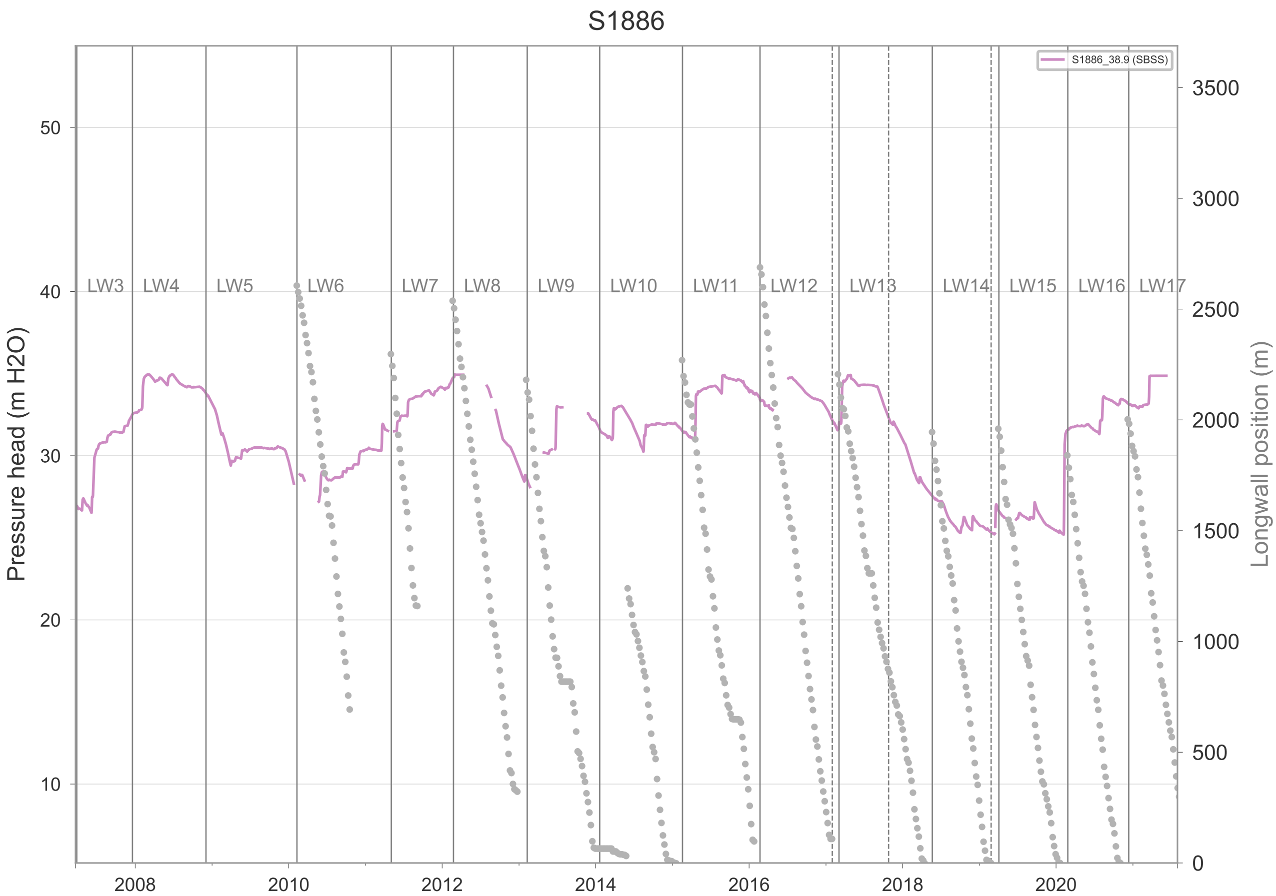

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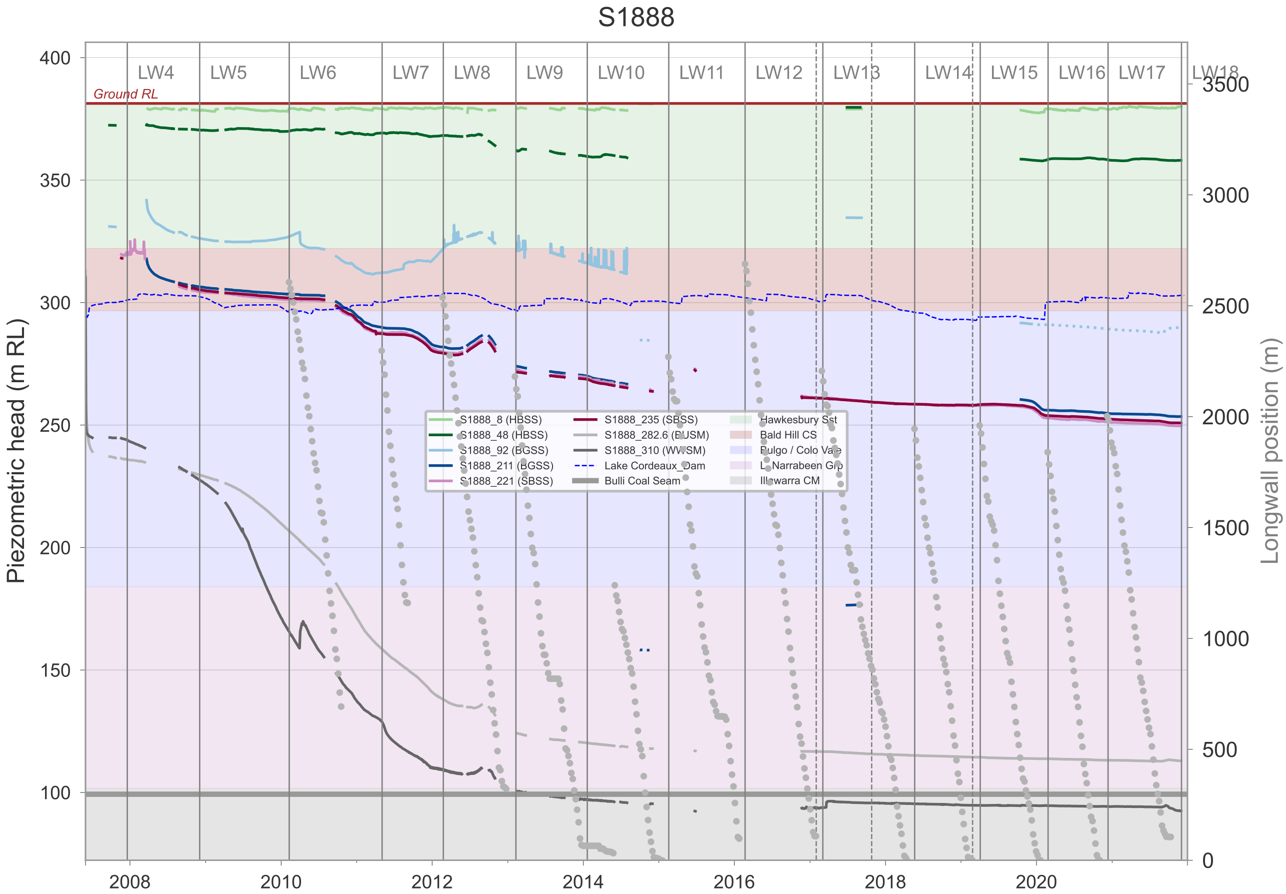
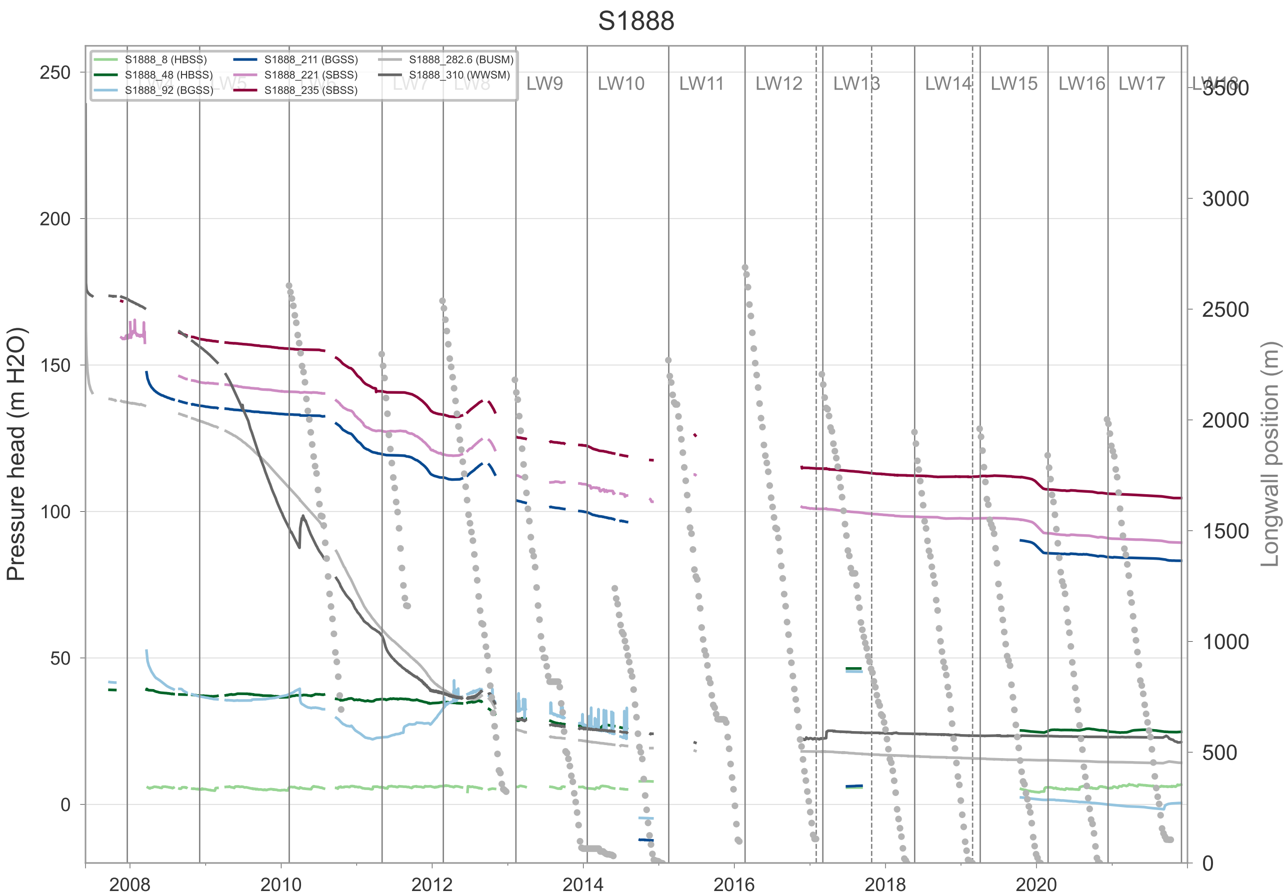
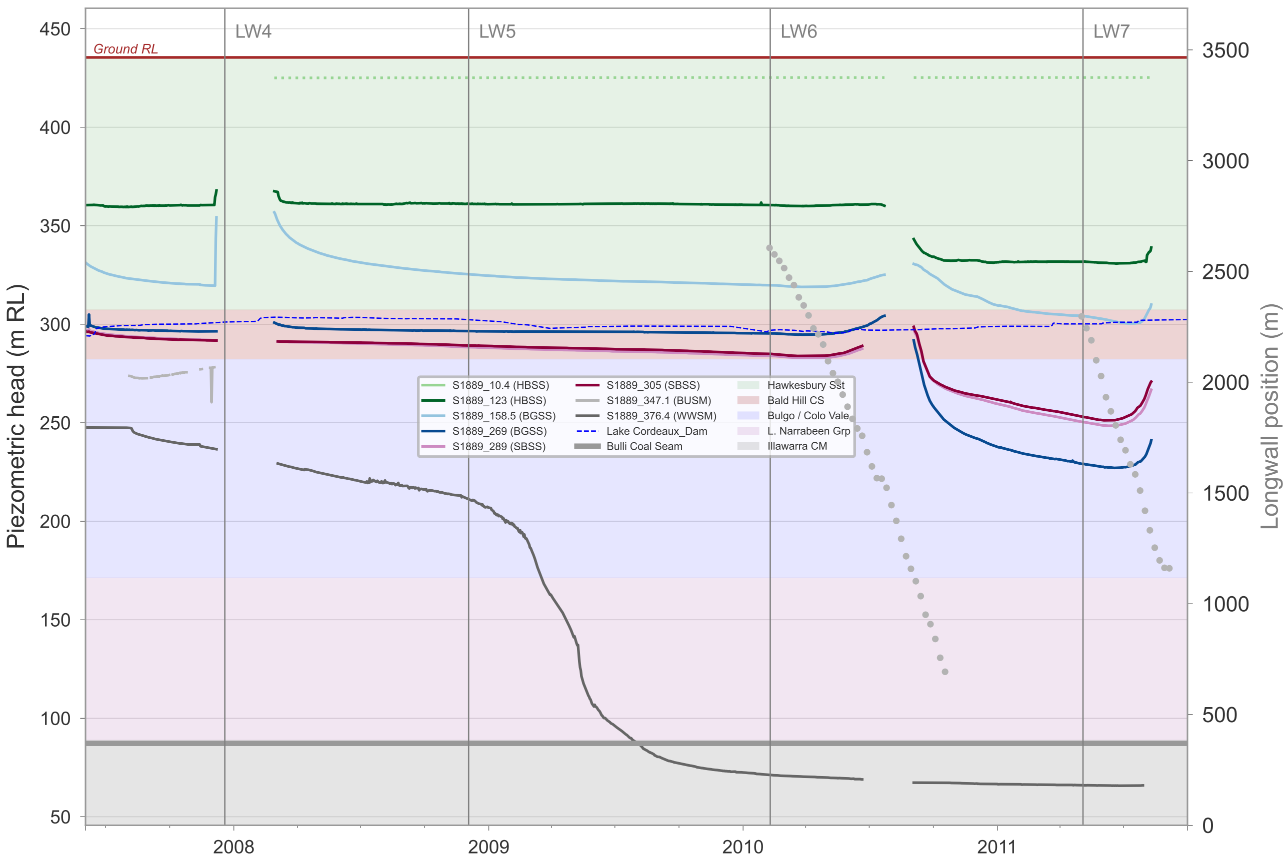




Groundwater hydrographs

S1889



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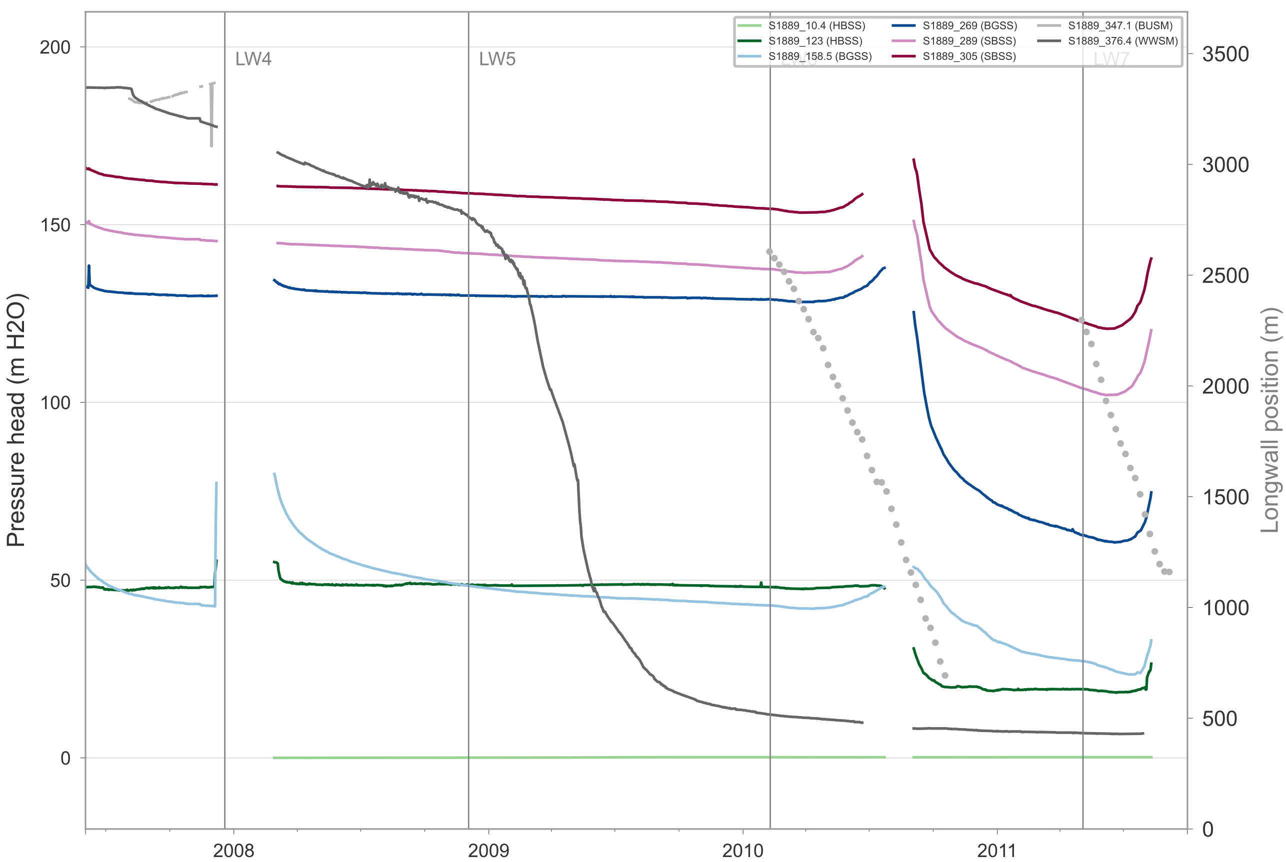
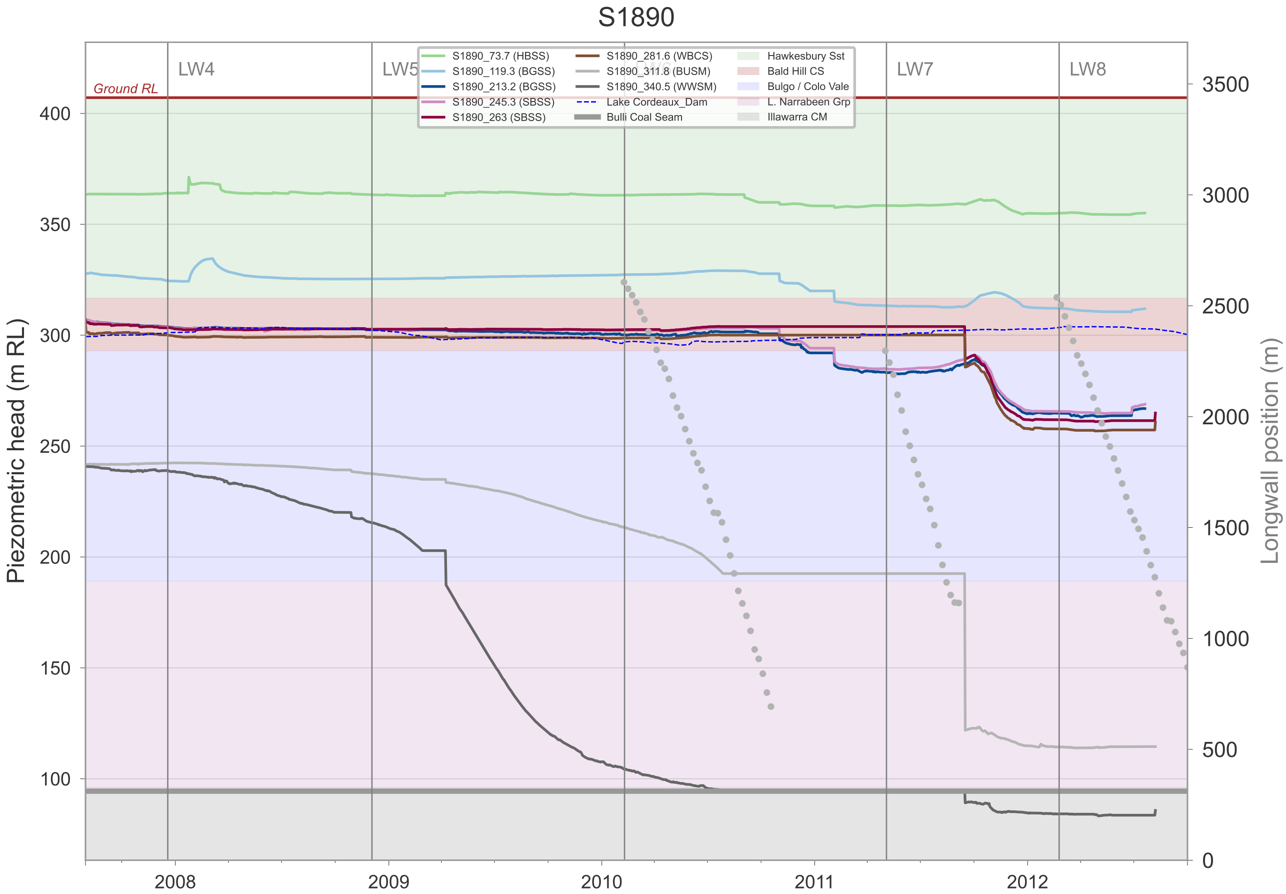
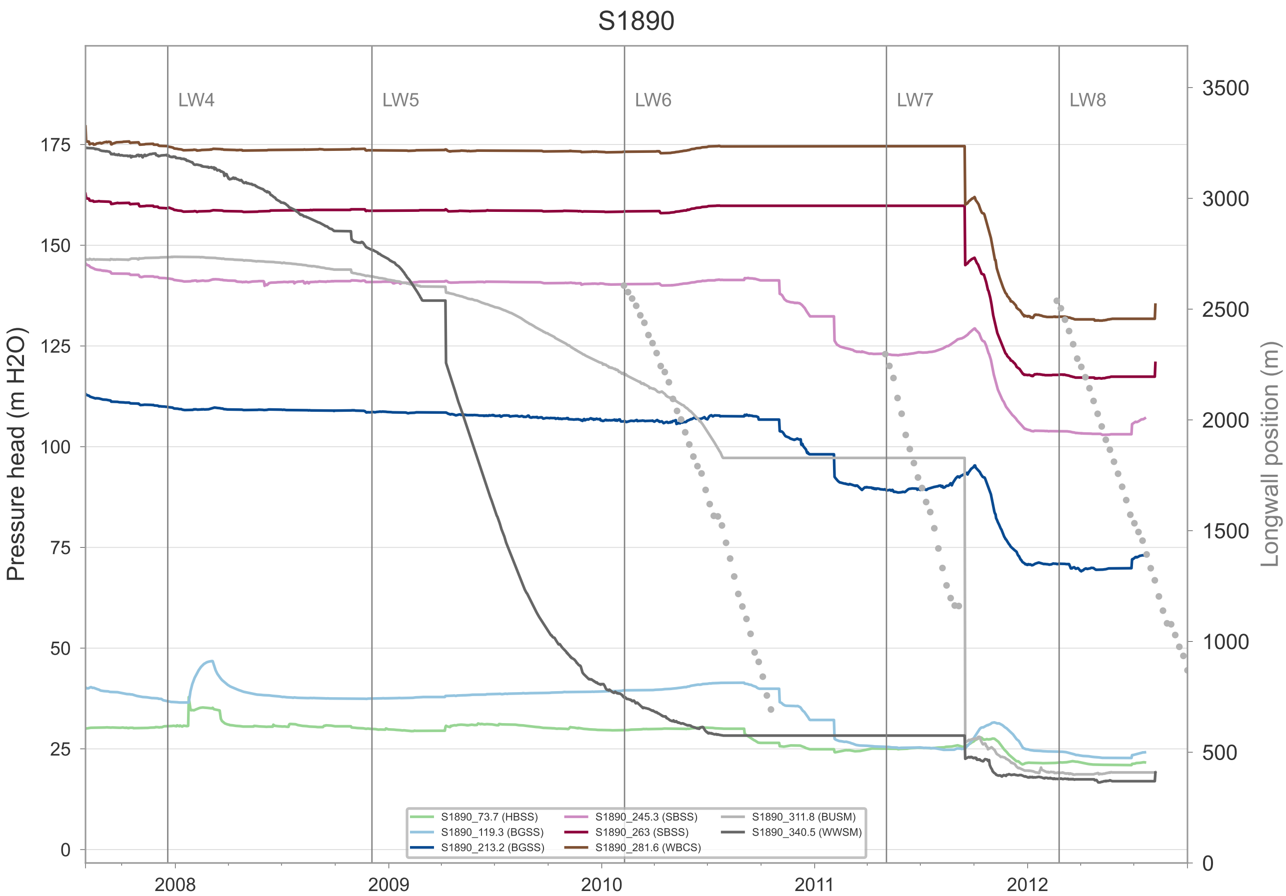
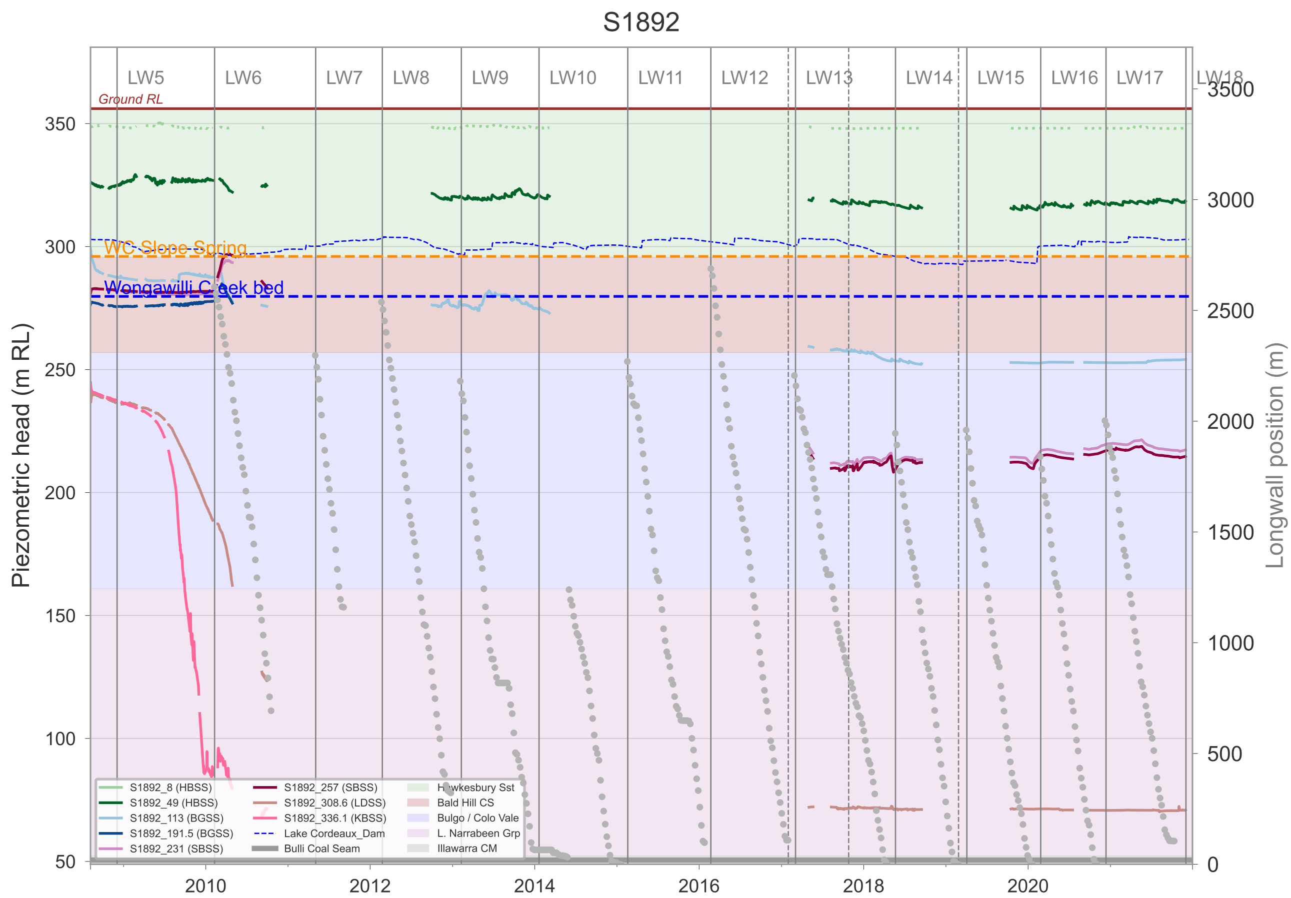


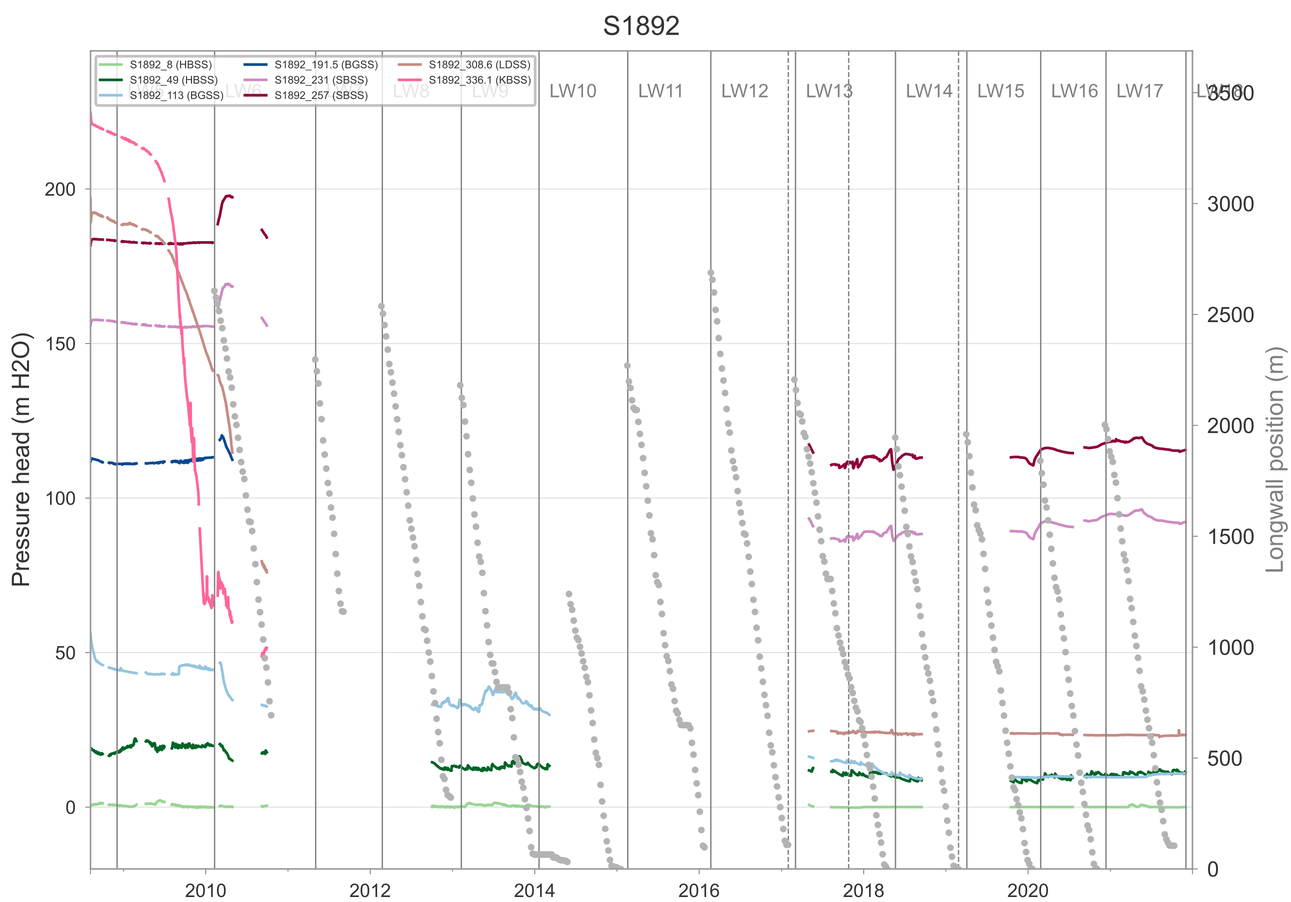
Groundwater hydrographs





Groundwater hydrographs





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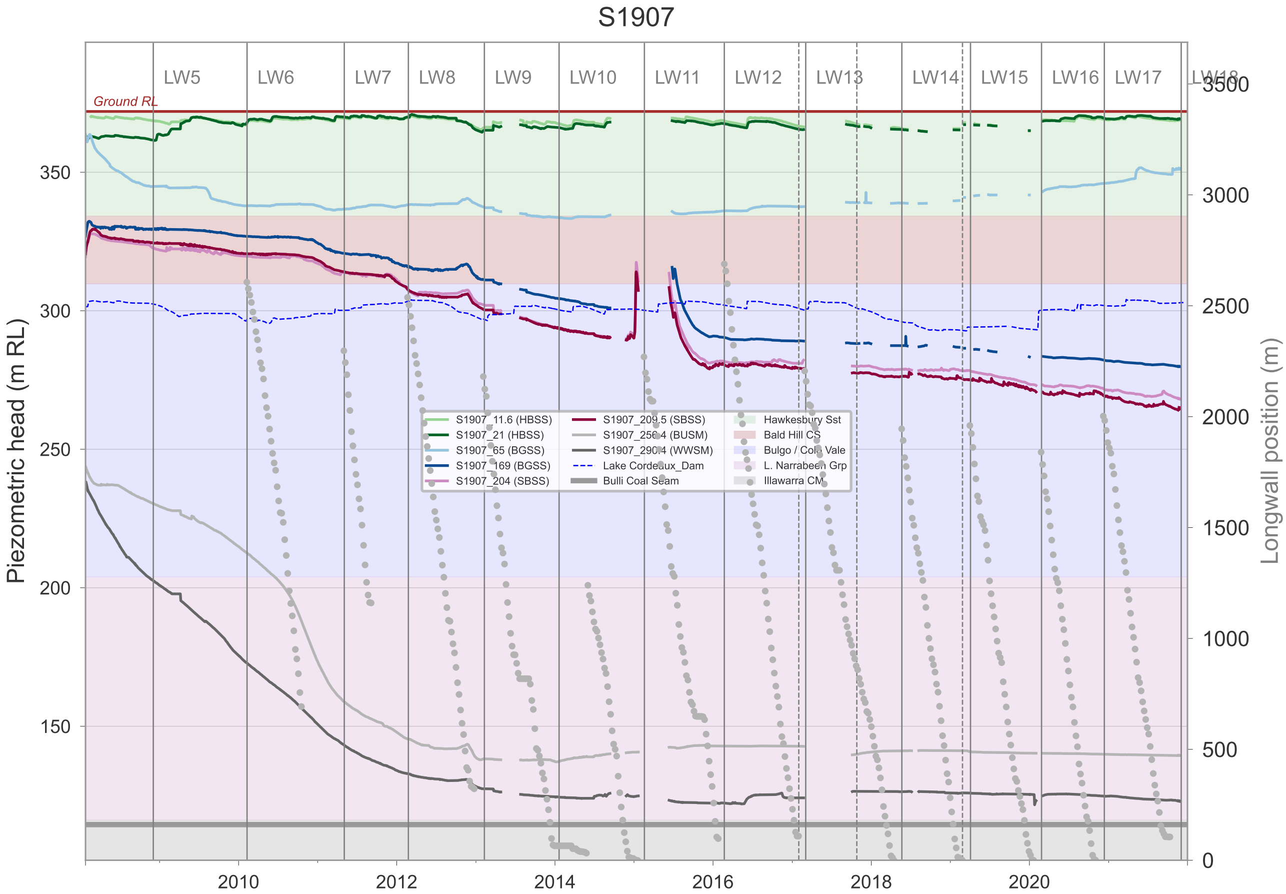
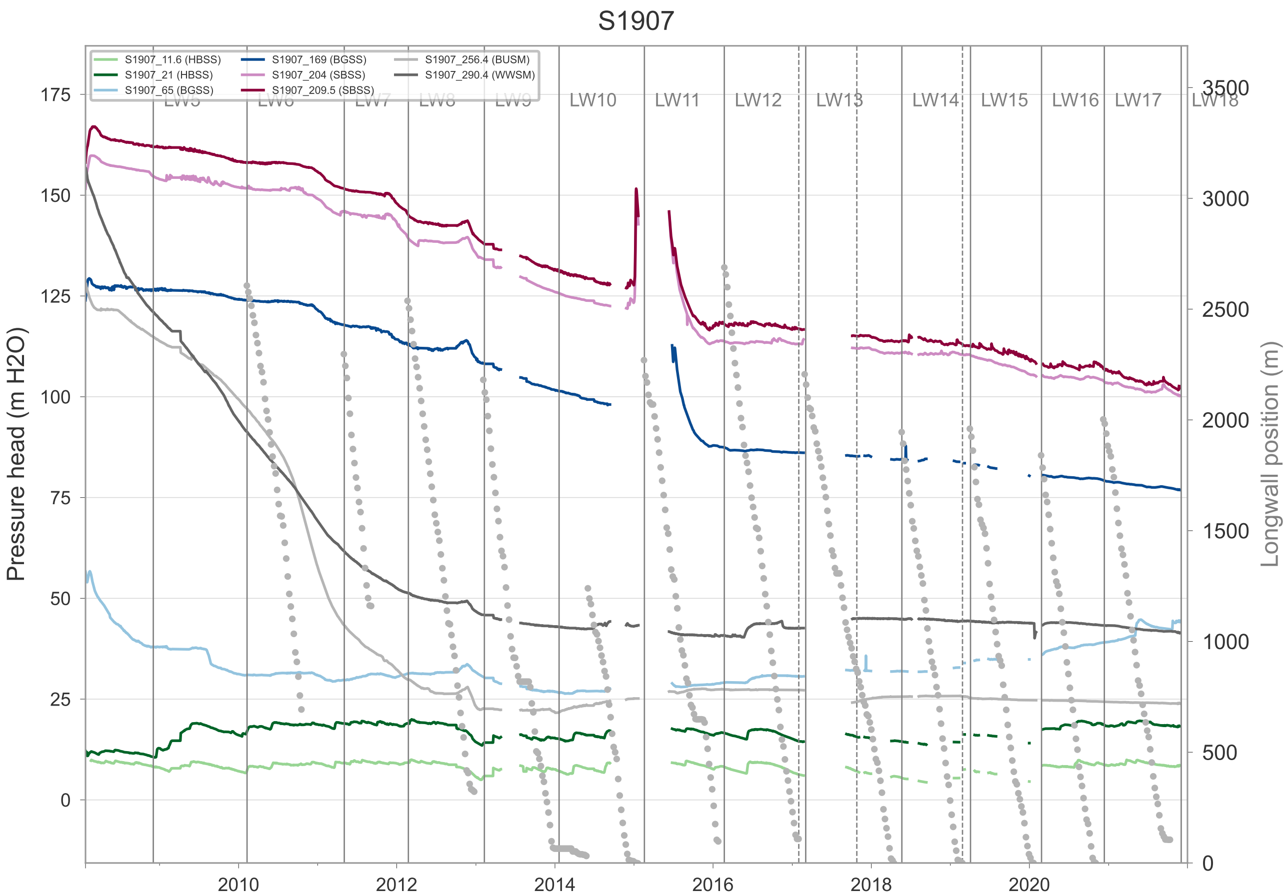
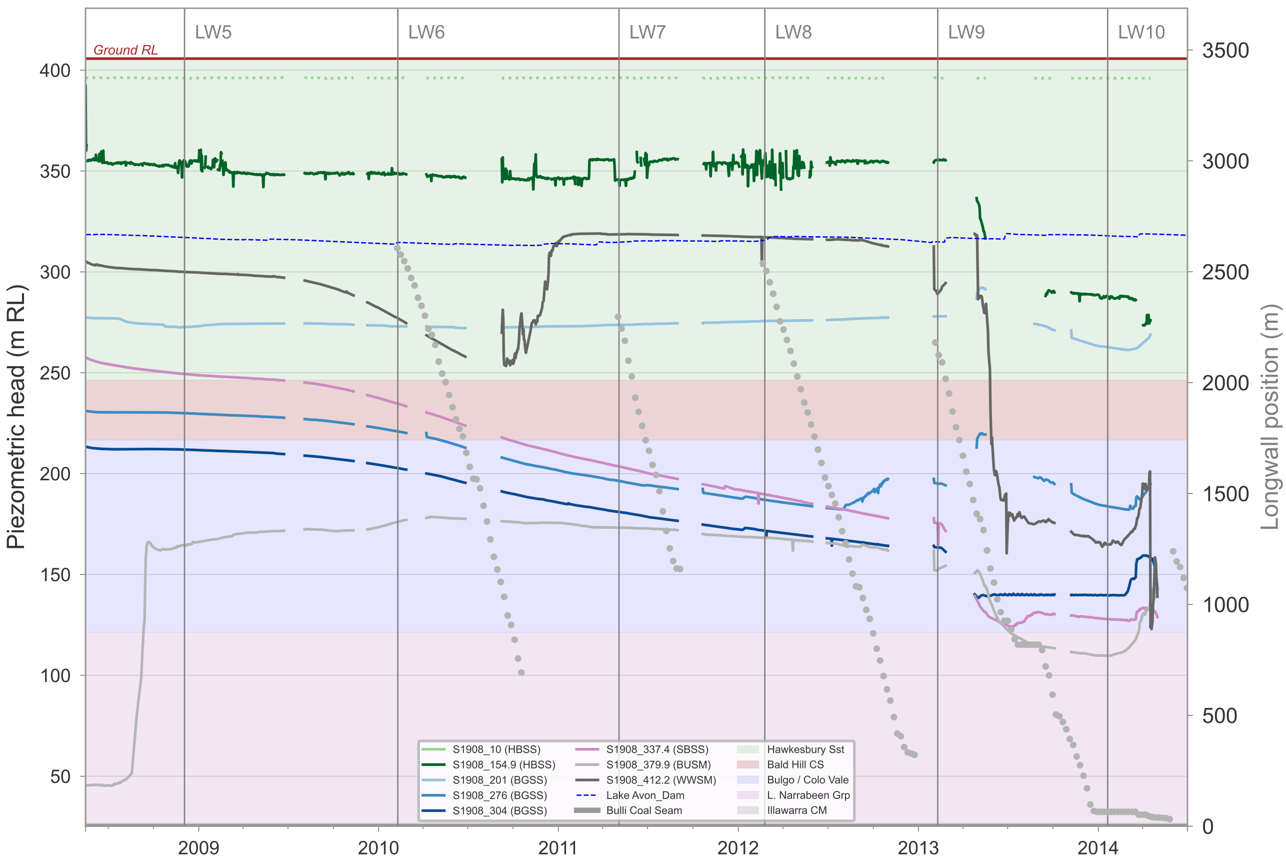




Groundwater hydrographs

S1908



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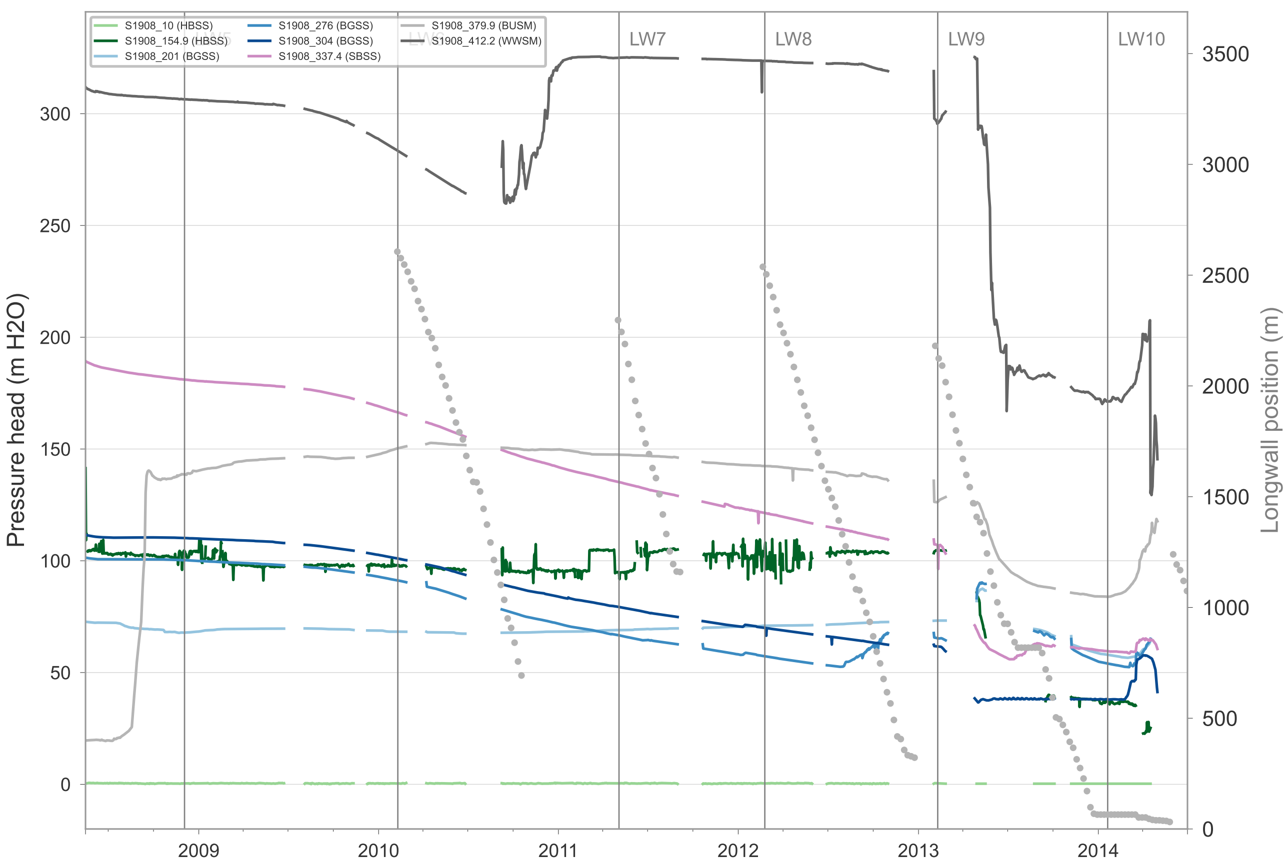
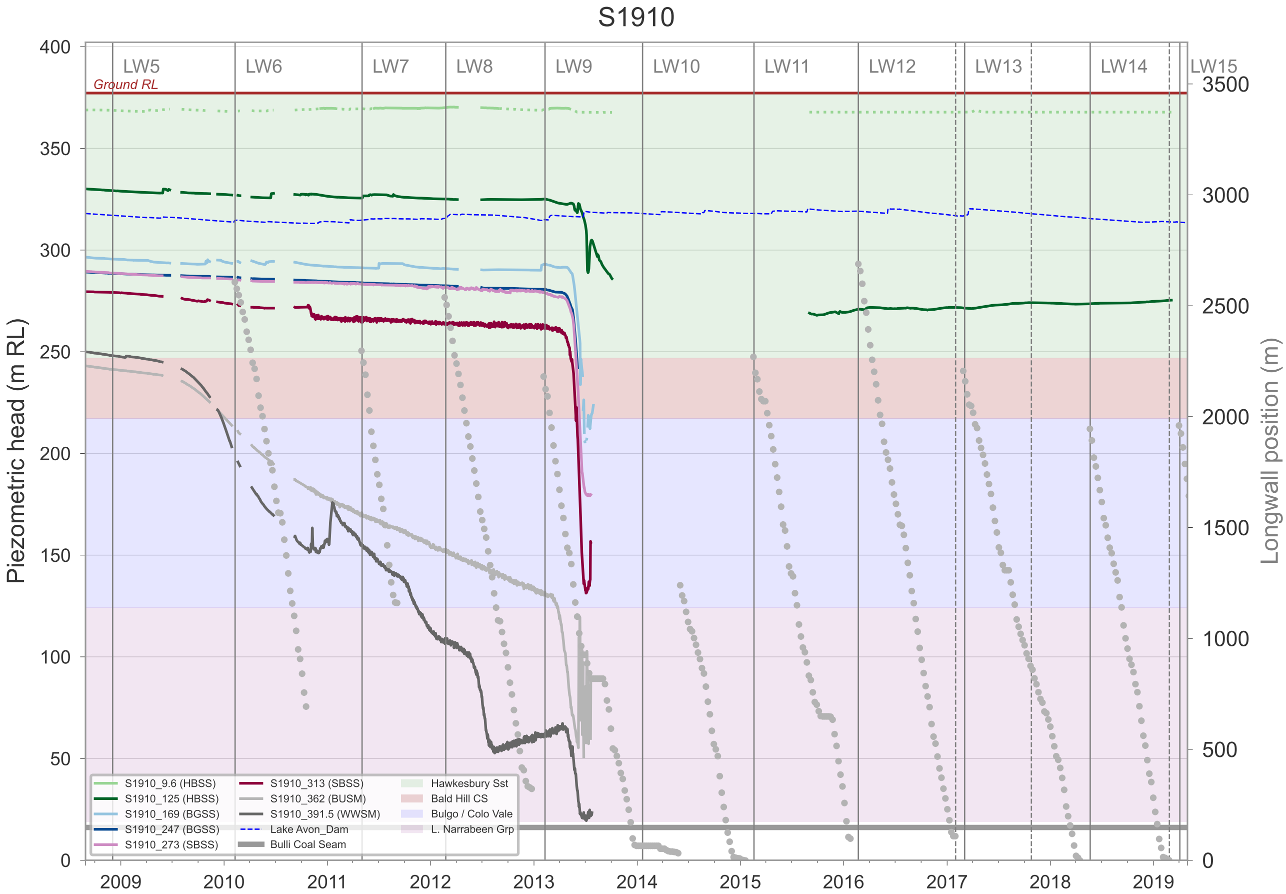
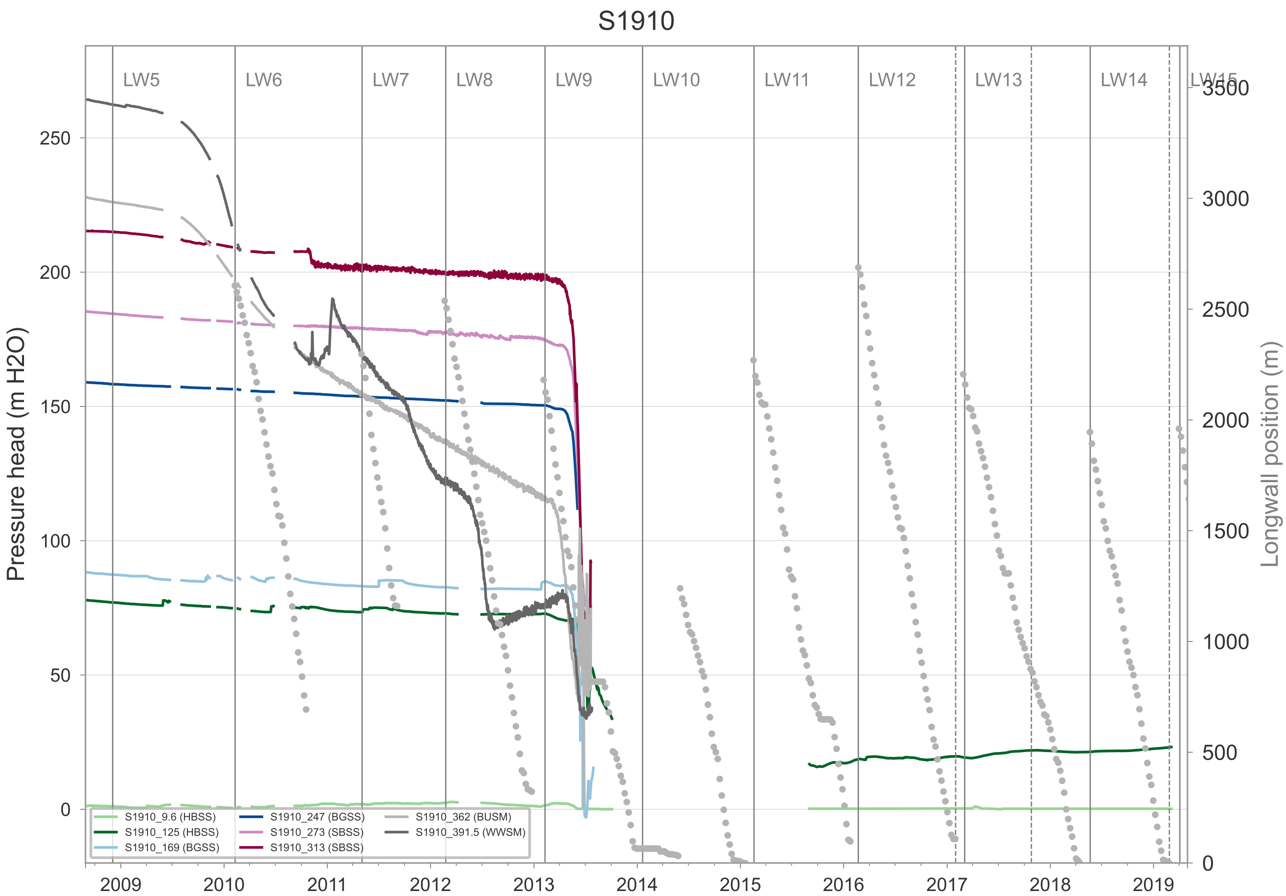
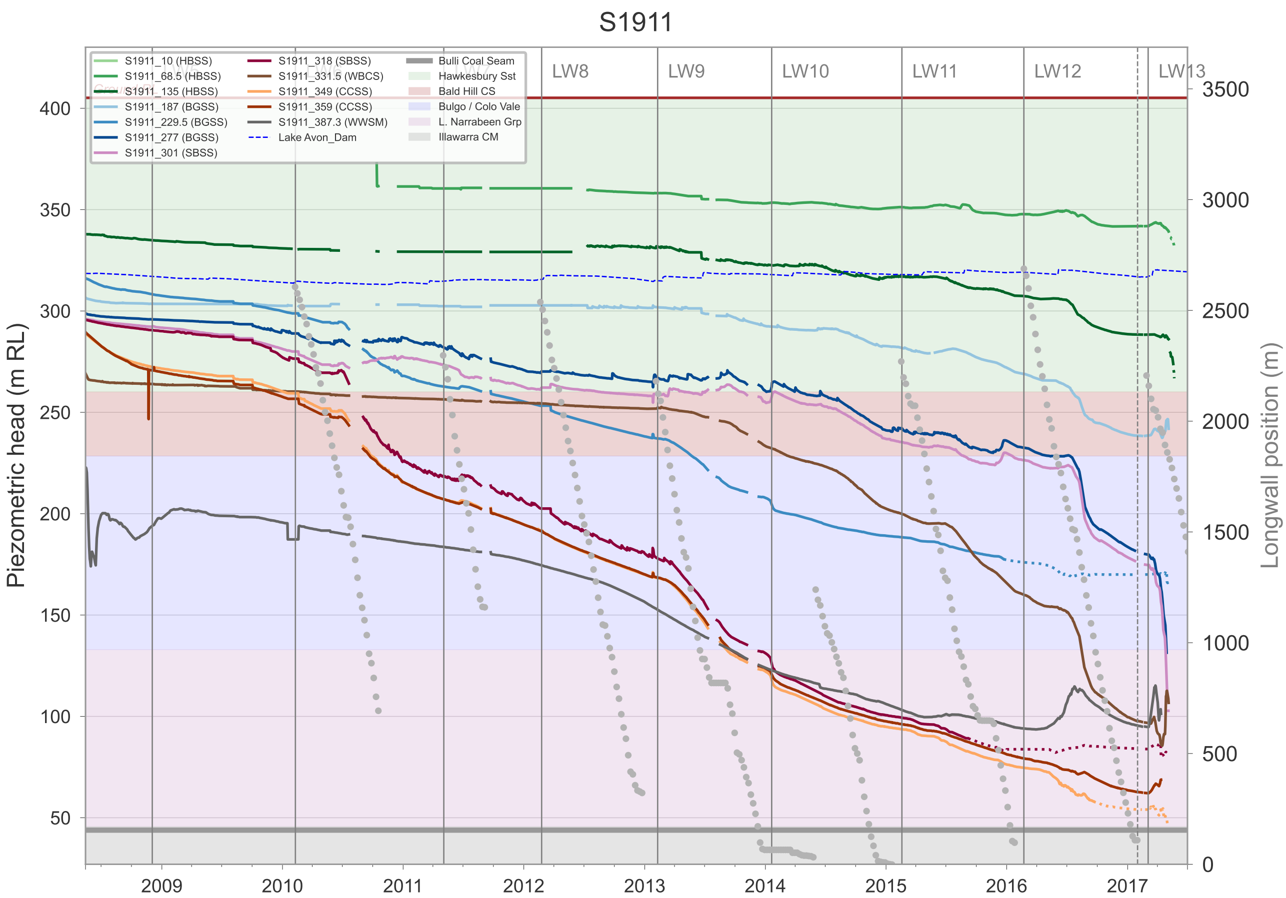


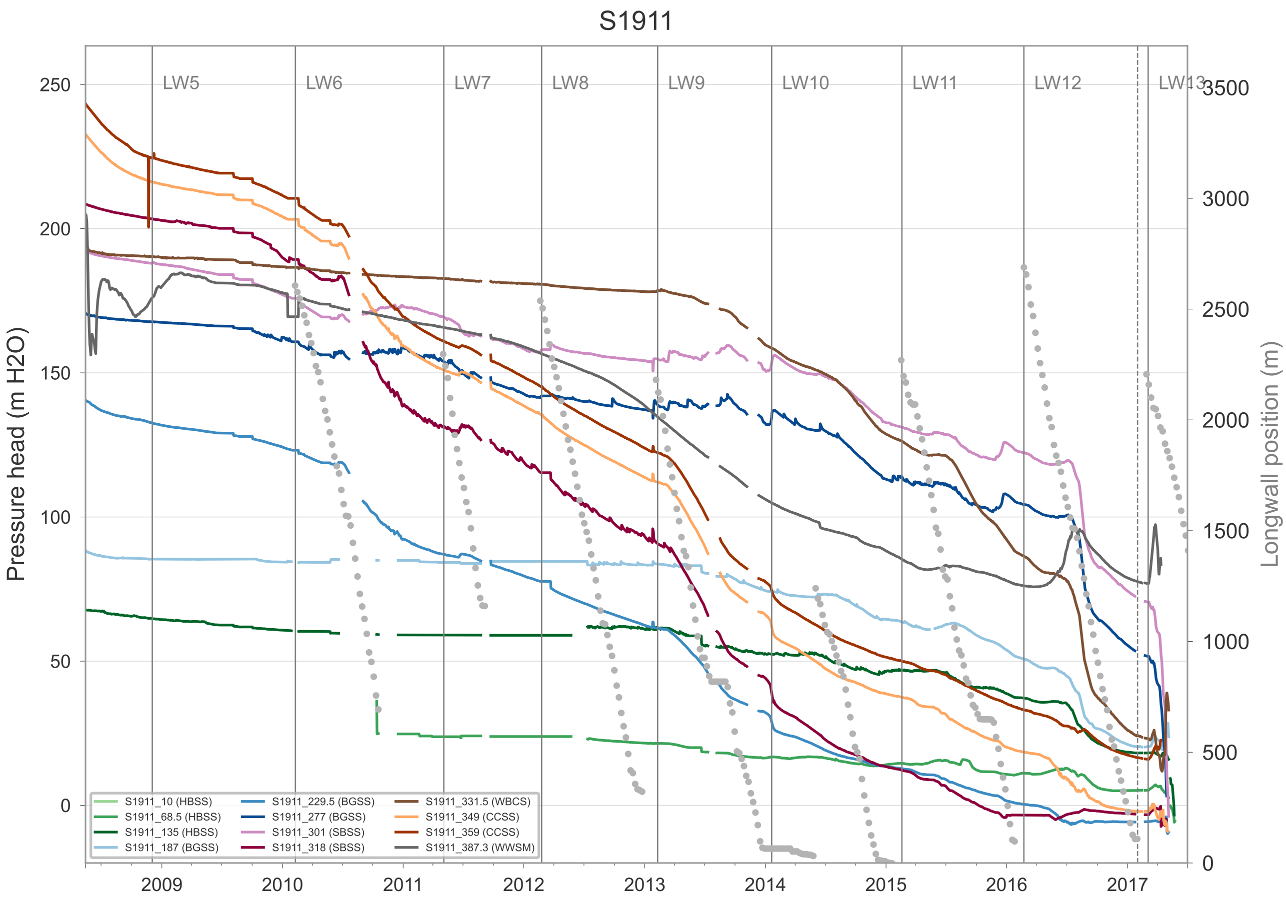
Groundwater hydrographs



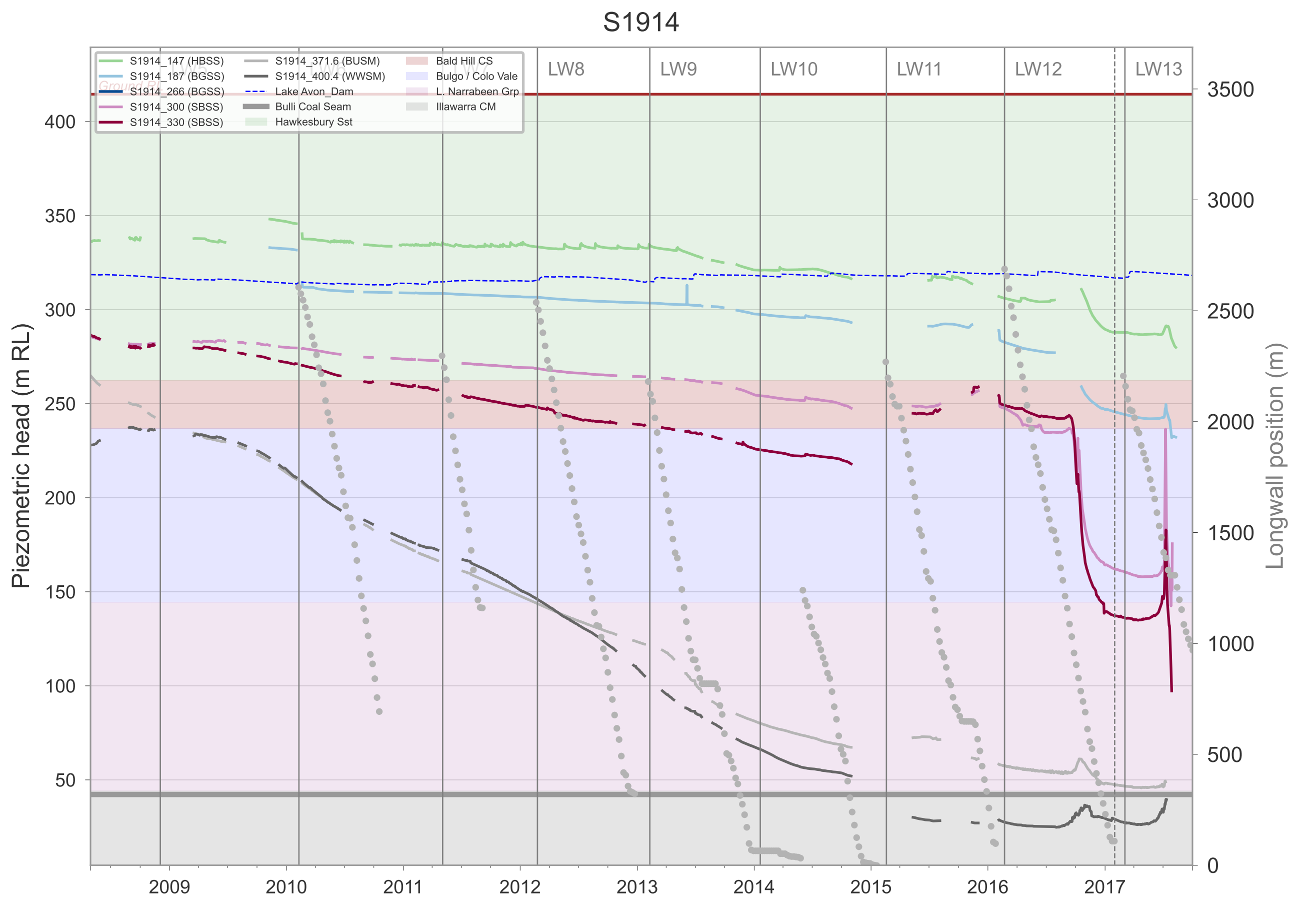


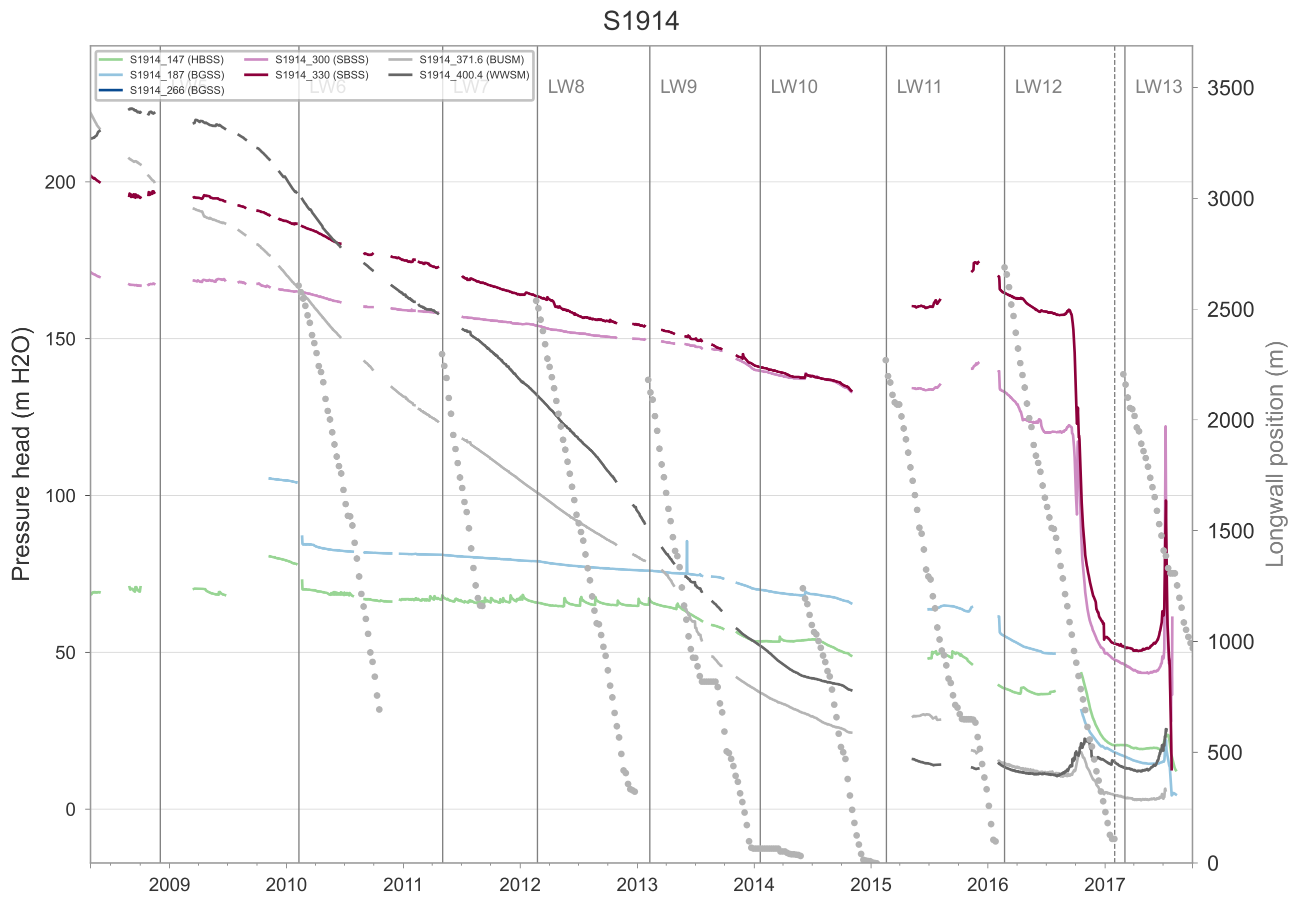
Groundwater hydrographs





Groundwater hydrographs





Groundwater hydrographs

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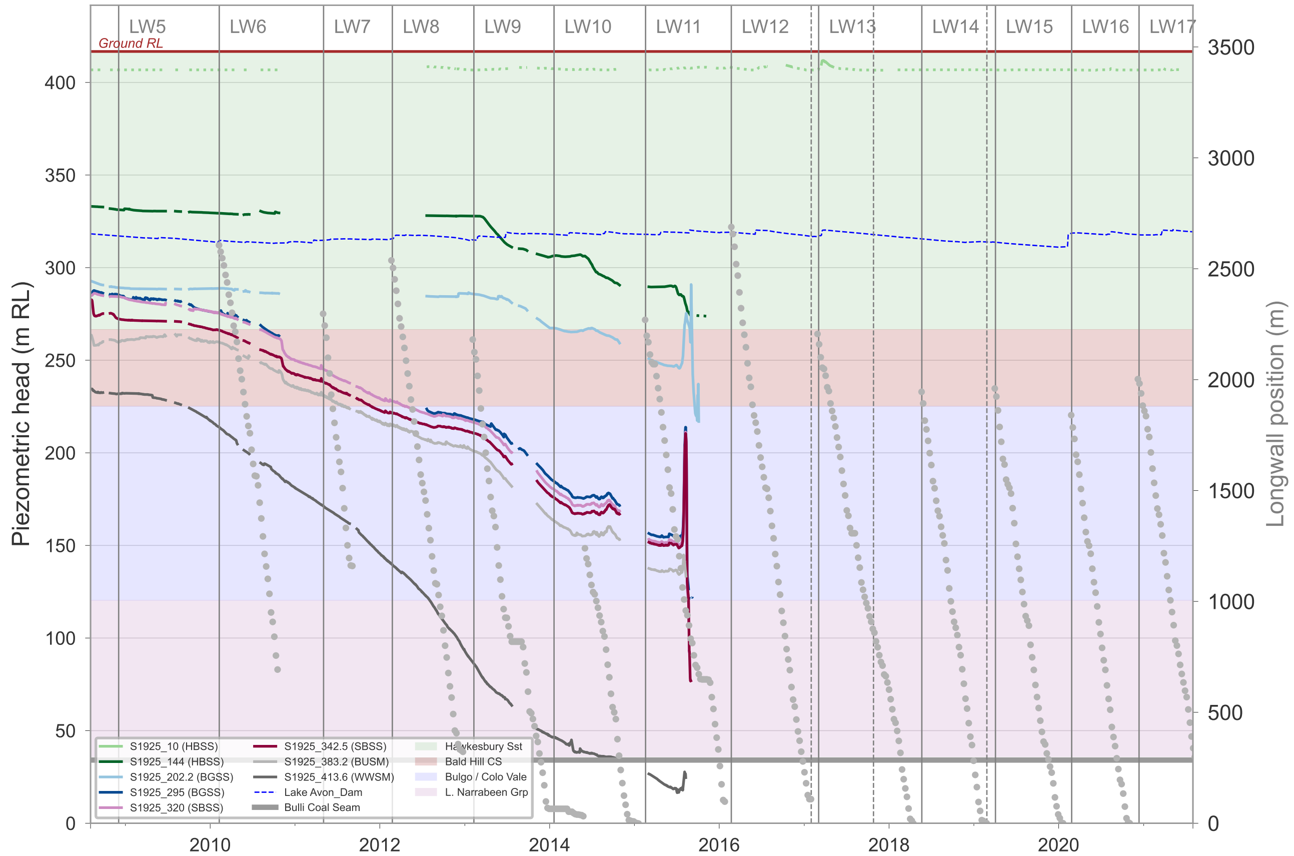

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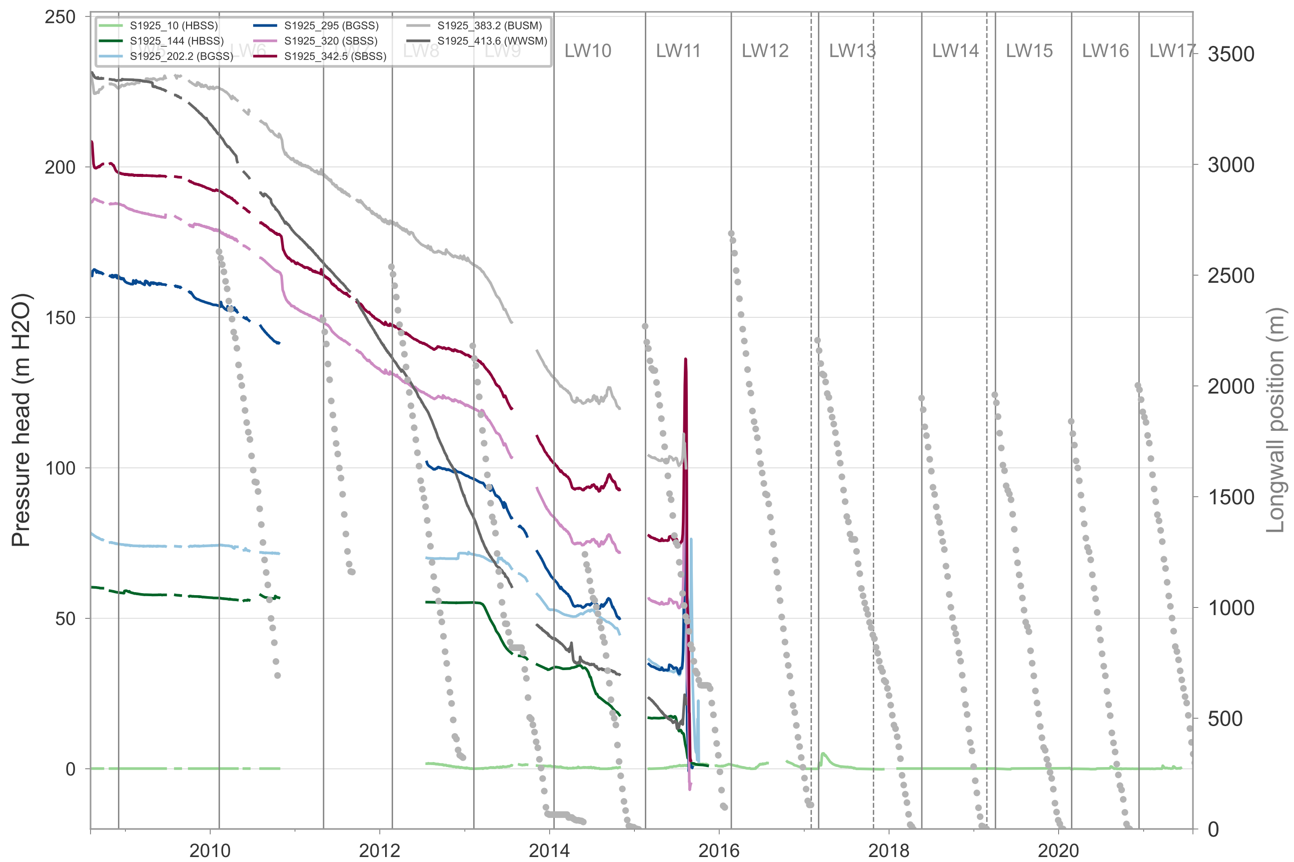
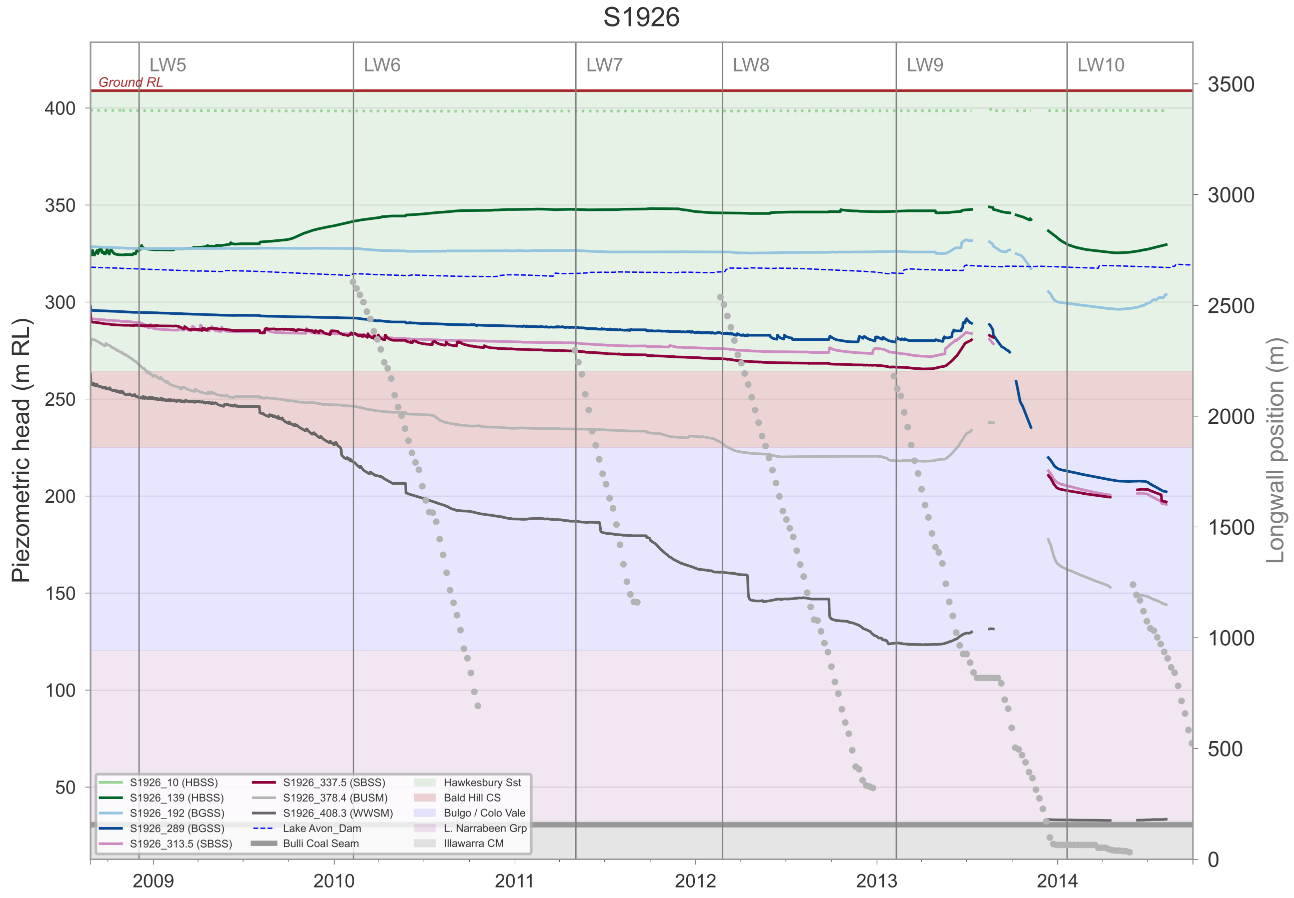
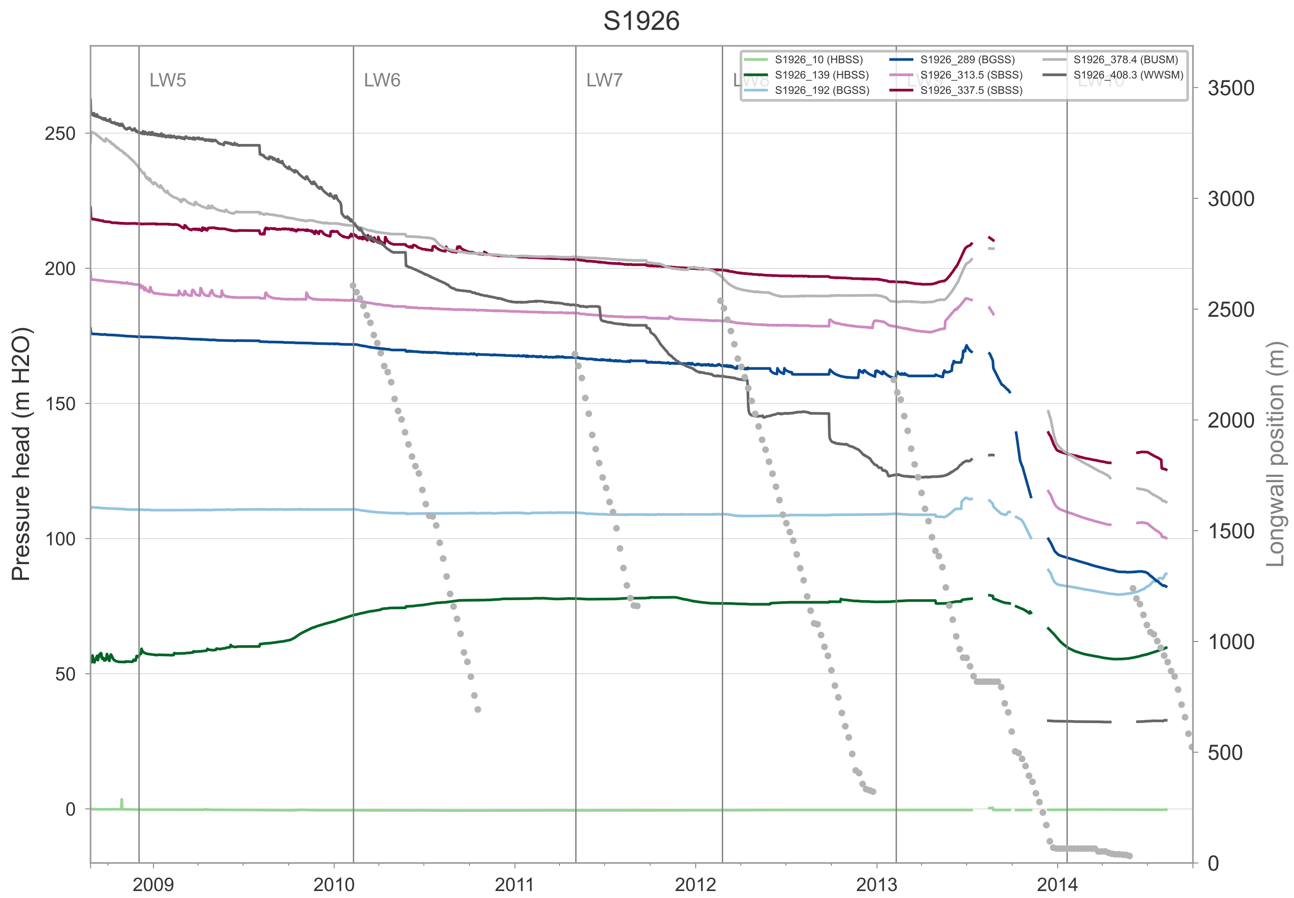


Groundwater hydrographs





Groundwater hydrographs

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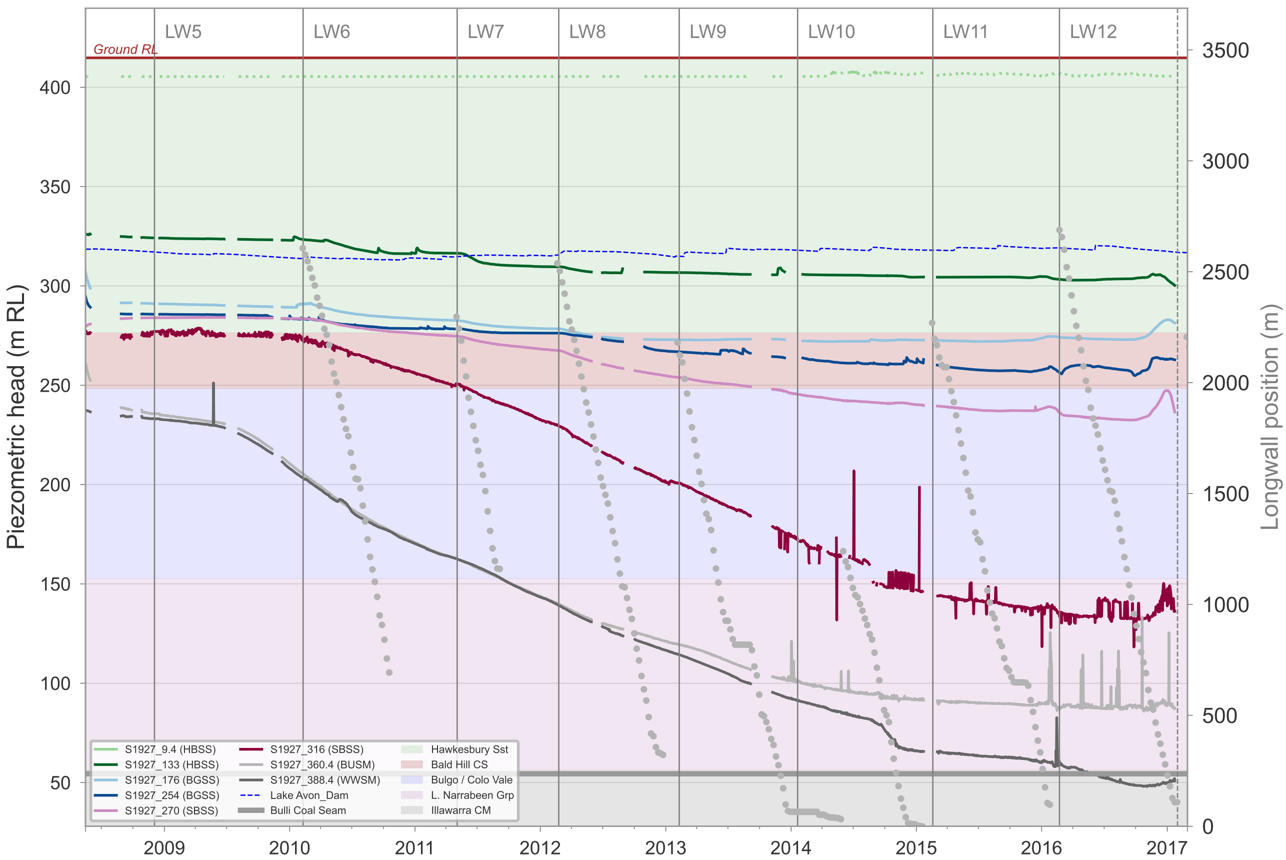

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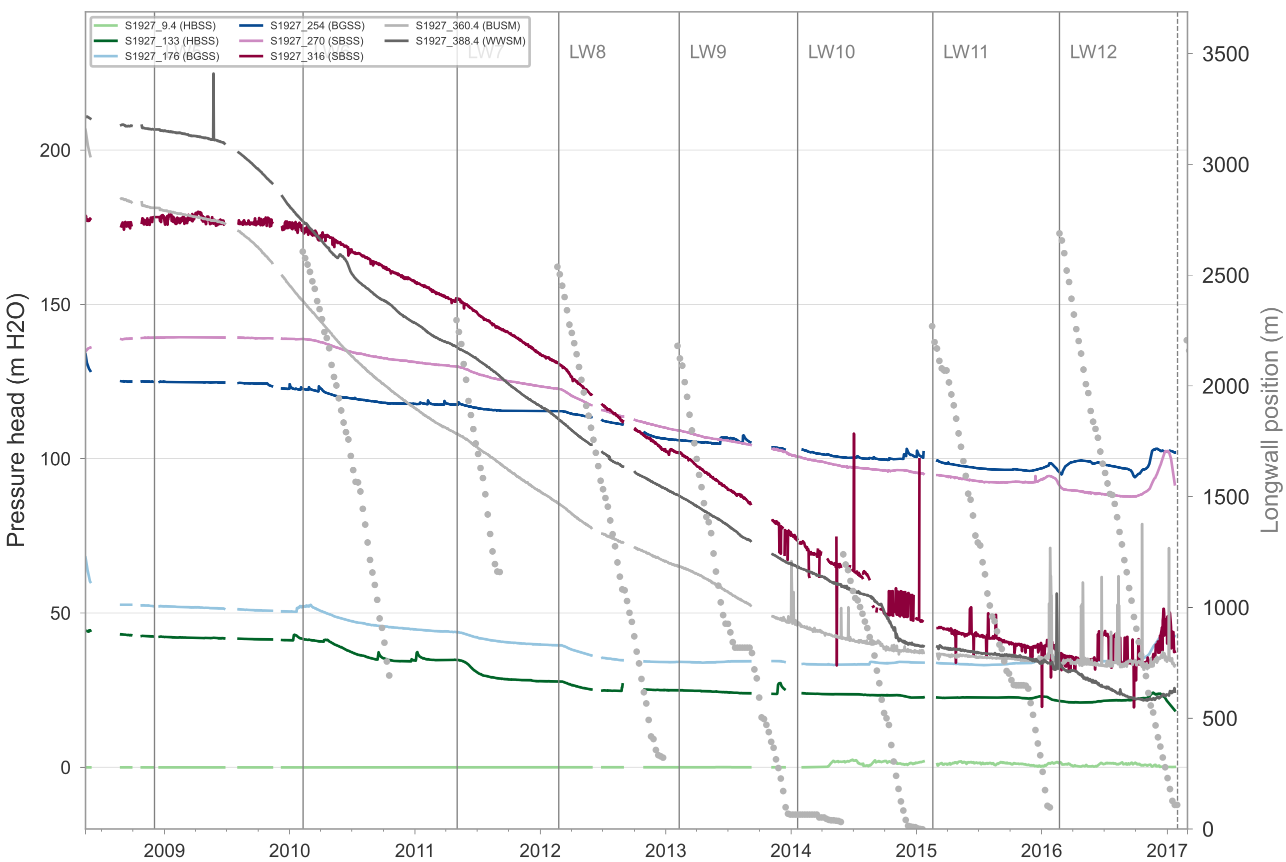
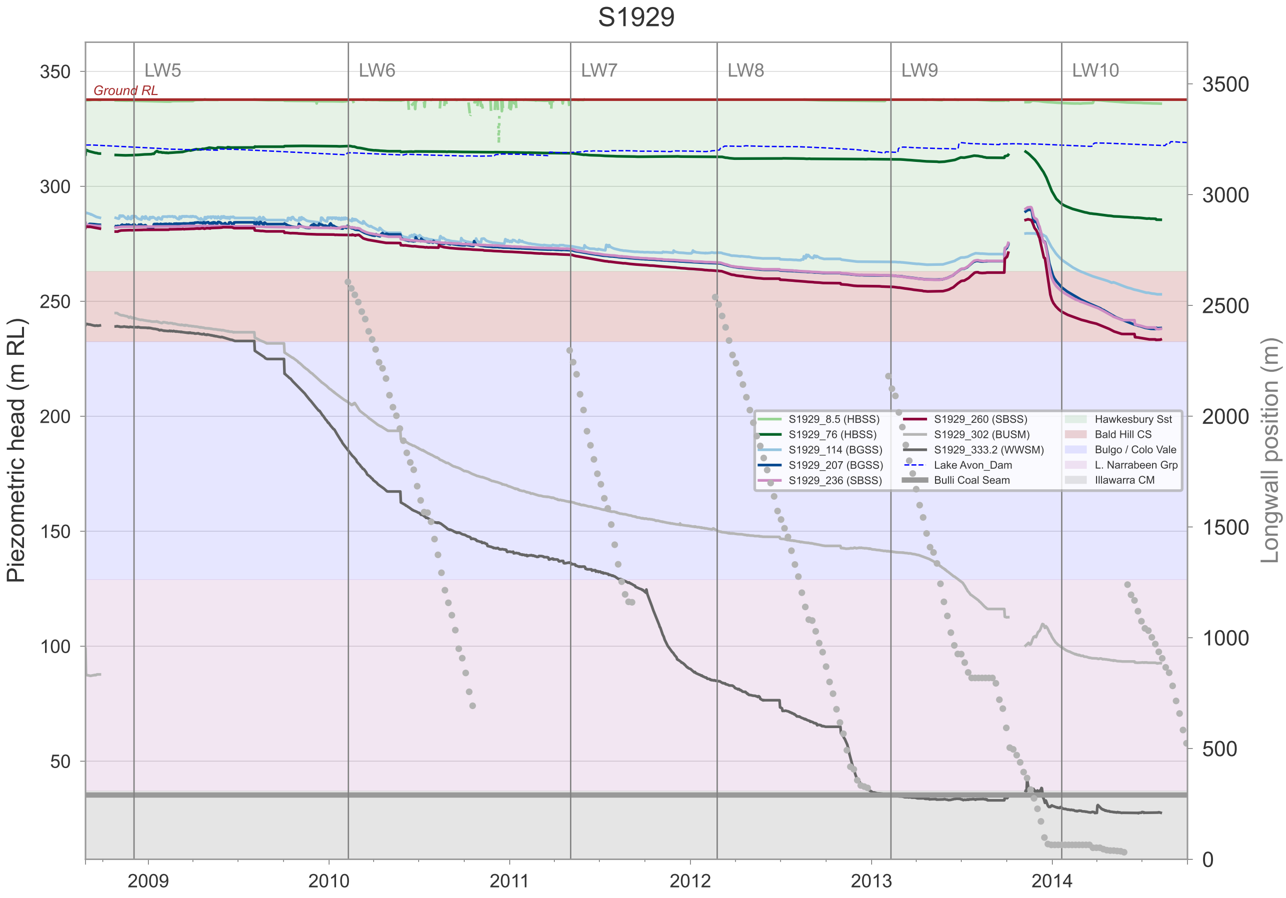
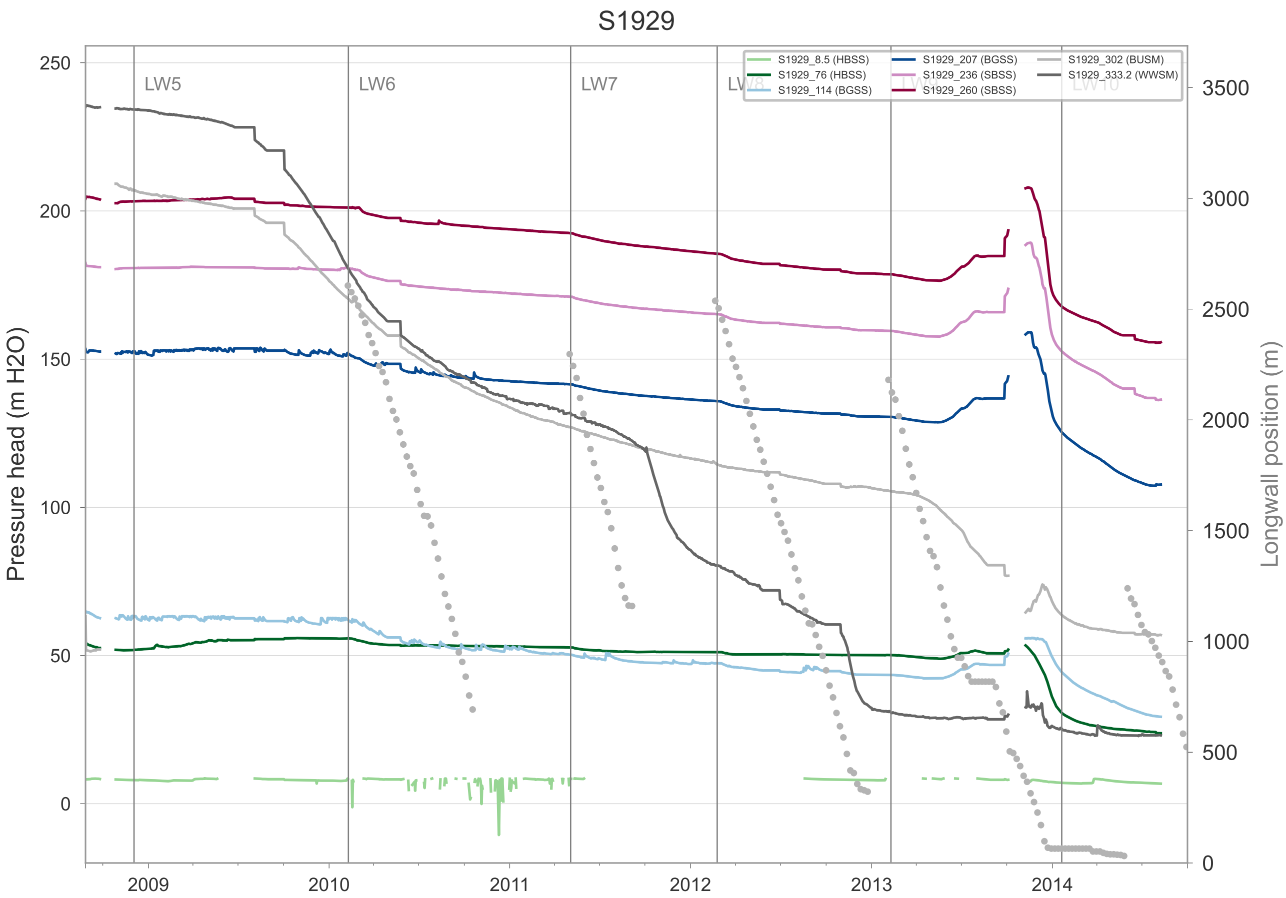


