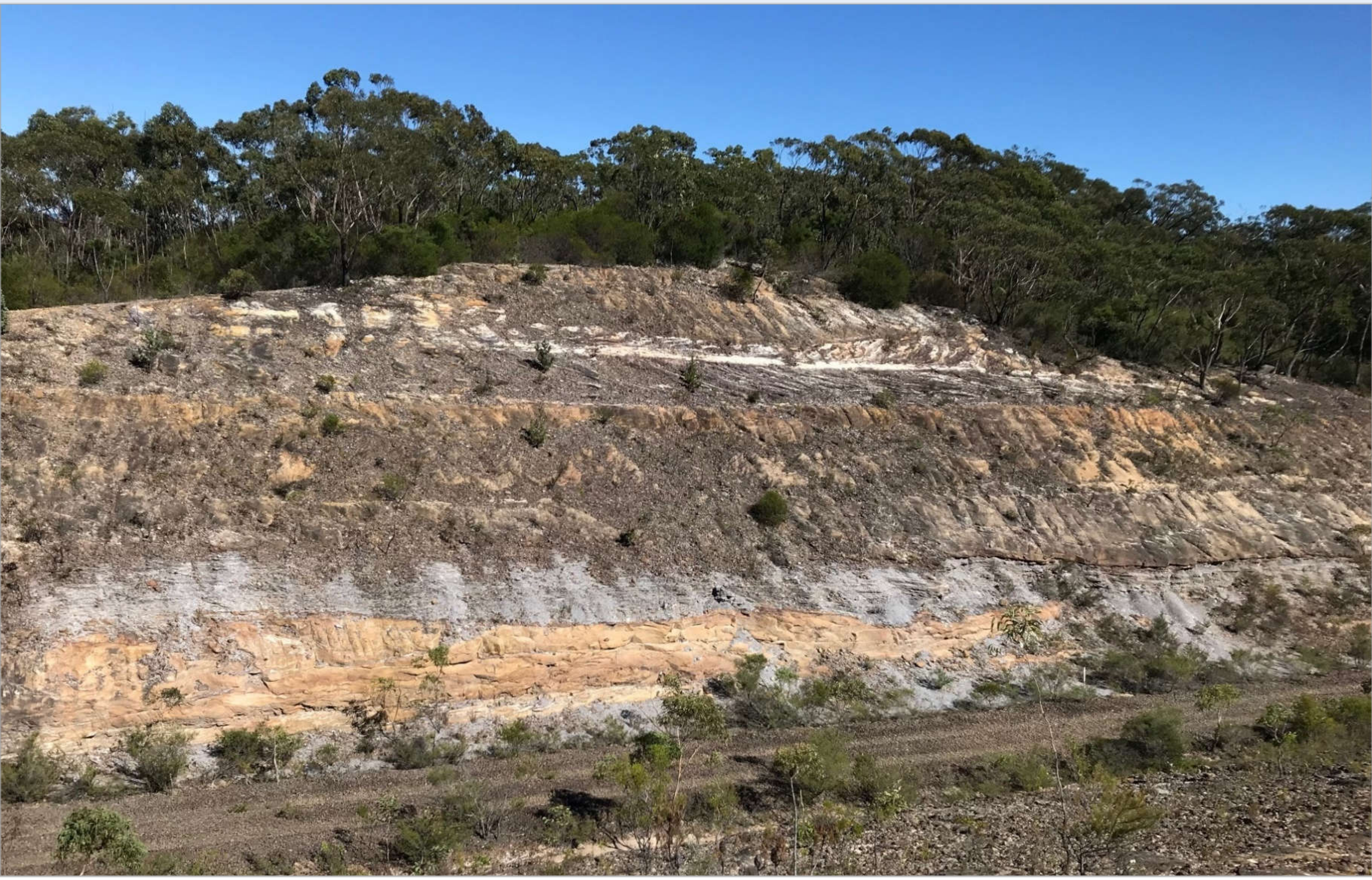
South32 - Illawarra Metallurgical Coal

DENDROBIUM MINE

End of Panel Groundwater Assessment for Longwall 15 (Area 3B)



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EXECUTIVE SUMMARY

This report provides an assessment of the hydrogeological effects of Longwall 15 (LW15) extraction in Area 3B at Dendrobium Mine, as required under the conditions of mining approval. Extraction of LW15 commenced on 4/4/2019 and was completed on 22/1/2020. LW15 is the seventh panel to be extracted in Area 3B, with an extracted length of 1952 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 LW15 extraction was 4.03 ML/day and total mine inflow was 5.75 ML/day, similar to inflows during the previous longwall. 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 8 - 17% of the total inflow. However, to date, the concentration of tritium (an isotopic indicator of modern water) in Area 3B mine inflow water is not statistically different from deep groundwater.

Groundwater salinity (as indicated by Electrical Conductivity – EC) shows a general increase with depth below the surface. Most bores that were sampled twice or more during the last three longwalls returned sample EC values within 20% of the previous samples. Samples collected from bore S2377 (at depth 113 m depth) returned lower EC during LW15 than the previous longwall. Given the location of the bore between LW14 and Lake Avon, it is recommended the bore be resampled.

Mining of LW15 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 that support mining approvals. As expected, the greatest depressurisation is within the Wongawilli Coal Seam, and decreases with height above the seam. Incremental drawdown in all strata is apparent in the areas immediately to the south-west of LW15.

During 2018 and 2019, IMC carried out investigation drilling above extracted longwalls (LW6, LW7, LW12, LW13, LW14 and LW15) to characterise the height of fracturing and assess groundwater conditions in strata above the longwall goaf. The investigation found that mining-induced fracturing, including high-angle 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, with complete depressurisation throughout the Hawkesbury Sandstone (HBSS) in most holes. Drawdown in the HBSS reduces with distance and is typically negligible at distances greater than 1 km from the goaf footprint.

IMC investigated anomalous groundwater levels at monitoring bore S2436 located near mapped lineaments associated with LA3 tributary. The investigation found no evidence for a transmissive structure associated with the lineament. New piezometers installed at the site confirm depressurisation of HBSS associated with mining in Area 3B, with average observed piezometric heads consistent with numerical model predictions.

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, but with little or no apparent 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 0.39 to 0.47 ML/day as at the end of LW15. The estimates are within the tolerable loss limit of 1 ML/day prescribed by Dams Safety NSW and supported by the declining mine inflow rates to Area 3B during the extraction of LW13-LW15 adjacent to Lake Avon.

1. INTRODUCTION

HGEO Pty Ltd (HGEO) was engaged by Illawarra Metallurgical Coal (IMC) to prepare an assessment of hydrogeological effects of LW15 extraction in Area 3B at Dendrobium Mine, as required under the conditions of mining approval. Extraction of LW15 commenced on 4/4/2019 and was completed on 22/1/2020. LW15 is the seventh panel to be extracted in Area 3B, with an extracted length of 1952 m, a void width of 305 m (including first workings) and a cutting height of up to 3.9 m.

Dendrobium Mine is located approximately 12 km west of Wollongong (NSW) in the Southern Coalfield and within the Metropolitan Special Catchment Area managed by WaterNSW. The three designated areas of extraction are Area 1 (east of Lake Cordeaux), Area 2 (west of Lake Cordeaux), and Area 3 (between Lake Cordeaux and Lake Avon) (Figure 1). Coal is extracted from the Wongawilli Seam by longwall mining. 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.

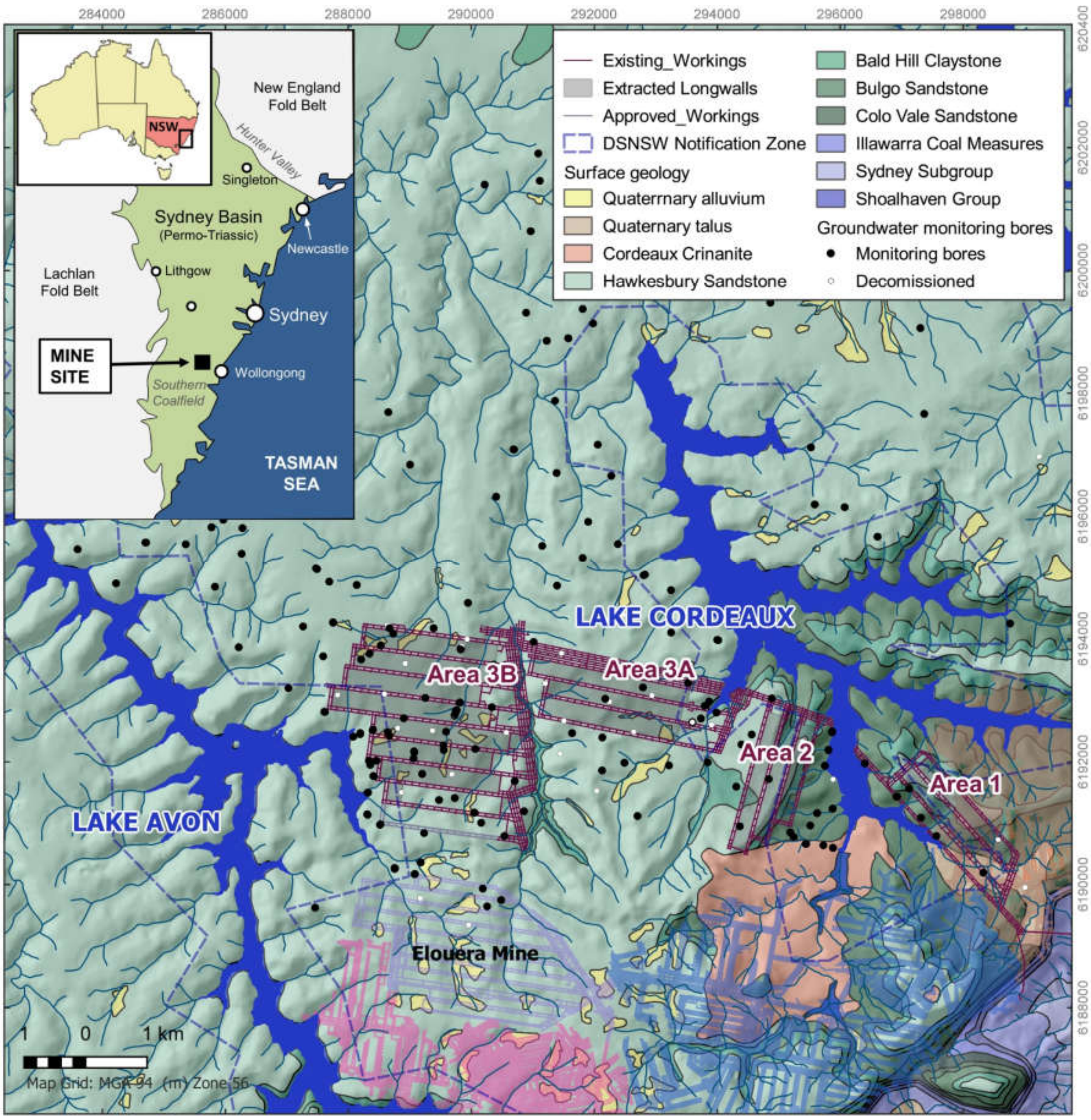

Figure 1. Location of Dendrobium Mine and surface geology

1.1 WaterNSW feedback on previous EOP report

WaterNSW reviewed the Longwall 14 End of Panel reports and provided comments to the NSW Department of Planning Industry and Environment in a letter dated 15 November 2019. Comments relevant to the groundwater assessment and actions taken are listed in Table 1.

Table 1. Comments on previous End of Panel reports by DPIE

WaterNSW comment	Response
WaterNSW supports the additional borehole investigations commenced over Longwalls 6, 12, 13 and 14. It is recommended that the findings in relation to height of fracturing/depressurisation be presented in a consolidated report and that the conceptual understanding of surface to mine connectivity and surface water component in mine inflow is evaluated and reported for each mined area. More detailed analysis could include: ▪ assessment of inflow rates during active mining vs postmining ▪ time lag between rainfall and inflow events ▪ changes in vertical hydraulic conductivity, and ▪ estimated transit time for a particle of water entering the system.	An investigation of fracturing above longwalls 6, 7, 12, 13, 14 and 15 was carried out in 2019. The final report is currently under review by Dr Bruce Hebblewhite. The main findings are summarised in Section 3.2.1.
The results from monitoring bores installed along the barrier zone between Avon Reservoir and Area 3B are concerning as three of the five bores after extraction of Longwall 14 indicate piezometric levels in the upper Hawkesbury Sandstone have declined to below Lake Avon. It is also reported that it is not clear if depressurisation at S2436 is related to current mining in Area 3B, or previous mining (Elouera Mine), or whether the depressurisation is controlled by a geological structure (lineament in LA3). WaterNSW strongly supports additional investigations to understand potential causes of observed groundwater response at this location.	Additional investigations at S2436 were completed in 2019. Results are summarised in Section 3.2.4.

1.2 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.

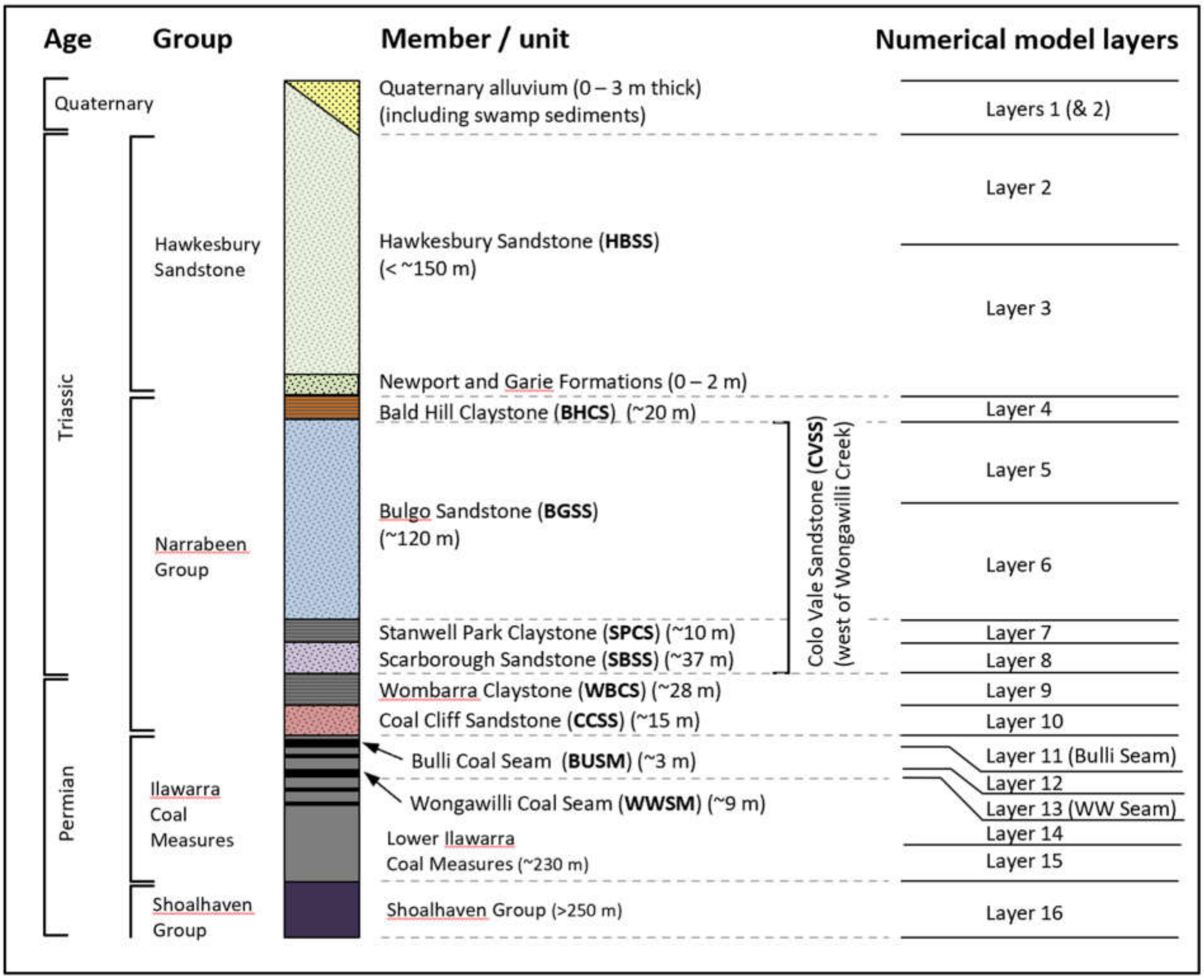

Figure 2. Stratigraphy of the Southern Coalfield

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.

1.3 Effects of mining

Underground mining activities result in depressurisation of the surrounding geological strata and drawdown of groundwater levels near the mine. Groundwater drawdown may result in impacts to surface water systems such as streams and wetlands that are partially sustained by groundwater discharge. The extent and distribution of mine-related drawdown is related to aquifer parameters such as hydraulic conductivity and storage coefficients; but also the extent of strata deformation and fracturing that extends above and outside of the mine workings.

Extraction of coal using longwall methods commonly results in ground subsidence and associated deformation and fracturing of overlying strata (Peng & Chiang 1984; Whittaker & Reddish 1989). Fracturing is most intense and vertically connected immediately above the collapsed longwall (goaf), and grades upwards through zones of less fractured strata (Booth 2002). Fracturing of the overburden can cause significant changes in aquifer characteristics such as permeability and storage, and potentially can provide pathways for vertical groundwater movement between shallow groundwater and surface water systems and underground mines (McNally & Evans 2007; Advisian 2016). The height to which vertically connected (and free-draining) fracture networks extend above the mined seam is therefore important in assessing potential 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).