Groundwater hydrographs





Groundwater hydrographs

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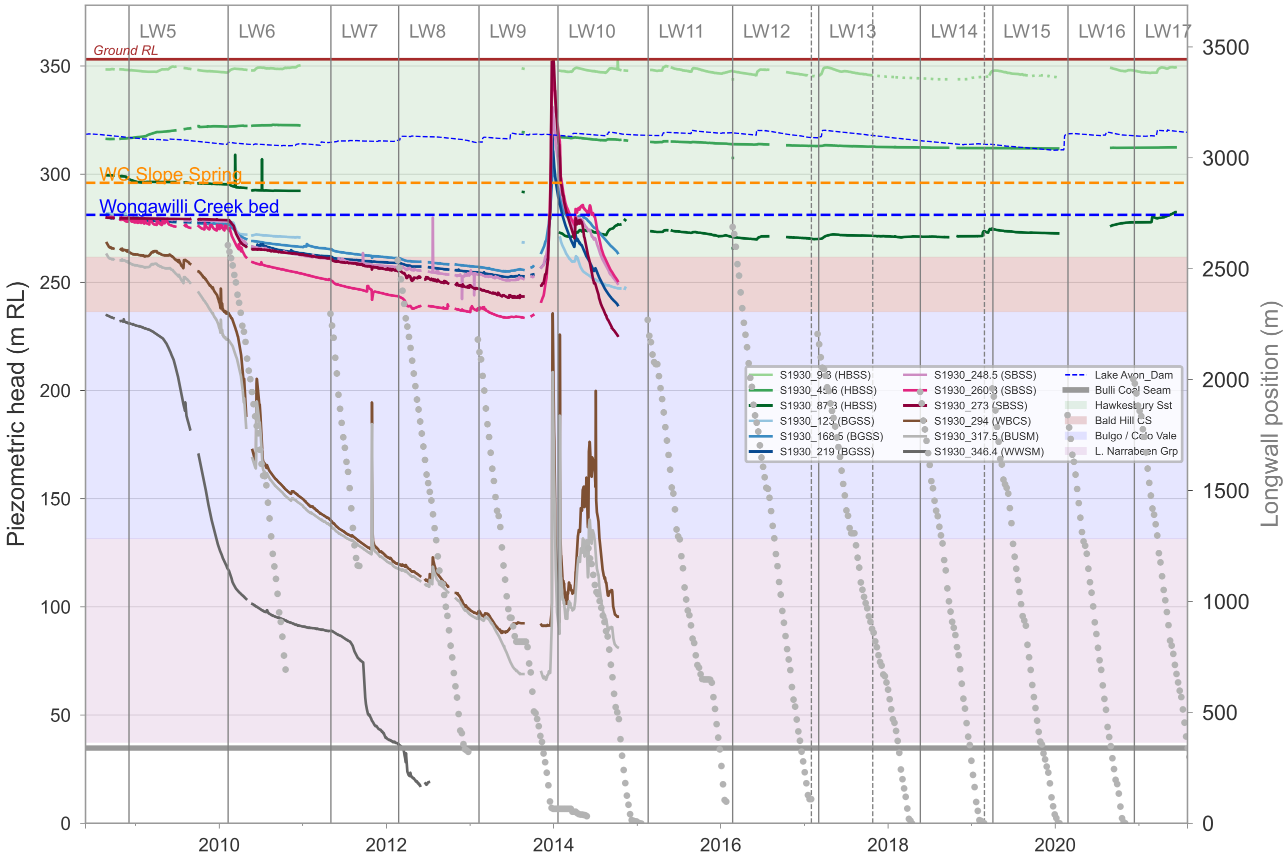

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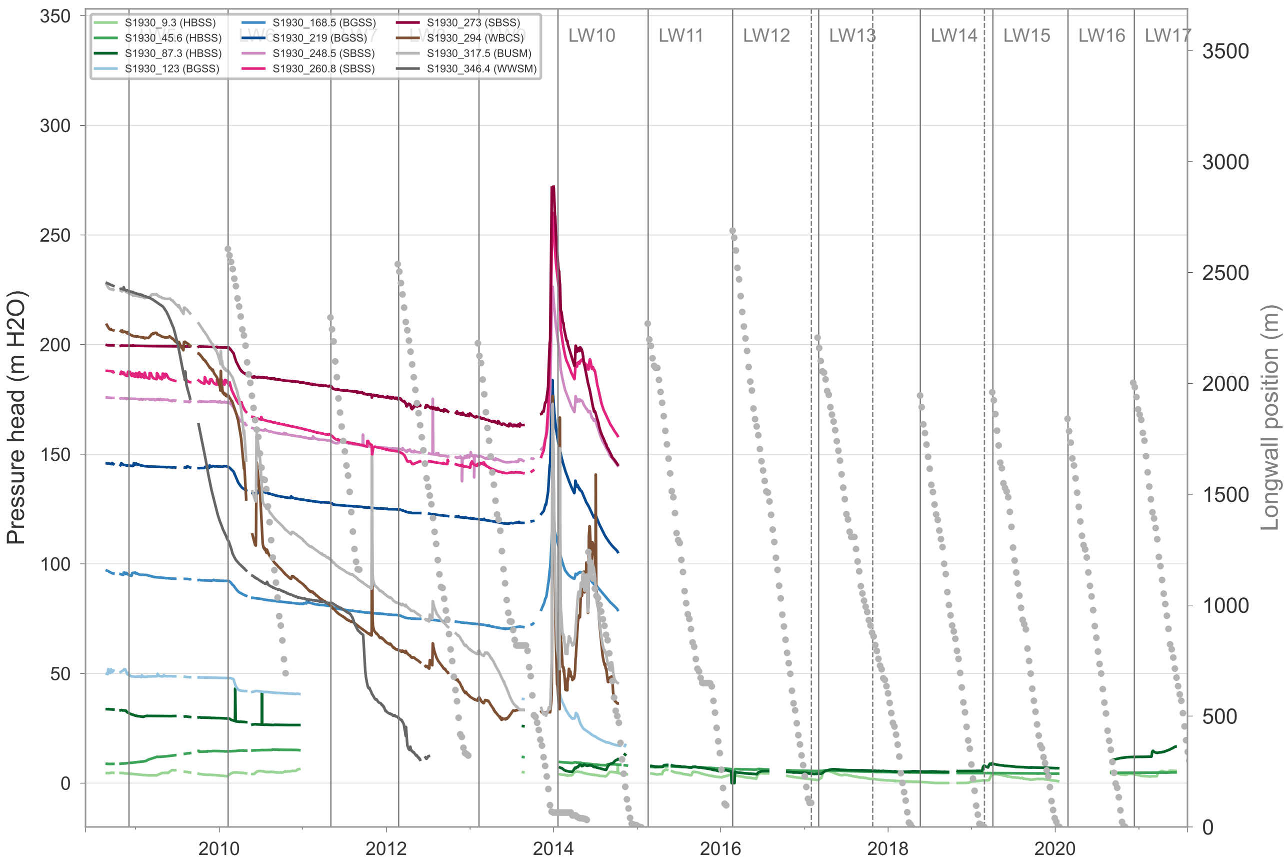

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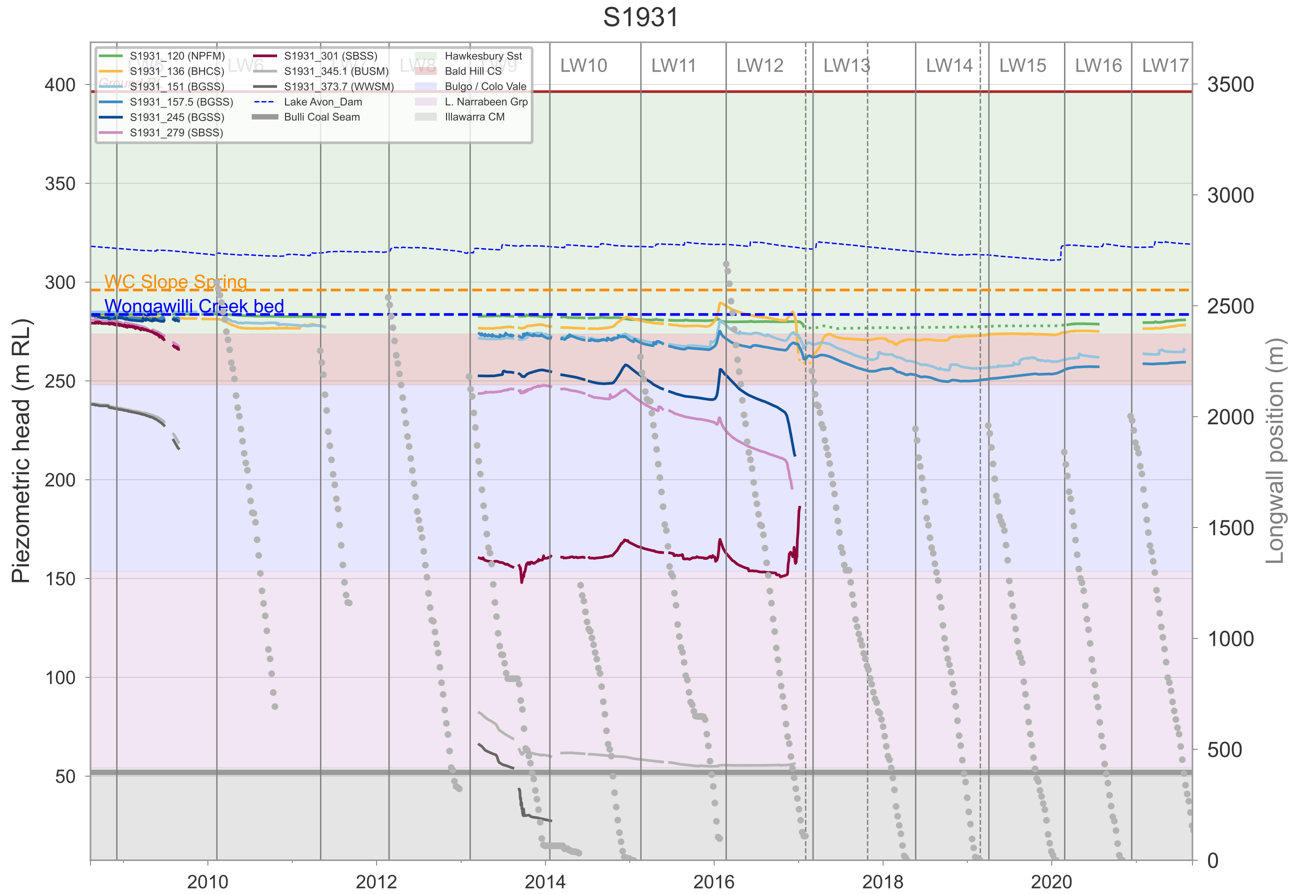

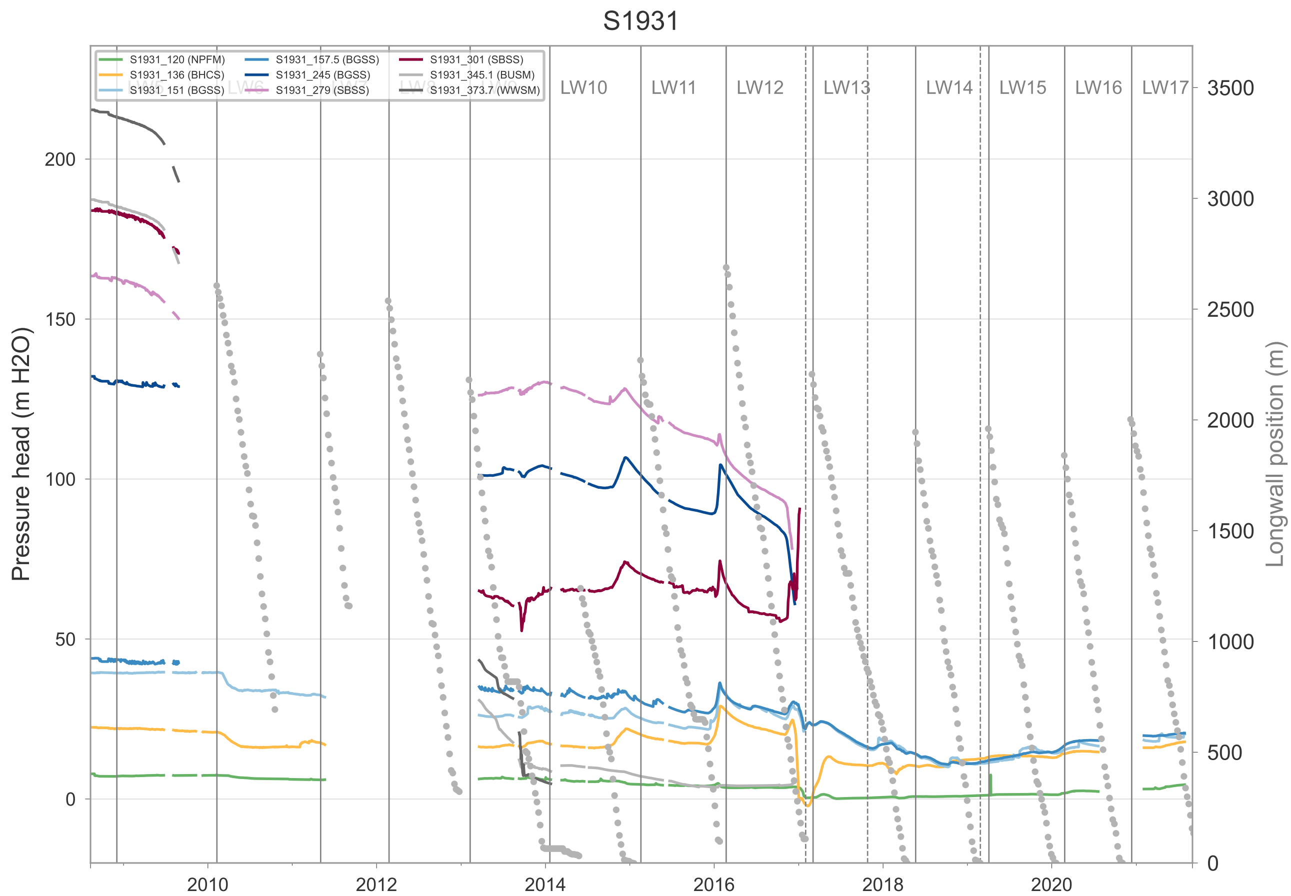

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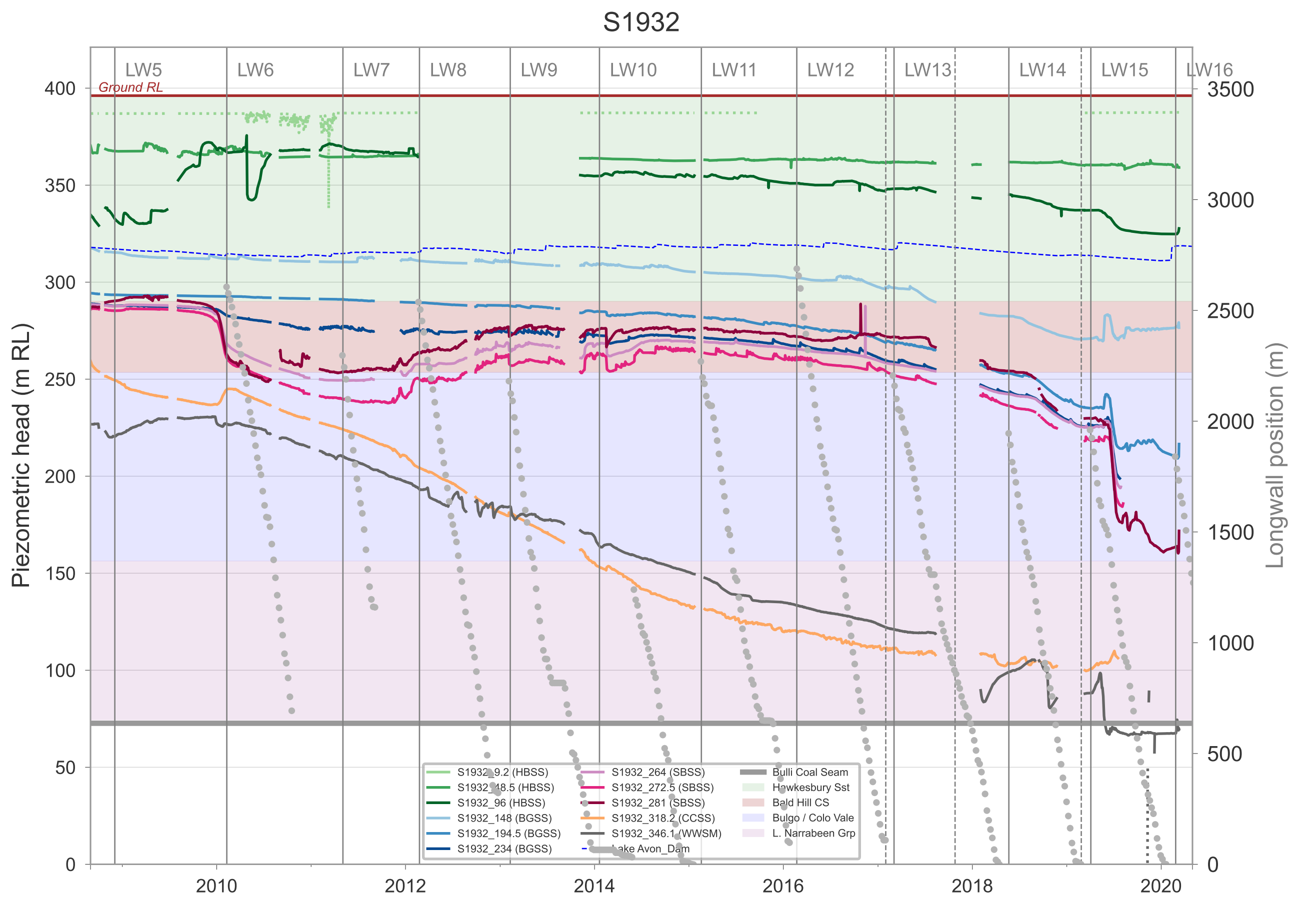

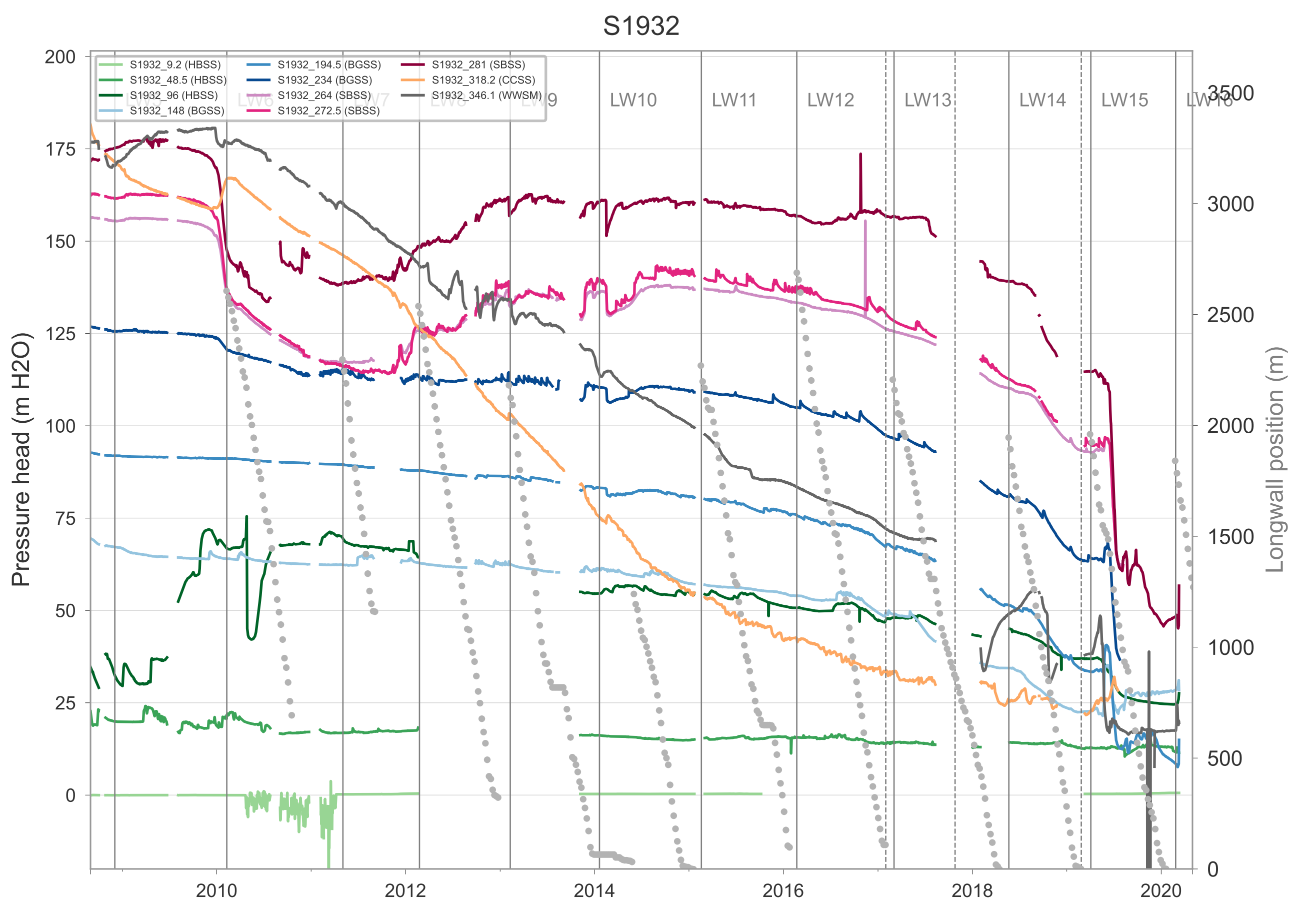

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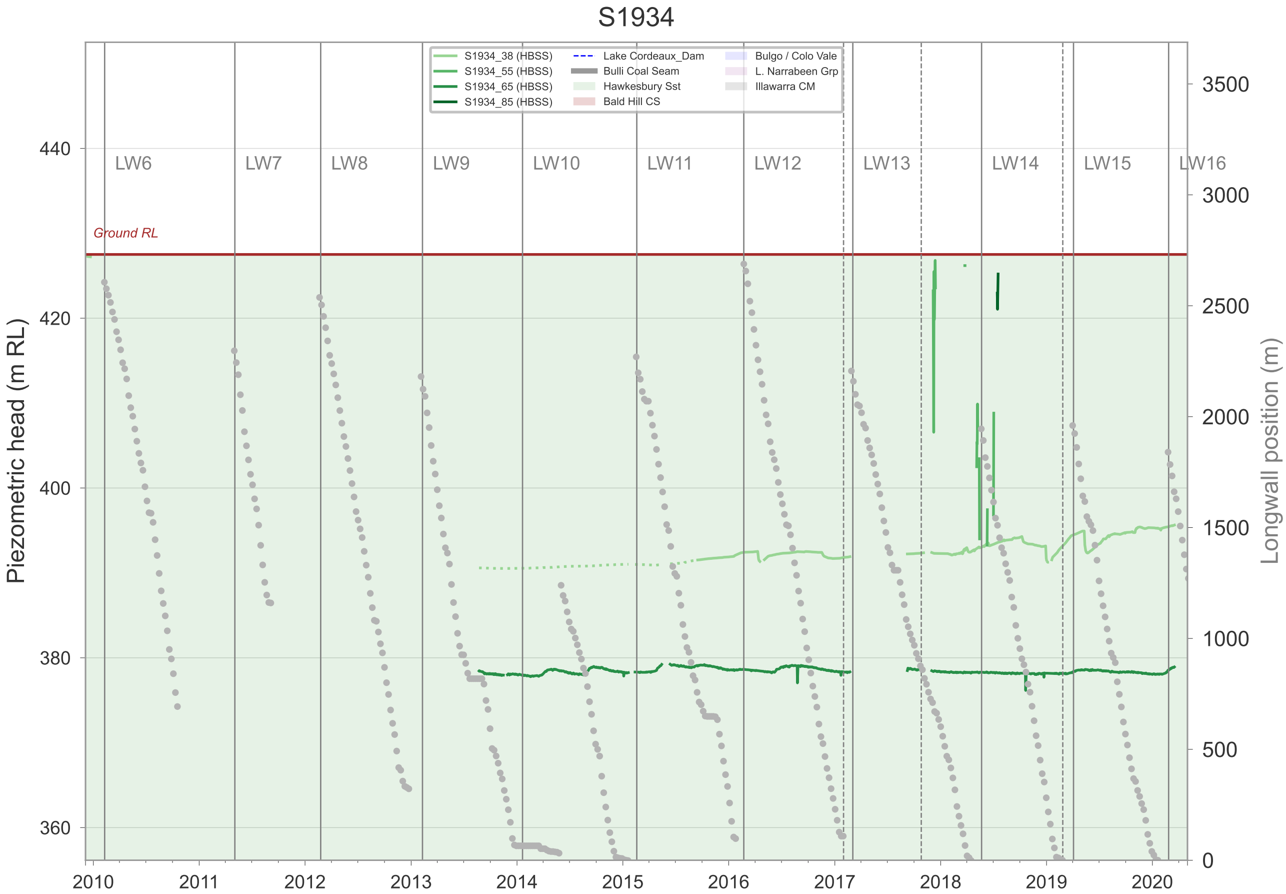
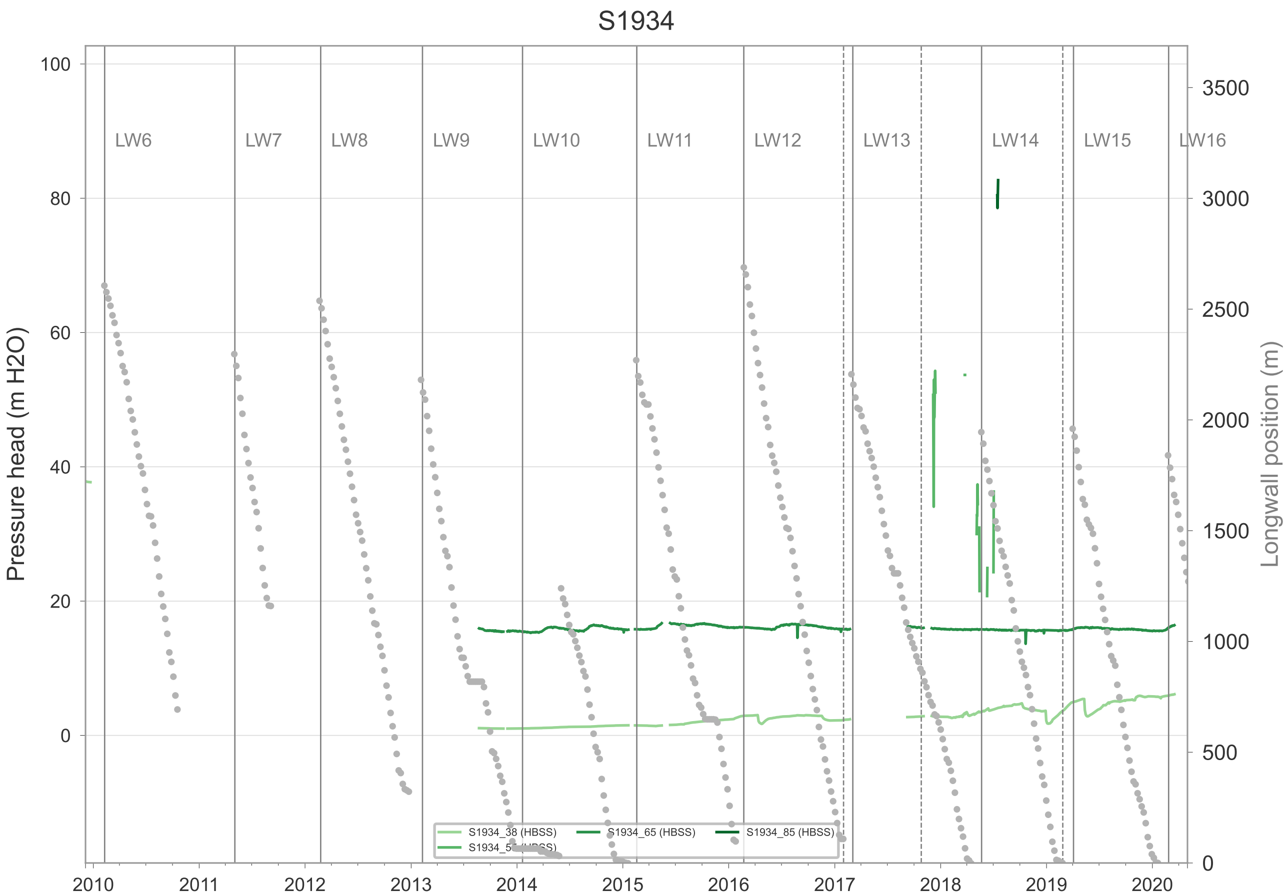
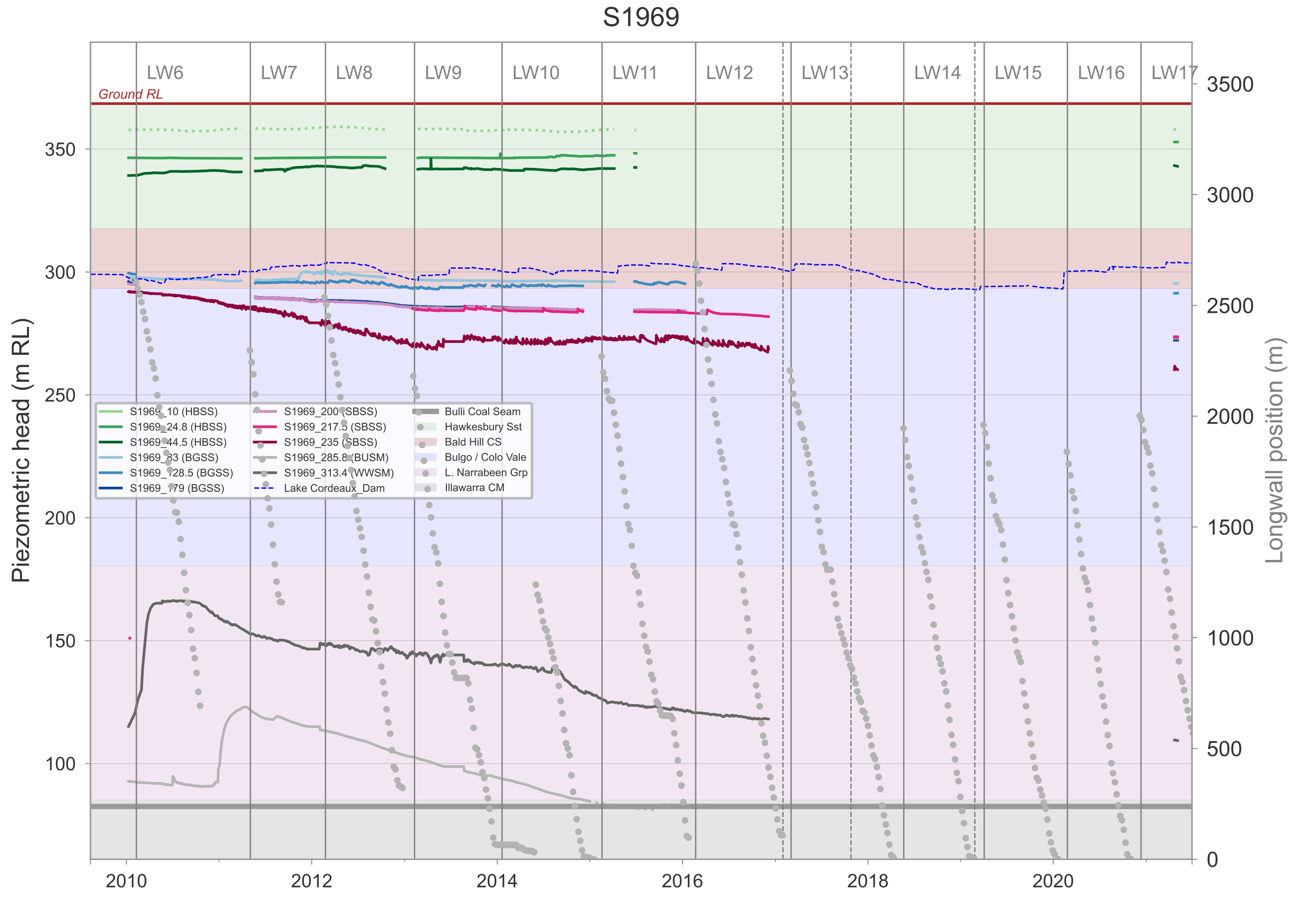
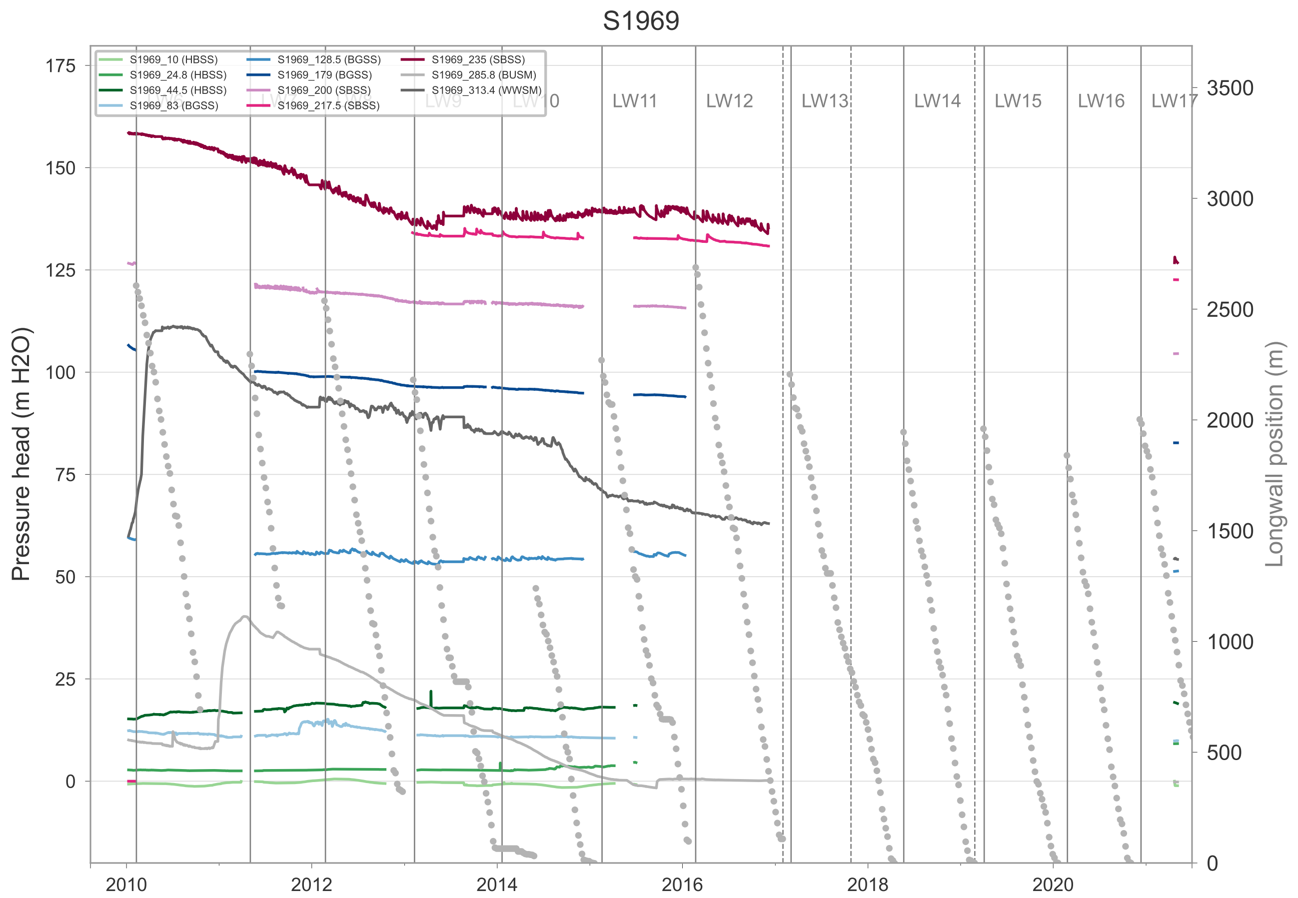




Groundwater hydrographs





Groundwater hydrographs

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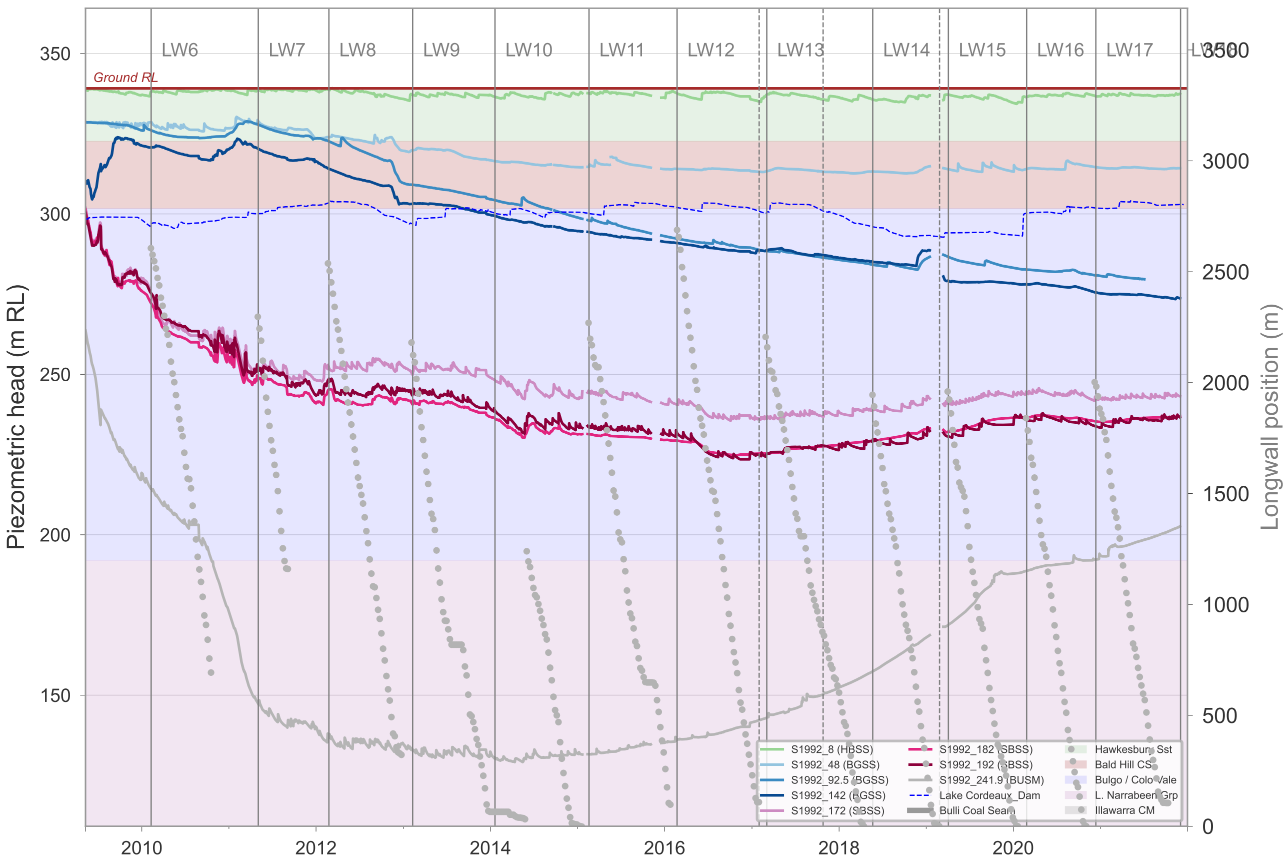

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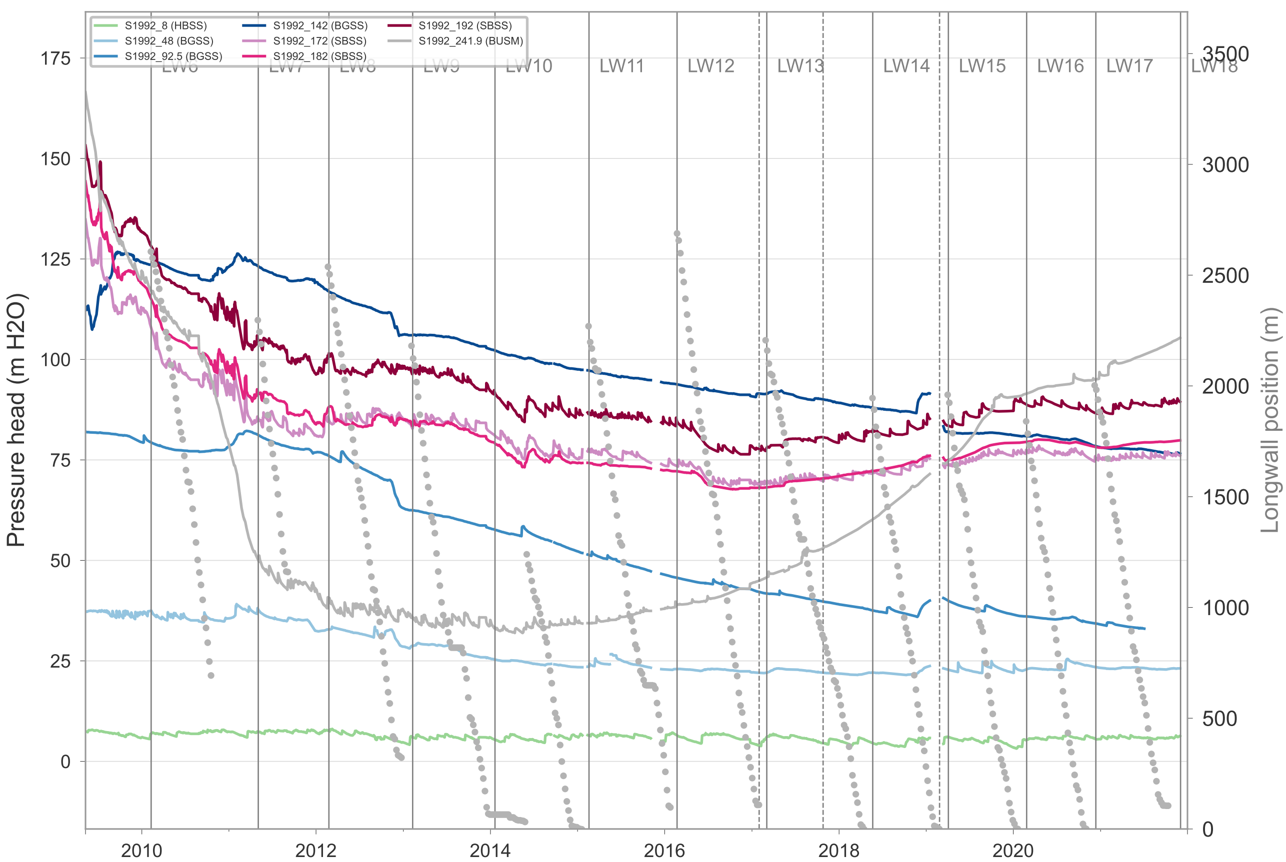
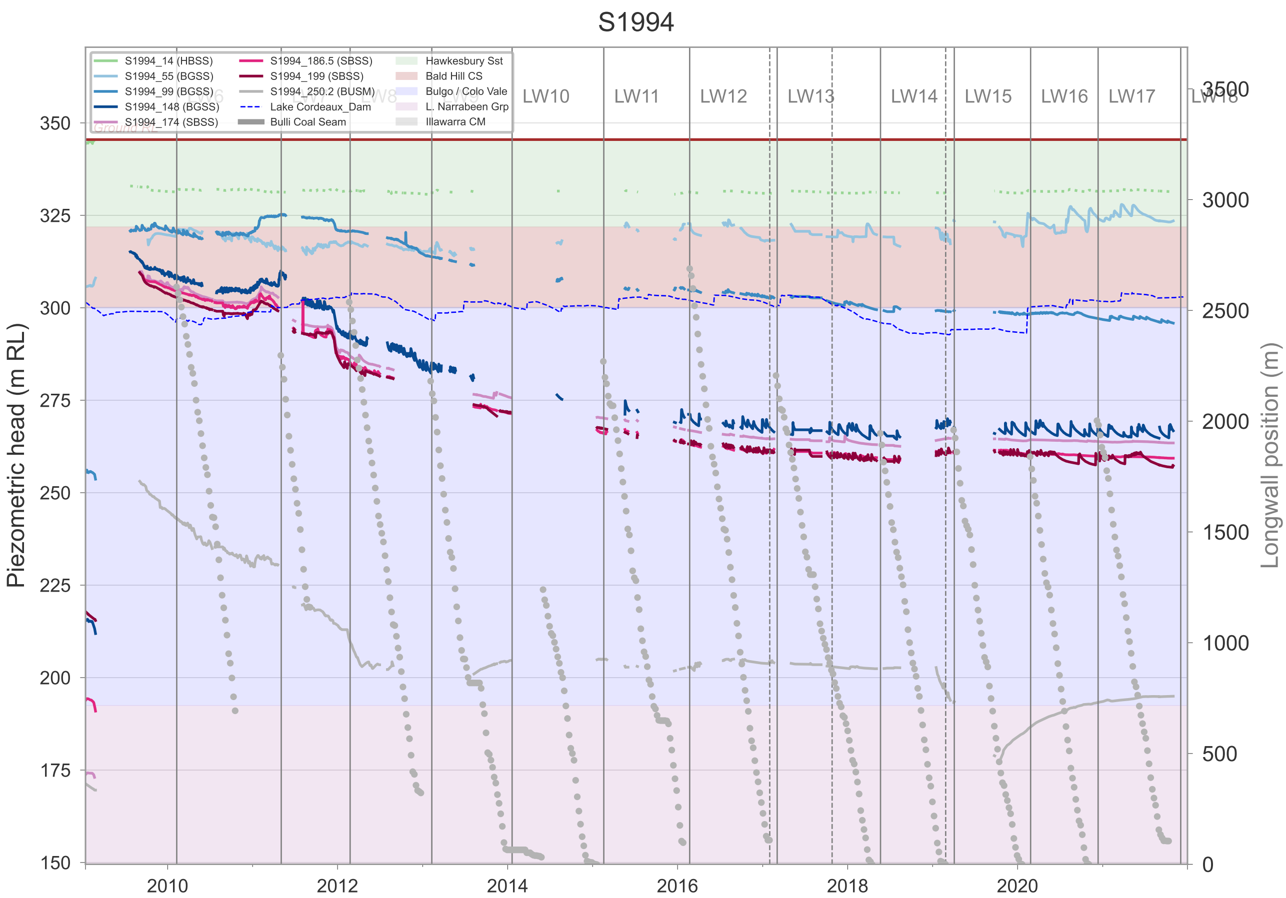
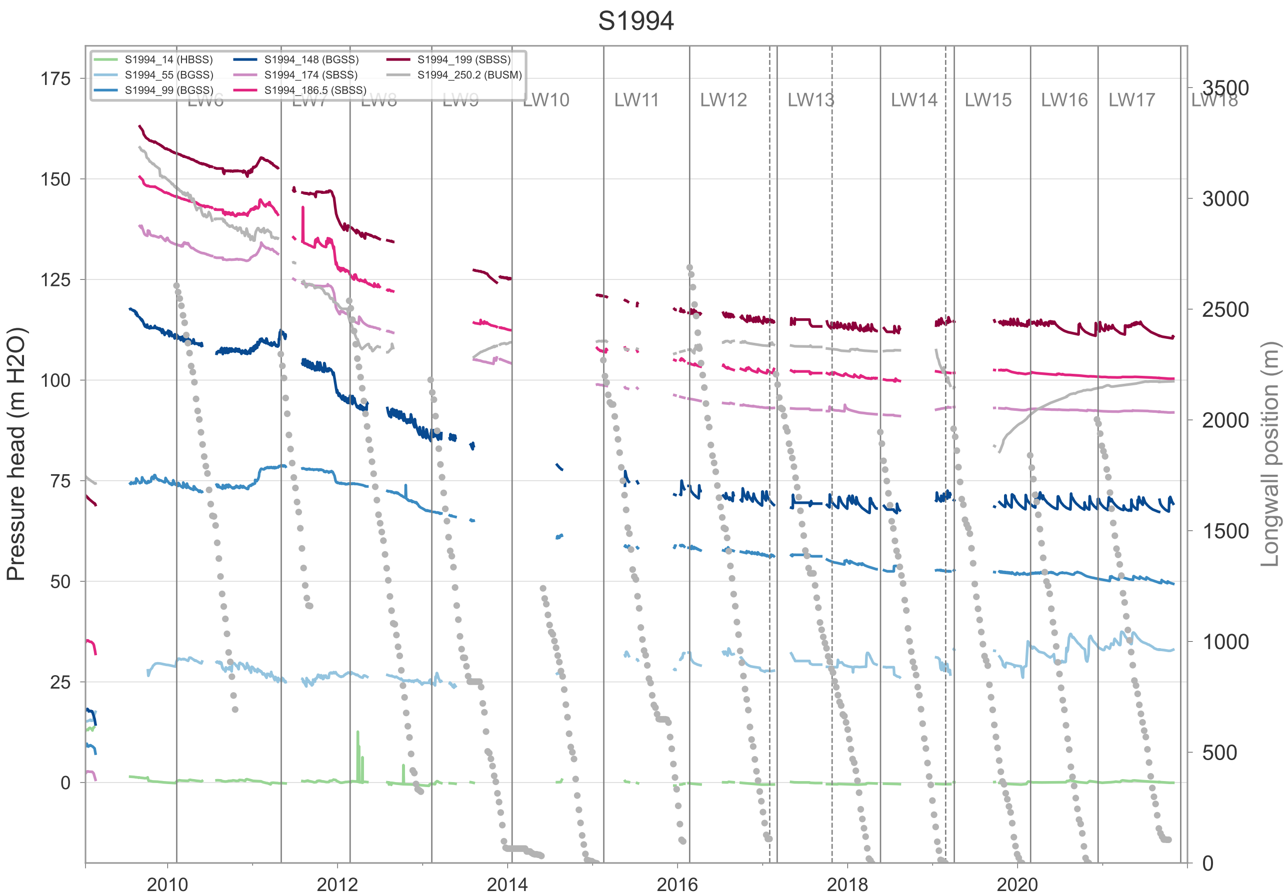


Groundwater hydrographs





Groundwater hydrographs

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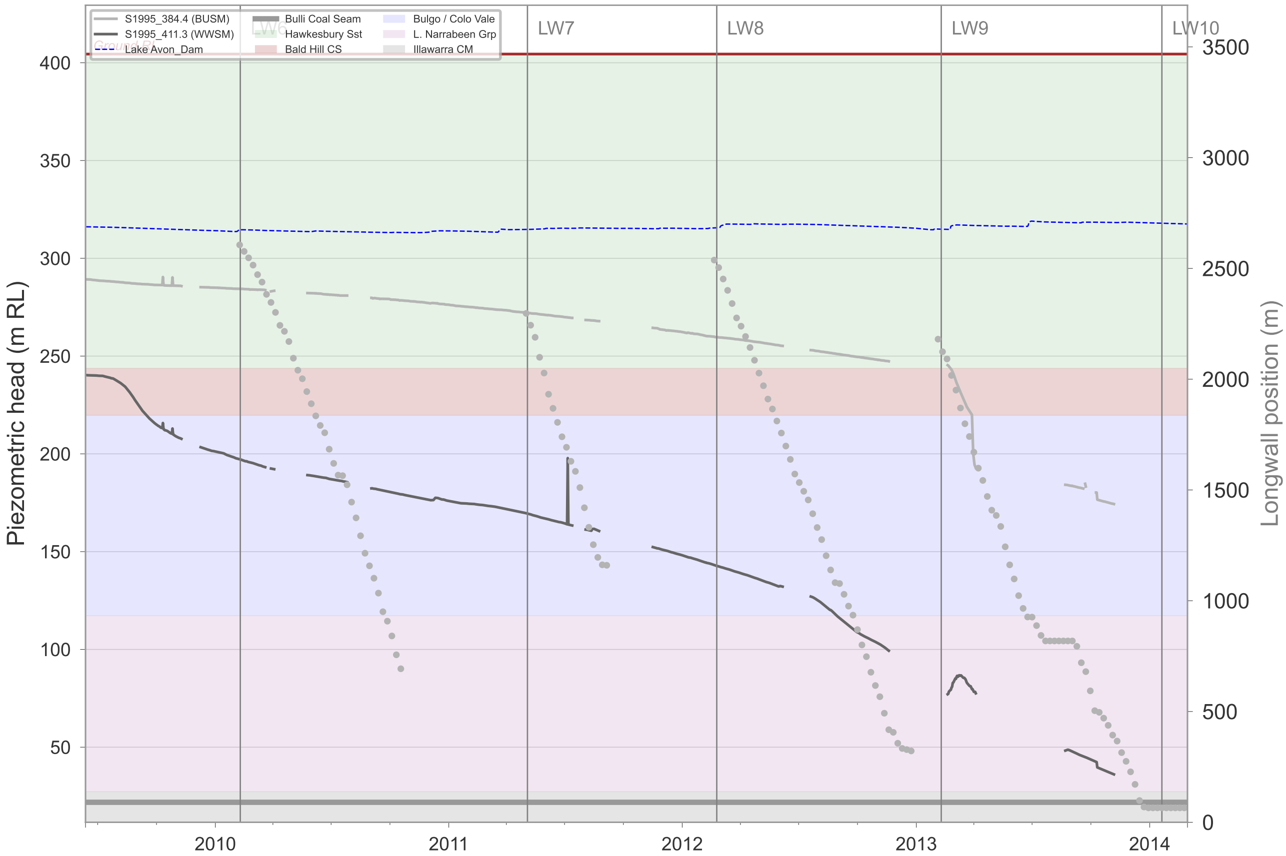

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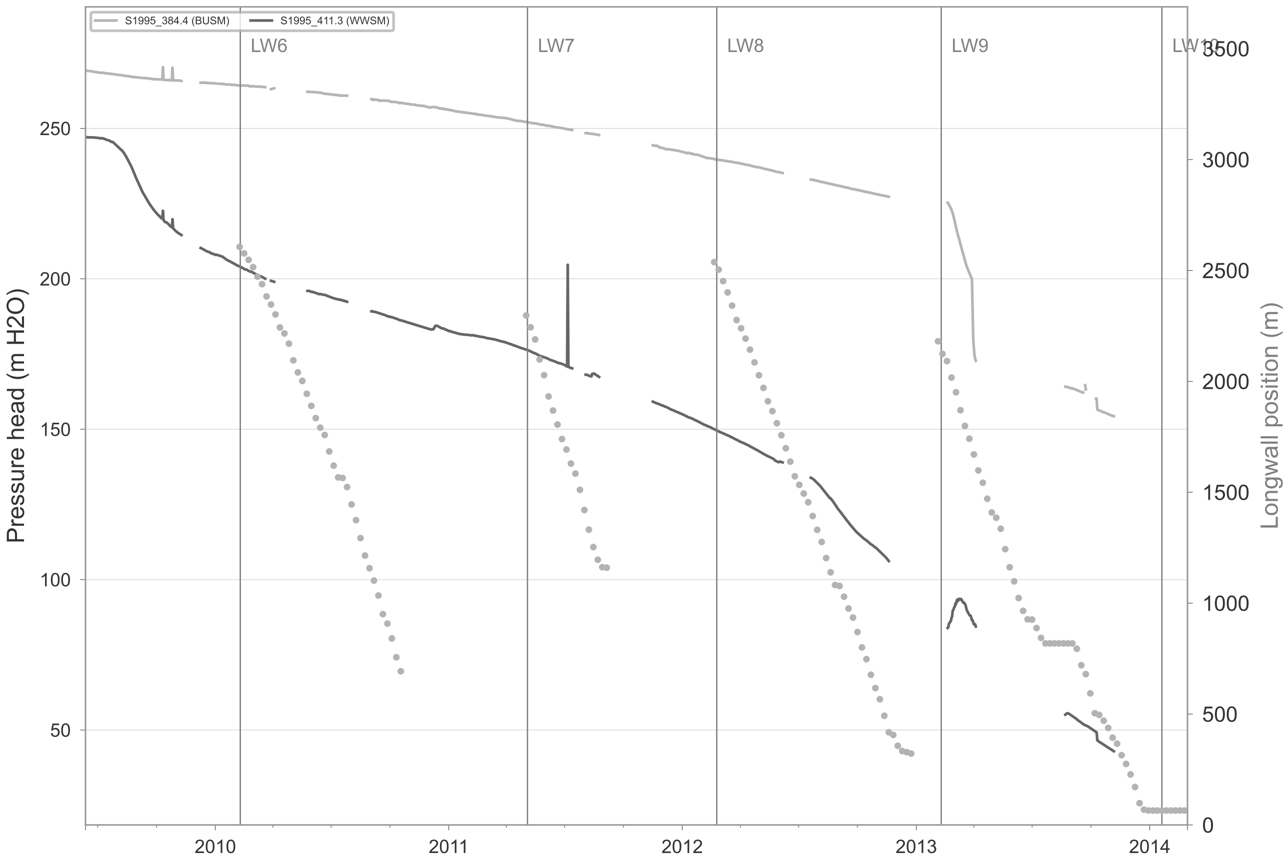
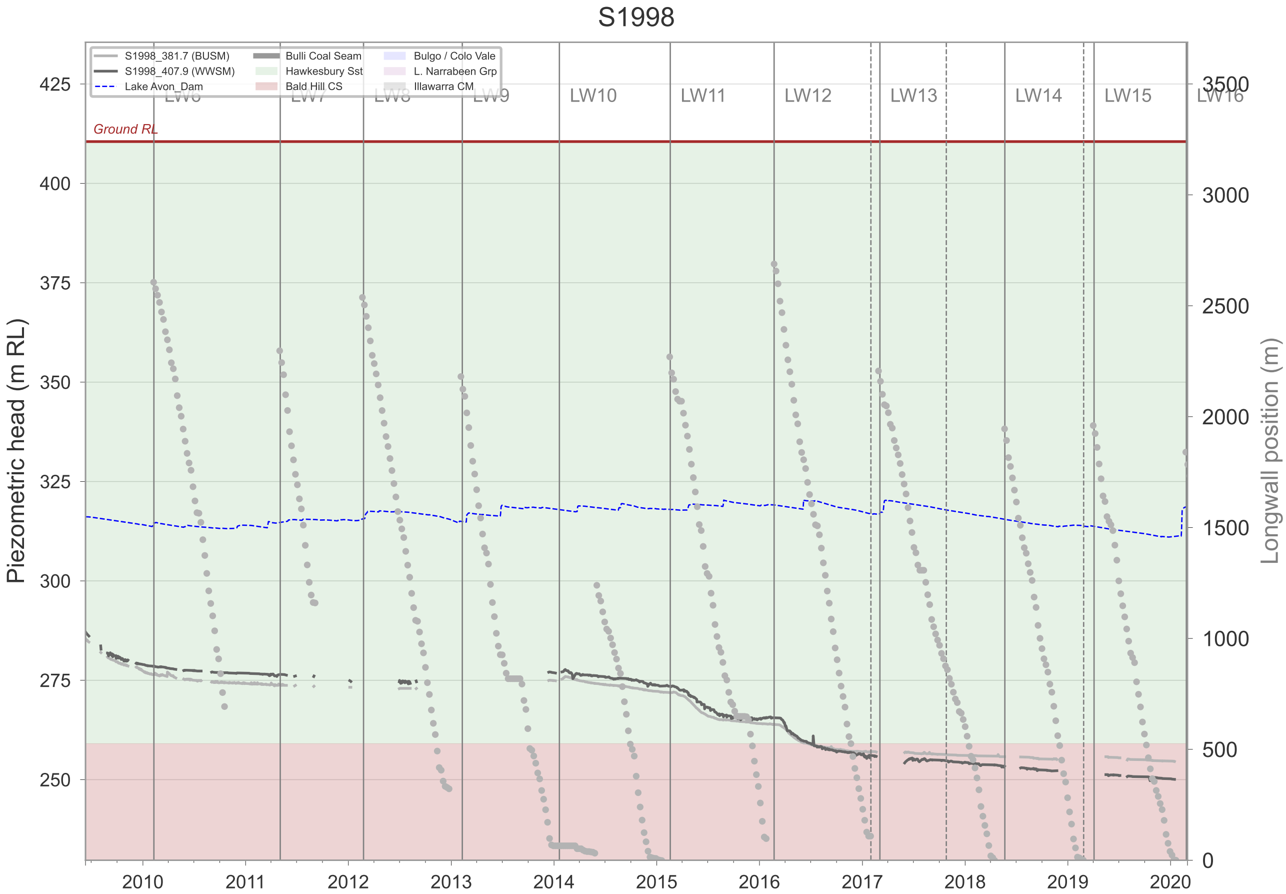
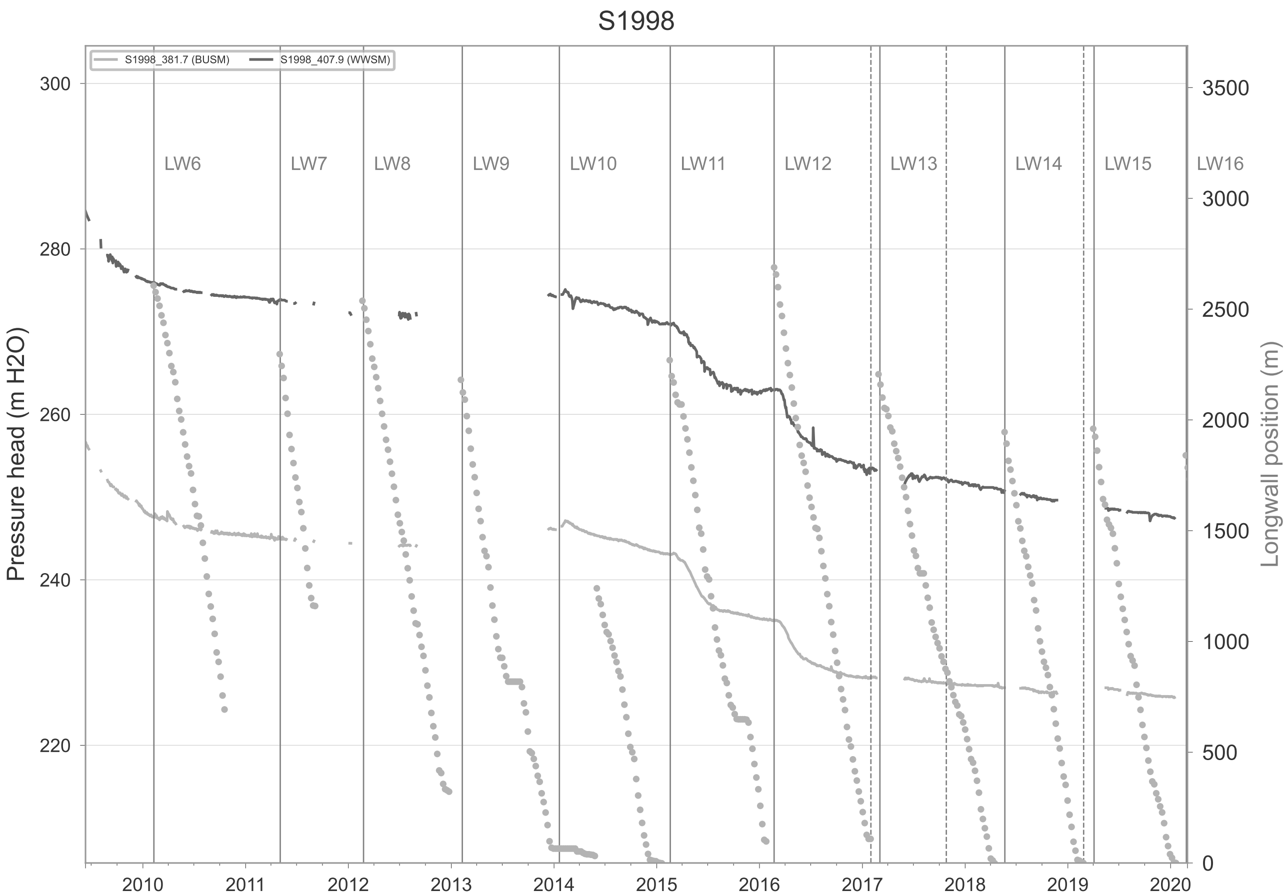


Groundwater hydrographs





Groundwater hydrographs

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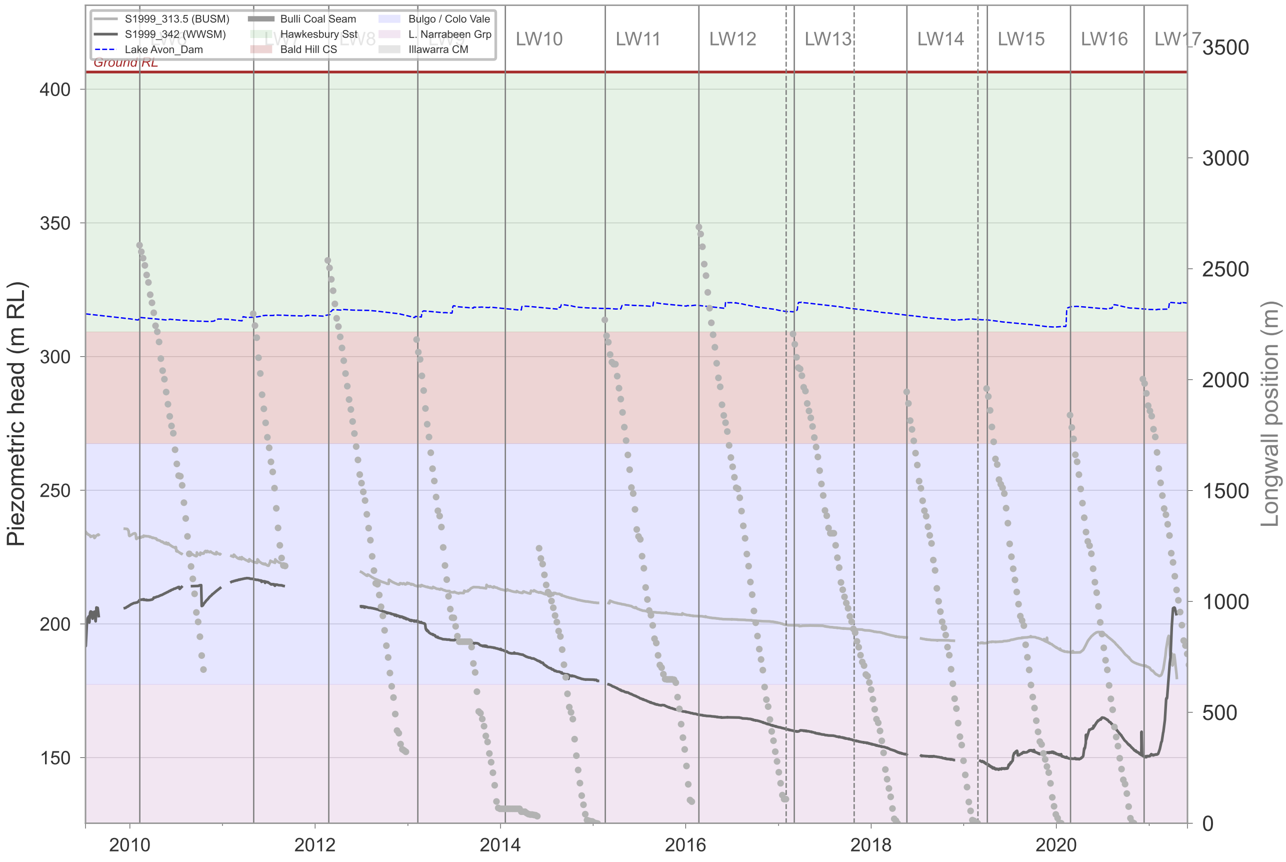

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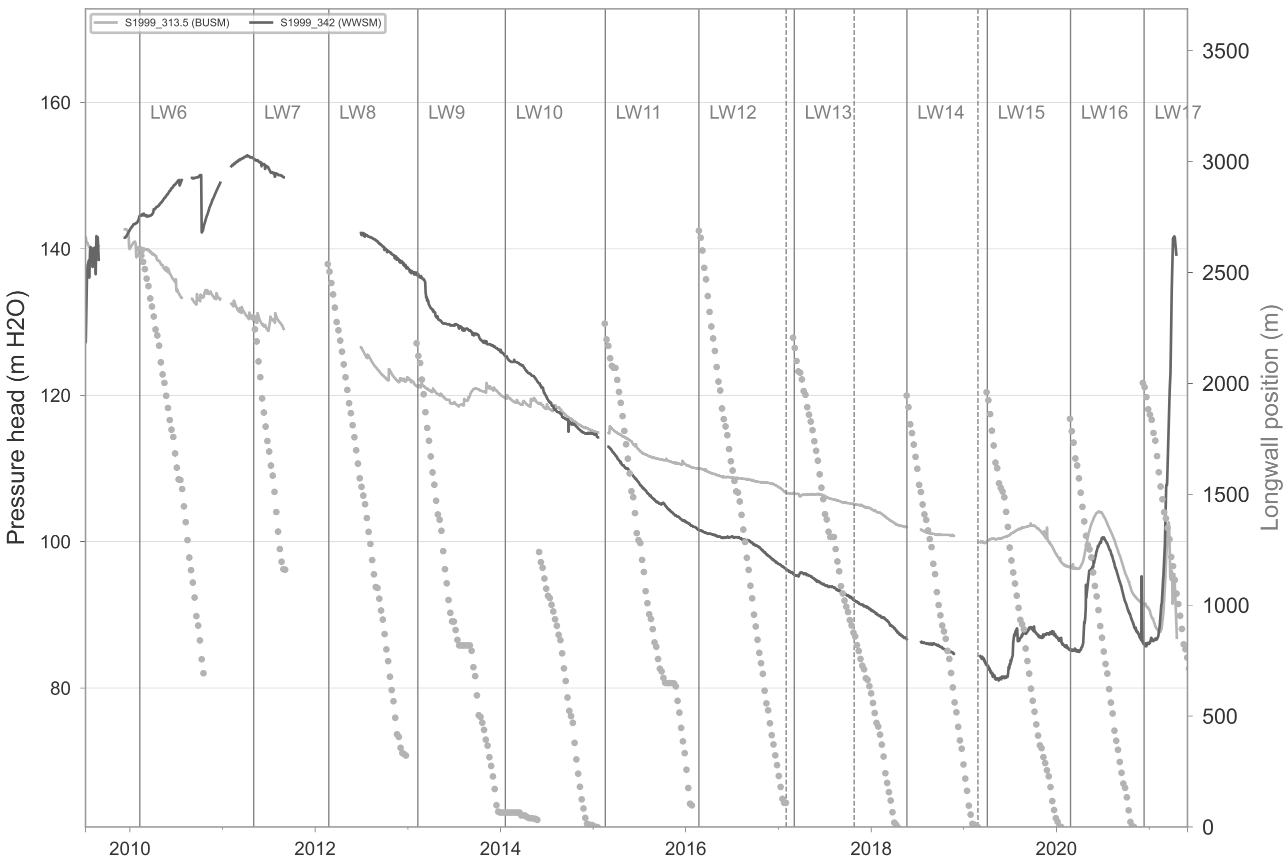
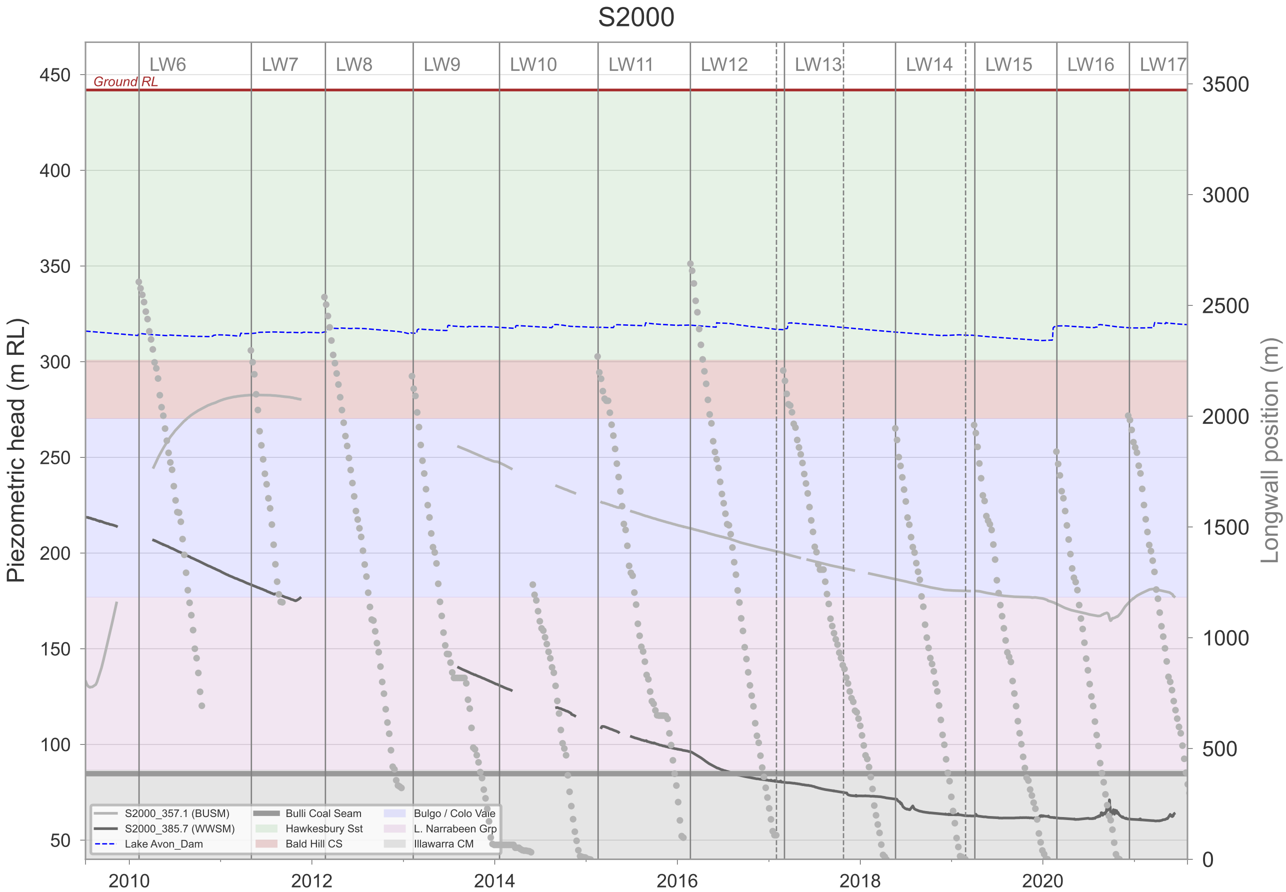
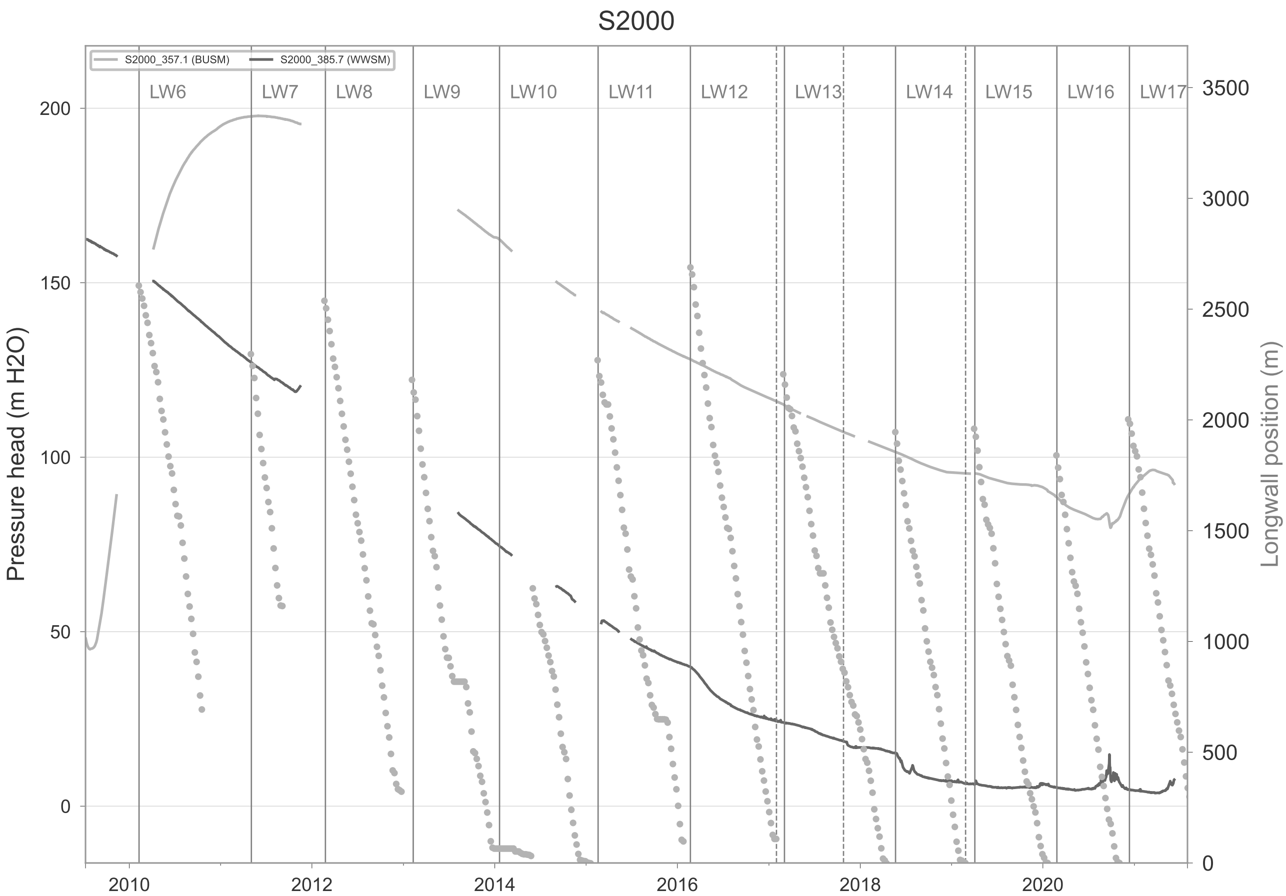
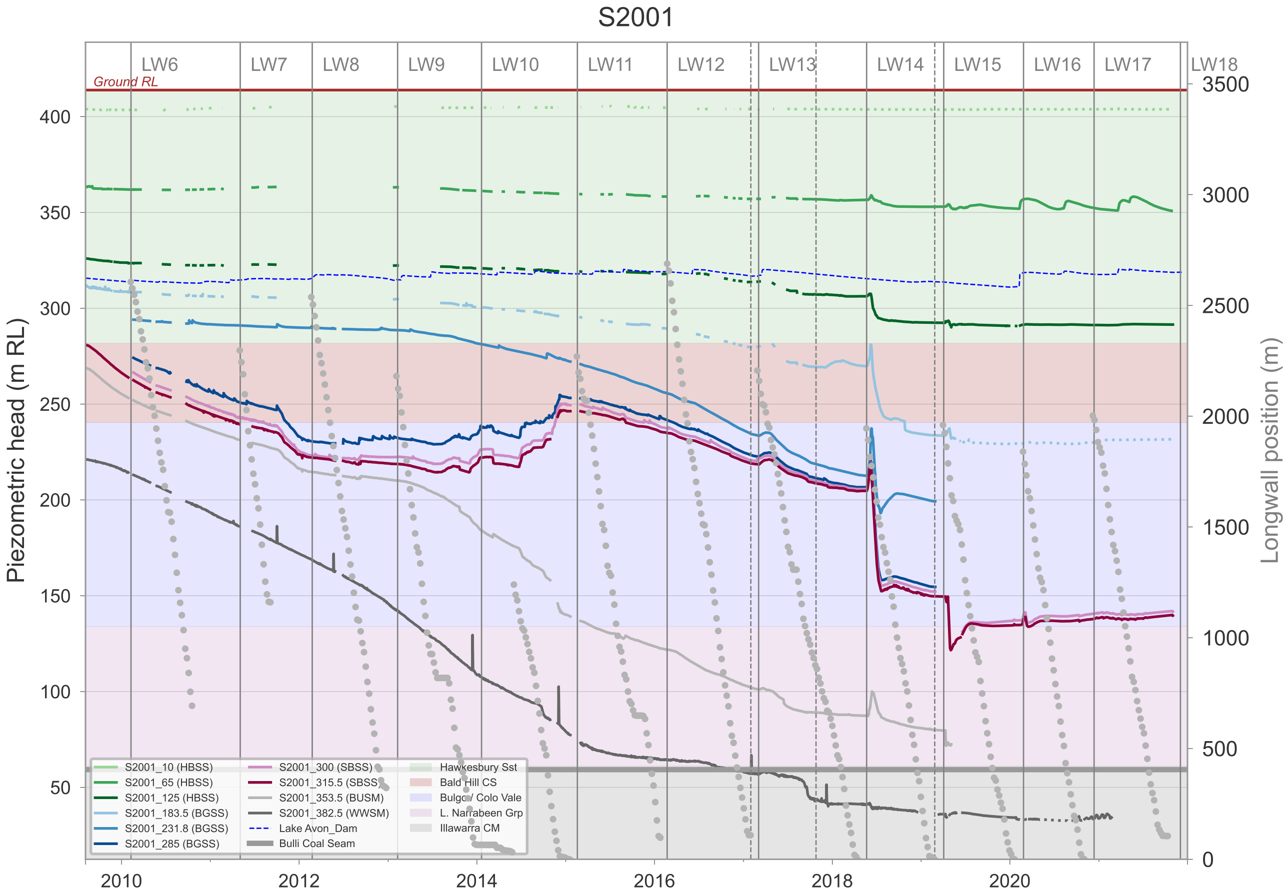


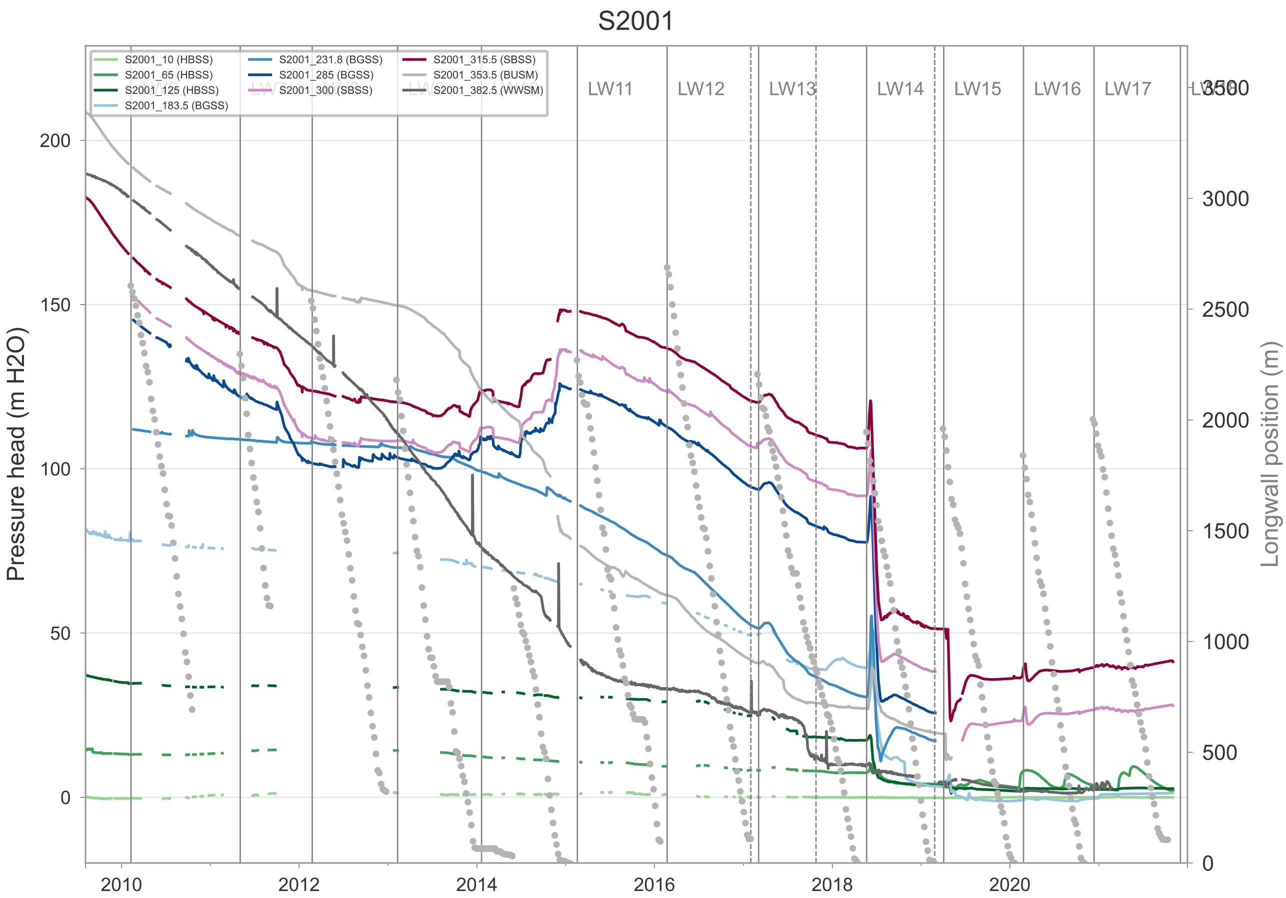
Groundwater hydrographs



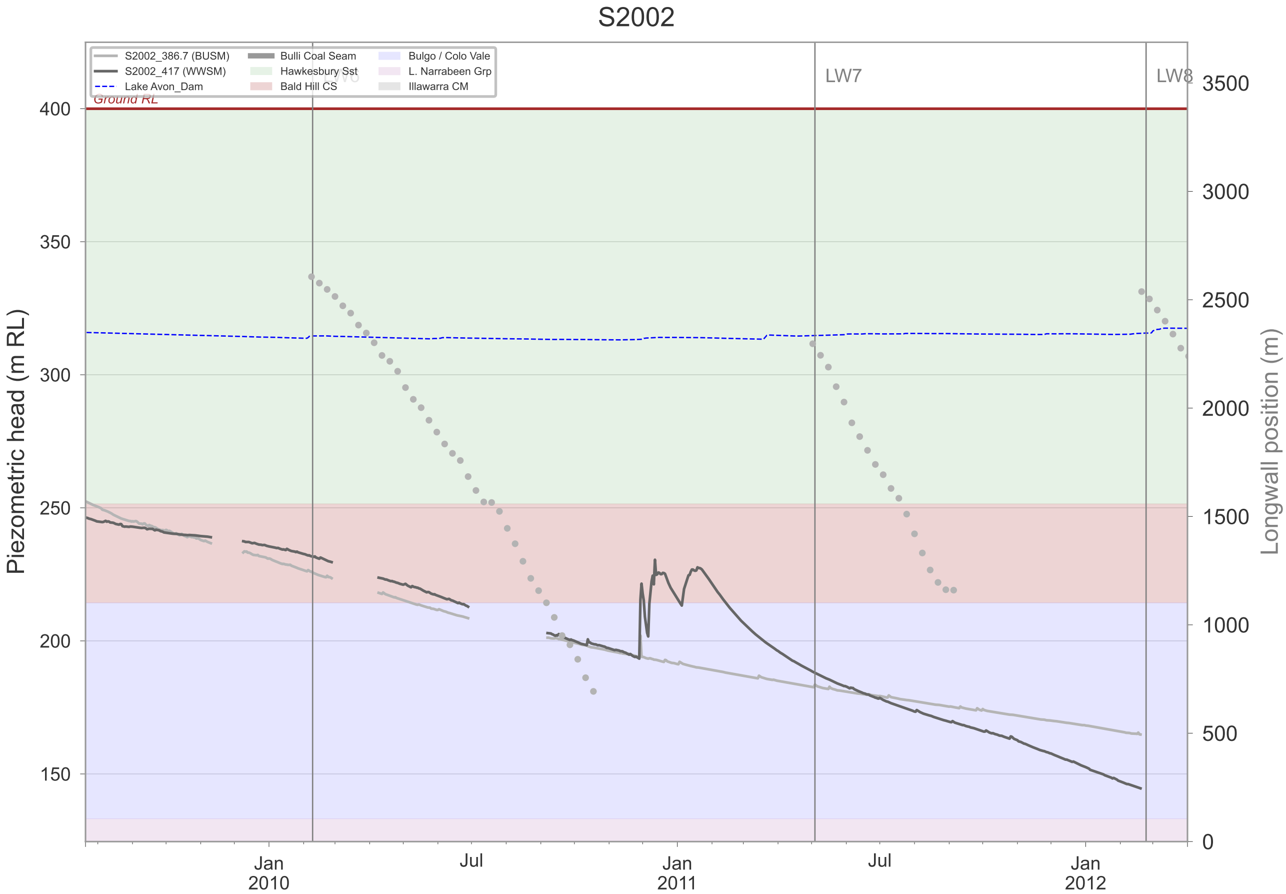


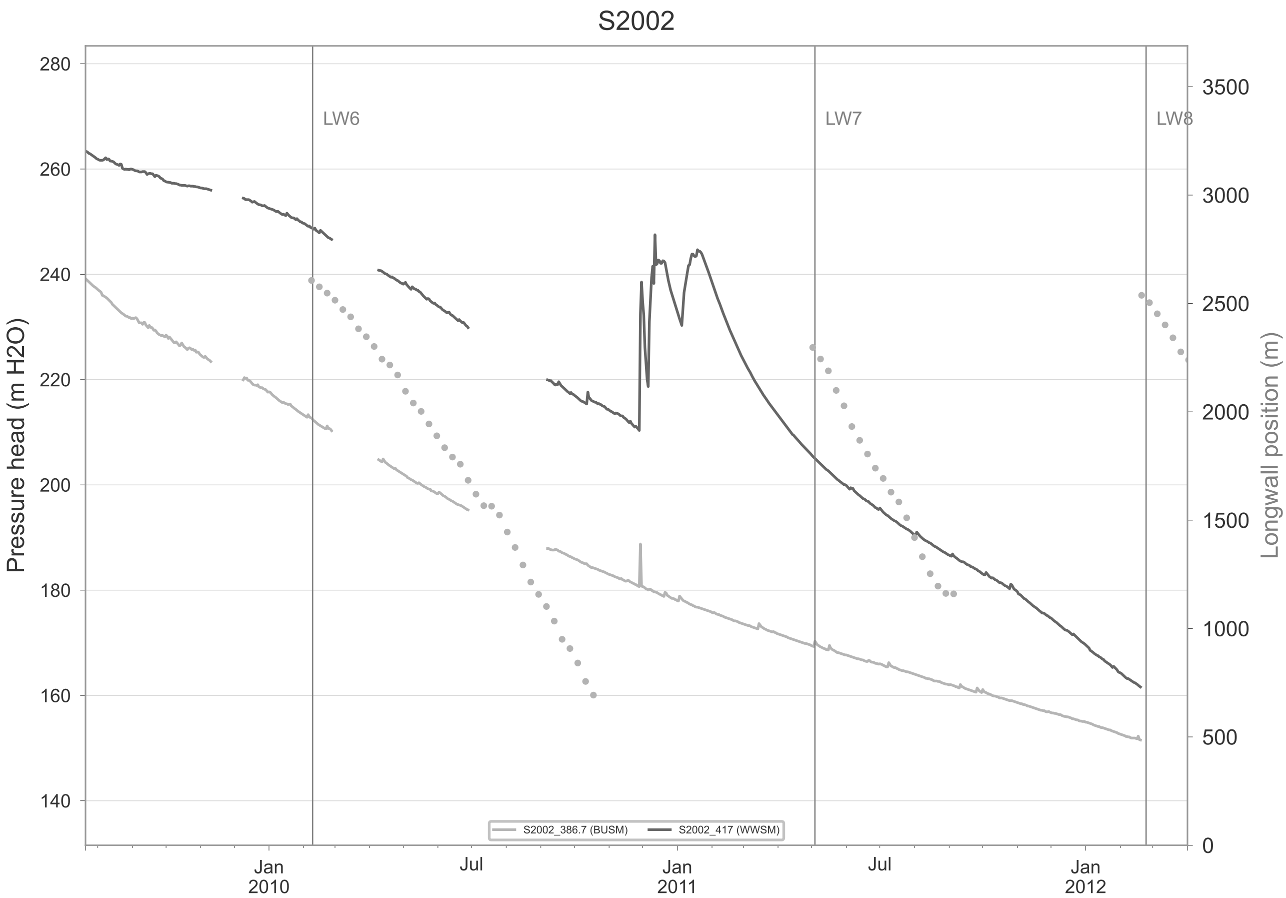
Groundwater hydrographs





Groundwater hydrographs





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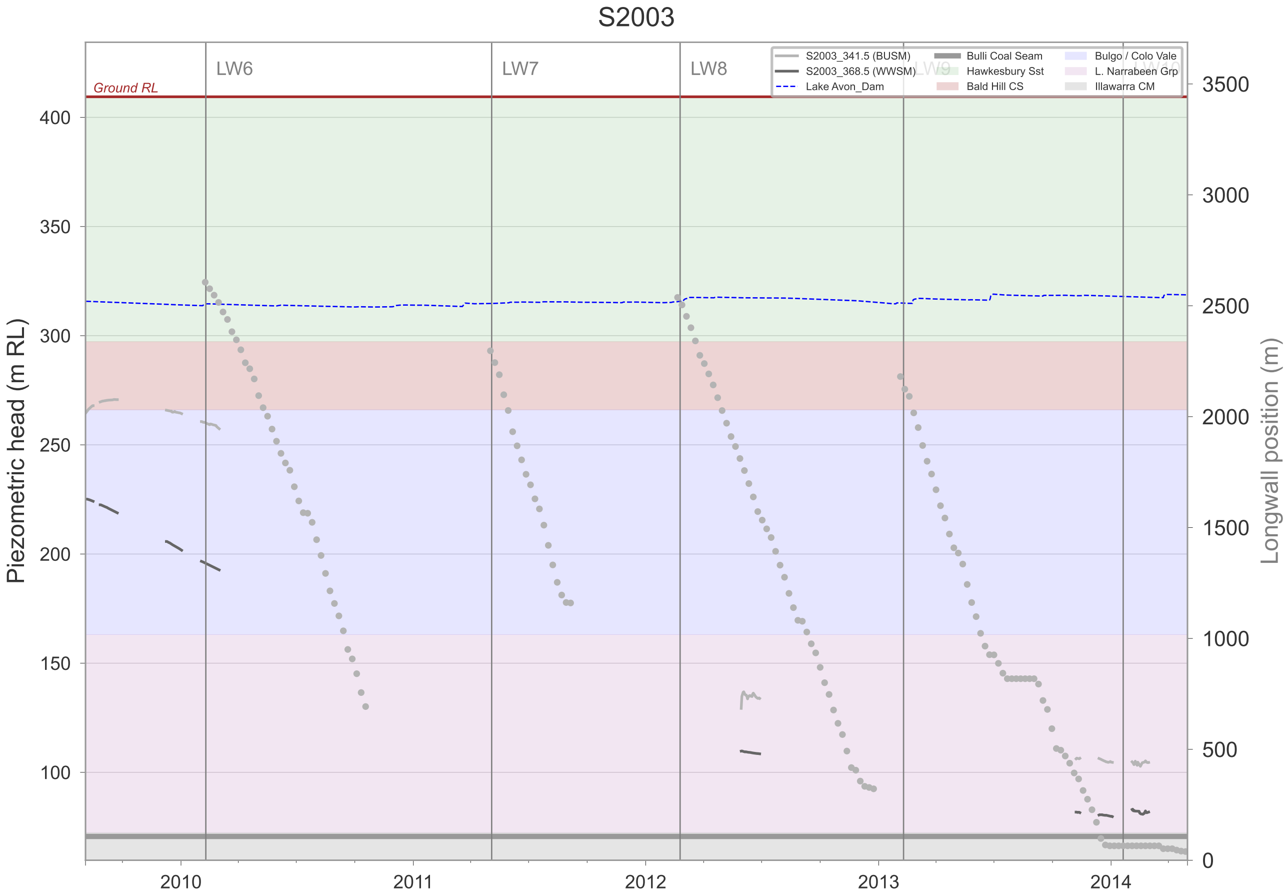