At Dendrobium, the methods of Ditton and Merrick (2014) and Tammetta (2013) yield estimates that are significantly different from each other. A review of longwall subsidence fracturing at Dendrobium by consultants PSM (2017) concluded that fracturing above the (305 m wide) panels in Area 3B likely extends to the surface (Galvin 2017; PSM 2017), consistent with the predictions of the Tammetta model at Dendrobium Area 3B, and recent investigations by IMC.

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, b). 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.*

Between 2018 and 2019 IMC carried out an investigation into the height of fracturing above completed longwalls at Dendrobium Mine. Investigation holes were drilled above both existing and planned Longwalls 12, 13, 14 and 15 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.

1.4 Numerical groundwater impact model

Regional numerical modelling by Coffey (Coffey 2012) supported the *Area 3B Subsidence Management Plan* (SMP) application and subsequent approval. The model was revised and updated in 2014 (HydroSimulations 2014) to include calibration to shallow (swamp) groundwater data and surface water (creek) flows, and again in 2016 (HydroSimulations 2016). The 2016 model addressed the Area 3B SMP approval conditions and provides the basis for this groundwater impact assessment. A new numerical model was developed using an unstructured grid approach for assessment of proposed Mine Areas 5 and 6 to the north of Area 3B (HydroSimulations 2019). The 2019 model will form the basis of assessments of developments beyond Area 3B.

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

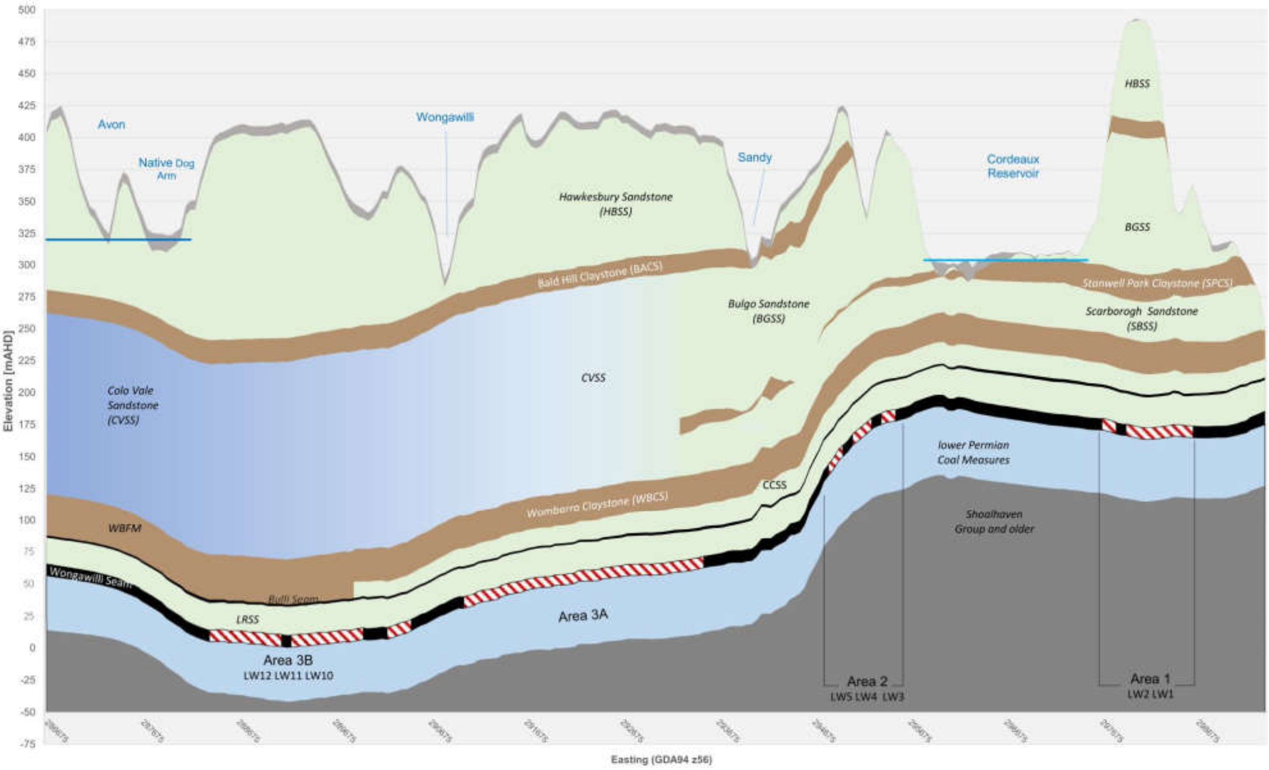

Figure 3. Geological cross-section (east-west) through Dendrobium Mine

2. MONITORING DATA

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

2.1 Management Plan

Groundwater monitoring at Dendrobium Mine is conducted in accordance with the "Dendrobium Colliery Area 3B SMP Groundwater Management Plan" (South32 2012) and the Area 3B Subsidence Management Plan (South32 2018a).

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 piezometers installed at Dendrobium is included in Appendix A.

There are approximately 121 active monitoring bores located across the Dendrobium mine lease, containing 734 piezometers, excluding those that are decommissioned or no longer monitored.

In the last year, new monitoring bores have been installed above mined and planned longwalls and between Lake Avon Reservoir and Area 3B. New sites include:

- Re-drilling of investigations holes at Avon Dam sites AD3, AD4 and AD8 following extraction of LW15 (S2377C, S2378B and S2436C);
- Completion of investigation holes above extracted longwalls (LW6, LW7, LW12, LW13, LW14, LW15), and an investigation hole above LW16 (S2354) prior to extraction.
- Installation of a monitoring bore and VWP array and groundwater sampling pumps between LW15 and Wongawilli Creek (S2487)
- Monitoring bores at Swamp 35 to the south of Area 3B, with sensors within the sandstone substrate (S2490, S2490A).
- Completion of investigation holes that intersect the Elouera Fault, south of Area 3B (S2441, S2441A, S2441B, S2443, S2444, S2465, S2474) and ongoing hydrogeological investigations.

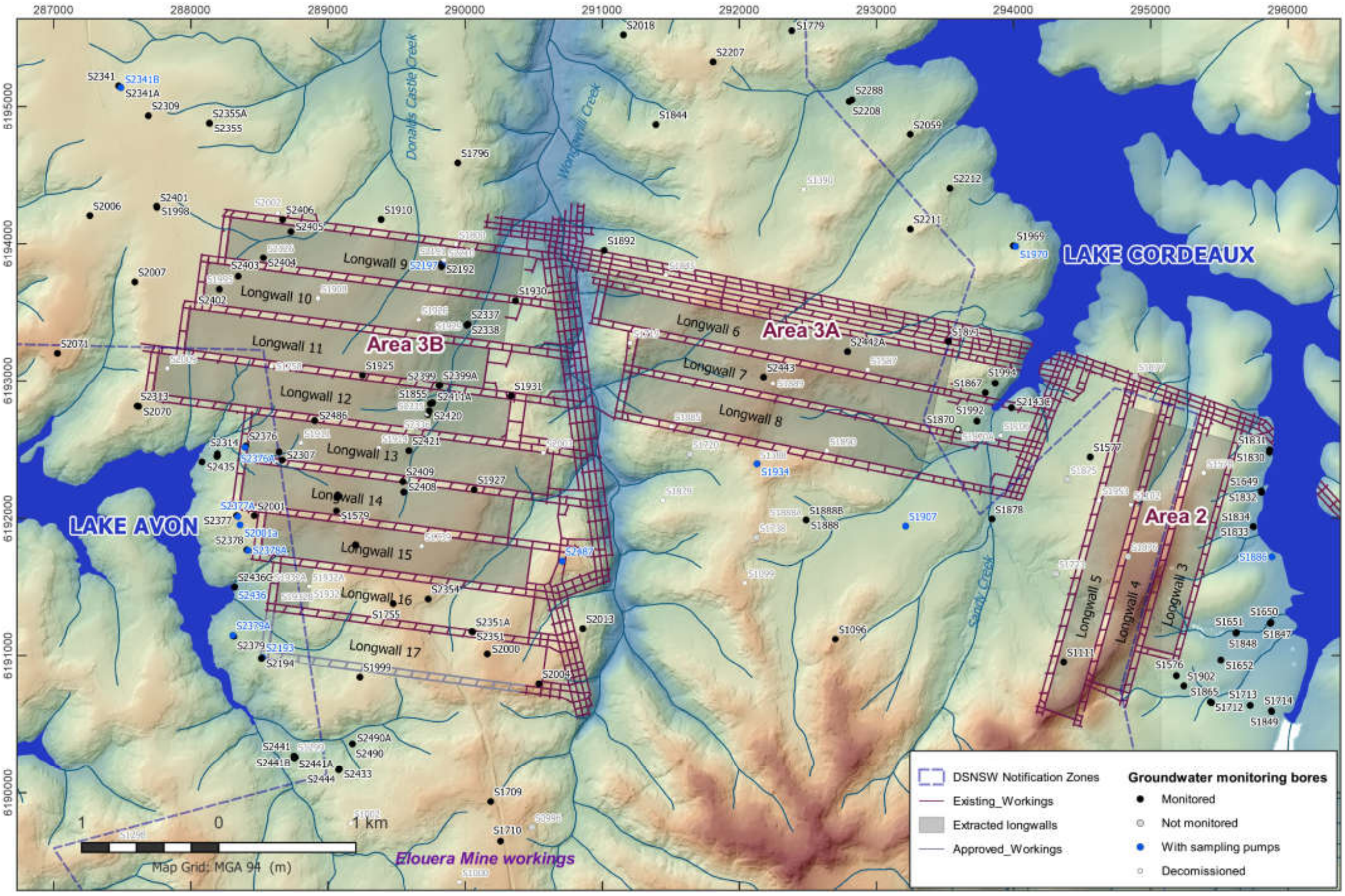

Figure 4. Deep groundwater monitoring network around Areas 2, 3A and 3B

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 (Mikkelson & Green 2003; Contreras *et al.* 2008).

Standpipe piezometers, consisting of a slotted open casing, are used in a small number of locations and are best suited to monitoring of relatively shallow groundwater systems within moderate to high permeability strata (e.g. swamp sediments and shallow 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 ***potentiometric head*** (mAHD) and ***pressure head*** (m H_2O). Potentiometric head can be thought of as the theoretical level to which water would rise in a bore that is open to an aquifer at a given elevation and is calculated by adding the measured pore pressure (at the VWP, expressed in m of water) to the elevation of the sensor (in m AHD). The potentiometric head in a confined aquifer system can be (and often is) different to the water table elevation at the same location.

Hydrographs presented in this assessment include surface water hydrographs for the nearest water supply reservoir (Lake Cordeaux for Area 3A and Lake Avon for Area 3B hydrographs). Note also that individual hydrograph traces are presented as dotted lines at times when the pressure head is below a threshold of 2 m. The ***pressure head*** is the absolute pore pressure at the sensor expressed in m of water. When the pressure head is below that threshold it is an indication that the rock matrix is approaching complete 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 response to feedback from WaterNSW (2019) and to better represent groundwater conditions in the HBSS, the calculation of drawdown and presentation of data was revised in 2019. In this assessment the 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 LW5 (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 LW5 (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 fortnightly.

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

2.5 Groundwater chemistry

Groundwater chemistry sampling sites relevant to this assessment are shown in Figure 4. 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), algae and isotopes of carbon, hydrogen and nitrogen. Weekly water samples are taken from the current longwall panel (roof and face) and from water pumped from the goaf. Monthly water samples are taken from the main discharge points of the mine and from completed longwall panels. The results of the sampling are reviewed each month and reported to 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.

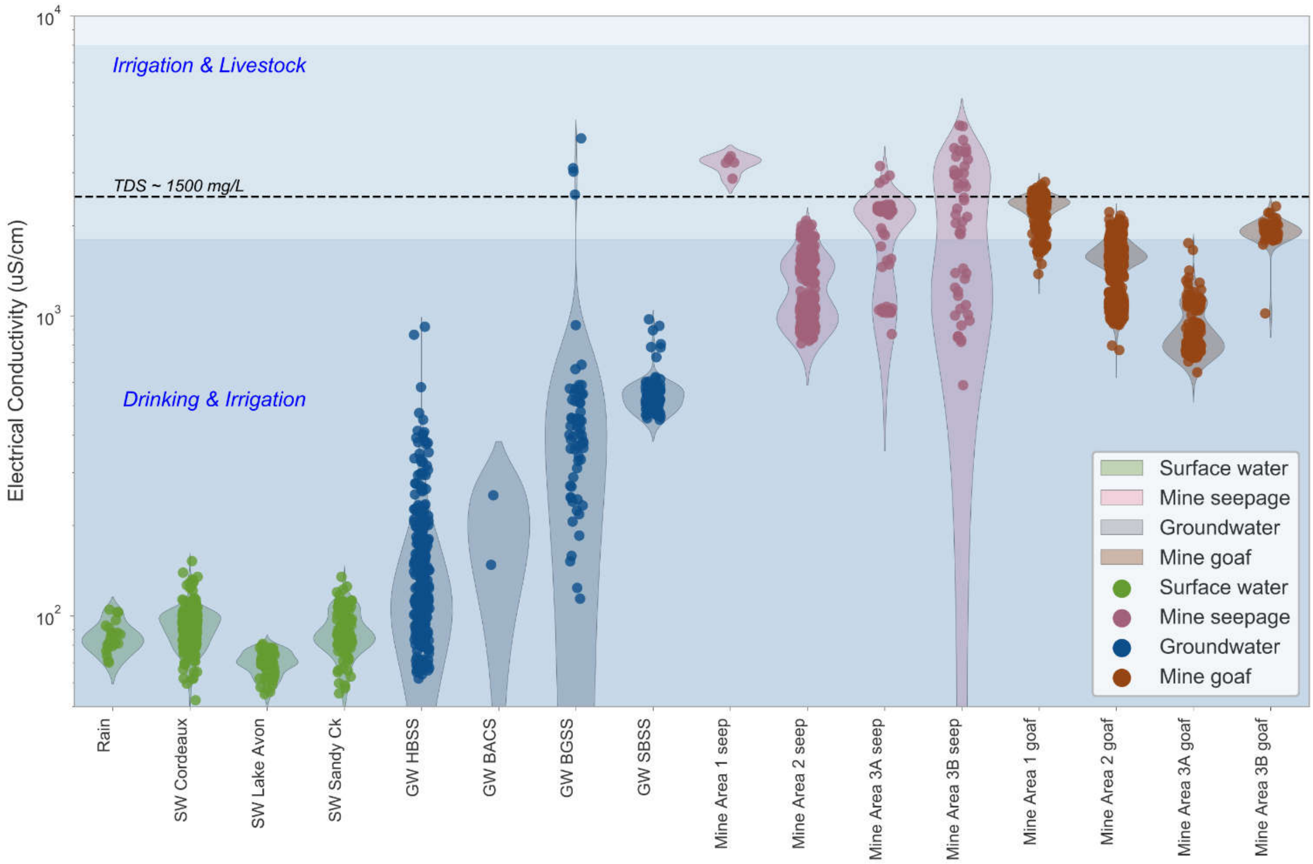

Figure 5. Violin plot showing the range in EC of surface water, groundwater and mine inflow

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 LW15 was extracted (4/4/2019 to 22/2/2020). The average daily inflow to Area 3B during LW15 extraction was 4.03 ML/day which represents approximately 70% of total mine inflow for the period. The average groundwater inflow component of the water balance for Area 3B and the total mine was similar during LW15 to that of the previous longwall (Table 2).

Table 2. Dendrobium Mine Inflow during the Extraction of Longwall 15 (in ML/day)

STATISTIC	AREA 1	AREA 2	AREA 3A	AREA 3B	TOTAL
MEAN	0.33	0.72	0.68	4.03	5.75
STANDARD DEVIATION	0.00	0.16	0.36	0.94	1.04
MINIMUM	0.33	0	0	0.17	0.50
MAXIMUM	0.33	1.14	2.01	7.18	8.22
MEAN (LW14)	*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 has declined (flattened) during the mining of LW12 and LW13 and the water balance decreased during the extraction of LW14 and LW15. 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). The decline in groundwater inflow to Area 3B during LW14 and LW15 is likely to be partly due to the unusually dry conditions during 2018-2019. As of LW12, 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 LW12, 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 LW12.