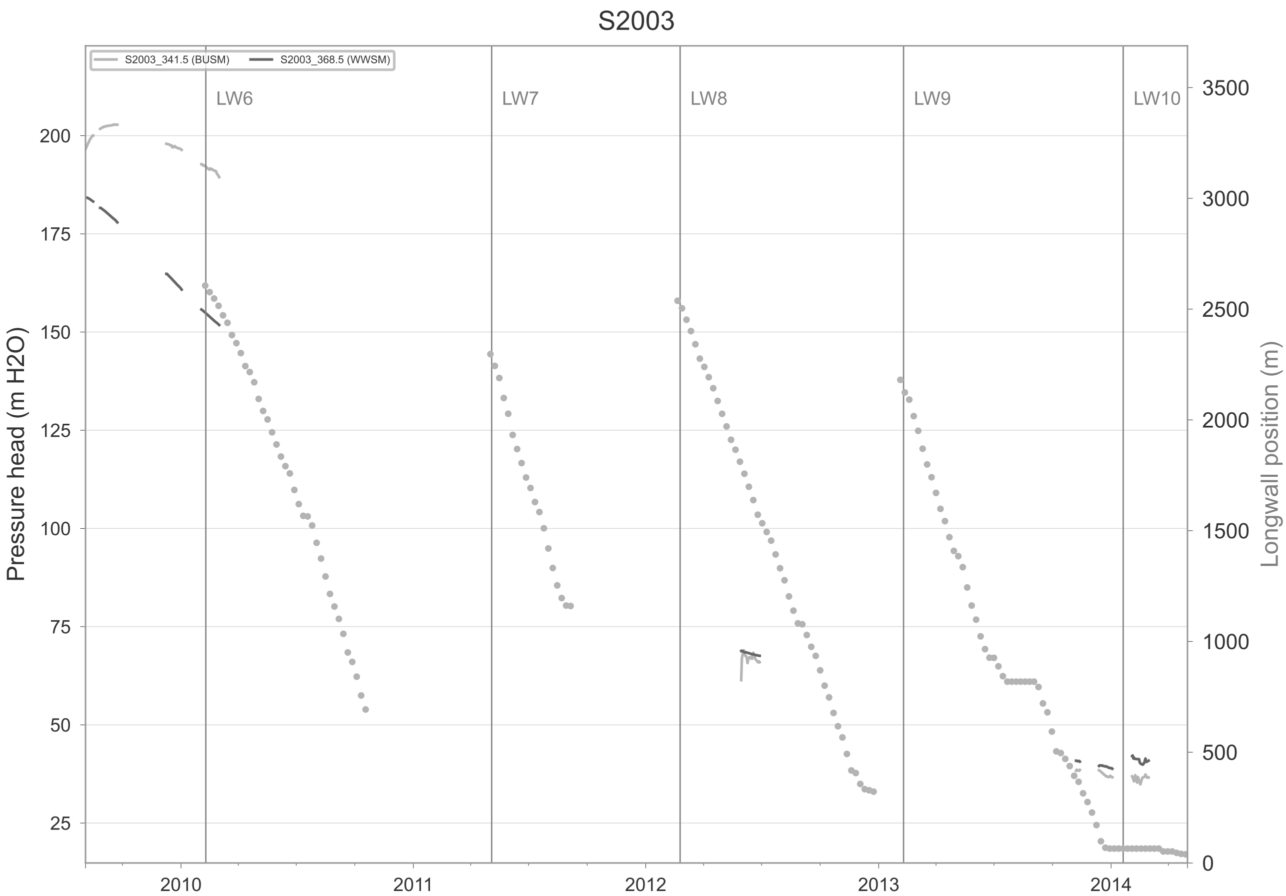

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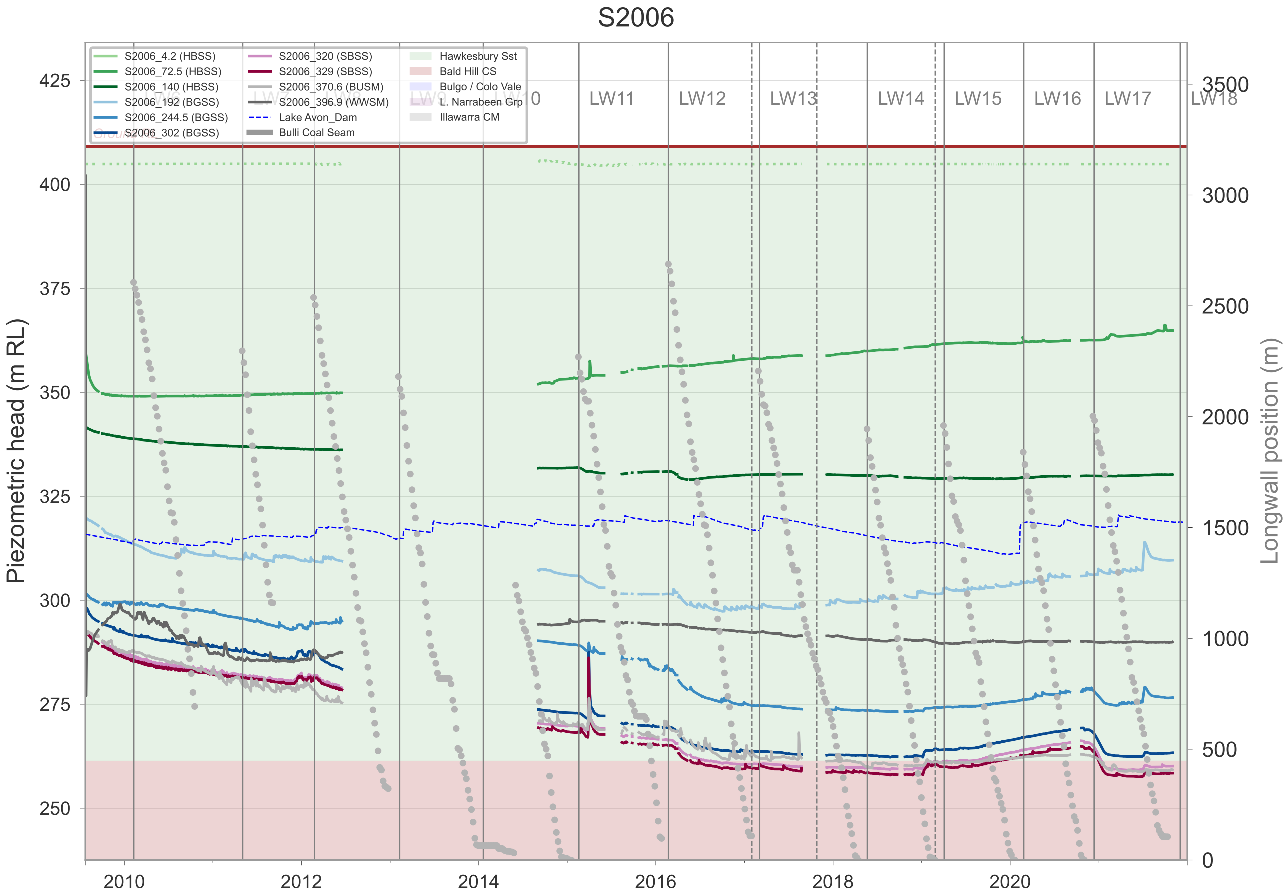
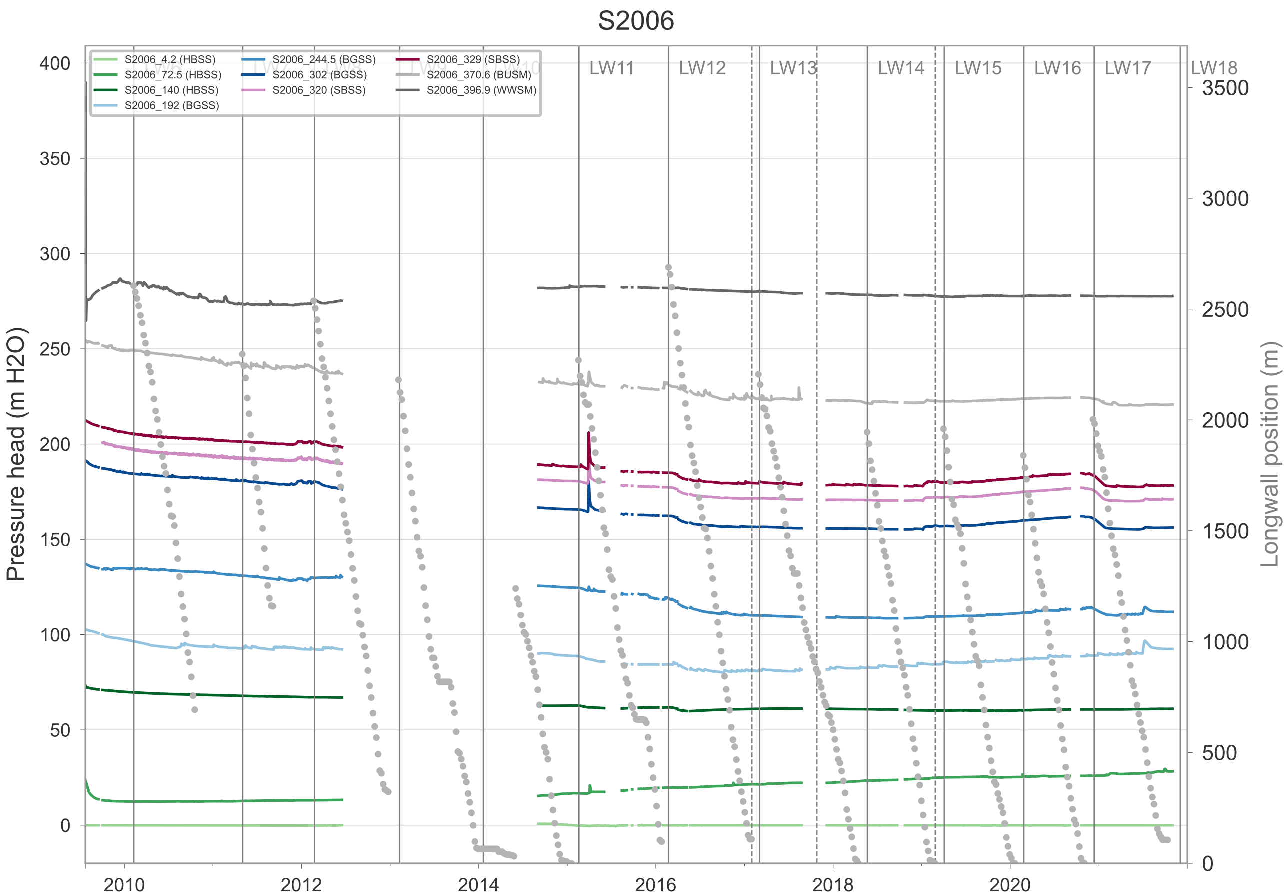
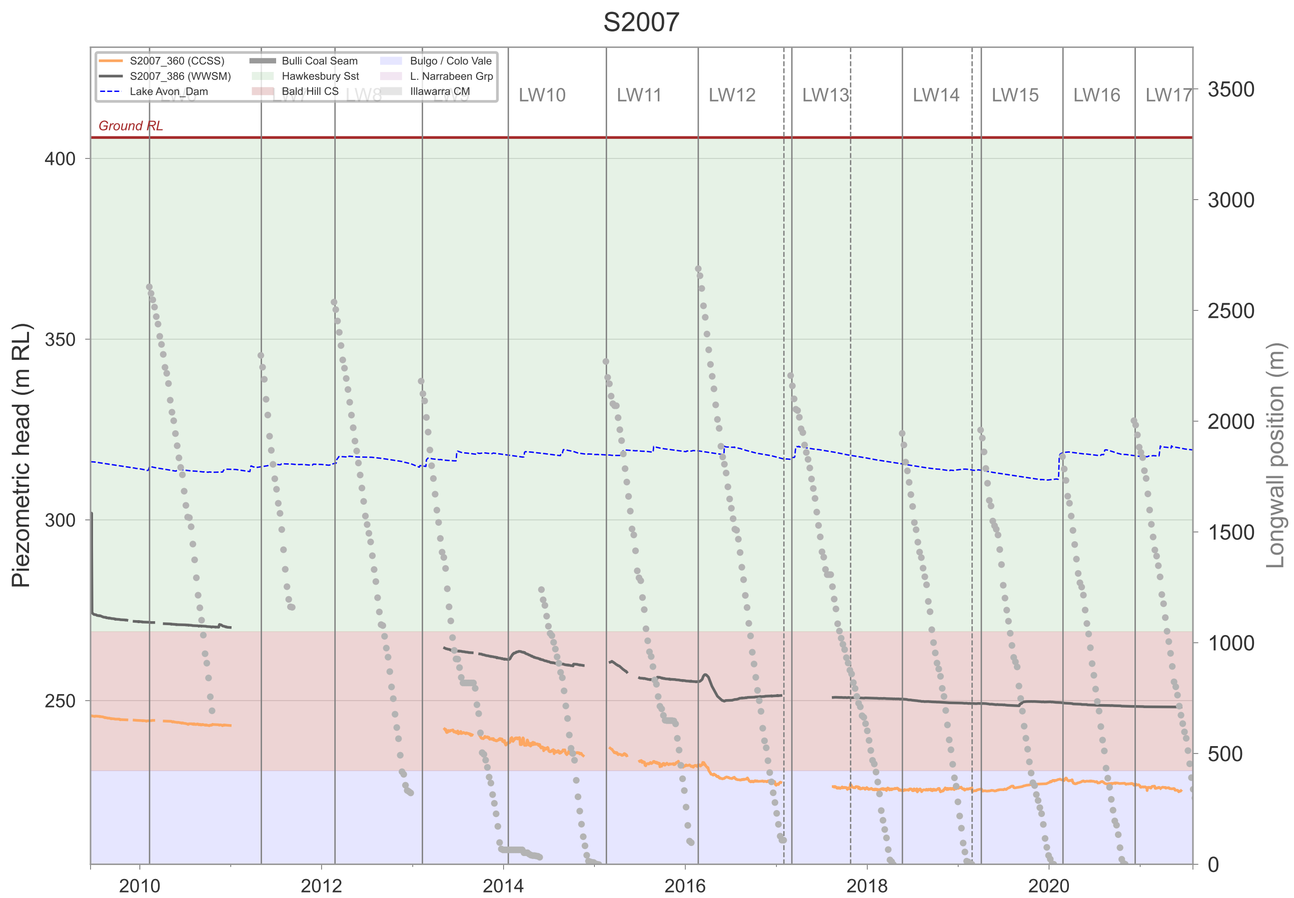
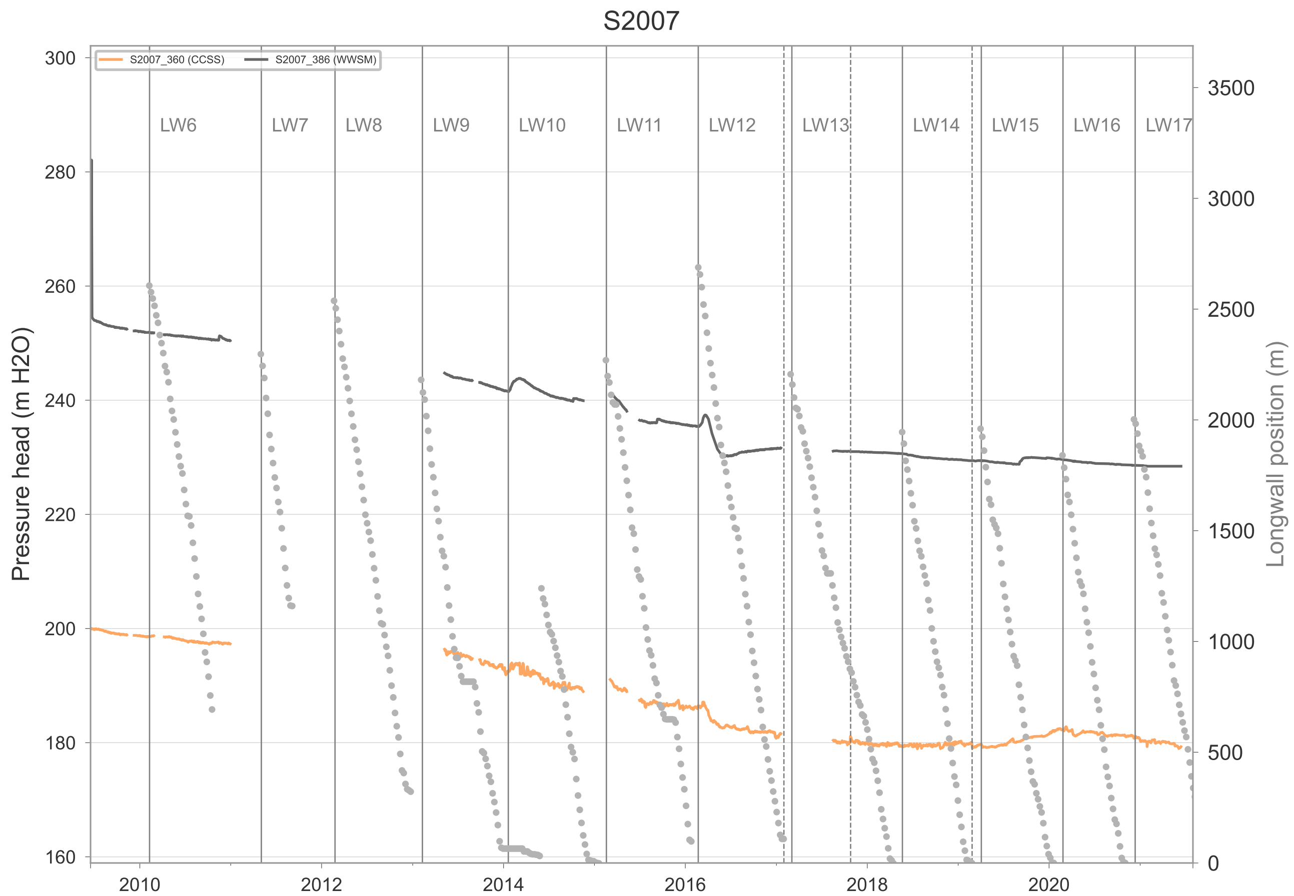




Groundwater hydrographs





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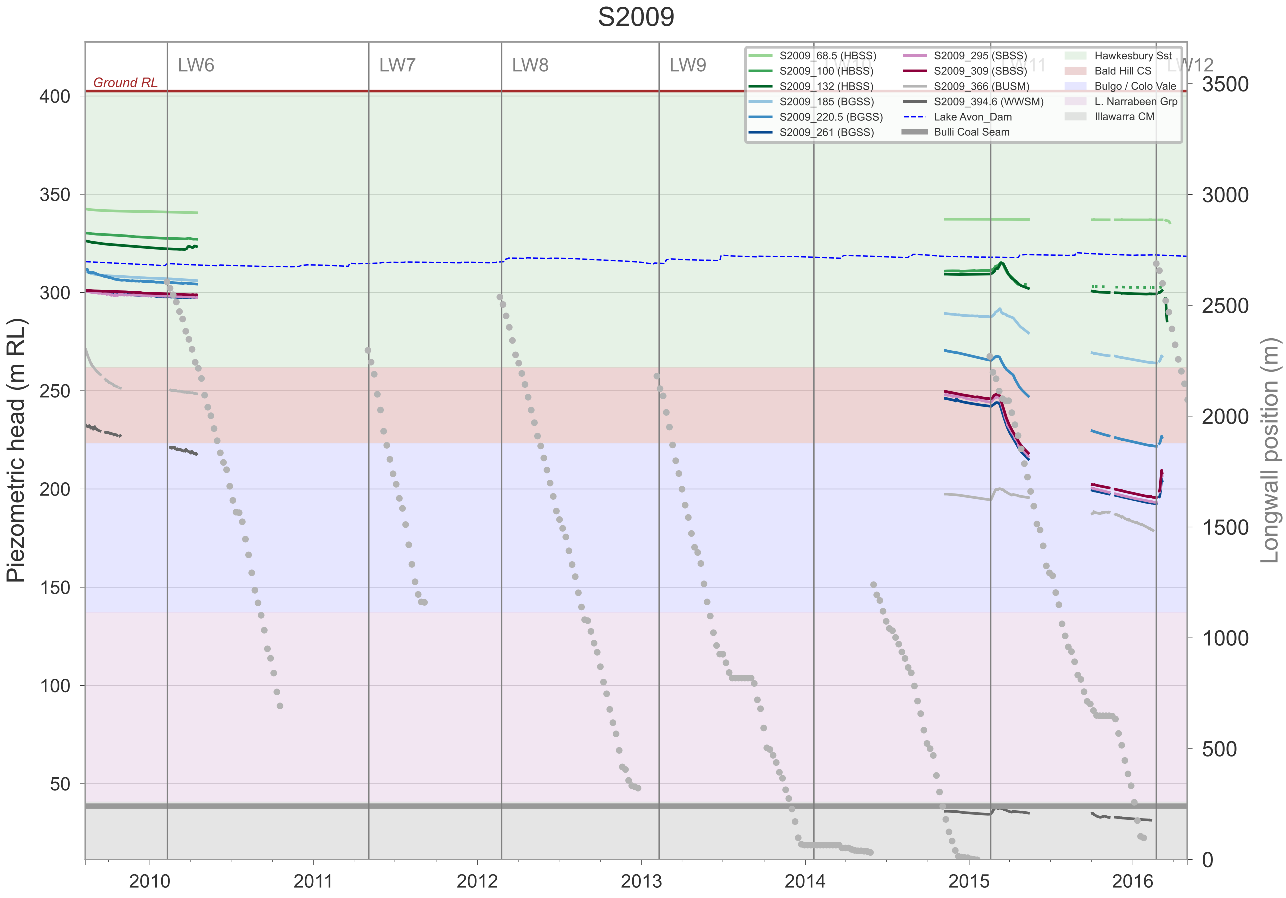

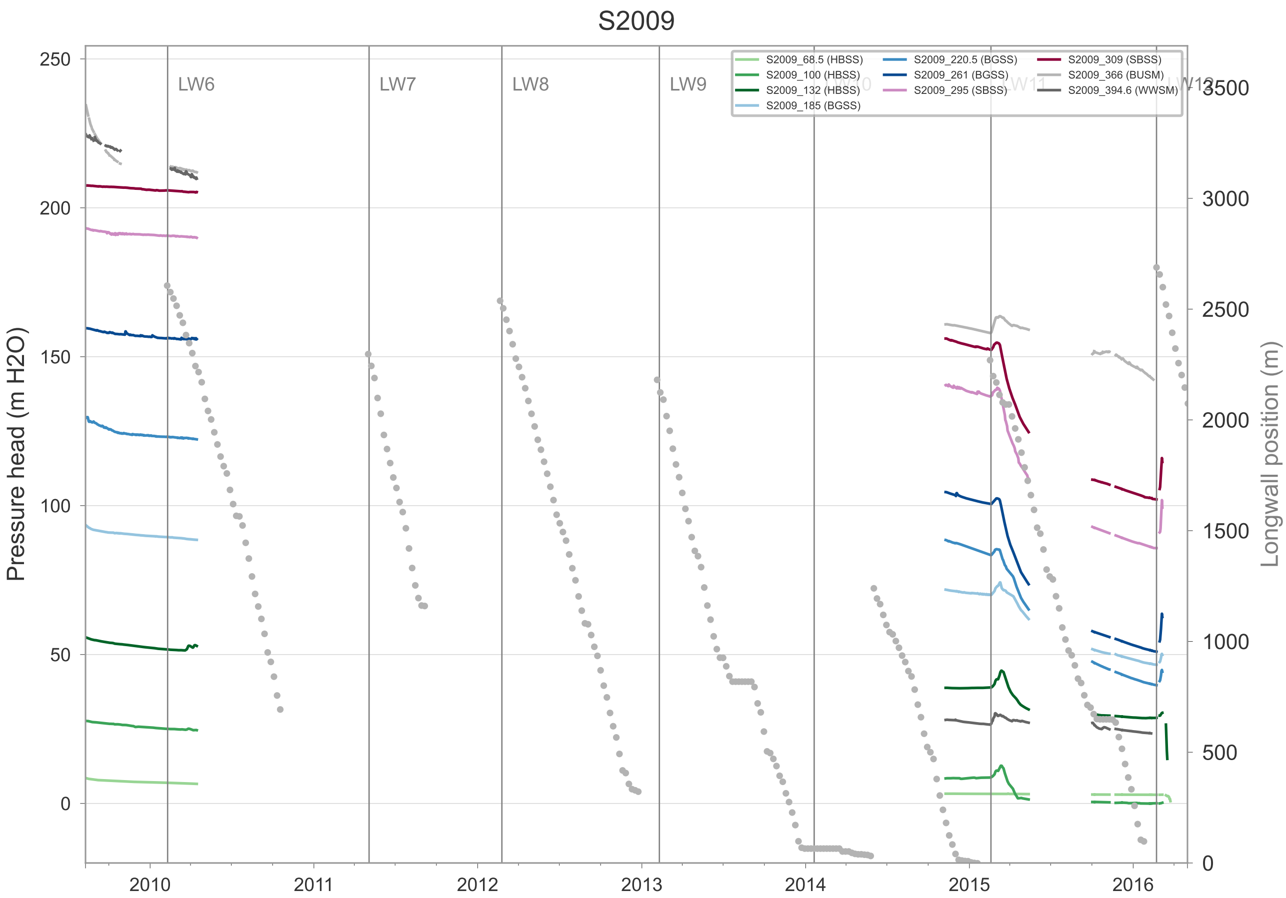

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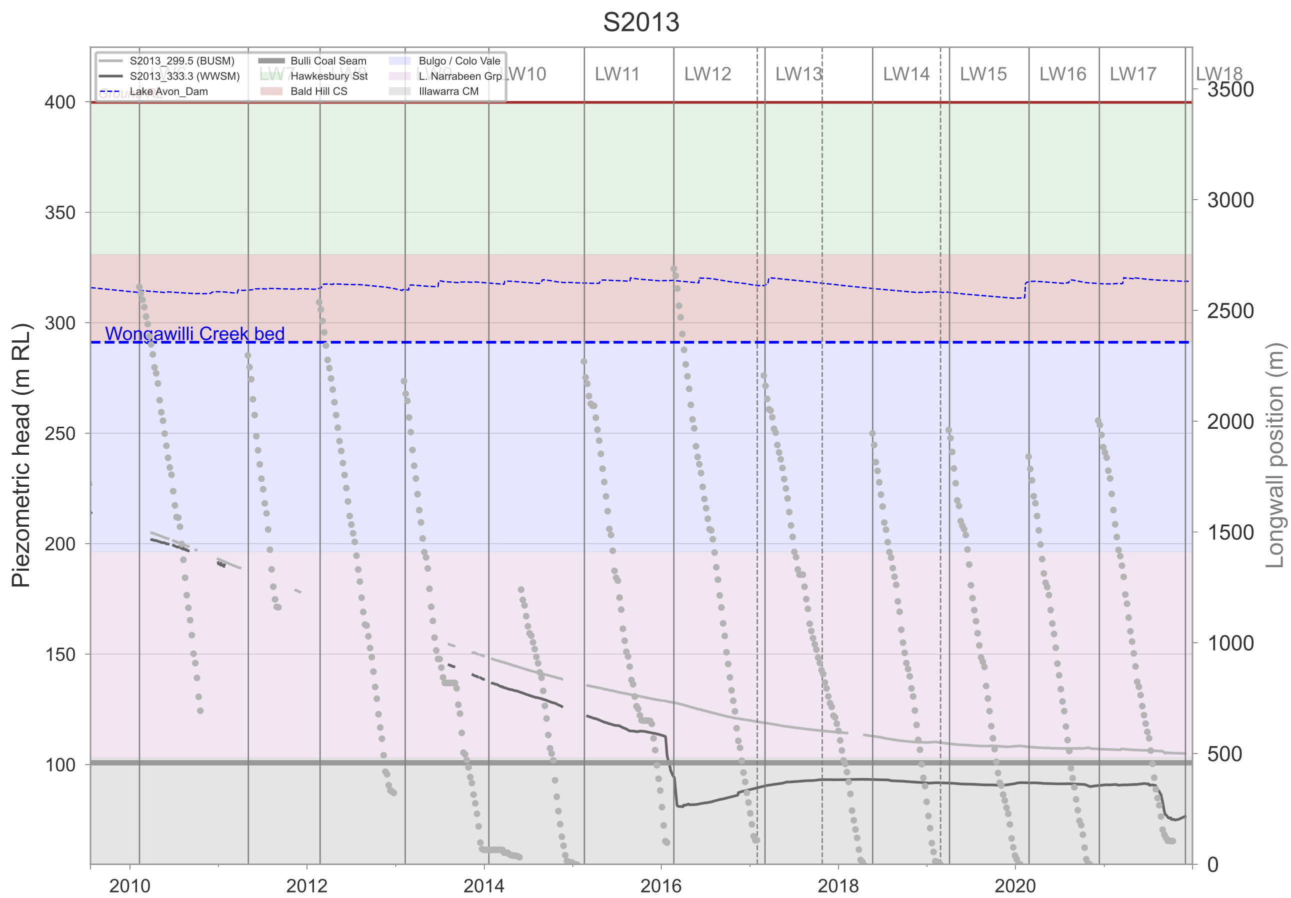
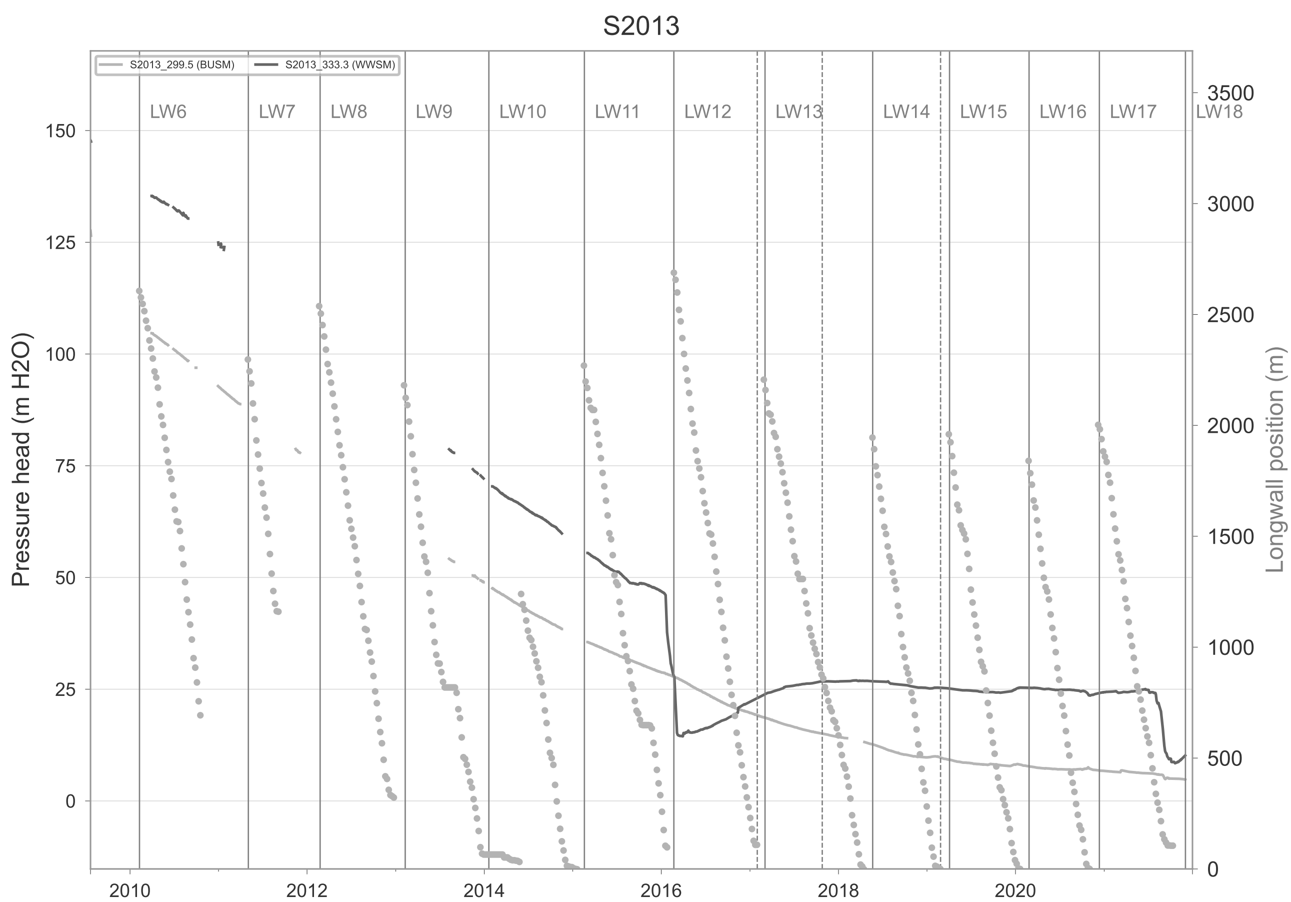
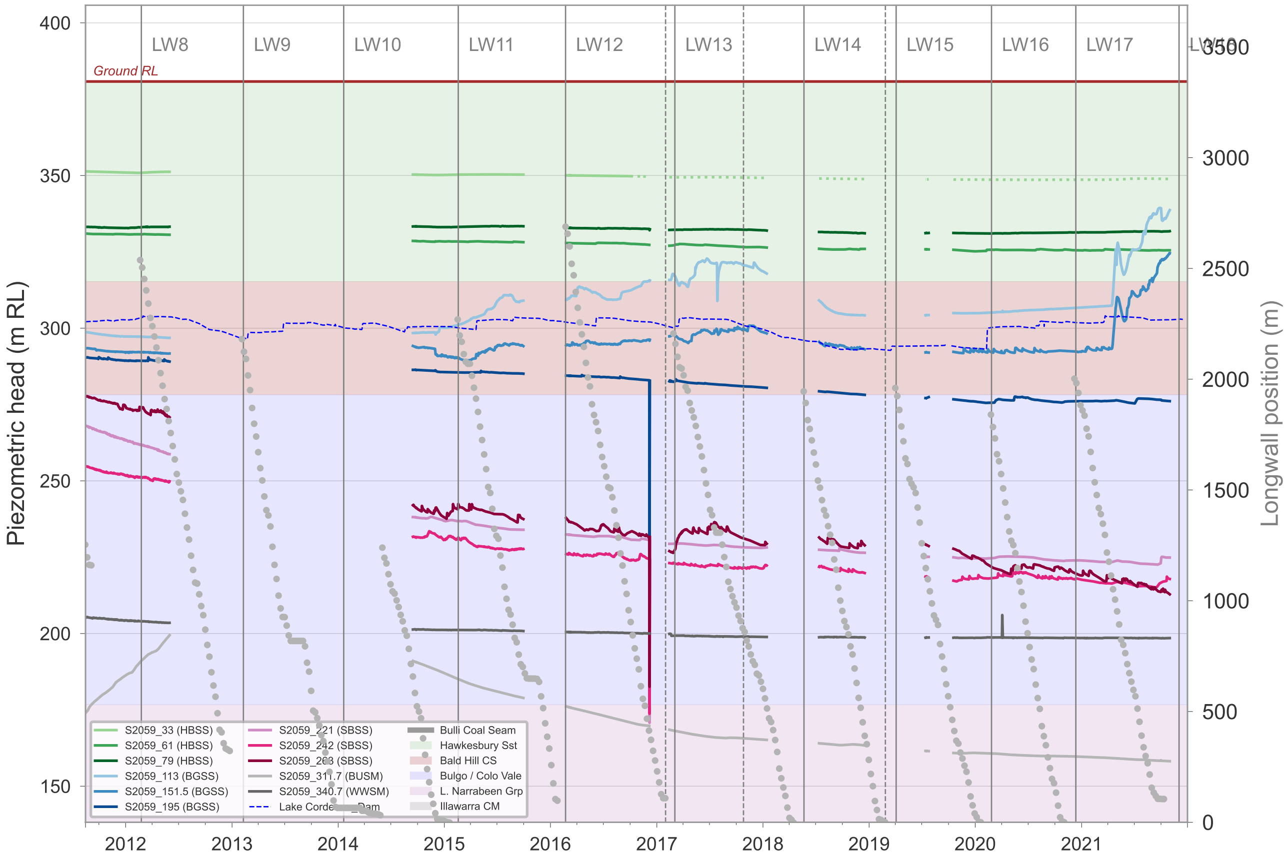




Groundwater hydrographs

S2059



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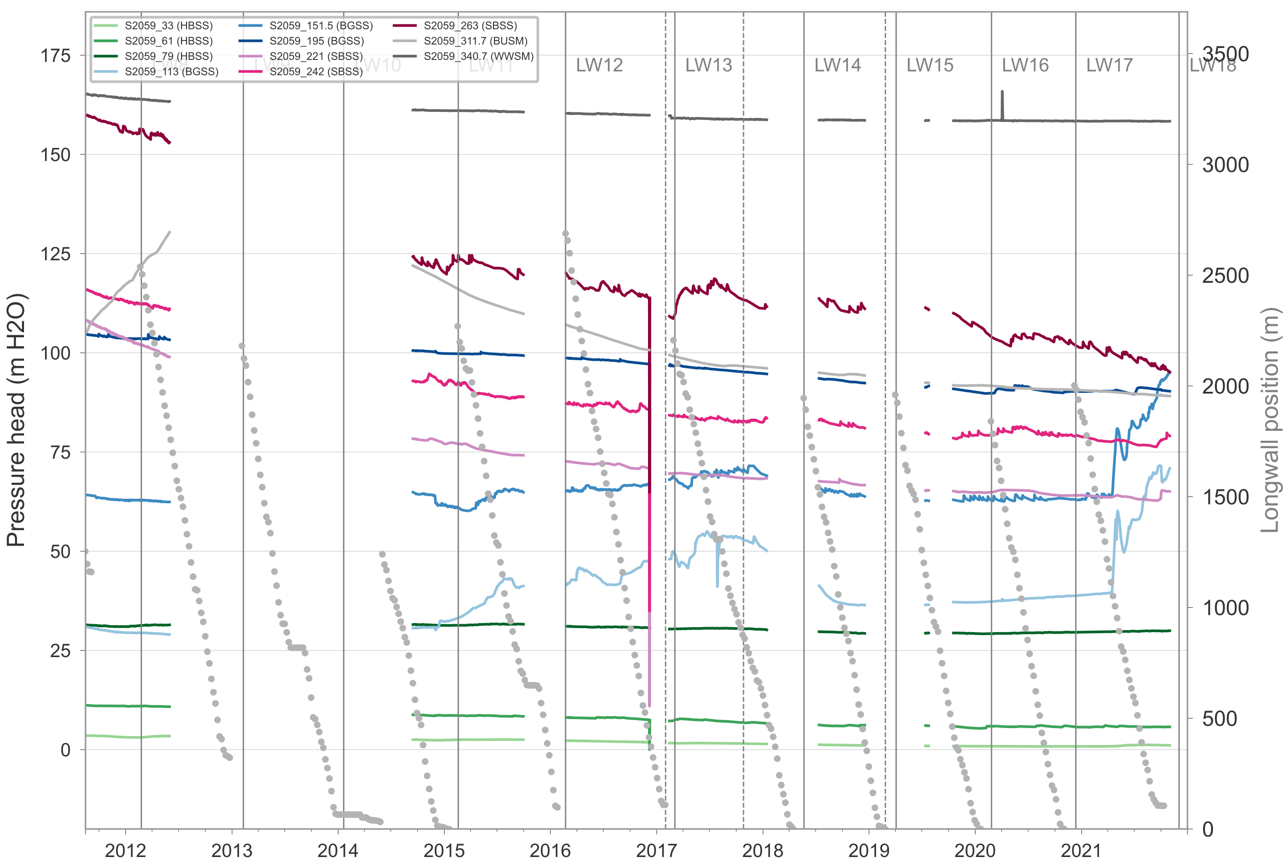
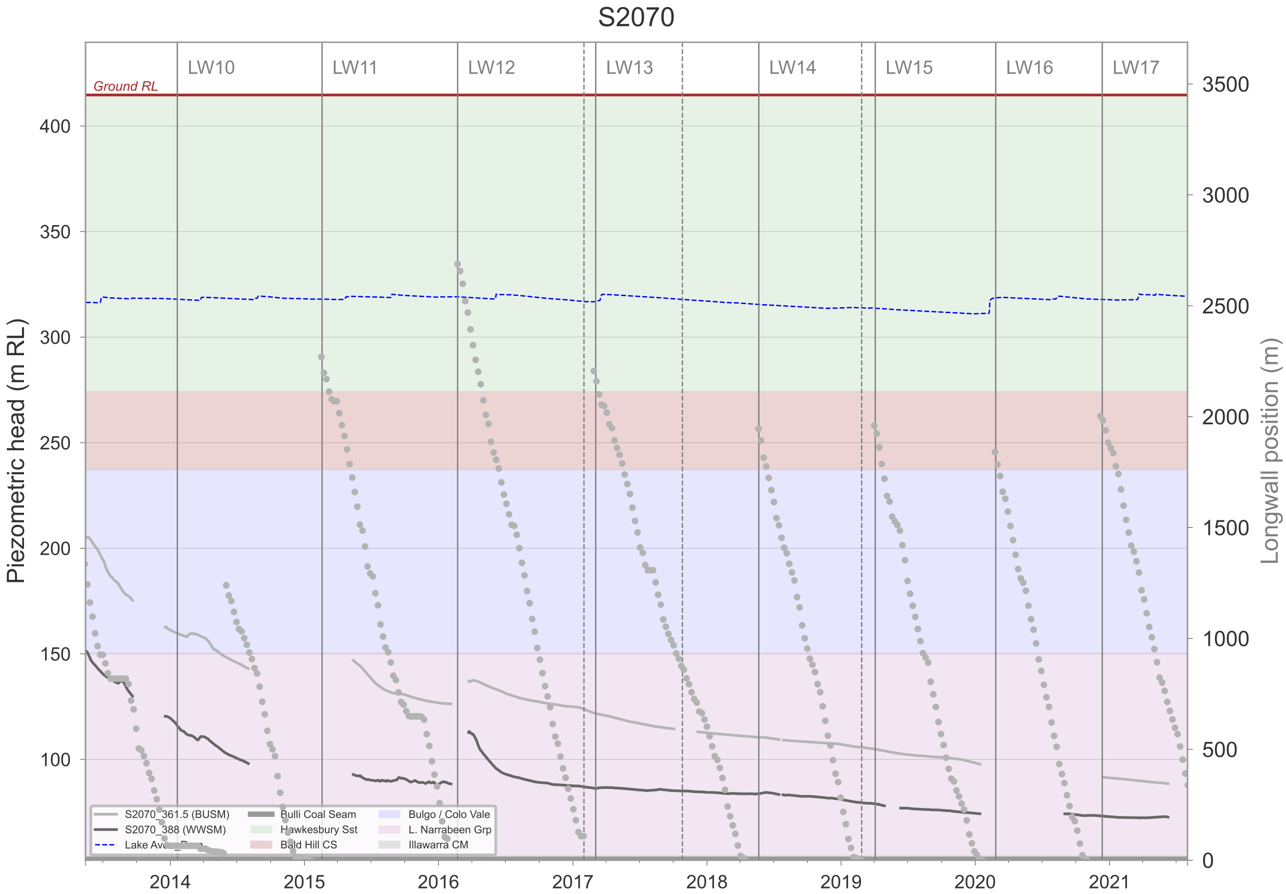
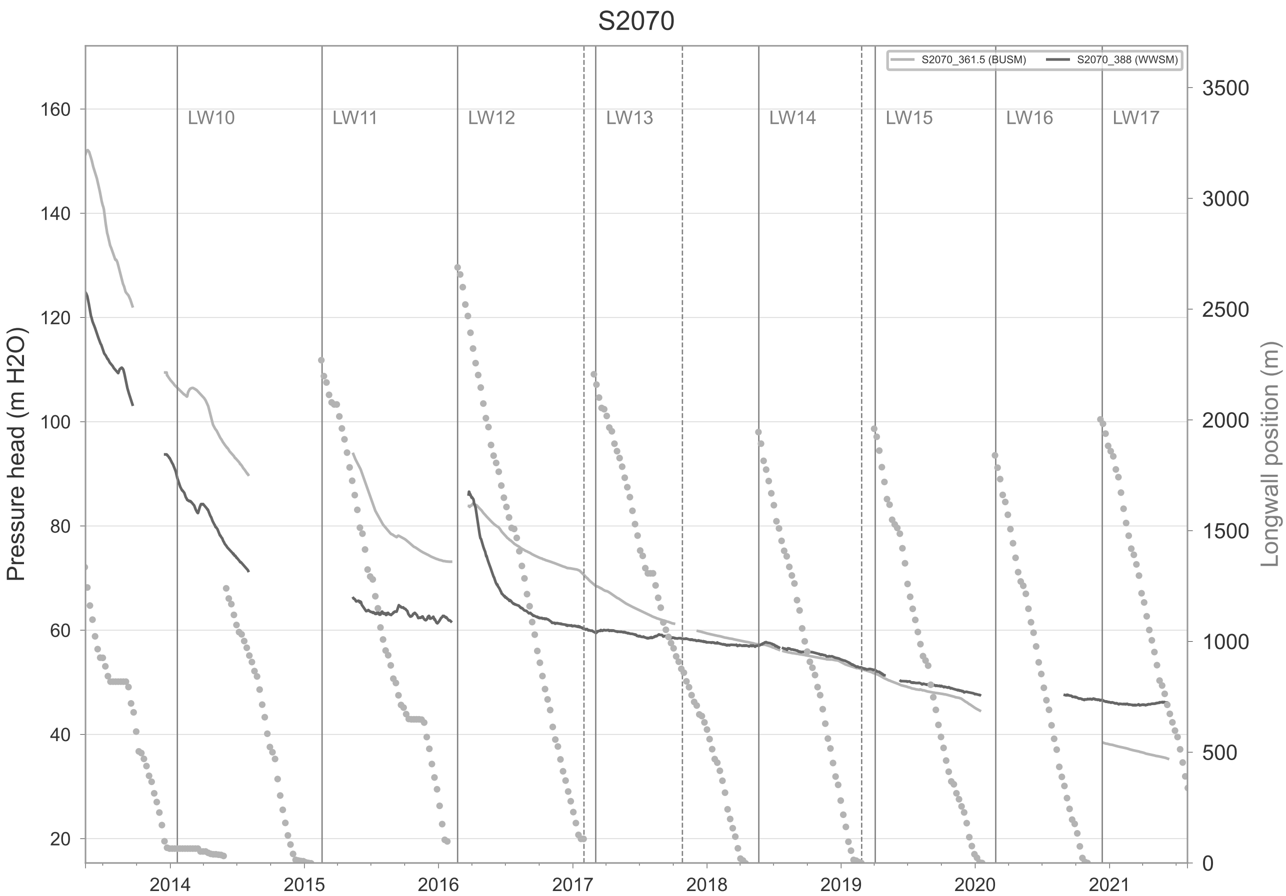


Groundwater hydrographs





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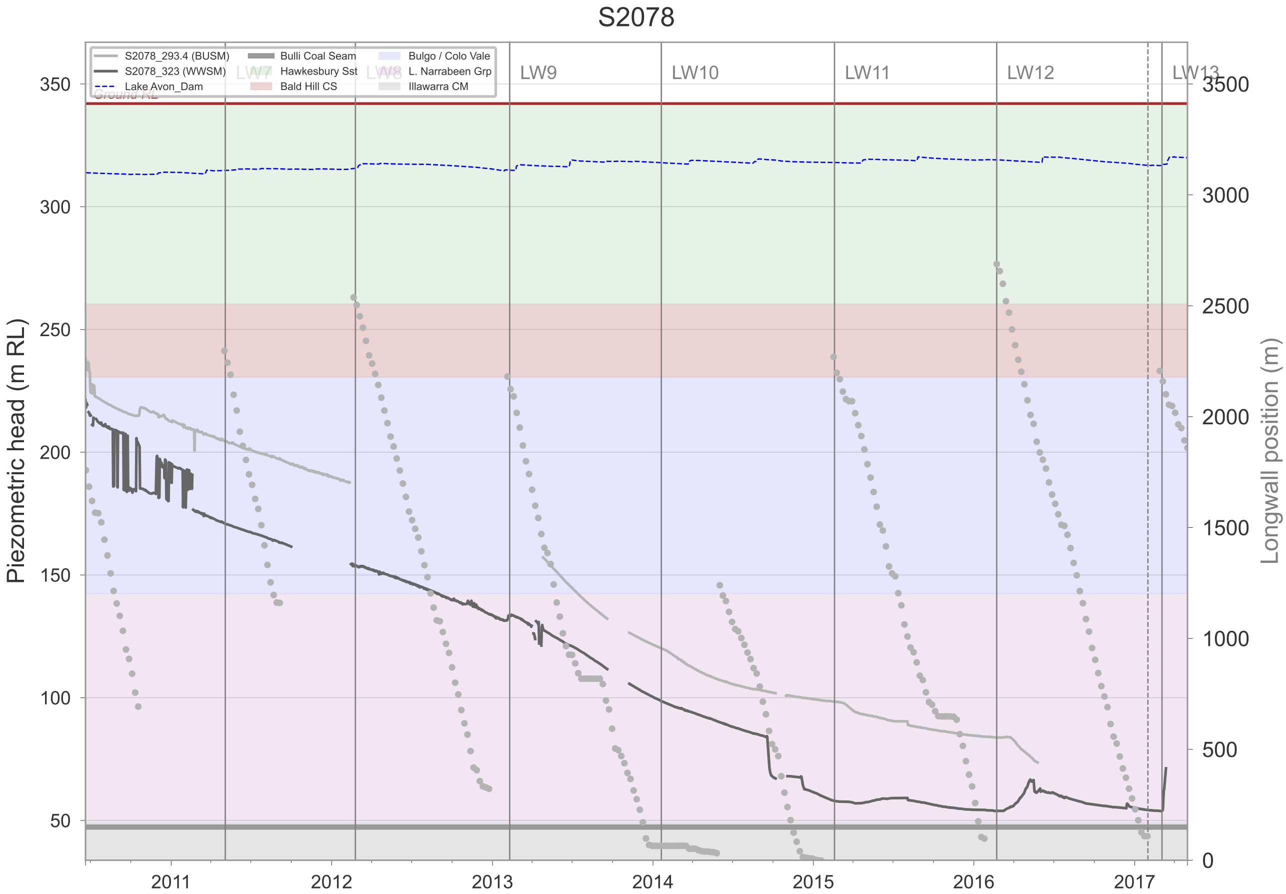
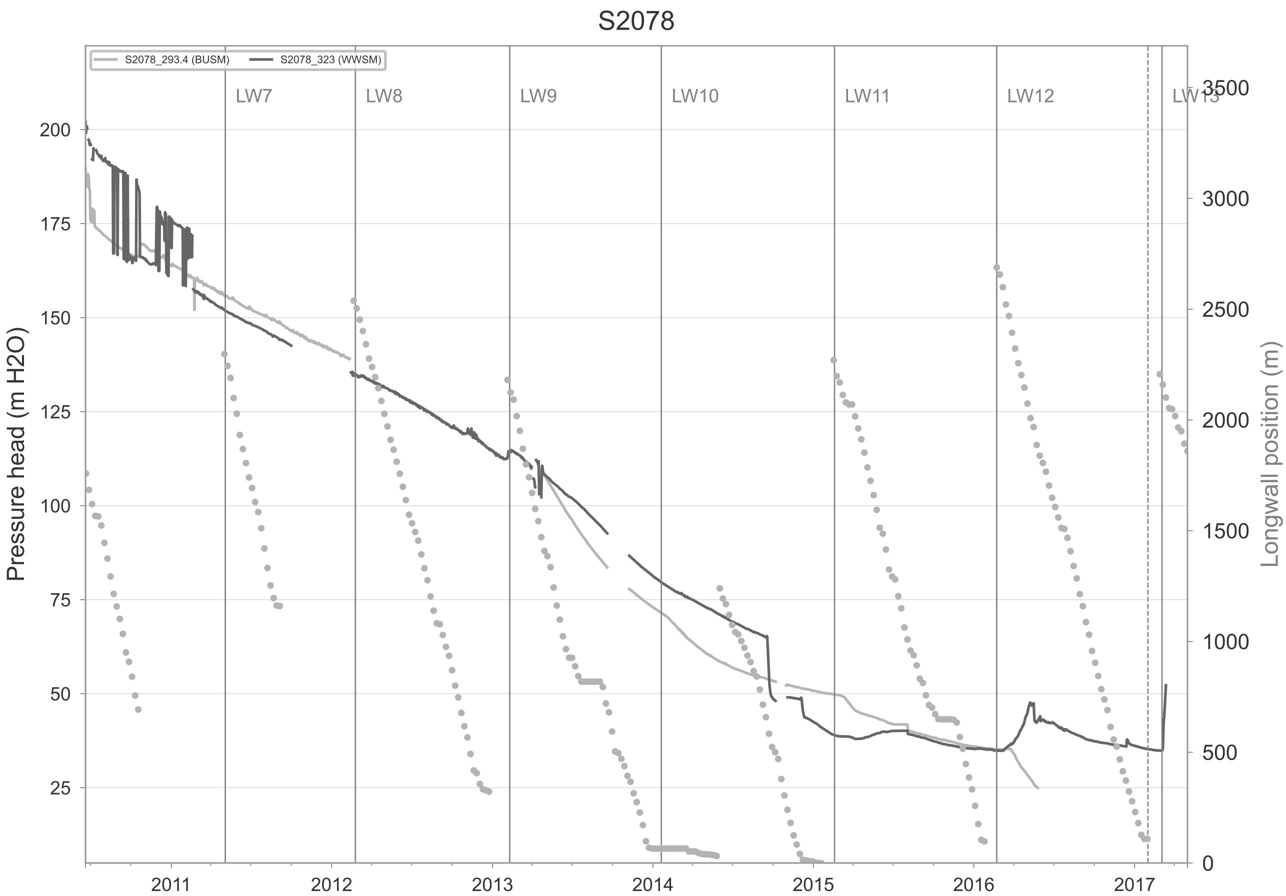
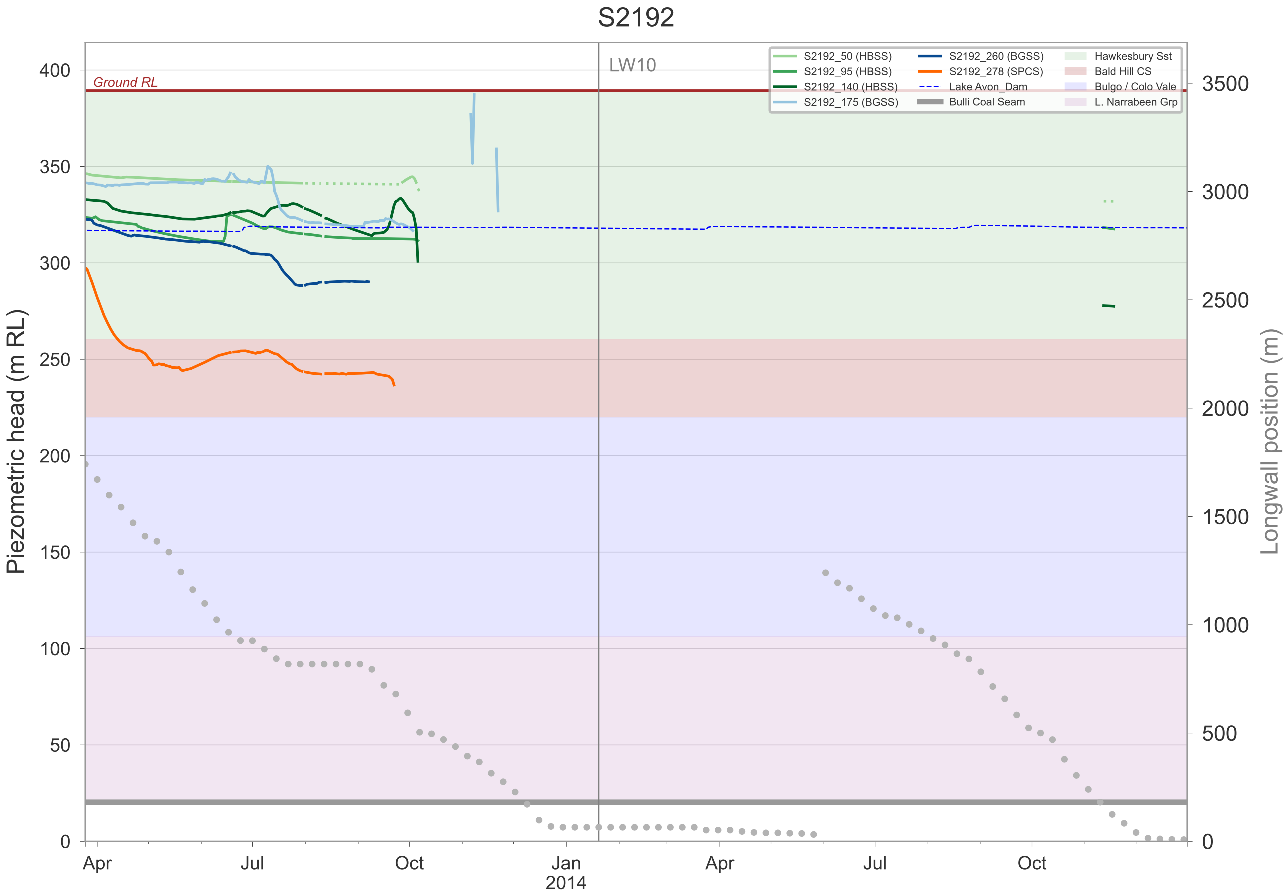
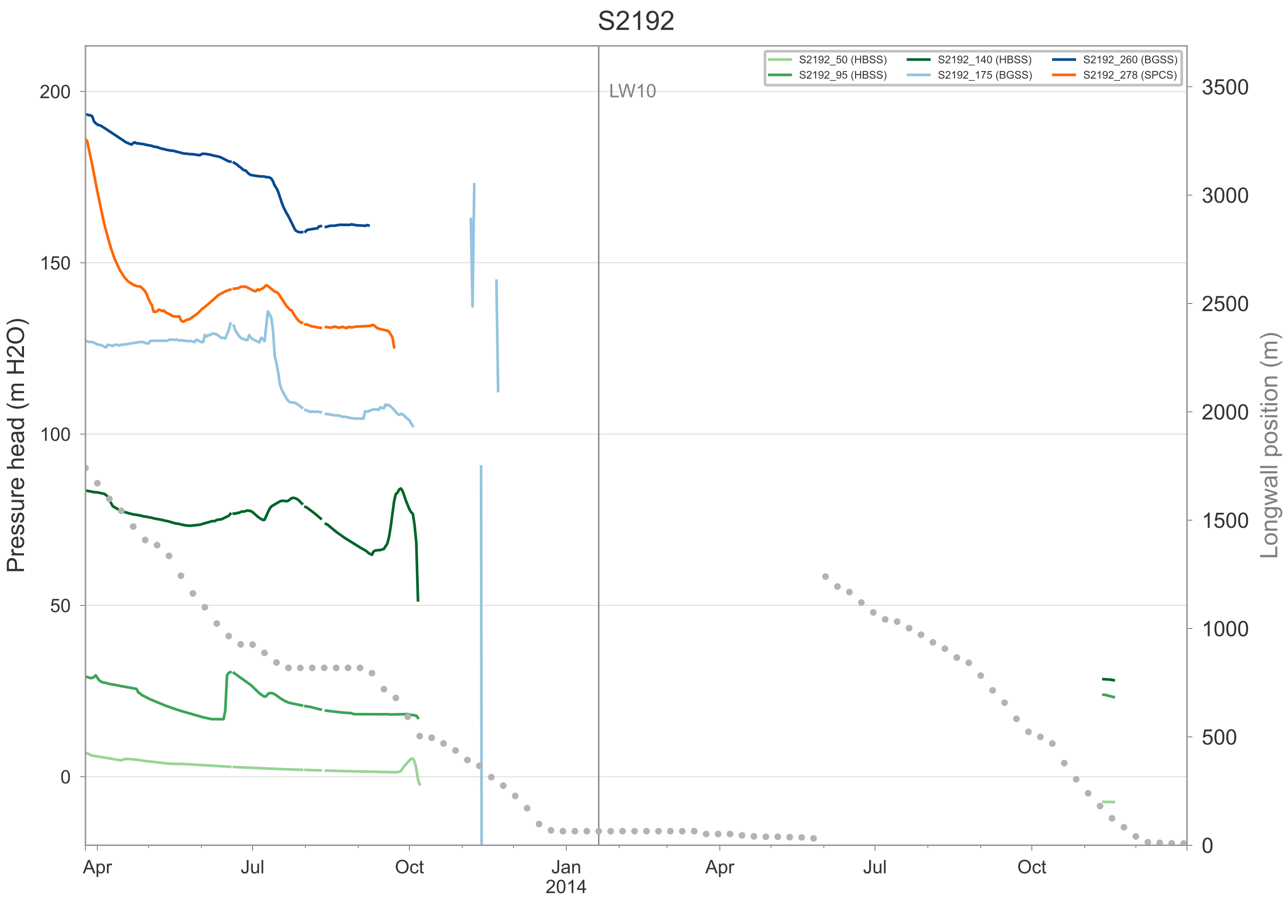