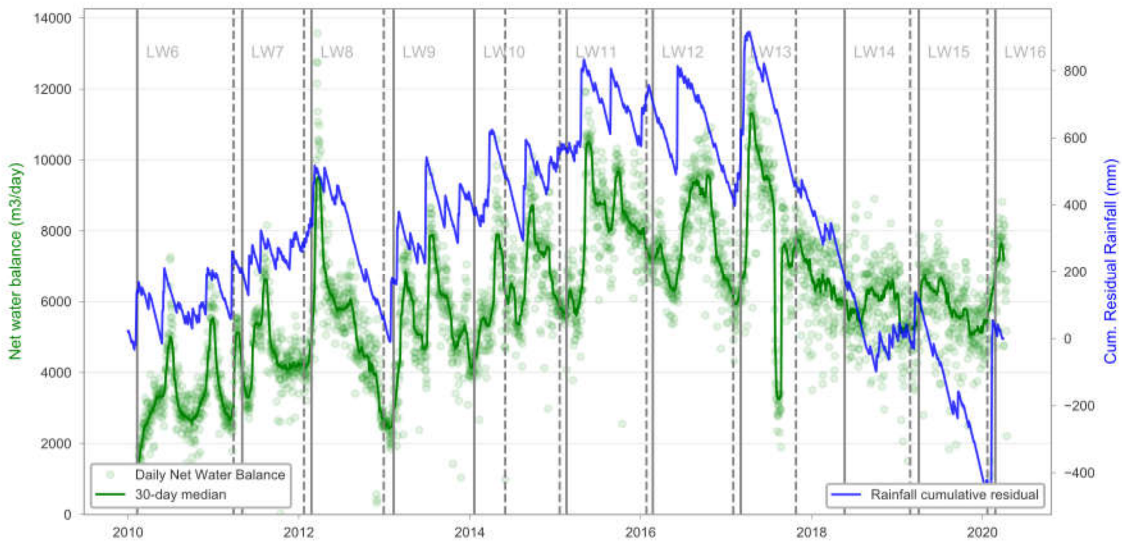

Figure 6. Groundwater inflow from water balance for all mine areas (kL/day)

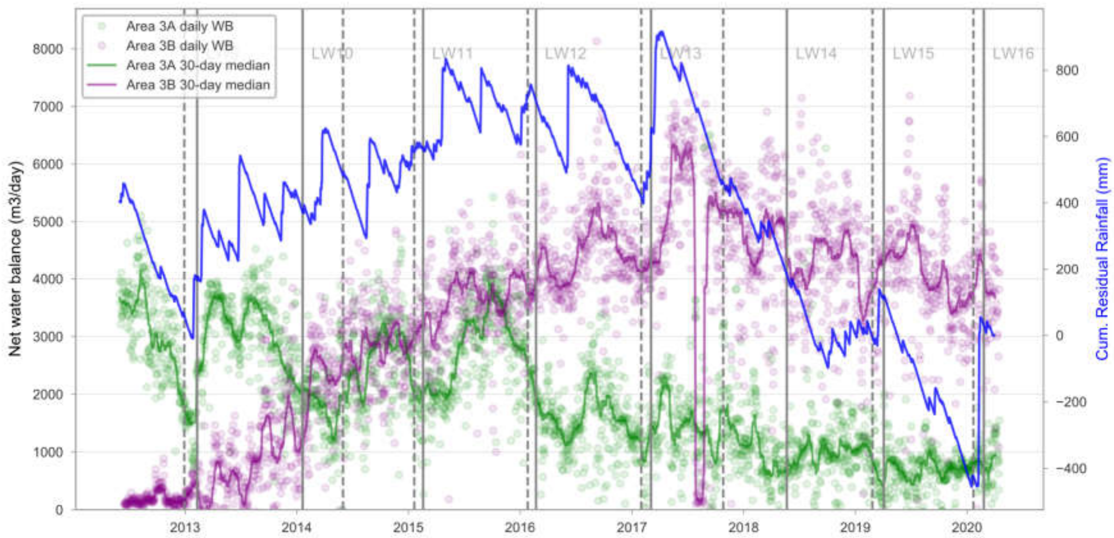

Figure 7. Groundwater inflow to the mine for Areas 3A and 3B (kL/d)

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 borrowed from stream flow analysis whereby the baseflow represents the component of stream flow due to groundwater discharge, as opposed to the 'quick flow' component of rainfall runoff represented by the hydrograph peaks.

2. Isotopic tracer approach, whereby a tracer of modern water (in this case, tritium) is 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[1] 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 the large rainfall events in 2015, 2016 and 2017. There is a two to three-month delay in mine inflow peak relative to a major rainfall event and therefor a peak in inflow associated with the February 2020 heavy rain events is not yet apparent.

Applying digital stream baseflow separation filters to the water balance data is problematic due to the high variability of the data. Therefore, the baseflow component has been approximated using a LOWES trend line (LOcally WEighted regression Smoothing; Cleveland 1979), translated to correspond with most of the troughs in the moving average. 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 LW15 was 13%, compared with 8% during LW14 and 17% during LW13.

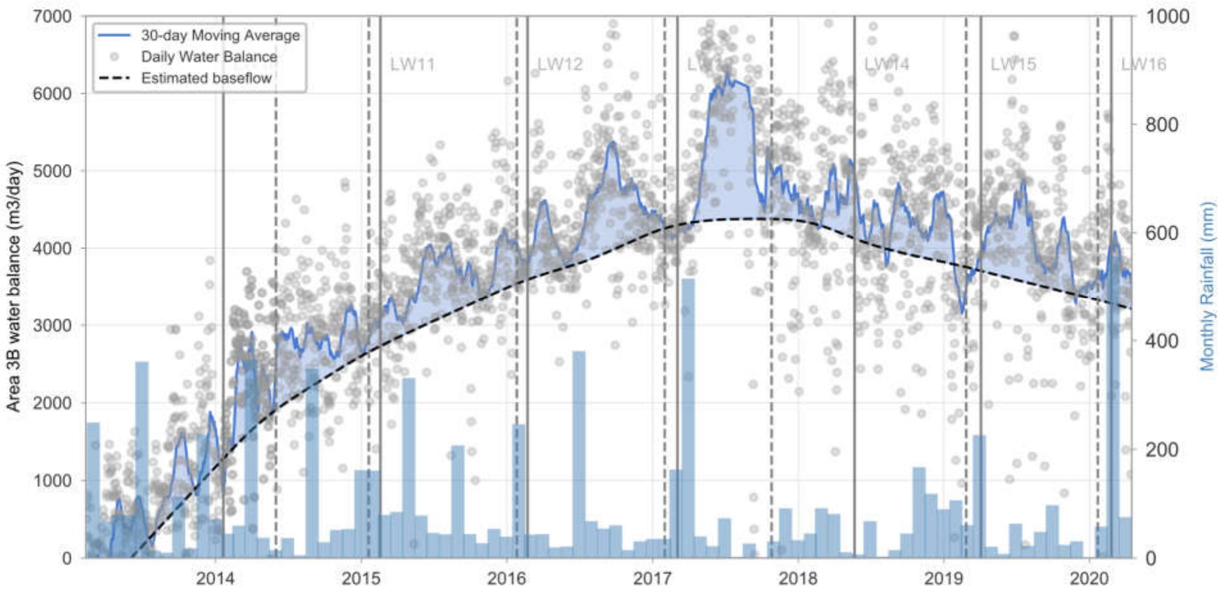

Figure 8. Estimate of potential surface water component to Area 3B water balance

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 Safety NSW. Tritium is an isotope of hydrogen (^3H), generated in the atmosphere through interactions

[1] 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.

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. As of the last sample analysis (23/9/2019) tritium in samples collected from the Area 3B goaf is not statistically different from deep groundwater baseline data (represented by the shaded area below 0.2 TU in Figure 9, from HGEO 2020). The most recent goaf outflow samples are collected from the main dam at Tailgate 9 from which all goaf drainage from Area 3B is pumped (DWS203; green circles). Therefore, as of 23 September 2019, there is no detectable component of modern water in Area 3B inflow. The laboratory processing time for high precision tritium analysis can be more than 6 months and therefore results for some samples collected in the latter part of LW15 are pending.

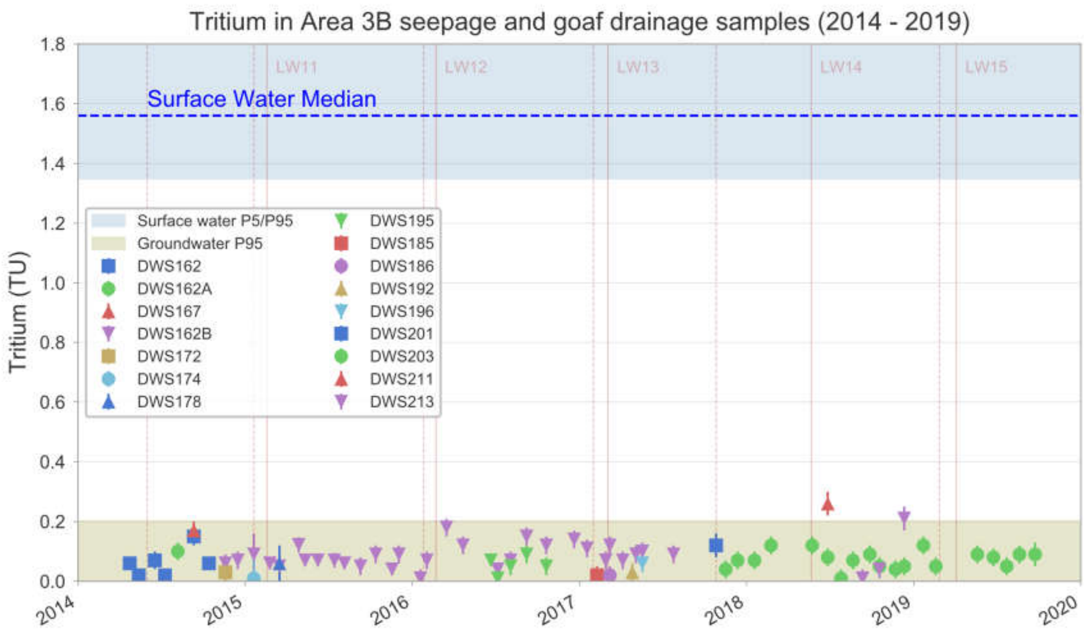

Figure 9. Tritium concentration in water samples from Area 3B (from HGEO, 2020)

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. During 2019, a number of new piezometer arrays were installed over previously mined longwalls 6, 7, 12, 13, 14 and 15.

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) (most recently seen in S2487 as LW15 approached). 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:

During 2018 and 2019, IMC carried out investigation drilling above extracted longwalls (LW6, LW7, LW12, LW13, LW14 and LW15) to characterise the height of fracturing and assess groundwater conditions in strata above the longwall goaf (HGEO 2020b, under review). Nine sites were drilled as part of the investigation, adding to five sites drilled as part of previous investigations above extracted longwalls (LW9, Swamp 1b and WC21). These investigations now provide a very good understanding of fracturing and depressurisation above extracted longwalls at Dendrobium. The height of fracturing investigation report is currently being peer-reviewed by Dr Bruce Hebblewhite and 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 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 LW11 and LW12, 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 will also decrease 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. Holes in both areas show positive pressure heads in some sensors in the upper CVSS and BACS, indicating localised perching or incomplete drainage of fractured rock domains. These findings are consistent with observations above LW9 and LW0 from previous drilling investigations (LW9 study, Swamp 1b and WC21 rehabilitation study).

In the context of previous models it is interpreted that the height of connected fracturing (and depressurisation) extend to the surface in Areas 3A and 3B and likely also in Areas 1 and 2. Observations from this investigation are most consistent with the empirical model of Tammetta (2013).

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 LW9) piezometric head deceased to their lowest level in most strata towards the end of LW14 and have shown recovery in levels during LW15 in mid-HBSS, BGSS and SBSS.

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.

Piezometers located to the south of the active longwalls in Area 3B (in bores S1932, S2001, S2194) show more pronounced depressurisation in the mid- to deep stratigraphic levels with some strata pressures dropping to zero well in advance of the longwall. It is likely that those piezometers are affected by depressurisation from the Elouera Mine to the south, as well as drawdown from Dendrobium Mine, an effect that is predicted from numerical groundwater modelling. Sensors in S2001 and S1932 bores showed accelerated declines in pressure during LW14 extraction and again after LW15, particularly in S2001 which is located 86 m from the edge of the LW14 goaf. At S1932 sudden drawdown in head within the HBSS (and deeper units) is noted as LW15 passed within 200 m of the monitoring bore. The datalogger at S2194 suffered a malfunction towards the end of LW14, possibly due to lightning strike, and was replaced. Since replacement, piezometric heads in most strata recovered significantly during LW15. This response is unusual given the approach of mining and, if not a result of malfunction, may reflect compression effects associated with subsidence.

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

3.2.3 Avon reservoir bores

Between 2015 and 2018, a series of monitoring bores were installed along the barrier zone between Lake Avon reservoir and Area 3B. Holes are typically re-drilled following extraction of the adjacent longwall(s). The objectives are to characterise the strata permeability before and/or after mining of adjacent longwall panels and to provide ongoing groundwater monitoring. Those observations provide critical information to allow more accurate calculation and modelling of potential seepage losses from the reservoir(s) to the mine. Results of drilling, permeability testing and monitoring have been reported as the investigation has expanded and hole re-drilling has been completed (e.g. SCT 2015b, 2016; HGEO 2017, 2018a). A recent review of data was reported by HGEO (2019) after the re-drilling of holes at sites AD3 (hole S2377C), AD4 (S2378B) and AD8 (S2436C) following the extraction of LW15. Monitoring bores that are installed and operational at the end of LW15 are listed in Table 3 with a summary of recent observations.

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

Bore ID	Location	Date installed	Groundwater observations
S2313 (AD1)	140m from the western corner of LW12	31/10/2015	Depressurisation in the lower HBSS and upper BGSS (Colo Vale SS at this location) in the months following the start of LW12, with continued drawdown in the lower BGSS to the end of LW14 (stabilising during LW15. Piezometric heads in lower HBSS and upper BGSS are below the level of Lake Avon. Upper HBSS shows no drawdown and head (371 m AHD) remains above the Lake Avon FSL, possibly reflecting perched conditions.
S2314 (AD2)	210 m from the western end of LW13	13/11/2015	Piezometers show depressurisation in HBSS and BGSS, with all showing heads below the Lake Avon FSL. Heads in the lower HBSS are strongly correlated with the level of Lake Avon. The shallowest HBSS sensor (29 m) now records near-zero pressure head. Head in the upper BGSS (CVSS) recovered by ~9 m during LW15.

Bore ID	Location	Date installed	Groundwater observations
S2377 (AD3)	100 m from LW14 and 200 m from LW15	25/1/2018	Piezometric heads in the lower HBSS and upper BGSS have declined to below the level of Lake Avon. Additional drawdown seen in lower HBSS after the start of LW15 with slight recovery towards the end of the longwall.
S2378 (AD4)	95 m from the western end of LW15	14/11/2017	Piezometric heads in the lower HBSS and upper BGSS have declined to below the level of Lake Avon following extraction of LW14 and LW15. The shallowest HBSS sensor (30 m) shows a possible perched aquifer with a piezometric head of ~352 m (above the lake level) which responds subtly to rainfall (although not apparent at the scale of the hydrographs).
S2379 (AD5)	265 m from the western end of LW17	22/2/2018	Piezometric heads in lower HBSS and upper BGSS are above the level of Lake Avon, both increasing during LW15. The shallowest HBSS sensor (30 m) shows zero pressure head.
S2376 (AD6)	10 m from the western end of LW13	6/10/2017	Post-mining hole only. Piezometric heads in the lower HBSS and upper BGSS have declined to below the level of Lake Avon. Upper HBSS sensor recording zero head. Lower HBSS sensor (107 m) shows response to large rainfall event in February 2020.
S2435 (AD7)	37 m from Lake Avon; 310 m west of LW14	12/11/2018	All sensors, including the shallowest HBSS sensor record piezometric head below current Lake Avon level. S2435_25 recorded 305.3 m AHD at the end of LW14.Slight recovery in the deepest HBSS sensor (100 m) during LW15.
S2436 (AD8)	~10 from Lake Avon FSL; 310 m west of LW16	19/11/2018	All sensors within the HBSS and Bald Hill Claystone (across three separate bores) show piezometric head below the level of Lake Avon as of the end of LW15. Three sensors in the HBSS show compressional pressure head increase at the start of LW15 followed by decline.

In summary, 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. 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.

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 10 is a summary of hydraulic conductivity in the HBSS in the elevation range between the top and base of Lake Avon at each site. At four of the eight sites, testing was carried out both before and after the adjacent longwall was extracted (AD1, AD2, AD3, AD4), and at a further two sites the tests were carried out only after the adjacent longwalls were extracted (AD6 and AD7). The testing results are shown on a logarithmic scale versus radial distance from the nearest longwall. The grey band represents the 10 to 90 percentile range for numerous packer tests carried out in pre-mining HBSS. The plot shows that at two locations (AD2 and AD7), 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 four locations (AD1, AD3, AD4 and AD6), testing after mining shows strata permeability that remains largely within the P10-P90 range for non-mining affected HBSS.

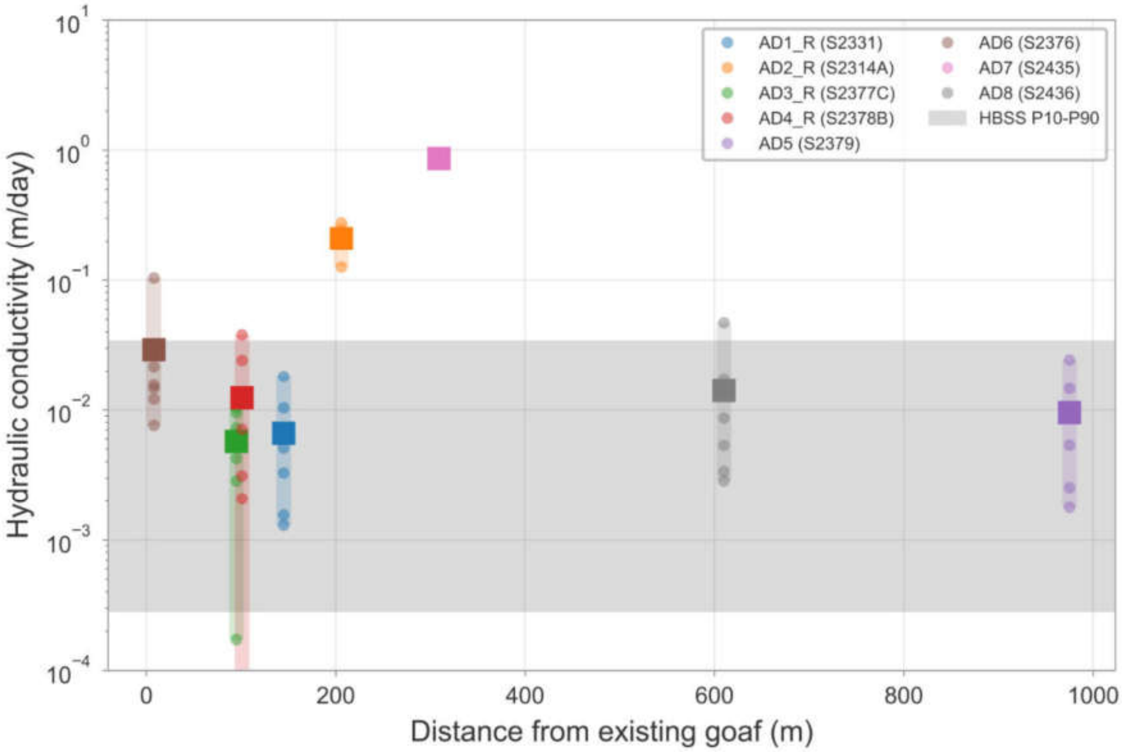

Figure 10. Permeability tests in Avon Dam bores.

The permeability at site AD3 has been tested three times; once prior to mining, then again after each of LW14 and LW15 were extracted. The results showed an apparent increase in strata permeability after the extraction of LW14 by 1.1 orders of magnitude (log_{10} units) compared with the pre-mining tests. Re-drilling and testing at the same site after the subsequent extraction of LW15 showed that strata permeability was 0.3 orders of magnitude ***lower*** than the original pre-mining tests (HGEO 2019). It is concluded that either strata movement associated with LW15 resulted in closure of some fractures that formed or dilated during LW14, or that strata permeability is highly variable such that open fractures may not persist laterally over distances of metres to tens of metres.

There is no simple 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 (2015a).

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 (BHPBilliton 2013). The geology between Avon Reservoir and Area 3B mine workings was further assessed by South32 (2018b) and the geology associated with proposed LW18 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.

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. Nevertheless, the potential for reactivation of fault zones during mine subsidence and subsequent connection with surface water bodies needs to be considered.

Two faults or lineaments are of particular interest in respect of planned longwall extractions in Area 3B: 1) The Elouera Fault, located south of Area 3B and defining the northern extent of the Elouera Mine; and 2) potential lineaments defined by the LA3 tributary.

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.

Hydrogeological investigations are currently underway 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 (HGEO 2019). As of April 2020, six inclined cored holes have been drilled at two sites along the fault, four of which have intersected the fault plane.

Preliminary results indicate that:

- the fault zone is typically observed as one or more broad zones of high joint and fracture density compared with adjacent strata (totalling ~25 to ~35 metres wide). Within the fault zone may be discrete fault planes defined by claystone fault gauge and/or breccia, and/or faulted lithological contacts.
- despite the high fracture density, the permeability of the fault zone is typically within the range of CVSS in pre-mining bores at Dendrobium. There is a zone of elevated permeability associated with the fault zone in S2441A (Site 1); however other holes do not show the same association, suggesting the fault zone is highly variable along its length (and down dip).
- both fault intersections within CVSS at Site 2 (immediately adjacent to Elouera LW8) are not associated with elevated permeability relative to un-faulted CVSS. Therefore, altered stress conditions within the fault due to adjacent mining at Elouera have not resulted in significant changes in permeability within the fault zone at Site 2.

- there is evidence for elevated permeability associated with high-angle joints at higher stratigraphic levels than the interpreted fault zone intersection (in the hanging wall of the fault). These joint zones appear not to be associated with significant stratigraphic displacement.

Further hydrogeological testing is currently underway, including:

- Interference testing (pumping) to determine cross-hole permeabilities, storage coefficients, and to thoroughly purge the holes for sample collection.
- Sampling of groundwater from the fault zone for chemical and isotopic analysis.
- Cross-hole tracer testing using saline water, heat and/or tracer dyes, similar to the testing carried out above LW9 in 2014.

Once testing is complete, the holes will be equipped with piezometer arrays and TDR cables to assess progressive depressurisation across the fault and to detect reactivation due to mining in Area 3B.

LA3 Creek

Structural mapping at Area 3B by South32 identifies two lineaments running approximately parallel to tributary LA3. Monitoring bore S2436 at Avon Dam investigation site AD8 is located close to the Full Supply Level (FSL) shoreline of Lake Avon Reservoir and adjacent to Lave Avon tributary LA3.

Two initial holes drilled at the site (S2436 and S2436A) indicated anomalously low groundwater levels in the HBSS adjacent to the lake. Dams Safety NSW requested that South32 carry out follow-up work to assess the groundwater levels, particularly with regard to the possible role of nearby mapped lineaments in transmitting drawdown between Longwall 15 and the lake. The investigation was included in conditions of approval for extraction of LW17.

In June 2019, a third hole (S2436B) was drilled to a total depth of 39.33 m, and in October 2019 a fourth inclined hole (S2436C) was drilled with the aim of assessing the geological conditions beneath LA3 and a previously mapped lineament (Figure 11). The results were reported by HGEO (2019) and are summarised below.

- A site inspection carried out on 3/10/2019 found no evidence in surface outcrop for faults or other subvertical structures in the vicinity of the creek or mapped lineament.
- Analysis of the inclined hole S2436C identified three zones of slightly elevated permeability associated with bedding parallel fractures. No sub-vertical faults or fracture zones were identified and there is no stratigraphic off-set associated with the mapped lineament.
- The two sensors within HBSS (S2436_25m and S2436B_35m) both indicate piezometric levels below the contemporaneous lake level. By contrast, observations of standing water level (SWL) in open holes (within HBSS only) prior to piezometer completion are above the lake level. Disregarding the possibility that the VWP sensors are not accurate, the observations may be reconciled if there are higher heads in perched, near surface horizons of the HBSS, but the lower HBSS is variably depressurised from mining at Area 3B.

In summary, the anomalous groundwater pressures at Avon Dame investigation site AD3 are interpreted to reflect depressurisation of the lower HBSS due to mining in Area 3B and does not appear to be associated with a fault or fracture zone in the vicinity of the mapped lineaments near tributary LA3. Modelled head within the lower HBSS at this location at the end of LW15 is 309.2 m AHD. The average observed head for all sensors within the HBSS at S2436(B, C) during LW15 is 307.9 m AHD. Therefore, drawdown at AD8 is broadly in line with numerical modelling, noting that one sensor records heads as low as 300.6 m AHD (S2436C_45.9).

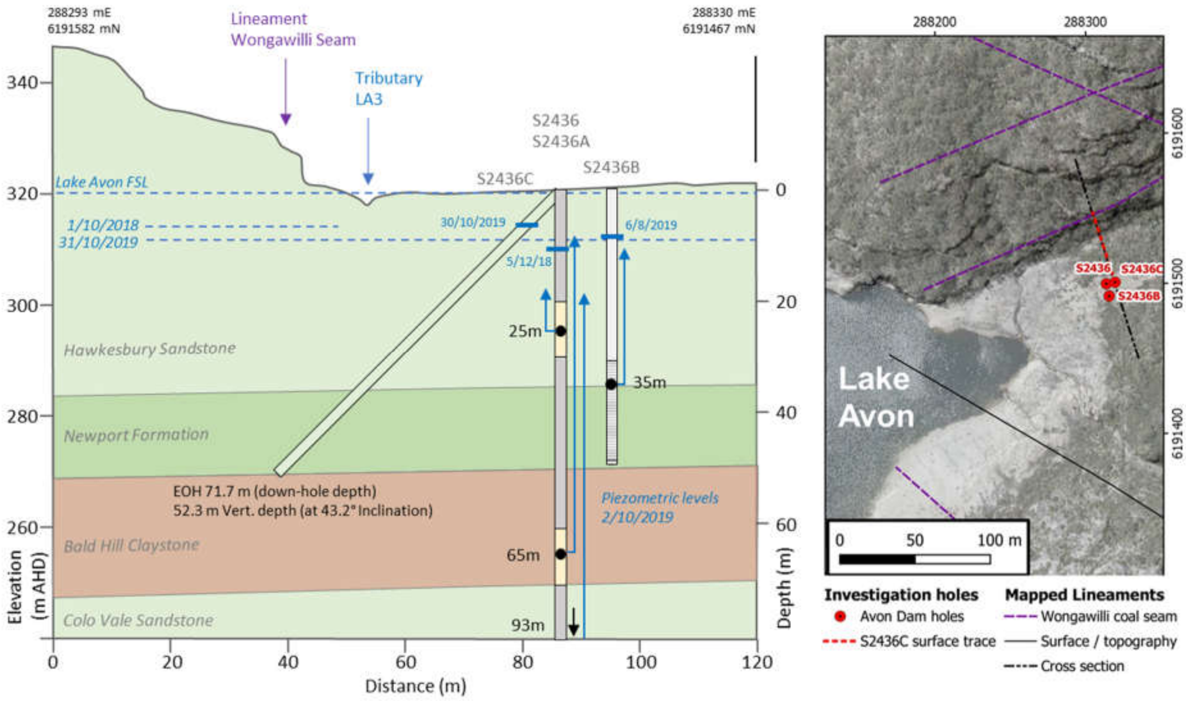

Figure 11. Cross section through investigation site AD3

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 LW5 (November 2009) and the end of LW15 (Figure 13 to Figure 17); and
3. The piezometric head in the lower HBSS relative to the Lake Avon FSL and recent lake levels (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 fully depressurised and perching is common. Therefore, drawdown values above extracted longwalls should be considered as minima. Drawdown in the HBSS reduces rapidly away from the mined longwalls with heads sustained by rainfall recharge. 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.

Piezometric head in the lower HBSS compared with the water level in Lake Avon is shown in Figure 14. It is apparent that all 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.

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 up to 140 m is estimated at several bores (e.g. S2486). Drawdown decreases away from the mined areas such that less than 20 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 and to the south of LW15. As with the BGSS, estimated drawdown decreases to the northwest with distance from Area 3B; however, depressurisation of ~70 m is observed to the northeast (S2059) and south (S2194) due to residual drawdown from neighbouring mines.

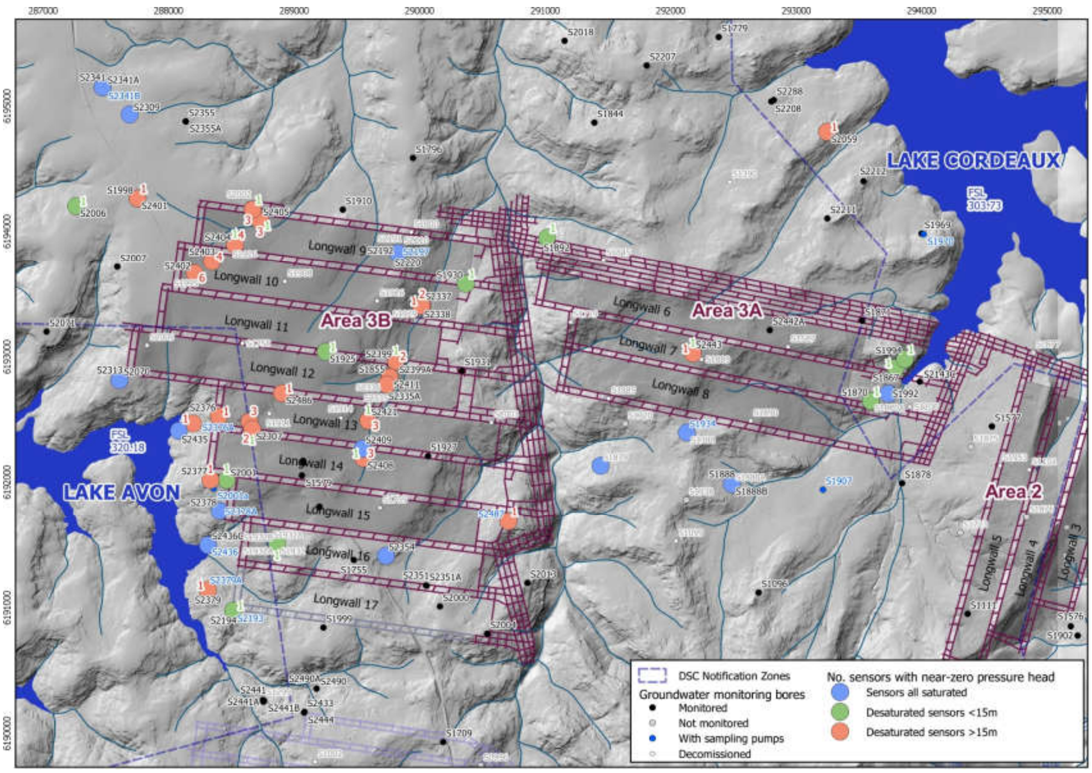

Figure 12. Sensors recording desaturated conditions in the Hawkesbury Sandstone (2019)

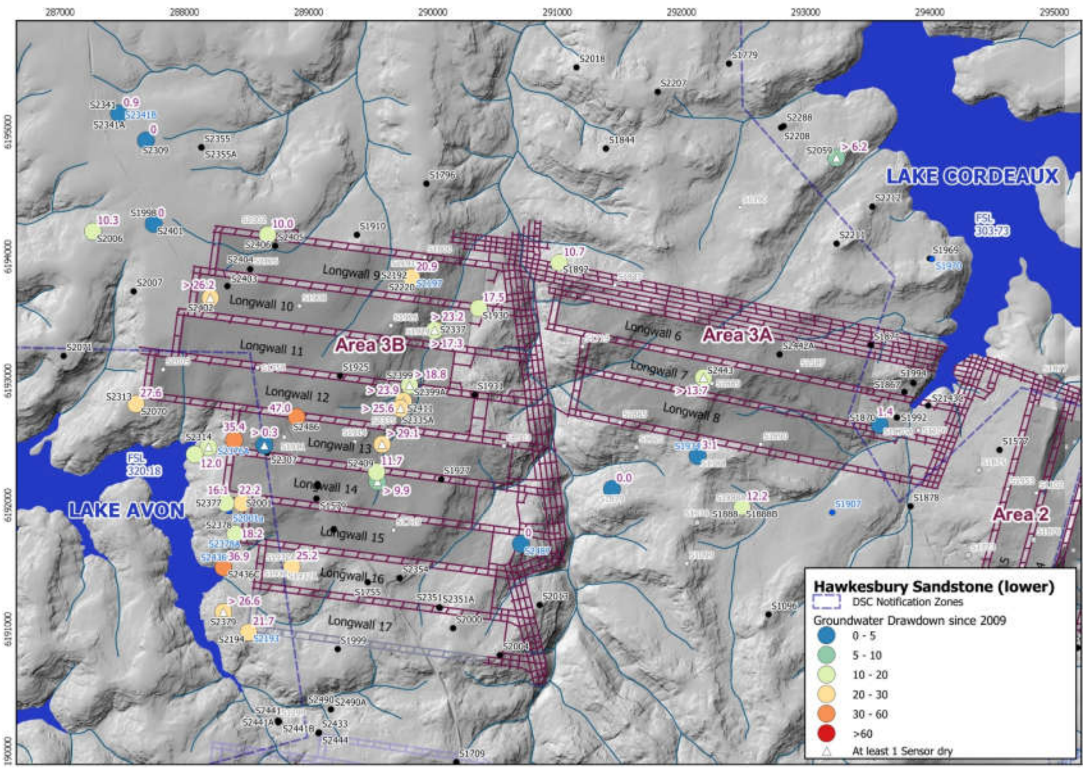

Figure 13. Drawdown in piezometric head in the lower Hawkesbury Sandstone (2009-2019)

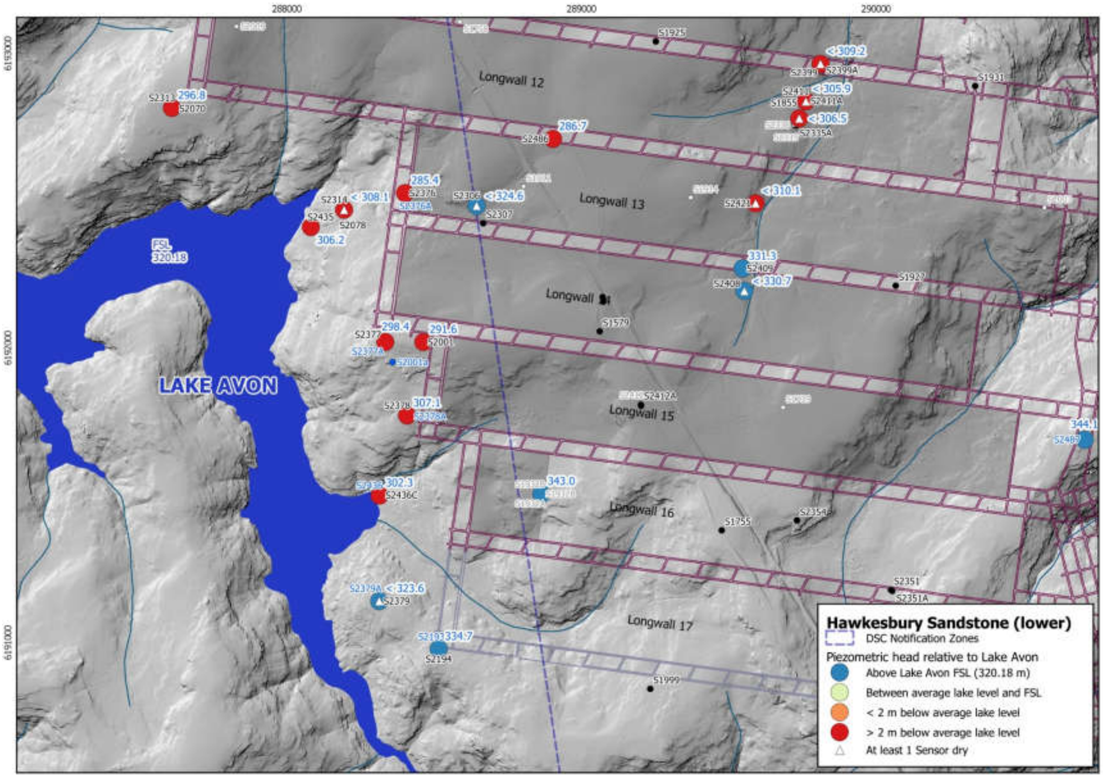

Figure 14. Piezometric head in the lower Hawkesbury Sandstone relative to Lake Avon