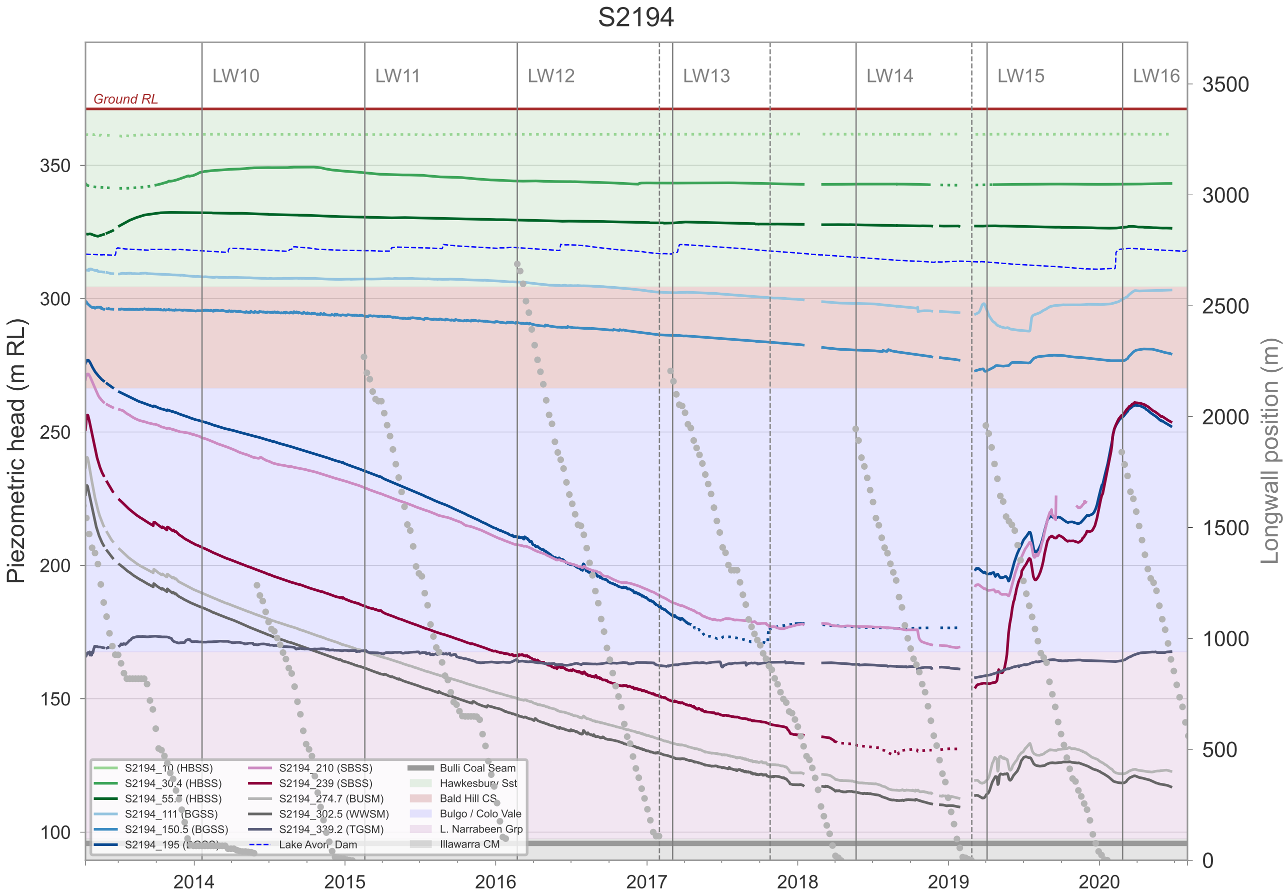


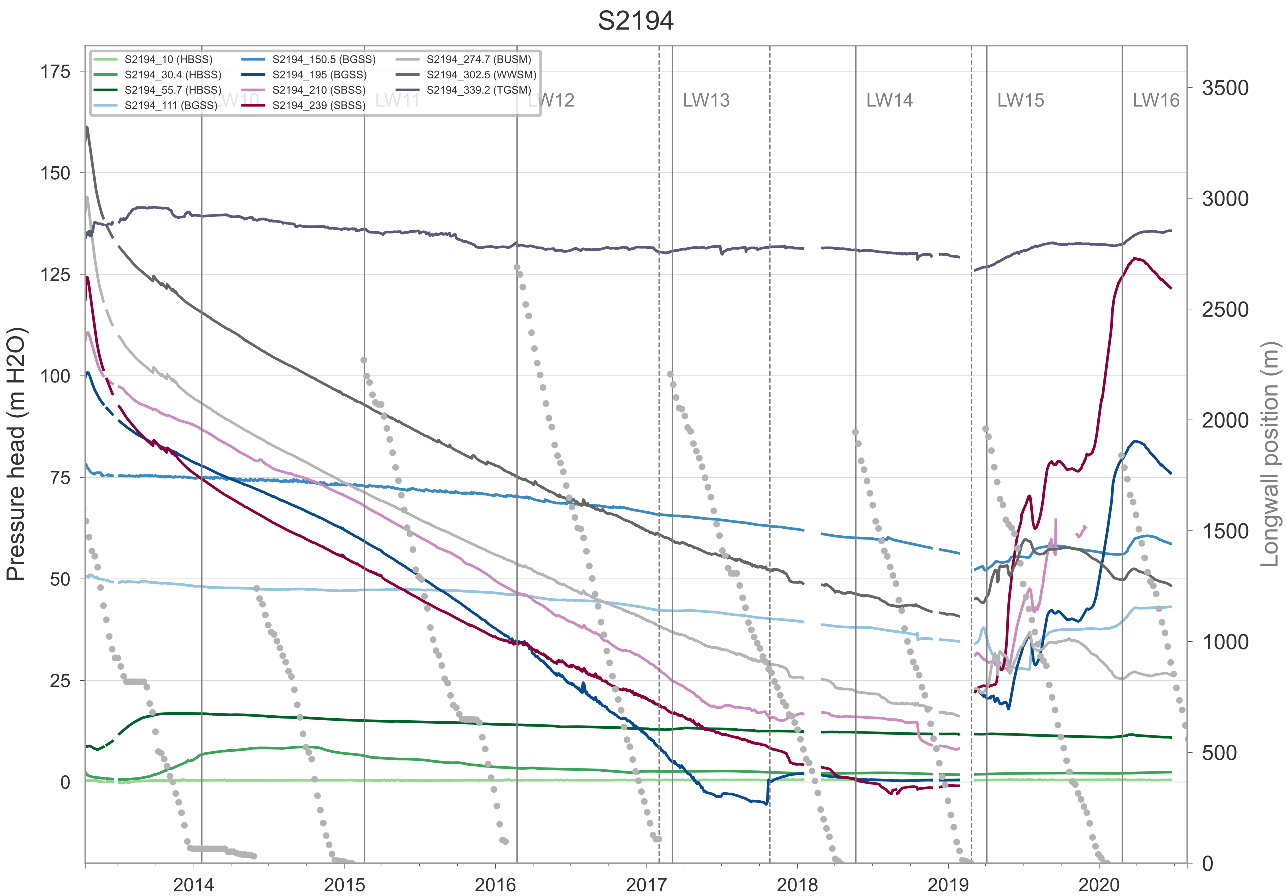
Groundwater hydrographs



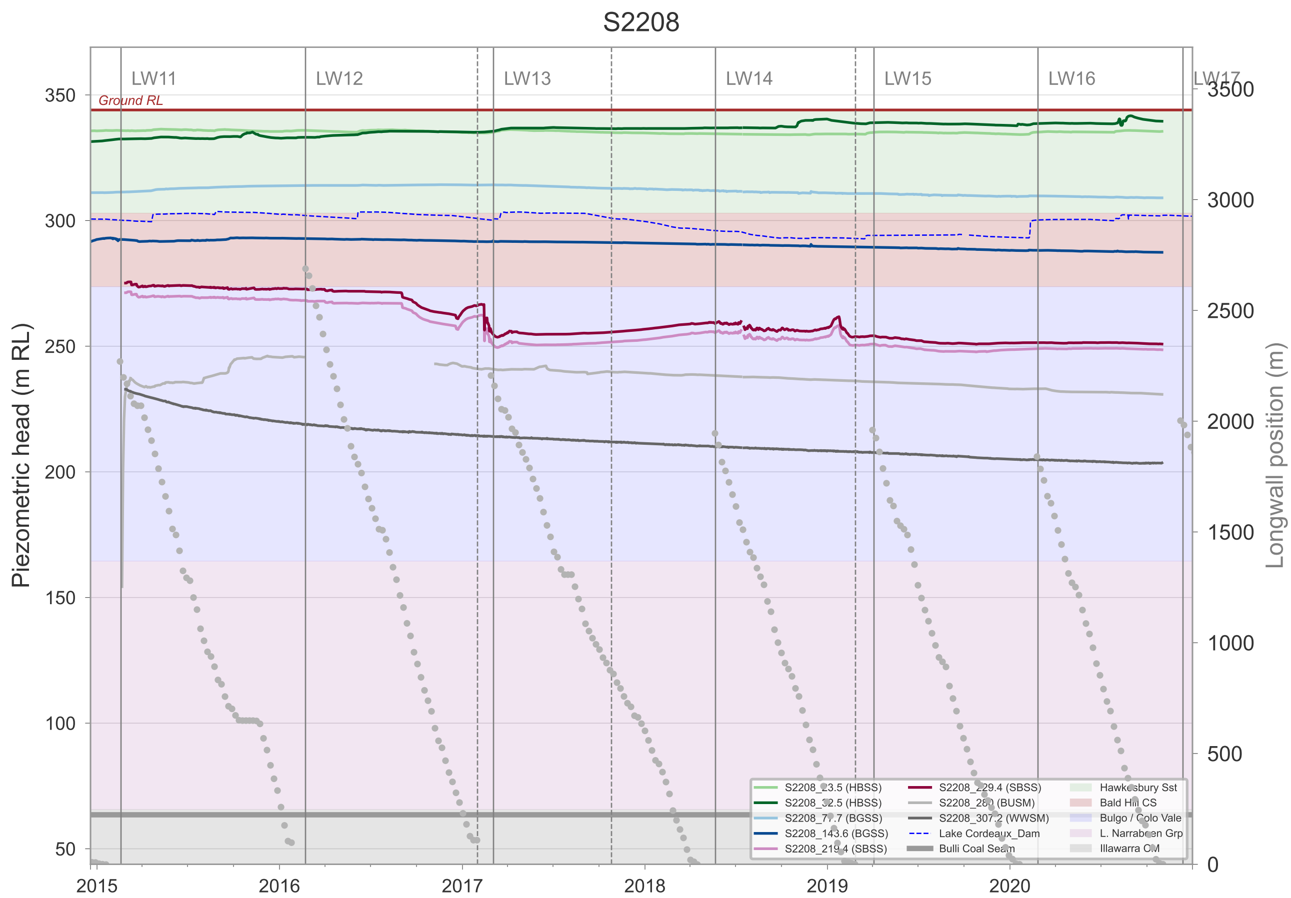


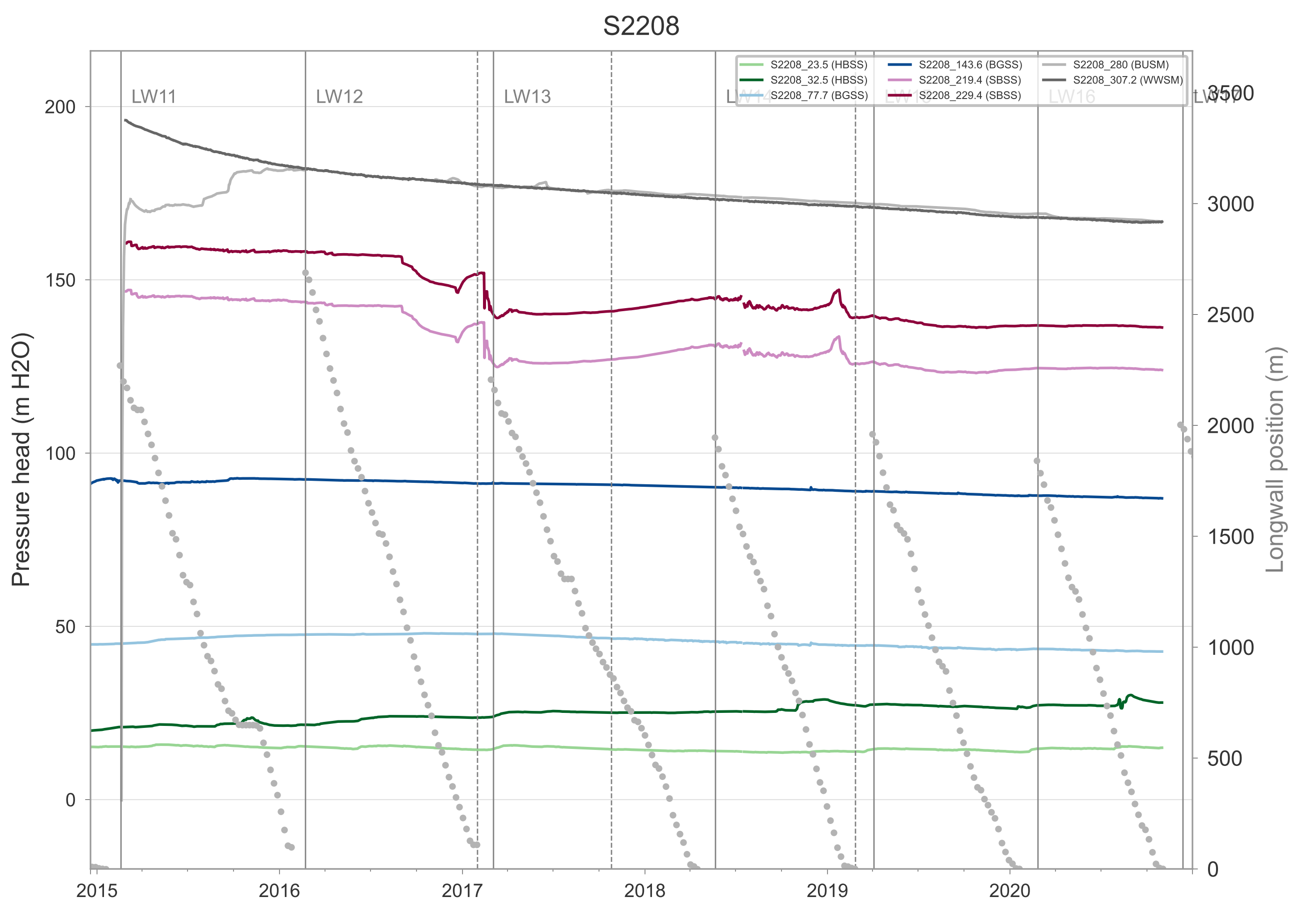
Groundwater hydrographs



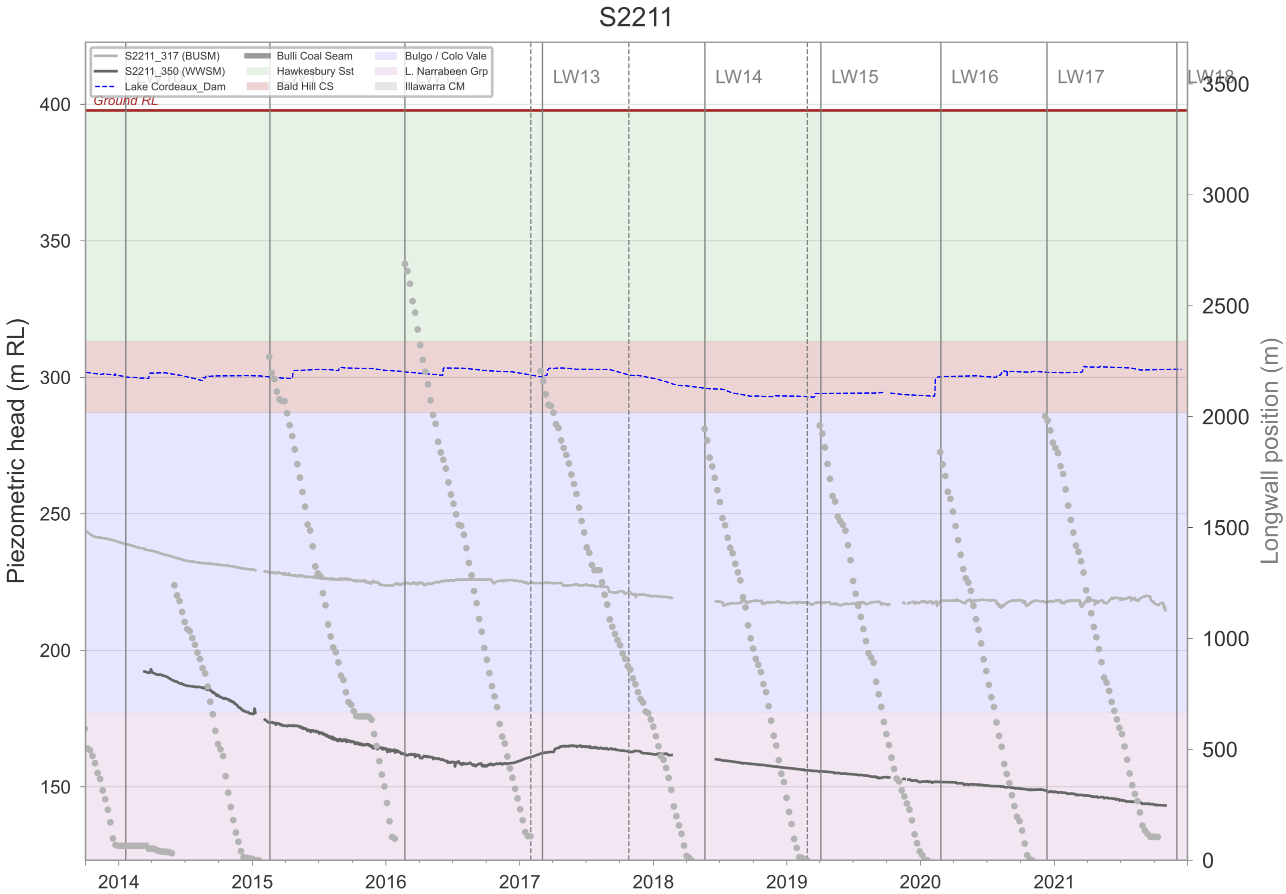


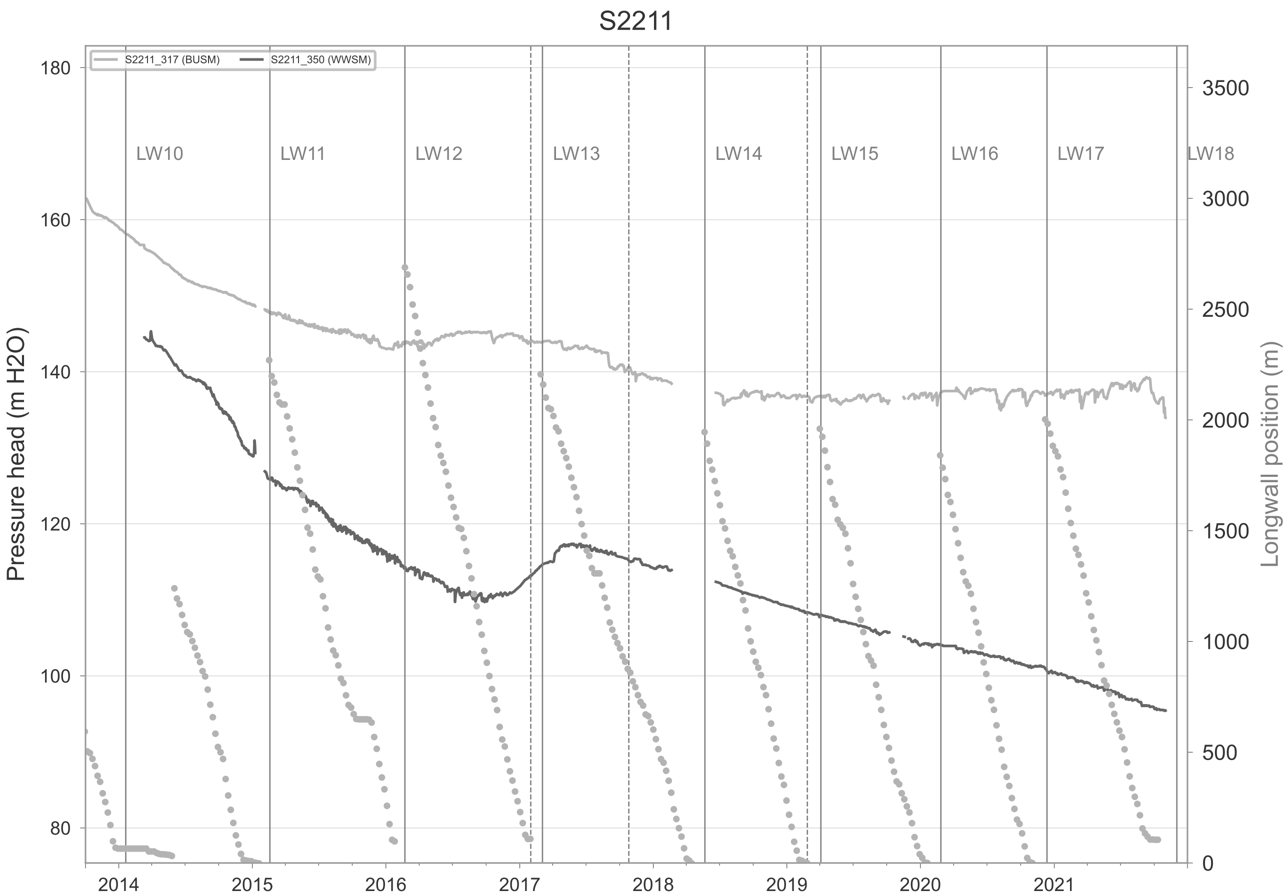
Groundwater hydrographs



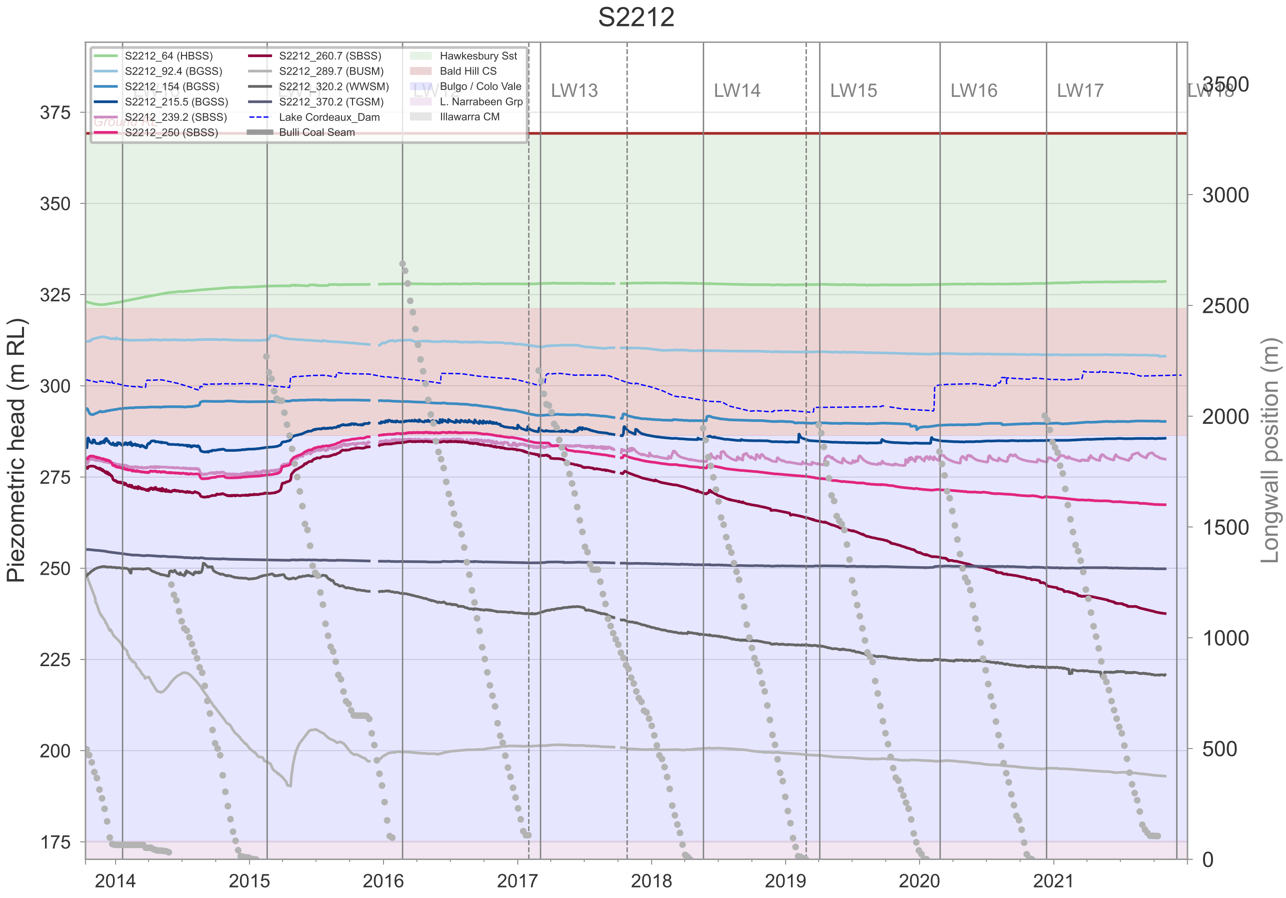


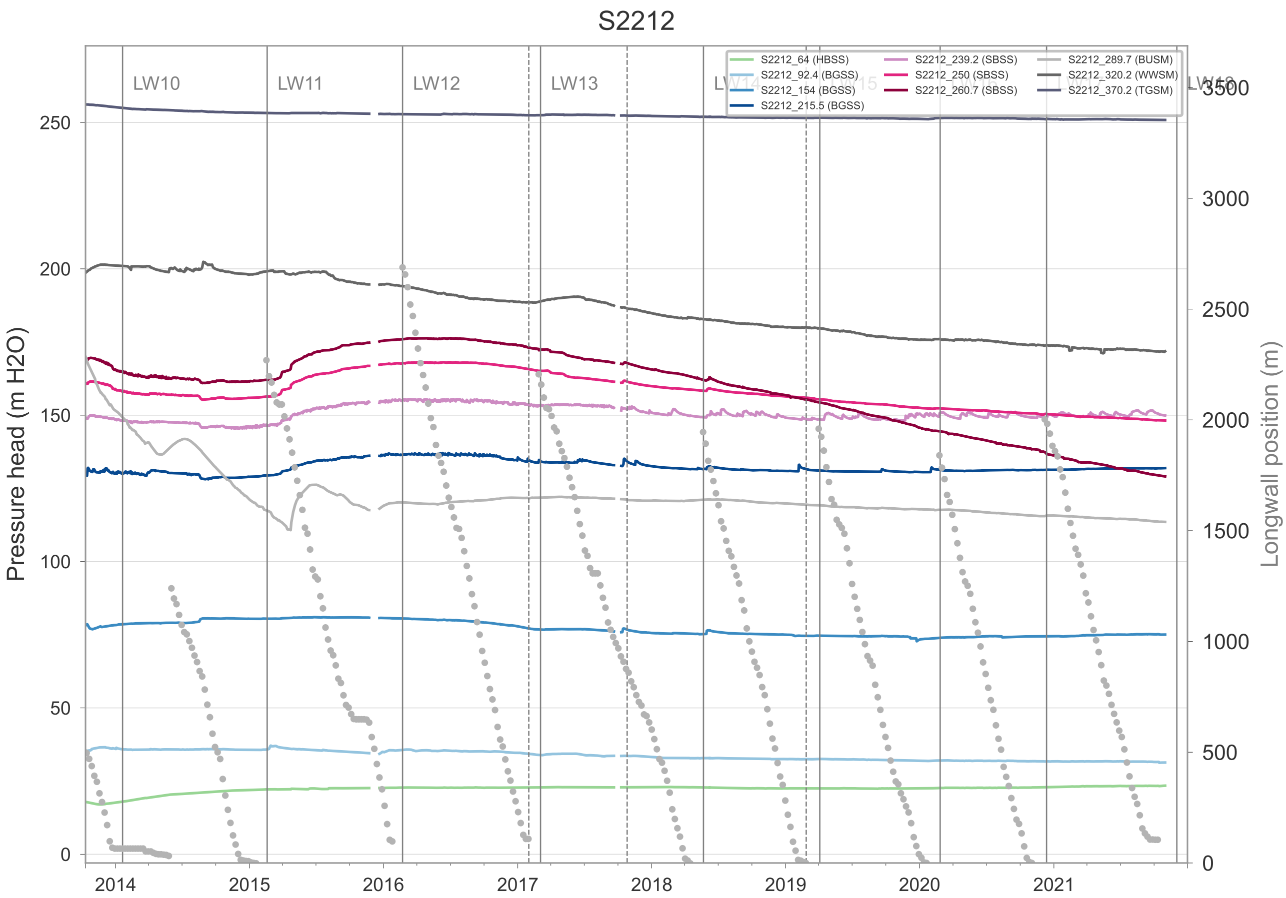
Groundwater hydrographs



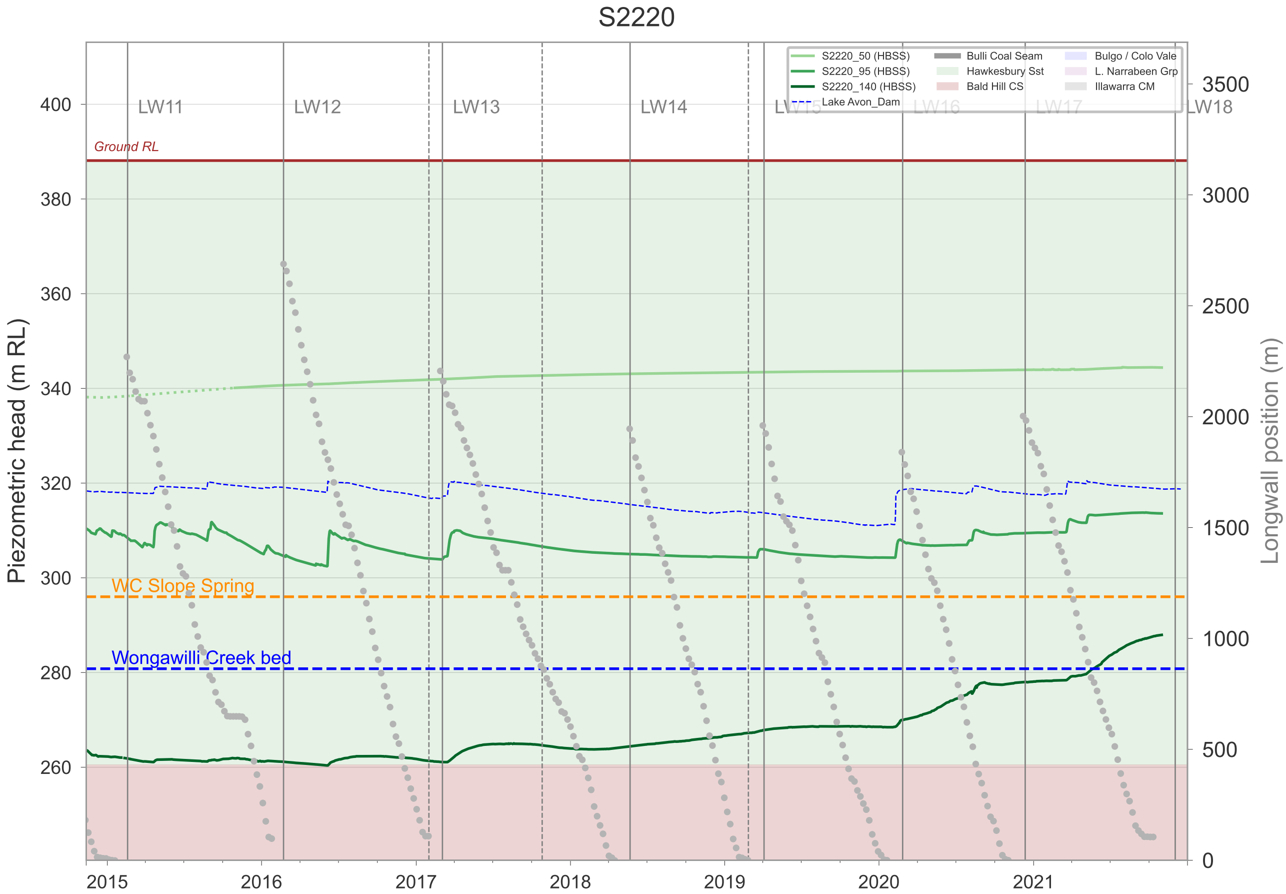


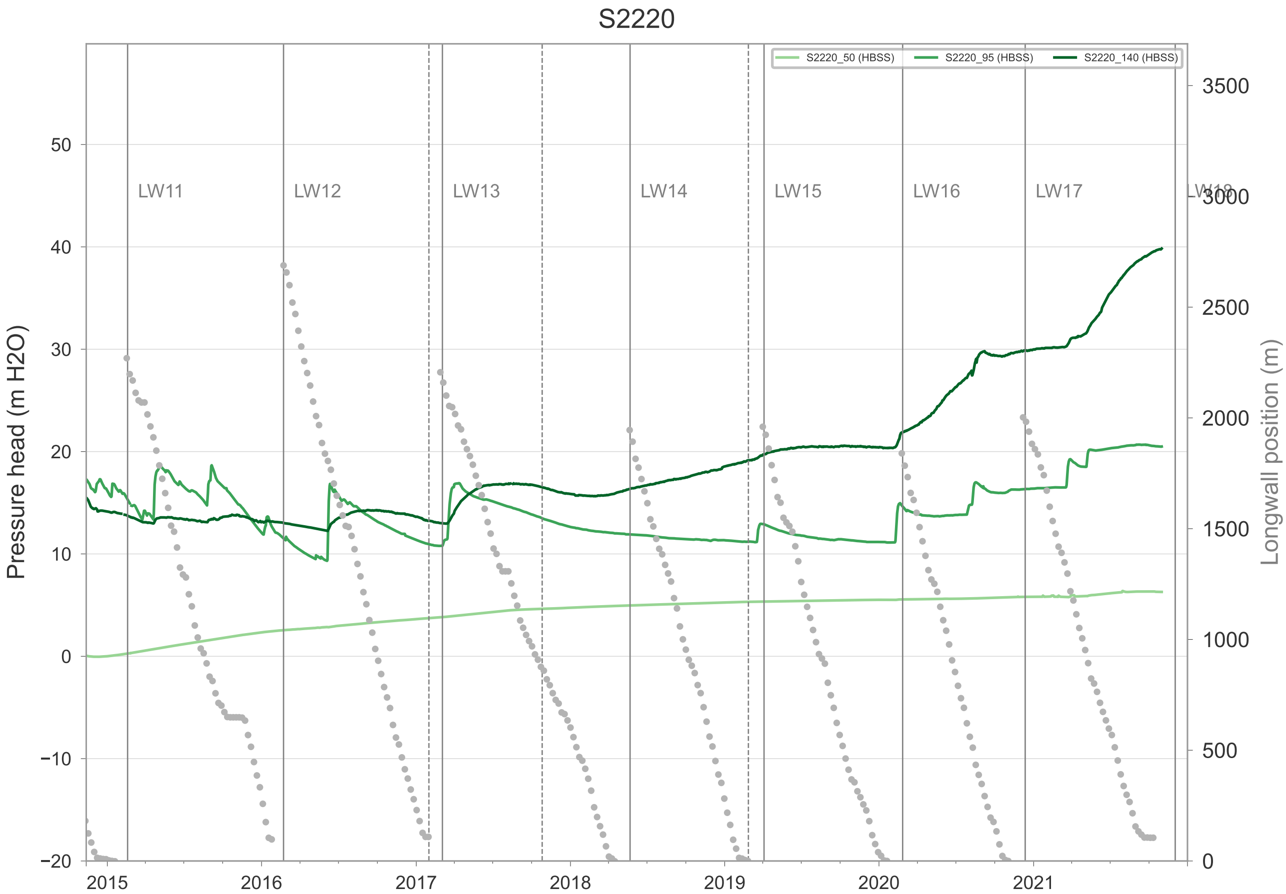
Groundwater hydrographs



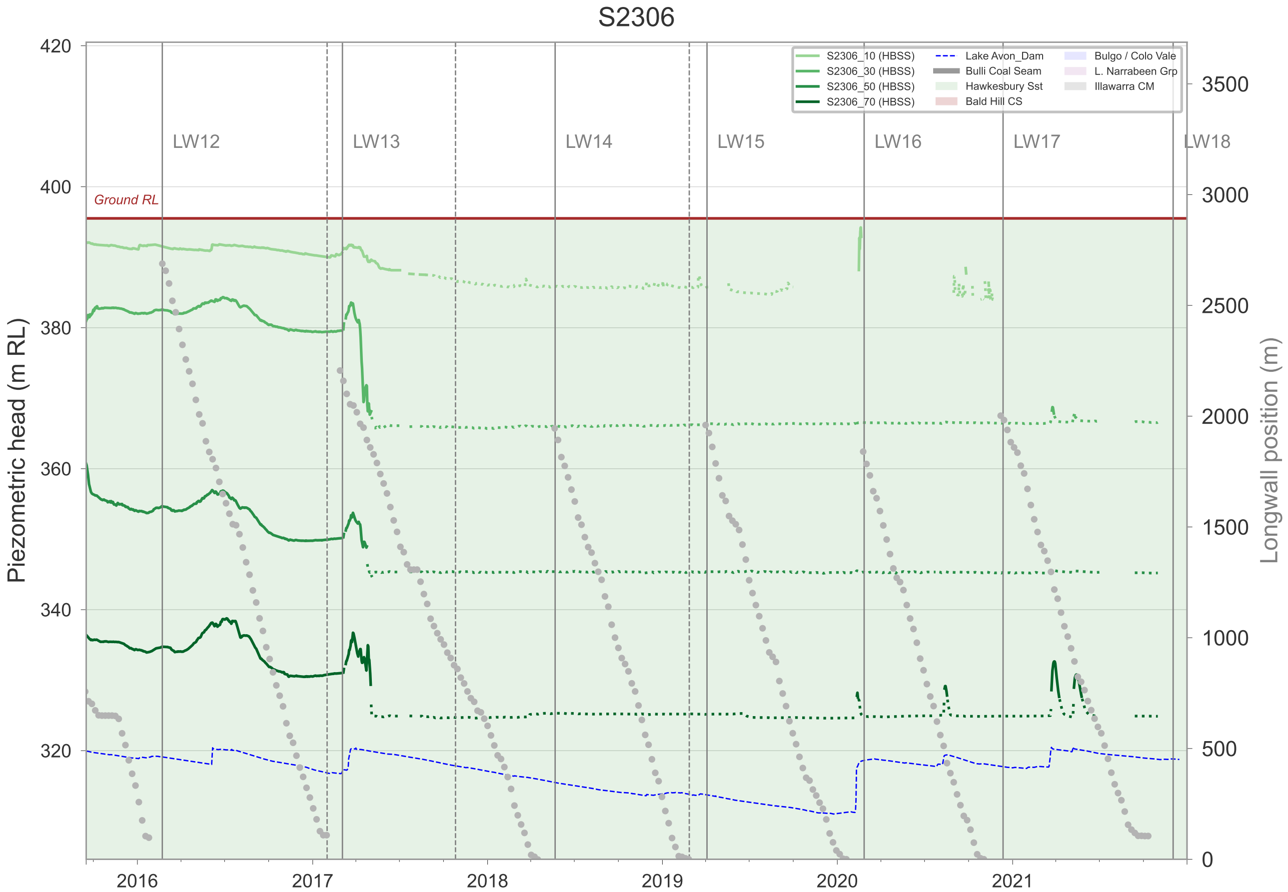


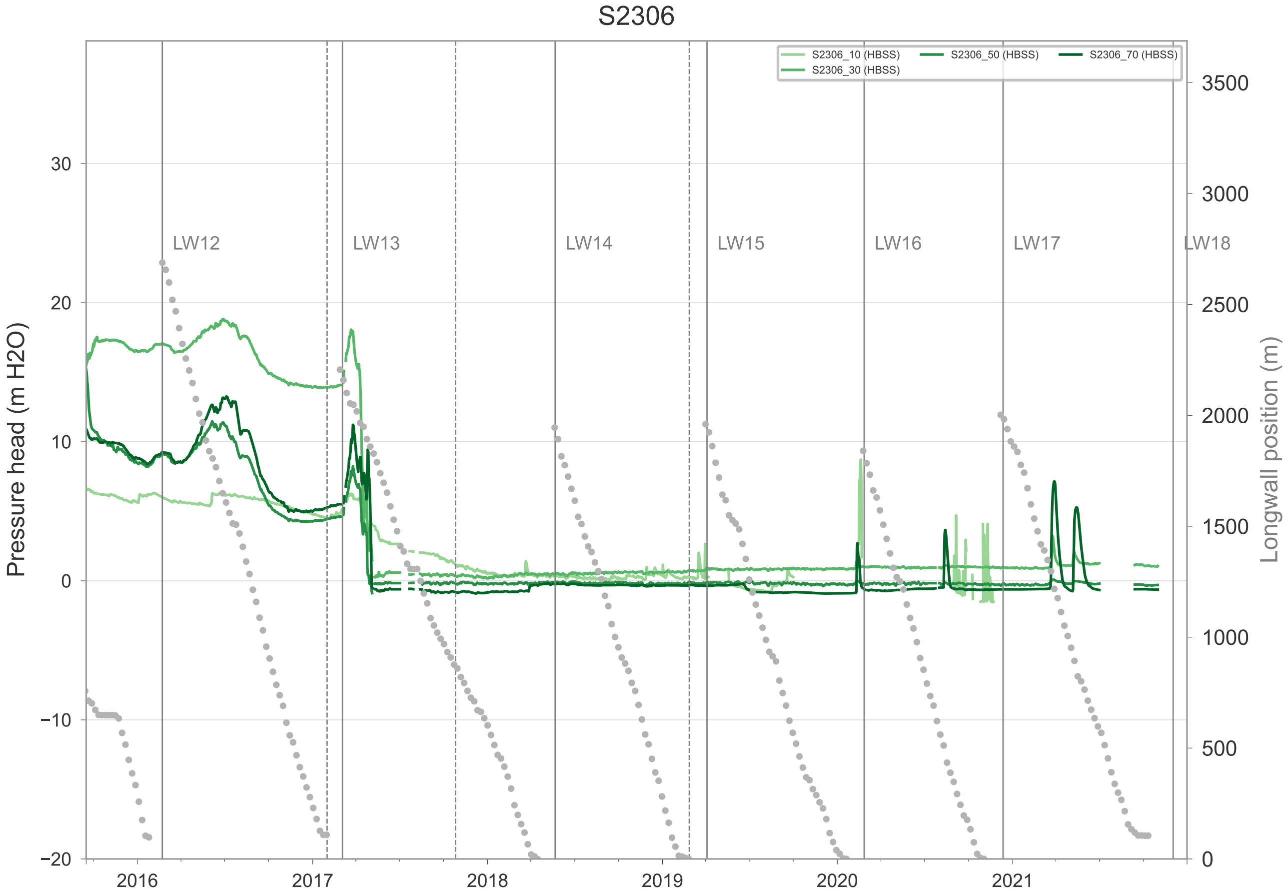
Groundwater hydrographs





Groundwater hydrographs





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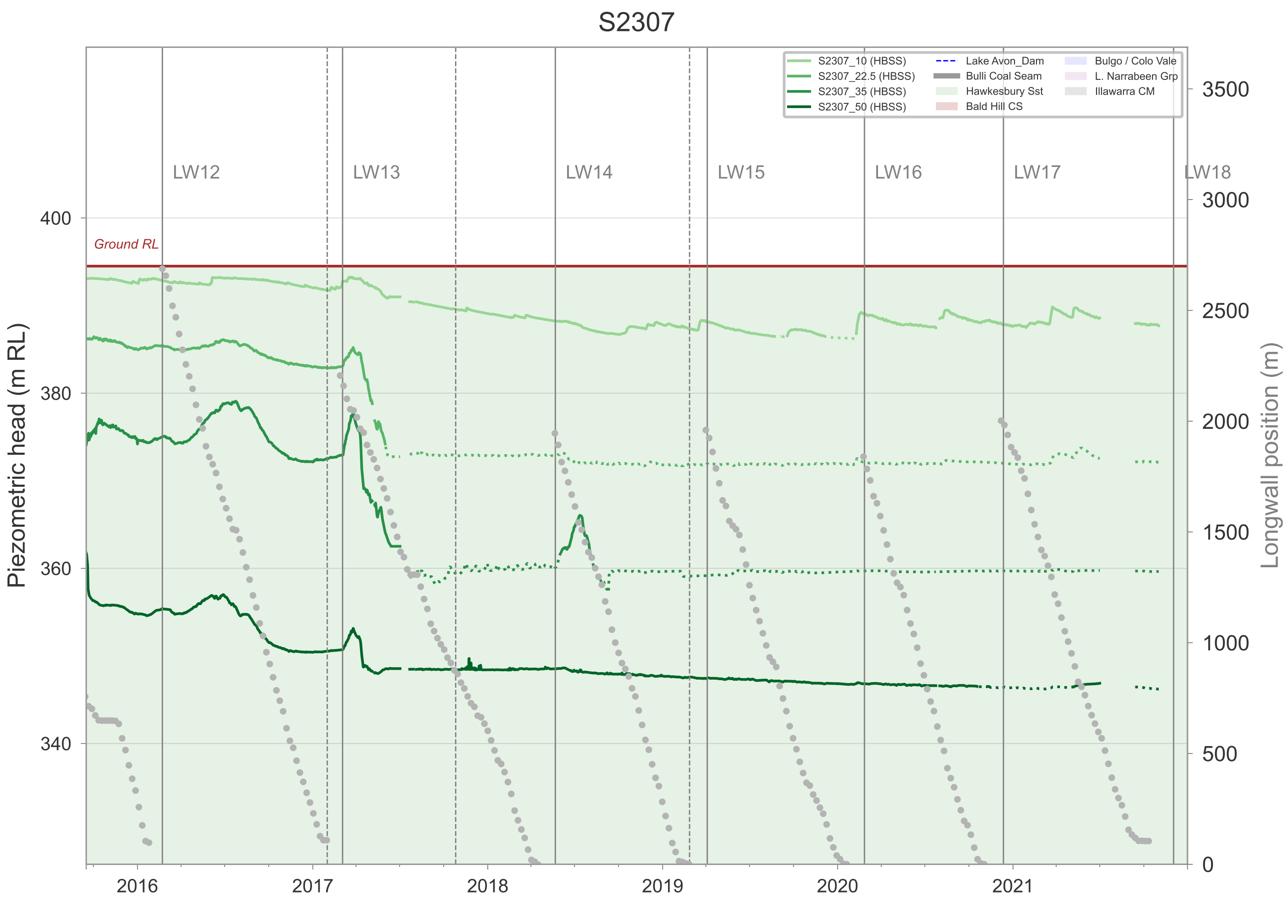
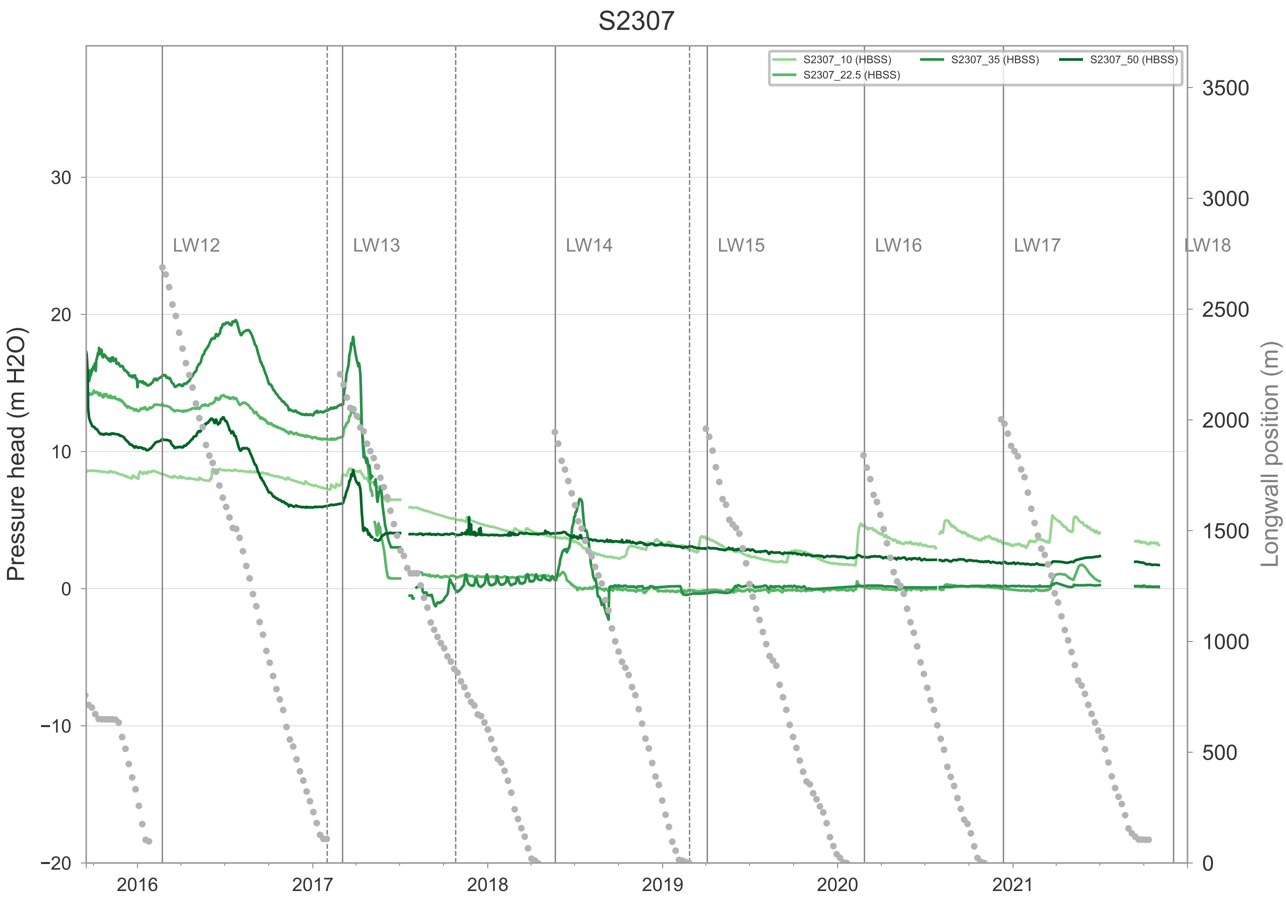
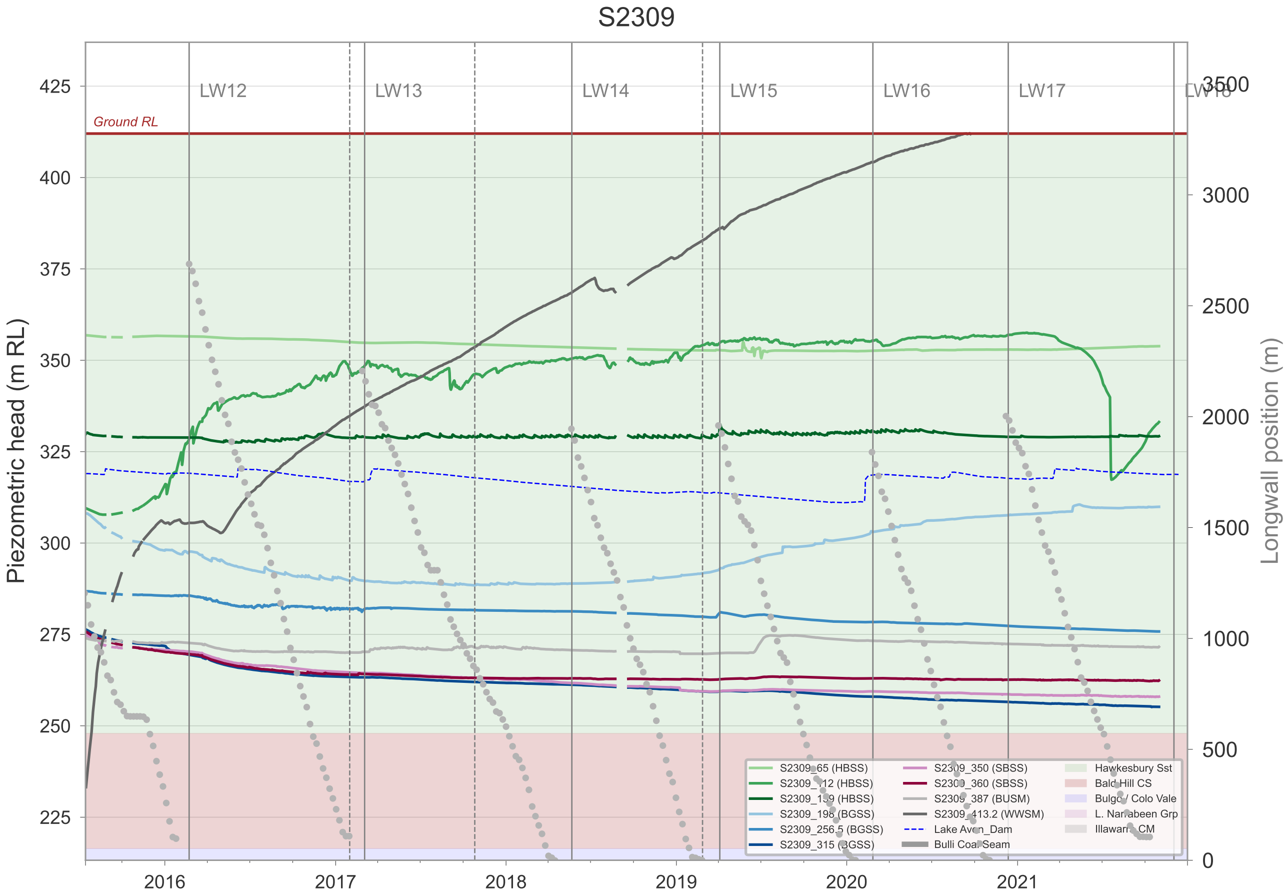
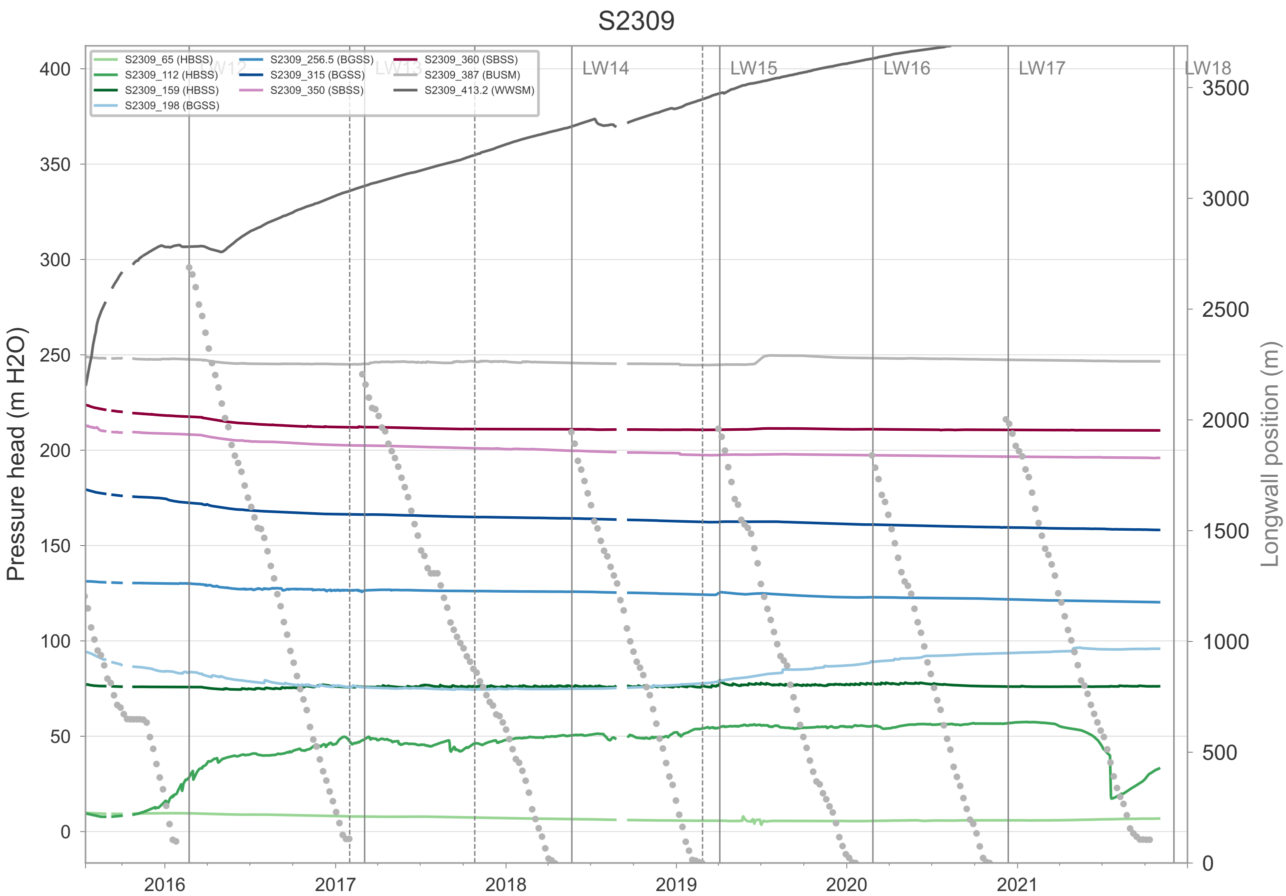


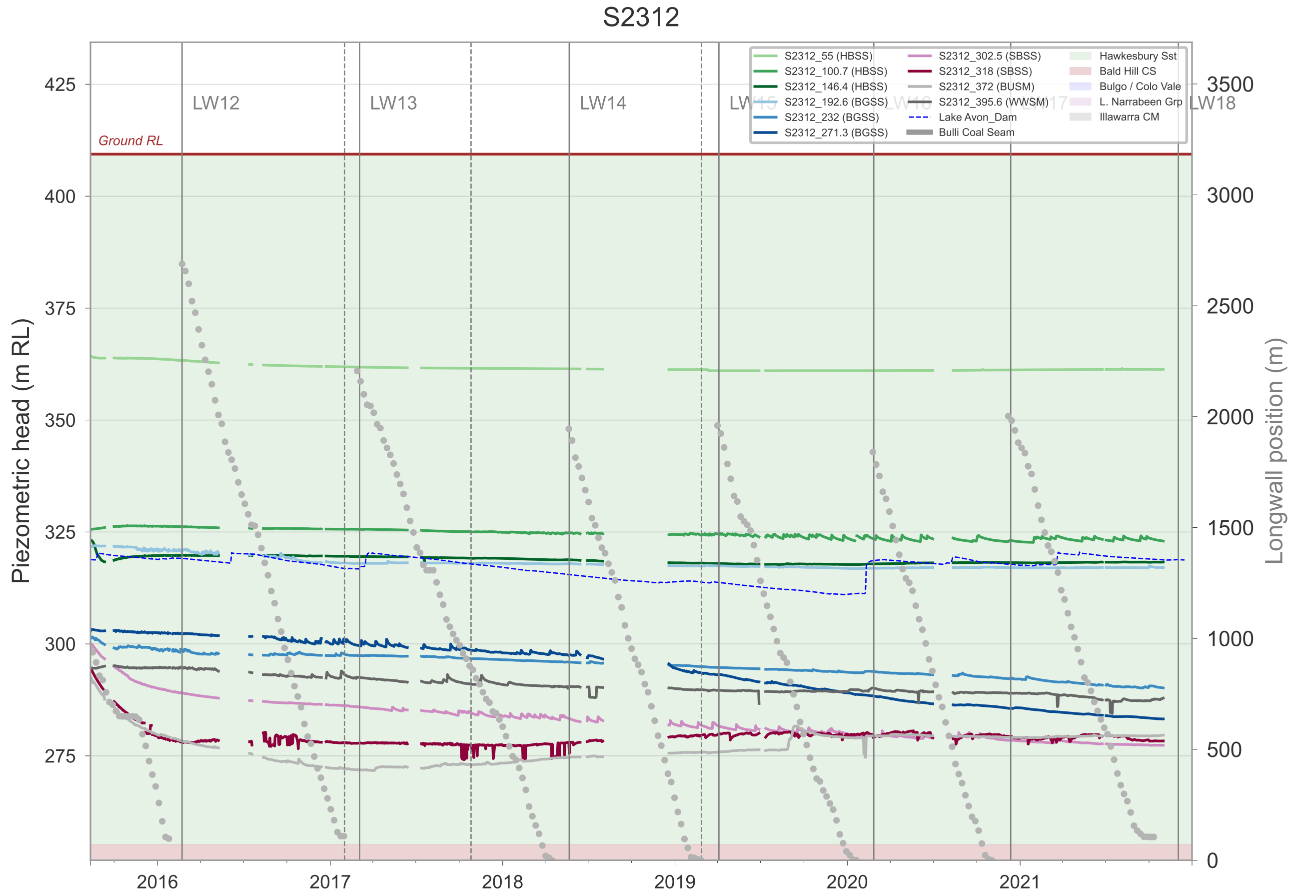


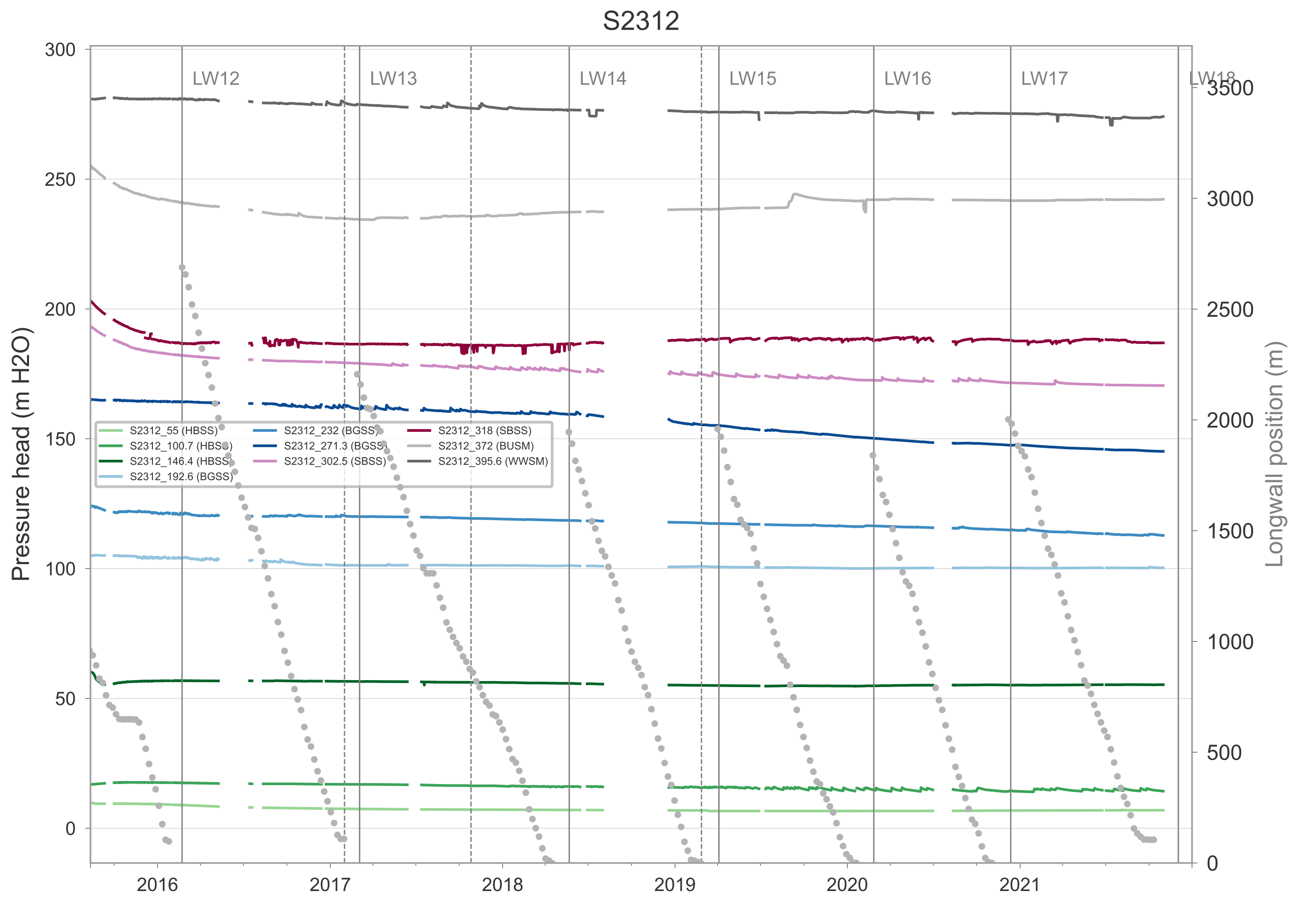
Groundwater hydrographs





Groundwater hydrographs





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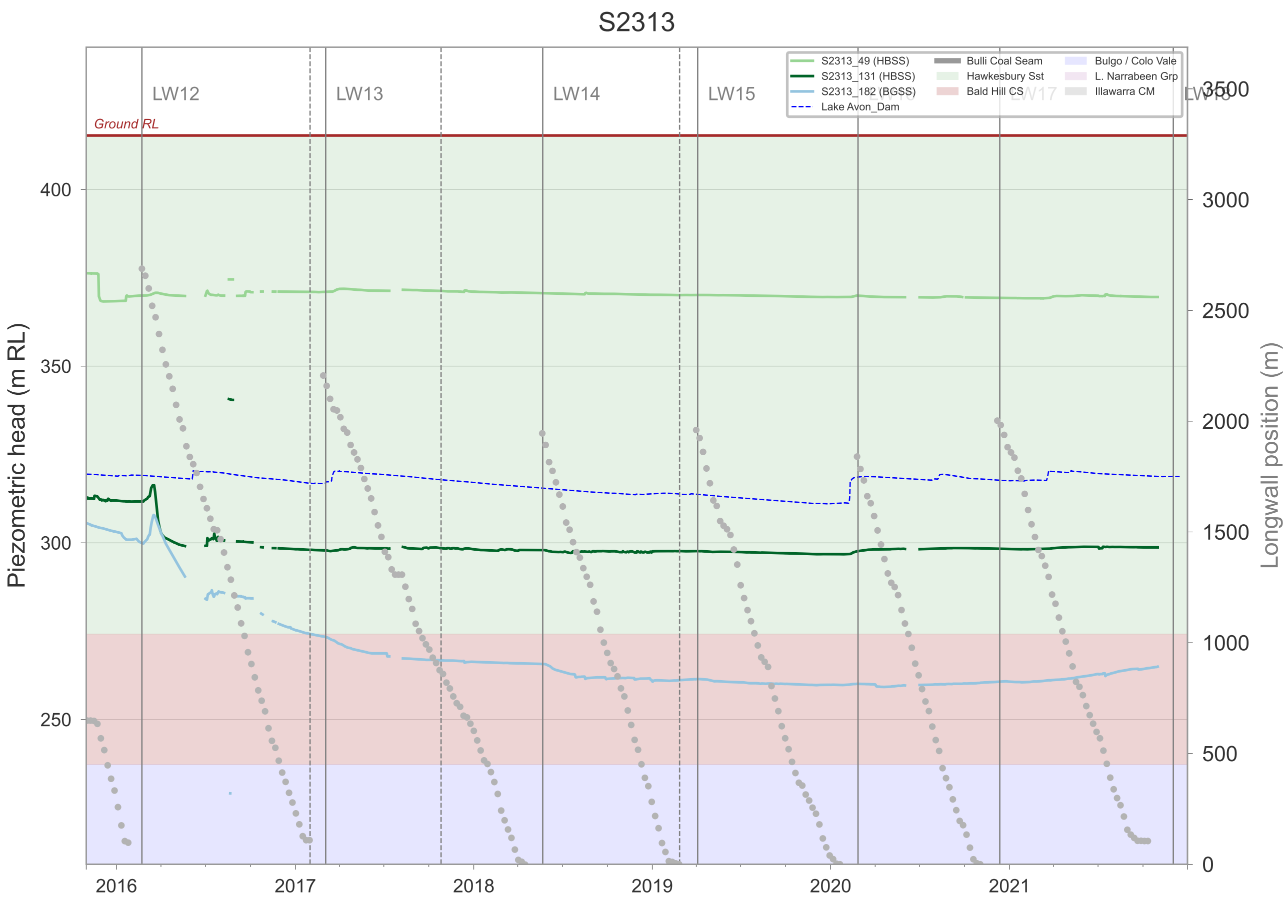

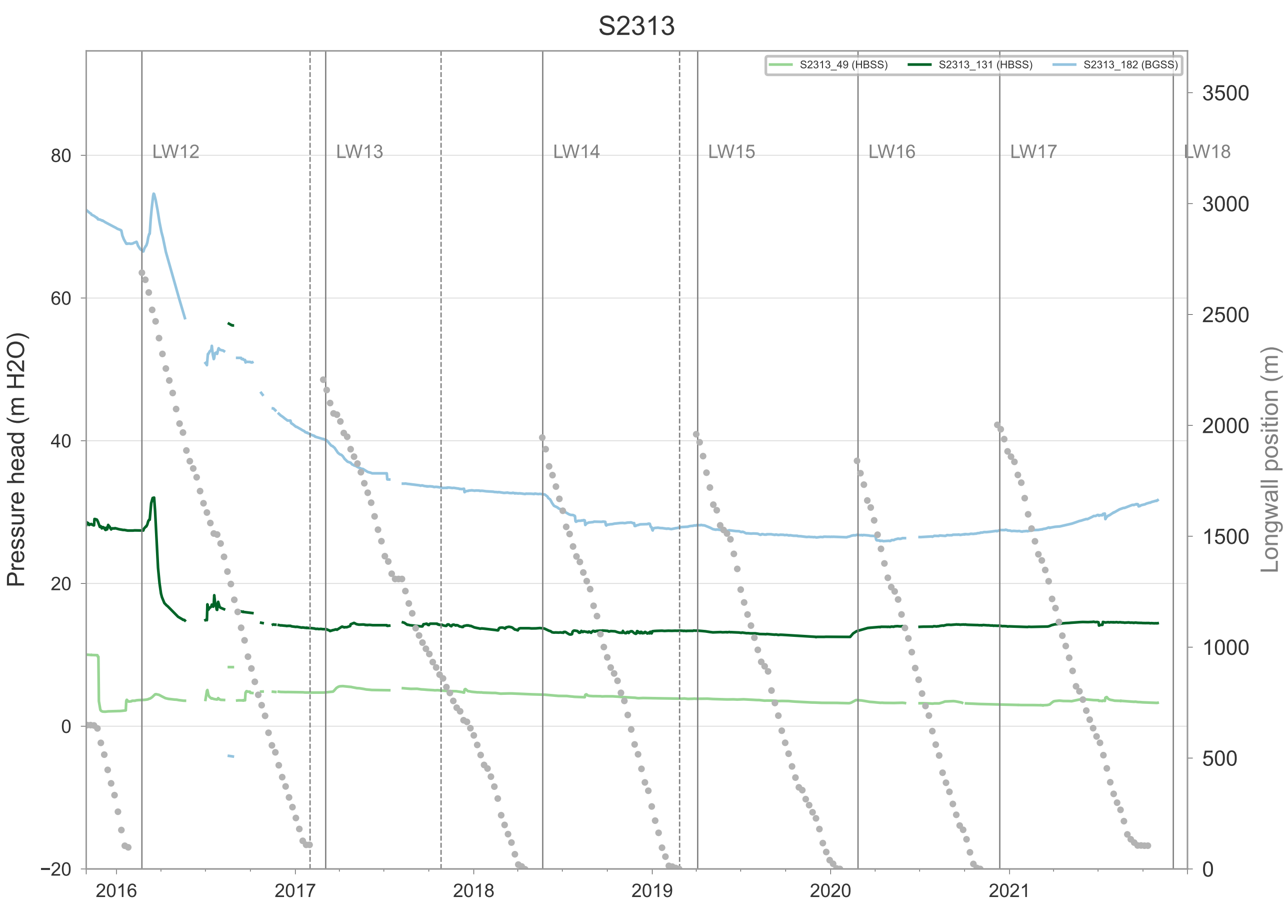

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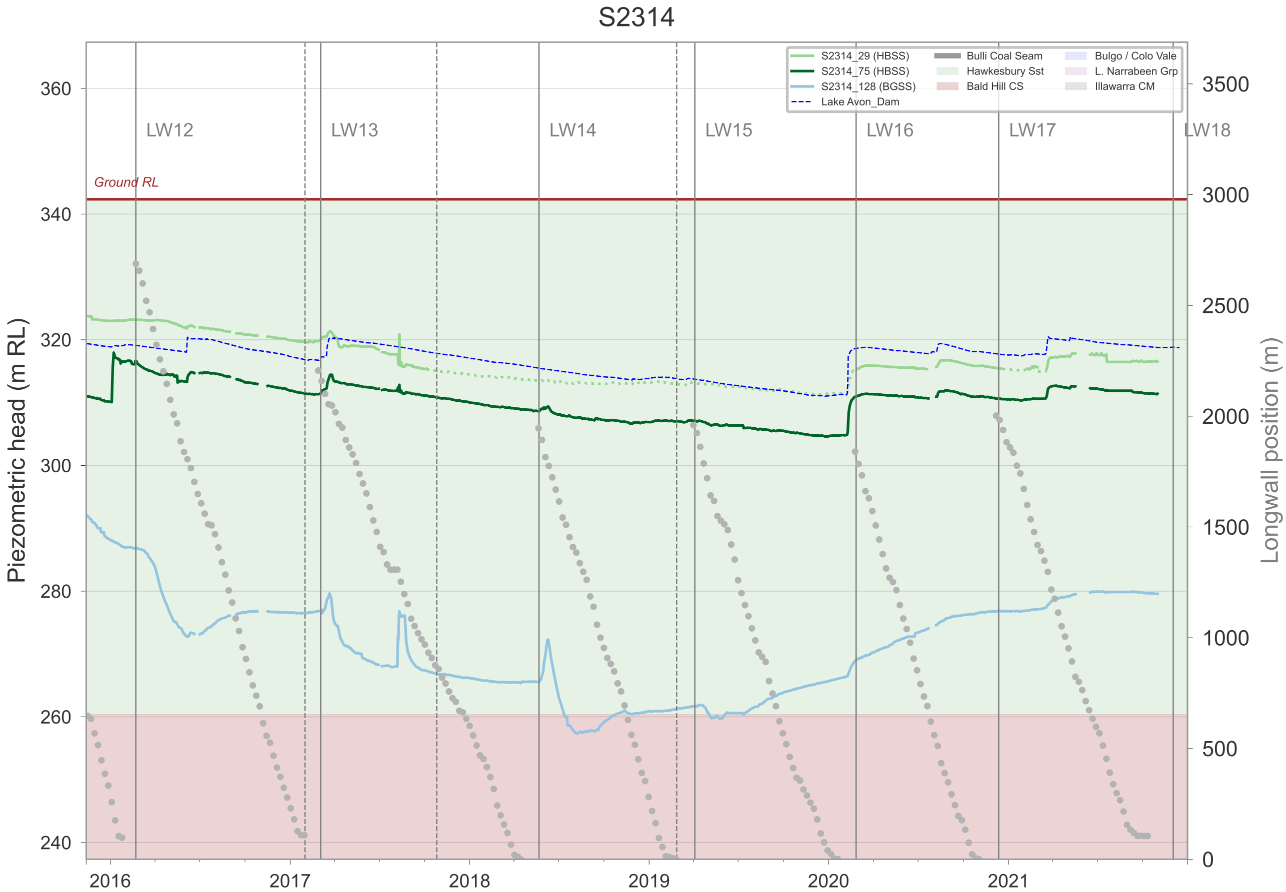
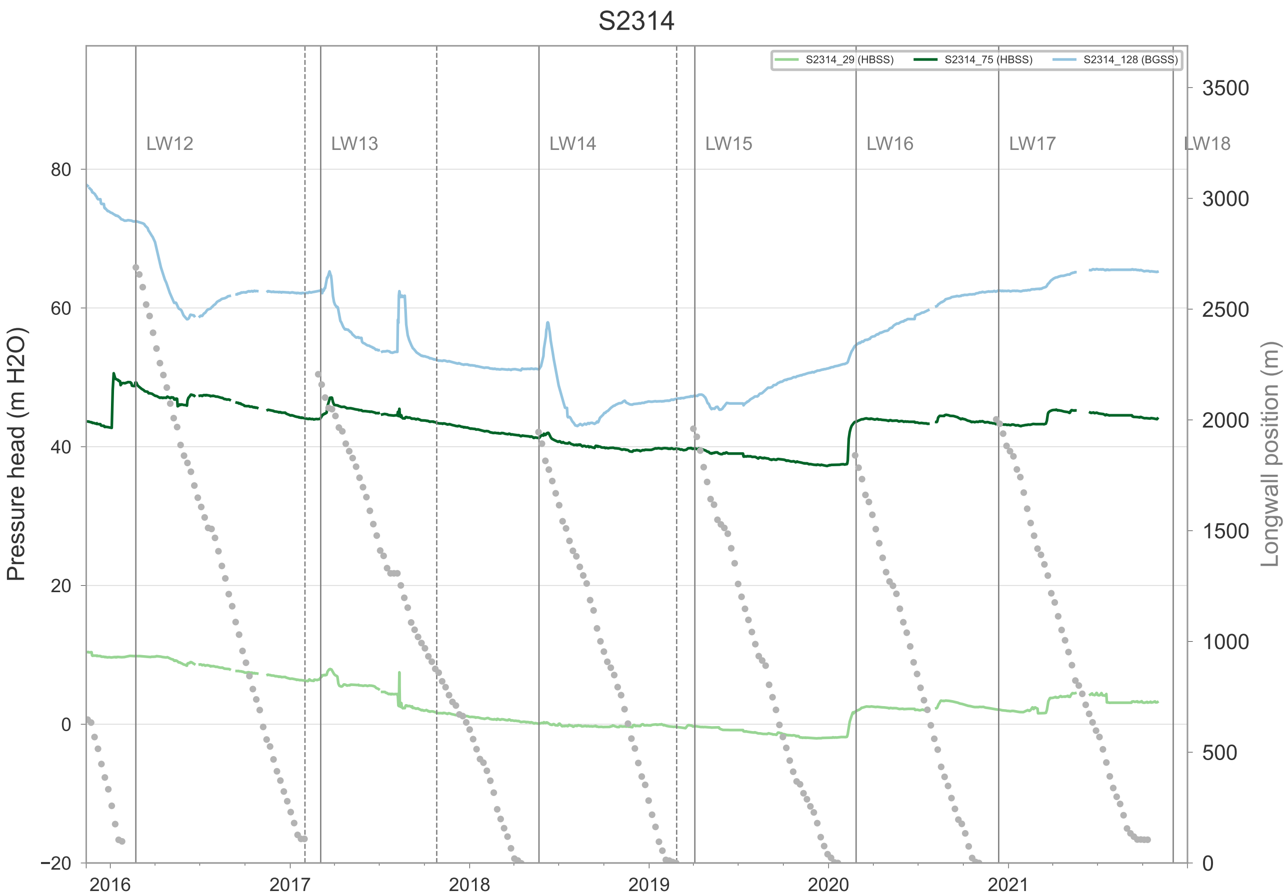
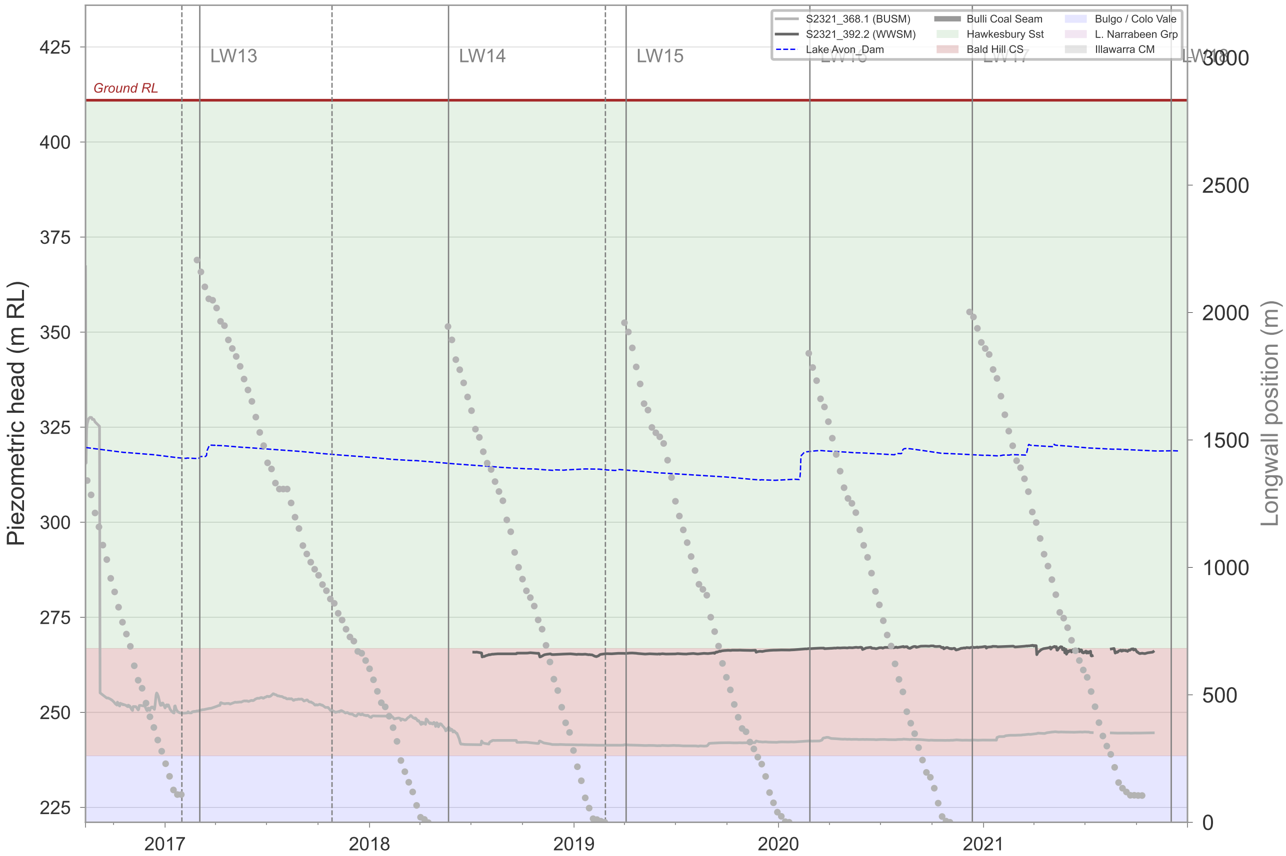




Groundwater hydrographs

S2321



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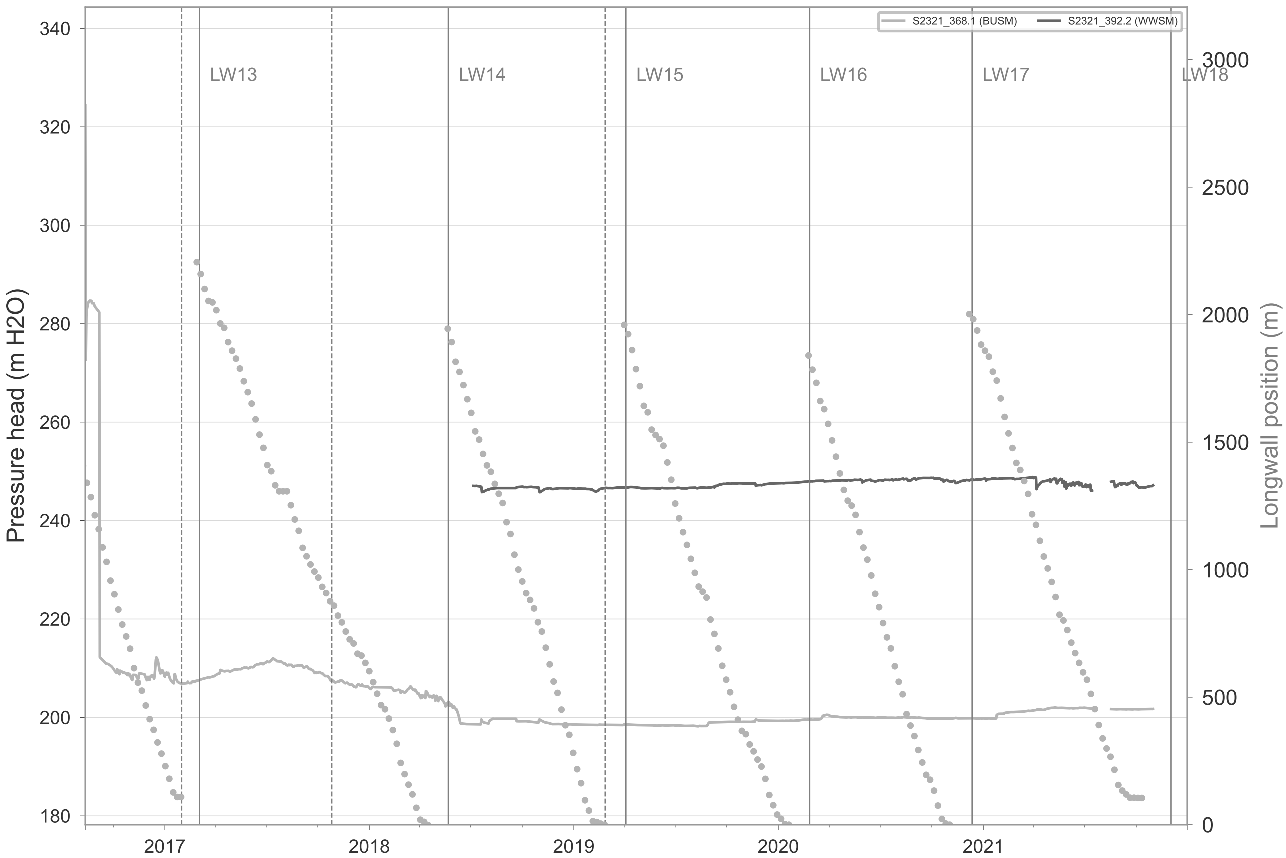
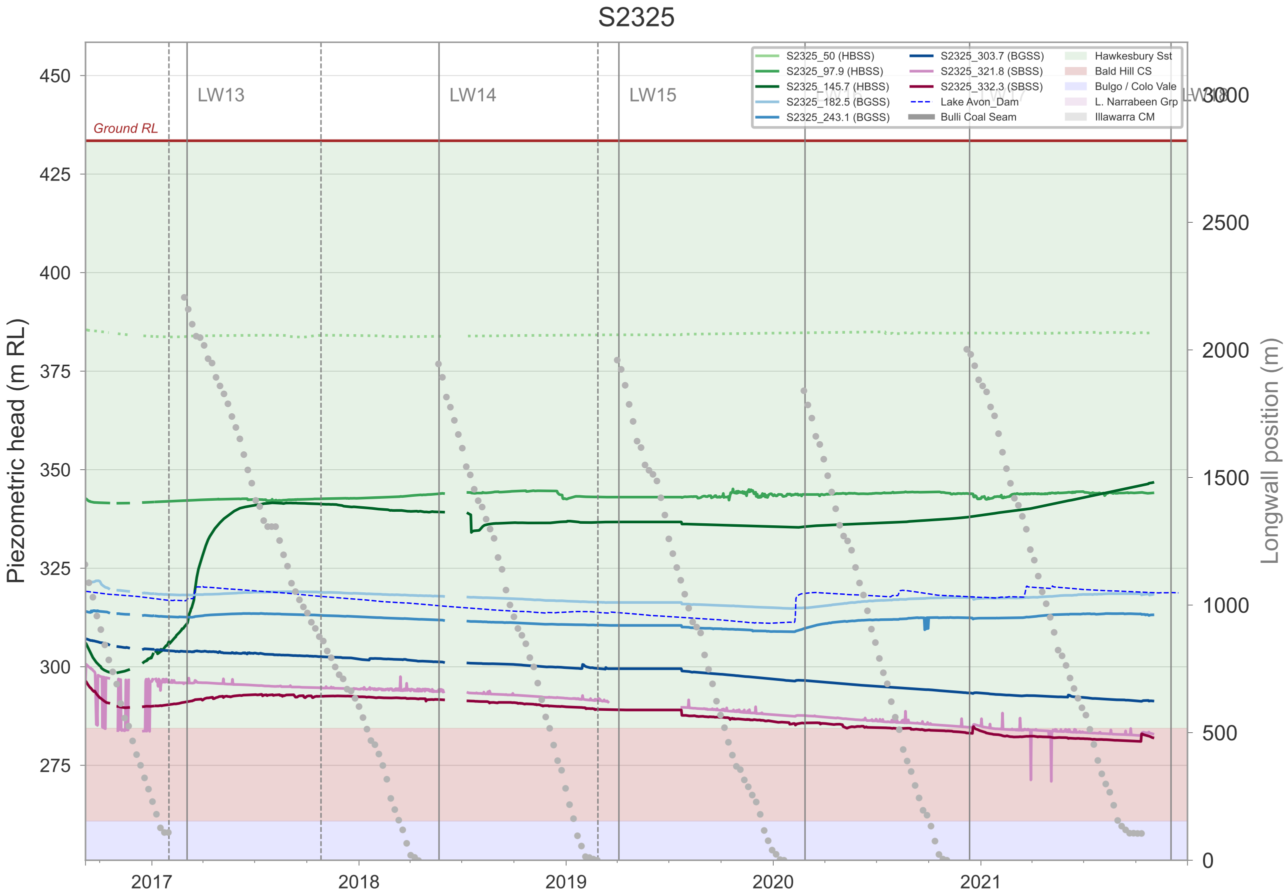
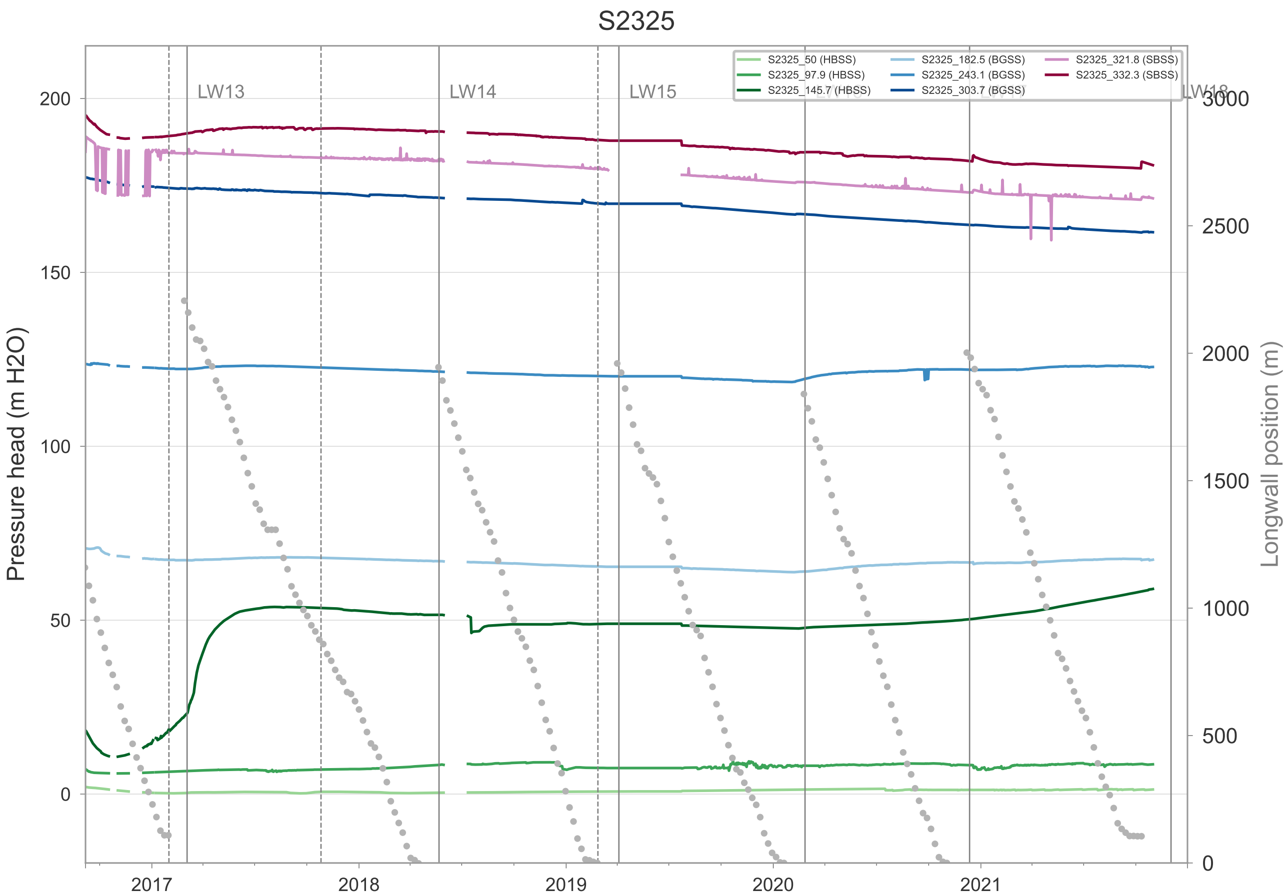
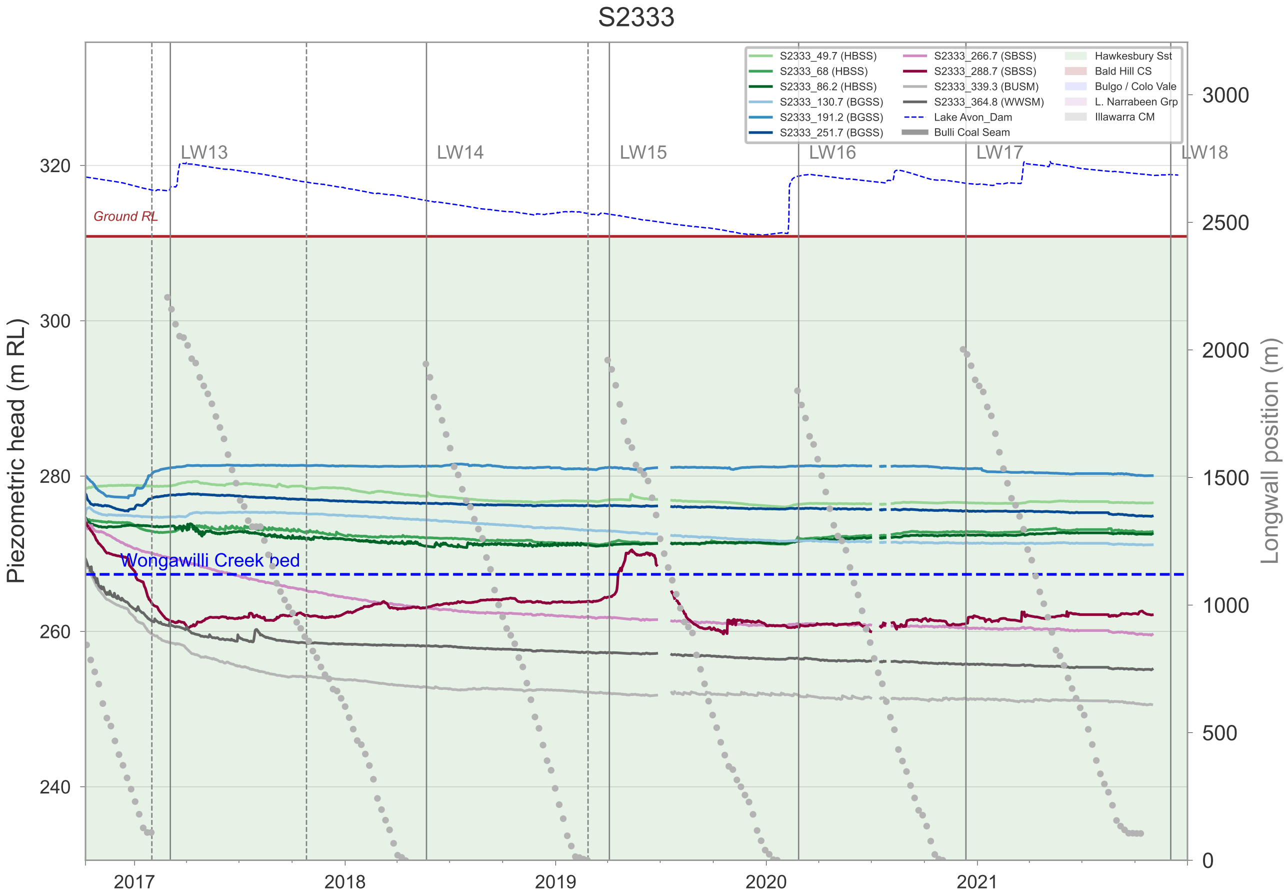


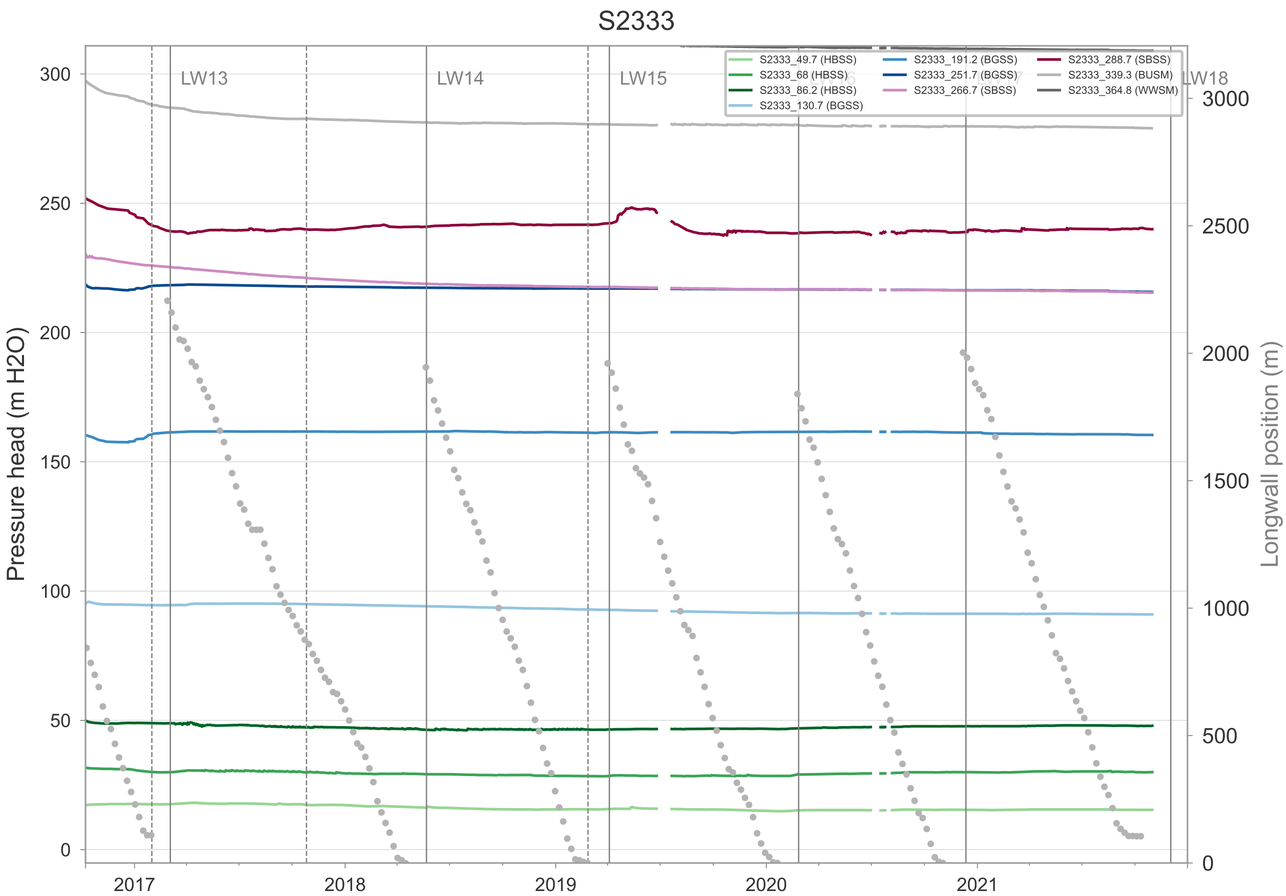
Groundwater hydrographs





Groundwater hydrographs





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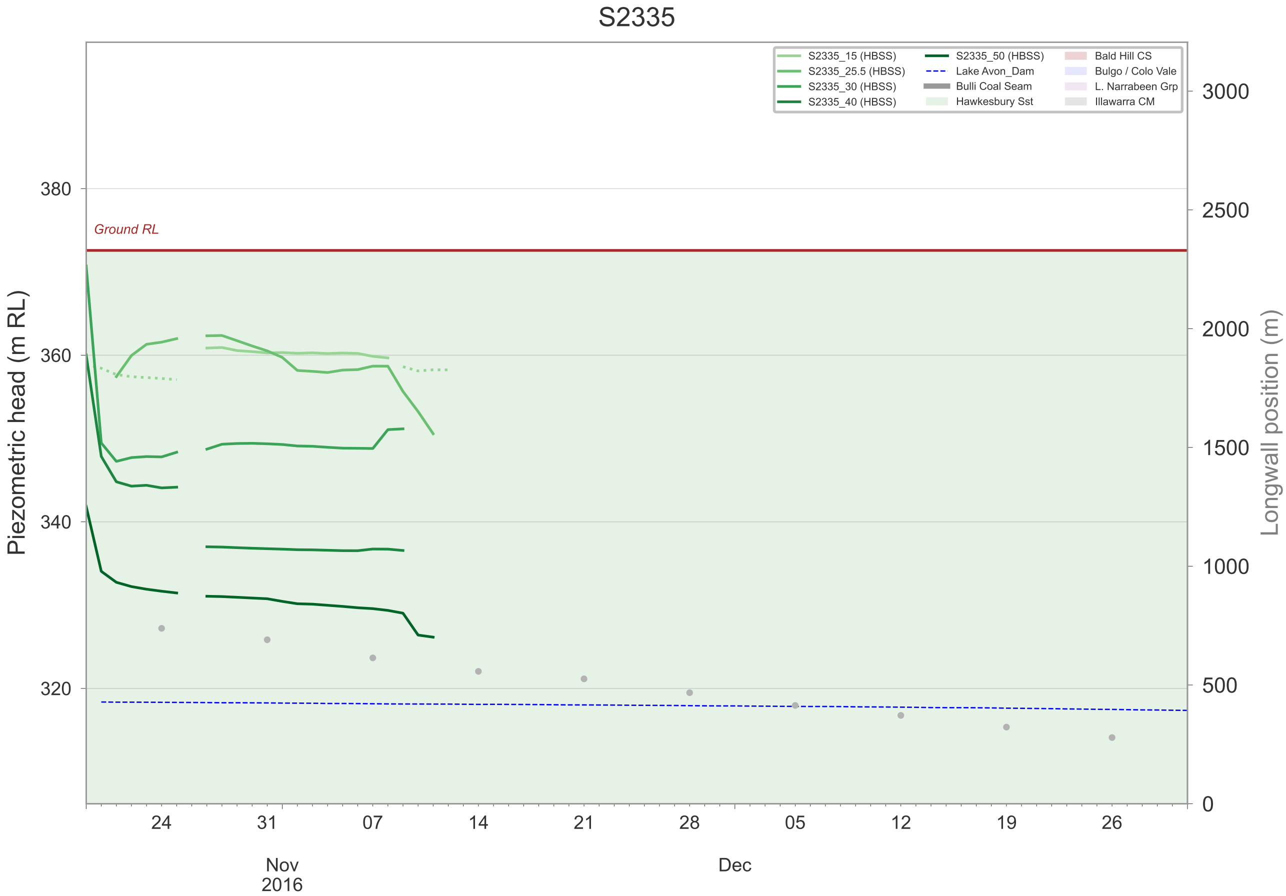

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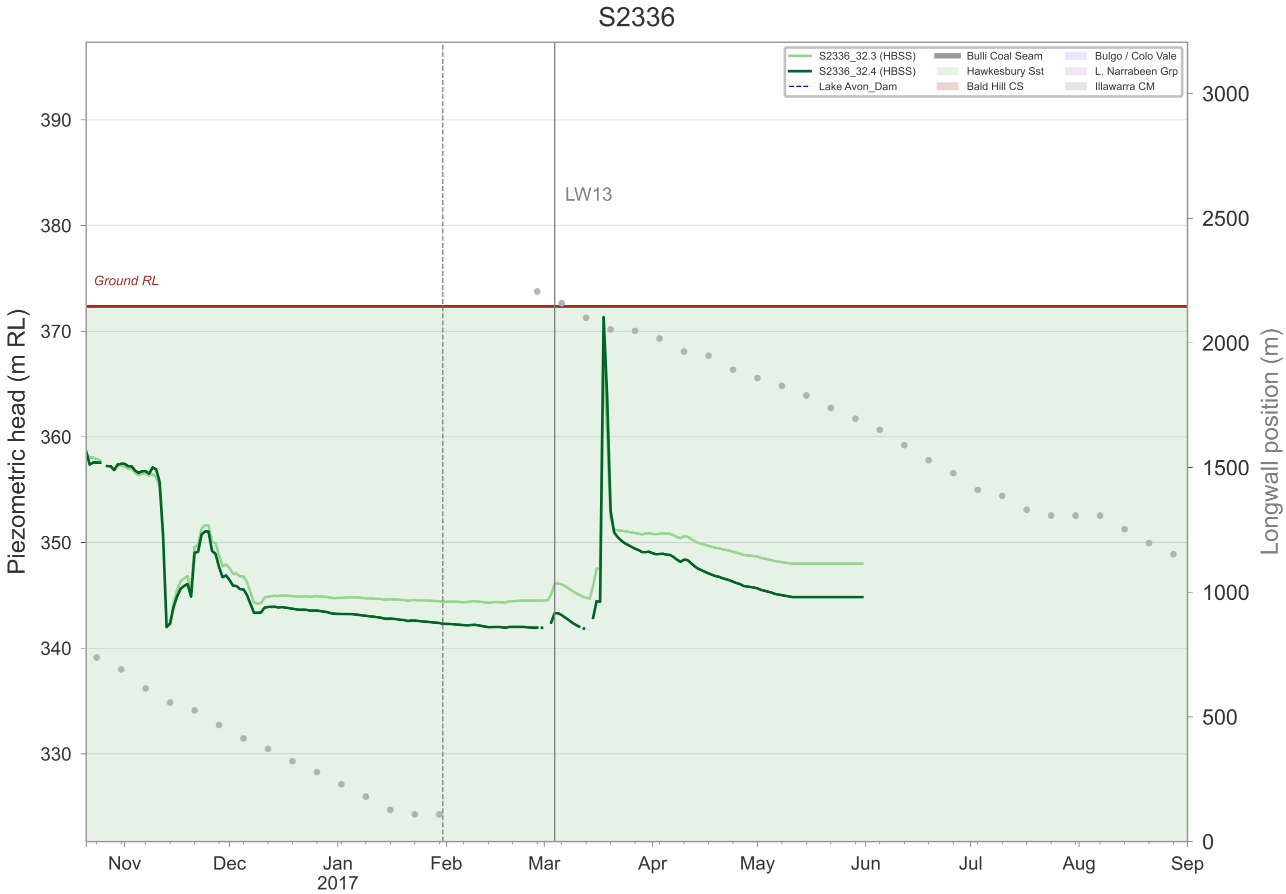
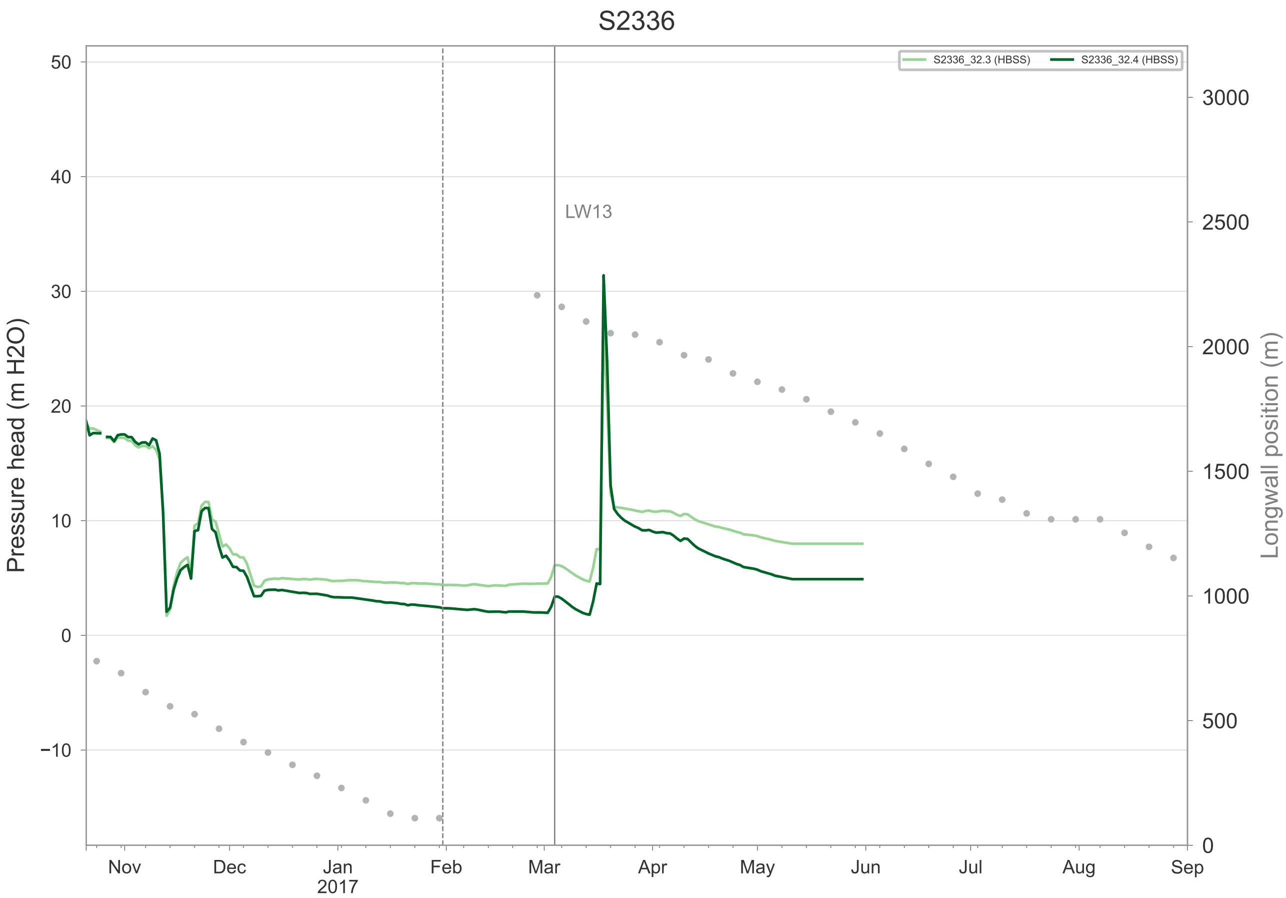
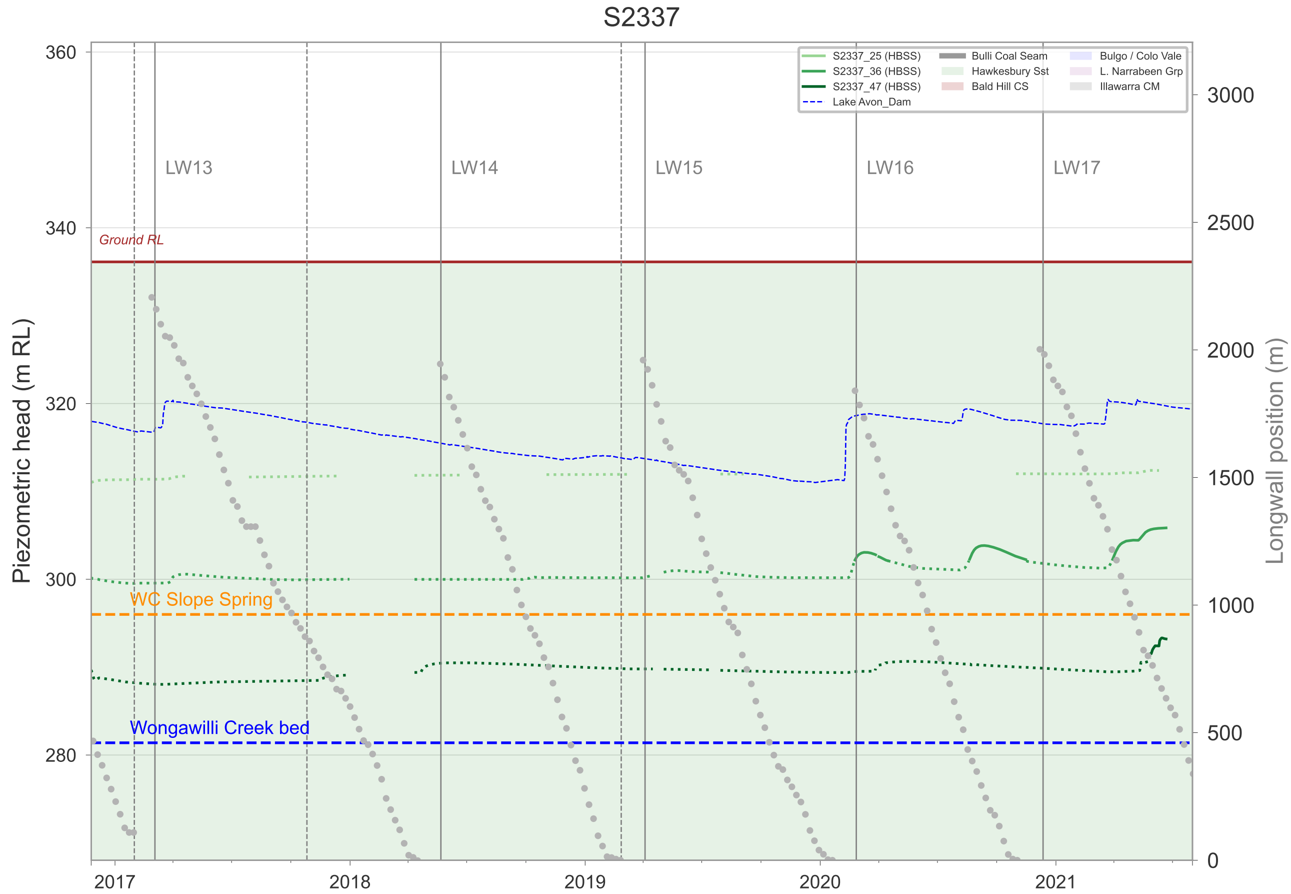
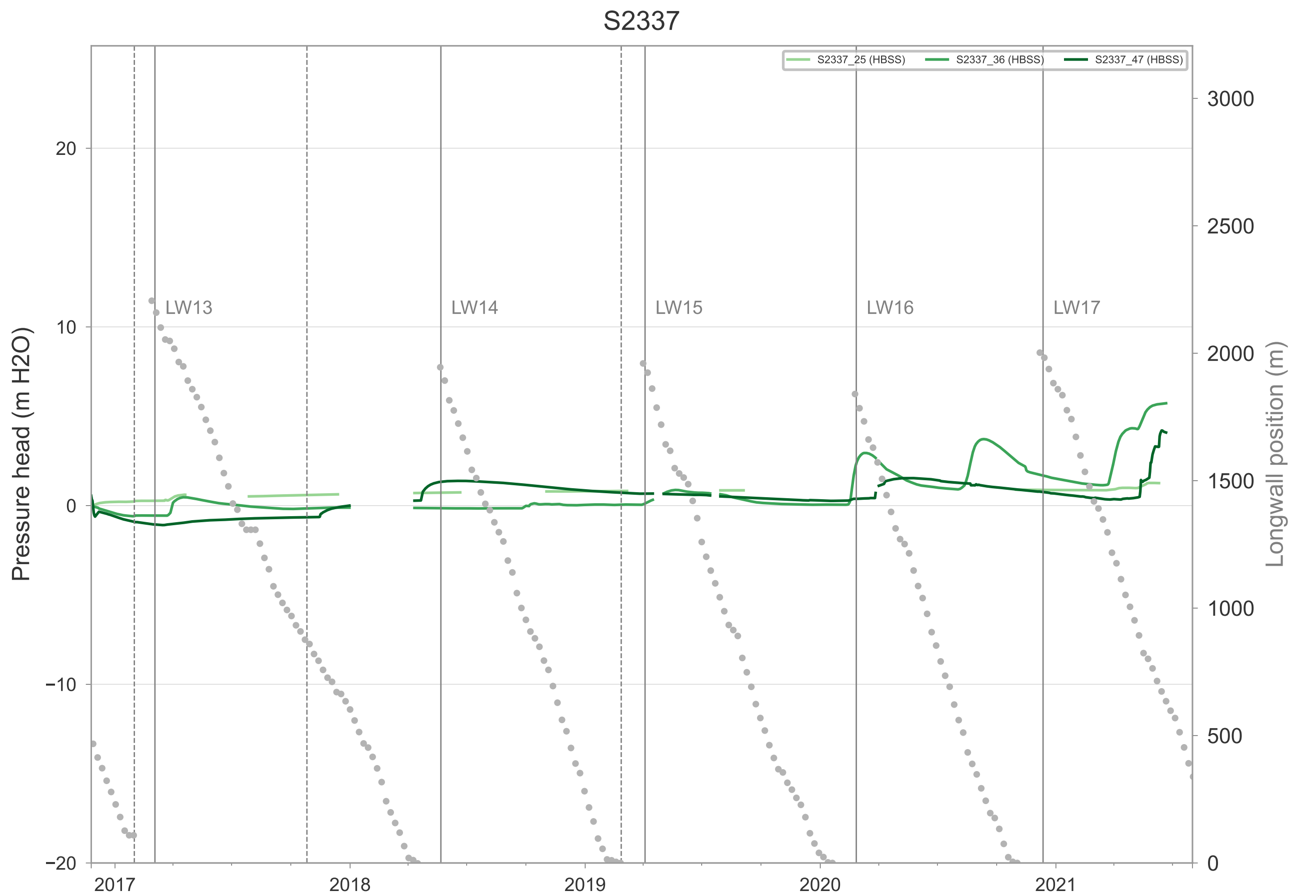