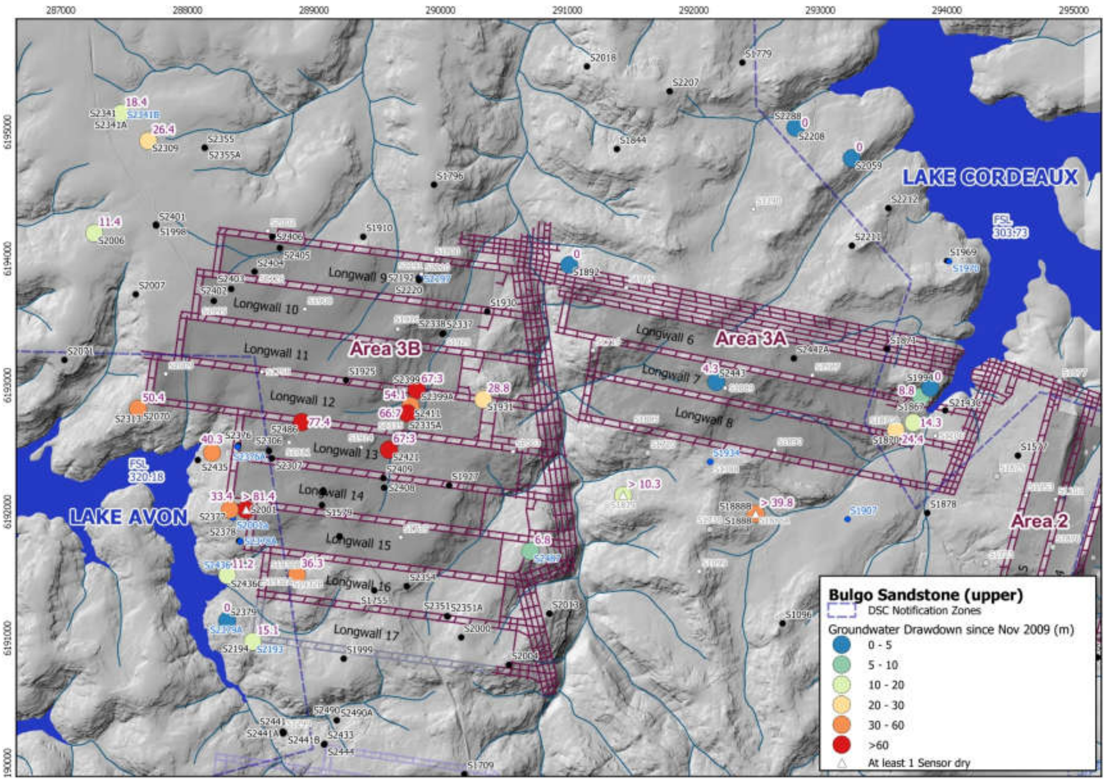

Figure 15. Drawdown in piezometric head in the upper Bulgo Sandstone (2009-2019)

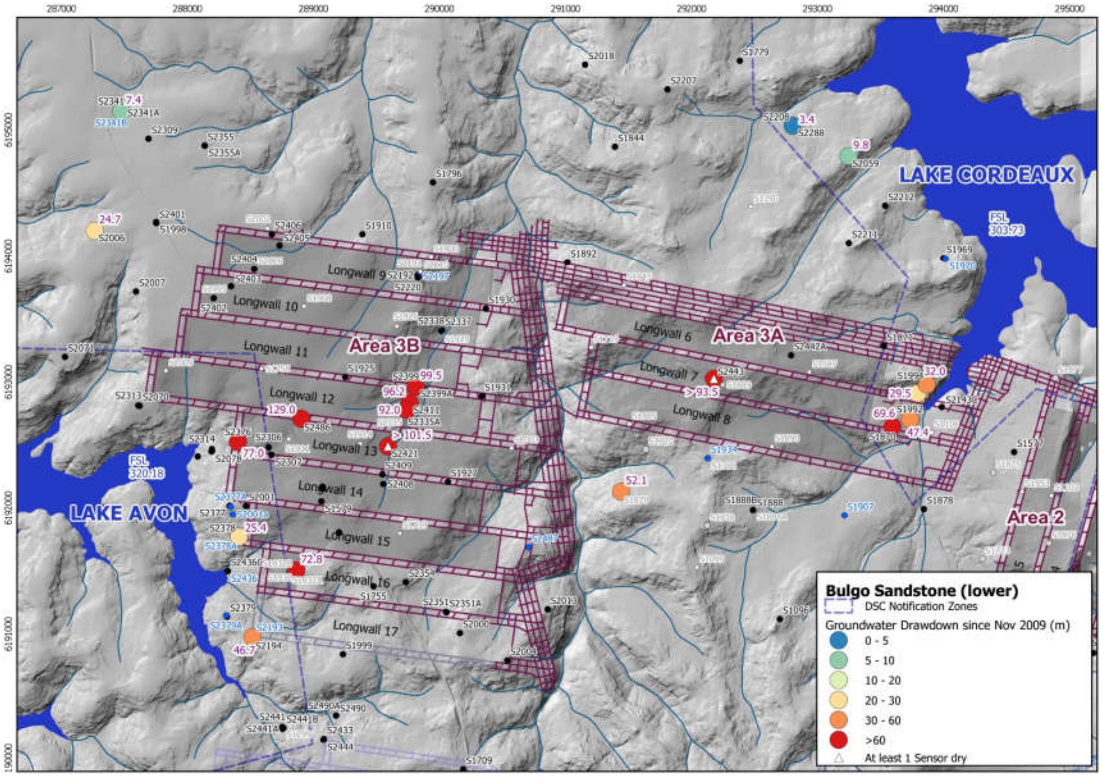

Figure 16. Drawdown in piezometric head in the lower Bulgo Sandstone (2009-2019)

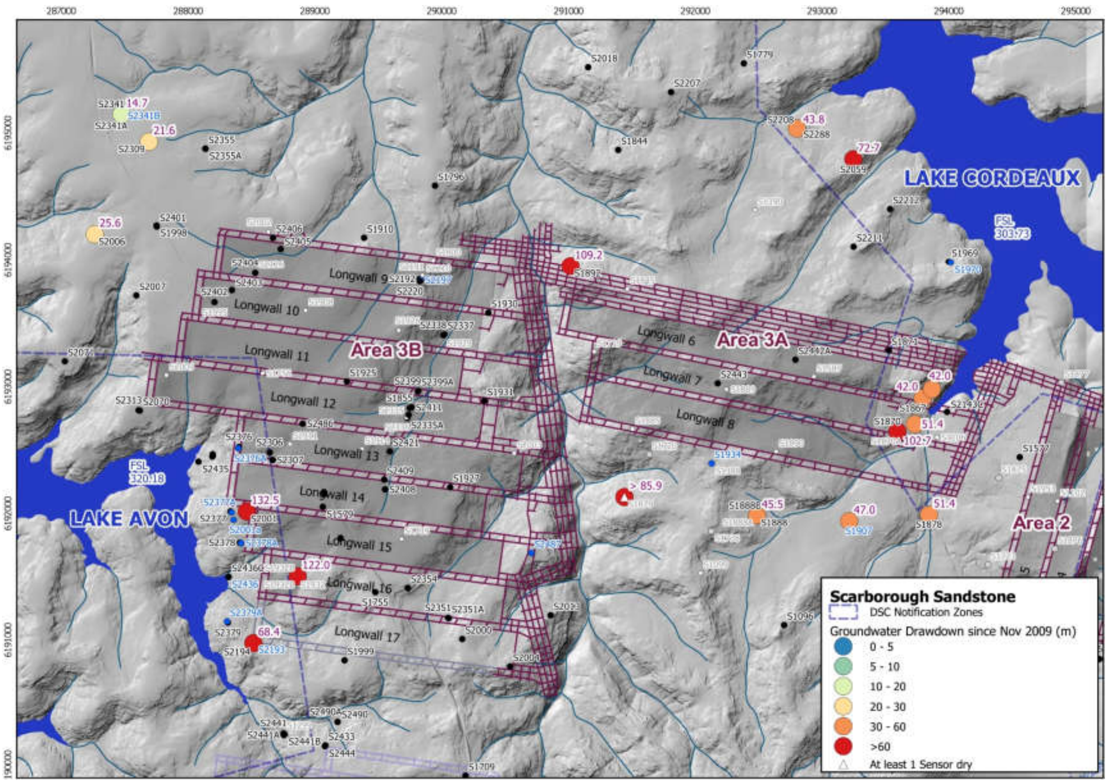

Figure 17. Drawdown in piezometric head in the Scarborough Sandstone (2009-2019)

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 groundwater impact model (HydroSimulations 2016). The comparison was carried out by extracting the predicted heads at representative sensors as of the end of LW15 from the original model output files (provided to HGEO by HydroSimulations), and plotting those heads against the observed heads at sensors within the same sub-units (as presented in Section 3.3). It is therefore an independent assessment of the ongoing accuracy of the 2016 model predictions.

Twenty-five piezometers were selected for comparison on the basis of their distribution across the site and their likelihood of providing ongoing monitoring data for future assessments. Importantly, piezometers adjacent to Lake Avon (The “Avon Dam” holes, S2313, S2314, S2376, S2377, S2378, S2379, S2435, S2436, and holes S2001, S2194) were included to allow assessment of the strata separating the mine from the stored waters of Lake Avon.

Figure 18 is a plot of the modelled and observed heads as of the end of LW15. The data are coloured according to the formation, and bores that are located adjacent to Lake Avon are highlighted. Data for an accurate and well-calibrated model should cluster along the diagonal 1:1 line. Points plotting 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.

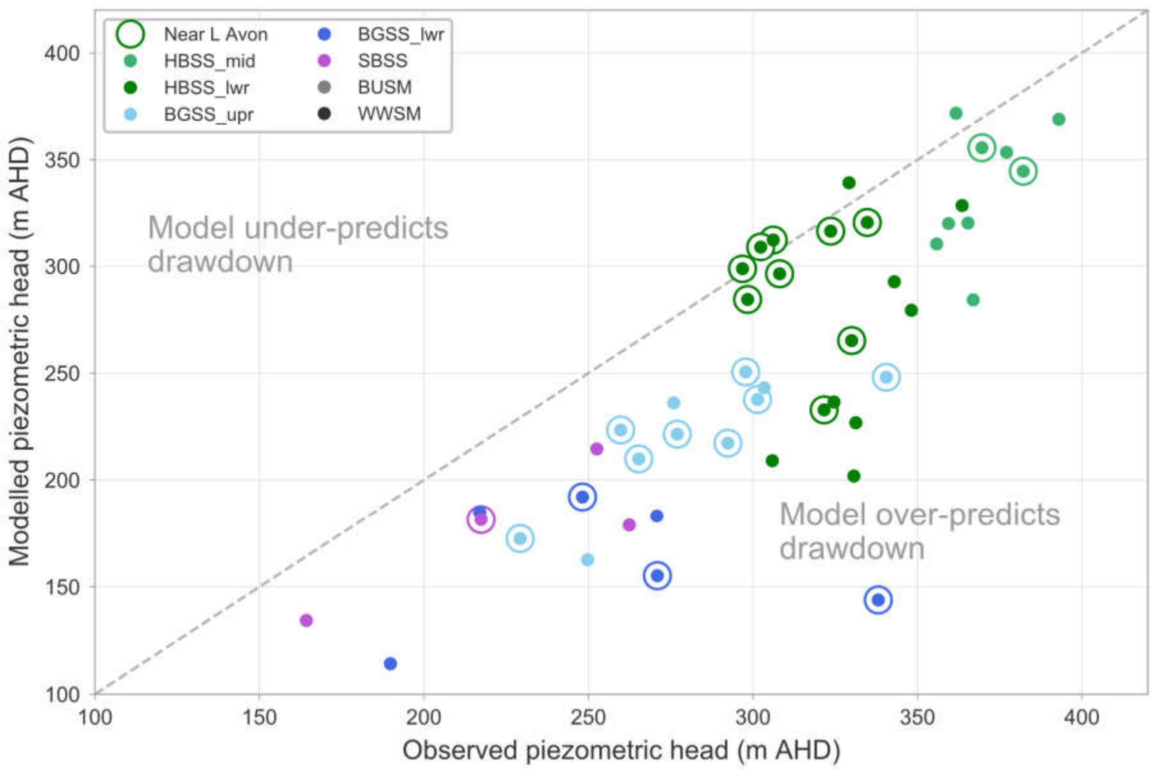

Figure 18. Observed versus model predicted heads at the end of Longwall 15

The following are concluded from the comparison in Figure 18:

- 88% 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.

- The model tends to overpredict drawdown in the BGSS and SBSS, but matches reasonably well for piezometers in the HBSS.
- Model and observed heads for piezometers within the HBSS adjacent to Lake Avon plot very close to the 1:1 line. Observed heads within this barrier zone are therefore 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 LW11 to LW15. 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 model continues to over-predict inflow to Area 3B by approximately 50%, which is conservative with respect to impact assessment.

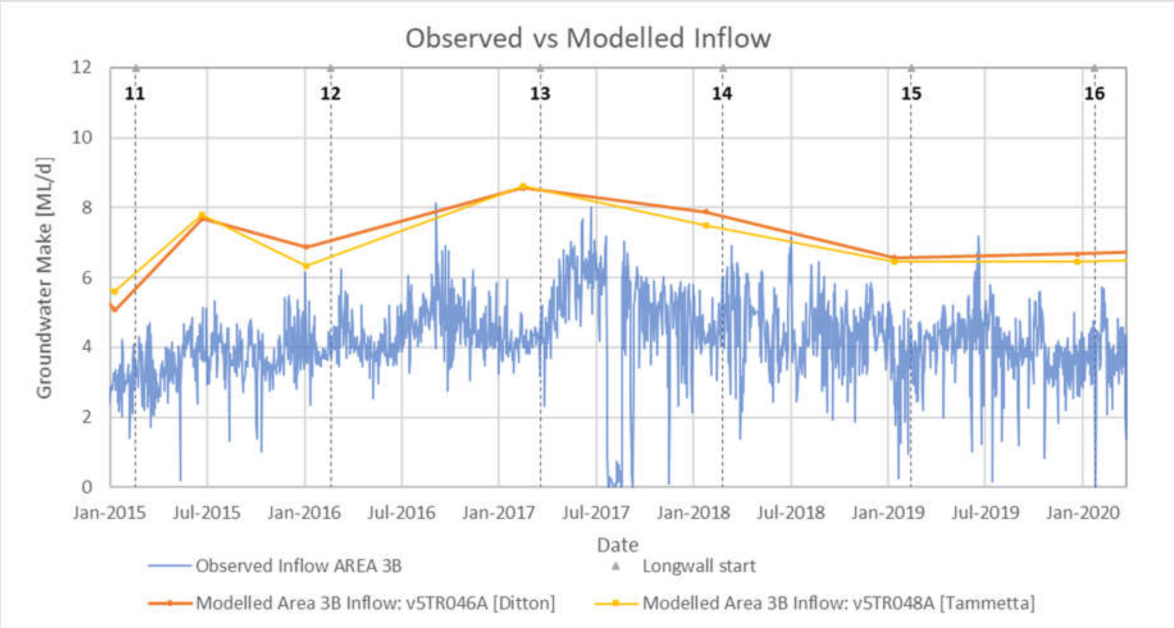

Figure 19. Observed versus model predicted mine groundwater inflow to mine Area 3B

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.

Estimates of the net loss (seepage) from Lake Avon as of the end of LW18, based on the regional groundwater model range between **0.39 and 0.47 ML/day** (HydroSimulations 2016). 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).

The regional groundwater model of HydroSimulations (2016) contains estimates of permeability for geological strata that are based on numerous packer tests across the model domain. The permeability parameters were then refined where necessary during the history-matching ("model calibration") process to match predicted piezometric heads with observed heads. As seen in the previous section, the model continues to perform well in terms of providing conservative estimates of drawdown at the regional and catchment scales.

Since the development of the regional groundwater model detailed hydrogeological investigations have been carried out within the barrier zone between Lake Avon and Dendrobium Area 3B. These investigations included testing of permeability both prior to, and following, extraction of the adjacent longwall panels (LW12 – LW15). The investigations showed that valley-closure movements and strata stress changes related to mine subsidence has resulted in an increase in strata permeability within the HBSS (HGEO 2018b). The investigation found that strata permeability increases by at least an order of magnitude at some locations, but with little or no apparent change in strata permeability at other locations (see Section 3.2.3).

A local-scale numerical model was developed by HGEO (2018c) 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 permeability 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 late 2019 to include the most recent testing of strata permeability following extraction of LW15 (HGEO 2019). The revised model estimates a seepage loss of 0.37 ML/day/km of shoreline. This equates to a seepage loss of ~0.45 ML/day adjacent to LW12 to LW15, within the range of estimates from regional scale numerical modelling.

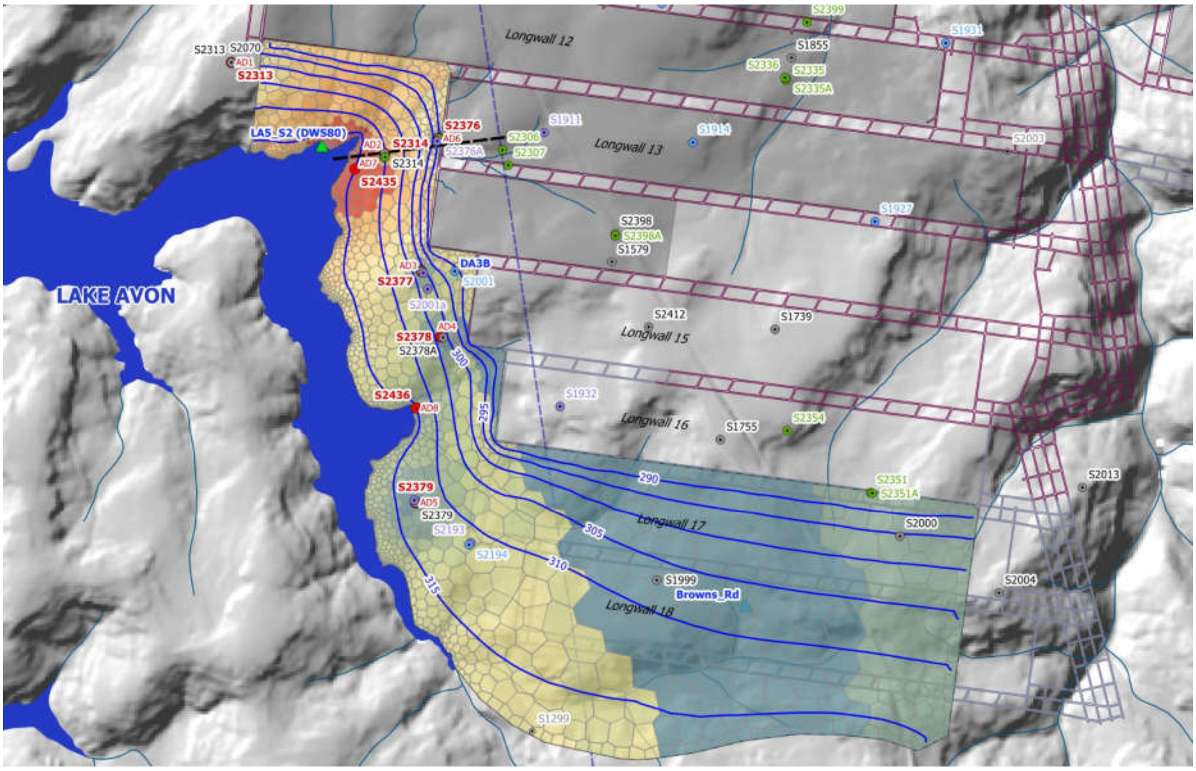

Figure 20. Map showing the layout of the simplified numerical model (colour shading represents variation in K)

The mine water balance for Area 3B shows that the mean groundwater inflow to the area has plateaued and decreased during extraction of longwalls adjacent to Lake Avon (Section 3.1, Figure 8). Therefore, it is apparent that the increase in seepage from the lake is insufficient to compensate for the decline in groundwater inflow to the mine due to strata depressurisation and low rainfall conditions between 2017 and 2019.

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 3A and 3B are summarised in Table 4. As with previous reviews, the groundwater salinity tends to increase with depth.

Instances where the average EC is > 20% lower during the recently completed longwall compared with the previous longwall are highlighted in light red. Samples collected from bore S2377 at depth 113 m reported lower EC during LW15 than the previous longwall. This monitoring bore is located in the barrier zone between Area 3B and Lake Avon (adjacent to LW14). Given the location of the bore relative to the reservoir, it is recommended that the bore is resampled as soon as practical.

All of the bores that were sampled twice or more during the last three longwalls returned sample EC values within 20% of the previous samples.

Table 4. Summary of EC measurements at monitoring bores

Bore ID	Depth (m)	Unit	Area	Mean EC (µS/cm)		
				LW13	LW14	LW15
S1870	10	HBSS	Den 3A	91		80
S1870	16.5	HBSS	Den 3A	105		87
S1879	10	HBSS	Den 3A			75
S1879	58	HBSS	Den 3A			233
S1888	10	HBSS	Den 3A			102
S1932	10	HBSS	Den 3B	124		
S1932	98	HBSS	Den 3B	210		
S1934	55	HBSS	Den 3A			115
S2001	63	HBSS	Den 3B	210		
S2001	106	HBSS	Den 3B	271		
S2313	54	HBSS	Den 3B	74	76	
S2313	138	HBSS	Den 3B	121	122	
S2314	30	HBSS	Den 3B	141	184	
S2314	75	HBSS	Den 3B	164	193	158
S2340	65	HBSS	Den 5			386
S2340	137	HBSS	Den 5			2020
S2341A	98	HBSS	Den 5		189	
S2341A	149	HBSS	Den 5		247	
S2361	70	HBSS	Den 5	207	272	
S2365	68	HBSS	Den 5		329	
S2376	30	HBSS	Den 3B			123
S2376	102	HBSS	Den 3B			193
S2377	34	HBSS	Den 3B		101	
S2377	113	HBSS	Den 3B		126	88
S2378	29	HBSS	Den 3B		132	
S2378	89	HBSS	Den 3B		172	149
S2379	47	HBSS	Den 3B		82	86
S1879	200	BGSS	Den 3A			639
S2313	194	BGSS	Den 3B	557	524	
S2314	128	BGSS	Den 3B	360	409	380
S2321	198	BGSS	Den 5	673		
S2340	215	BGSS	Den 5			129
S2341A	228	BGSS	Den 5		1400	
S2376	169	BGSS	Den 3B			396
S2378	164	BGSS	Den 3B		153	
S2379	128	BGSS	Den 3B		291	484
S2436	35	BGSS	Den 3B			222
S2436	90	BGSS	Den 3B			4910*
S1870	160	SBSS	Den 3A			319
S1886	22	SBSS	Den 2	530	410	486
S1886	30	SBSS	Den 2	565	416	524
S1886	38	SBSS	Den 2	538	530	621

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

4. CONCLUSION

The following conclusions are made with respect to the assessment of groundwater conditions following the completion of LW15:

- The average daily inflow to Area 3B during LW15 extraction was 4.03 ML/d and total inflow to the mine was 5.75 ML/day on average. Inflows during LW15 are similar to those during LW14 and there has been a general decrease in inflow to Area 3B since LW13.
- 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 13% of the total inflow during LW15. The concentration of tritium (an isotopic indicator of modern water) in Area 3B mine inflow water remains low and consistent with negligible modern water.
- Groundwater salinity (EC) shows a general increase with depth below the surface. Most bores that were sampled twice or more during the last three longwalls returned sample EC values within 20% of the previous samples. Samples collected from bore S2377 (at depth 113 m depth) returned lower EC during LW15 than the previous longwall. Given the location of the bore between LW14 and Lake Avon, the bore should be resampled as soon as practical.
- Mining of LW15 resulted in continued depressurisation of the target coal seams and overlying strata. The observed changes in groundwater levels are in line with numerical model predictions.
- An investigation into the height of fracturing above extracted longwalls (LW6, LW7, LW12, LW13, LW14 and LW15) found that mining-induced fracturing, including high-angle 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, with complete depressurisation throughout the HBSS in most holes. Drawdown in the HBSS reduces with distance and is typically negligible at distances greater than 1 km from the goaf footprint.
- Anomalous groundwater levels were noted in early 2019 at monitoring bore S2436 located near mapped lineaments associated with LA3 tributary. An investigation into the cause found no evidence for a transmissive structure associated with the lineament. New piezometers installed at the site confirm depressurisation of HBSS associated with mining in Area 3B, with average observed piezometric heads consistent with numerical model predictions.
- 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, but with little or no apparent 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 0.39 to 0.47 ML/day as at the end of LW15. The estimates are within the tolerable loss limit of 1 ML/day prescribed by Dams Safety NSW. Estimates of low seepage rates (<1 ML/day) are consistent with the mine water balance which shows declining mine inflow rates to Area 3B during the extraction of LW13-LW15 adjacent to Lake Avon.

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APPENDIX A: List of monitoring bores

Dendrobium groundwater monitoring bores

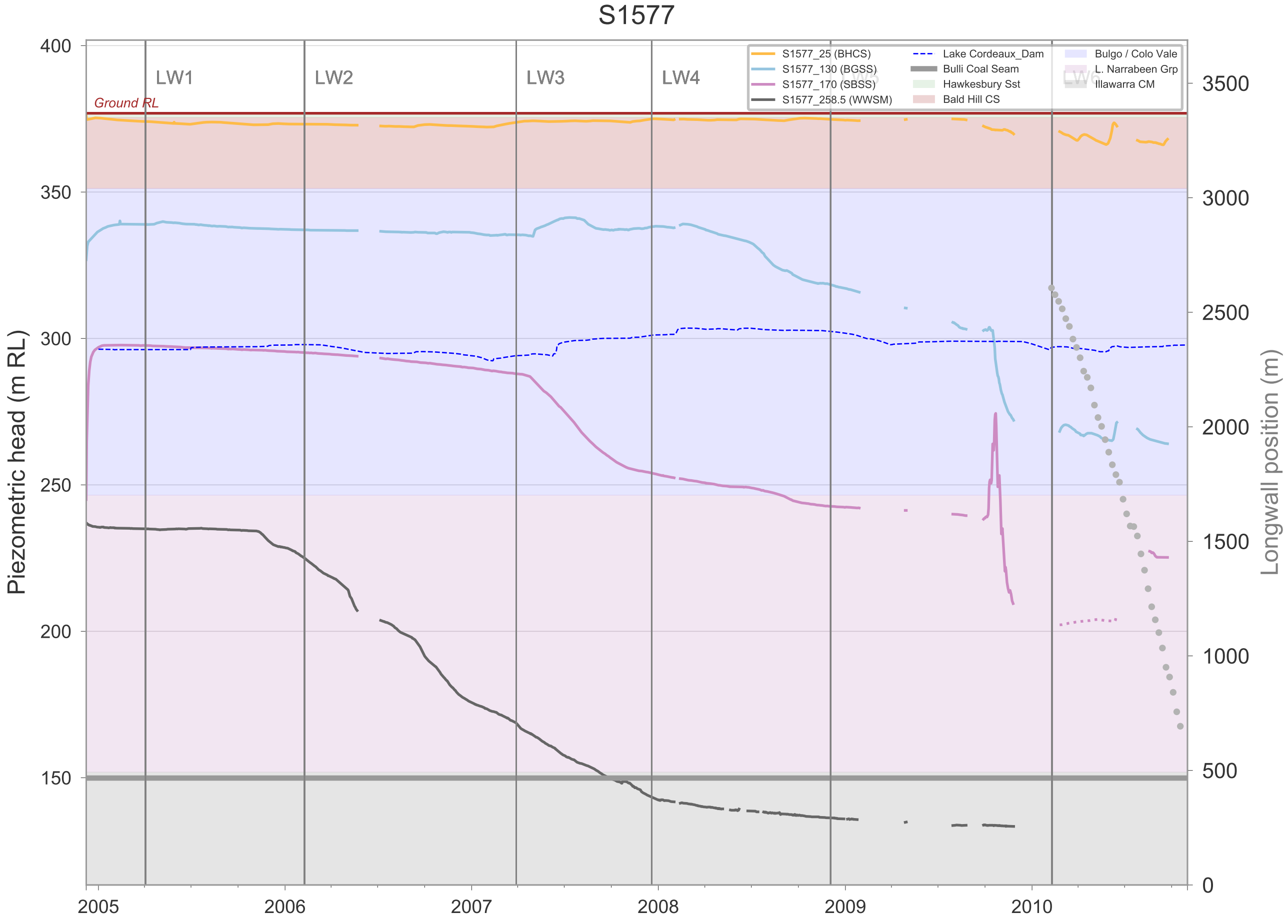
Bore ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_Area	Sensors	First_record	Last_record	Days	Years	%with data	HBSS	BGSS	CVSS	SBSS	BUSM	WWSM
S1577	Dendrobium DDH 38	294558.0	6192446.6	376.9	Den 2	4	8/12/2004	23/09/2010	1720	5.8	81.3		X		X		X
S1710	DC Elouera DDH 9	290258.0	6189645.7	432.5	Den Other	4	19/05/2005	21/09/2019	4596	14.3	87.7	X					
S1719	DC Dendrobium DDH 56	291202.0	6193277.0	413.6	Den 3A	1	16/06/2005	18/02/2010	1570	4.7	91.9						X
S1739	DC Dendrobium DDH 62	289683.6	6191798.7	423.7	Den 3B	1	2/09/2005	19/01/2019	3487	13.4	71.3						X
S1755	DC Dendrobium DDH64	289475.4	6191380.2	433.3	Den 3B	2	10/01/2006	15/01/2020	3750	14	73.3					X	X
S1758	Dendrobium DDH 65	288586.6	6193106.9	408.8	Den 3B	2	26/01/2006	10/06/2014	2205	8.4	72.1					X	X
S1796	Dendrobium DDH 69	289946.6	6194587.4	398.6	Den 3B	1	5/04/2006	11/01/2020	3031	13.8	60.3						X
S1800	Dendrobium DDH 70	289933.4	6193996.5	392.5	Den 3B	2	25/04/2006	31/08/2011	1953	5.4	99.9					X	X
S1844	Dendrobium DDH 76	291391.1	6194868.8	375.6	Den 3C	2	22/08/2006	28/02/2020	3180	13.5	64.4					X	X
S1845	Dendrobium DDH 77	291464.0	6193770.0	399.7	Den 3A	2	29/11/2006	4/01/2010	1026	3.1	90.6					X	X
S1855	Dendrobium DDH 82	289746.5	6192833.2	366.6	Den 3B	2	11/12/2006	27/07/2016	3123	9.6	88.8					X	X
S1867	ED Dendrobium DDH 84	293792.6	6192912.5	346.0	Den 3A	11	20/03/2007	31/12/2019	4329	12.8	92.7	X	X		X	X	X
S1870	ED Dendrobium DDH 85	293593.2	6192648.2	351.5	Den 3A	12	2/02/2007	29/02/2020	4311	13.1	90.3	X	X		X	X	X
S1871	ED Dendrobium DDH 86	293525.0	6193287.1	375.6	Den 3A	12	17/02/2007	3/09/2019	4046	12.5	88.3	X	X		X	X	X
S1878	ED Dendrobium DDH 91	293842.3	6191994.3	337.1	Den 3A	11	24/04/2007	6/11/2019	4358	12.5	95.2		X		X	X	X
S1879	ED Dendrobium DDH 92	291440.3	6192133.4	379.7	Den 3A	12	7/06/2007	29/02/2020	3699	12.7	79.5	X	X		X	X	X
S1885	ED Dendrobium DDH 93	291504.4	6192667.9	420.0	Den 3A	12	7/06/2007	17/05/2012	1644	4.9	91	X	X		X	X	X
S1888	ED Dendrobium DDH 96	292486.5	6191987.4	381.3	Den 3A	8	31/05/2007	29/02/2020	3226	12.8	69.3	X	X		X	X	X
S1889	ED Dendrobium DDH 97	292244.8	6192980.4	435.4	Den 3A	8	2/06/2007	10/08/2011	1408	4.2	92	X	X		X	X	X
S1890	ED Dendrobium DDH 98	292637.3	6192490.5	407.1	Den 3A	8	31/07/2007	7/08/2012	1835	5	100	X	X		X	X	X
S1892	ED Dendrobium DDH 99	291014.1	6193952.0	356.1	Den 3A	8	7/08/2008	29/02/2020	1649	11.6	39	X	X		X		
S1902	ED Dendrobium DDH 100	295241.3	6190779.8	343.1	Den 2	4	4/10/2007	25/06/2019	3853	11.7	90				X		
S1907	ED Dendrobium DDH 103	293212.2	6191943.1	371.9	Den 3A	8	25/01/2008	5/02/2020	3861	12	87.8	X	X		X	X	X
S1908	ED Dendrobium DDH 104	288925.9	6193601.4	405.7	Den 3B	8	16/05/2008	1/05/2014	1734	6	79.7	X	X		X	X	X
S1910	EDEN105	289387.4	6194176.3	377.2	Den 3B	8	29/08/2008	5/03/2019	2940	10.5	76.5	X	X		X	X	X
S1911	EDEN106	288802.8	6192549.4	405.2	Den 3B	12	15/05/2008	24/05/2017	3187	9	96.7	X	X		X		X
S1914	EDEN107	289370.0	6192511.9	414.5	Den 3B	7	29/04/2008	10/08/2017	2692	9.3	79.4	X	X		X	X	X
S1925	ED Dendrobium DDH 108	289251.6	6193041.1	416.7	Den 3B	8	4/08/2008	15/01/2020	3593	11.4	85.9	X	X		X	X	X
S1926	ED Dendrobium DDH 109	289660.4	6193444.9	409.0	Den 3B	8	27/08/2008	8/08/2014	2092	5.9	96.3	X	X		X	X	X
S1927	ED Dendrobium DDH 110	290066.0	6192211.0	414.8	Den 3B	8	16/05/2008	23/01/2017	2822	8.7	88.9	X	X		X	X	X
S1929	ED Dendrobium DDH 111	290010.6	6193398.1	337.7	Den 3B	8	27/08/2008	8/08/2014	2108	5.9	97	X	X		X	X	X
S1930	ED Dendrobium DDH 112	290367.3	6193582.9	353.1	Den 3B	12	27/05/2008	14/01/2020	3673	11.6	86.4	X	X		X	X	X
S1931	ED Dendrobium DDH 113	290335.6	6192889.9	396.4	Den 3B	9	11/08/2008	29/02/2020	3362	11.6	79.7		X		X	X	X
S1932	ED Dendrobium DDH 114	288863.3	6191505.4	396.1	Den 3B	11	31/08/2008	29/02/2020	3770	11.5	89.8	X	X		X		X
S1934	ED Dendrobium DDH 115	292128.0	6192398.0	427.5	Den 3A	4	5/12/2009	17/03/2020	2130	10.3	56.7	X					
S1969	EDEN118	293998.1	6193985.7	368.5	Den 3C	11	12/08/2009	5/12/2016	2525	7.3	94.5	X	X		X	X	X
S1992	EDEN119	293732.1	6192706.8	339.1	Den 3A	8	10/05/2009	29/02/2020	3821	10.8	96.8	X	X		X	X	
S1994	EDEN120	293865.2	6192982.4	345.5	Den 3A	8	13/01/2009	29/02/2020	2429	11.1	59.8	X	X		X	X	
S1995	EDEN121	288212.4	6193662.3	404.5	Den 3B	2	12/06/2009	28/01/2014	1110	4.6	65.6					X	X
S1998	EDEN122	287750.6	6194273.1	410.5	Den 3B	2	11/06/2009	15/01/2020	2458	10.6	63.5					X	X
S1999	EDEN123	289232.8	6190843.7	406.4	Den 3B	2	10/07/2009	15/01/2020	3151	10.5	82					X	X
S2000	EDEN124	290161.4	6191011.2	442.0	Den 3B	2	10/07/2009	3/03/2020	2775	10.7	71.3					X	X
S2001	EDEN125	288462.6	6192020.0	413.9	Den 3B	10	6/08/2009	1/03/2020	3690	10.6	95.6	X	X		X	X	X
S2002	EDEN126	288633.4	6194222.1	400.0	Den 3B	2	21/07/2009	19/02/2012	805	2.6	85.3					X	X
S2003	EDEN127	290571.1	6192478.0	409.4	Den 3B	2	4/08/2009	1/03/2014	181	4.6	10.8					X	X
S2004	EDEN128	290538.5	6190794.8	443.5	Den 3B	2	14/10/2010	2/03/2020	0	9.4	0					X	X
S2006	EDEN129	287263.2	6194204.3	409.1	Den 3B	10	24/07/2009	29/02/2020	2756	10.6	71.2	X	X		X	X	X
S2007	EDEN130	287590.8	6193718.9	405.8	Den 3B	2	17/06/2009	14/01/2020	2540	10.6	65.7						X
S2009	EDEN131	287828.2	6193092.0	402.5	Den 3B	10	10/08/2009	24/03/2016	582	6.6	24.1	X	X		X	X	X
S2013	EDEN134	290857.7	6191198.2	399.7	Den 3B	2	22/07/2009	3/03/2020	2417	10.6	62.3					X	X
S2059	EDEN148	293245.7	6194795.1	380.8	Den 3C	11	16/08/2011	29/02/2020	1592	8.5	51	X	X		X	X	X
S2070	EDEN150	287619.3	6192813.2	414.7	Den 3B	2	15/05/2013	14/01/2020	2004	6.7	82.3					X	X
S2078	EDEN154	288190.0	6192451.9	342.0	Den 3B	2	20/06/2010	13/03/2017	2379	6.7	96.7					X	X
S2192	S2192	289826.7	6193848.7	389.3	Den 3B	6	25/03/2013	18/11/2014	213	1.7	35.3	X	X				
S2194	S2194	288514.9	6190978.8	371.1	Den 3B	11	13/04/2013	13/02/2020	2364	6.8	94.6	X	X		X	X	X
S2208	S2208	292801.1	6195037.3	344.1	Den 3C	8	19/12/2014	29/02/2020	1894	5.2	99.7	X	X		X	X	X
S2211	S2211	293247.0	6194106.0	397.7	Den 3C	2	2/10/2013	7/12/2018	1748	5.2	92.3					X	X
S2212	S2212	293534.8	6194402.9	369.2	Den 3C	10	11/10/2013	14/08/2018	1722	4.8	97.3	X	X		X	X	X
S2220	S2220 (AQ5)	289827.2	6193830.7	388.1	Den 3B	3	12/11/2014	29/02/2020	1933	5.3	99.8	X					
S2306	Swamp Bore 3 (adjacent)	288643.3	6192483.7	395.5	Den 3B	4	16/09/2015	29/02/2020	1587	4.5	97.5	X					
S2307	Swamp Bore 4	288665.9	6192424.6	394.5	Den 3B	4	16/09/2015	1/03/2020	1600	4.5	98.2	X					
S2309	Dendrobium S2309_R	287689.9	6194933.2	412.0	Den 3D	10	15/07/2015	18/03/2020	1638	4.7	95.8	X	X		X	X	X
S2312	Dendrobium S2312	284450.1	6196150.7	409.4	Den 3D	10	12/08/2015	29/02/2020	1311	4.6	78.8	X	X		X	X	X
S2313	Avon 1	287609.0	6192815.5	415.3	Den 3B	3	31/10/2015	29/02/2020	1451	4.3	91.7	X	X				
S2314	Avon 2	288193.5	6192470.3	342.4	Den 3B	3	13/11/2015	29/02/2020	1515	4.3	96.5	X	X				
S2321	Dend S2321	284710.0	6195575.5	411.0	Den 3D	2	12/08/2016	29/02/2020	1073	3.6	82.7					X	X
S2325	Dend S2325	283596.2	6195466.7	433.5	Den 3D	8	6/09/2016	1/03/2020	1187	3.5	93.2	X	X		X		
S2333	Dend s2333 (D-A3C-14-12)	290697.1	6197087.4	310.9	Den 3C	10	8/10/2016	29/02/2020	1210	3.4	97.6	X	X		X	X	X
S2335	WC21Project Hole1Site 2	289725.4	6192748.7	372.6	Den 3B	5	19/10/2016	12/11/2016	24	0.1	96	X					
S2336	WC21Hole2,Site2	289721.9	6192758.1	372.4	Den 3B	2	21/10/2016	20/07/2017	222	0.7	81.3	X					
S2337	WC21Project Hole1Site 5	290021.0	6193411.9	336.1	Den 3B	3	25/11/2016	29/02/2020	1061	3.3	89	X					
S2338	WC21Hole2,Site5	290012.2	6193406.7	336.1	Den 3B	3	24/11/2016	29/02/2020	1062	3.3	89	X					
S2340	D-A5-25	285468.1	6197978.9	396.9	Den 5	9	7/12/2016	29/02/2020	1080	3.2	91.5	X	X		X	X	
S2341	D-A5-28	287473.5	6195149.8	401.6	Den 5	10	7/12/2016	29/02/2020	1178	3.2	99.8	X	X		X	X	X
S2341A	D-A5-28A	287489.0	6195138.2	402.6	Den 5	4	21/12/2016	29/02/2020	1083	3.2	92.9	X					
S2342	D-A5-12	287953.2	6196755.8	403.2	Den 5	10	23/12/2016	21/02/2020	1156	3.2	100	X	X		X	X	X
S2345	D-A5-19	285356.8	6196094.9	402.0	Den 5	12	29/04/2017	29/02/2020	1000	2.8	96.4	X	X		X	X	
S2348	D-A5-17	286450.5	6196461.9	396.3	Den 5	13	11/08/2017	2/03/2020	628	2.6	67.2	X	X		X	X	X
S2352	D-A5-6	286264.6	6195393.3	408.8	Den 5	10	27/04/2017	29/02/2020	821	2.8	79	X	X		X	X	X
S2354	S14_05	289730.9	6191413.7	424.6	Den 3B	1	7/09/2017	29/02/2020	906	2.5	100	X					
S2355	A5_S85_DBH	288136.2	6194877.8	396.6	Den 5	5	4/08/2017	16/09/2019	774	2.1	100	X					
S2357	A5-S100_DBH	286809.6	6196991.8	394.0	Den 5	4	29/07/2017	16/09/2019	643	2.1	82.4	X					