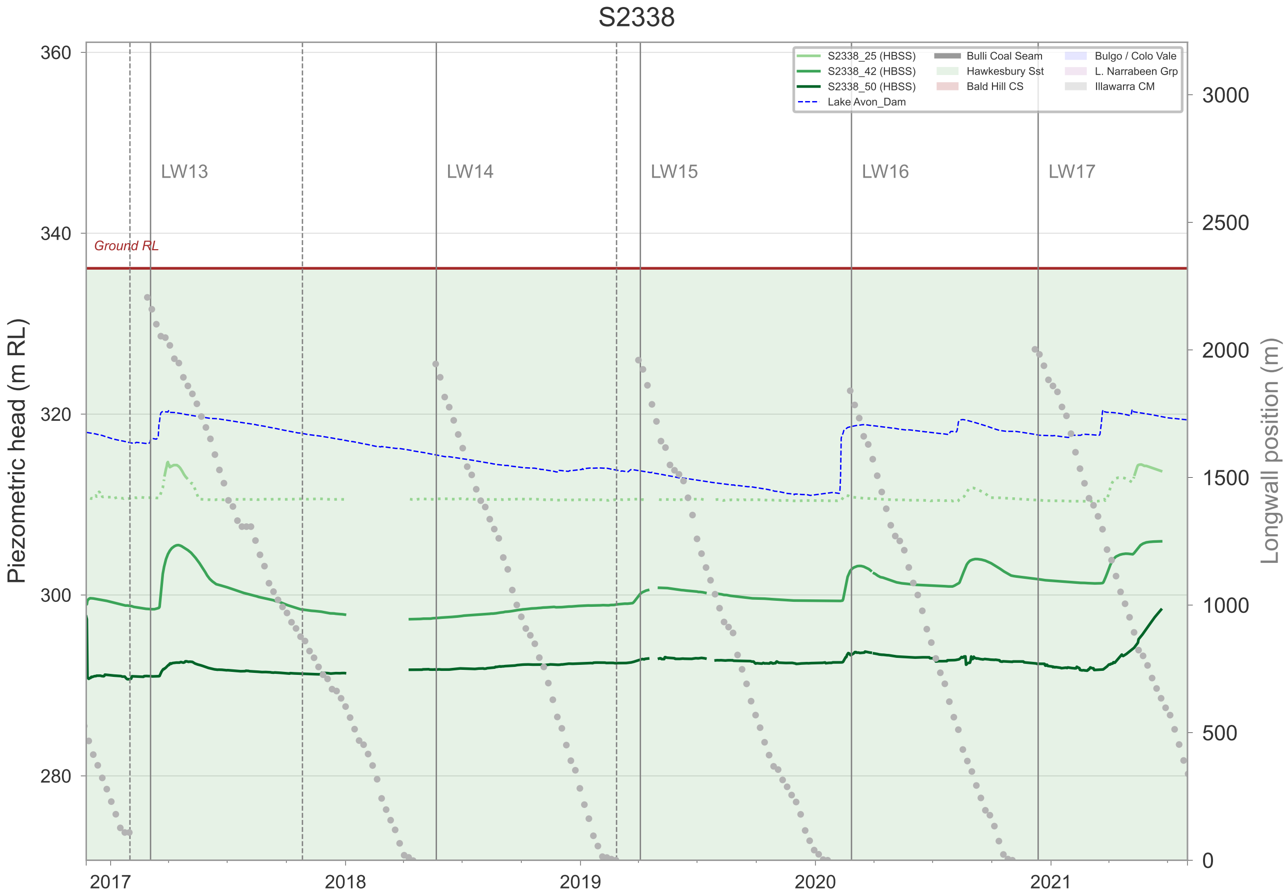


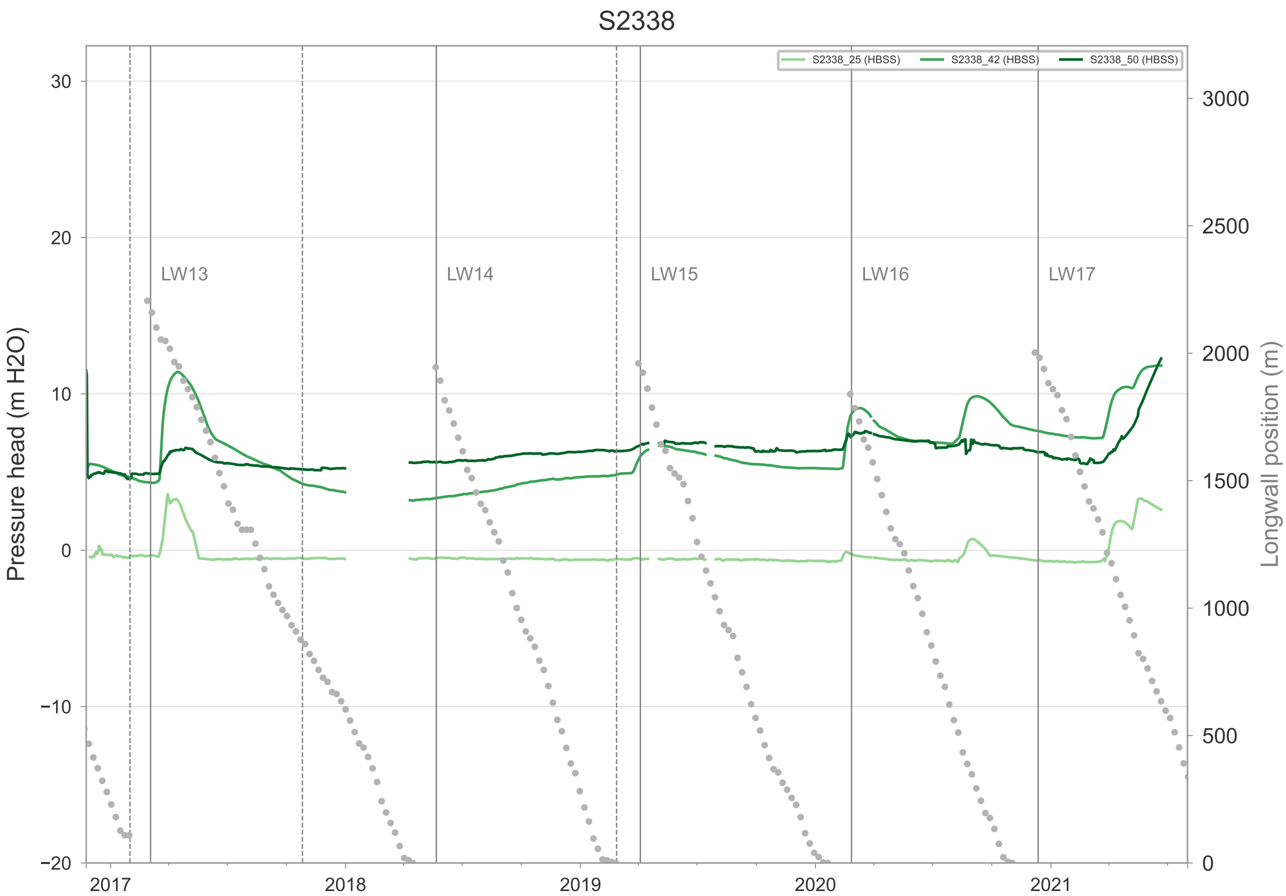
Groundwater hydrographs



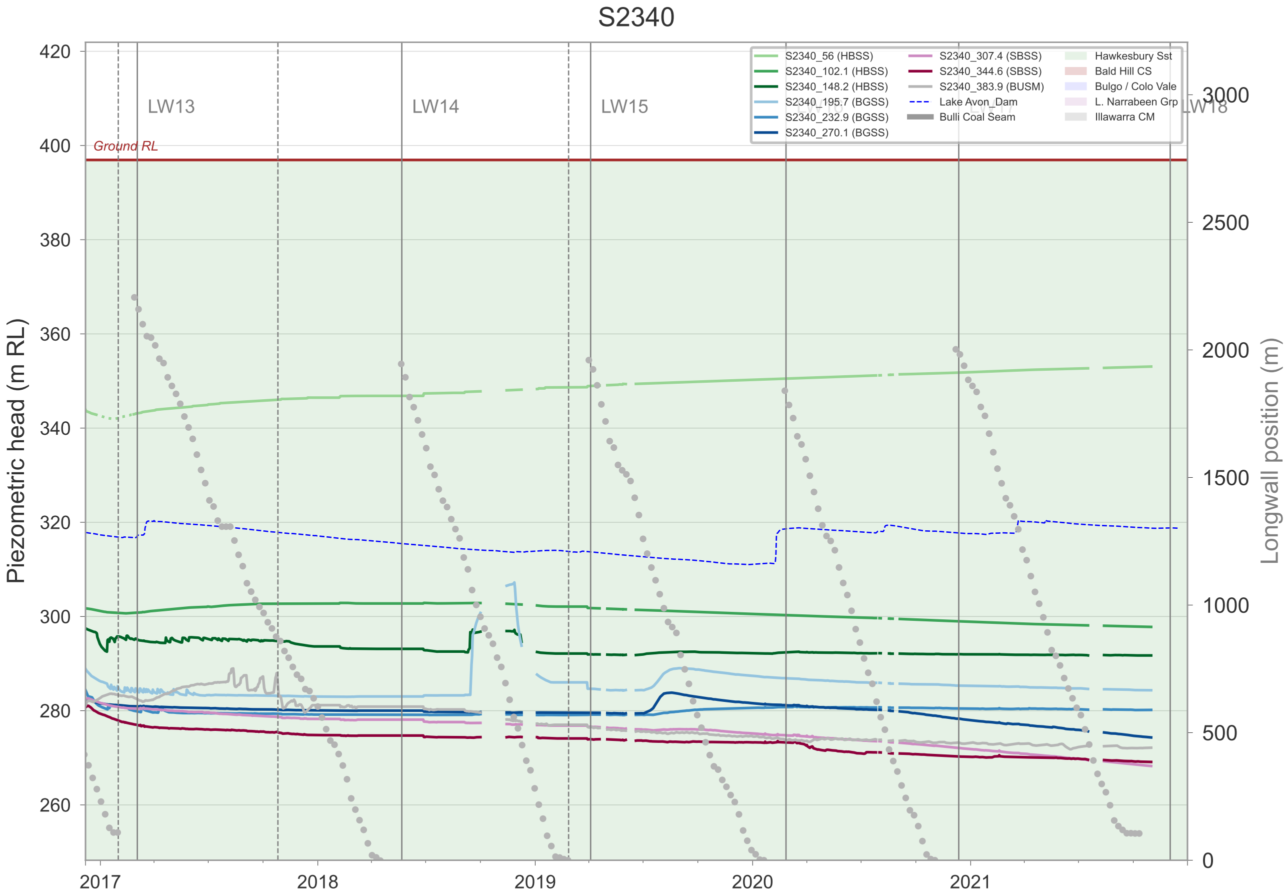


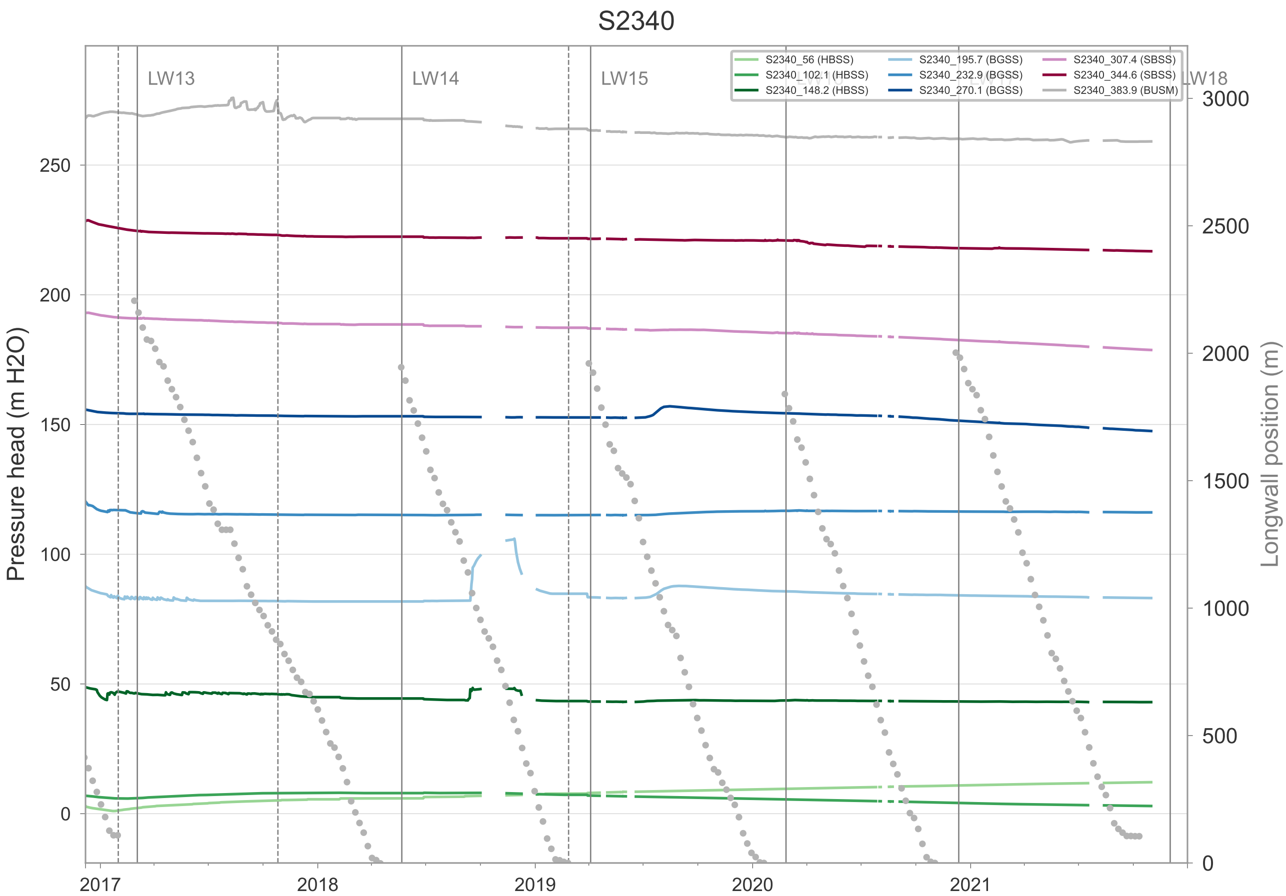
Groundwater hydrographs





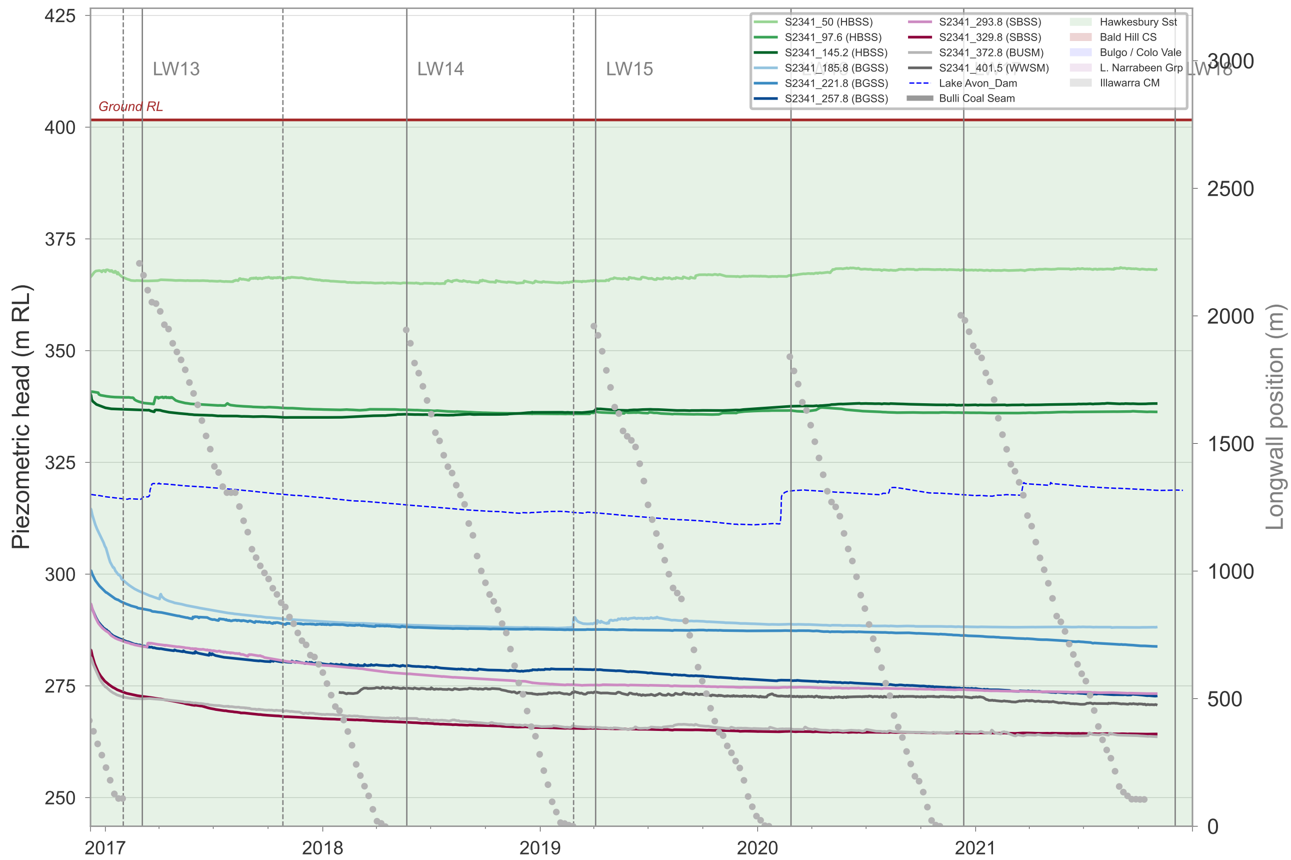
Groundwater hydrographs





Groundwater hydrographs

S2341



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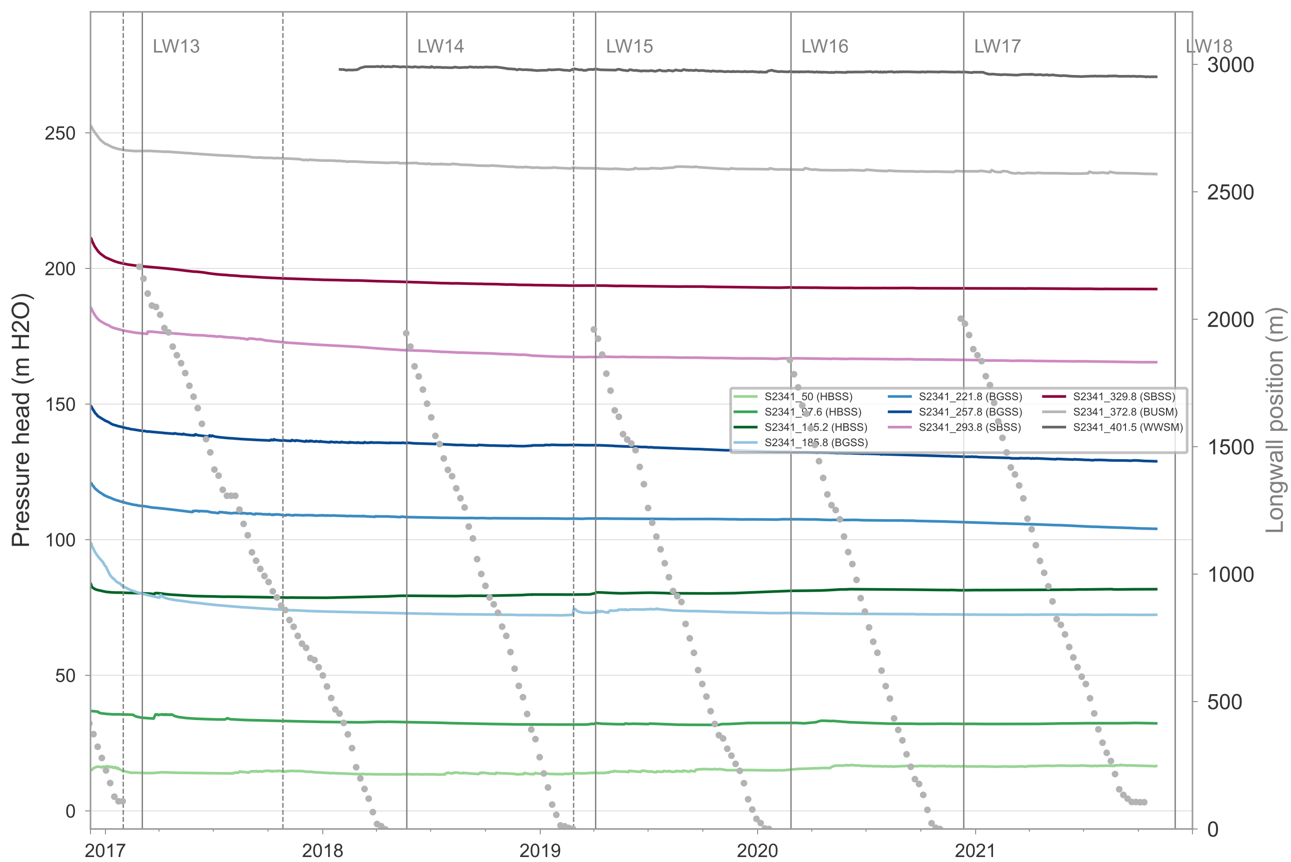
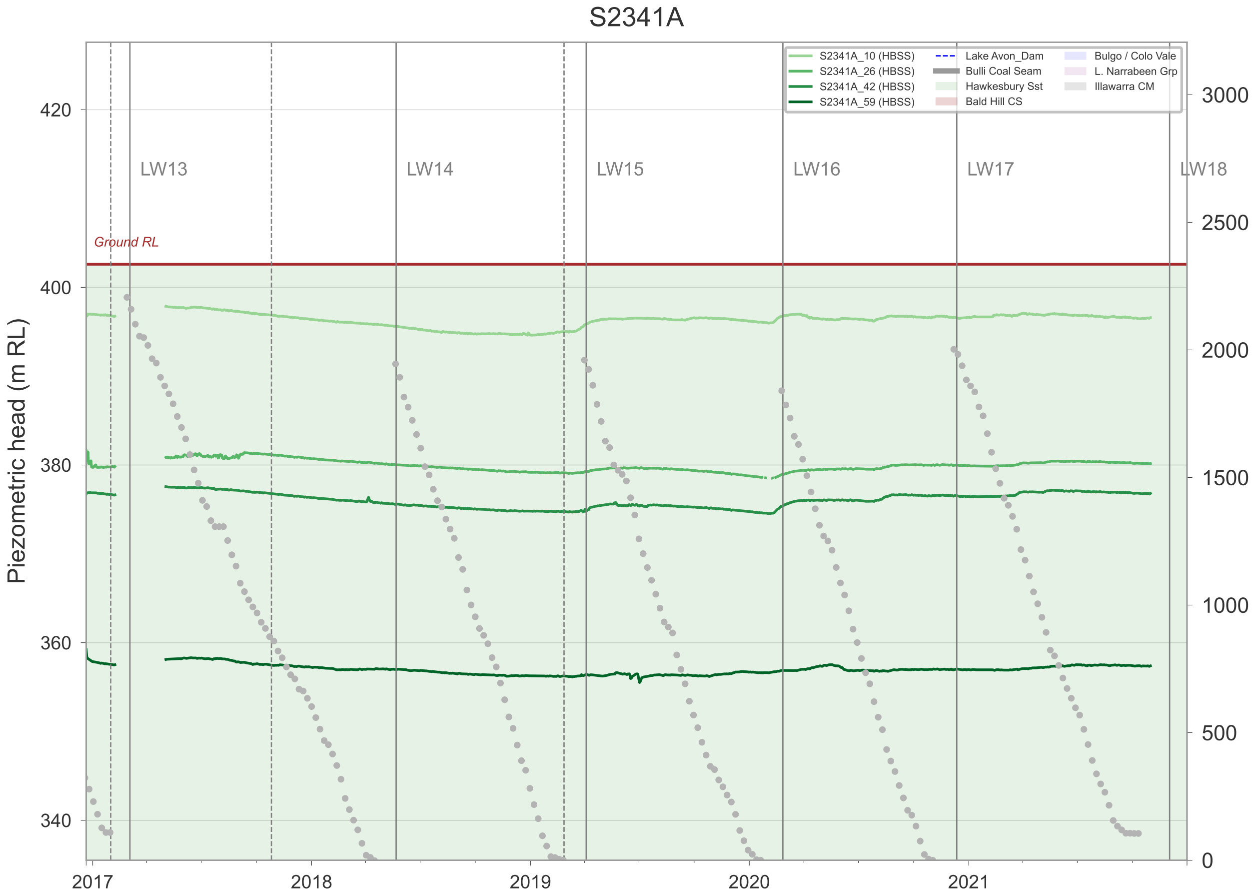
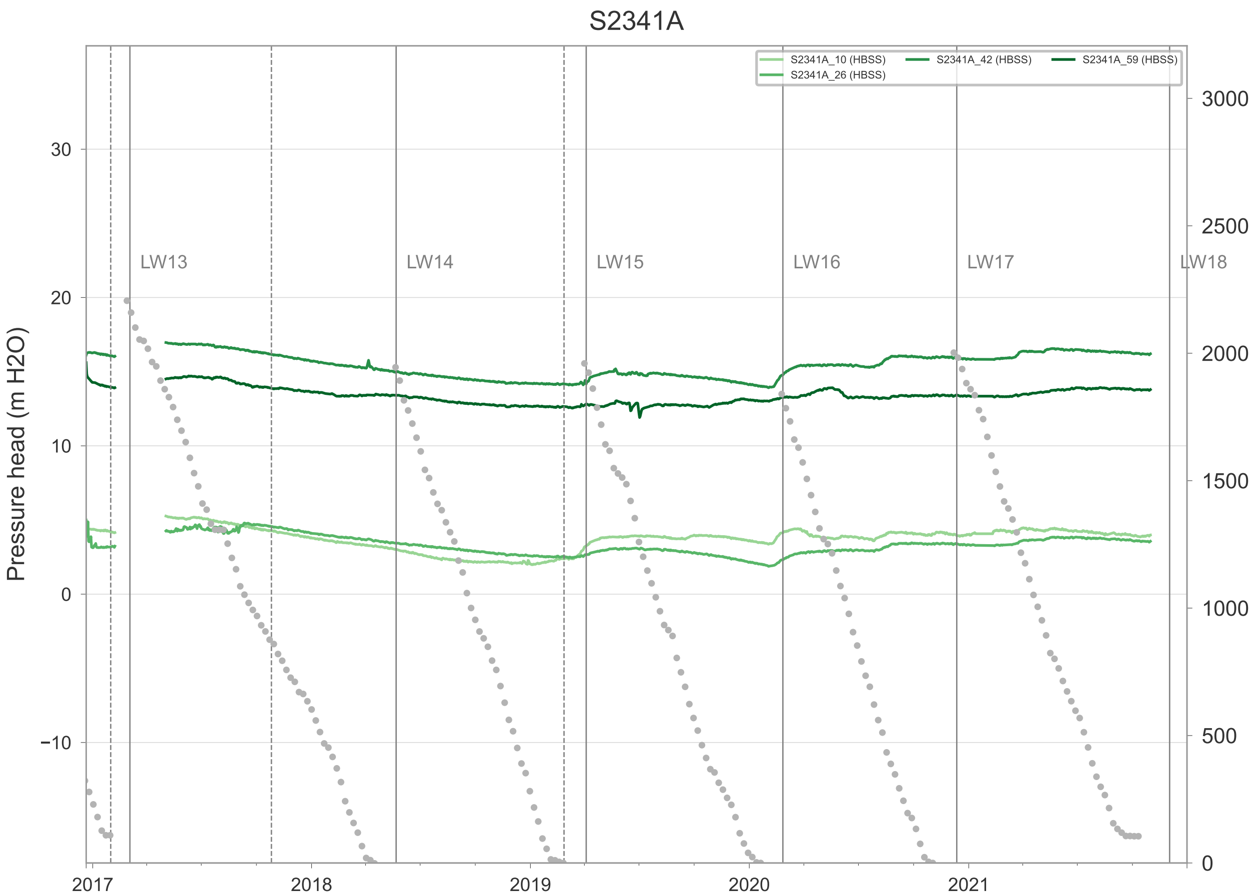
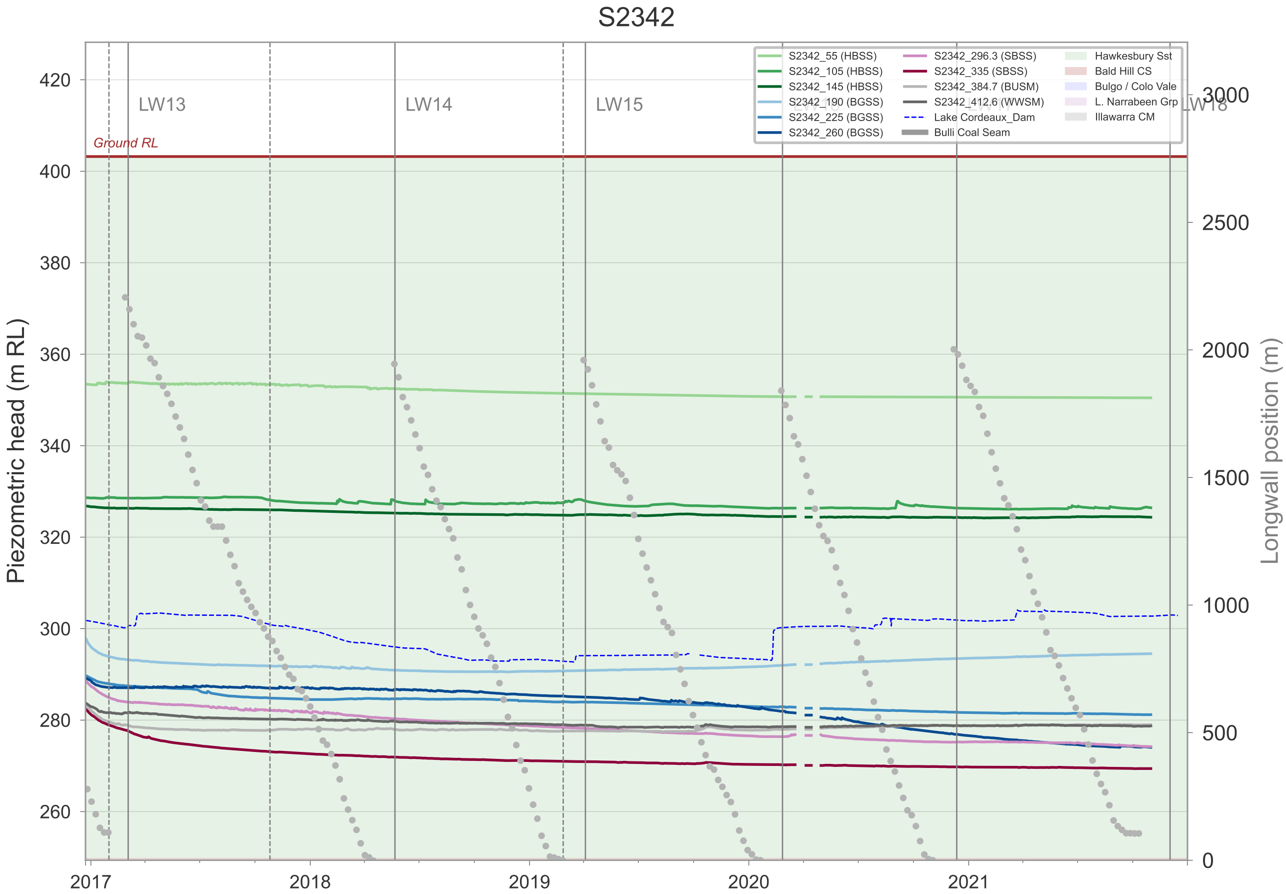


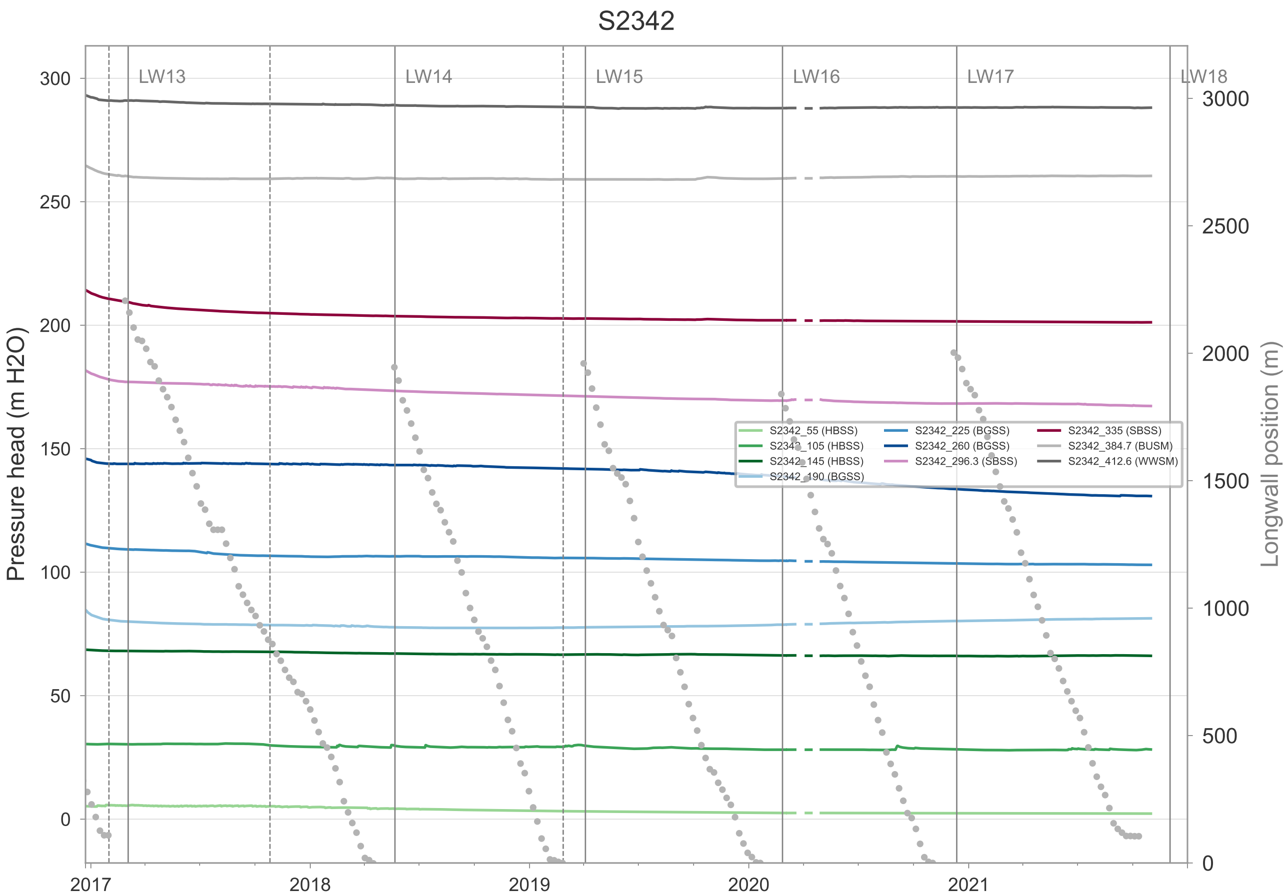
Groundwater hydrographs



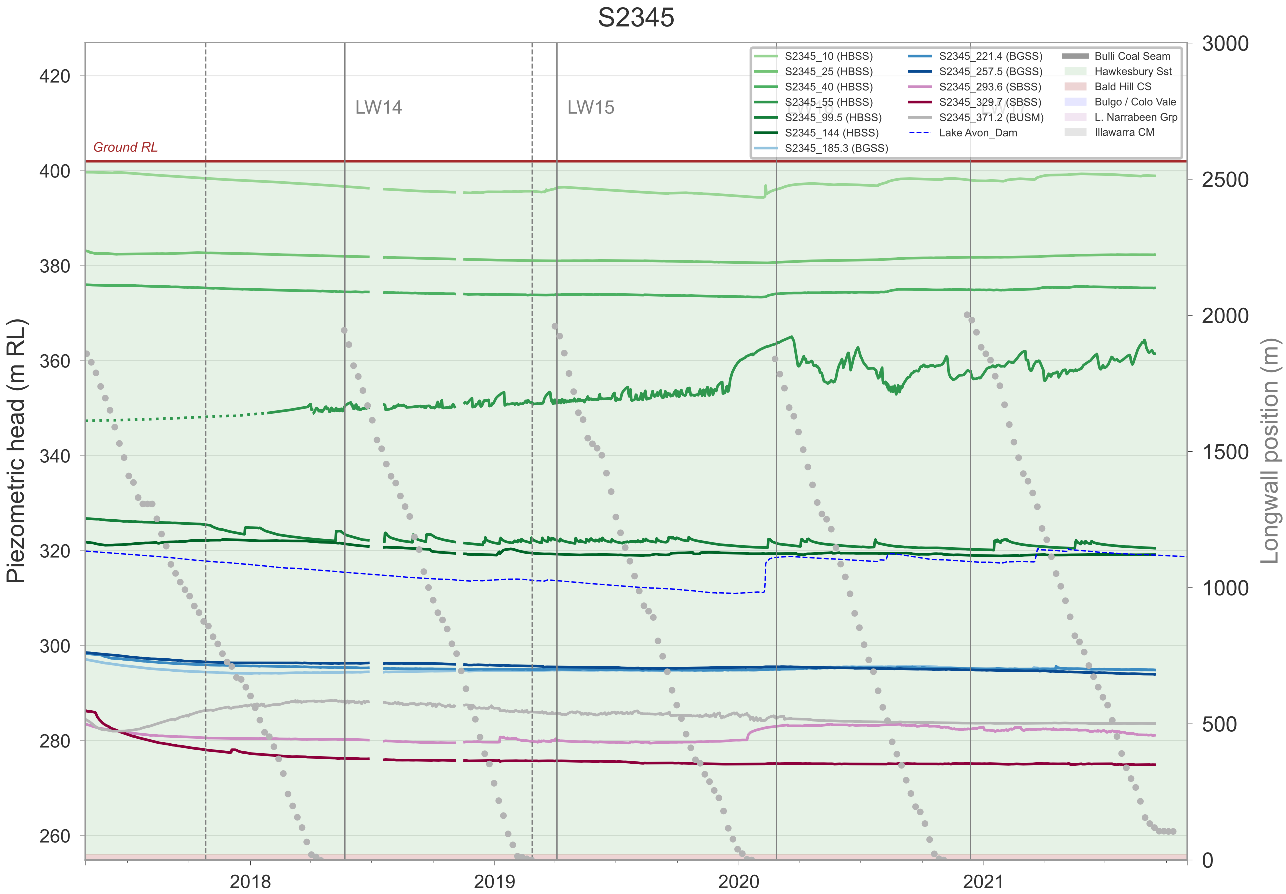


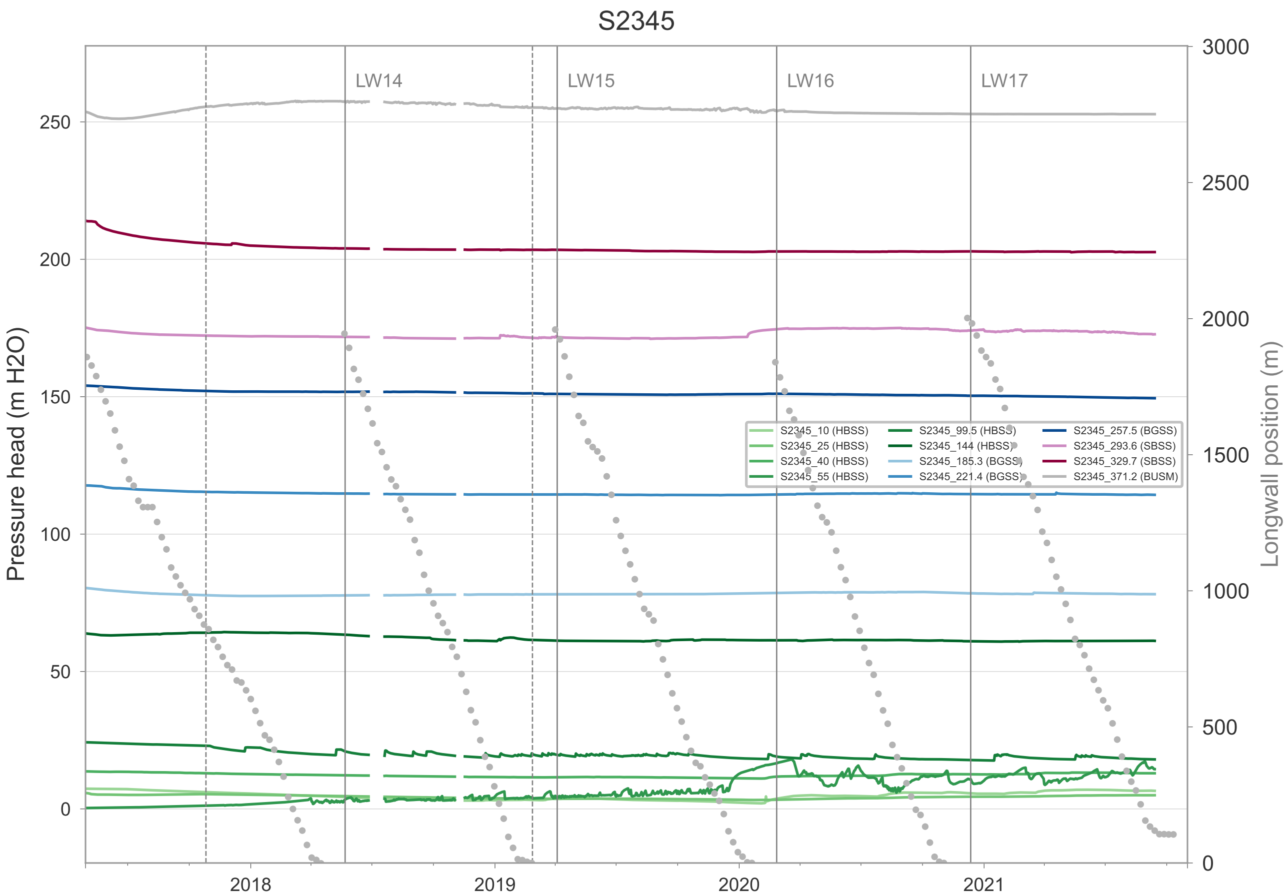
Groundwater hydrographs



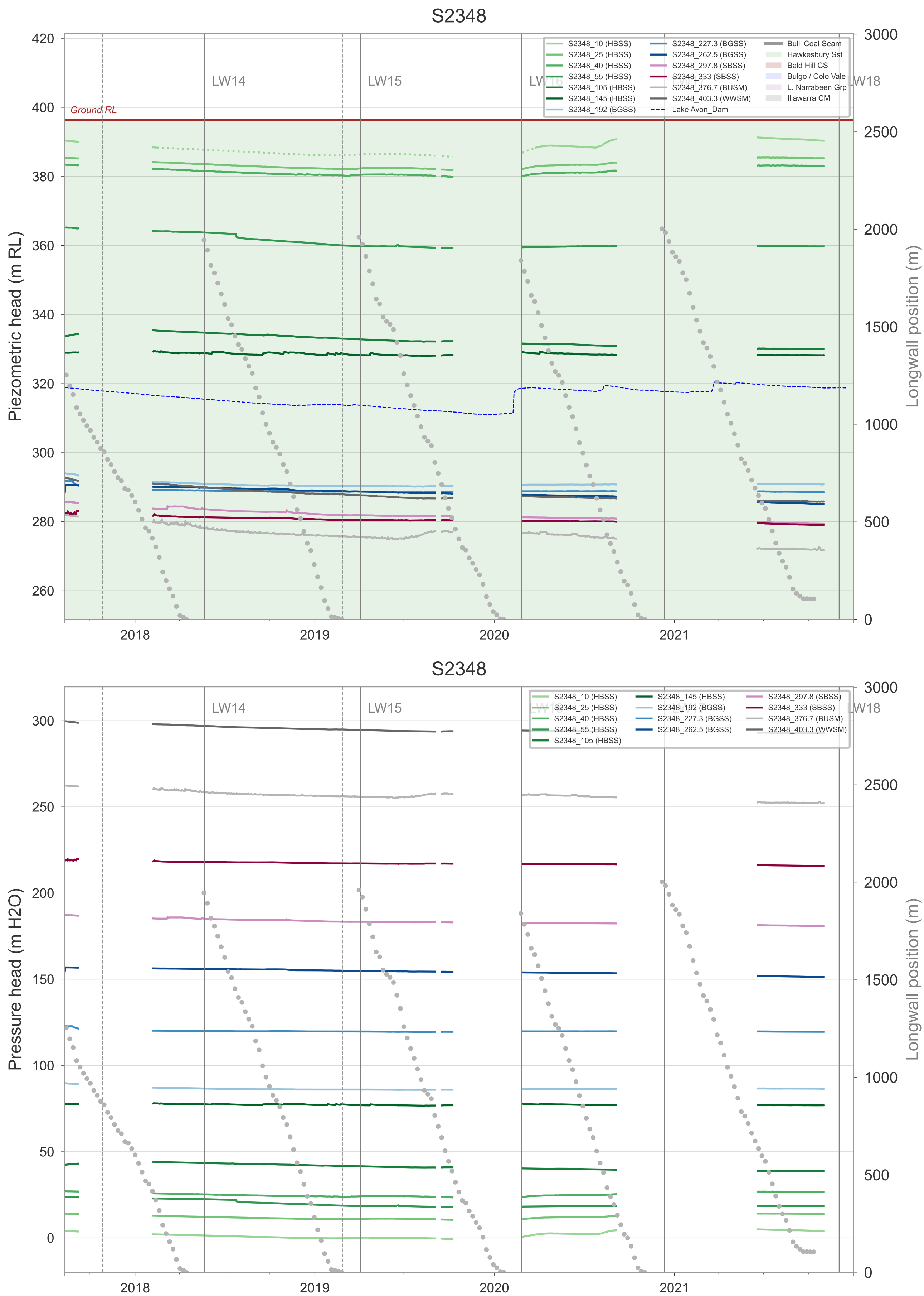


Groundwater hydrographs

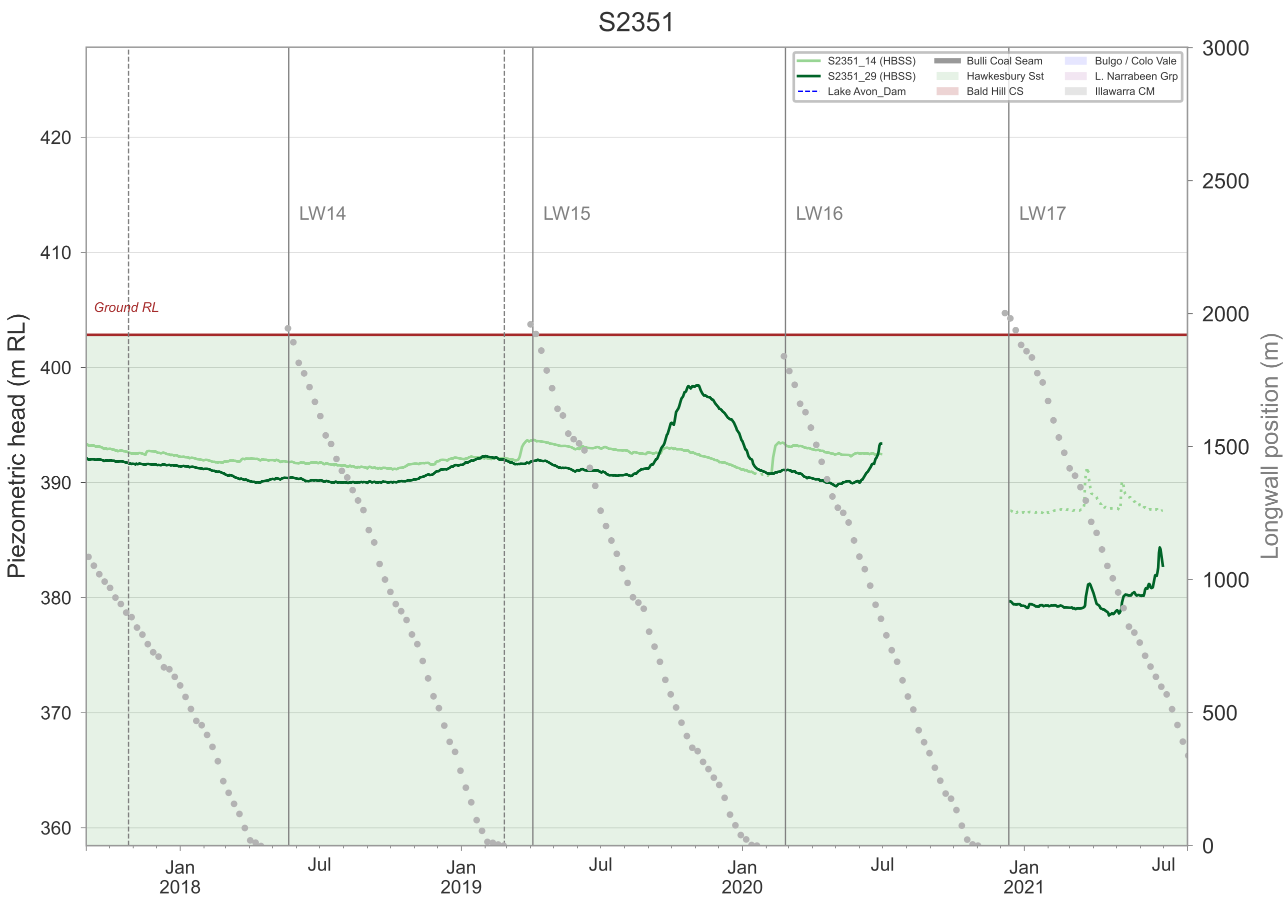


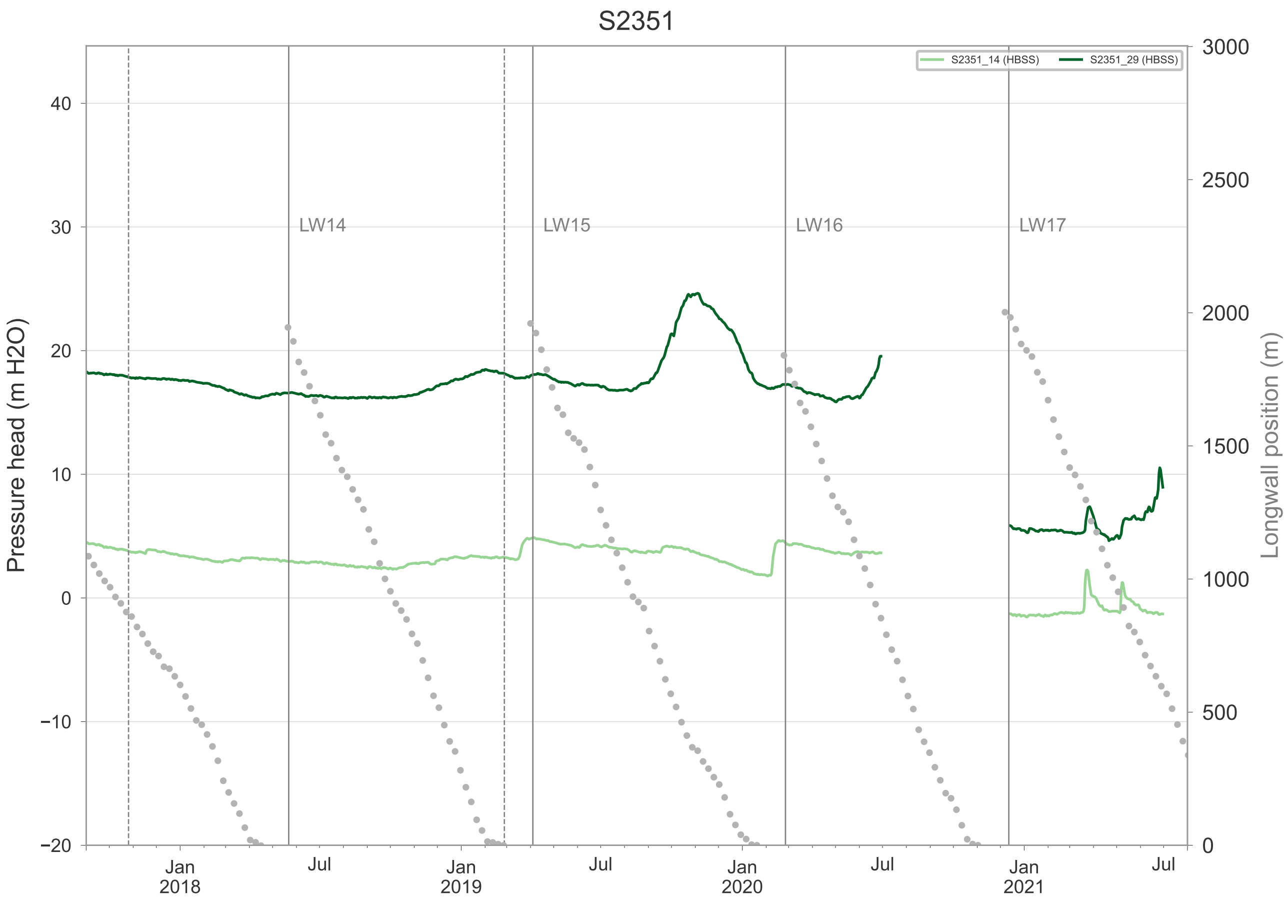


Groundwater hydrographs

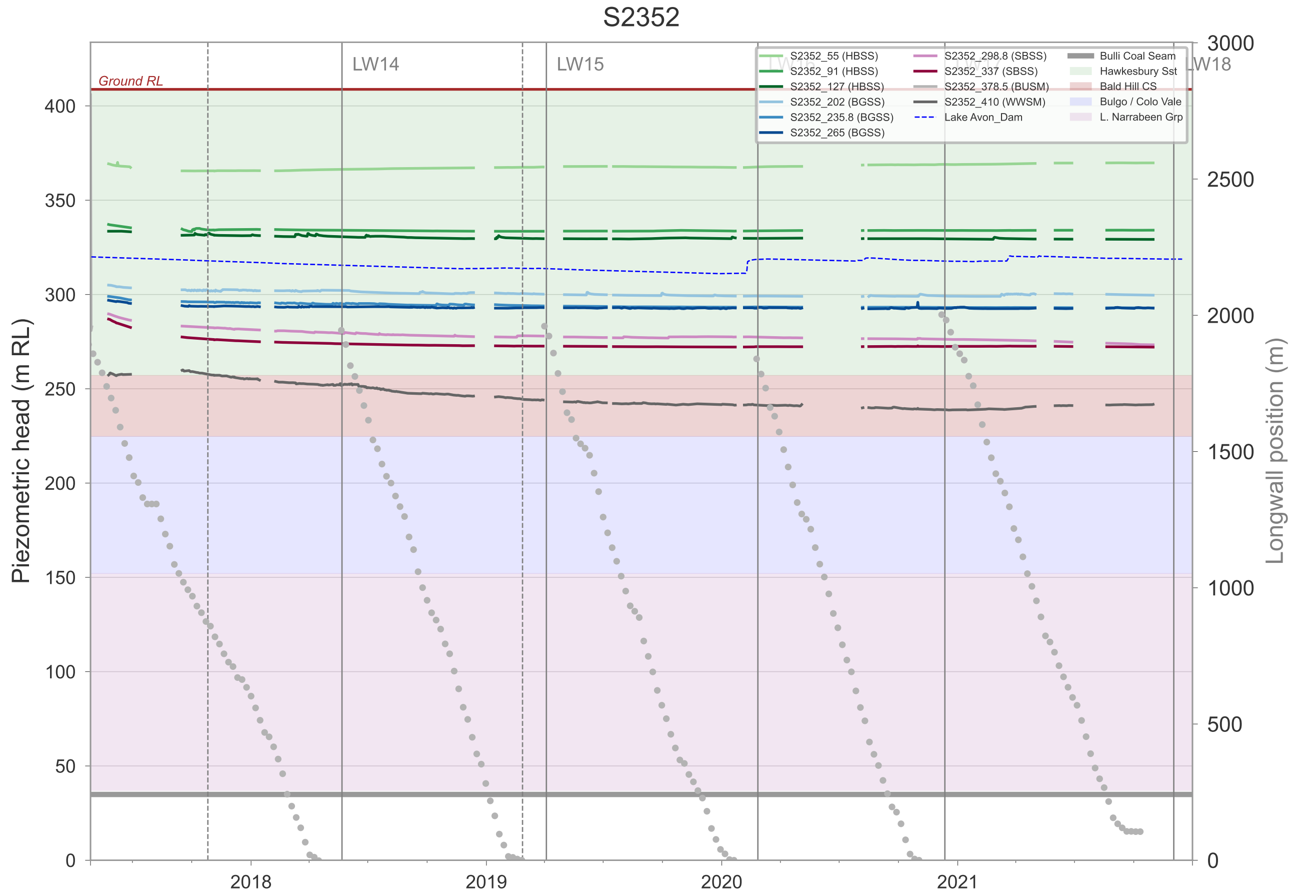


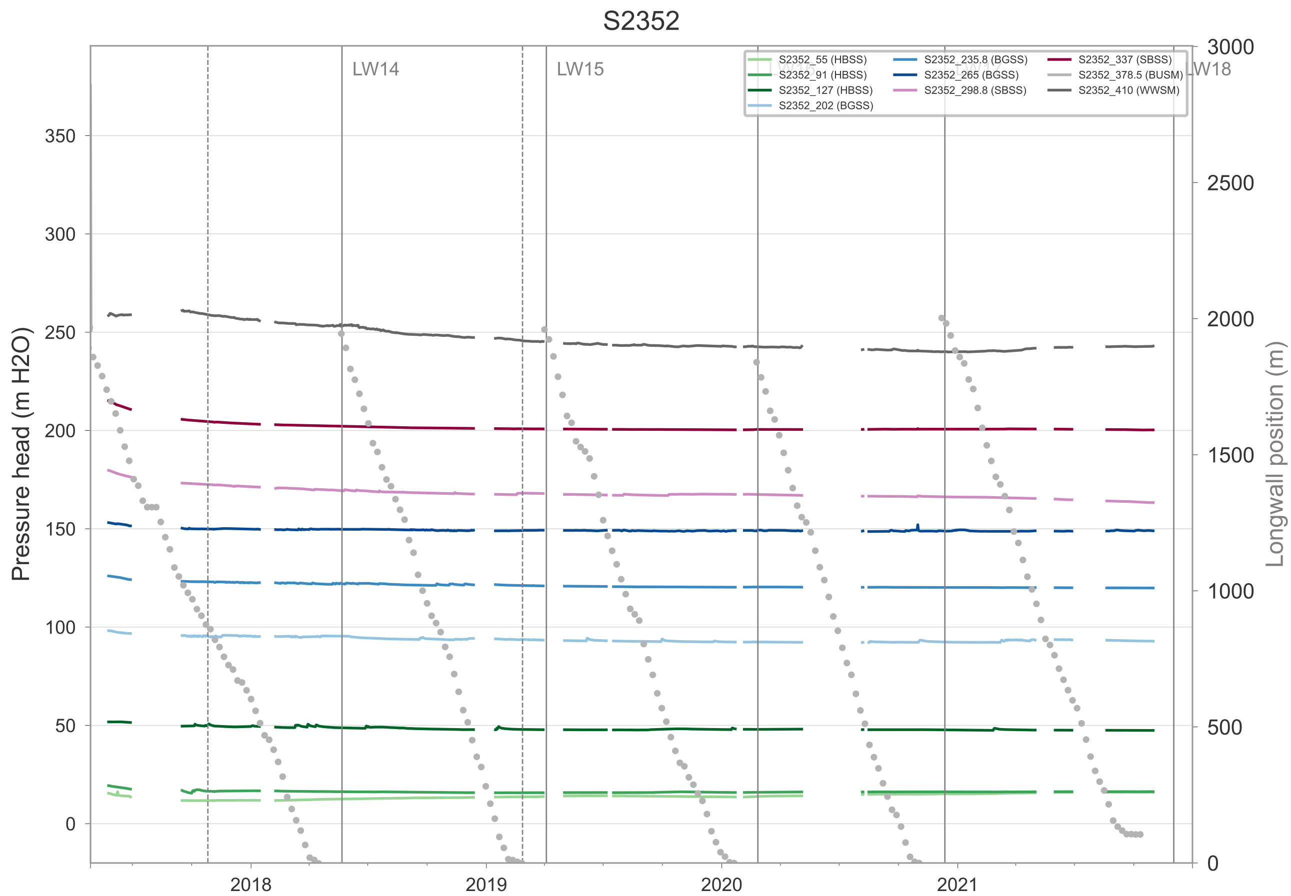
Groundwater hydrographs





Groundwater hydrographs





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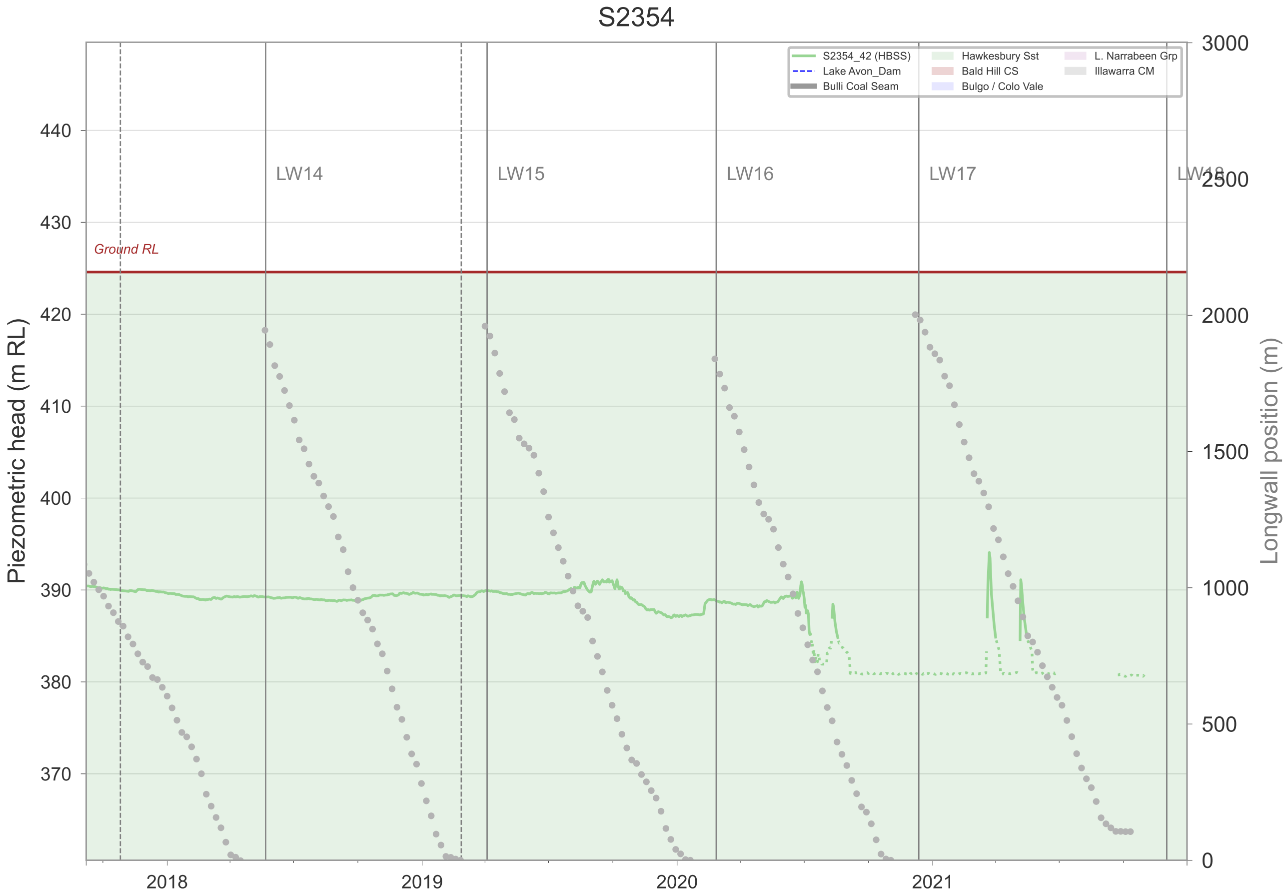
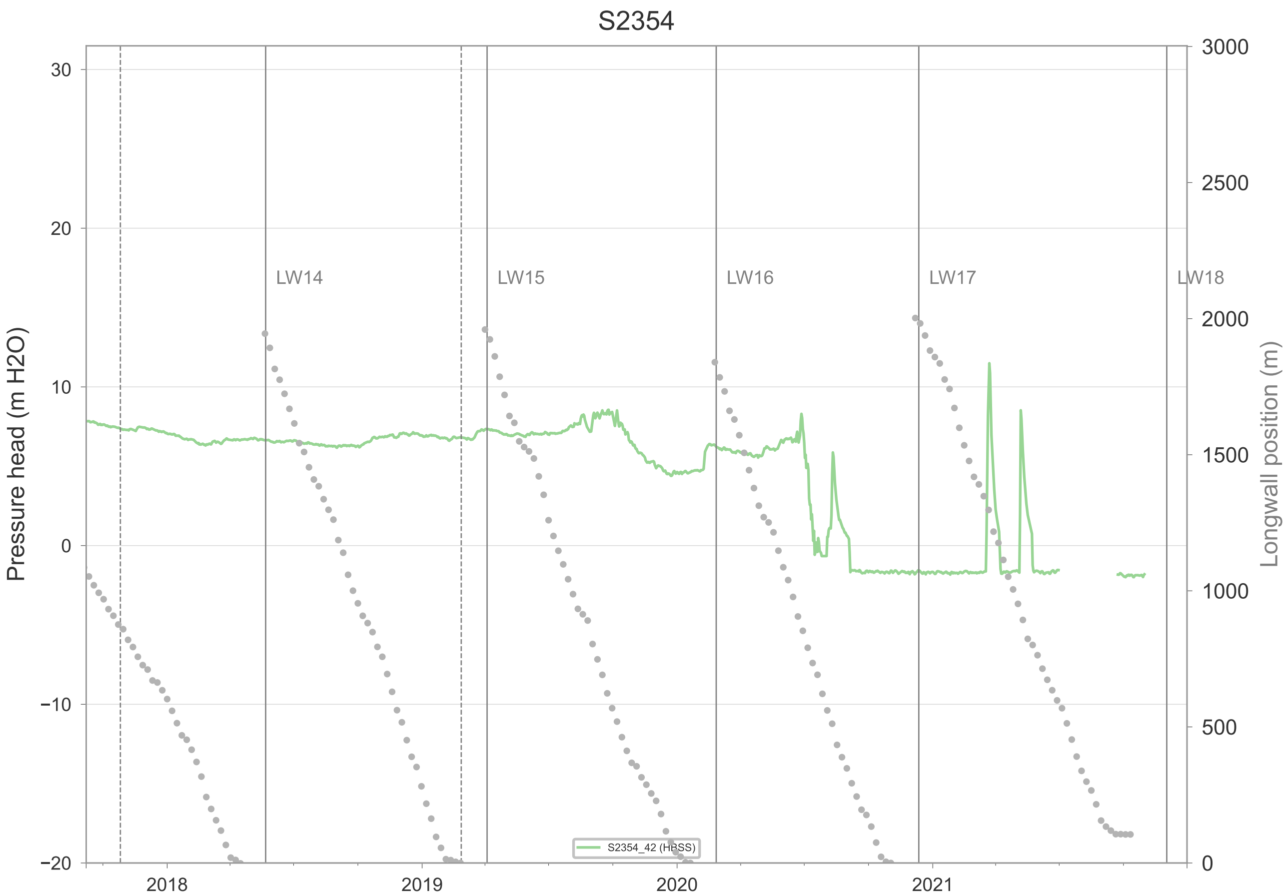
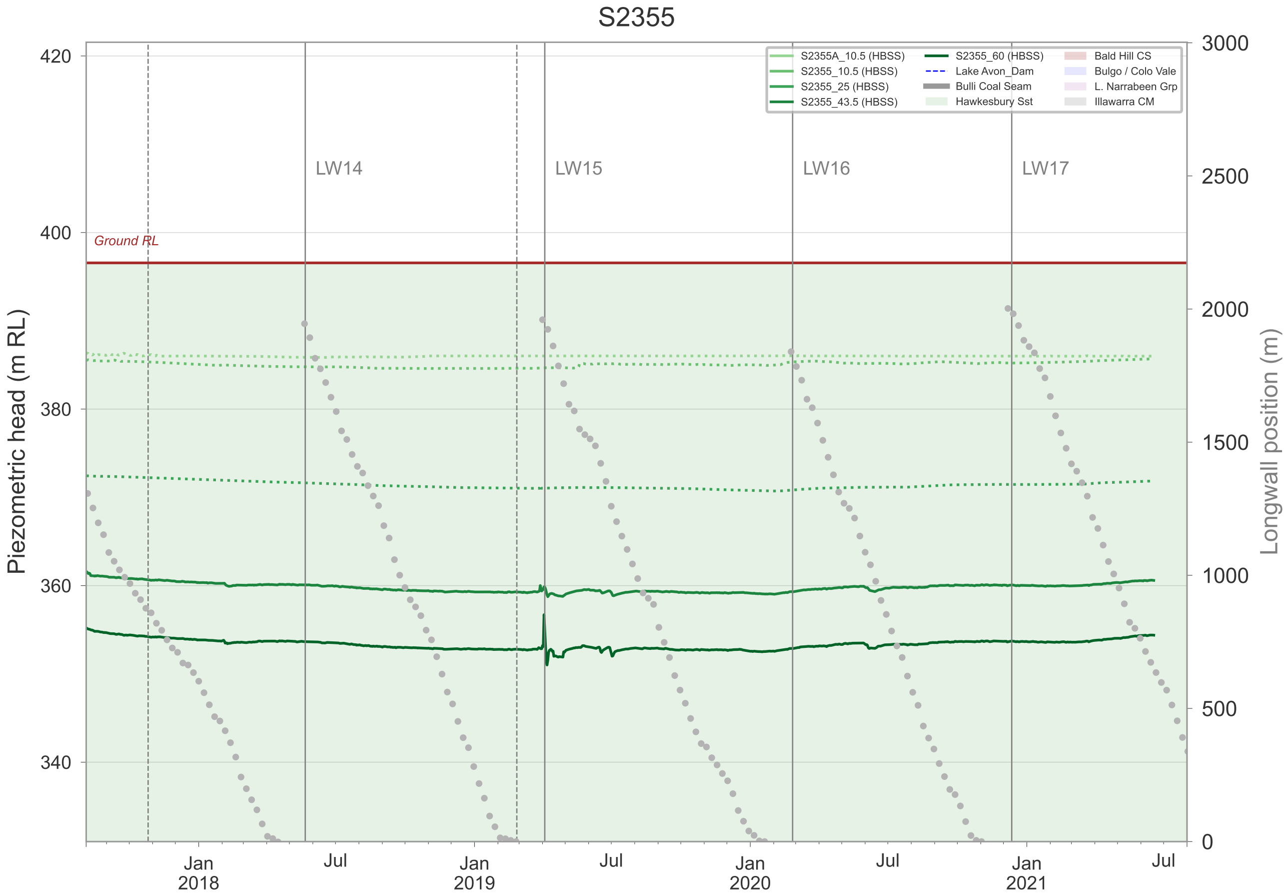
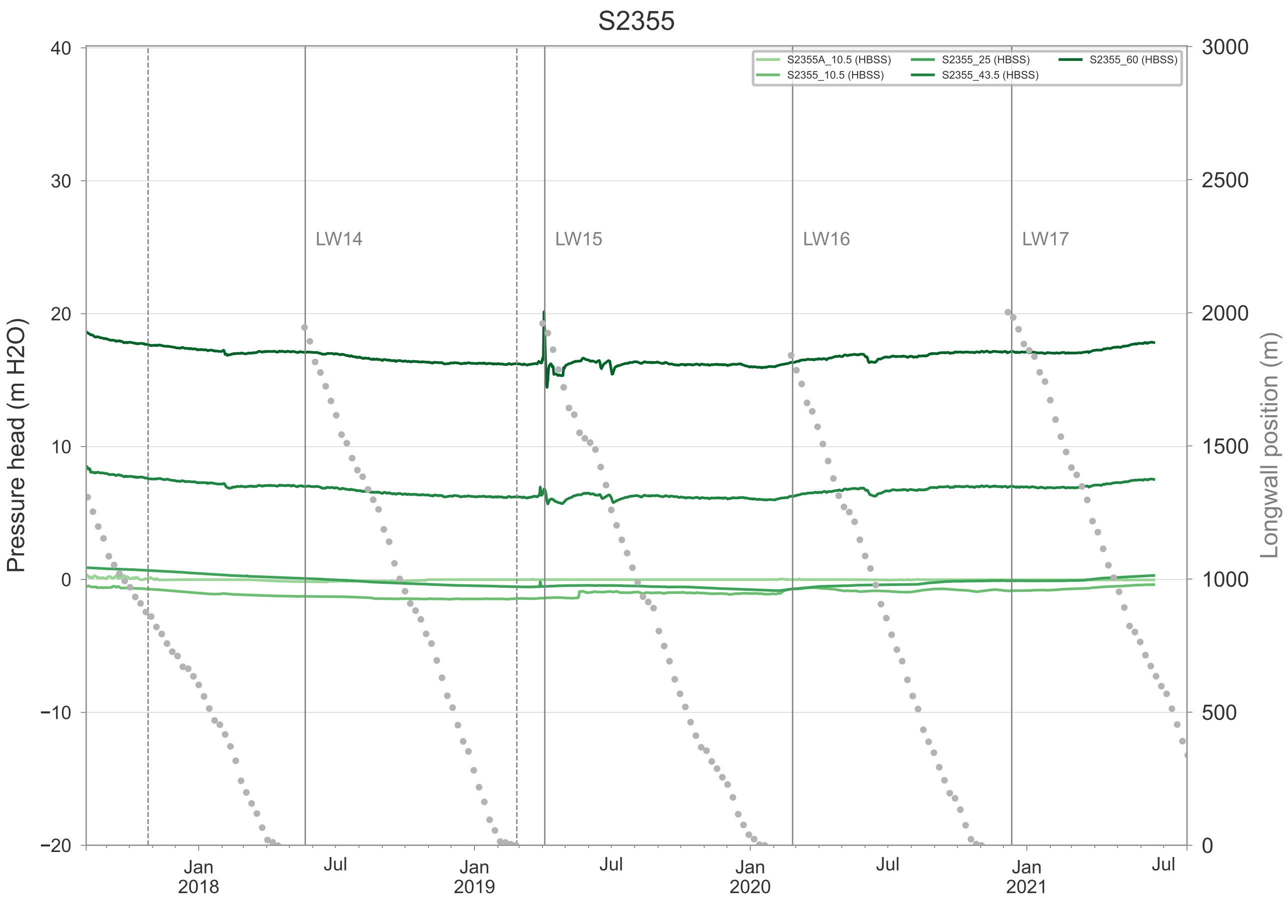


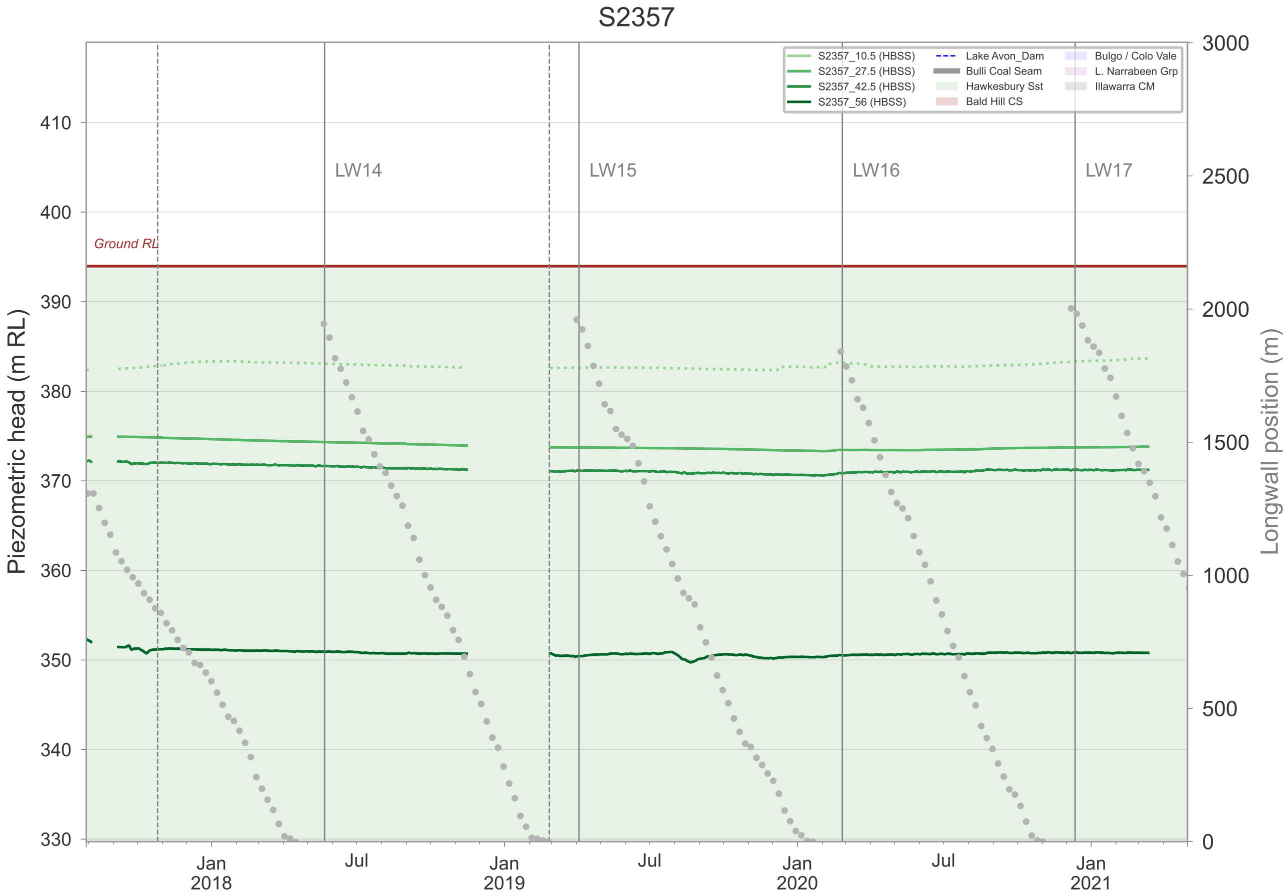


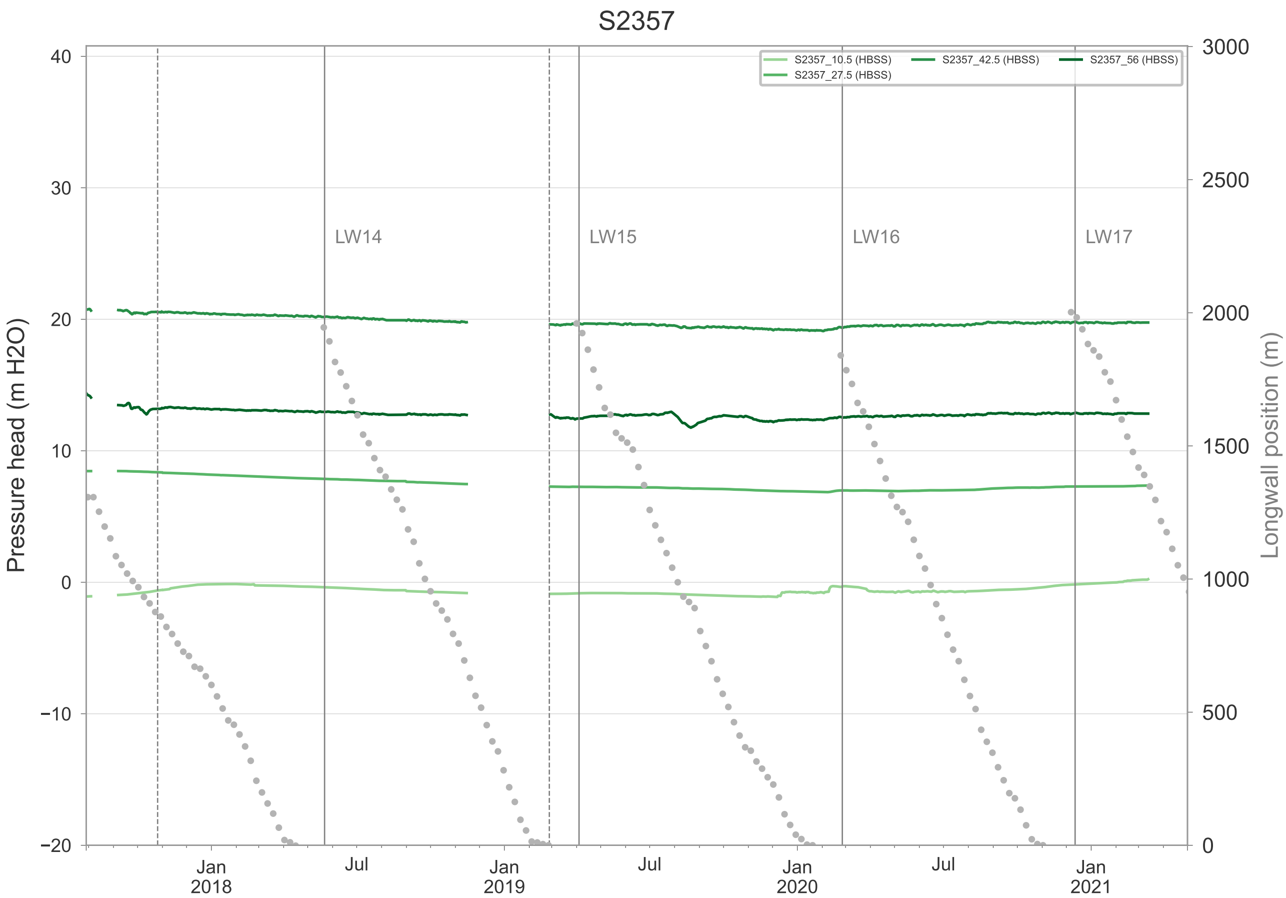
Groundwater hydrographs



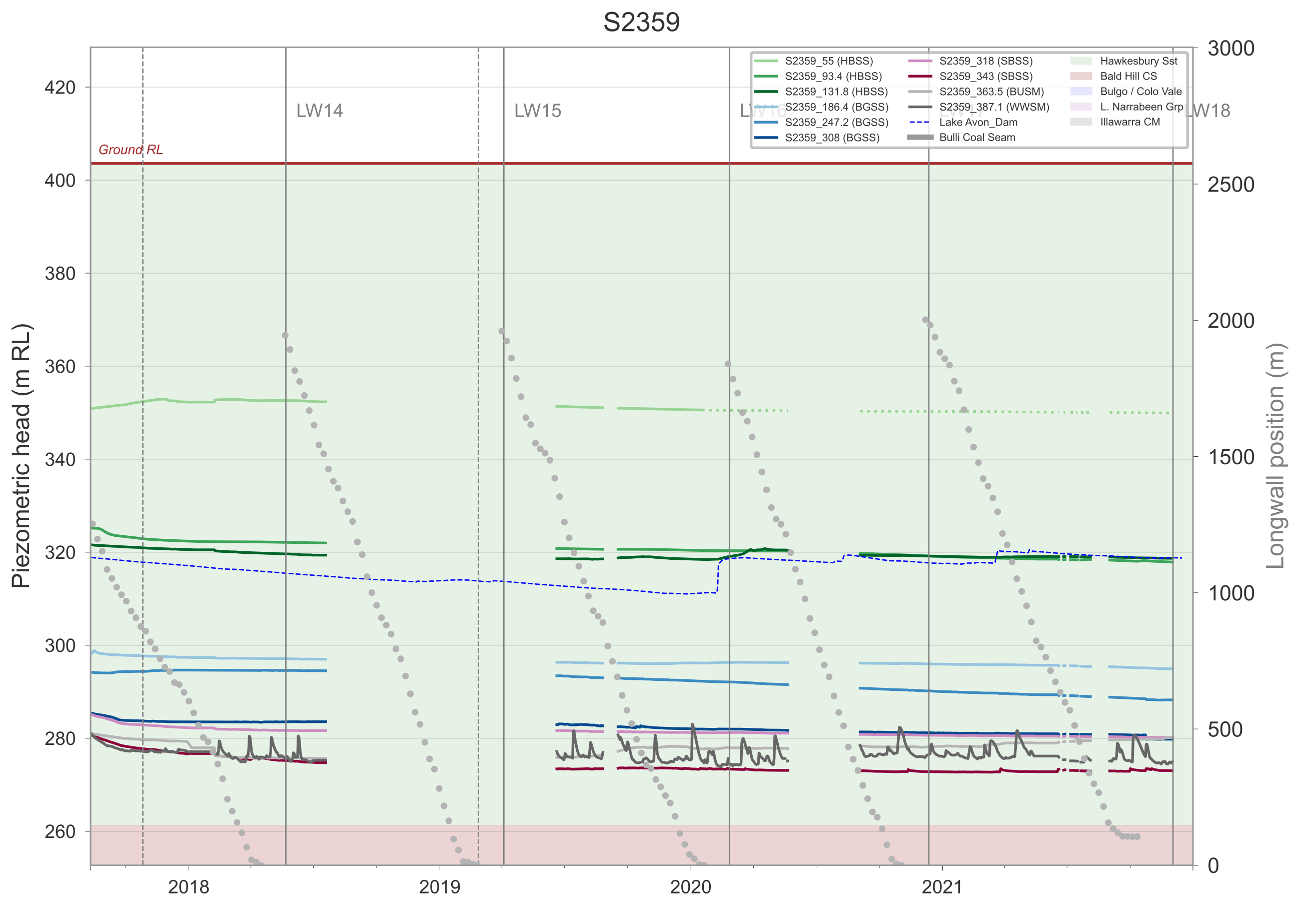


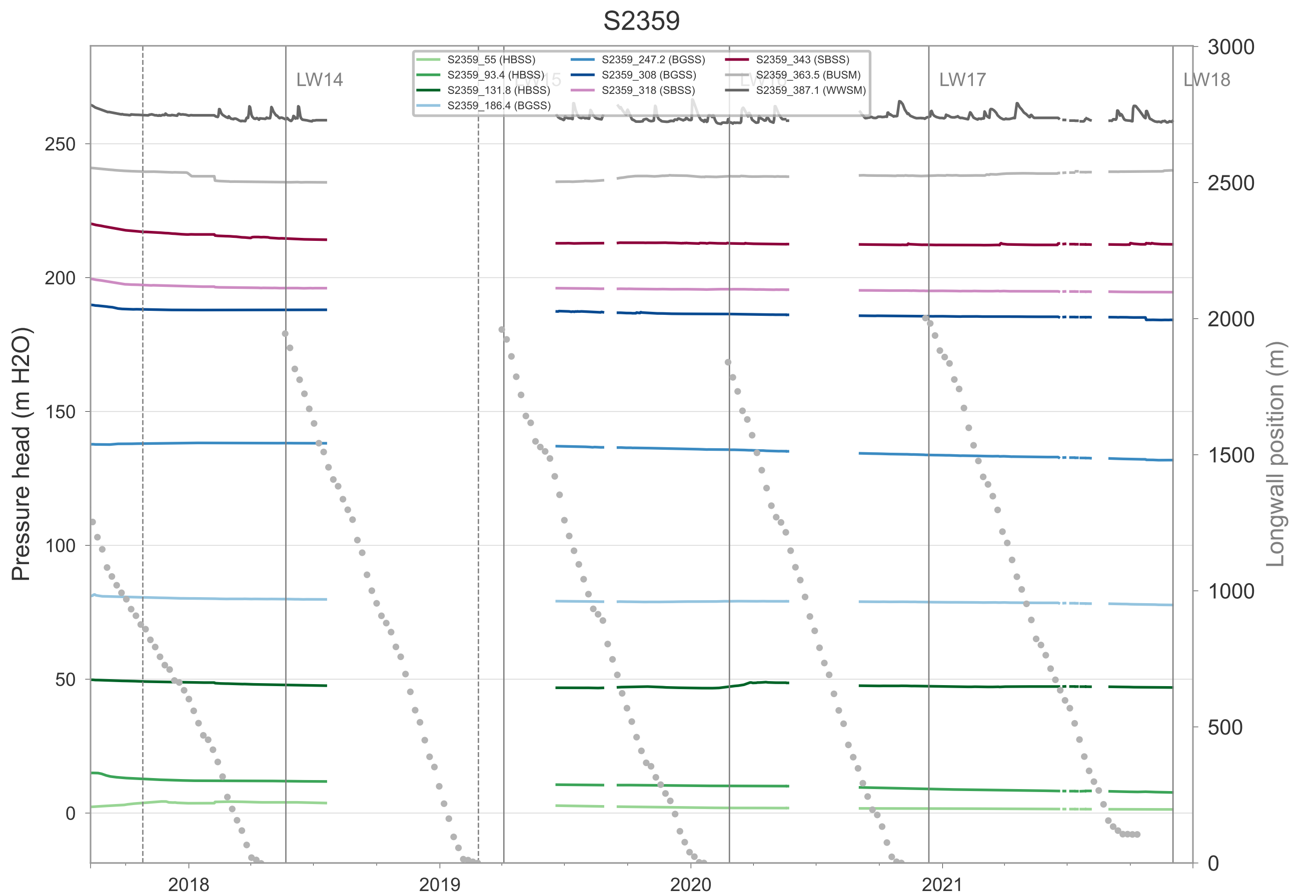
Groundwater hydrographs



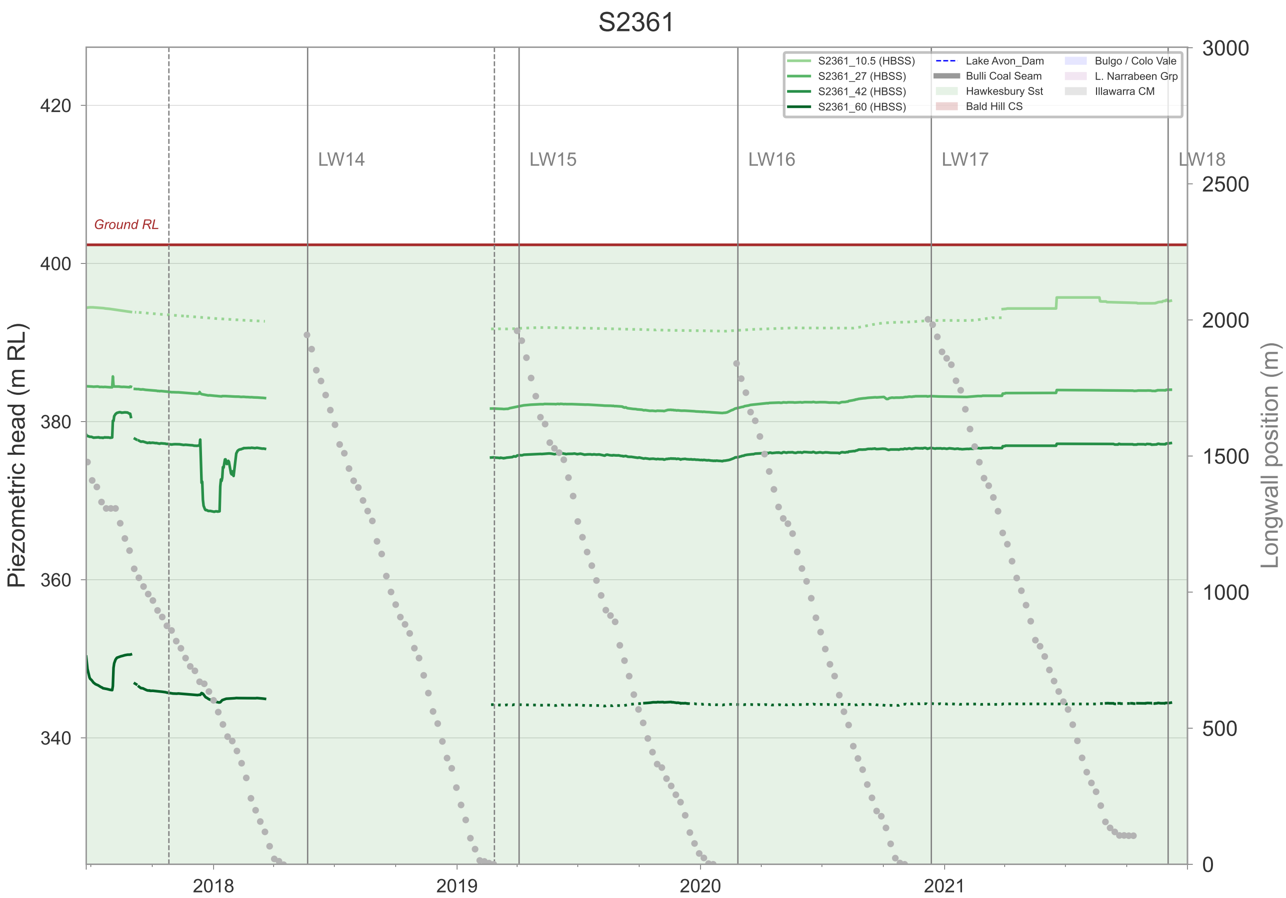


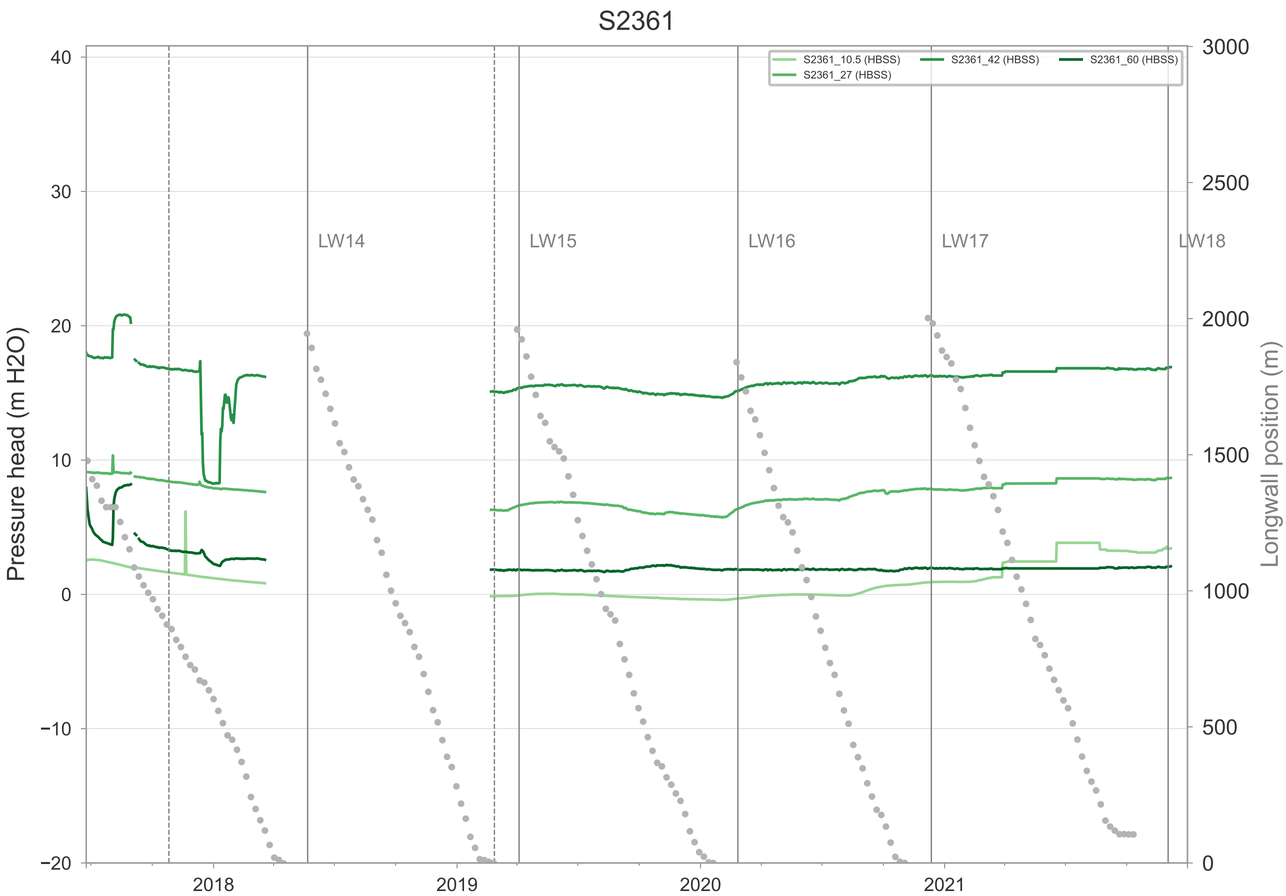
Groundwater hydrographs



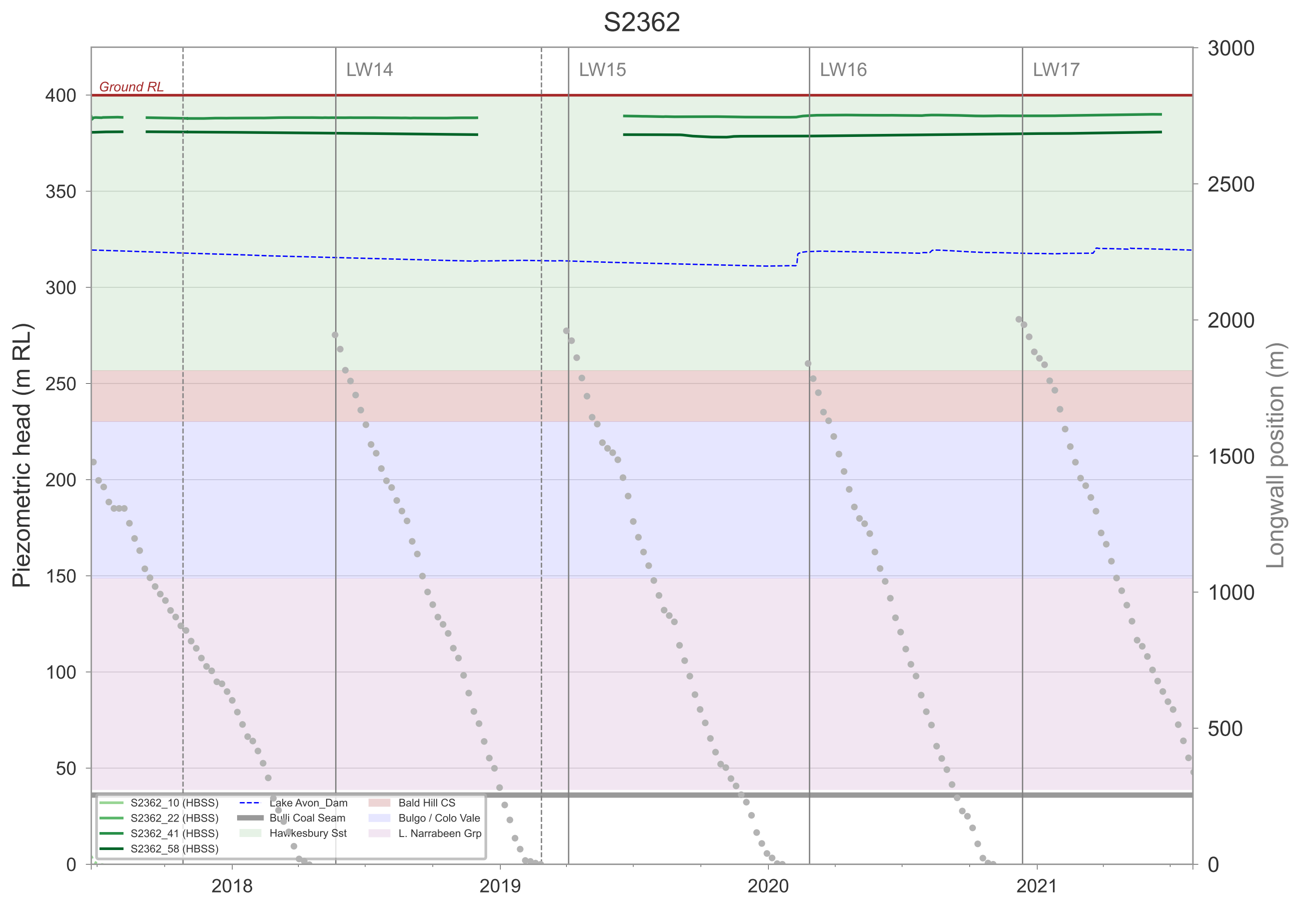


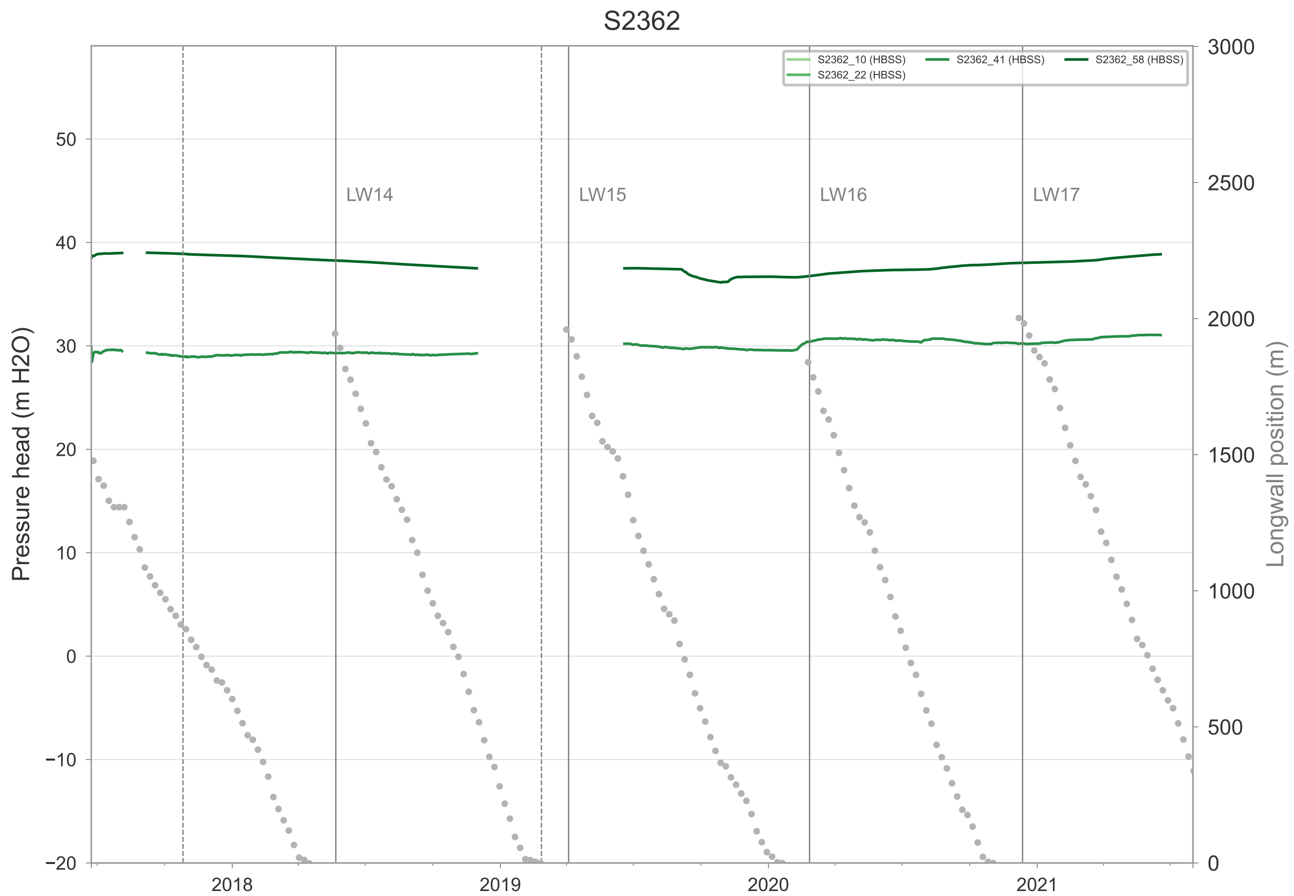
Groundwater hydrographs



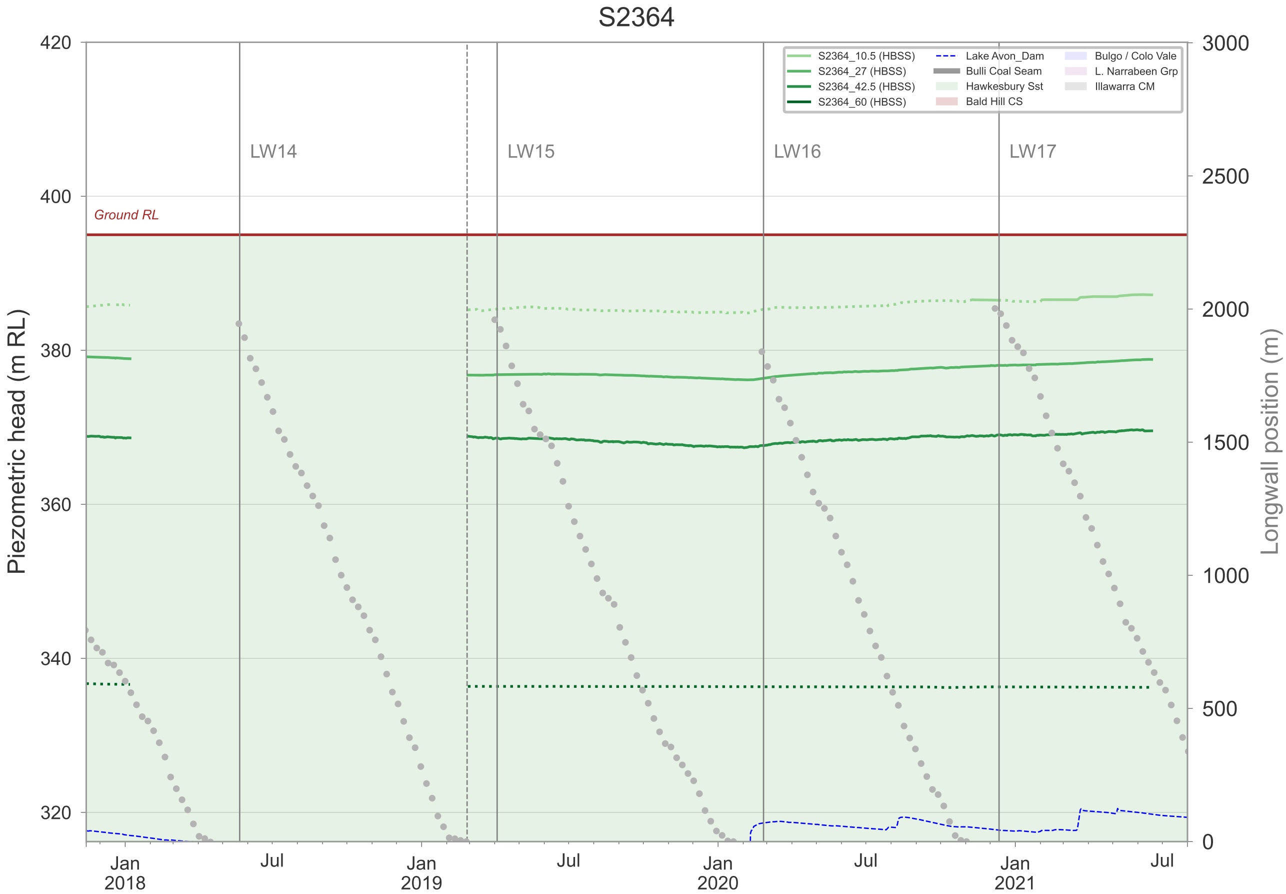


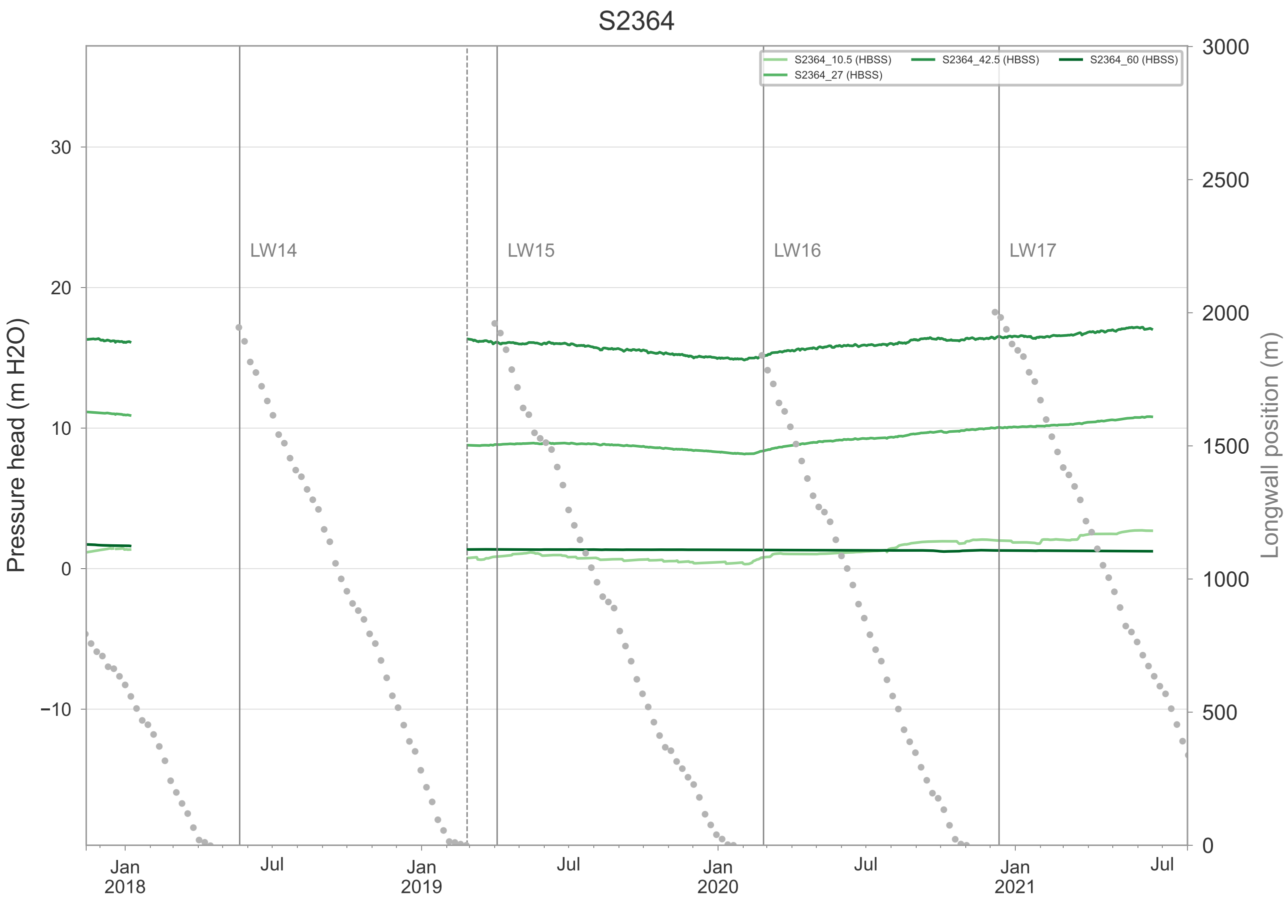
Groundwater hydrographs





Groundwater hydrographs





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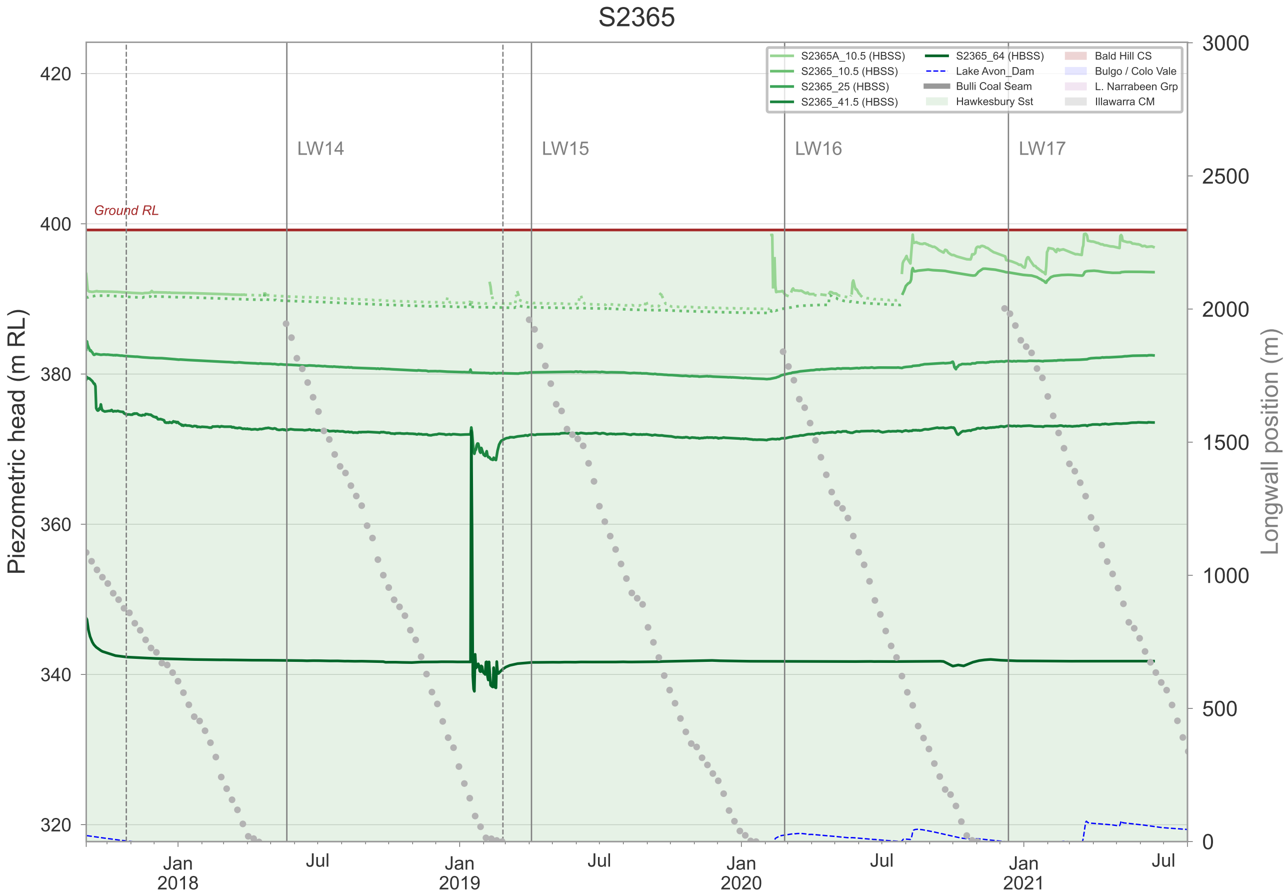

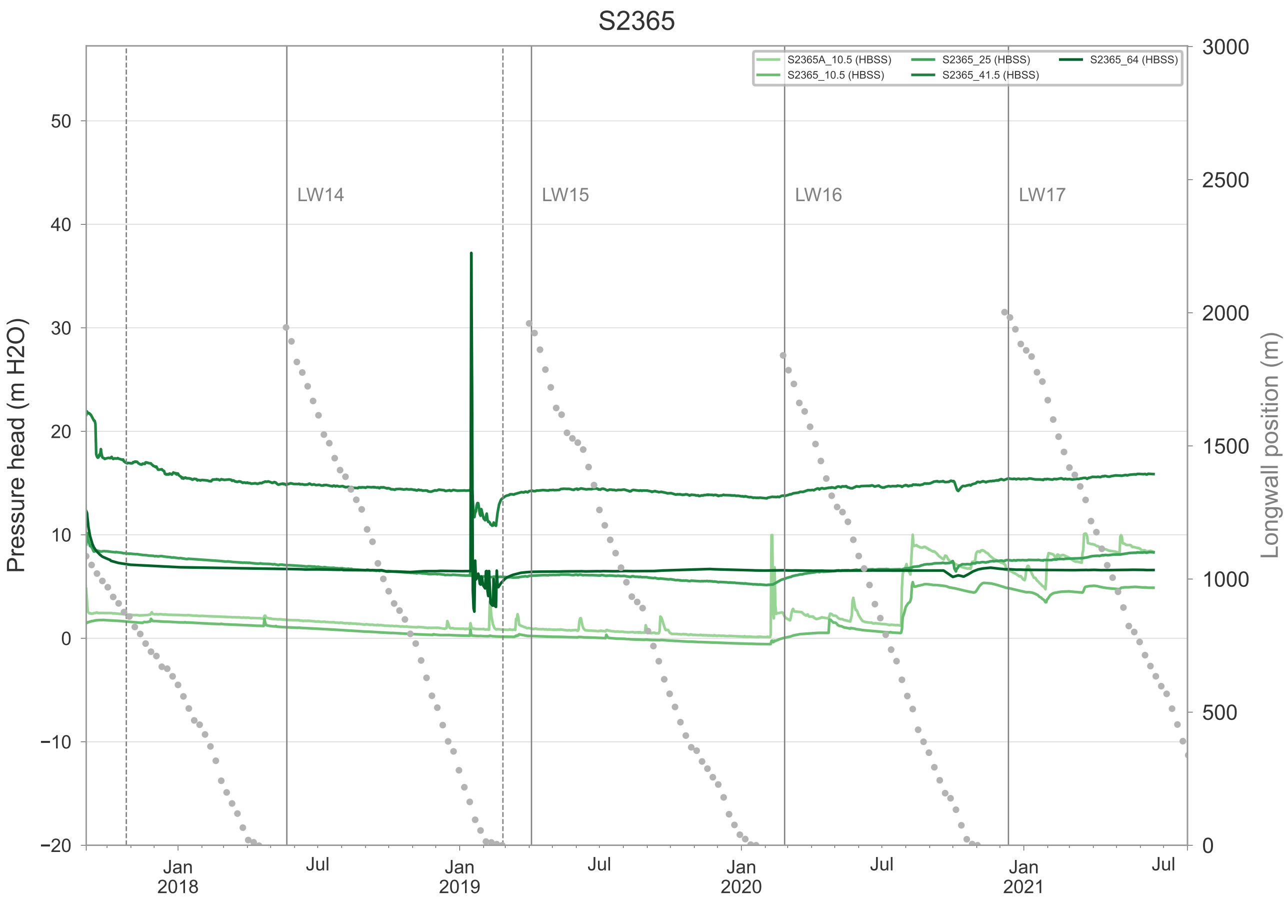

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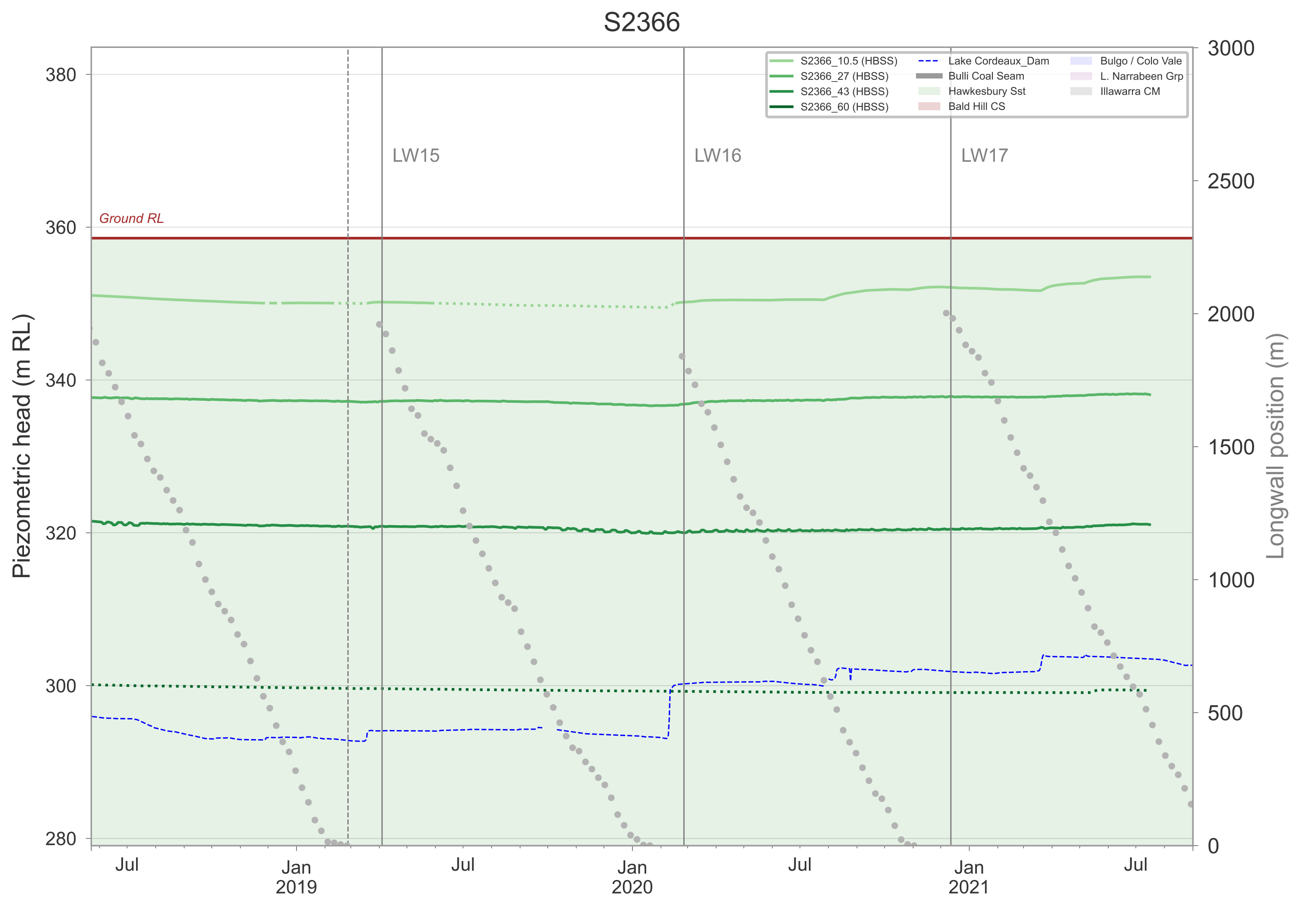

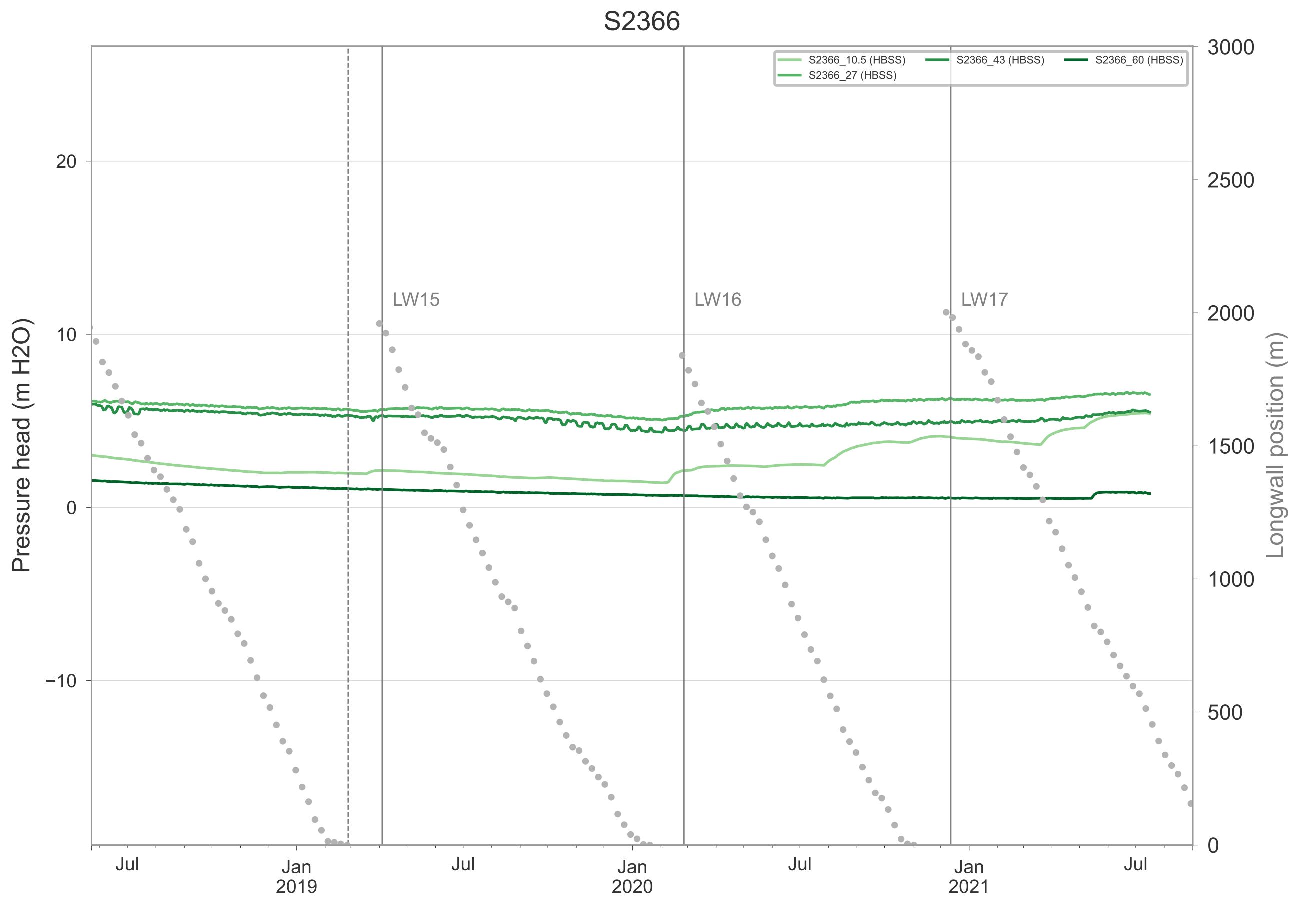

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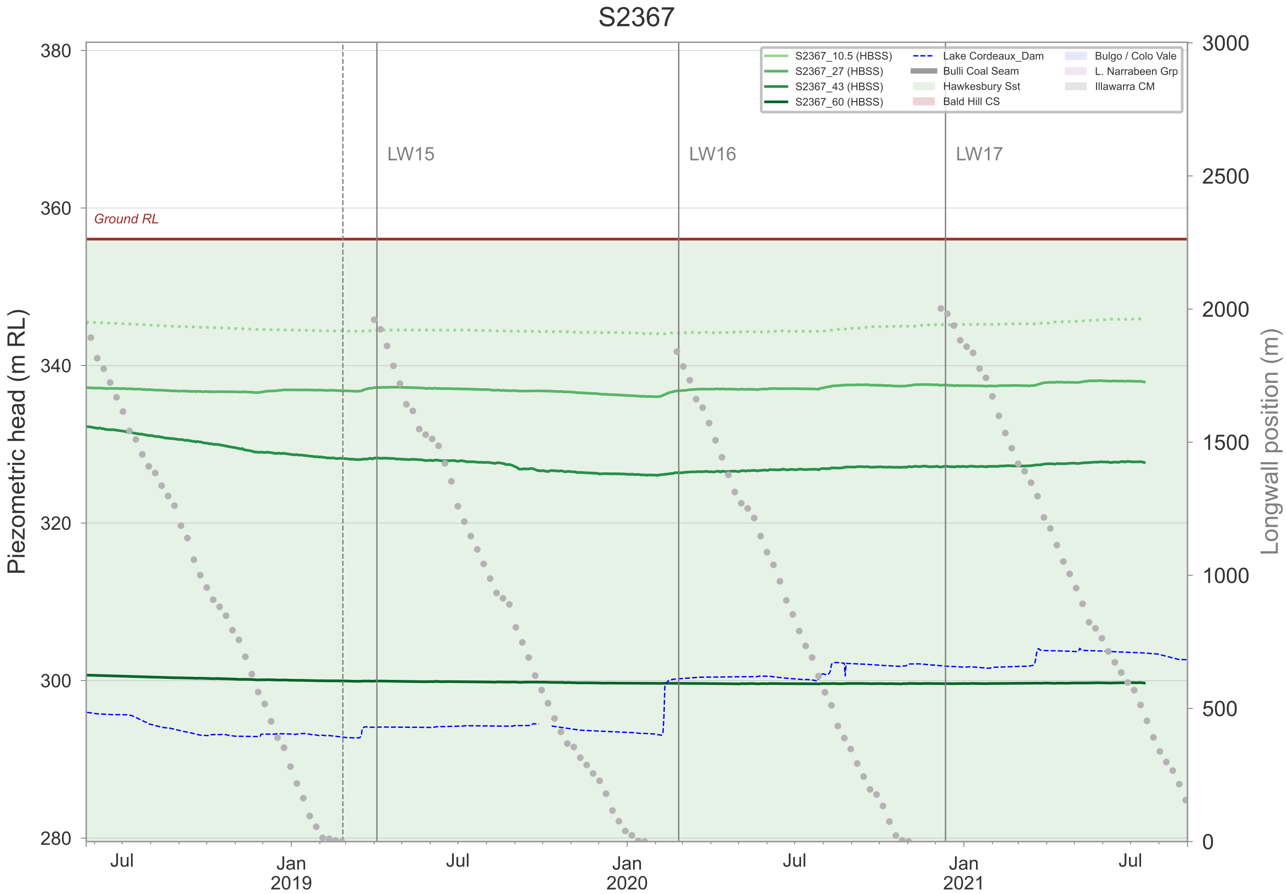

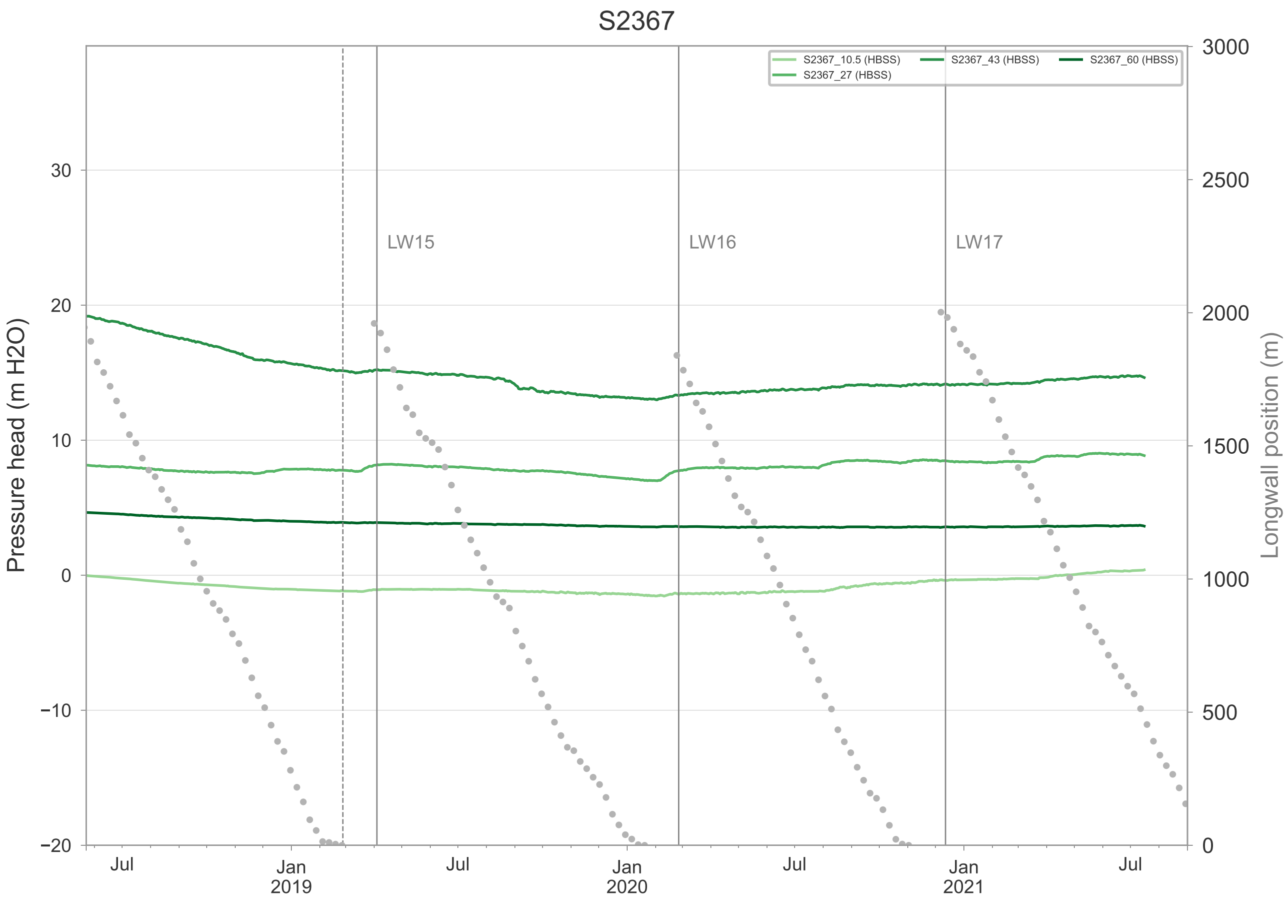

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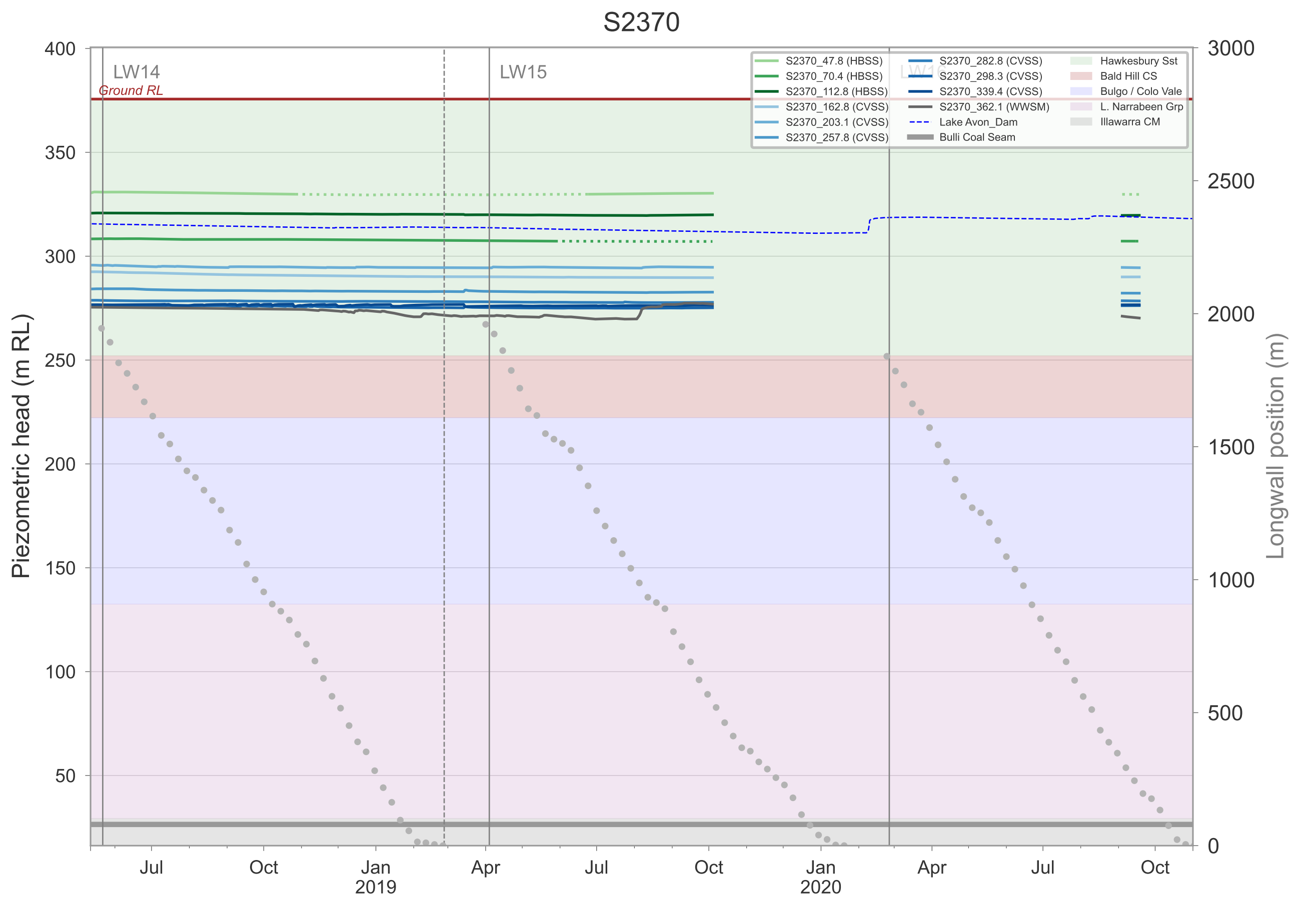

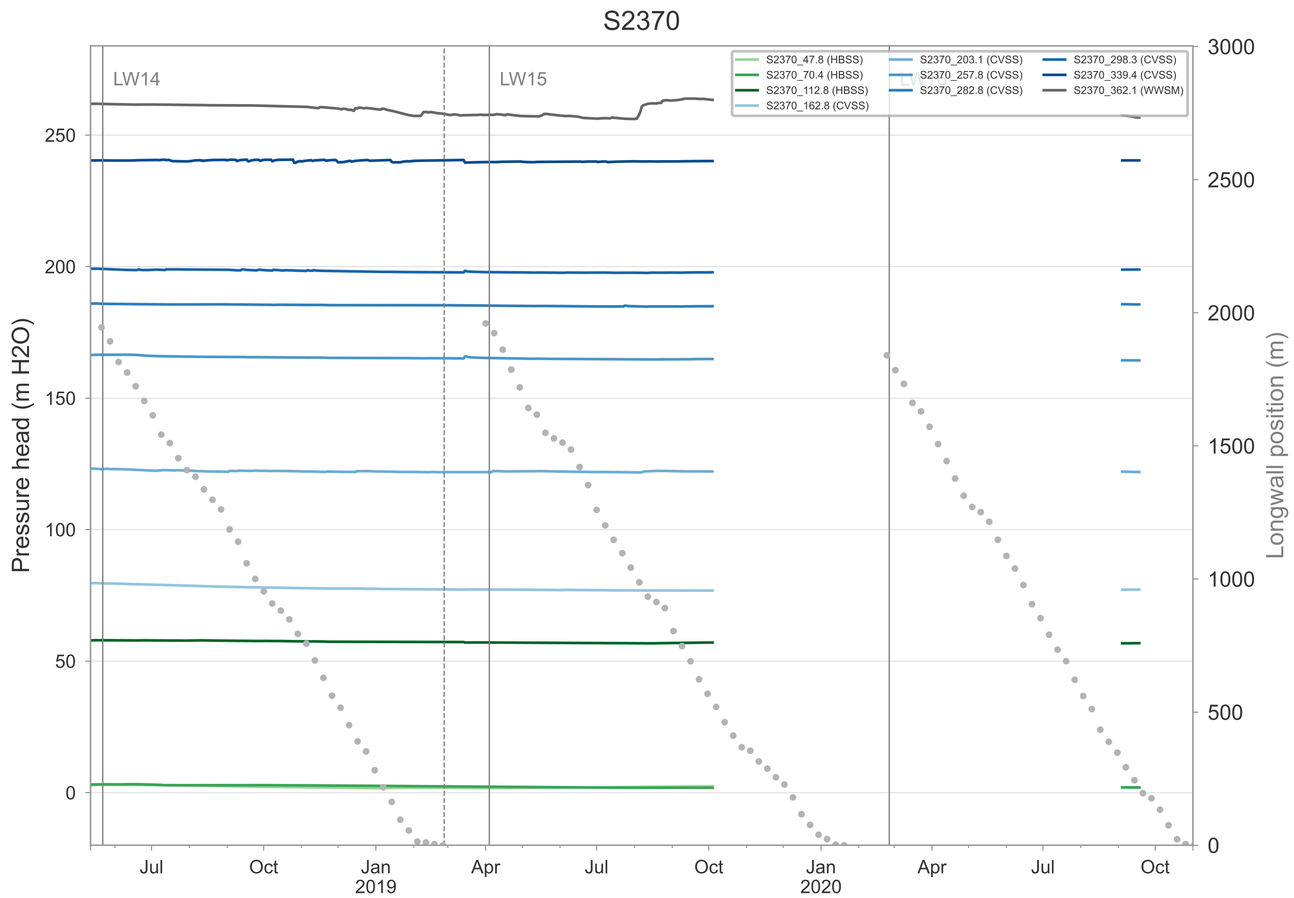

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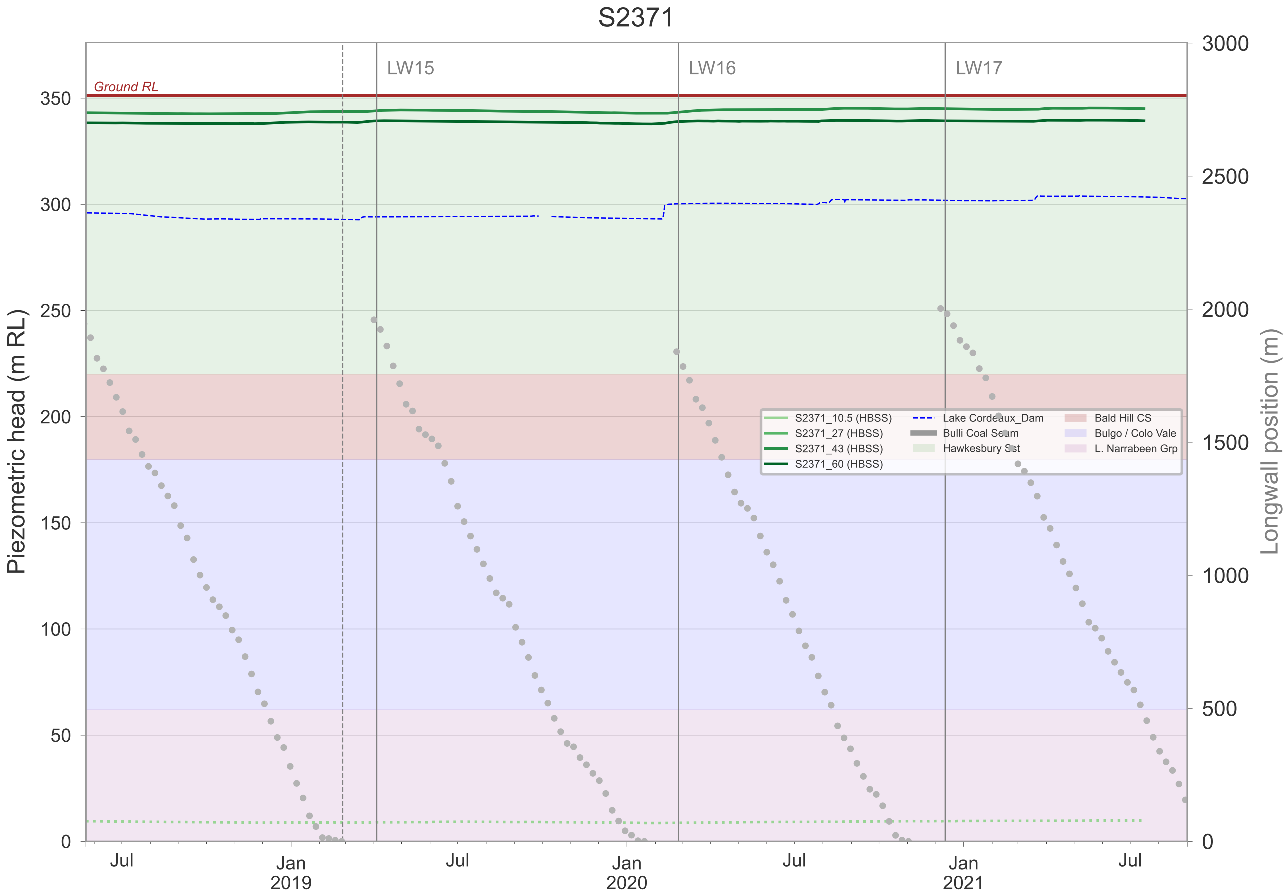

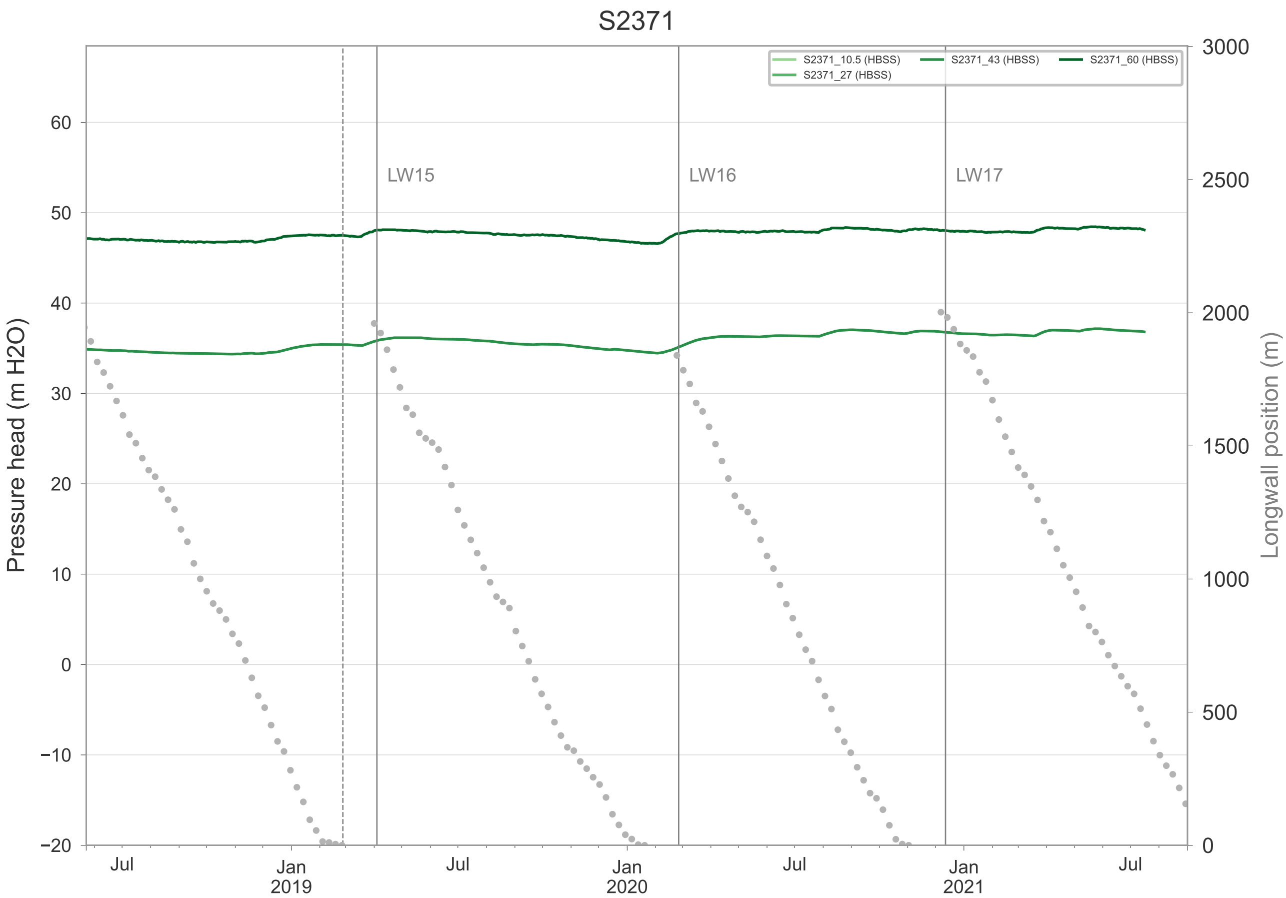

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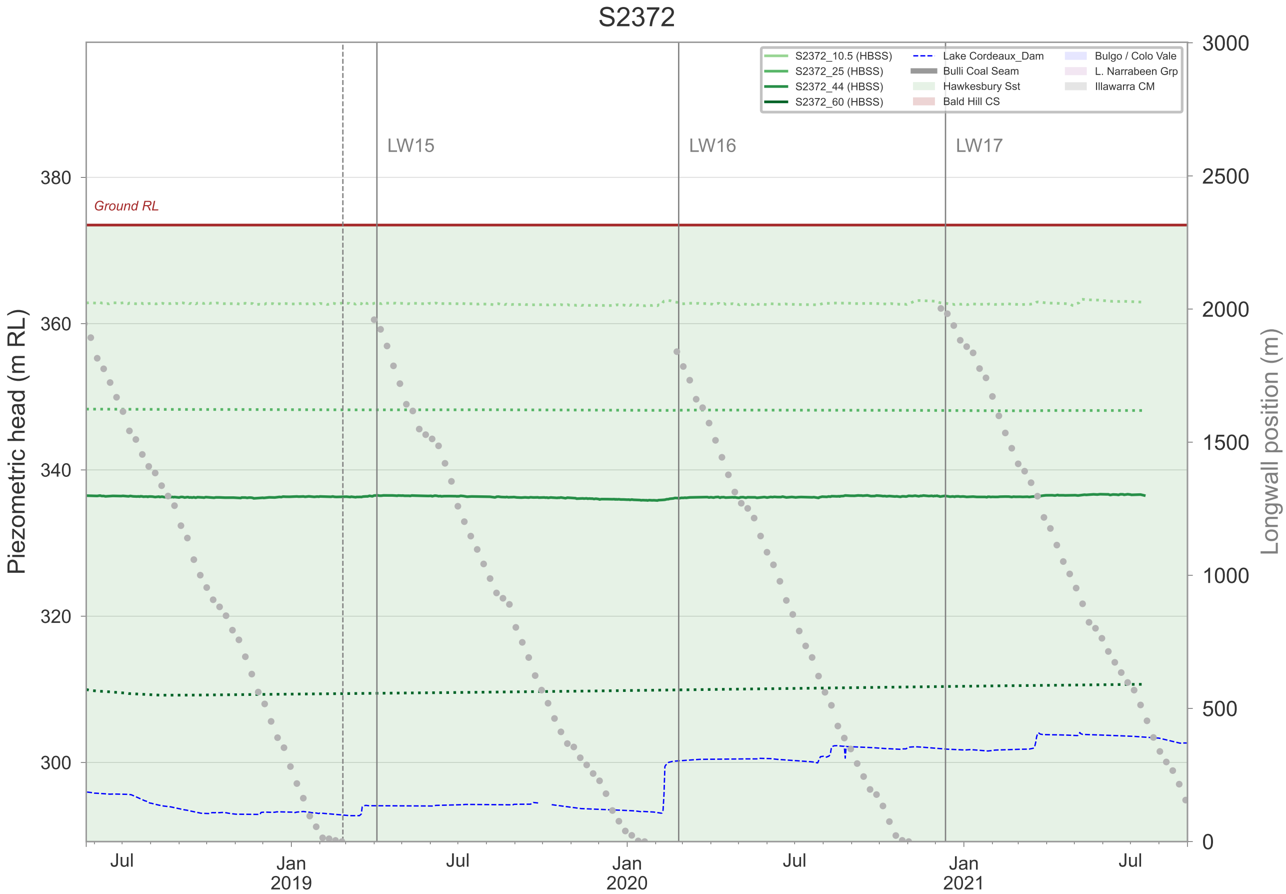

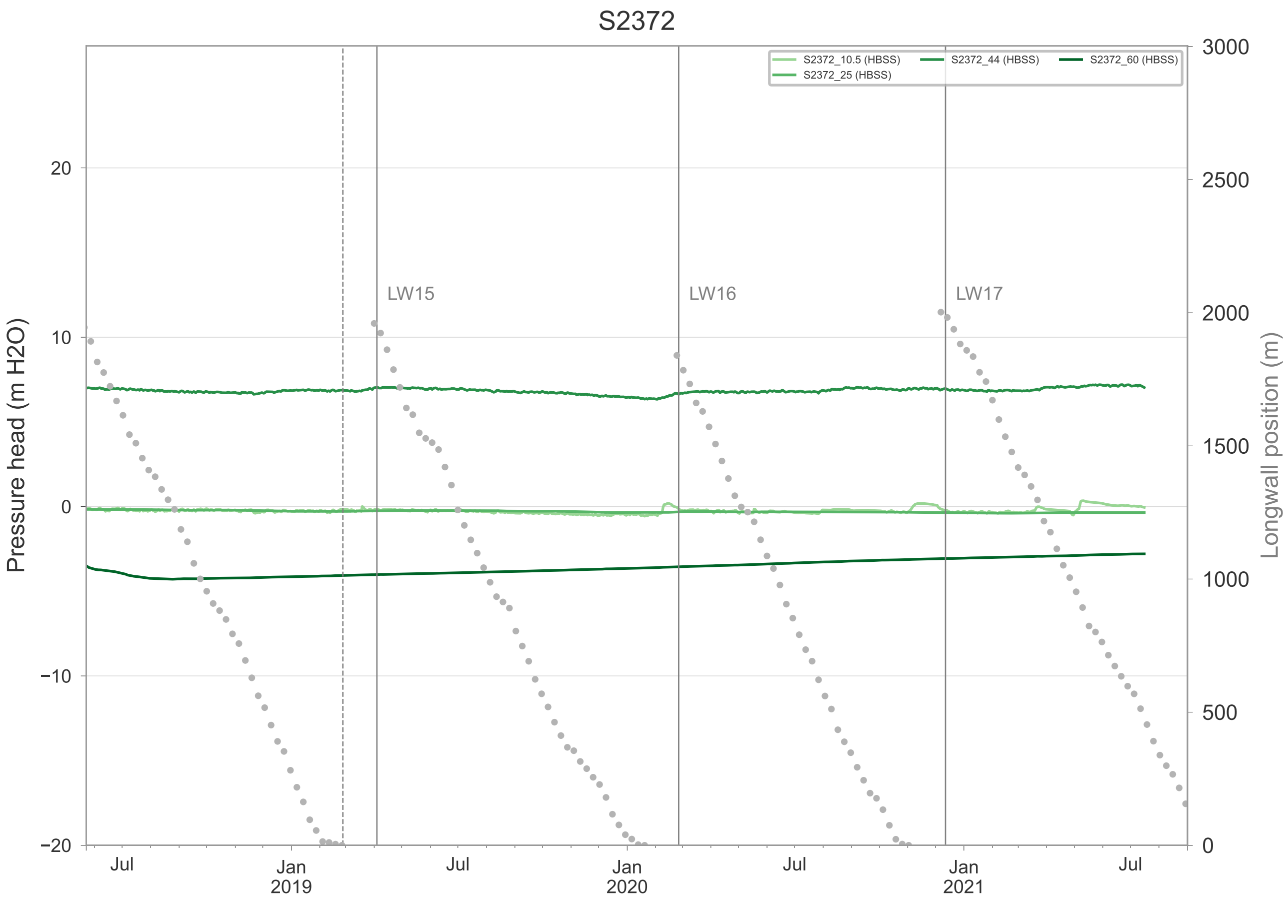

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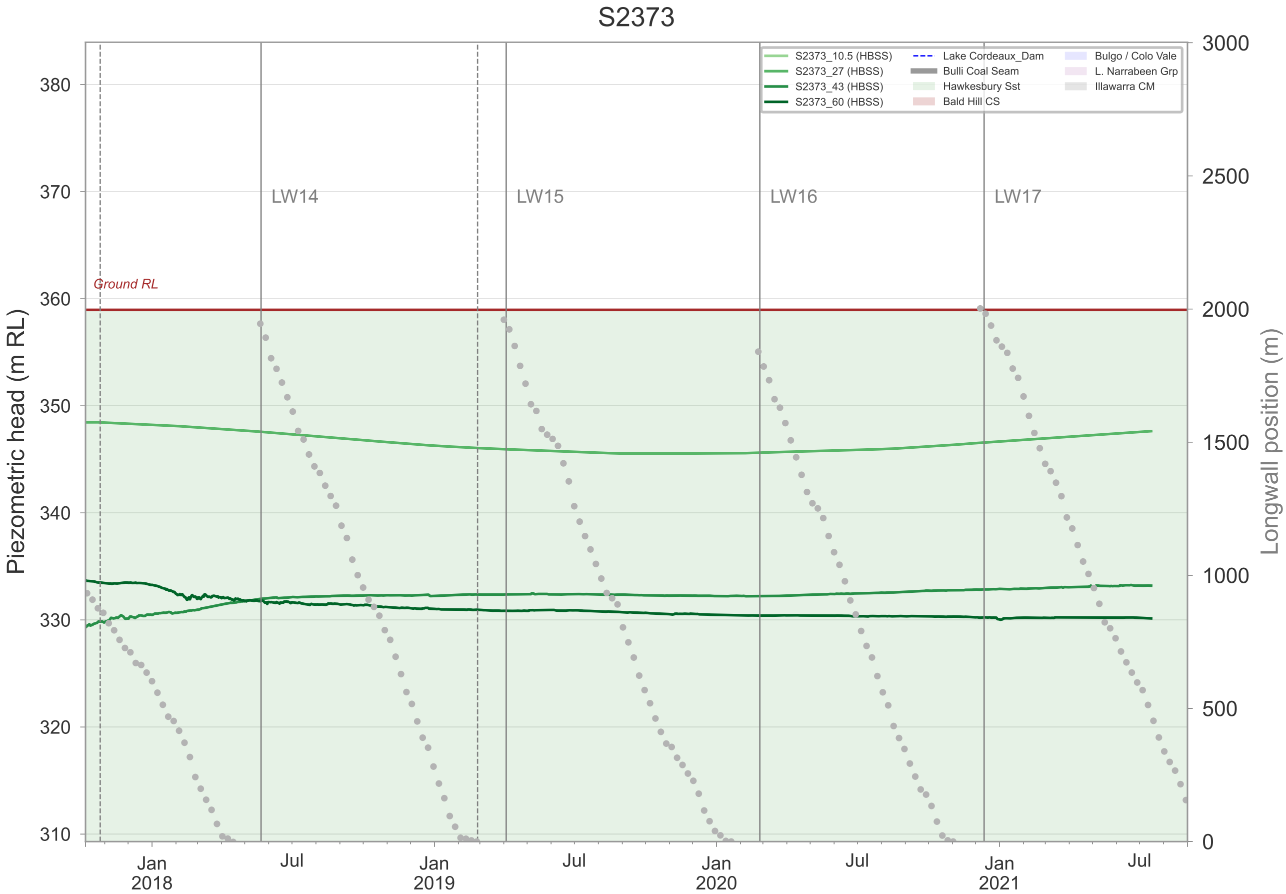

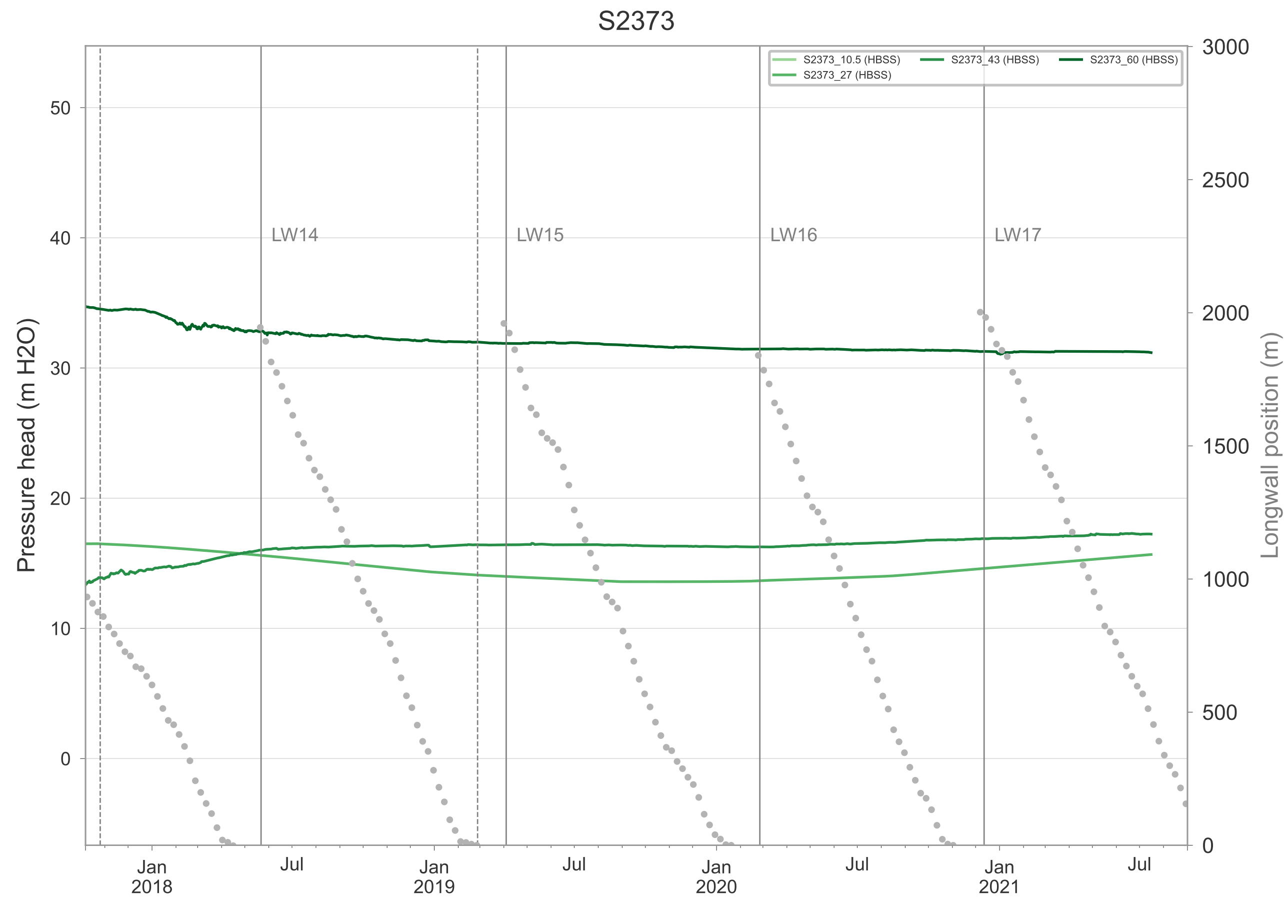

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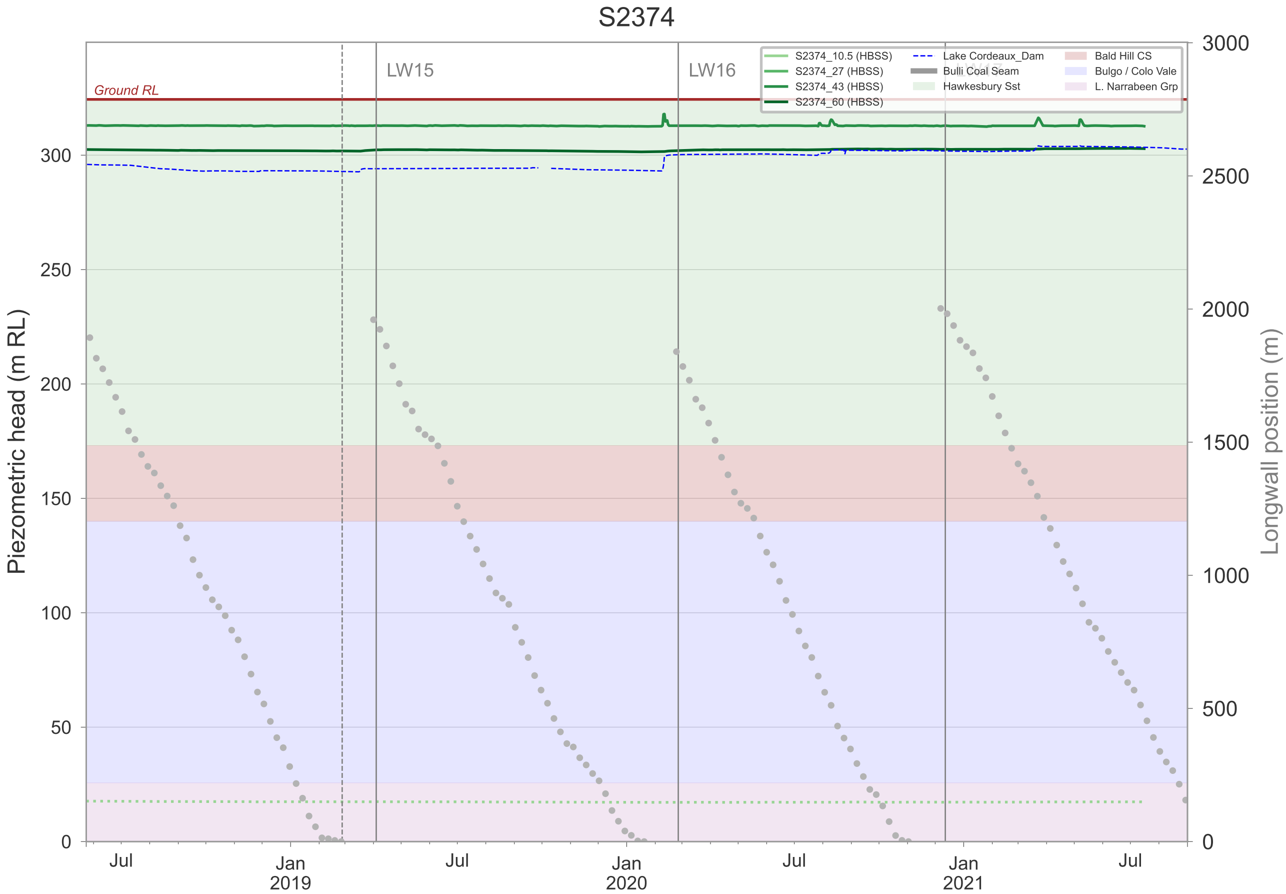

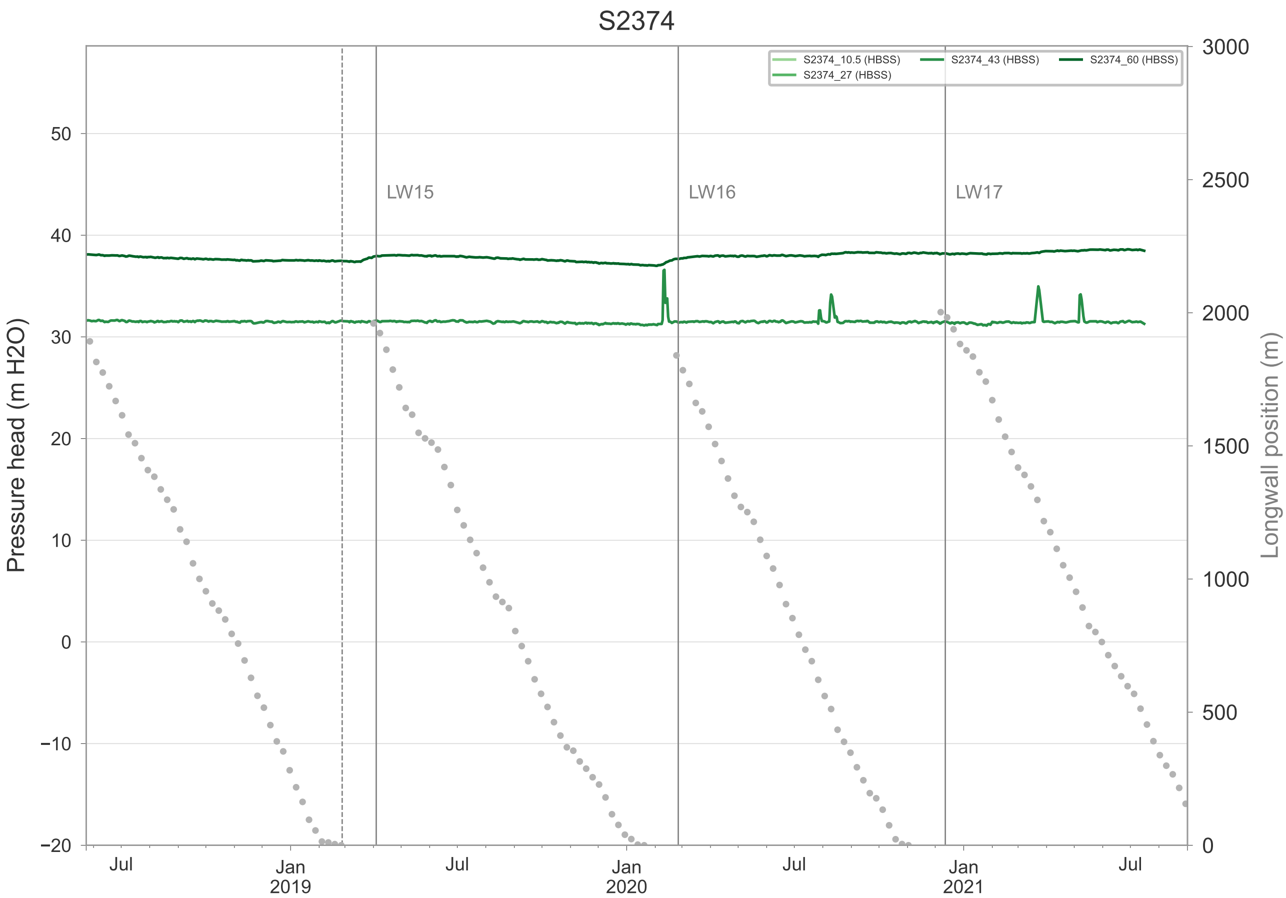

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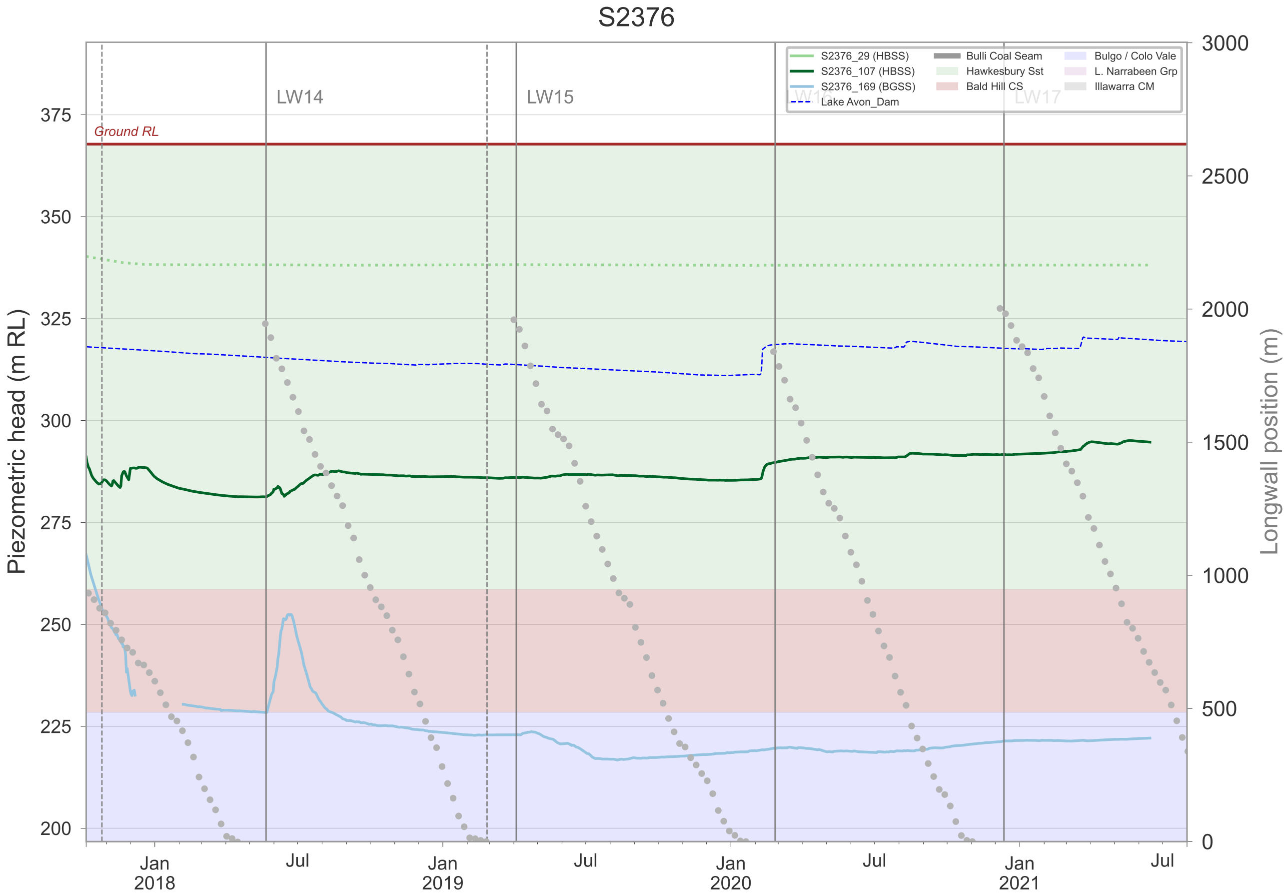

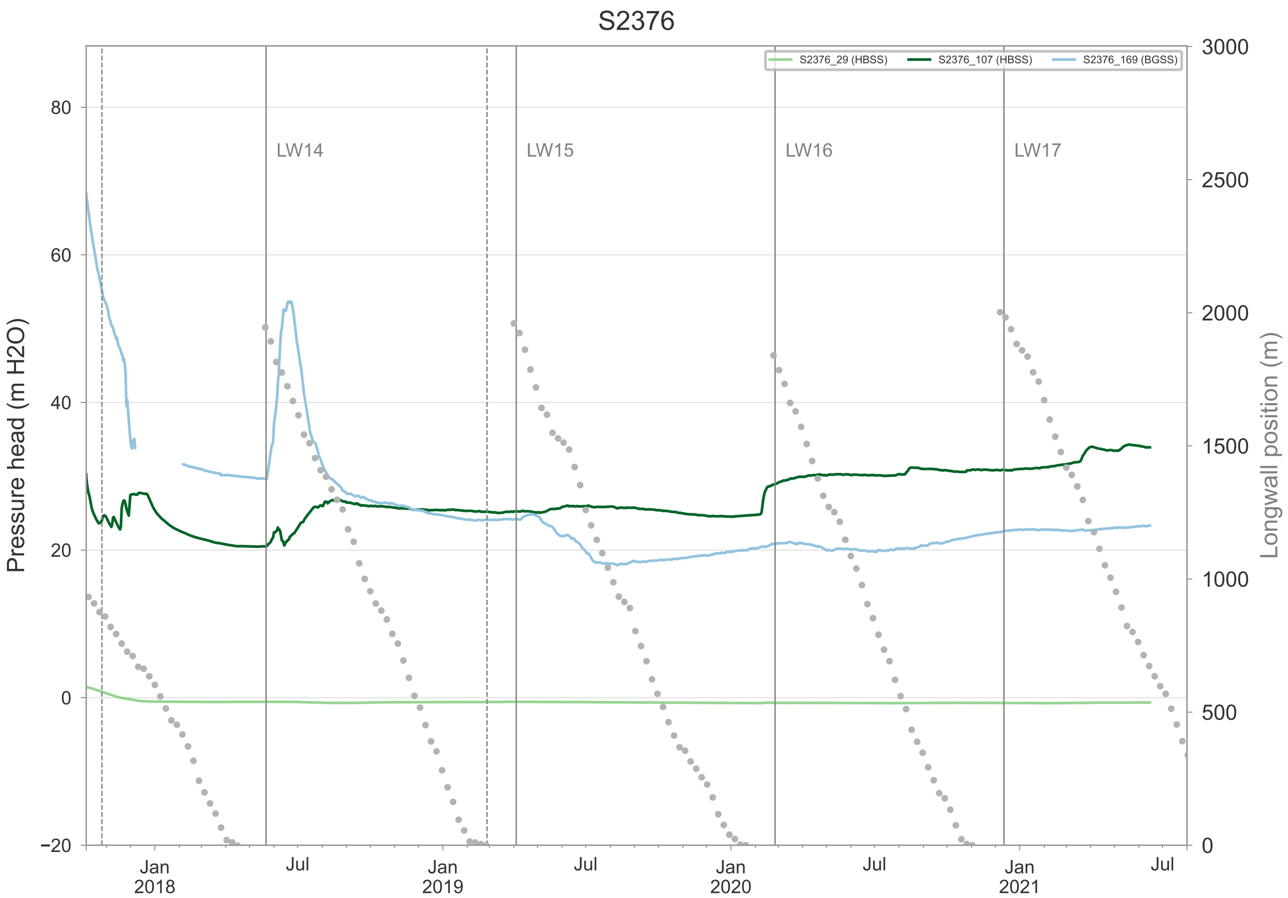

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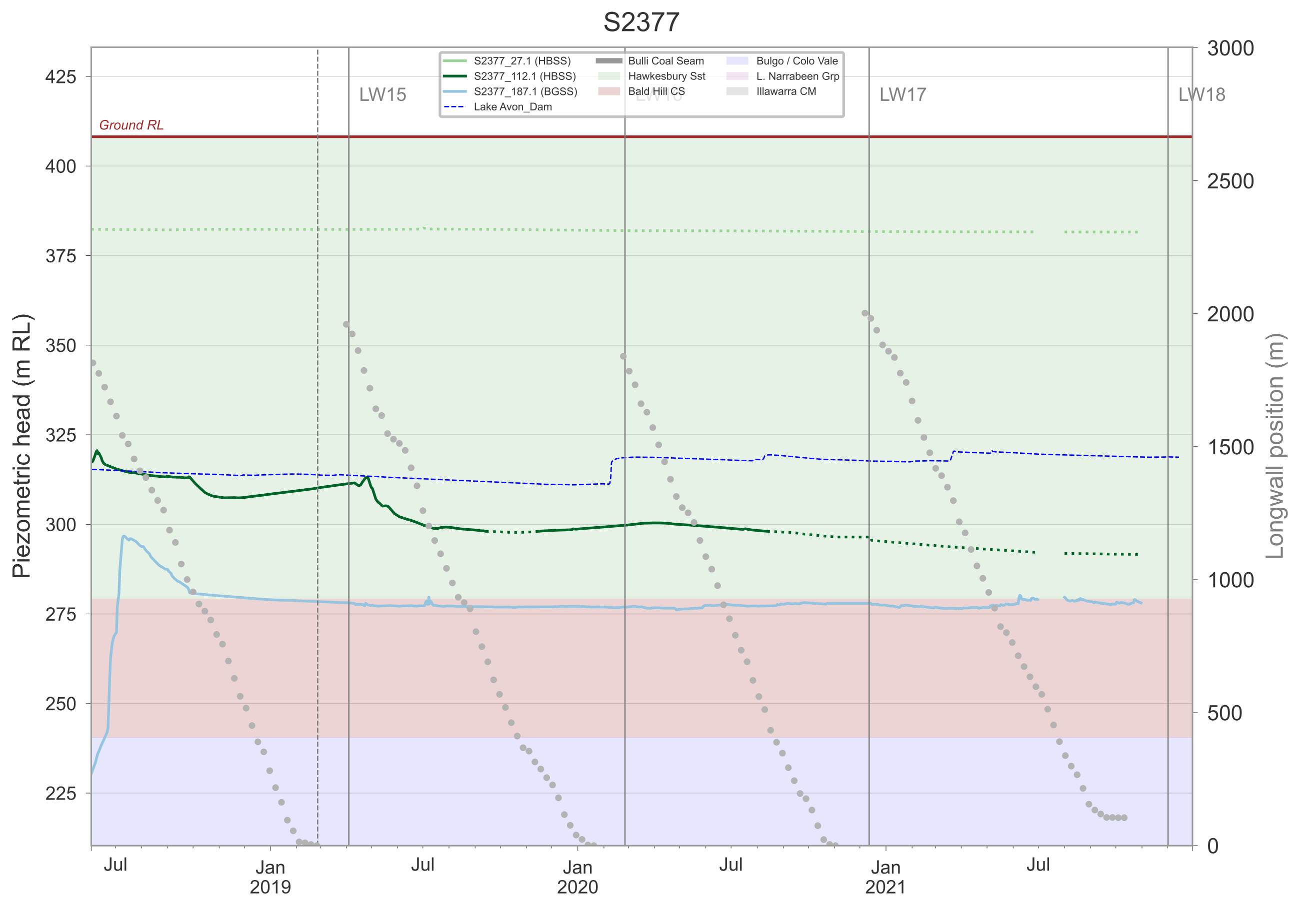

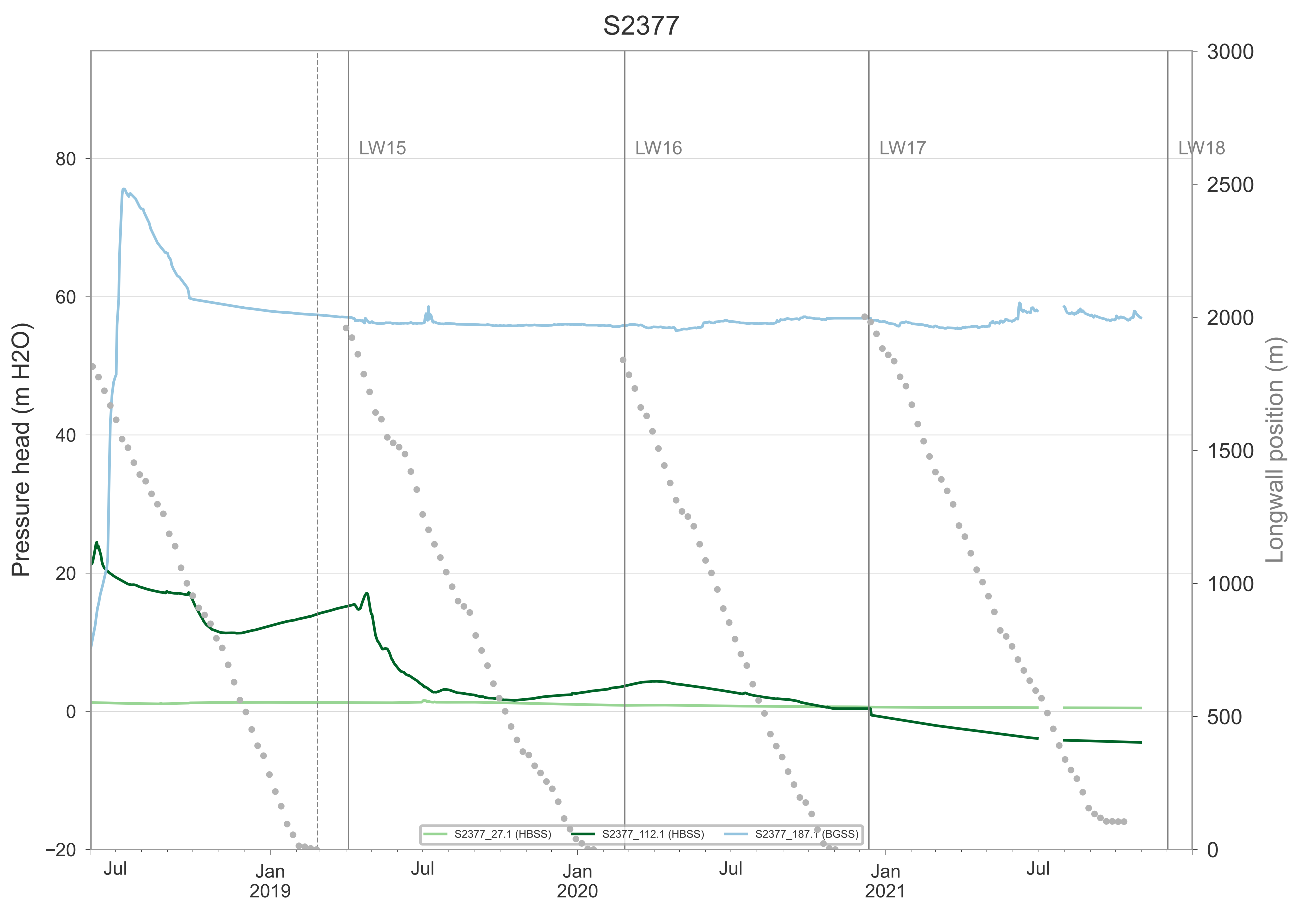

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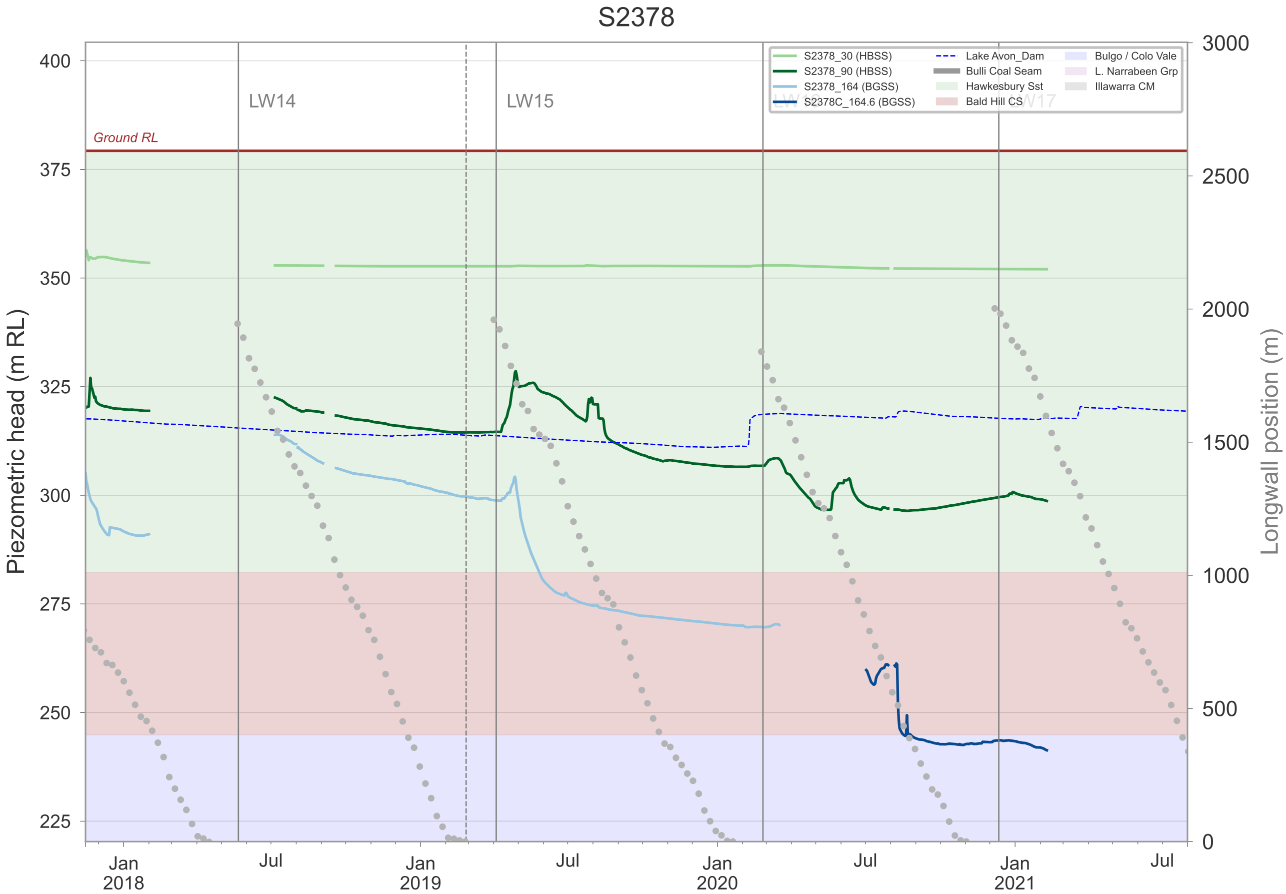