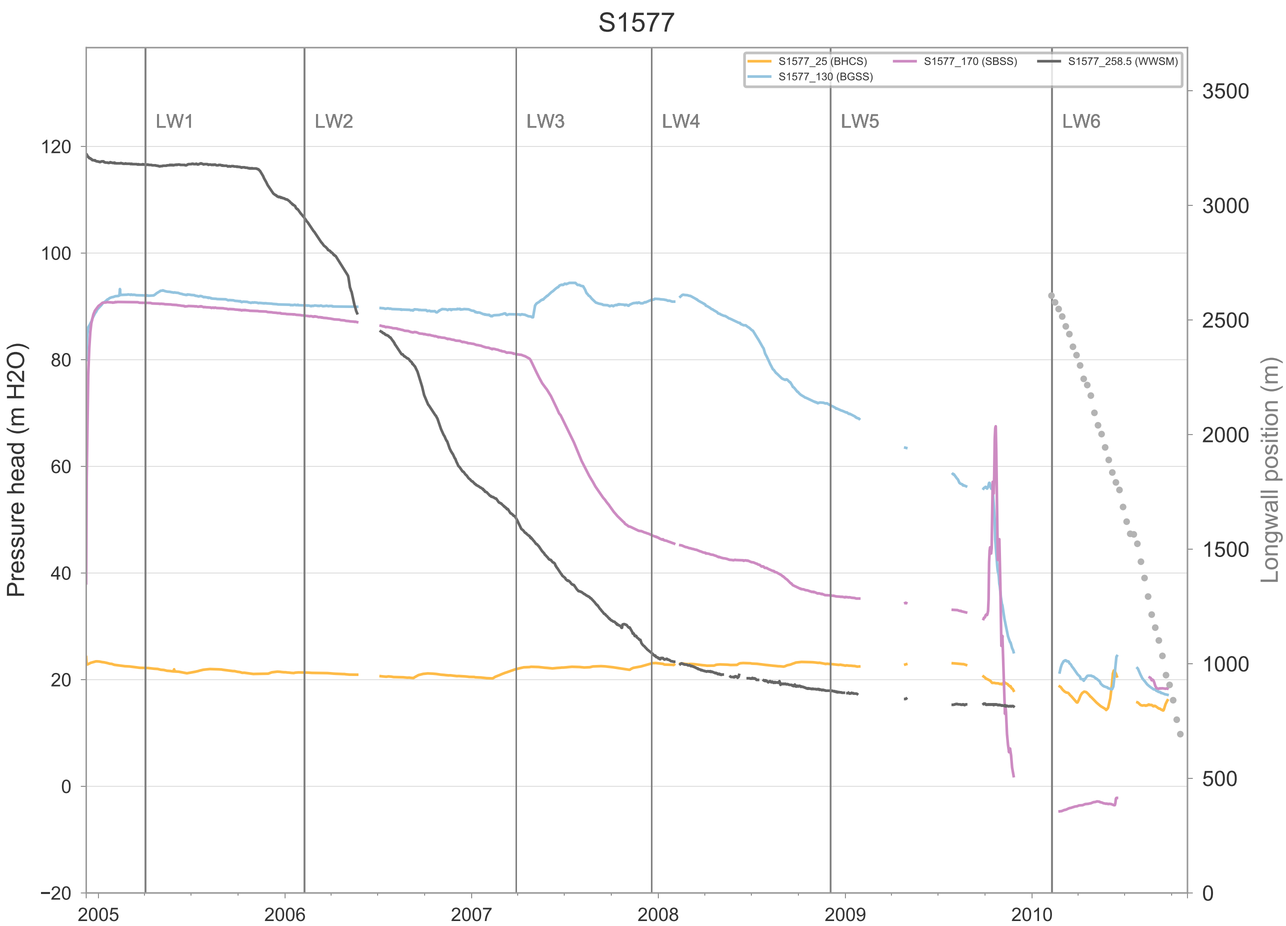
Dendrobium groundwater monitoring bores

Bore ID	Alt_Name	MGA_mE	MGA_mN	Col_RL	Mine_Area	Sensors	First_record	Last_record	Days	Years	%with data	HBSS	BGSS	CVSS	SBSS	BUSM	WWSM
S2359	D-A5-5	285354.6	6195547.7	403.6	Den 5	10	11/08/2017	29/02/2020	577	2.6	61.8	X	X		X	X	X
S2361	A5_S109_DBH	286277.9	6195810.7	402.4	Den 5	4	24/06/2017	16/09/2019	469	2.2	57.5	X					
S2362	A5_S110_DBH	285772.9	6195823.0	399.9	Den 5	4	23/06/2017	16/09/2019	582	2.2	71.3	X					
S2364	A5_S103_DBH	285982.8	6196782.1	395.0	Den 5	4	14/11/2017	16/09/2019	257	1.8	38.2	X					
S2365	A5_101/102_DBH	286042.3	6196448.9	399.2	Den 5	5	4/09/2017	16/09/2019	743	2	100	X					
S2366	A6_S113_DBH	291865.1	6200199.1	358.6	Den 6	4	23/05/2018	21/01/2020	609	1.7	100	X					
S2367	A6_S117_DBH	291630.7	6199726.5	356.1	Den 6	4	23/05/2018	21/01/2020	609	1.7	100	X					
S2370	D-A5-2	285554.8	6196642.7	375.6	Den 5	10	12/05/2018	4/10/2019	511	1.4	100	X		X			X
S2371	A6_S116_DBH	291977.5	6199135.2	351.2	Den 6	4	23/05/2018	21/01/2020	609	1.7	100	X					
S2372	A6_S115_DBH	291576.9	6198891.4	373.5	Den 6	4	23/05/2018	21/01/2020	609	1.7	100	X					
S2373	A6_S112_DBH	292043.2	6200899.2	359.0	Den 6	4	7/10/2017	21/01/2020	837	2.3	100	X					
S2374	A6_S83_DBH	291114.8	6201461.1	324.4	Den 6	4	24/05/2018	21/01/2020	608	1.7	100	X					
S2376	Avon 6	288400.4	6192527.0	367.8	Den 3B	3	6/10/2017	3/03/2020	880	2.4	100	X	X				
S2377	Avon 3	288333.4	6192020.4	408.2	Den 3B	3	2/06/2018	1/03/2020	639	1.7	100	X	X				
S2378	Avon 4	288407.4	6191770.9	379.3	Den 3B	3	15/11/2017	1/03/2020	668	2.3	79.7	X	X				
S2379	Avon 5	288312.9	6191140.5	356.6	Den 3B	3	17/07/2018	15/01/2020	330	1.5	60.2	X	X				
S2398B	LW14-1 post extraction Redrill	289070.9	6192172.6	418.0	Den 3B	8	8/03/2019	31/08/2019	177	0.5	100	X		X			
S2399	LW12_1	289810.5	6192965.1	355.1	Den 3B	8	3/05/2018	29/02/2020	647	1.8	96.9	X		X			
S2401	Den01b_R1	287752.2	6194264.9	411.1	Den 3B	6	16/11/2018	15/01/2020	348	1.2	81.7	X					
S2402	Den01b_R2	288207.8	6193666.6	403.4	Den 3B	6	6/07/2018	15/01/2020	455	1.5	81.4	X					
S2403	Den01b_R3	288345.1	6193761.1	400.7	Den 3B	6	16/11/2018	15/01/2020	376	1.2	88.3	X					
S2404	Den01b_R4	288528.6	6193896.8	396.2	Den 3B	6	22/11/2018	15/01/2020	371	1.1	88.3	X					
S2405	Den01b_R5	288729.5	6194087.6	386.1	Den 3B	6	17/11/2018	15/01/2020	375	1.2	88.2	X					
S2406	Den01b_R6	288669.1	6194176.5	396.6	Den 3B	6	17/11/2018	15/01/2020	376	1.2	88.5	X					
S2408	GW14-2	289552.1	6192193.4	398.1	Den 3B	7	3/10/2018	29/02/2020	514	1.4	99.8	X					
S2409	GW14-3	289546.1	6192269.7	394.6	Den 3B	6	3/10/2018	29/02/2020	449	1.4	87.2	X					
S2411	LW12_2	289761.1	6192837.7	364.0	Den 3B	8	5/07/2018	29/02/2020	596	1.7	98.5	X		X			
S2412	LW15-1	289201.1	6191807.4	427.3	Den 3B	8	12/05/2018	17/06/2019	390	1.1	97	X		X			
S2412B	GW15-1	289201.6	6191803.7	425.2	Den 3B	8	18/12/2019	29/02/2020	69	0.2	93.2	X		X			
S2420	LW12-3	289738.4	6192780.0	367.8	Den 3B	8	3/10/2018	29/02/2020	437	1.4	84.9	X		X			
S2421	LW13-1	289590.4	6192492.2	381.8	Den 3B	8	8/02/2019	31/01/2020	329	1	91.9	X		X			
S2435	AD7	288080.8	6192411.6	328.2	Den 3B	3	21/11/2018	31/01/2020	437	1.2	100	X					
S2436	AD8	288313.8	6191499.7	320.3	Den 3B	5	4/12/2018	11/12/2019	373	1	100	X		X			
S2438		287944.9	6197535.1	399.3	Den 3C	9	23/11/2018	31/01/2020	435	1.2	100	X		X		X	
S2442A	S2442A-SandyCreek	292788.5	6193213.2	407.6	Den 3A	6	14/03/2019	1/02/2020	325	0.9	100	X		X			
S2443	Sandy Creek series	292176.0	6193027.4	426.7	Den 3A	6	3/08/2019	1/03/2020	212	0.6	100	X		X			
S2486	GW-12-4	288902.8	6192710.7	412.1	Den 3B	7	18/12/2019	13/03/2020	87	0.2	100	X	X				
S2487	GW15-2	290707.0	6191689.0	435.3	Den 3B	5	28/11/2019	29/02/2020	94	0.3	100	X	X				