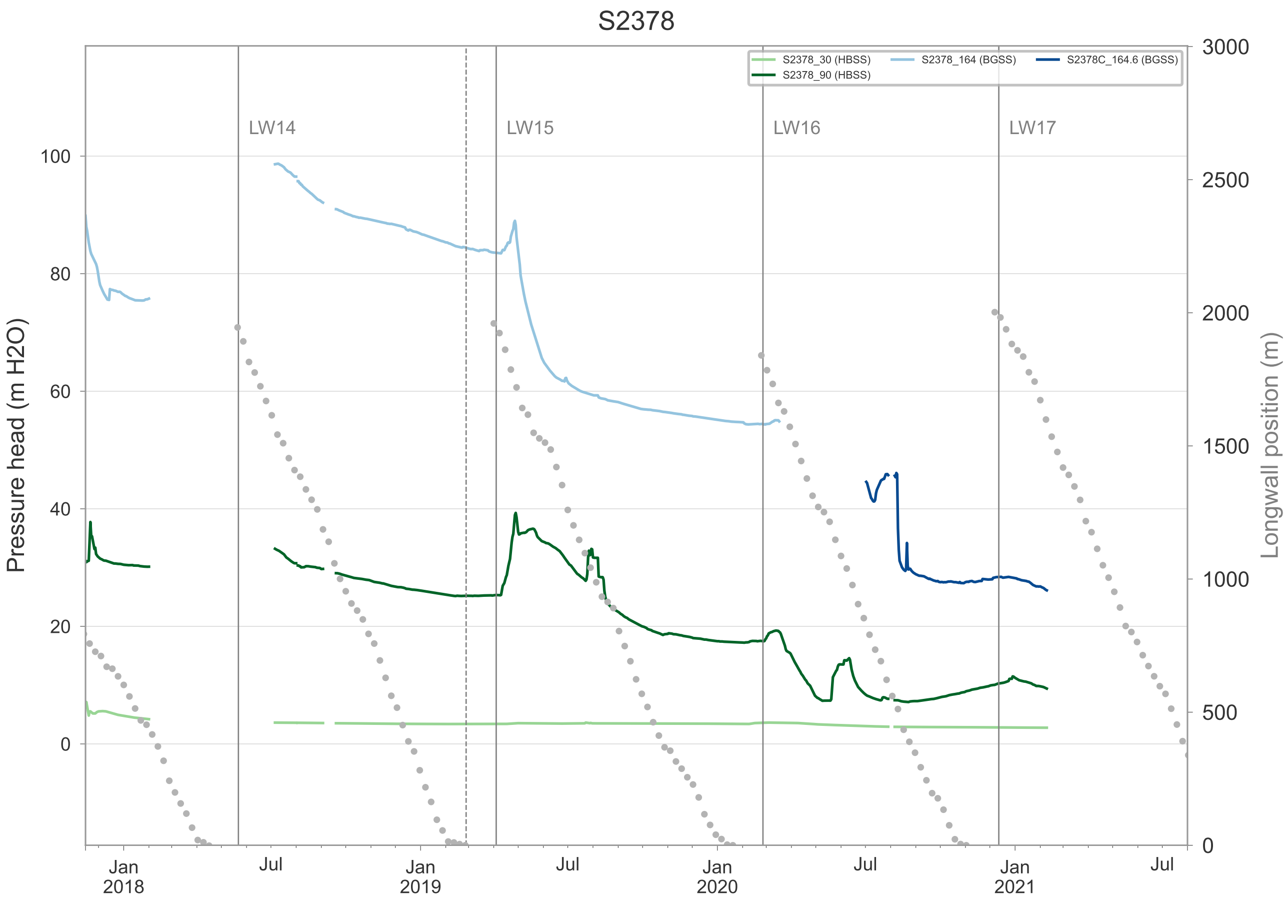

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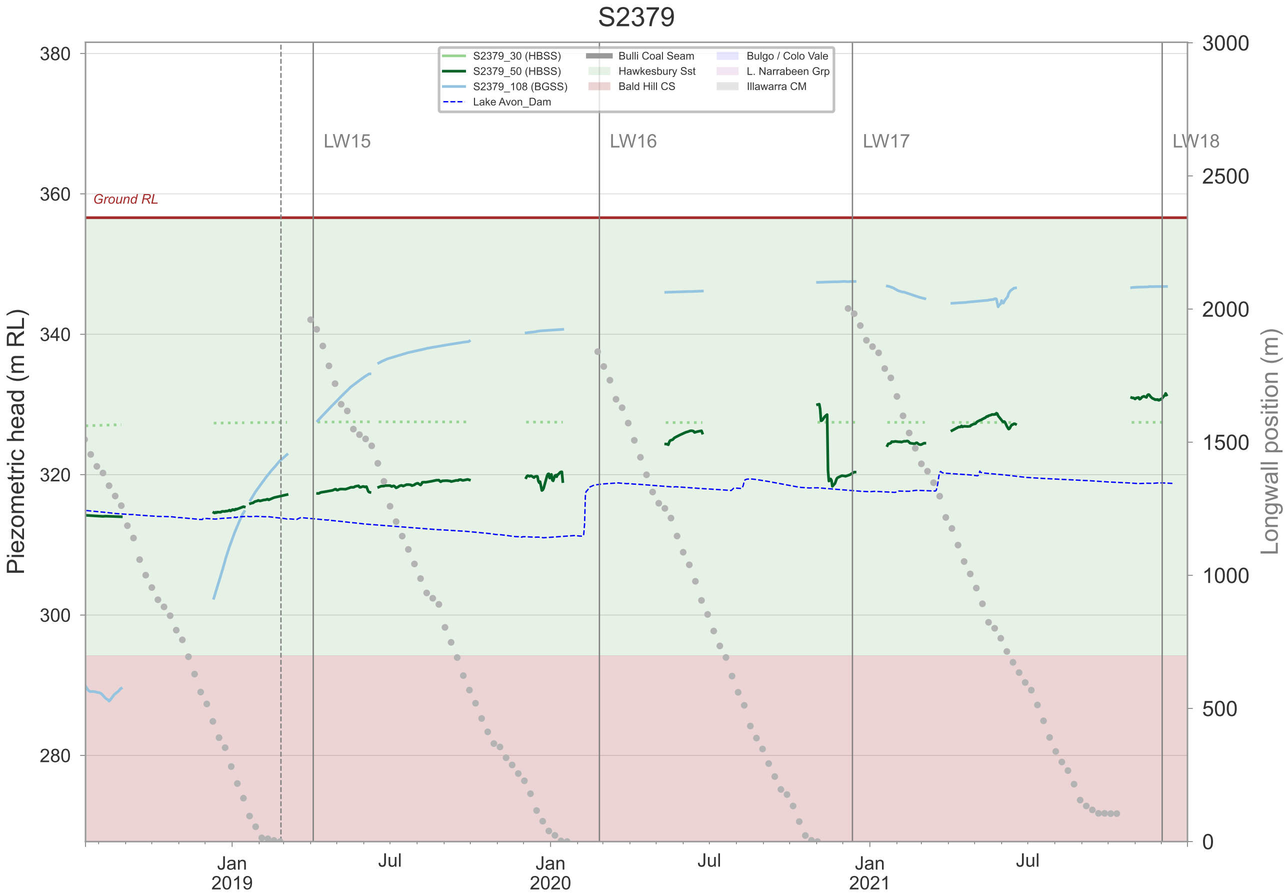
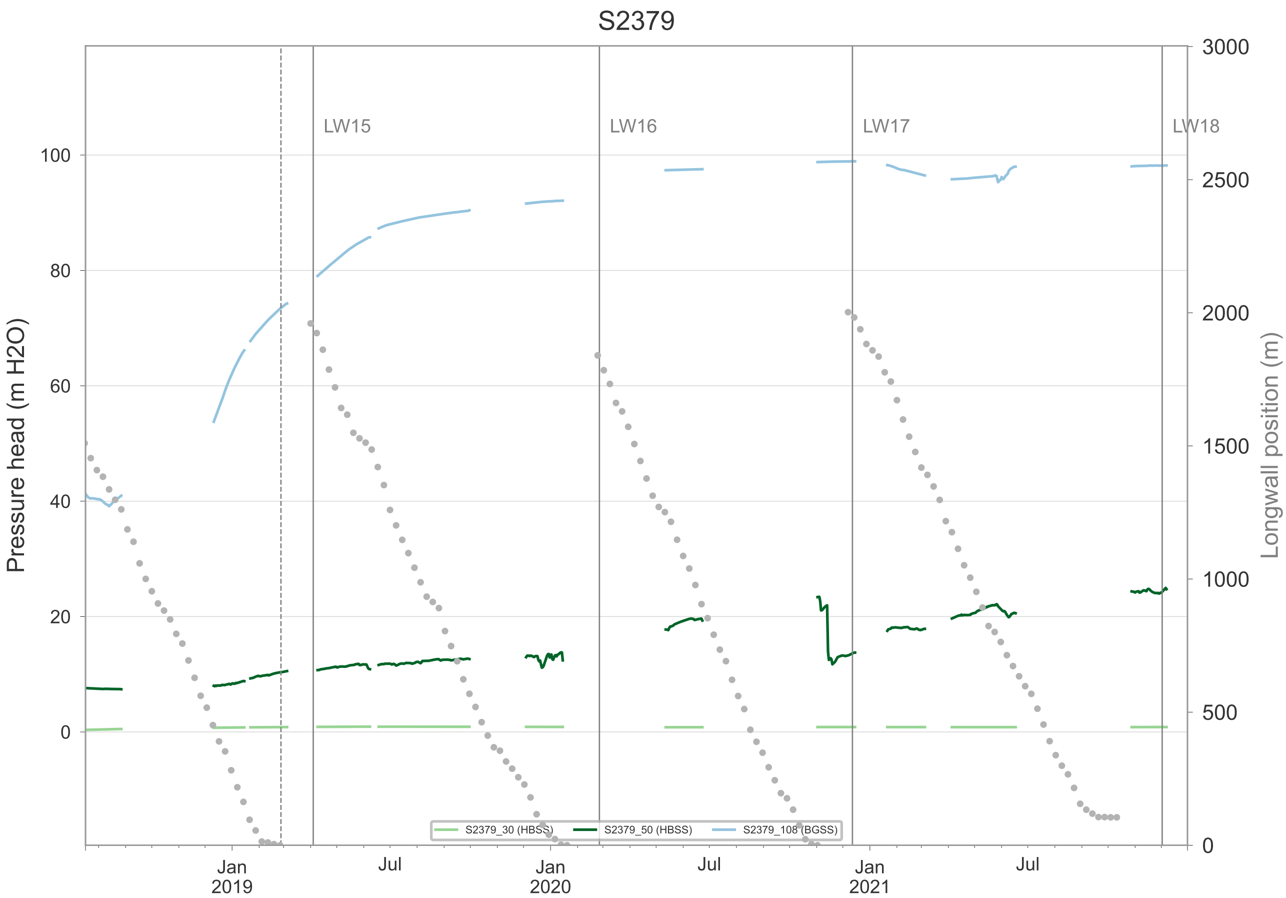
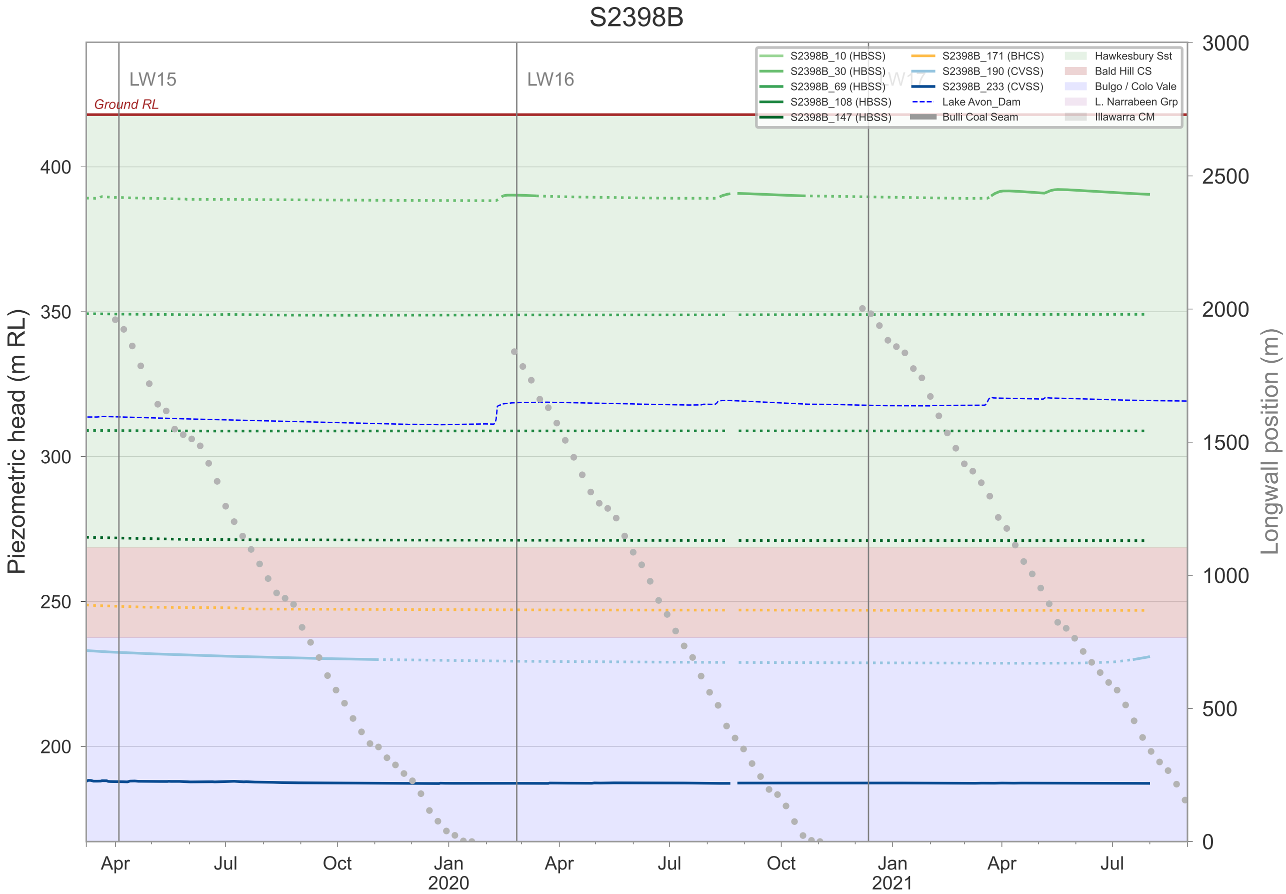
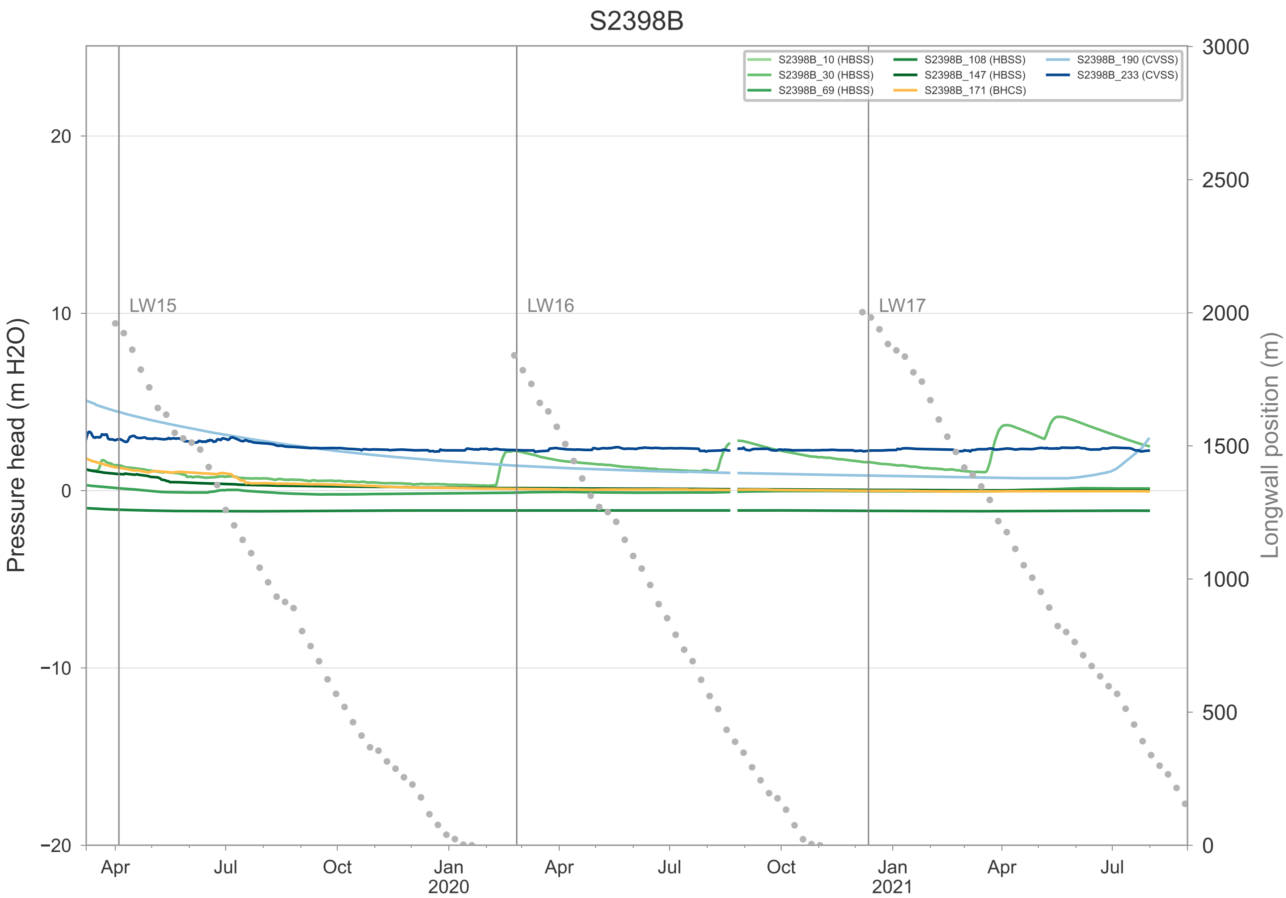




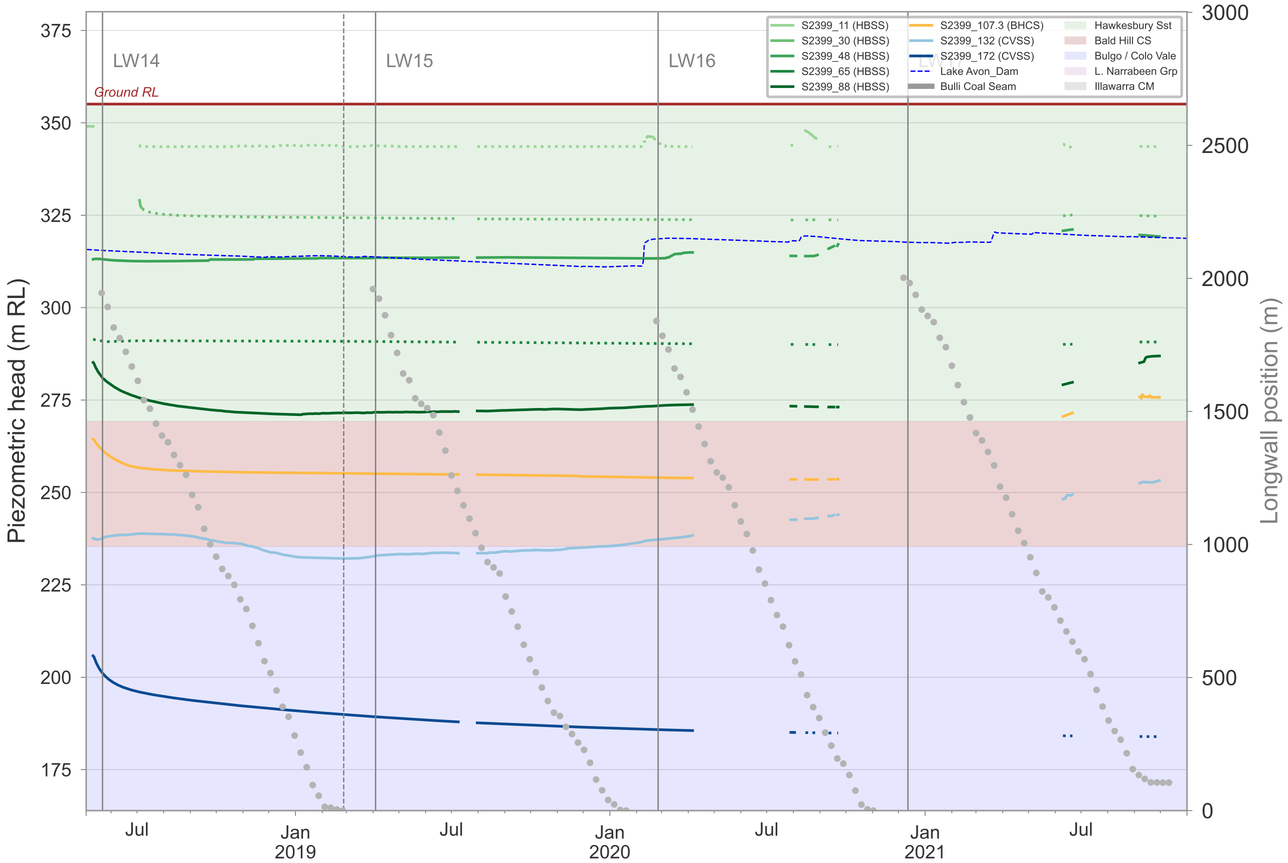
Groundwater hydrographs





Groundwater hydrographs

S2399



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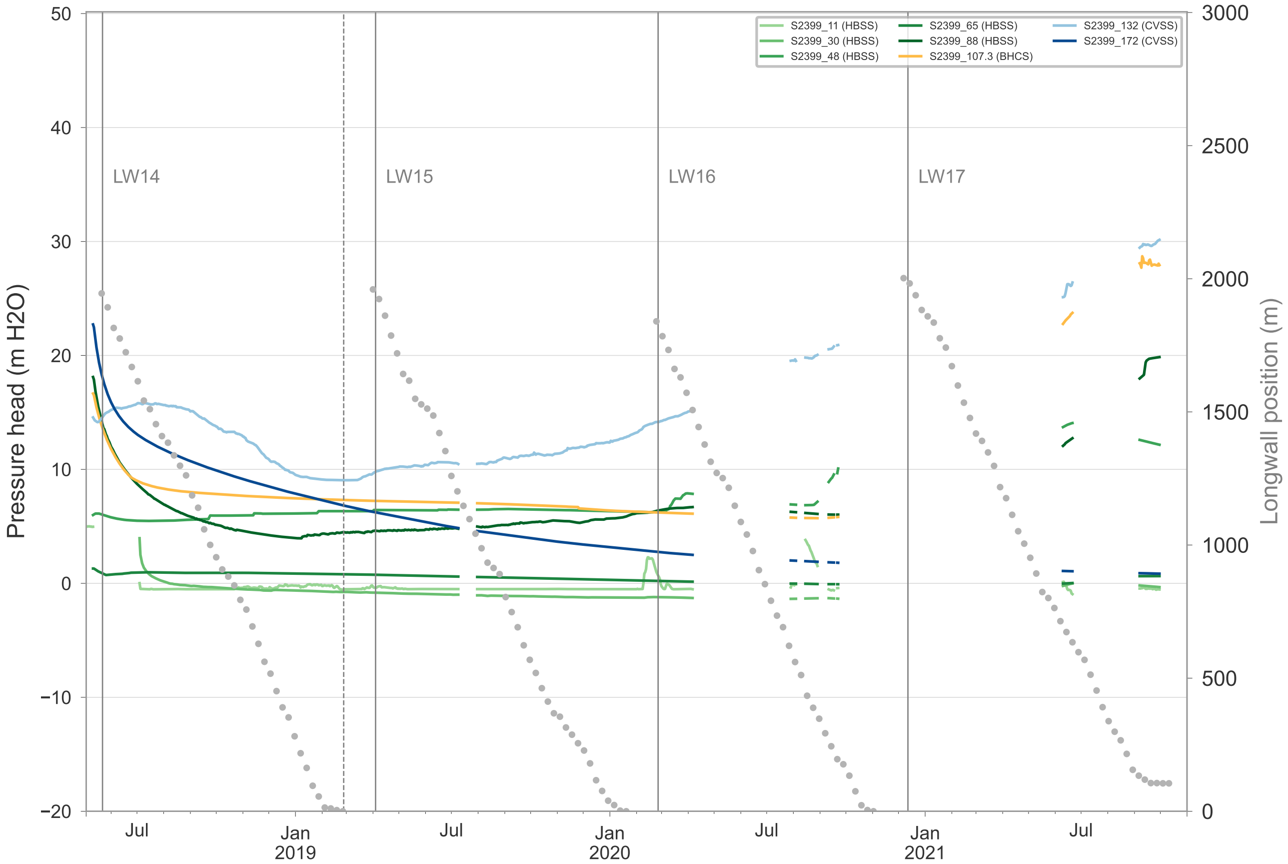
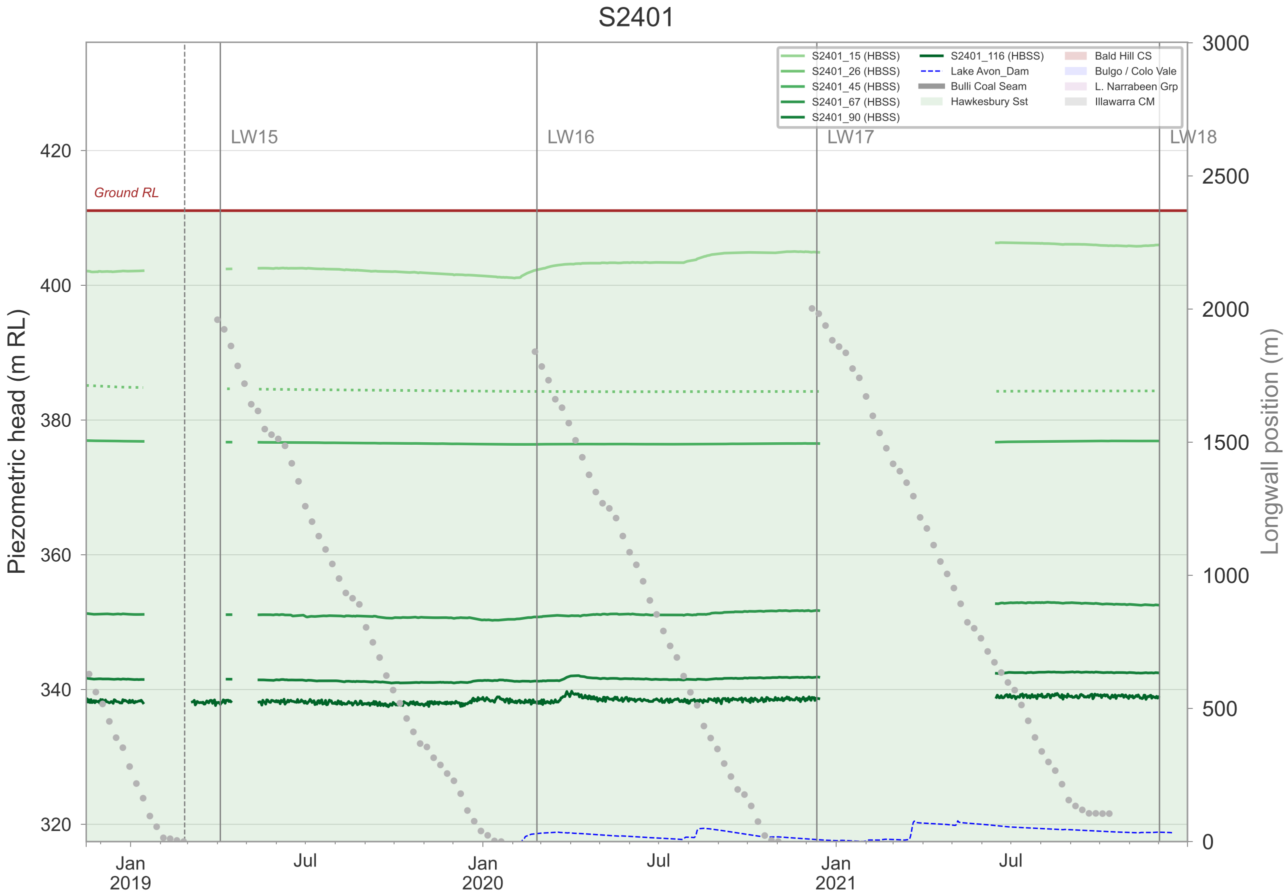
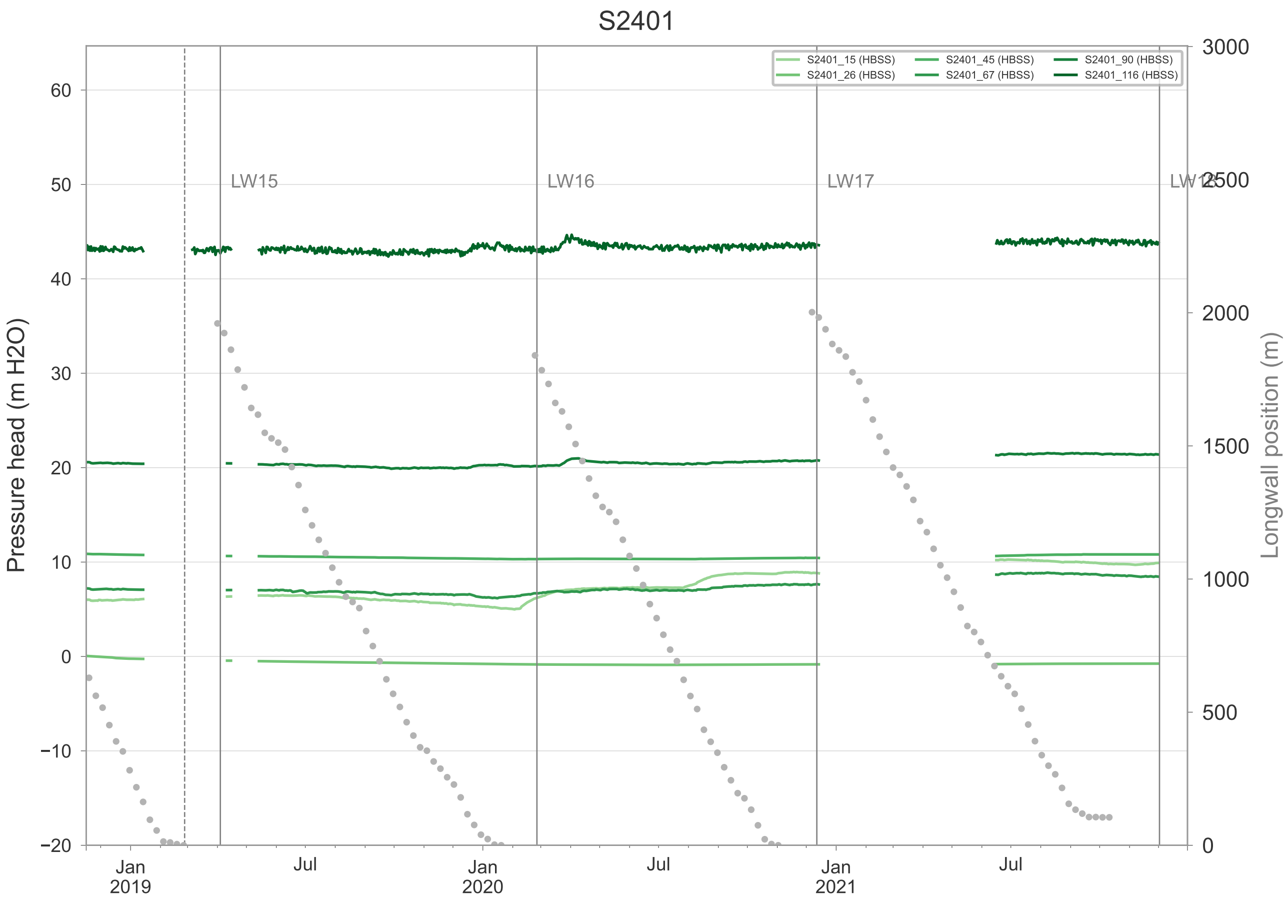
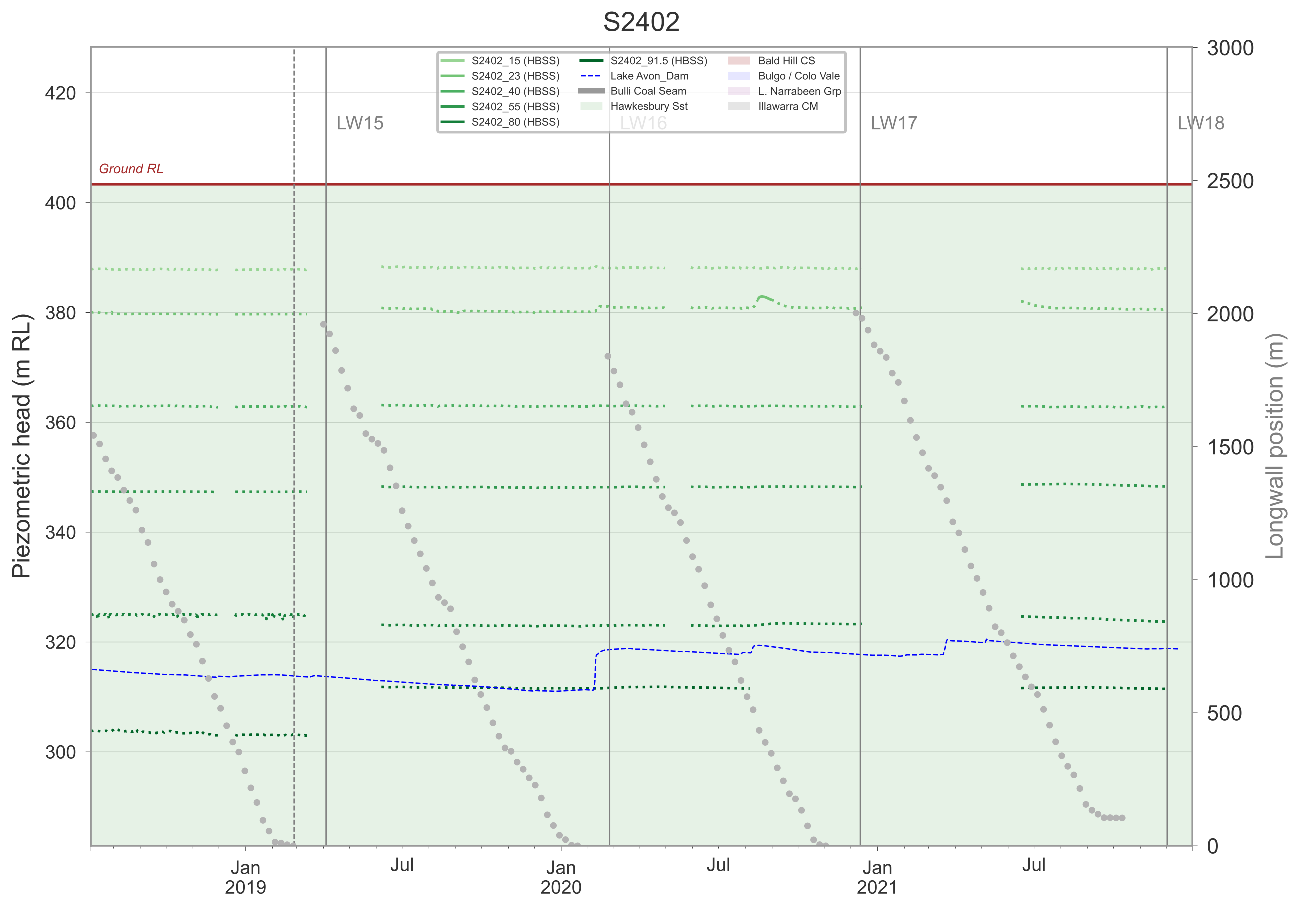


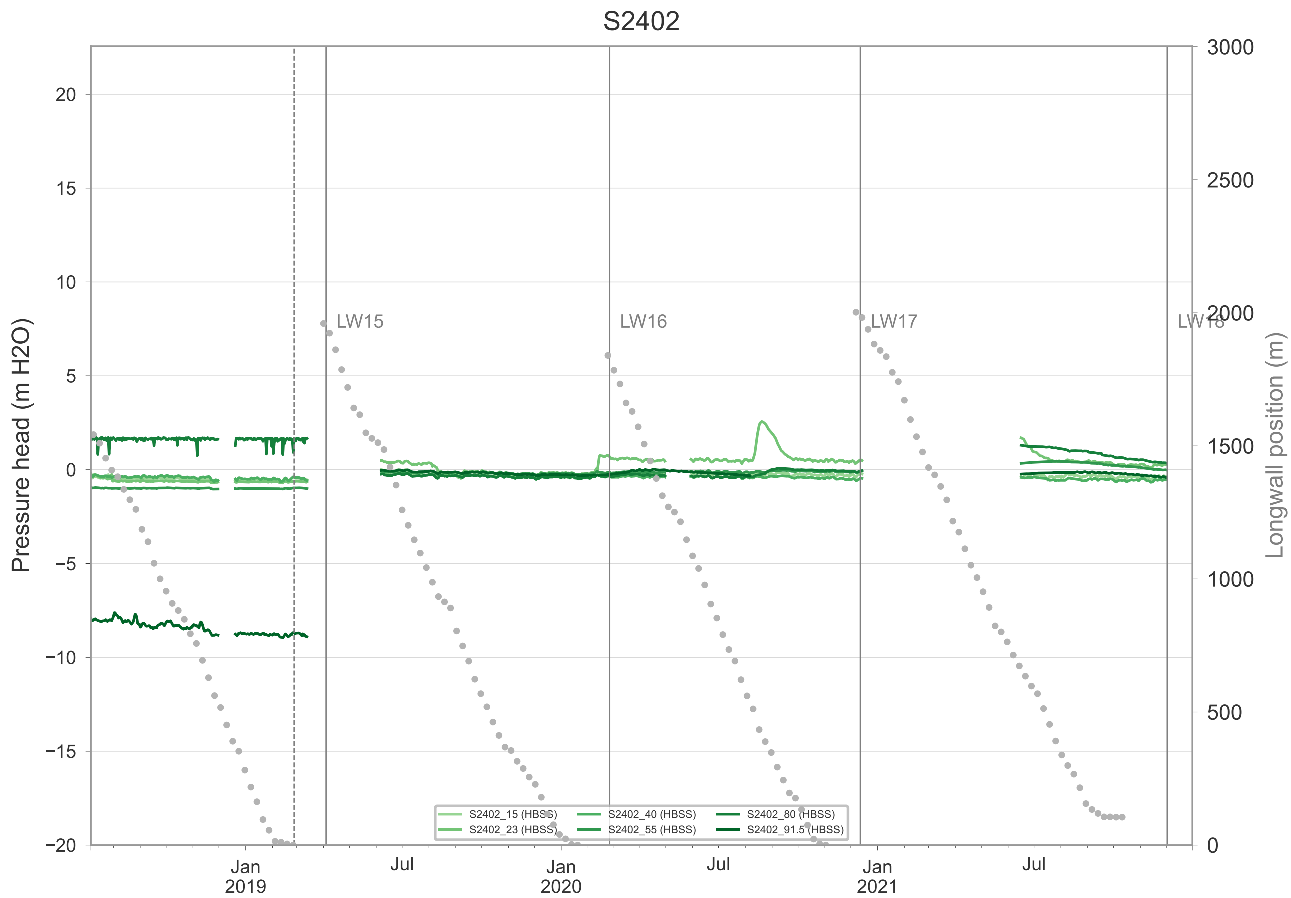
Groundwater hydrographs



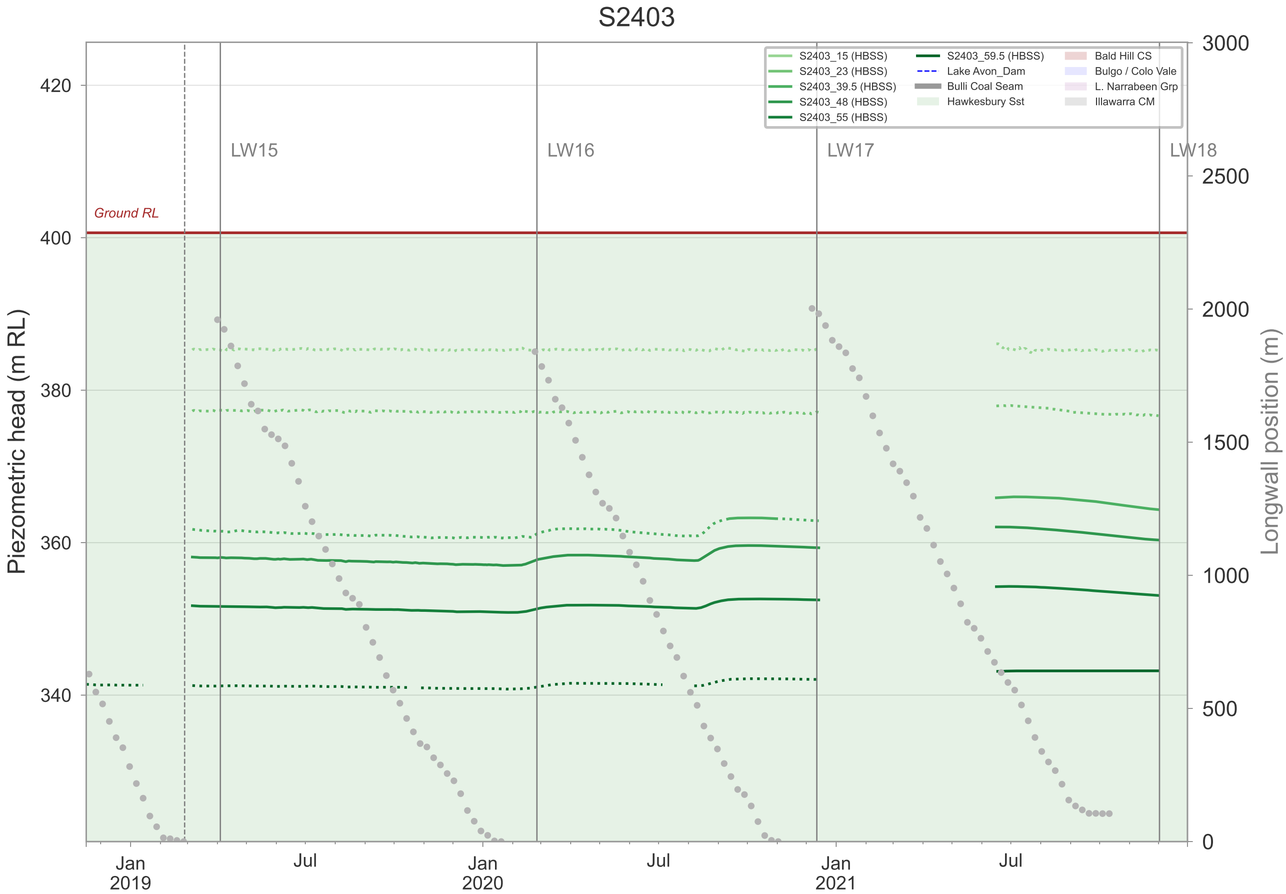


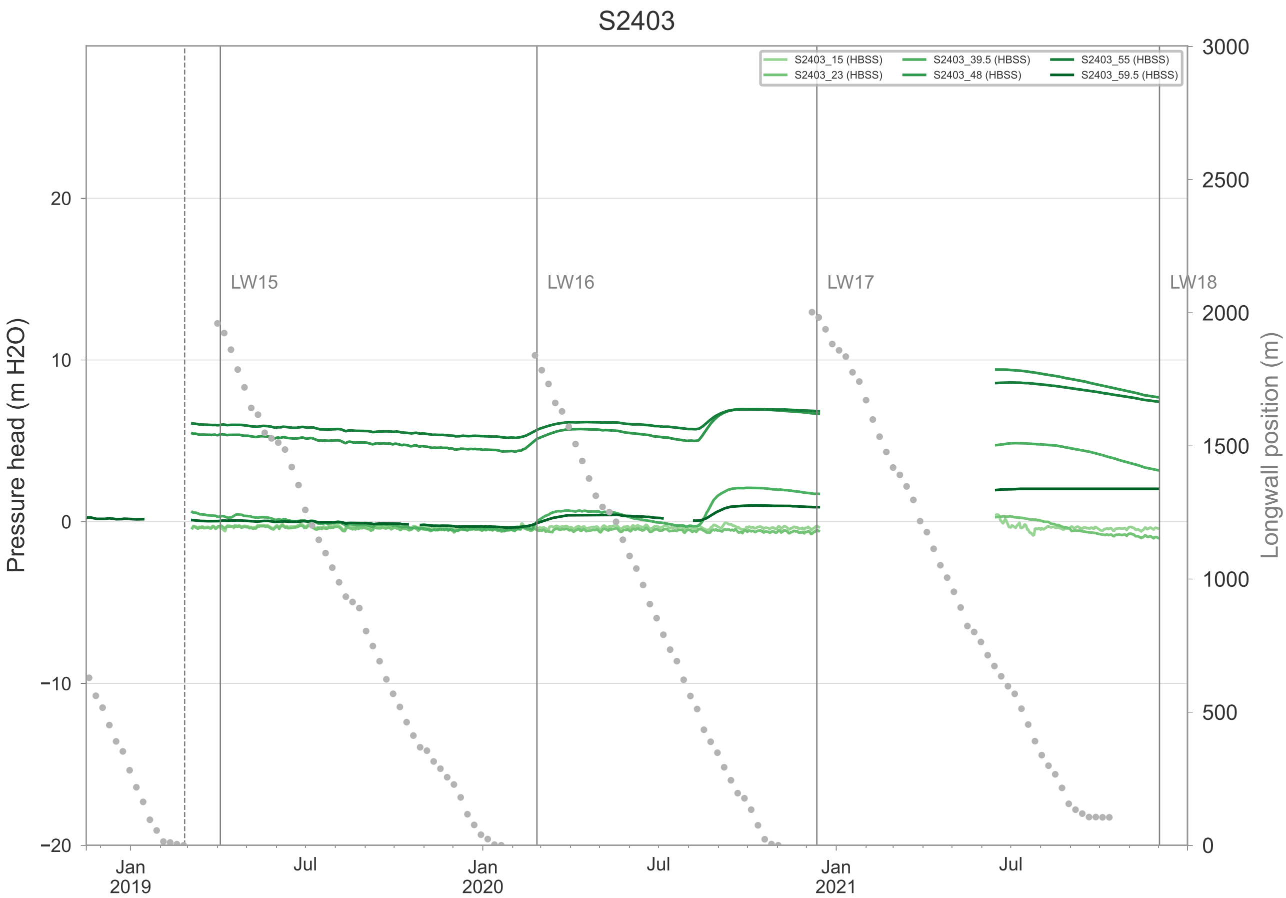
Groundwater hydrographs



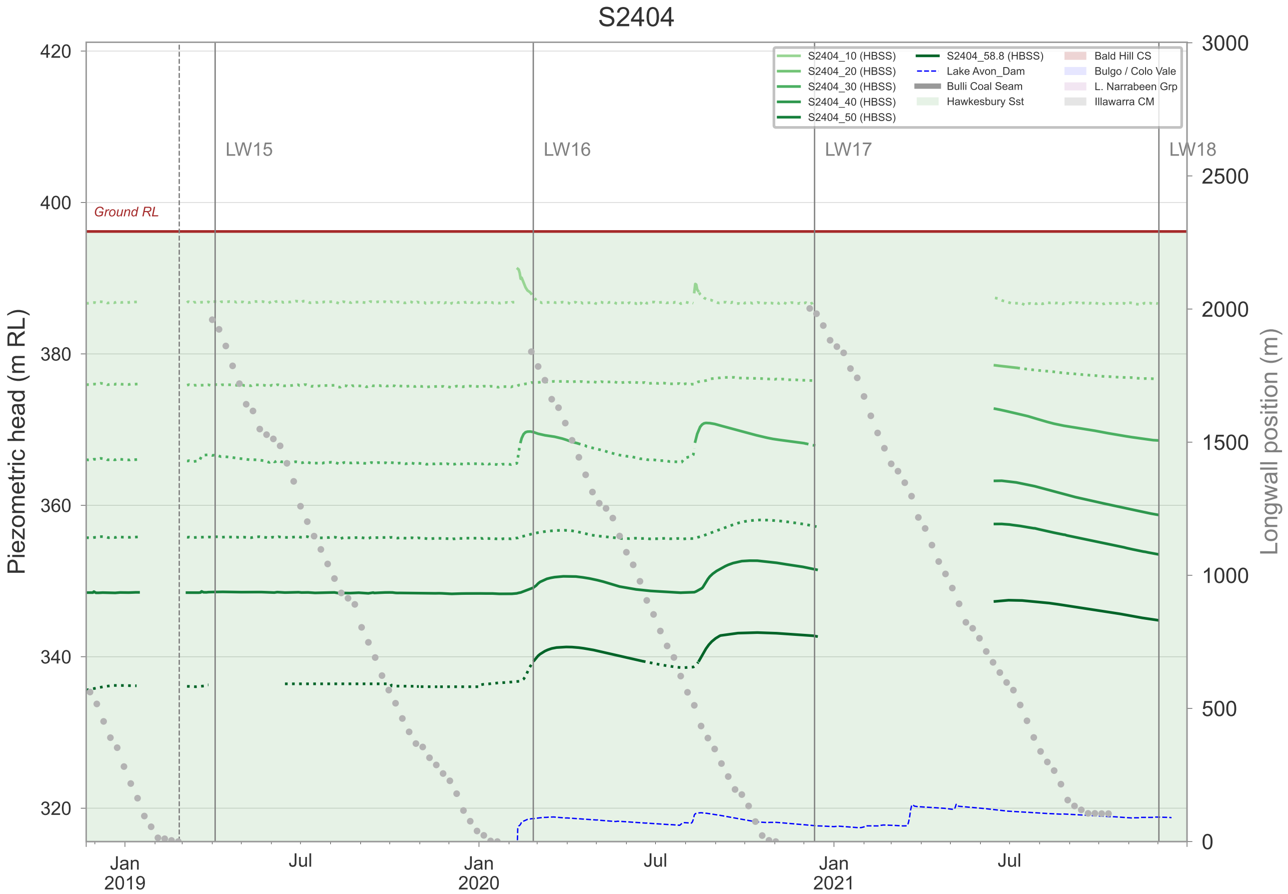


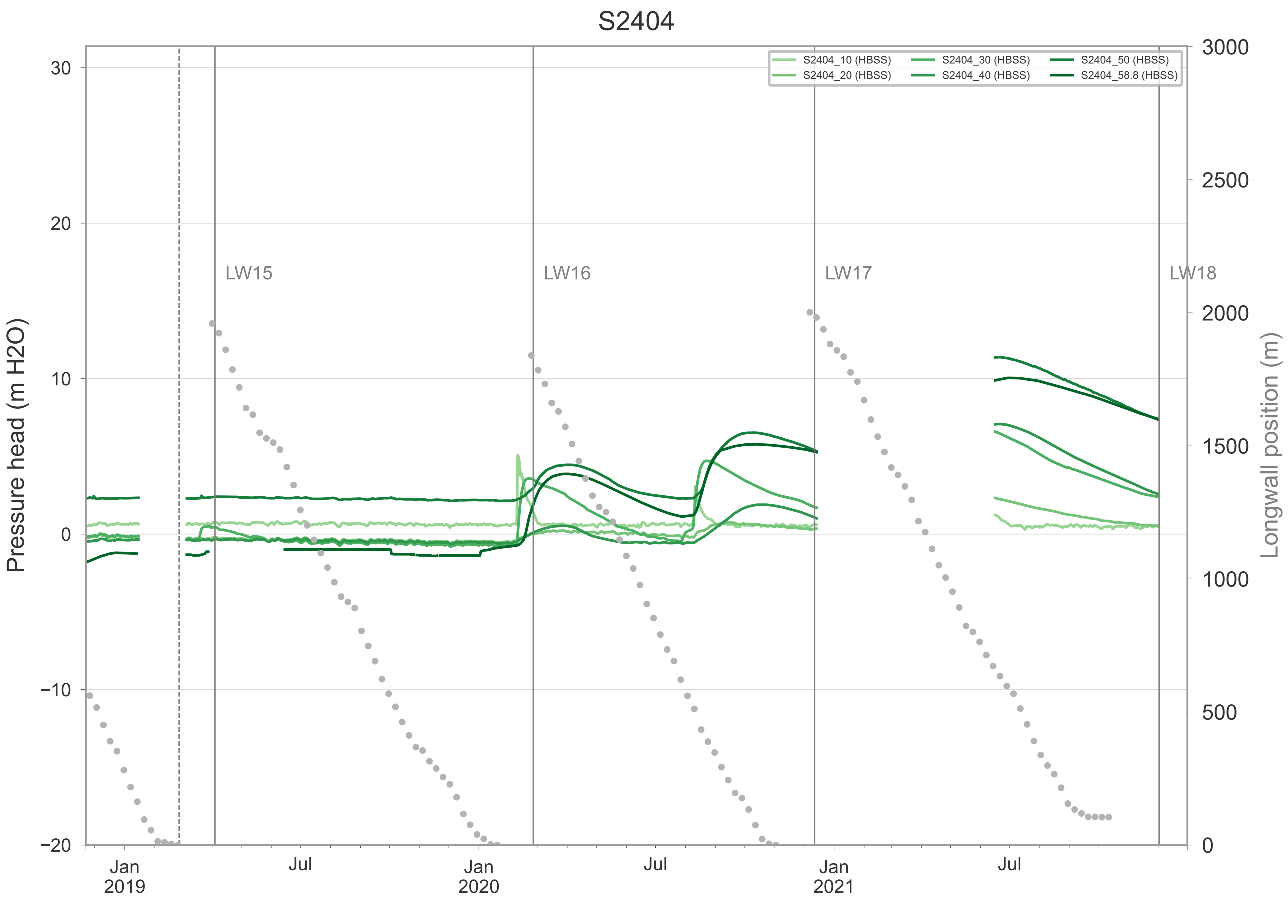
Groundwater hydrographs





Groundwater hydrographs





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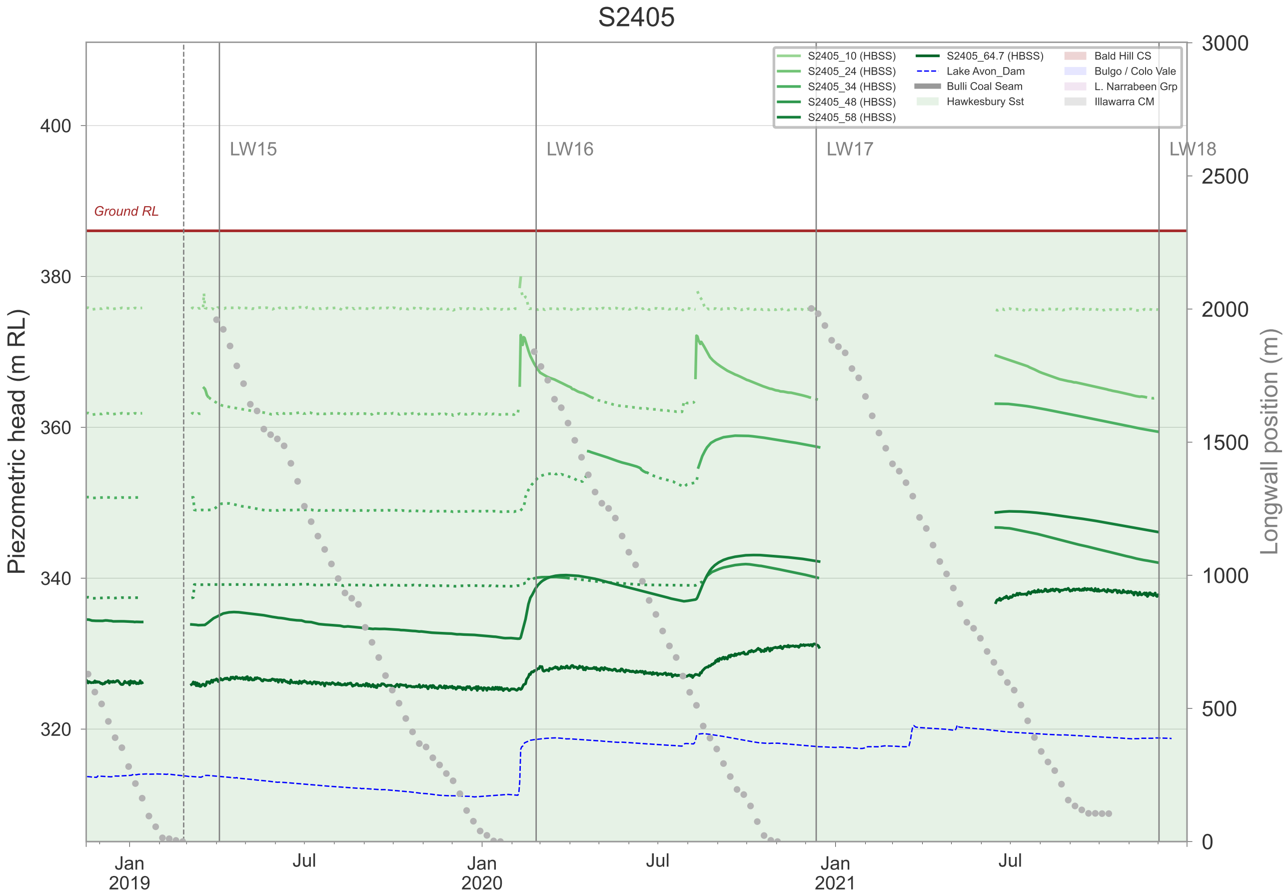

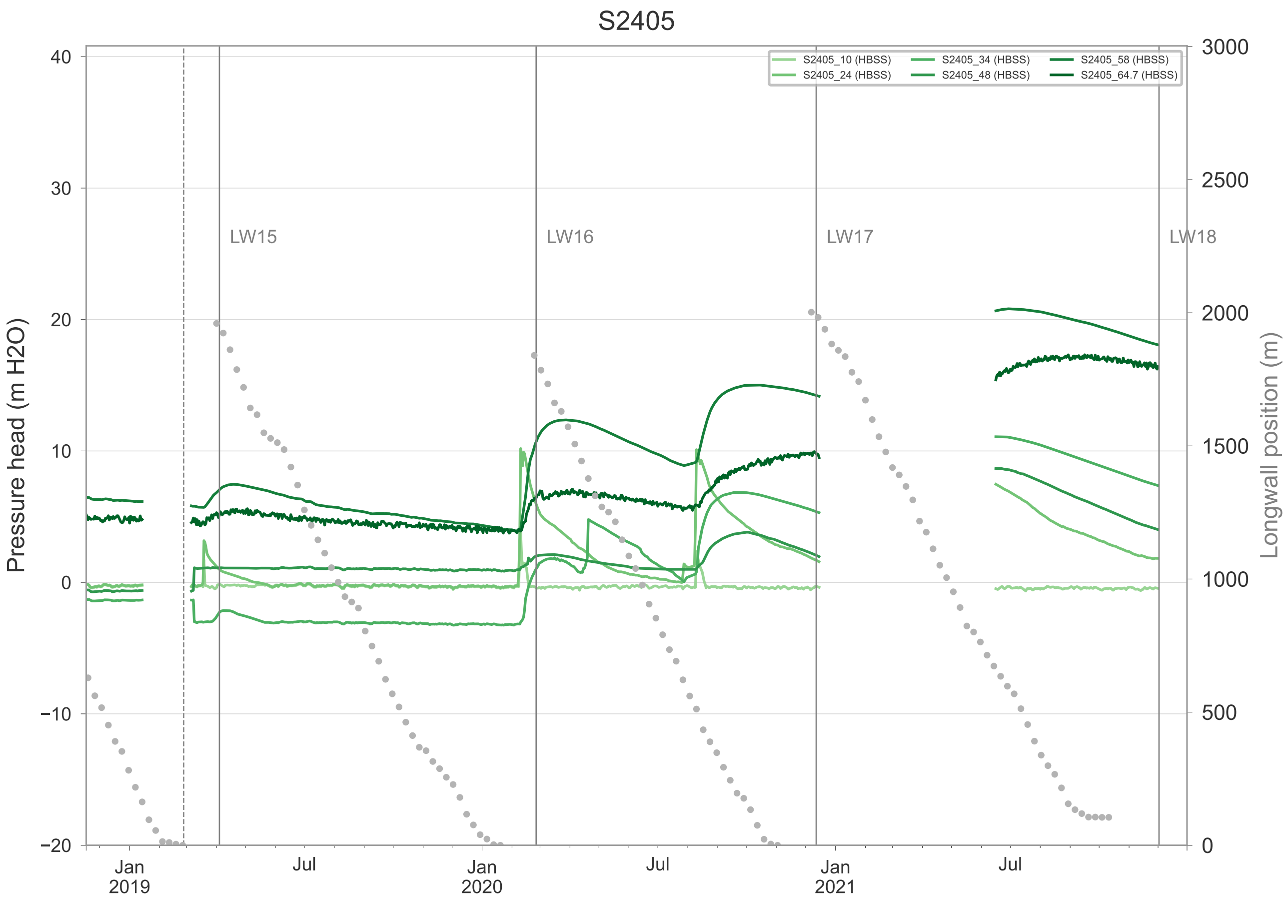

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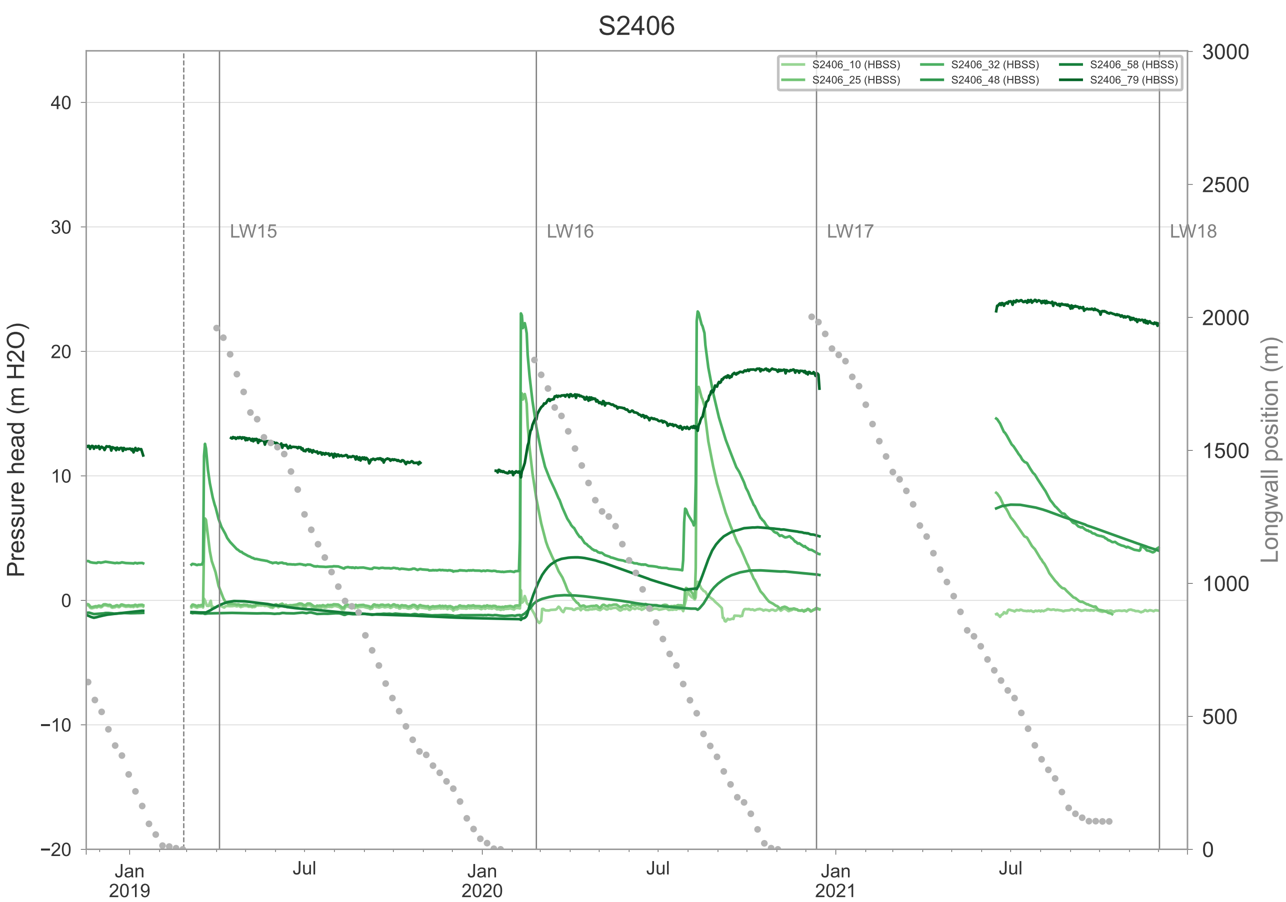

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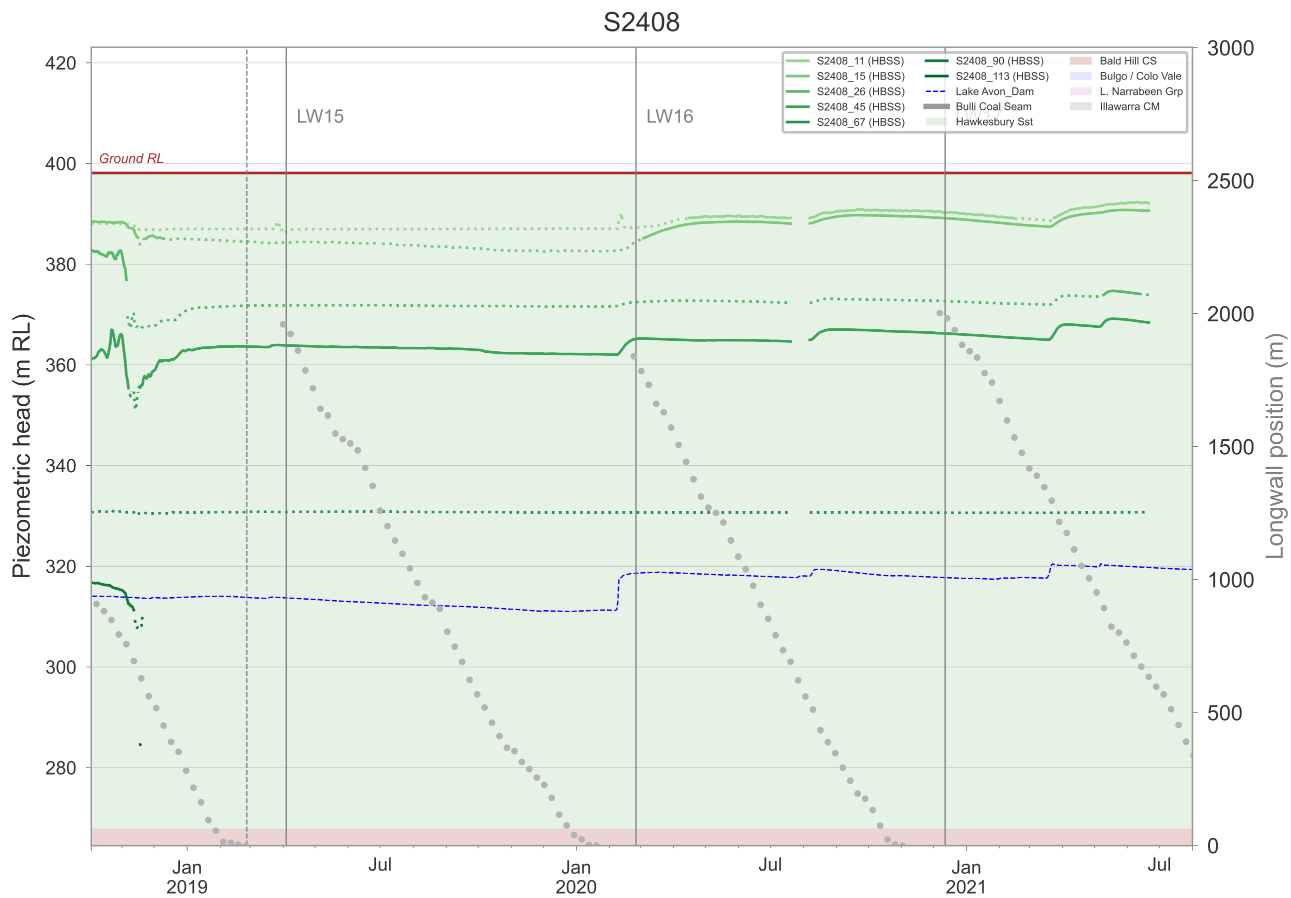
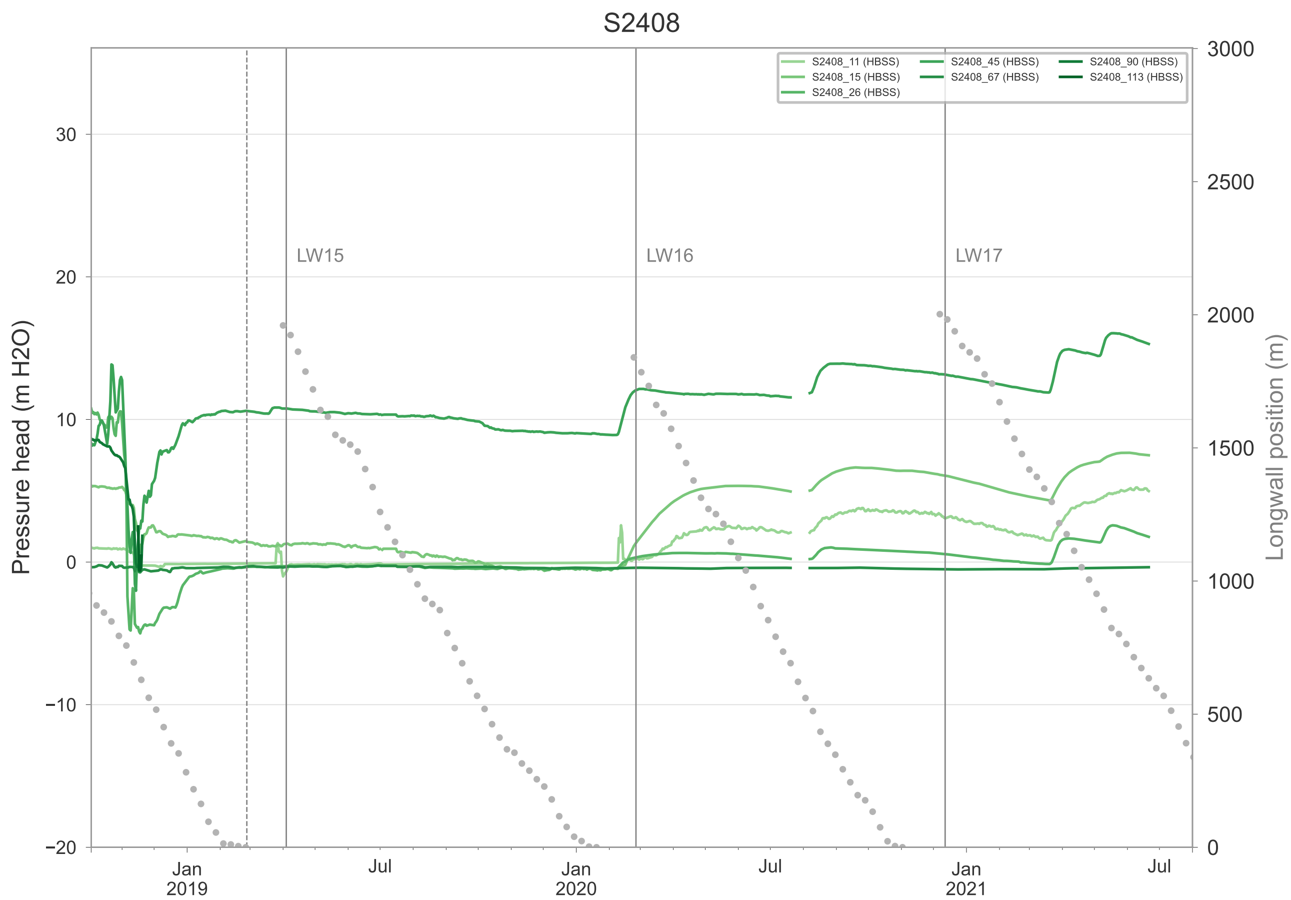
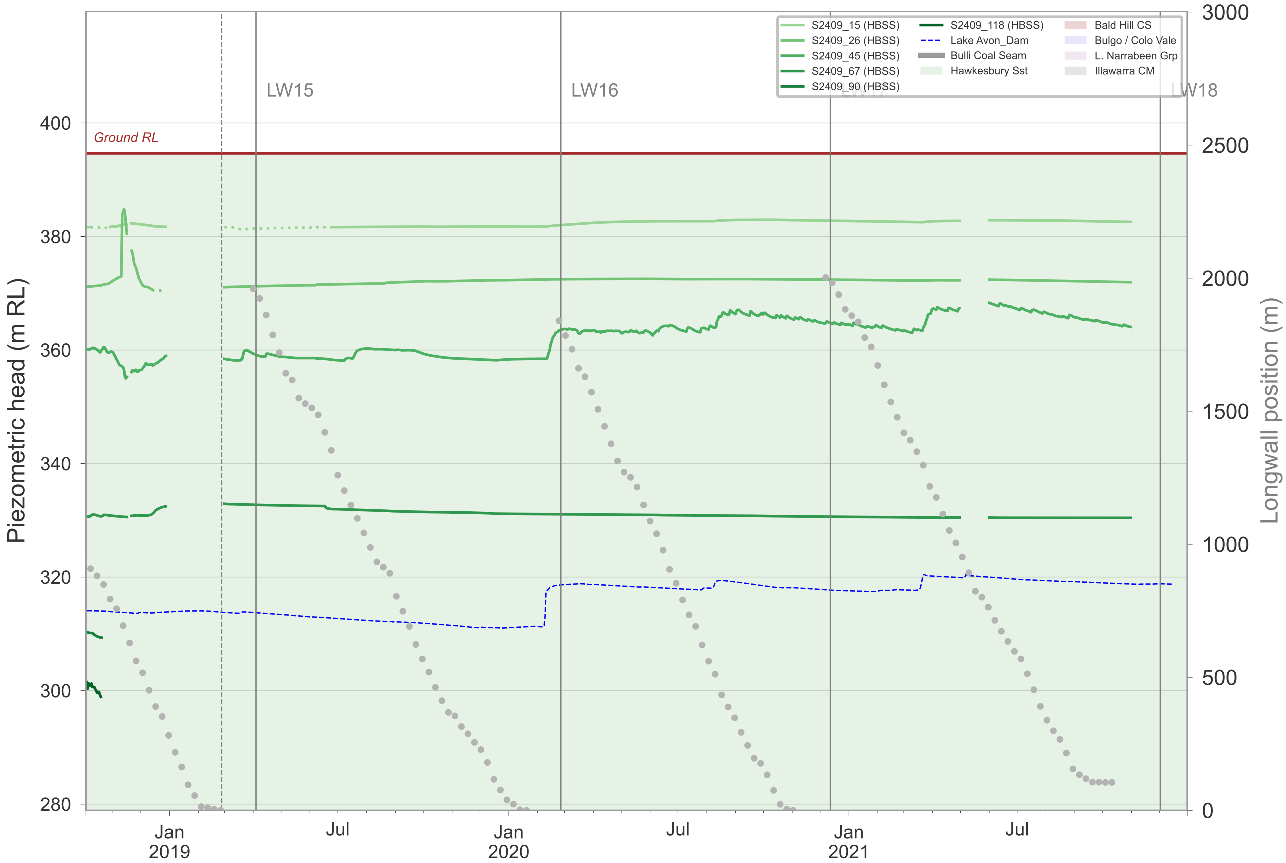




Groundwater hydrographs

S2409



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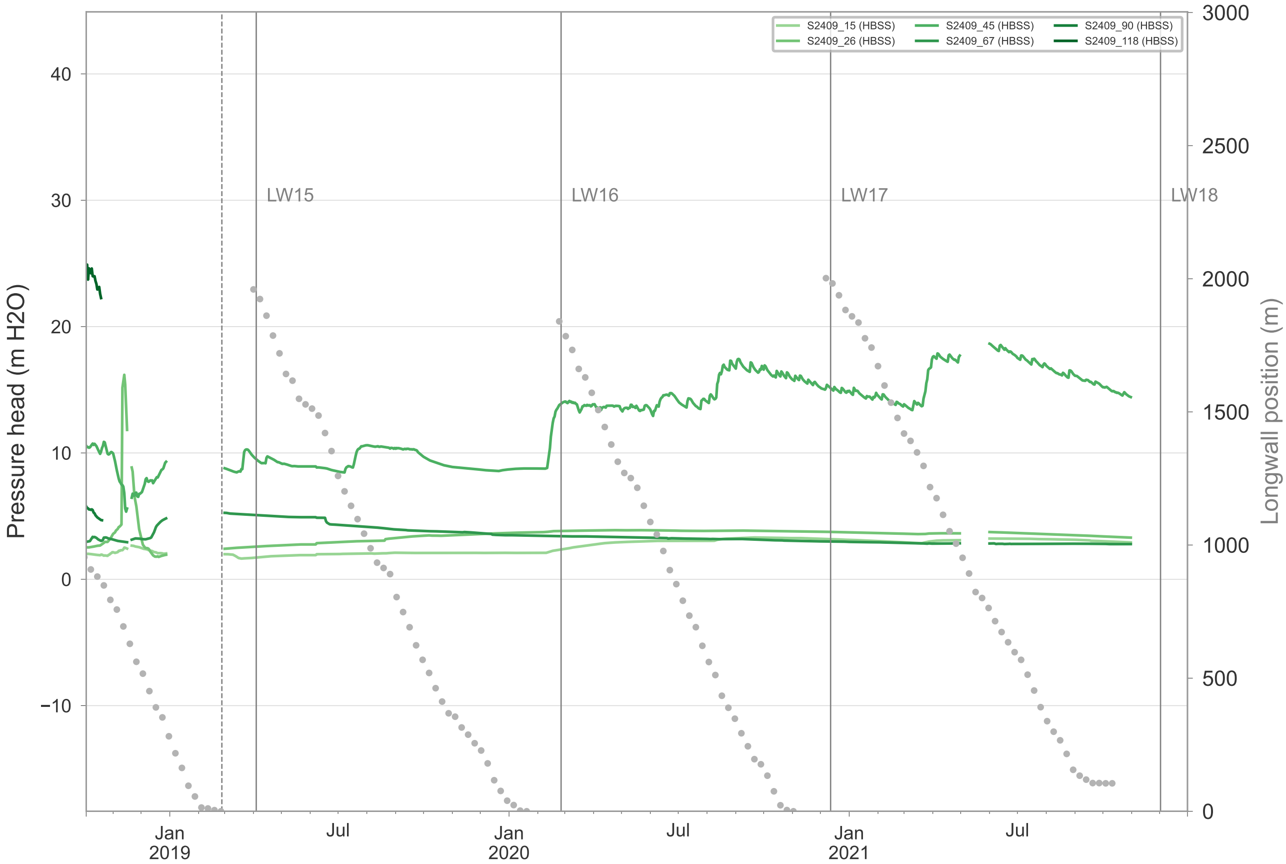
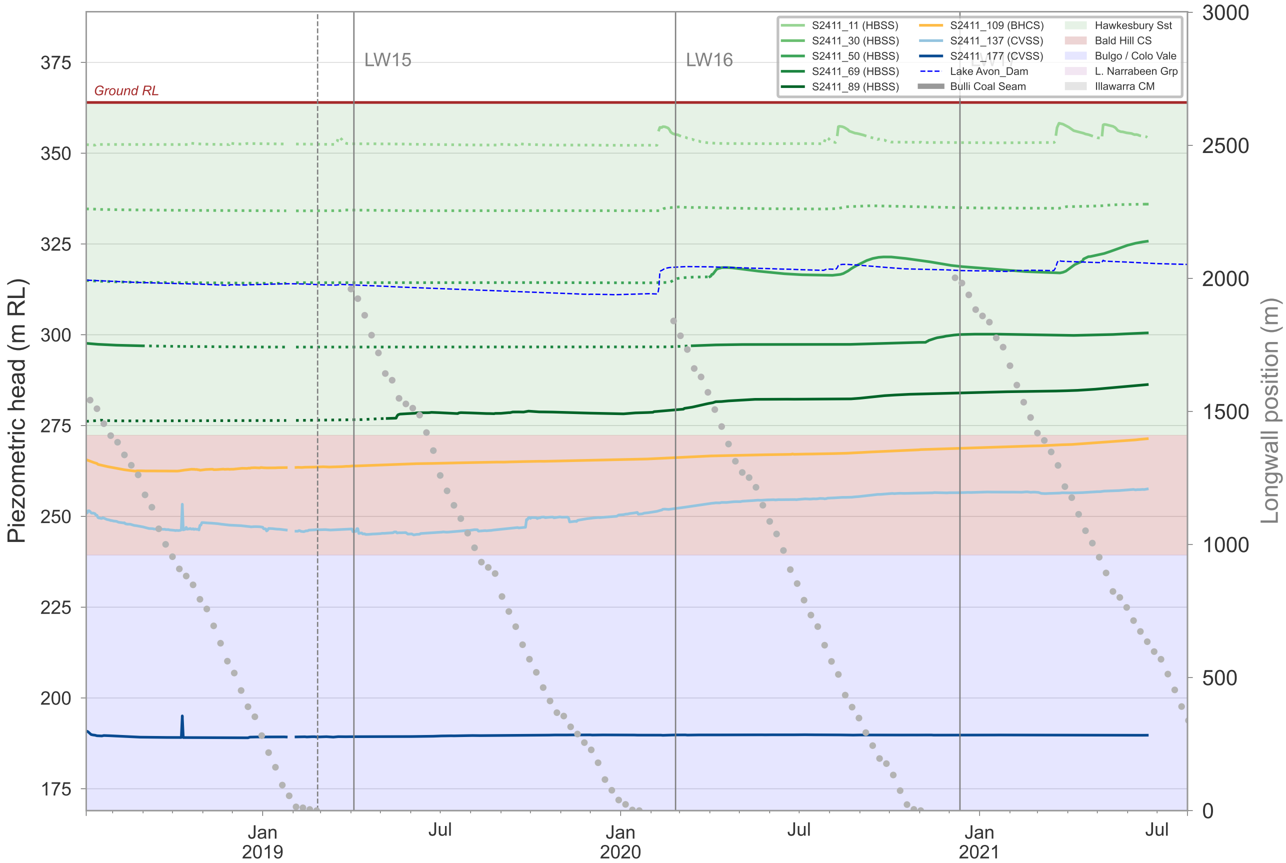


Groundwater hydrographs

S2411



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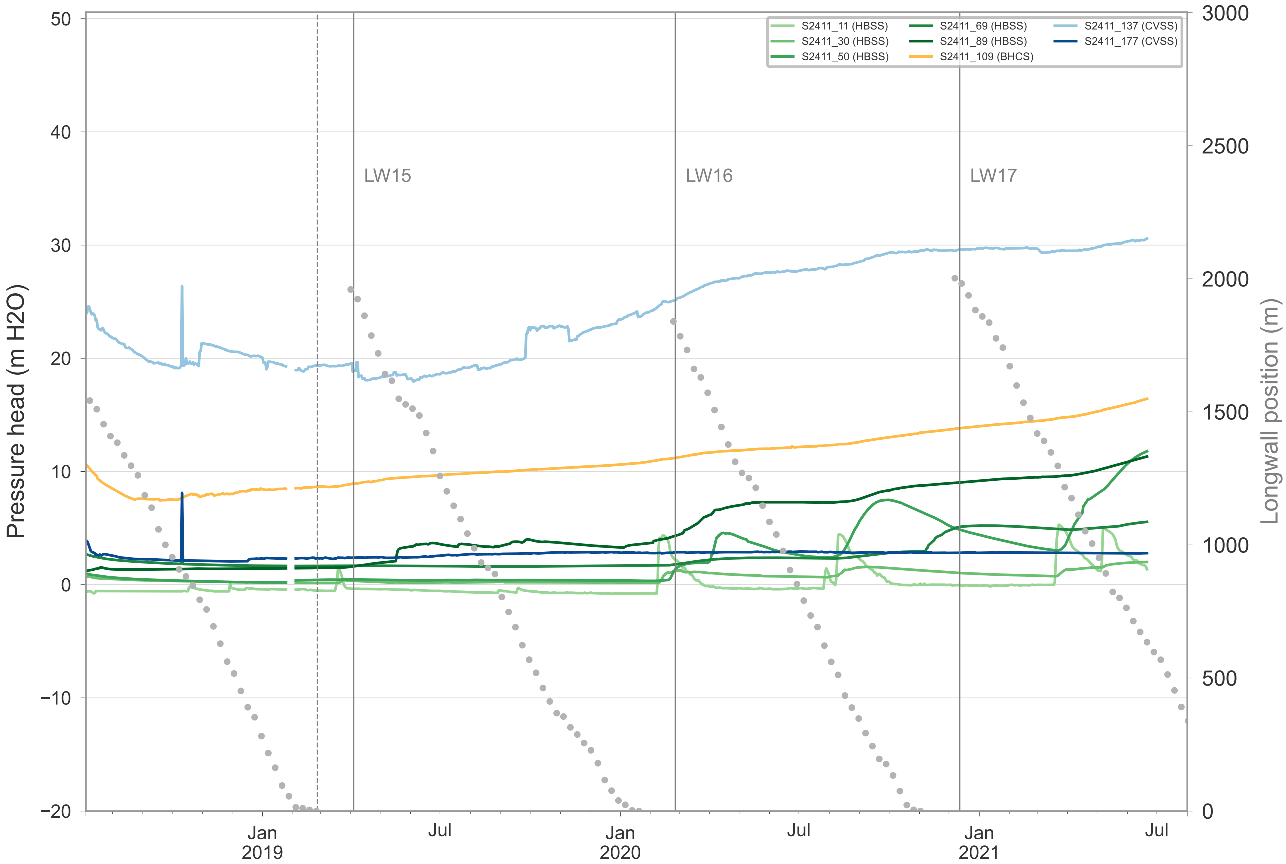
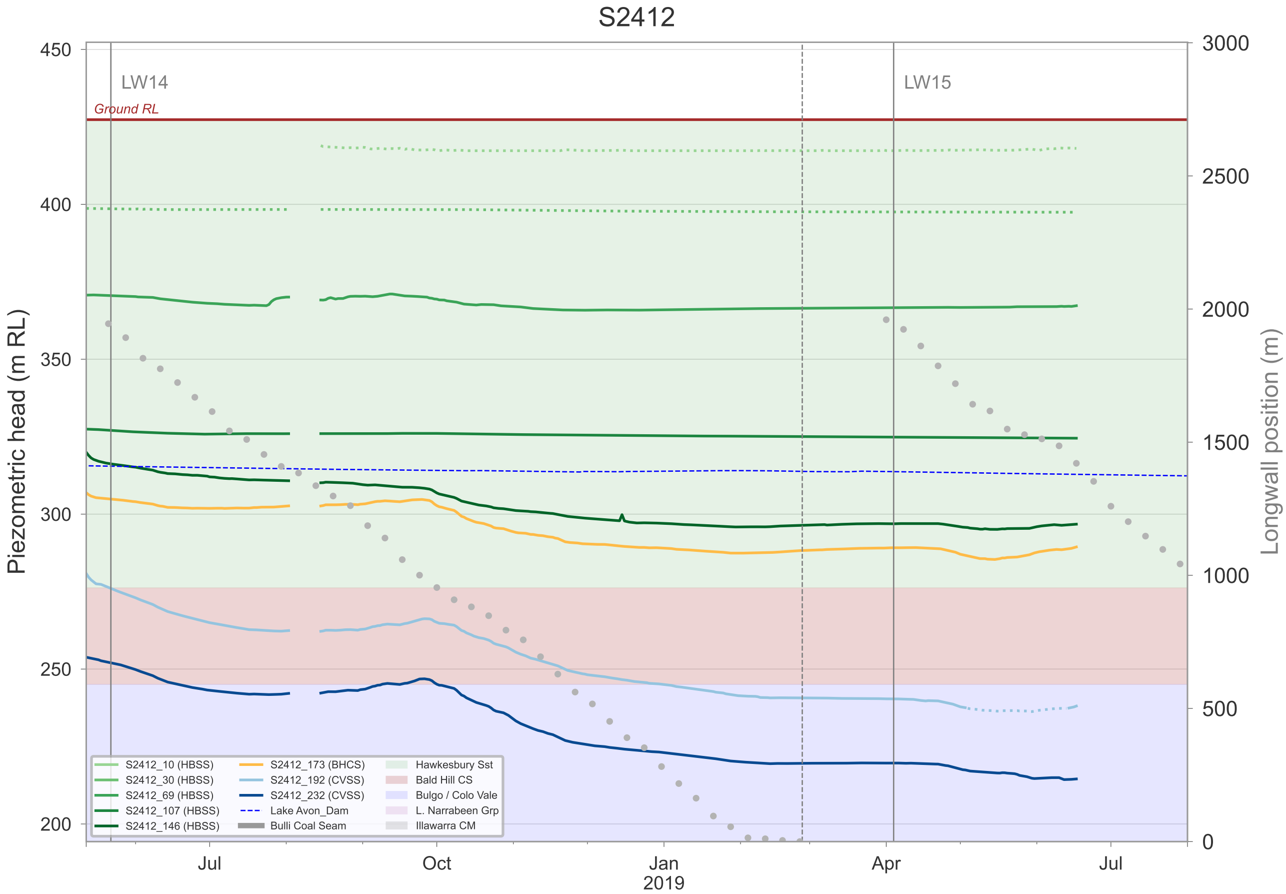
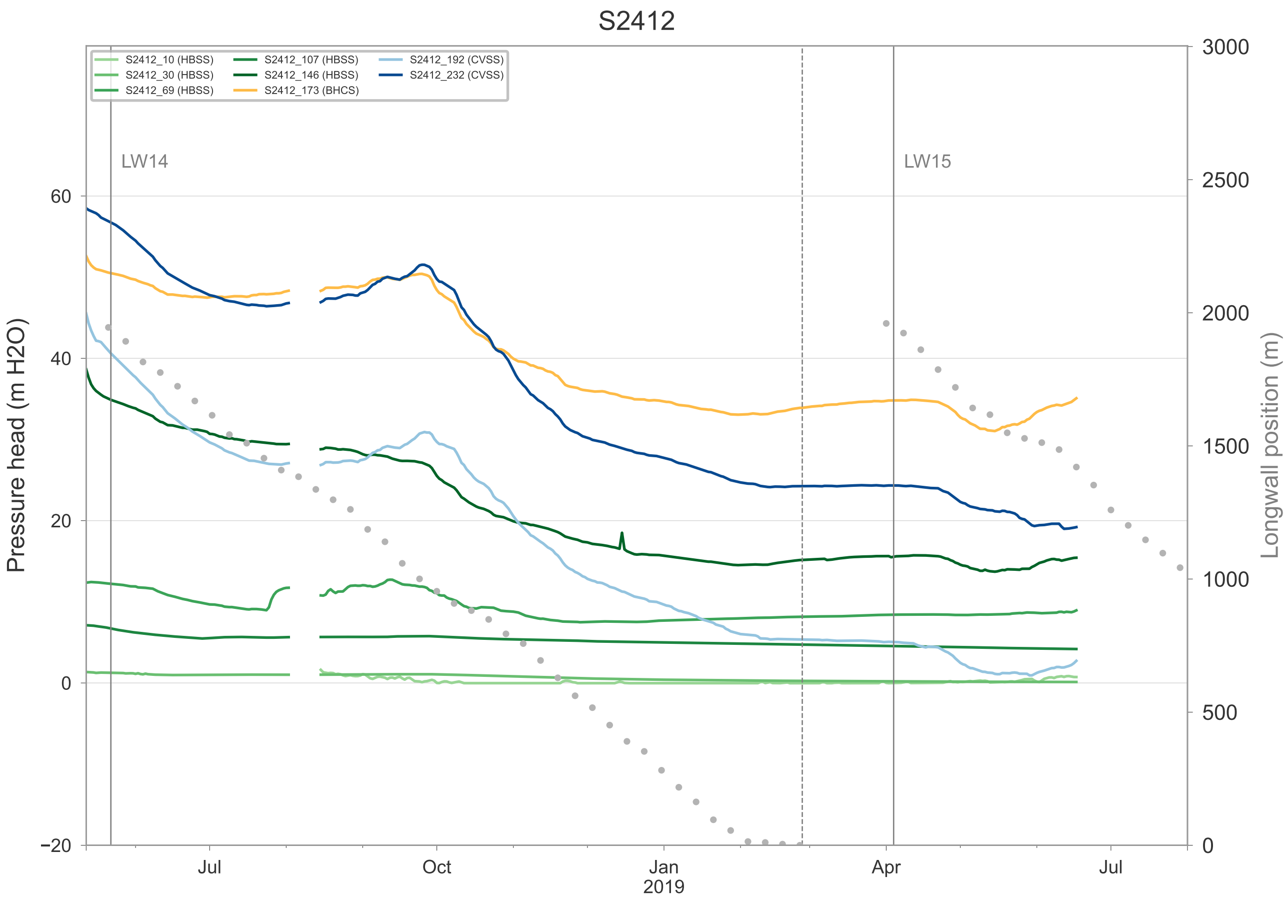
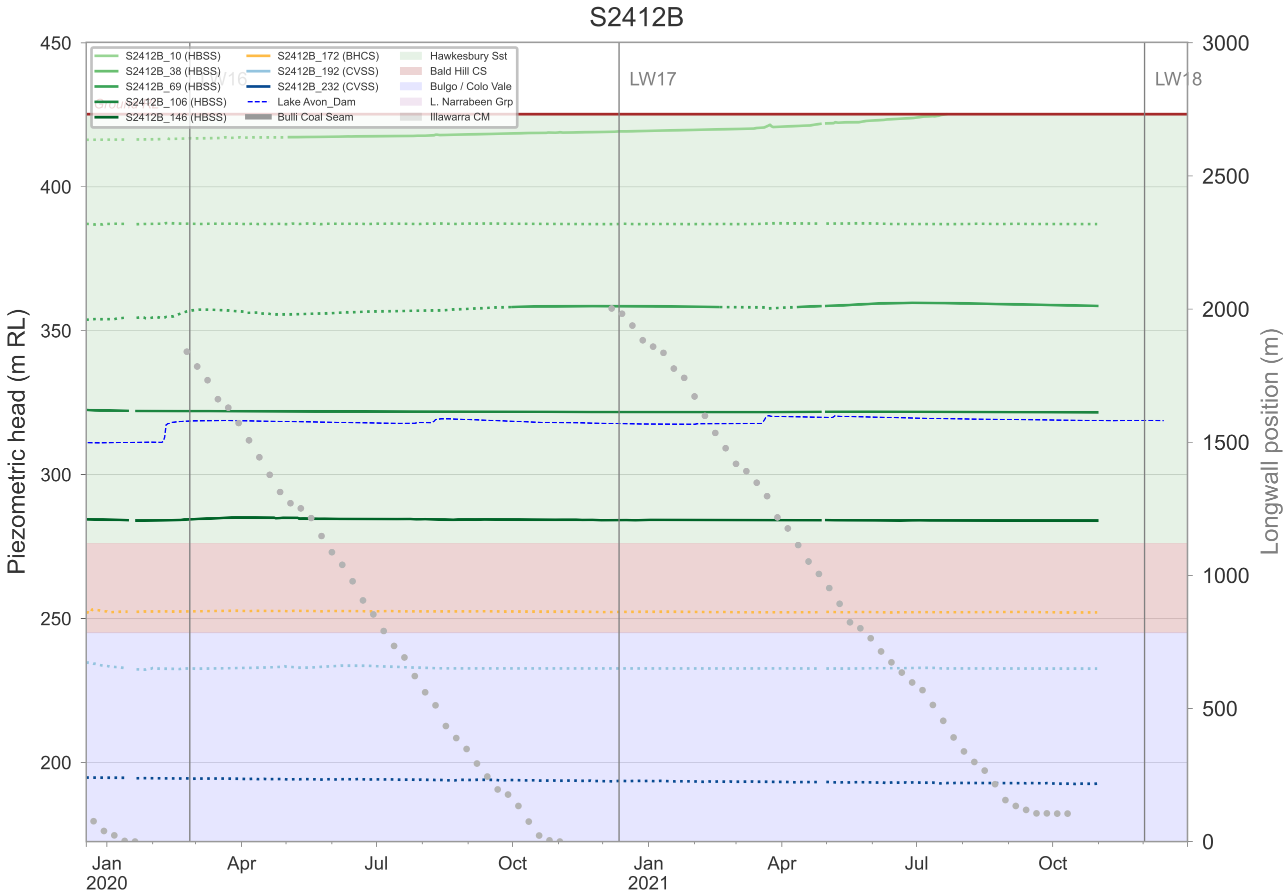


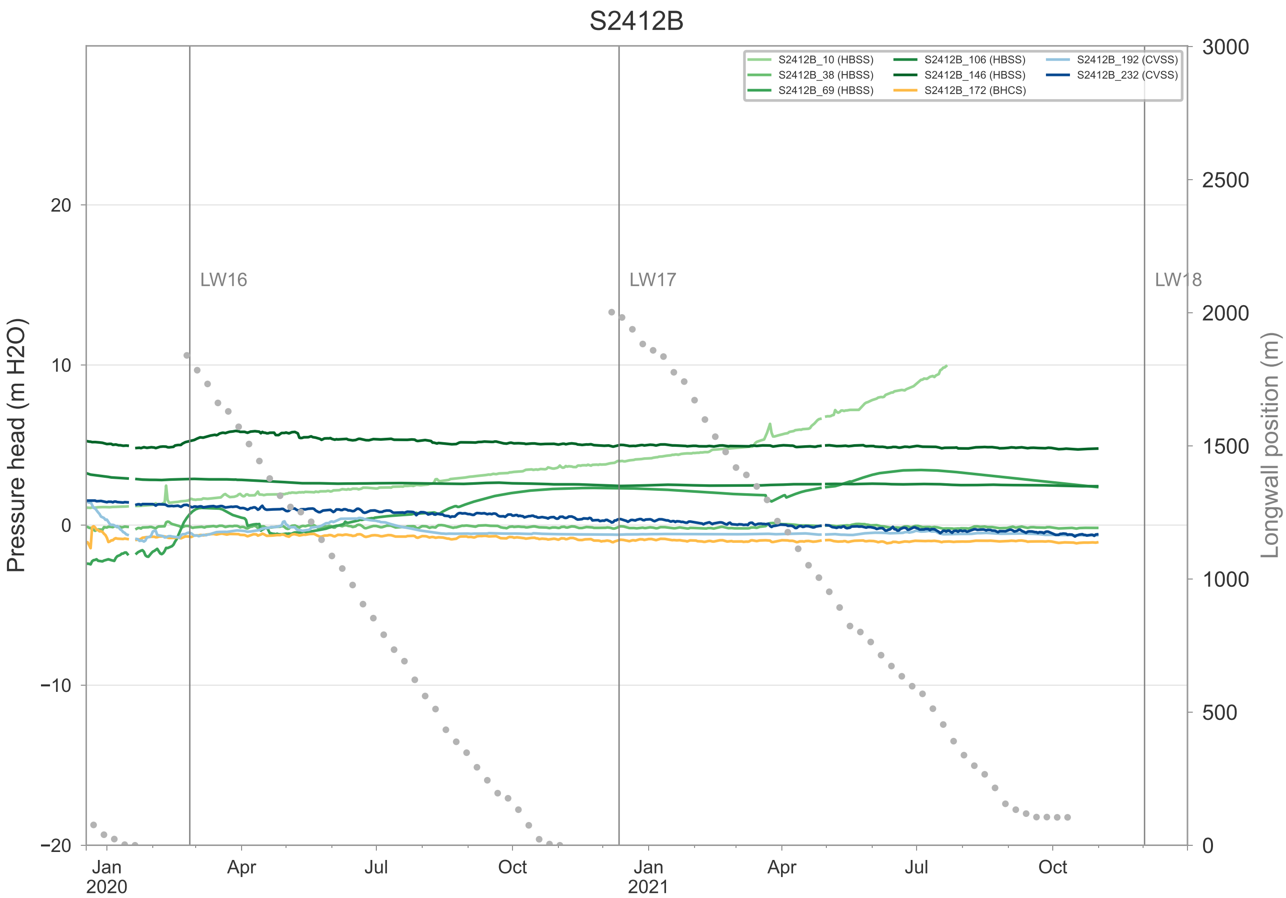
Groundwater hydrographs



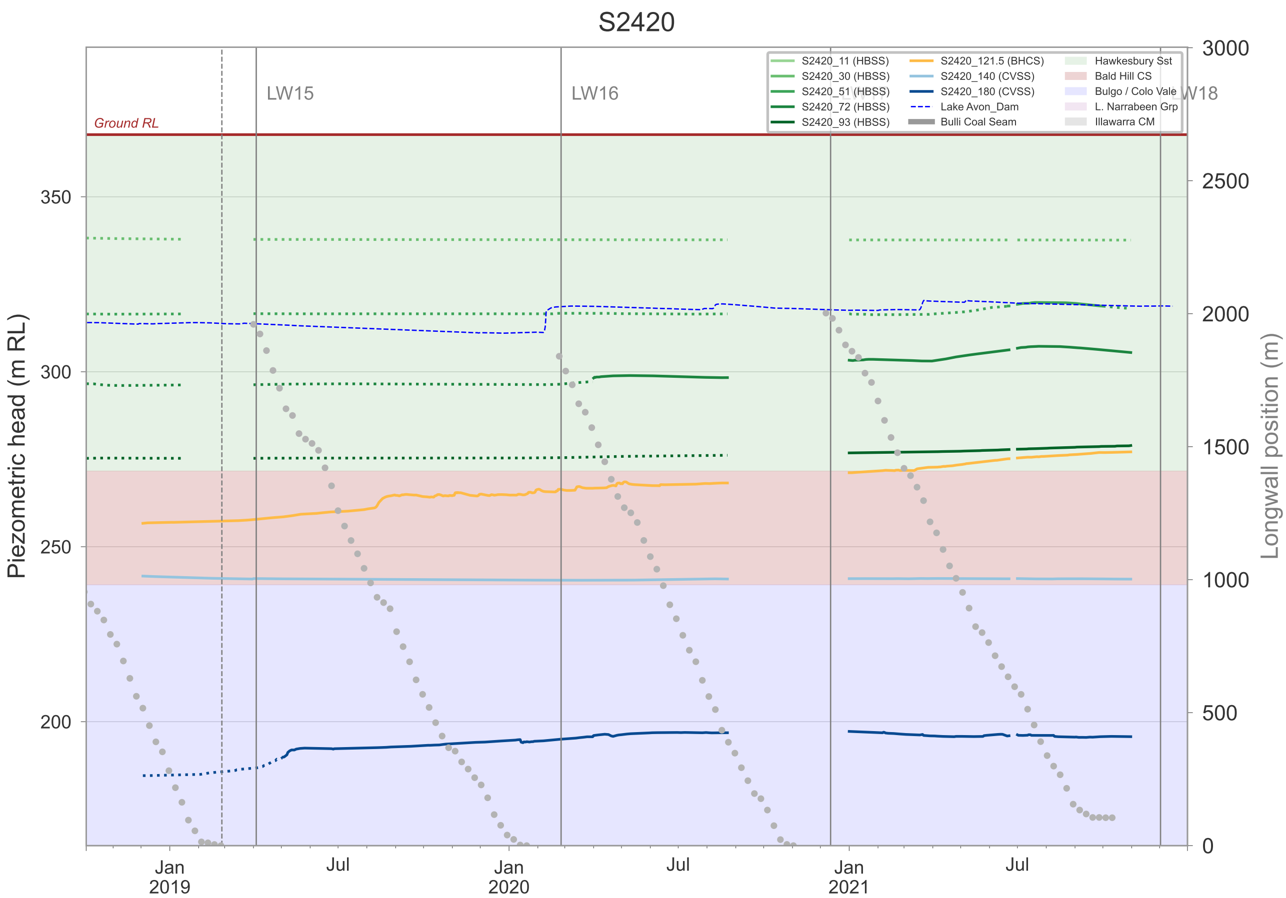


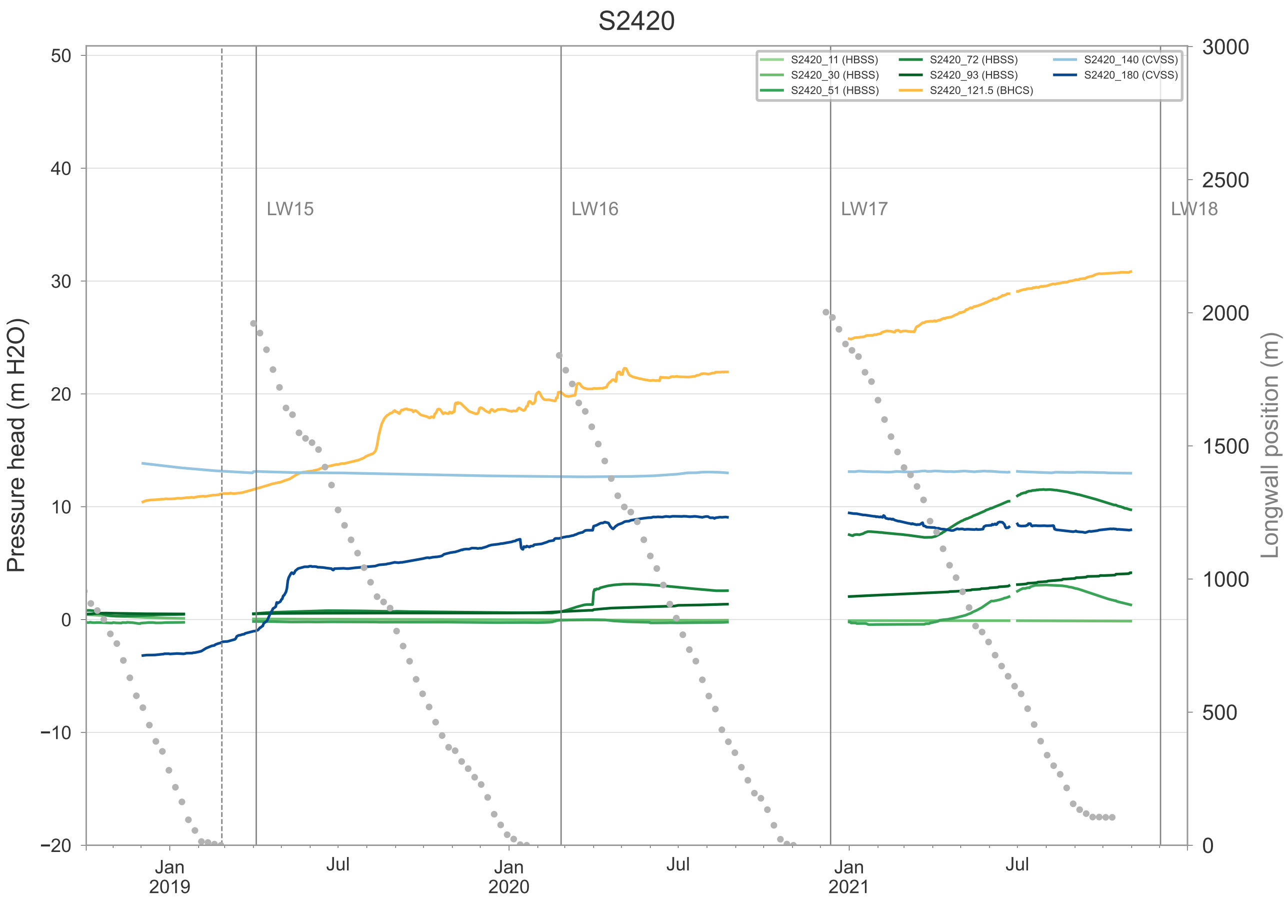
Groundwater hydrographs



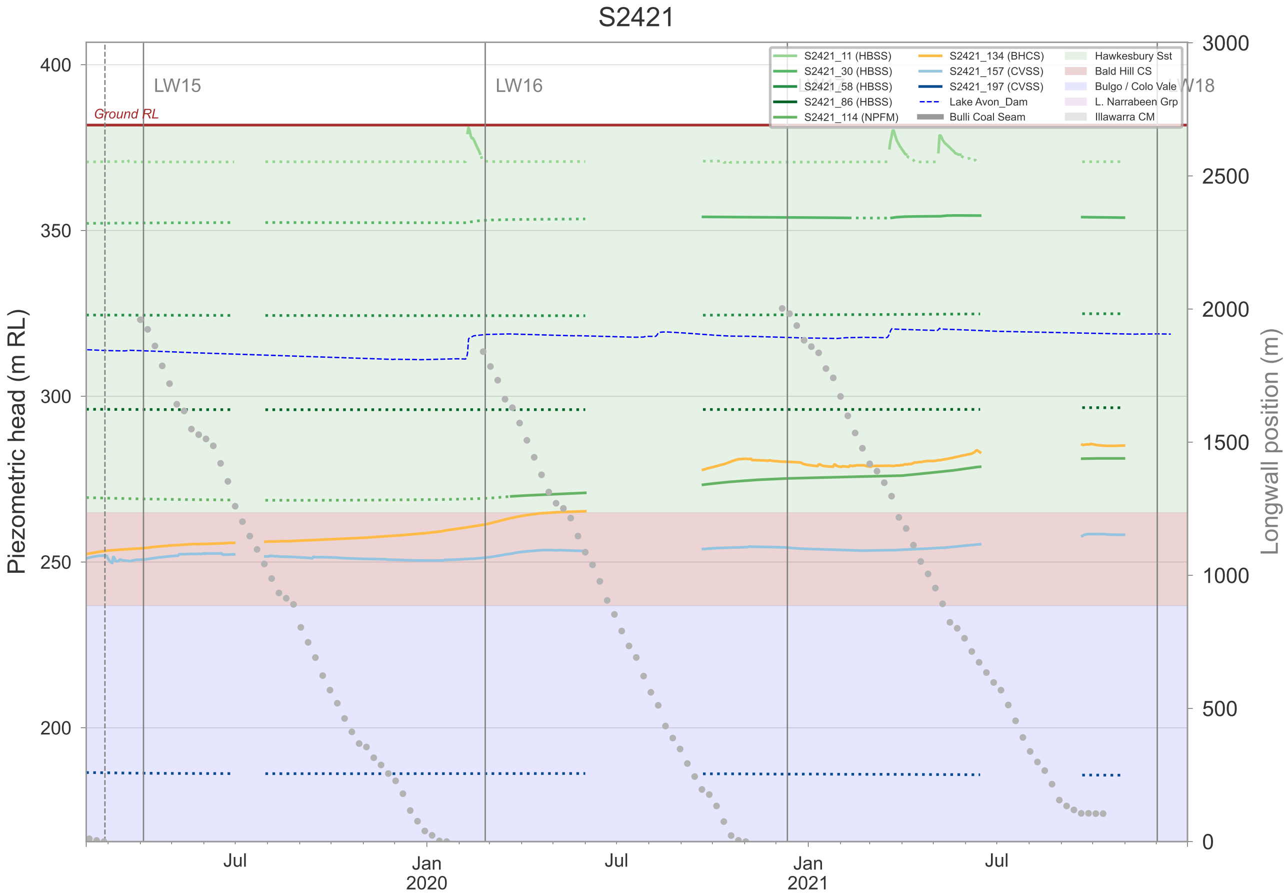


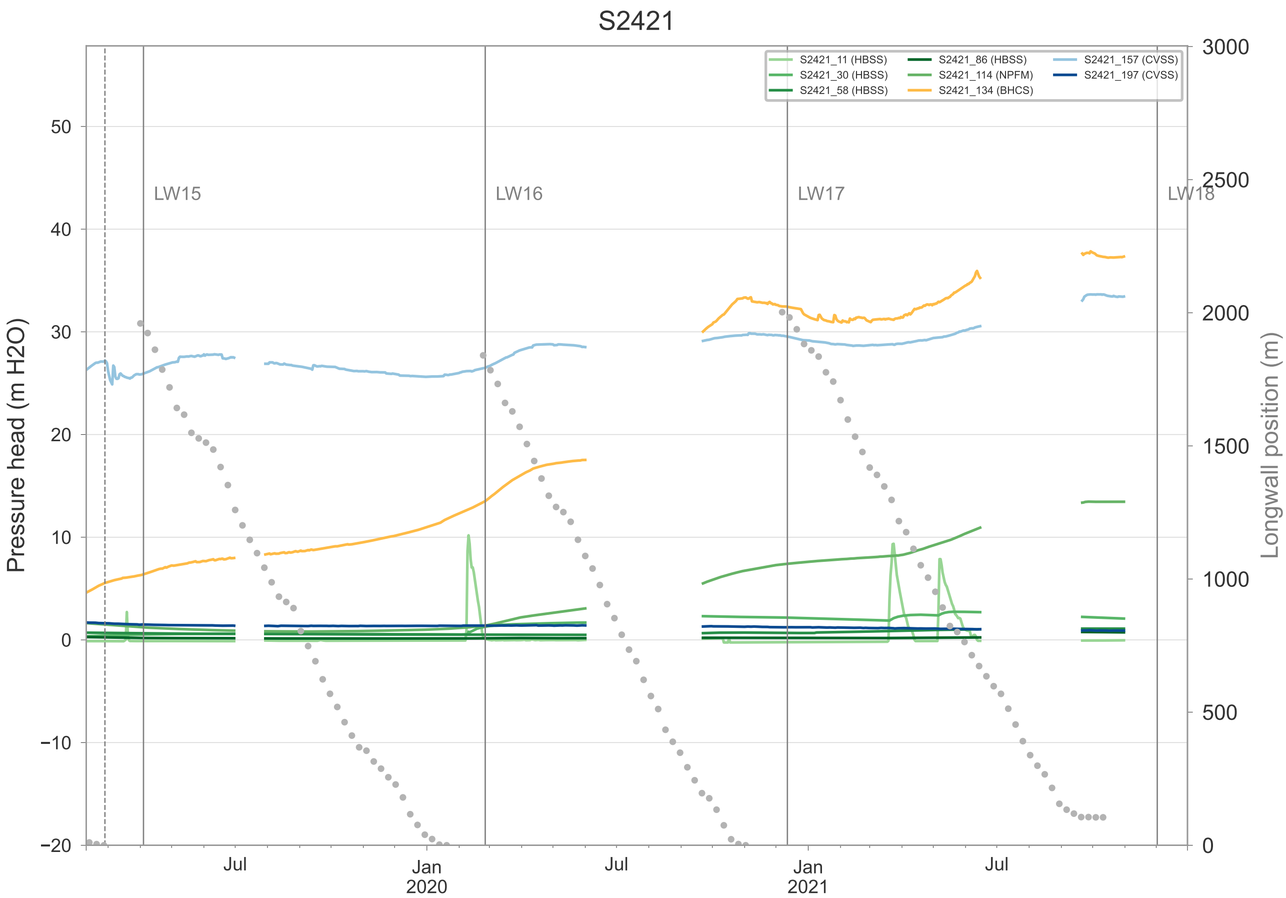
Groundwater hydrographs



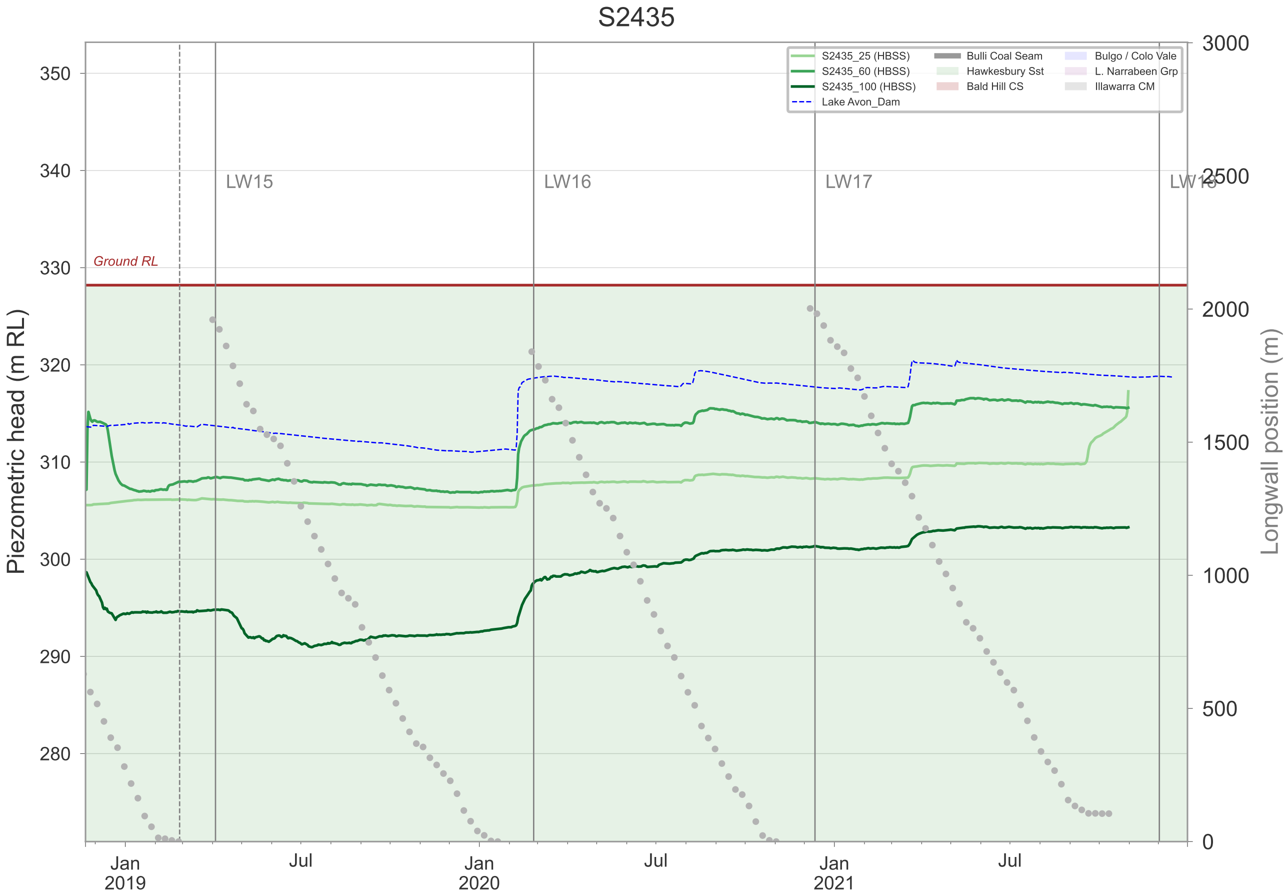


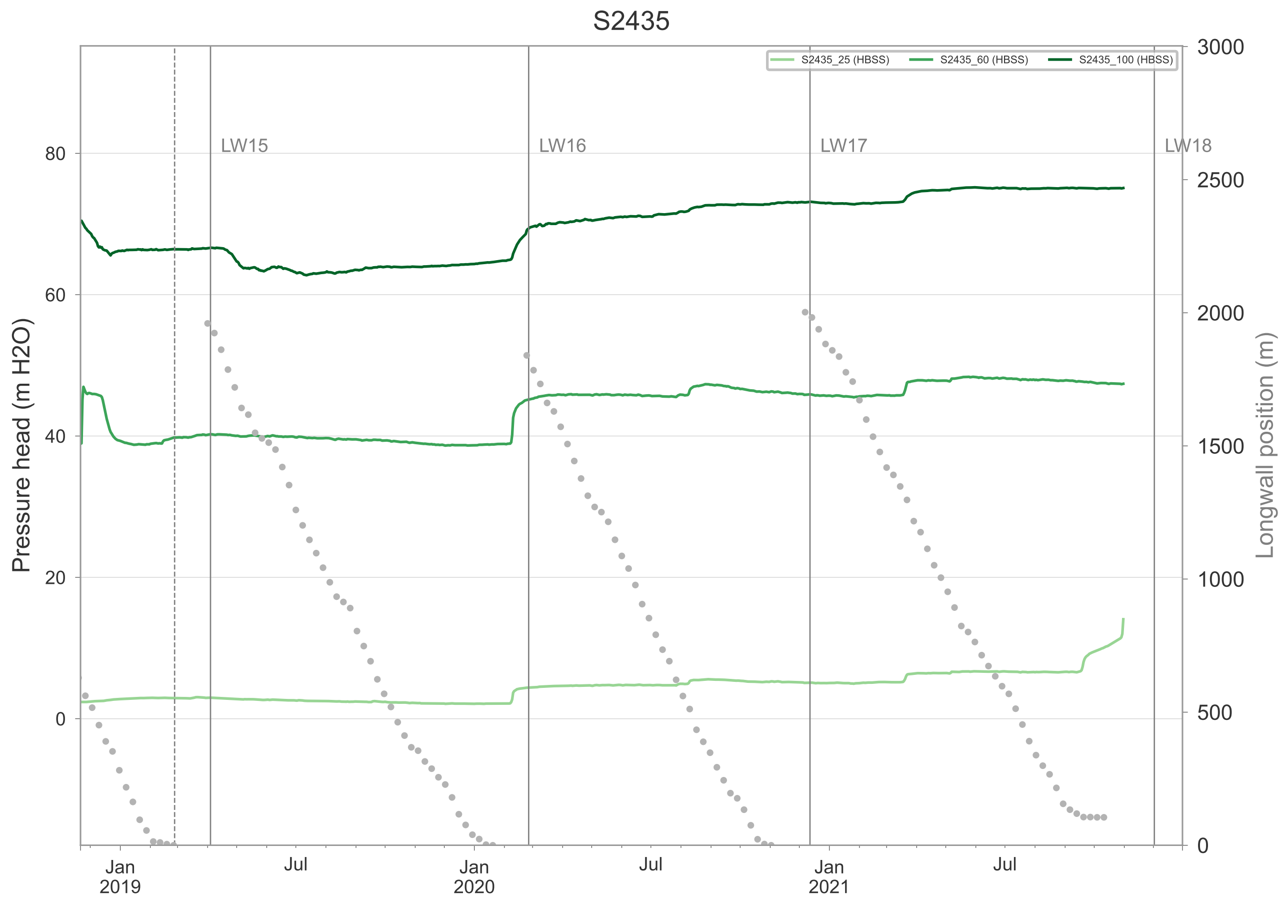
Groundwater hydrographs



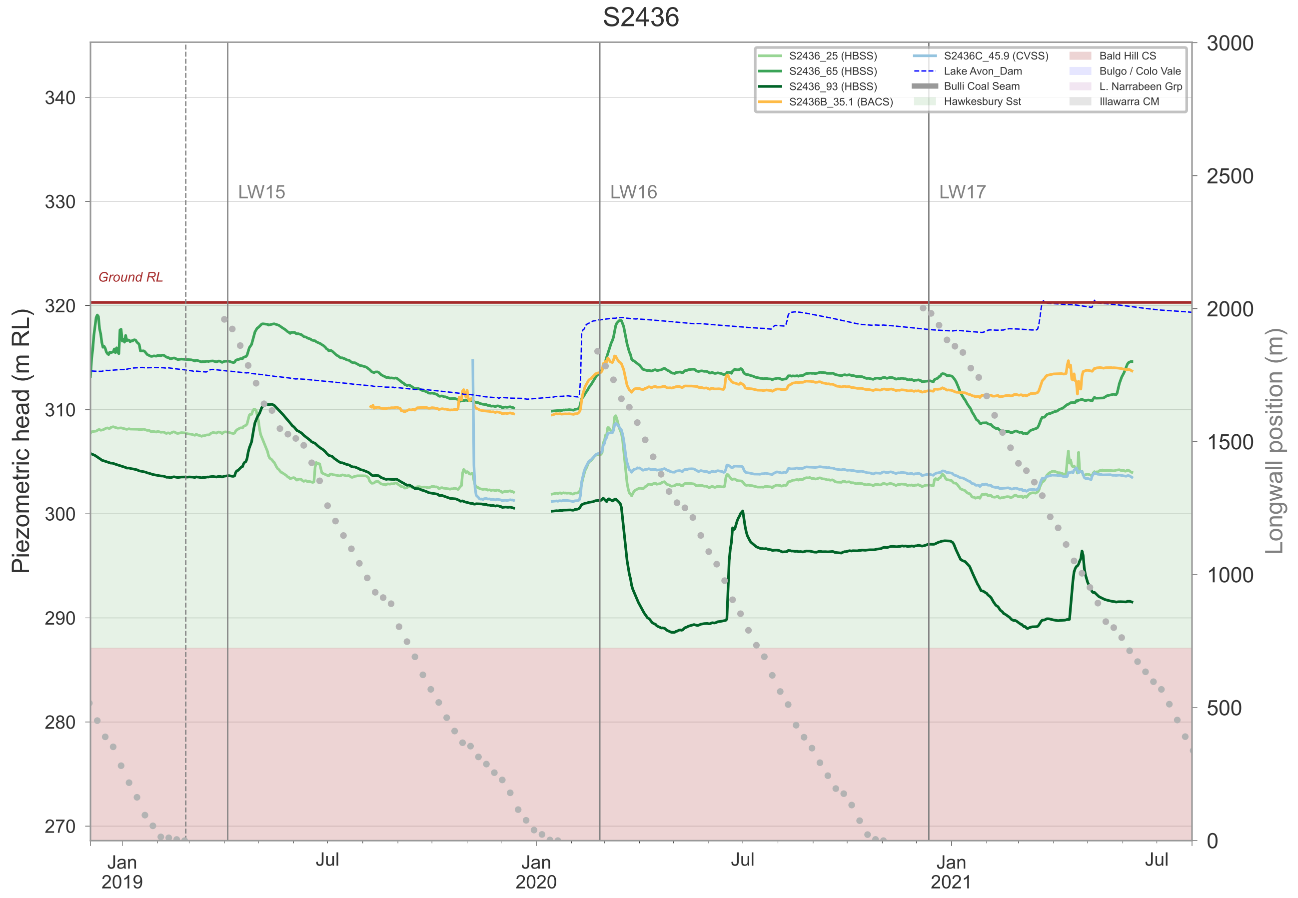


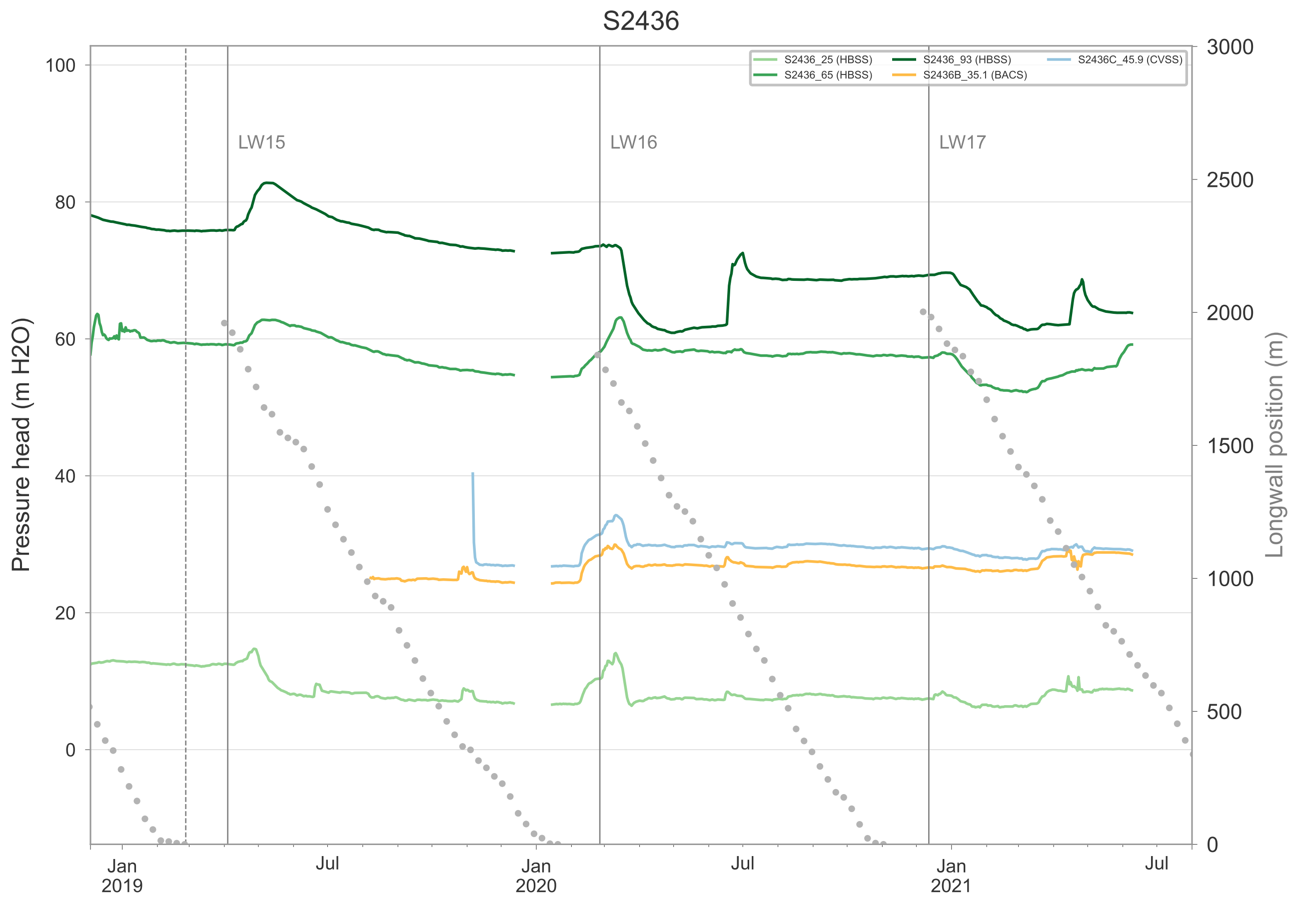
Groundwater hydrographs



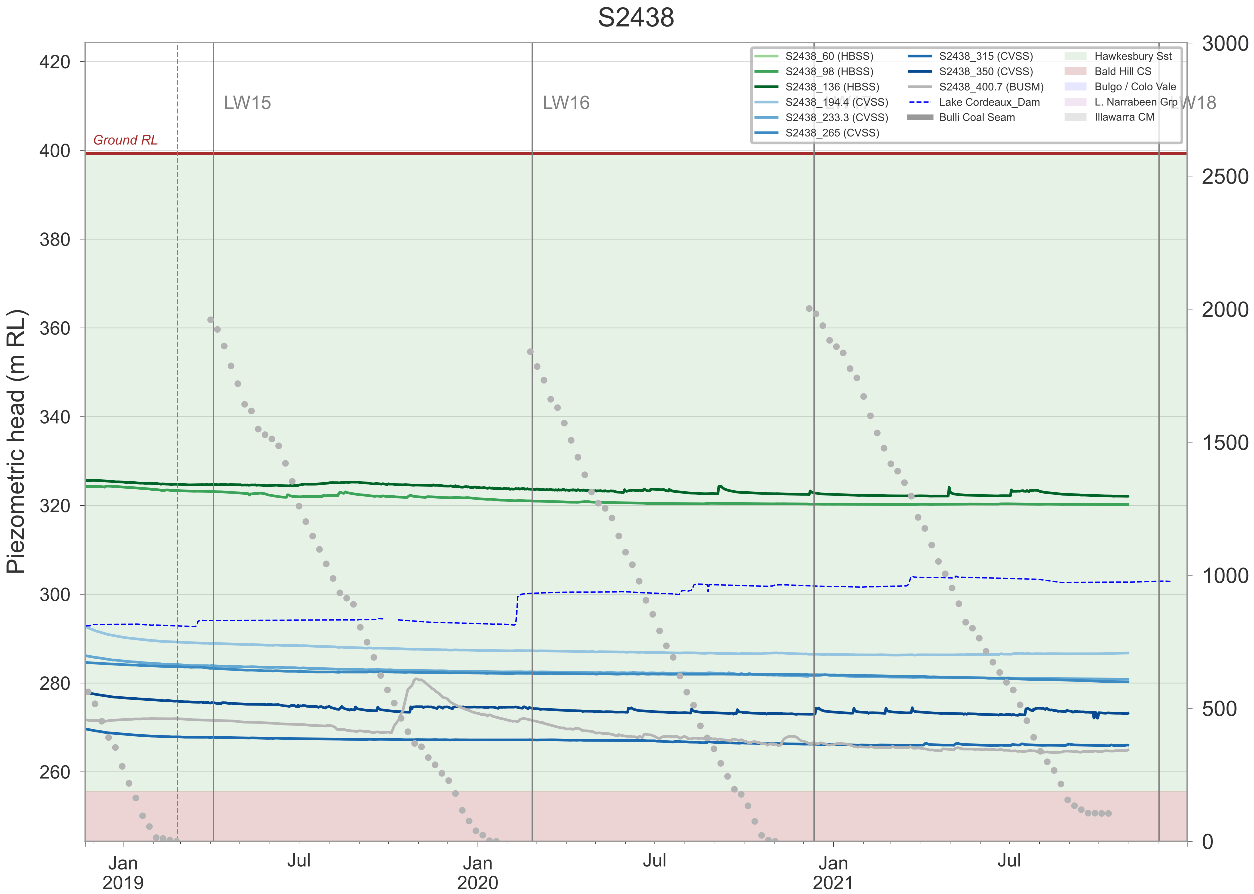


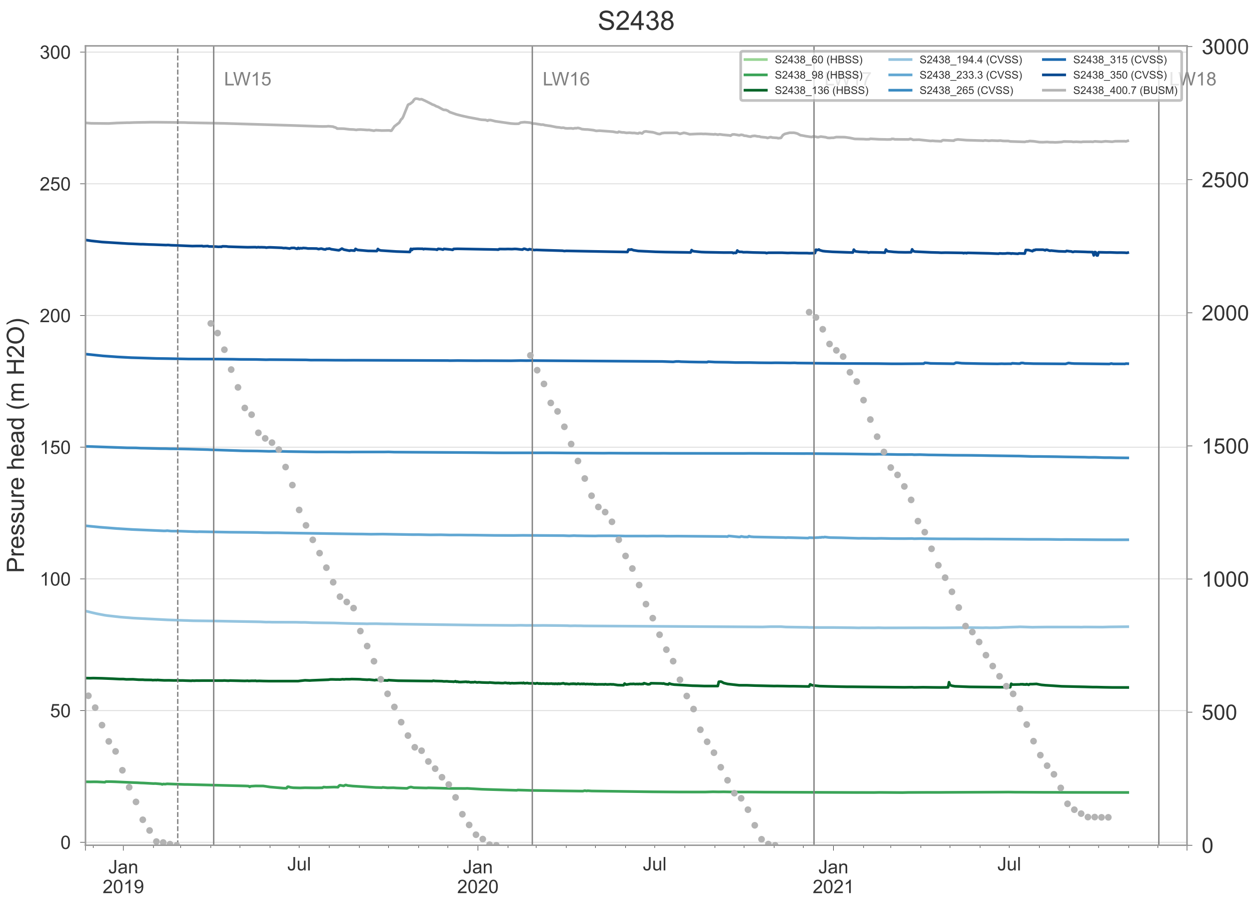
Groundwater hydrographs





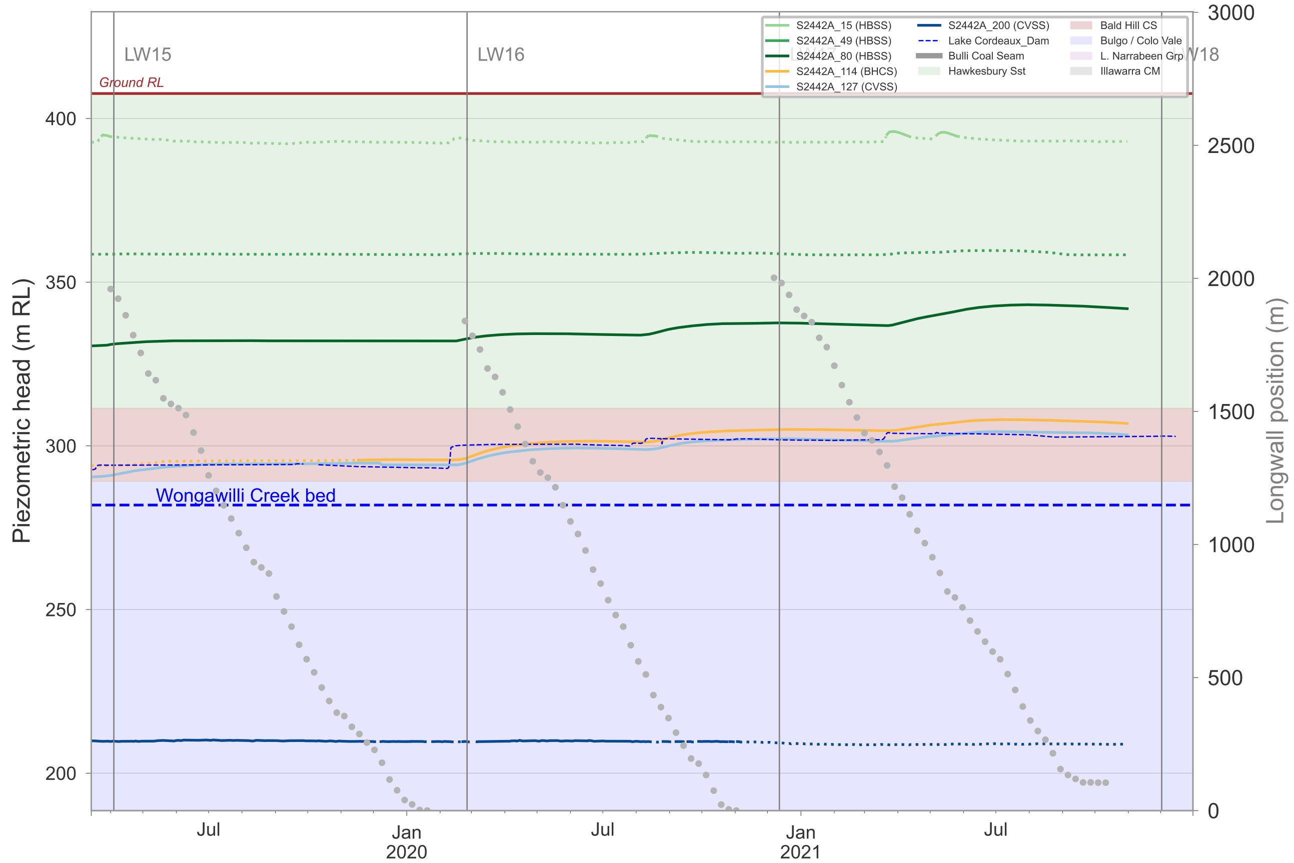
Groundwater hydrographs





Groundwater hydrographs

S2442A



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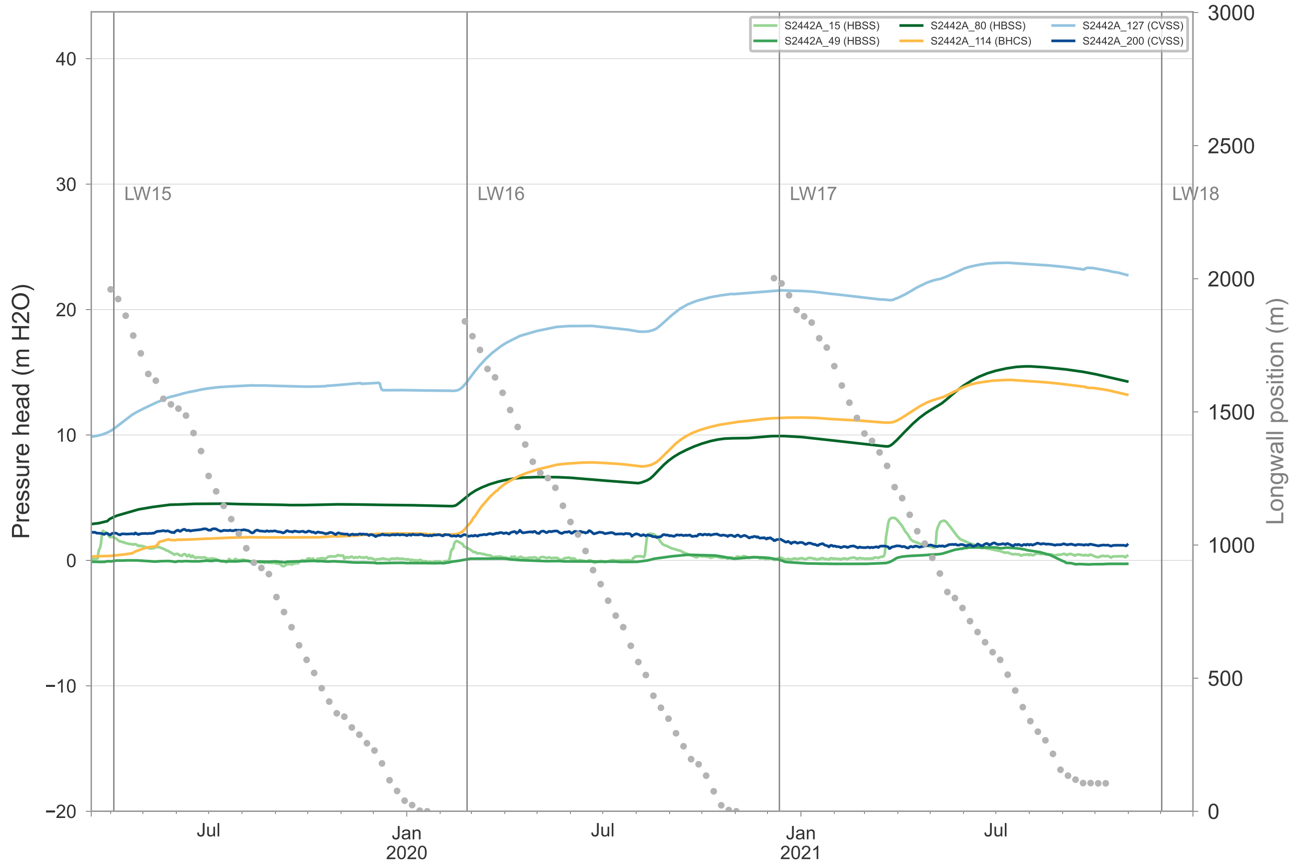
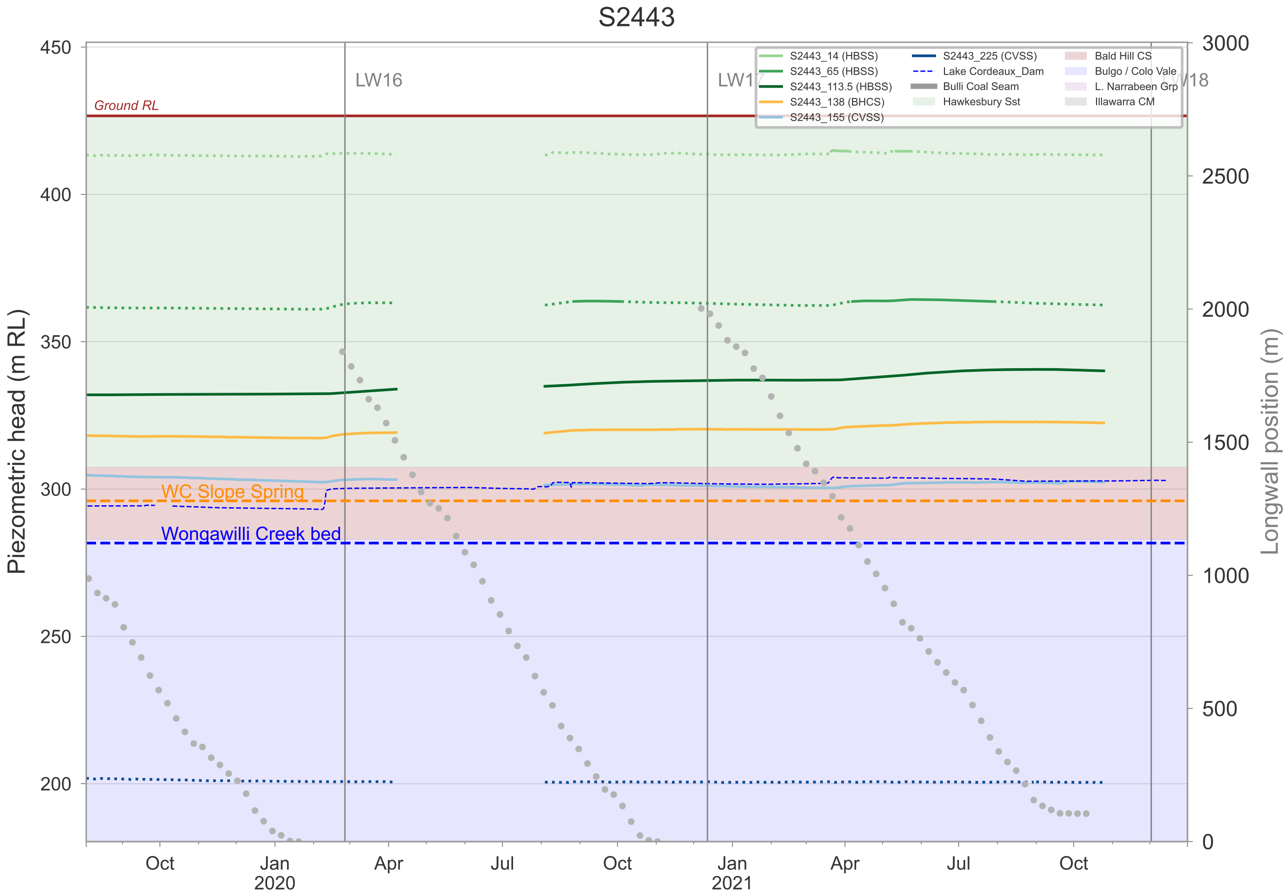
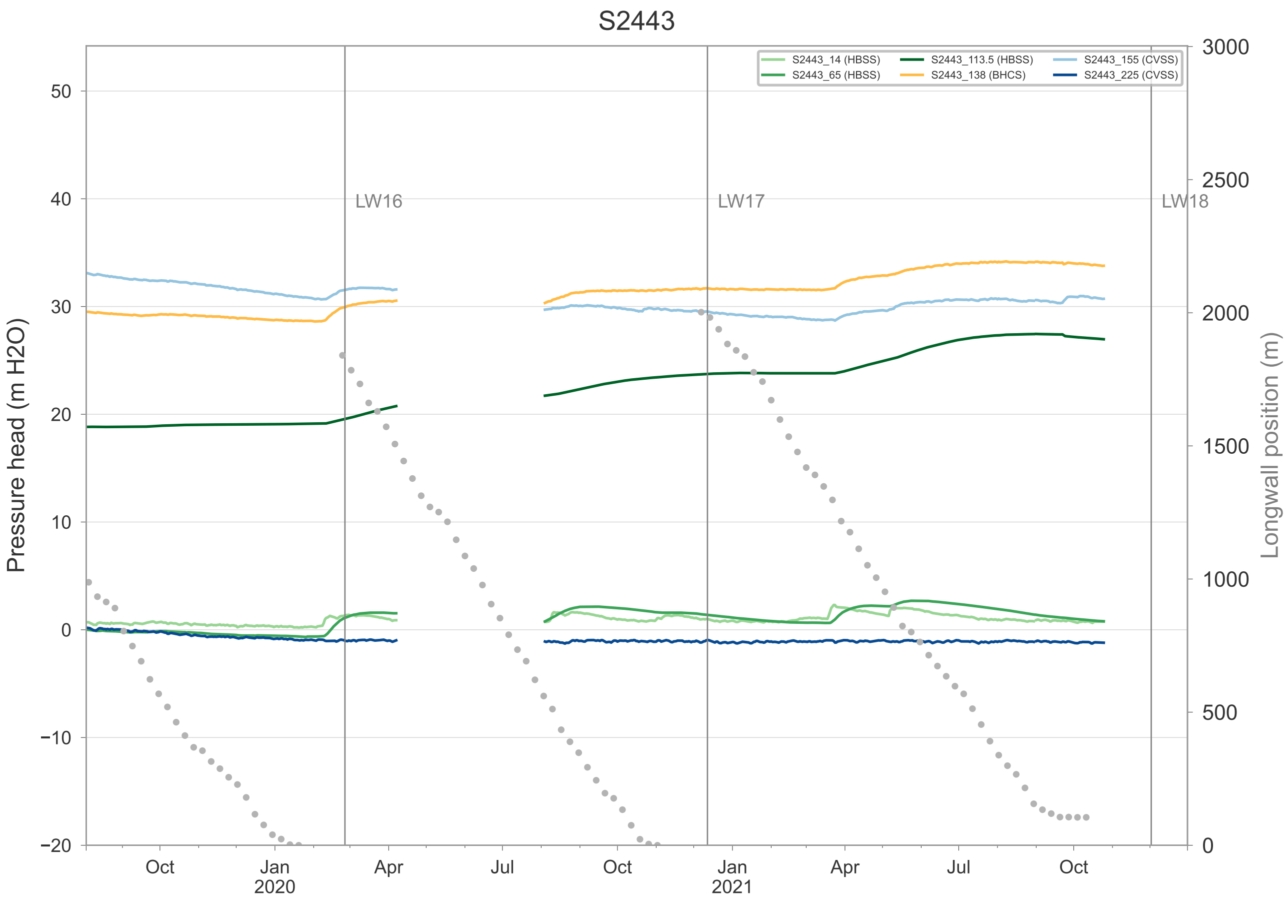
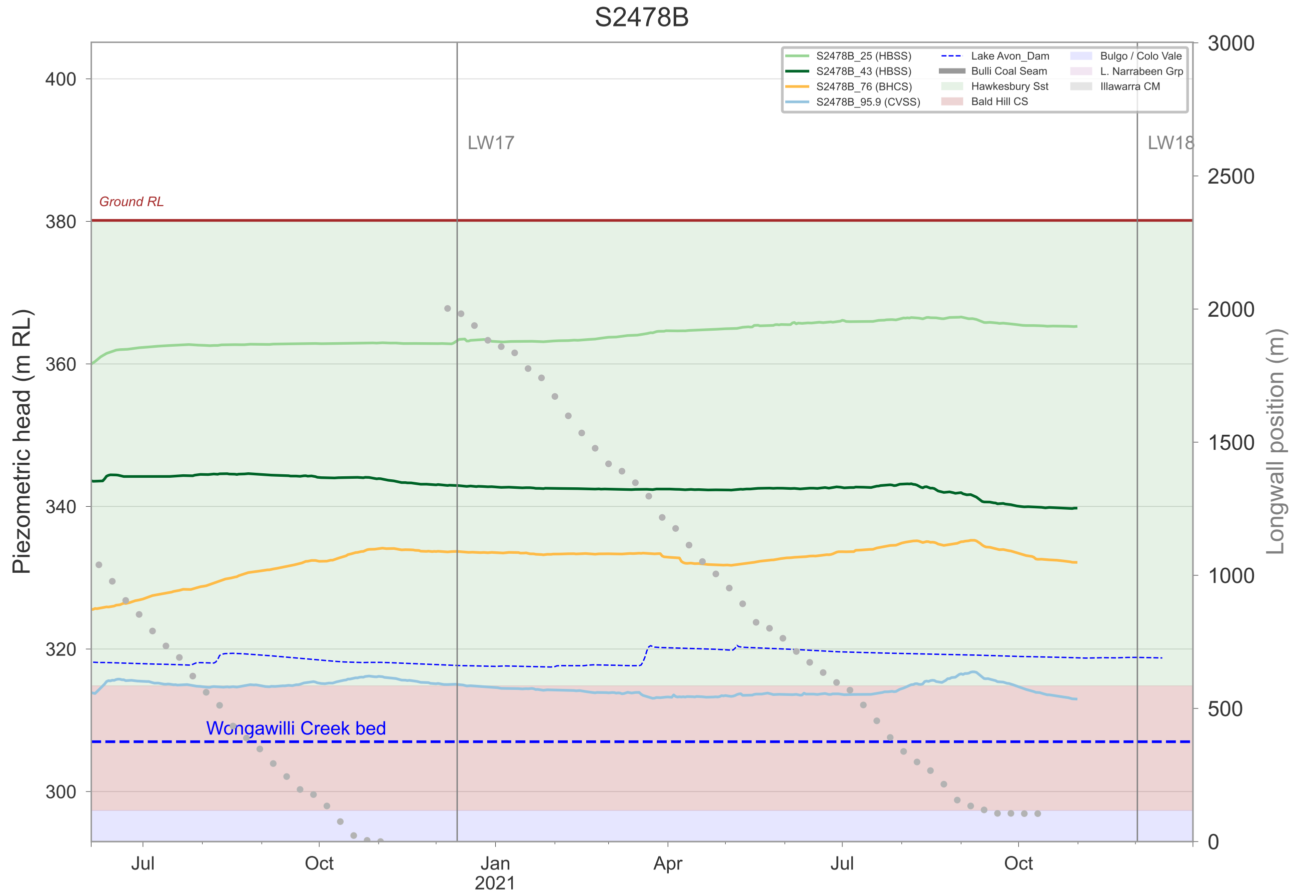


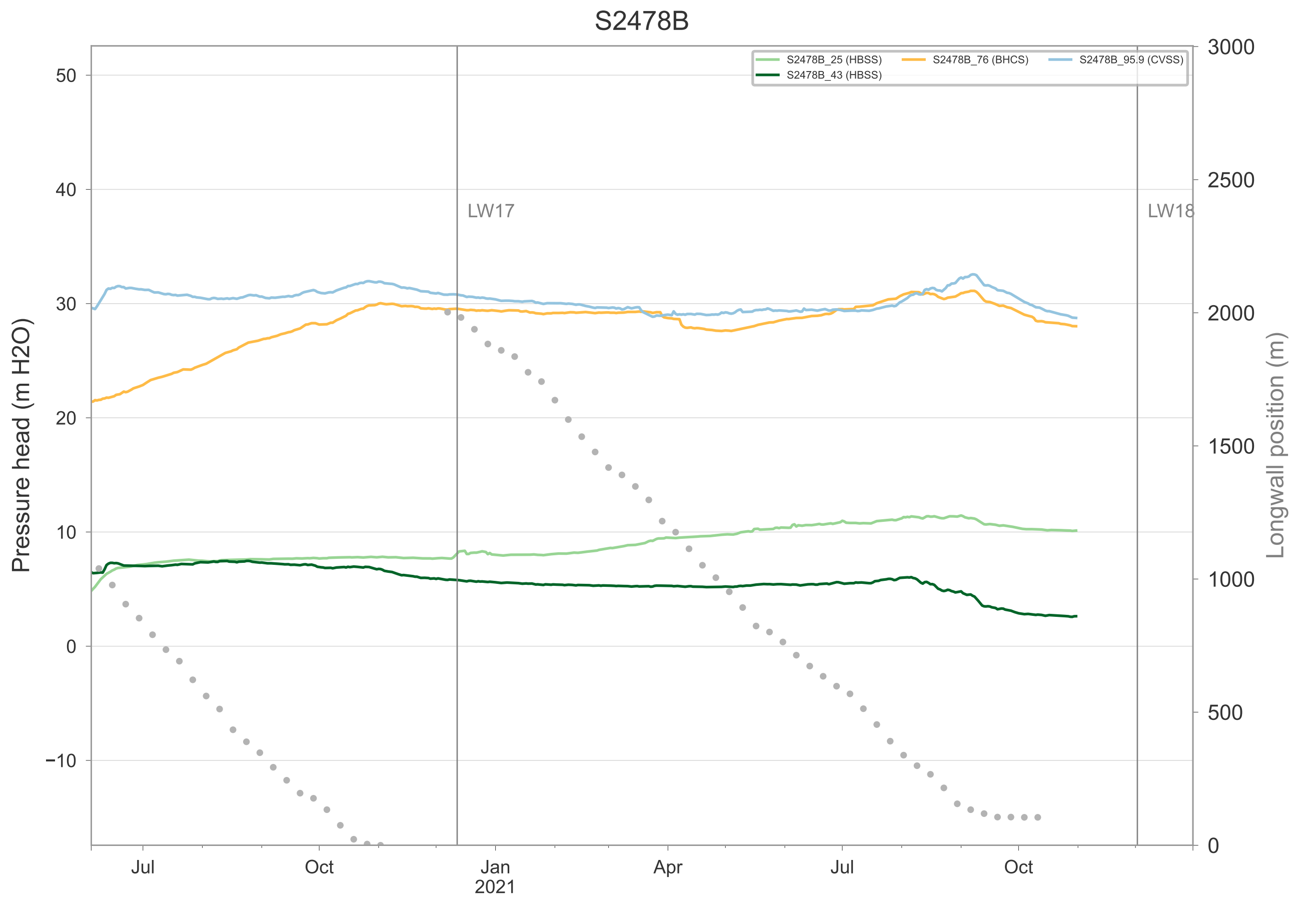
Groundwater hydrographs



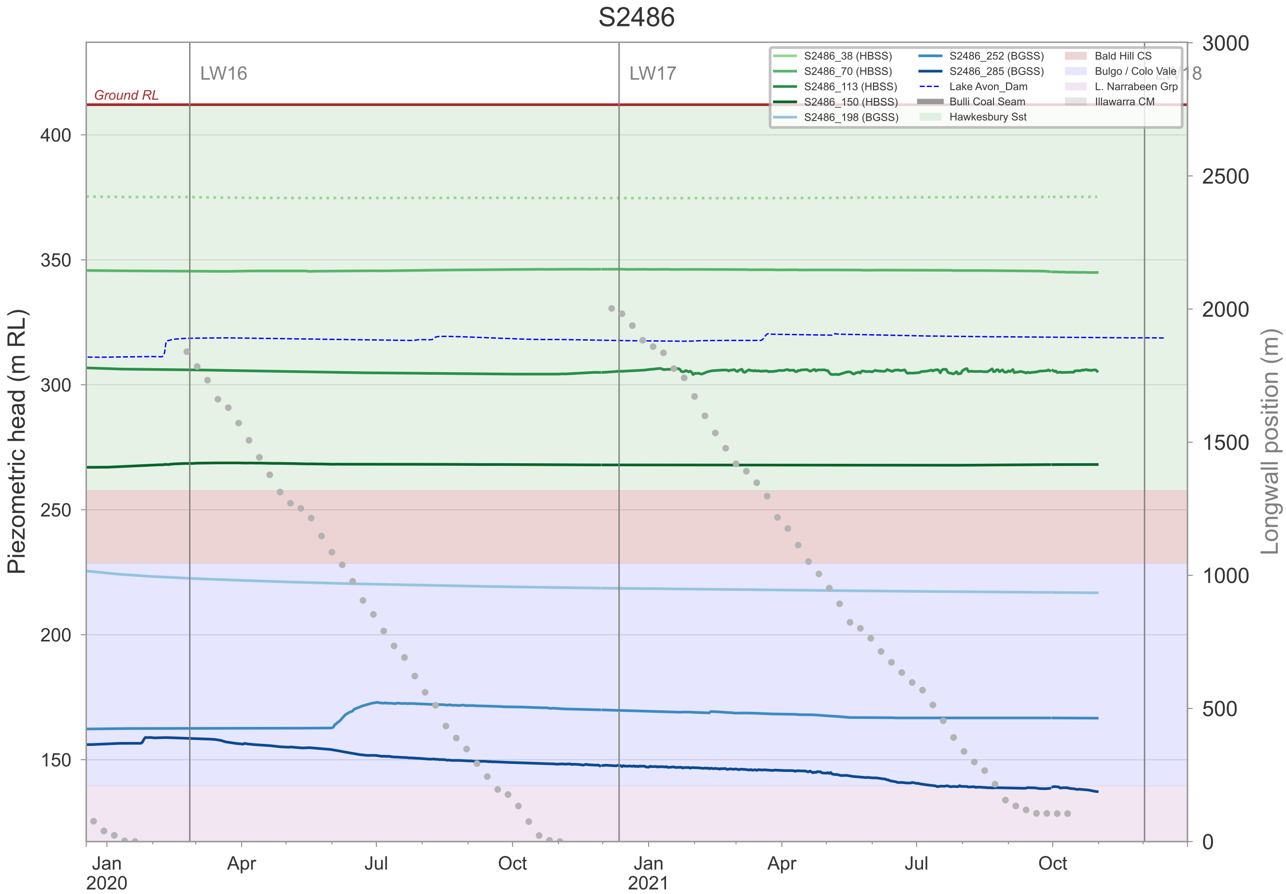


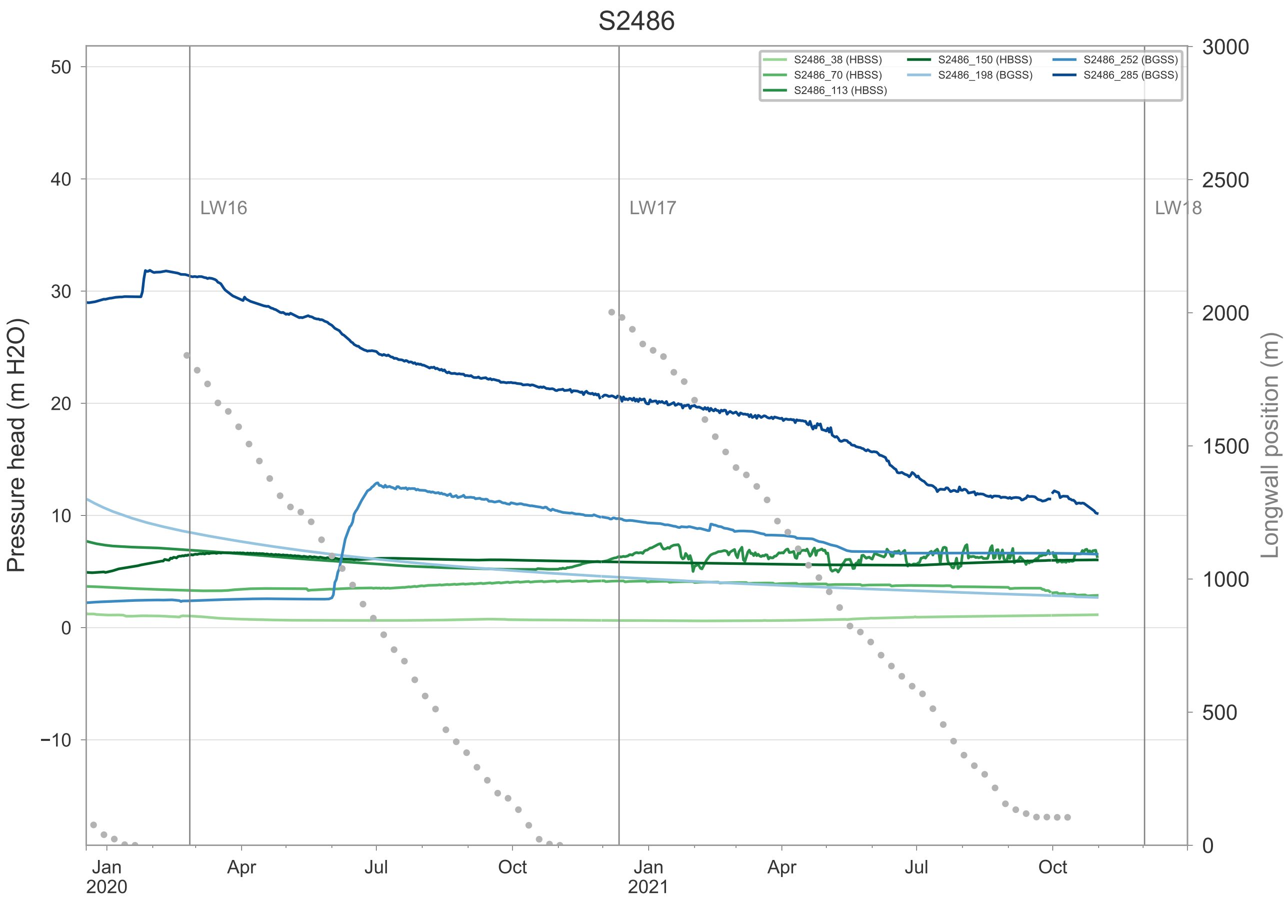
Groundwater hydrographs



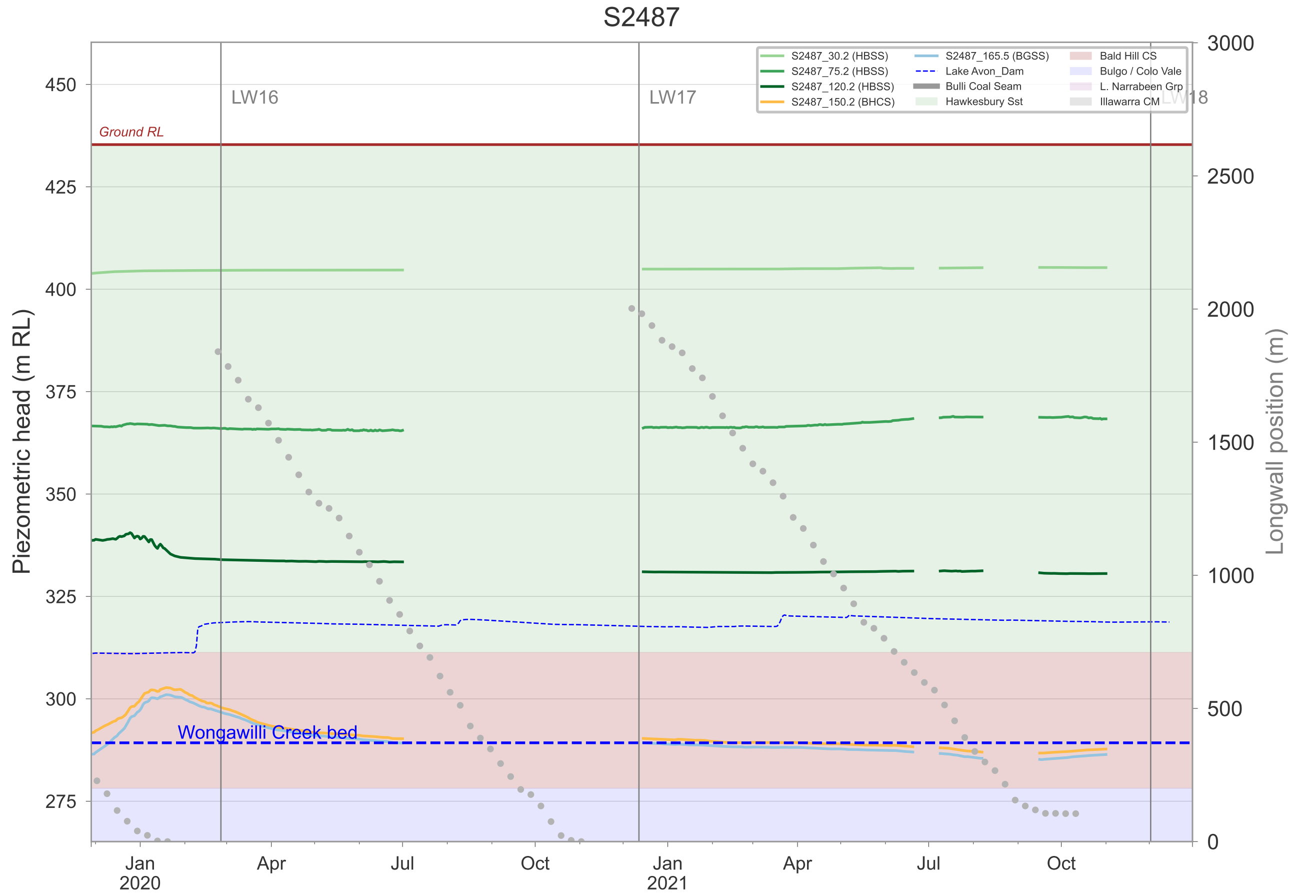


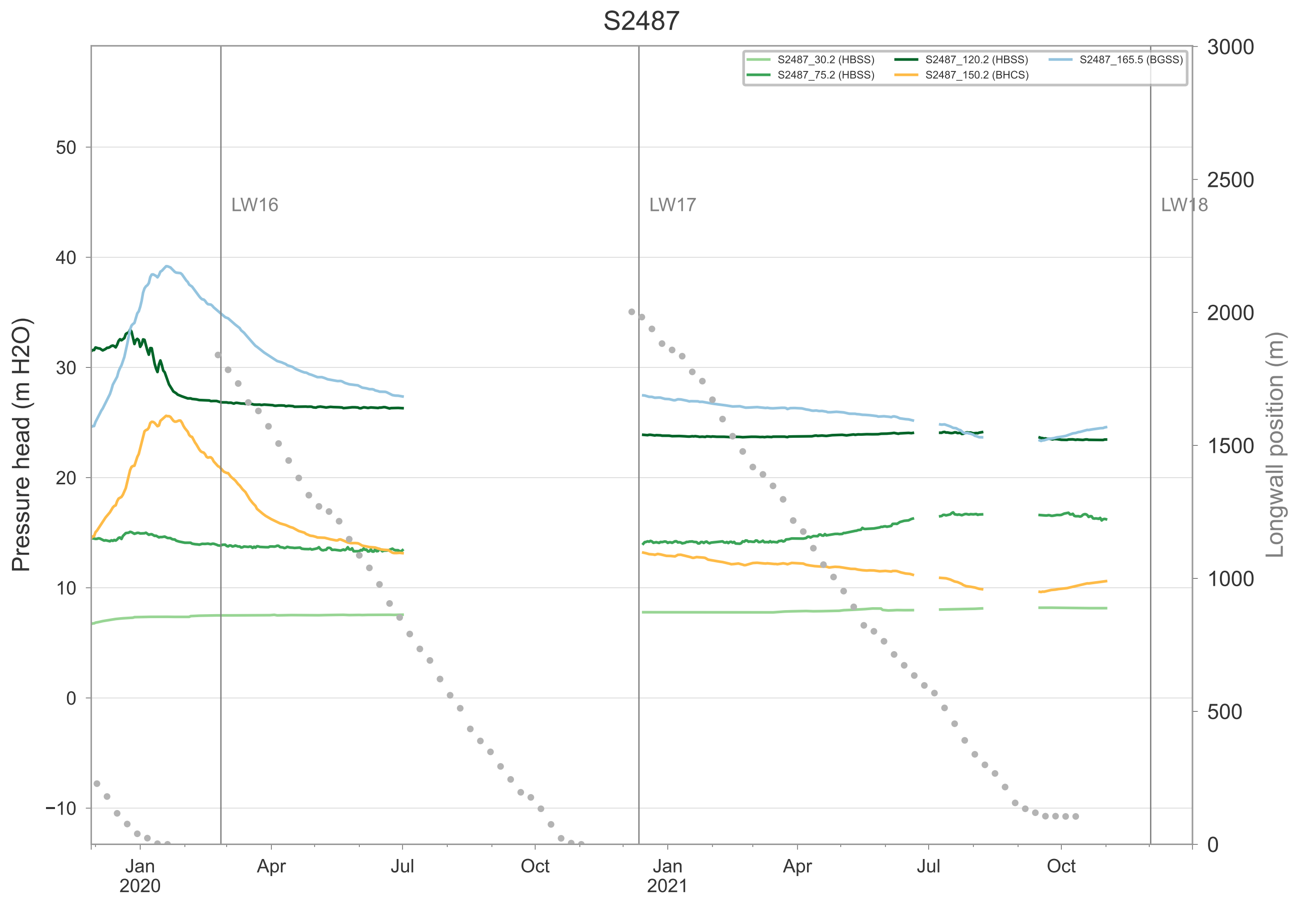
Groundwater hydrographs



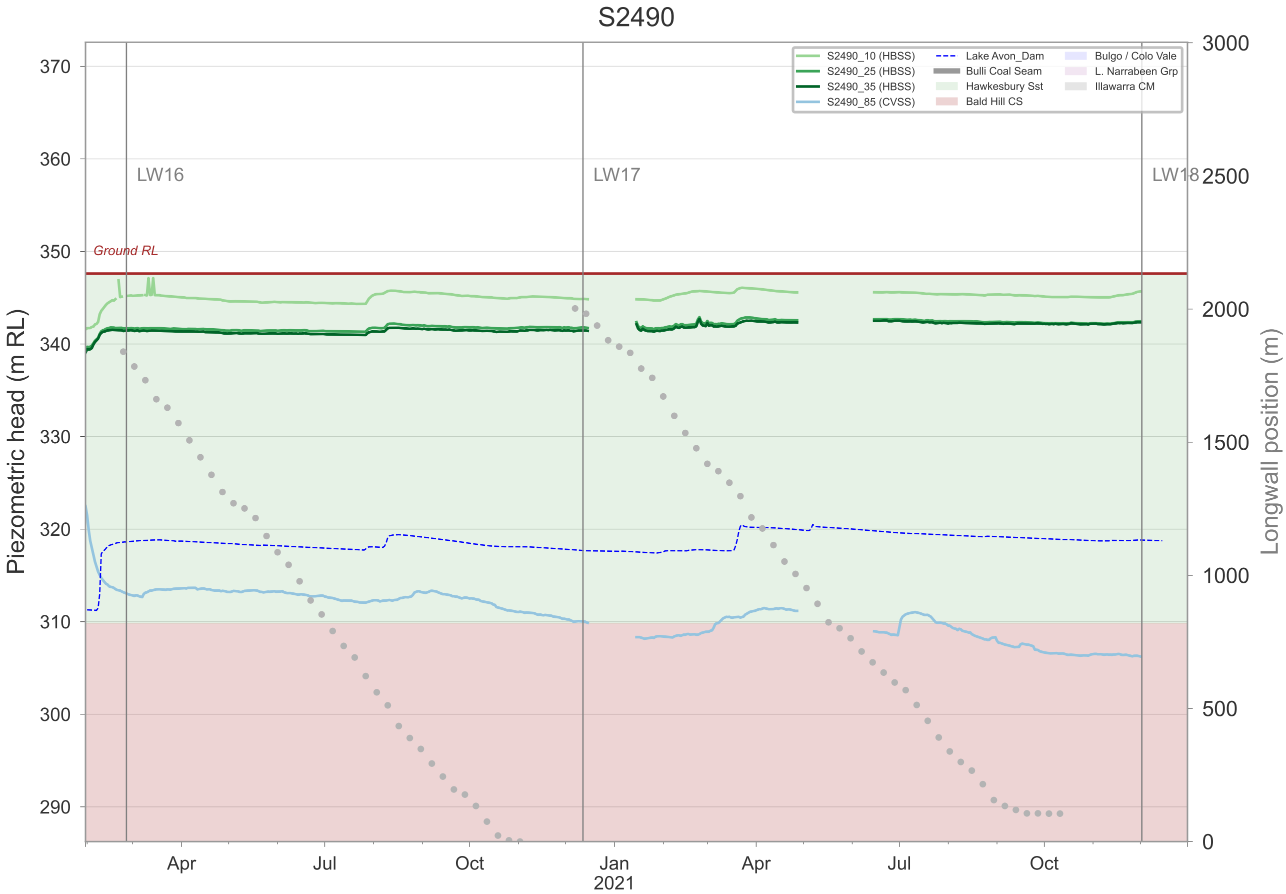


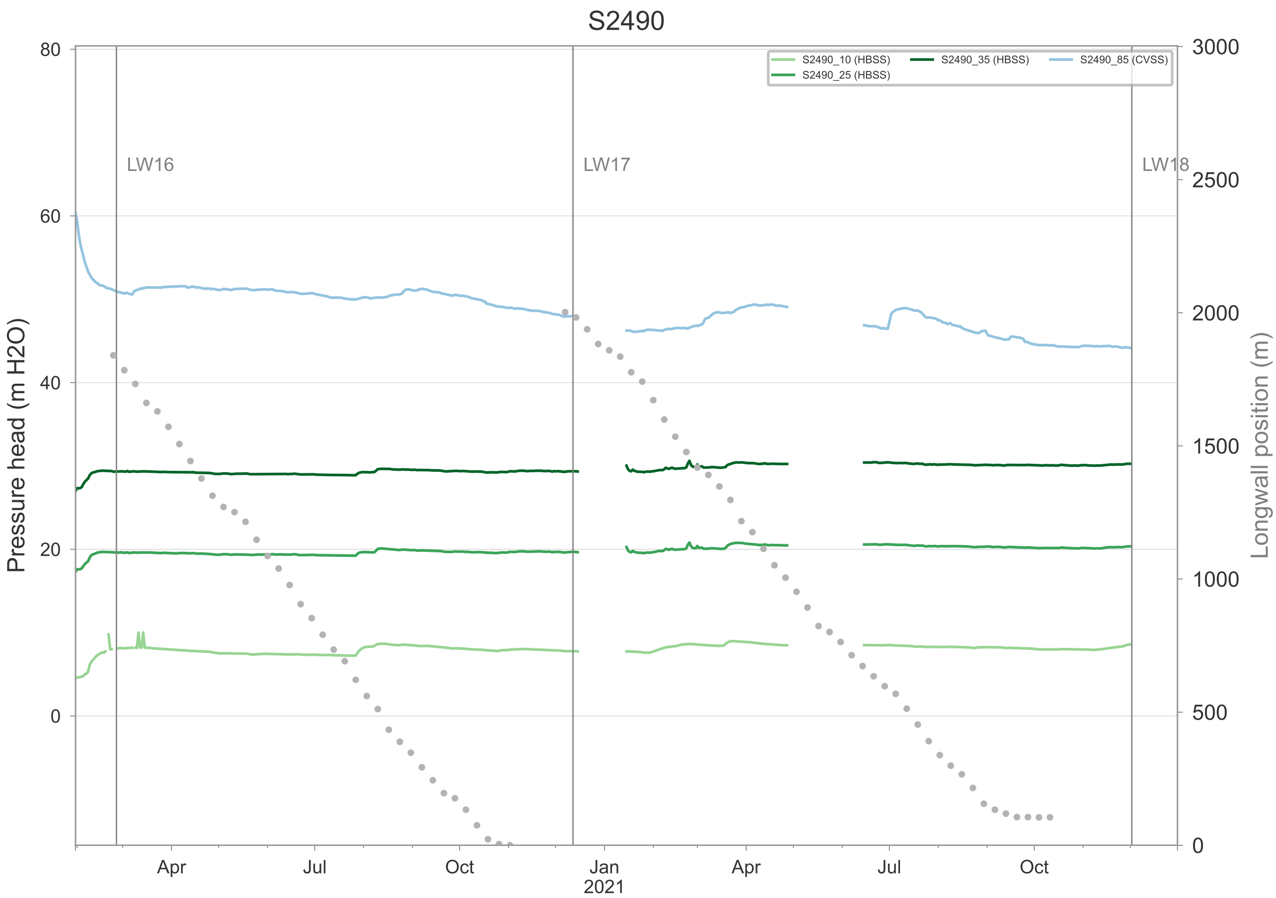
Groundwater hydrographs



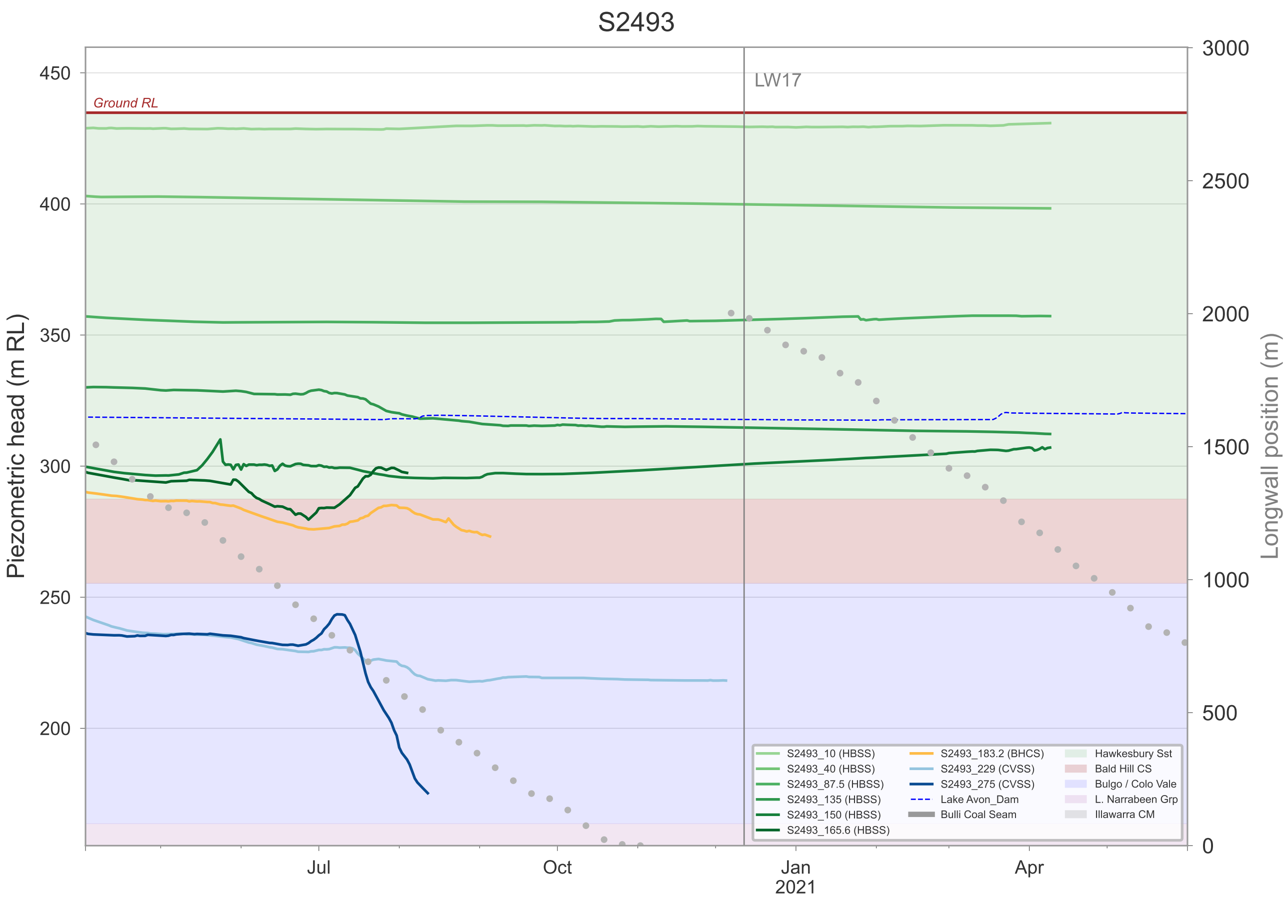


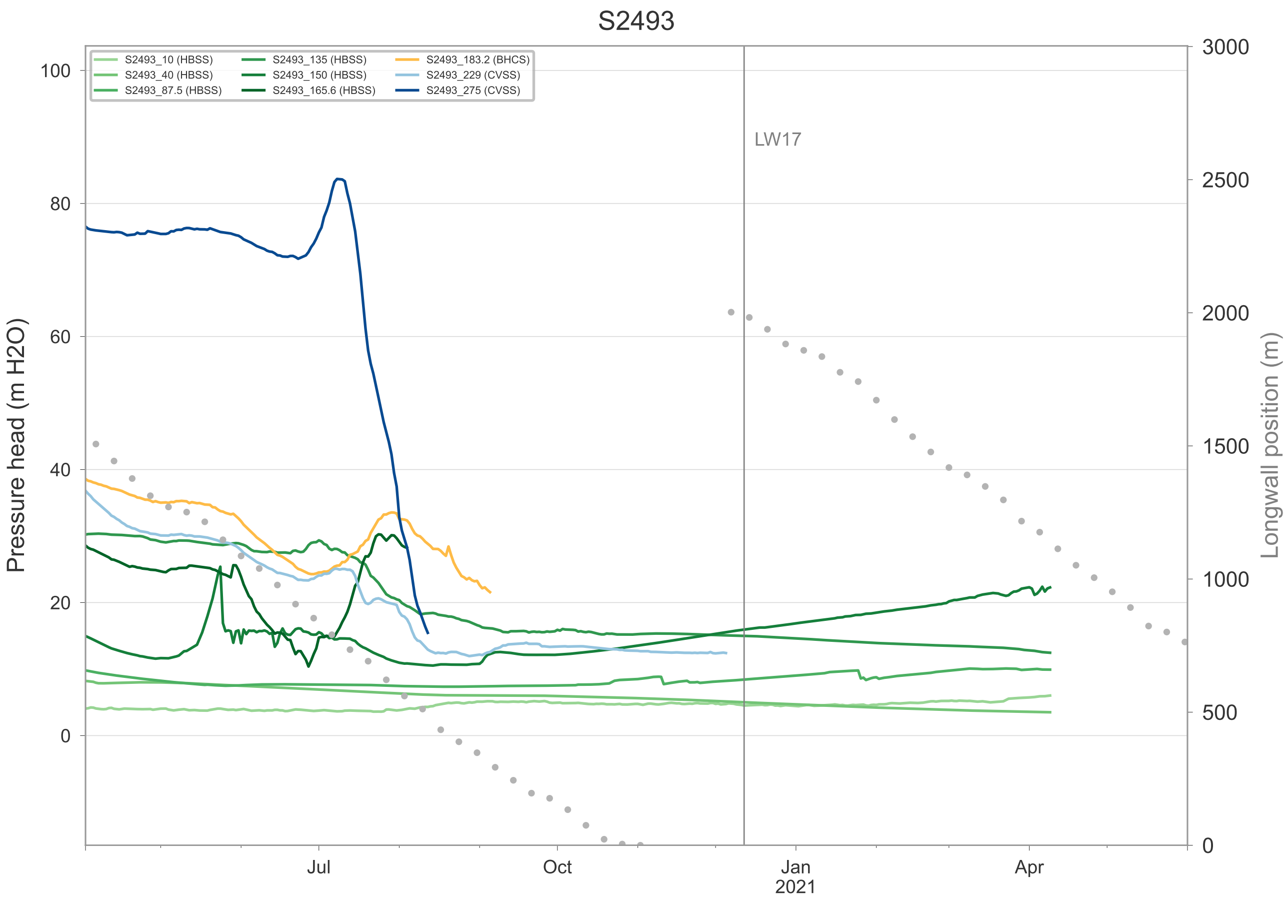
Groundwater hydrographs



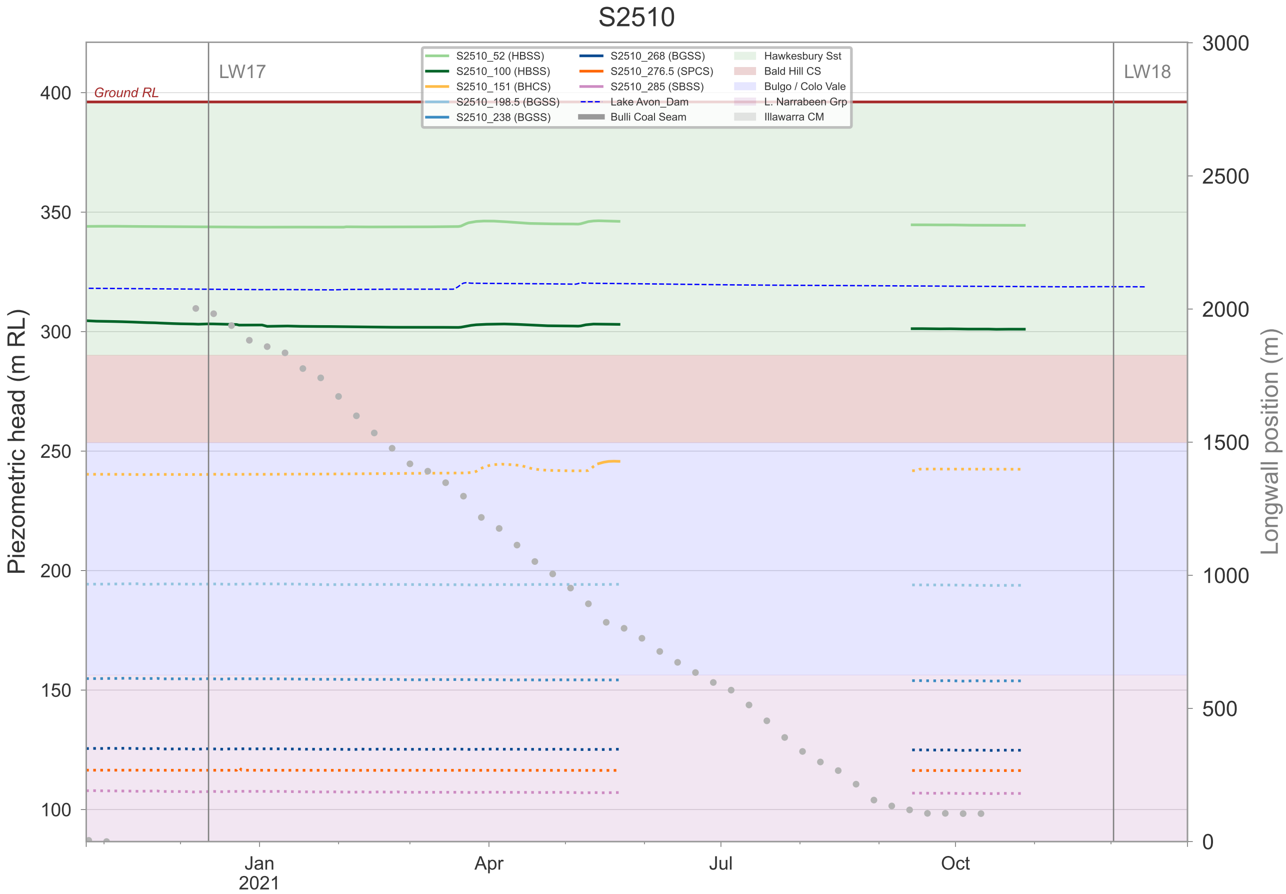


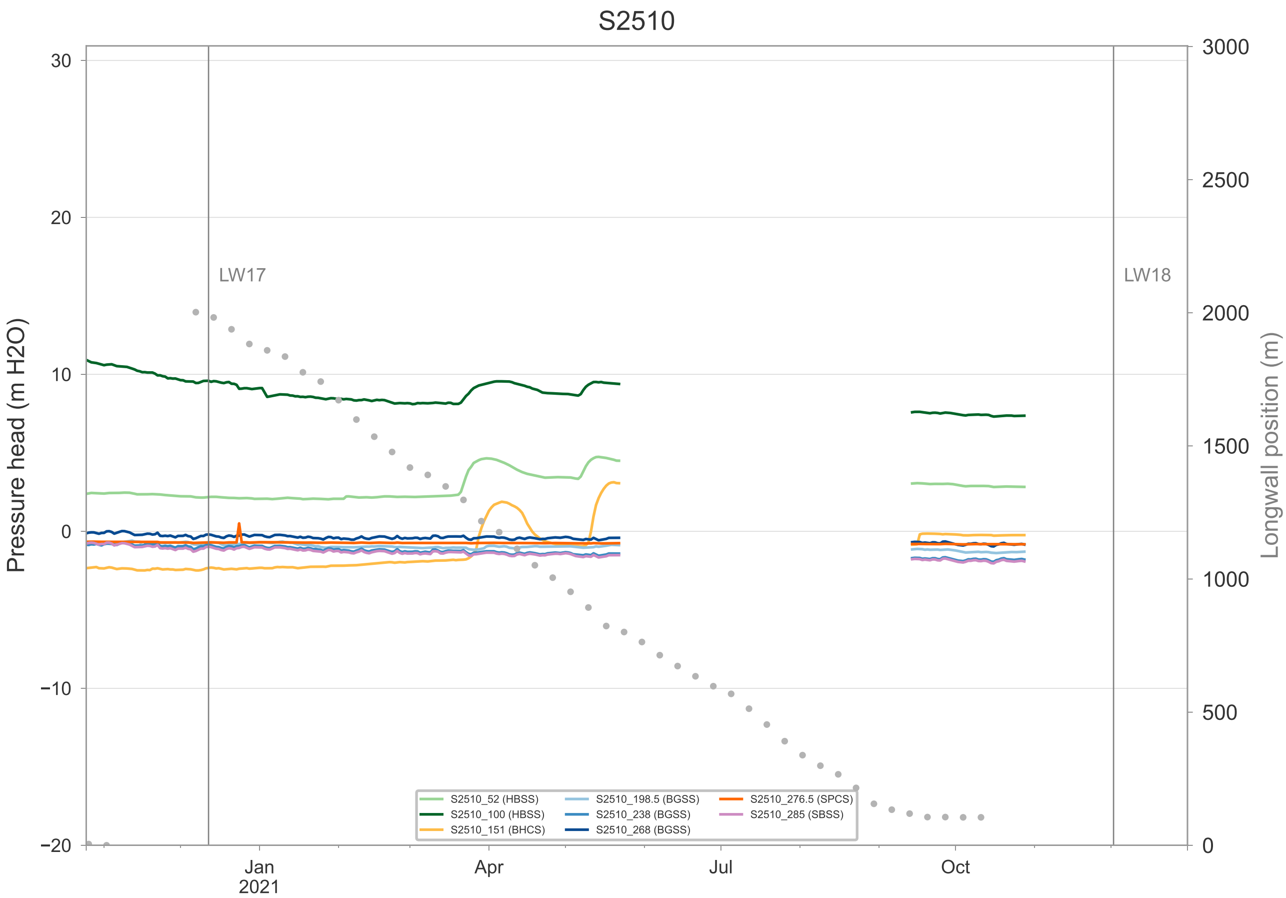
Groundwater hydrographs





Groundwater hydrographs





Groundwater hydrographs