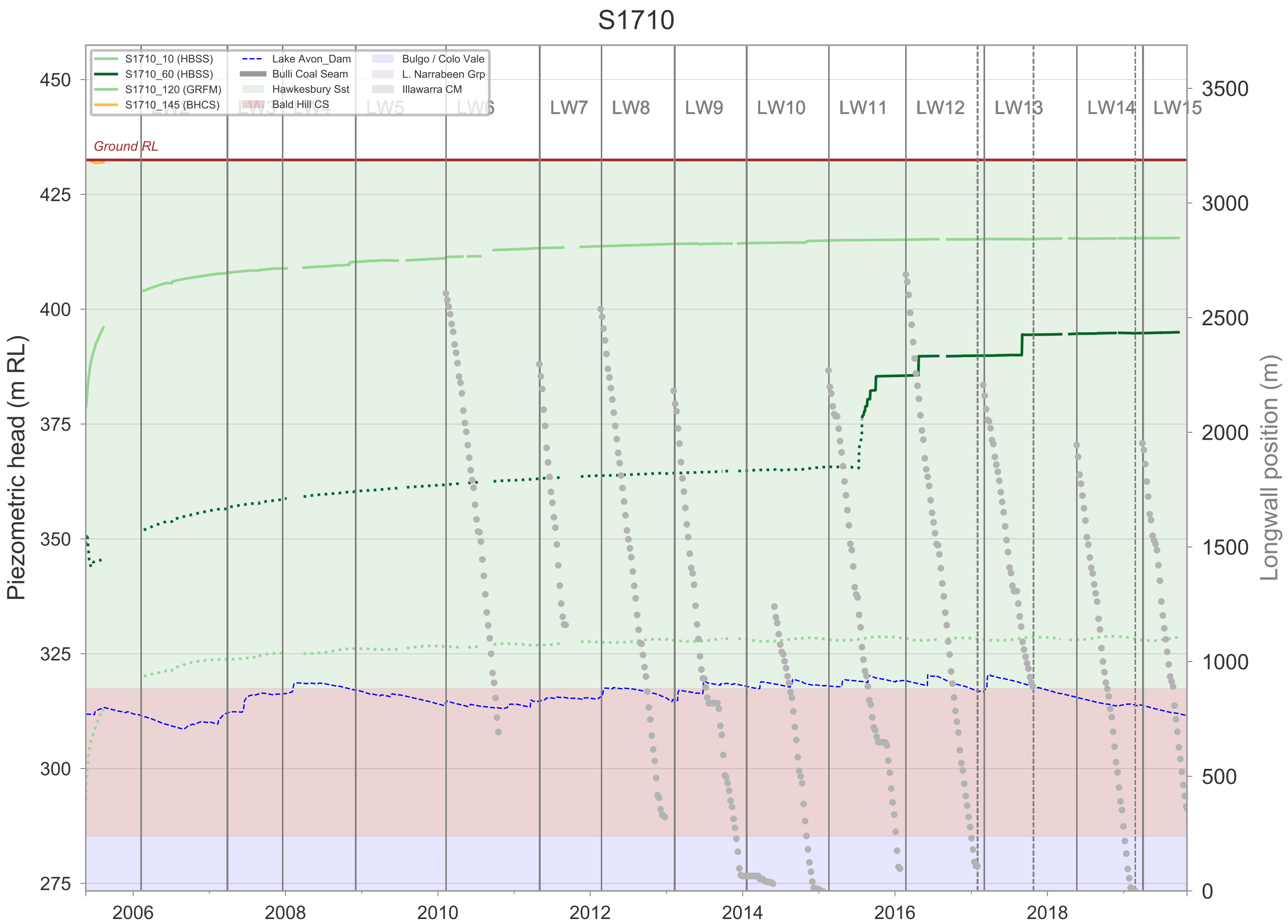
APPENDIX B: Groundwater hydrographs

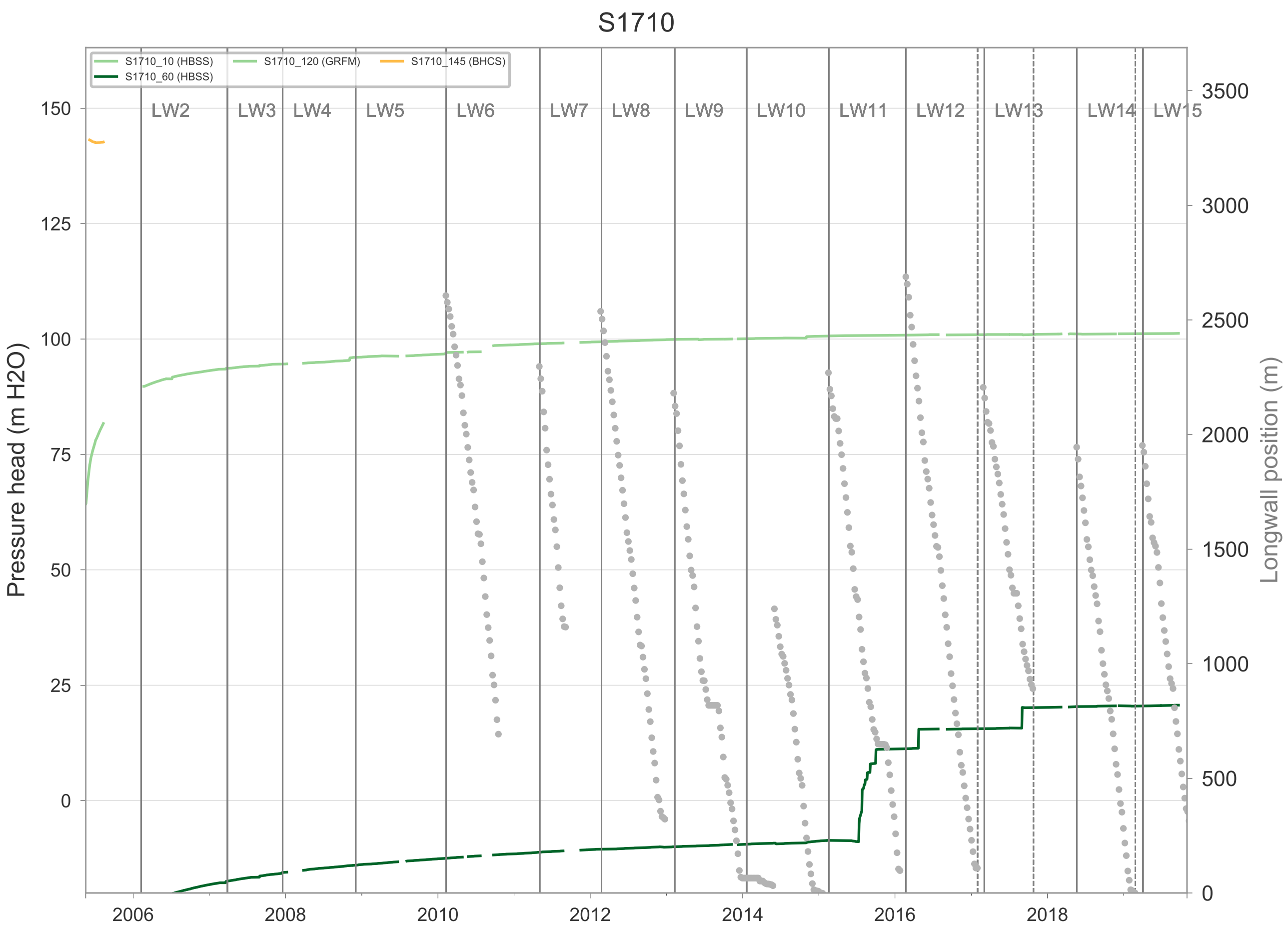
Groundwater hydrographs



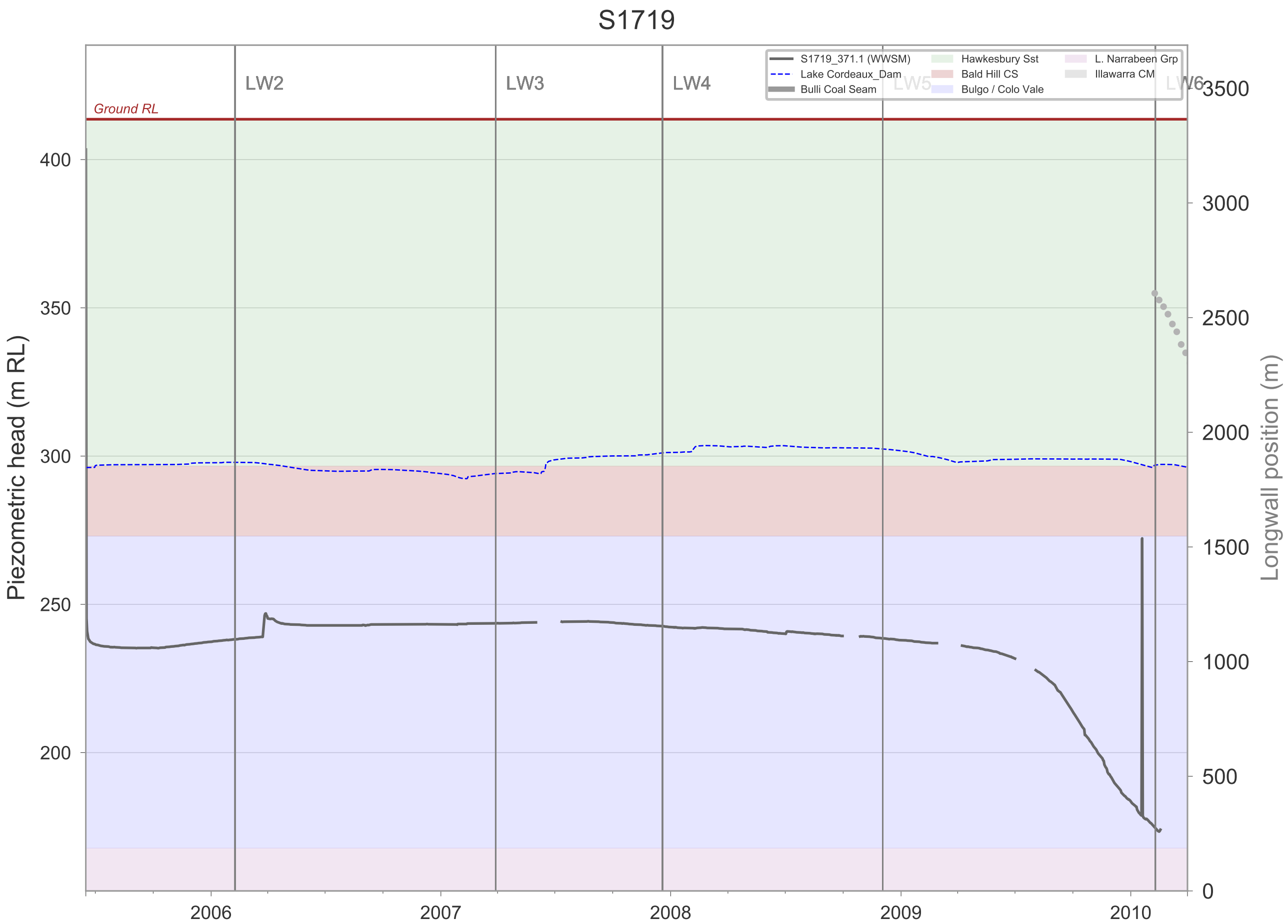


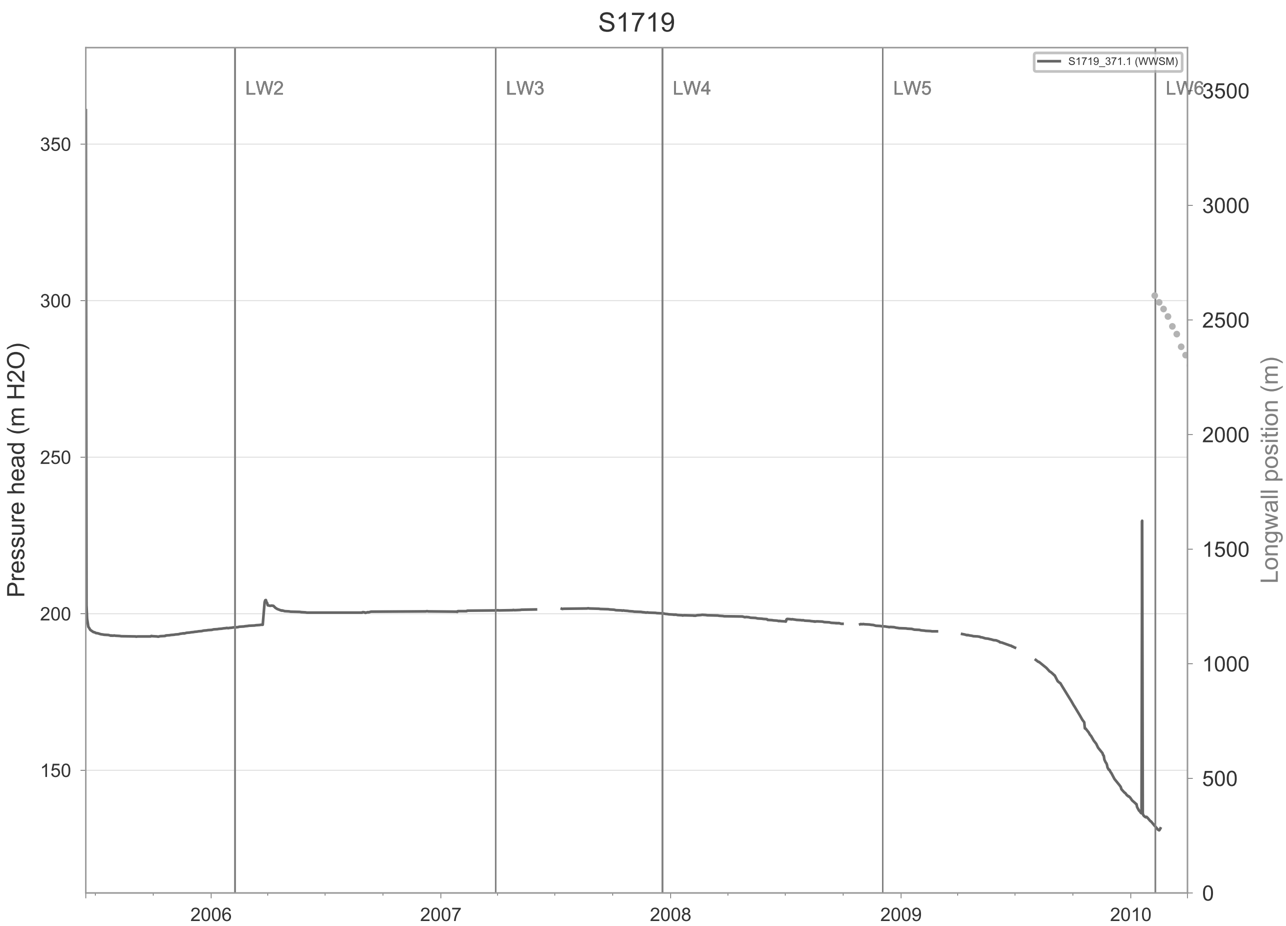
Groundwater hydrographs



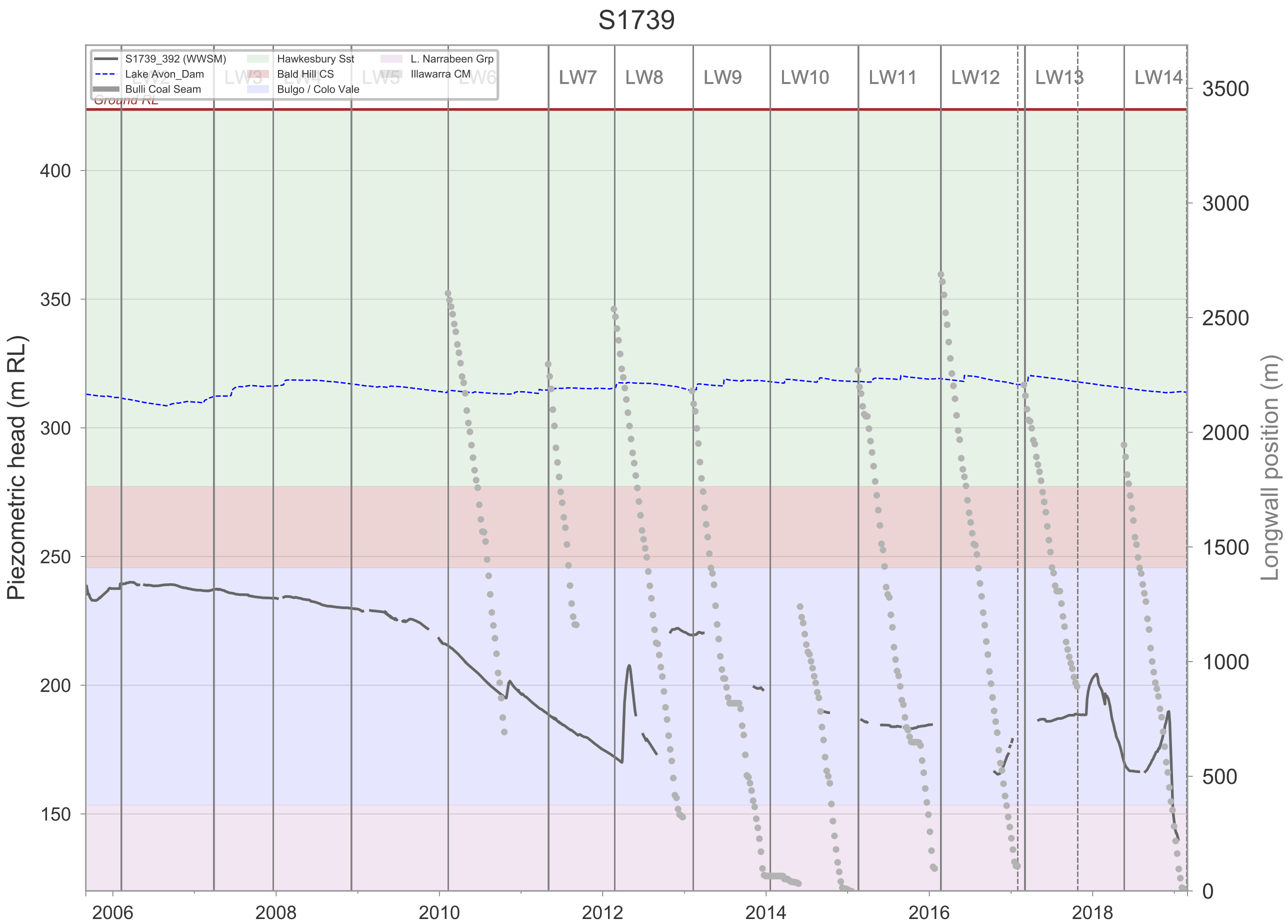


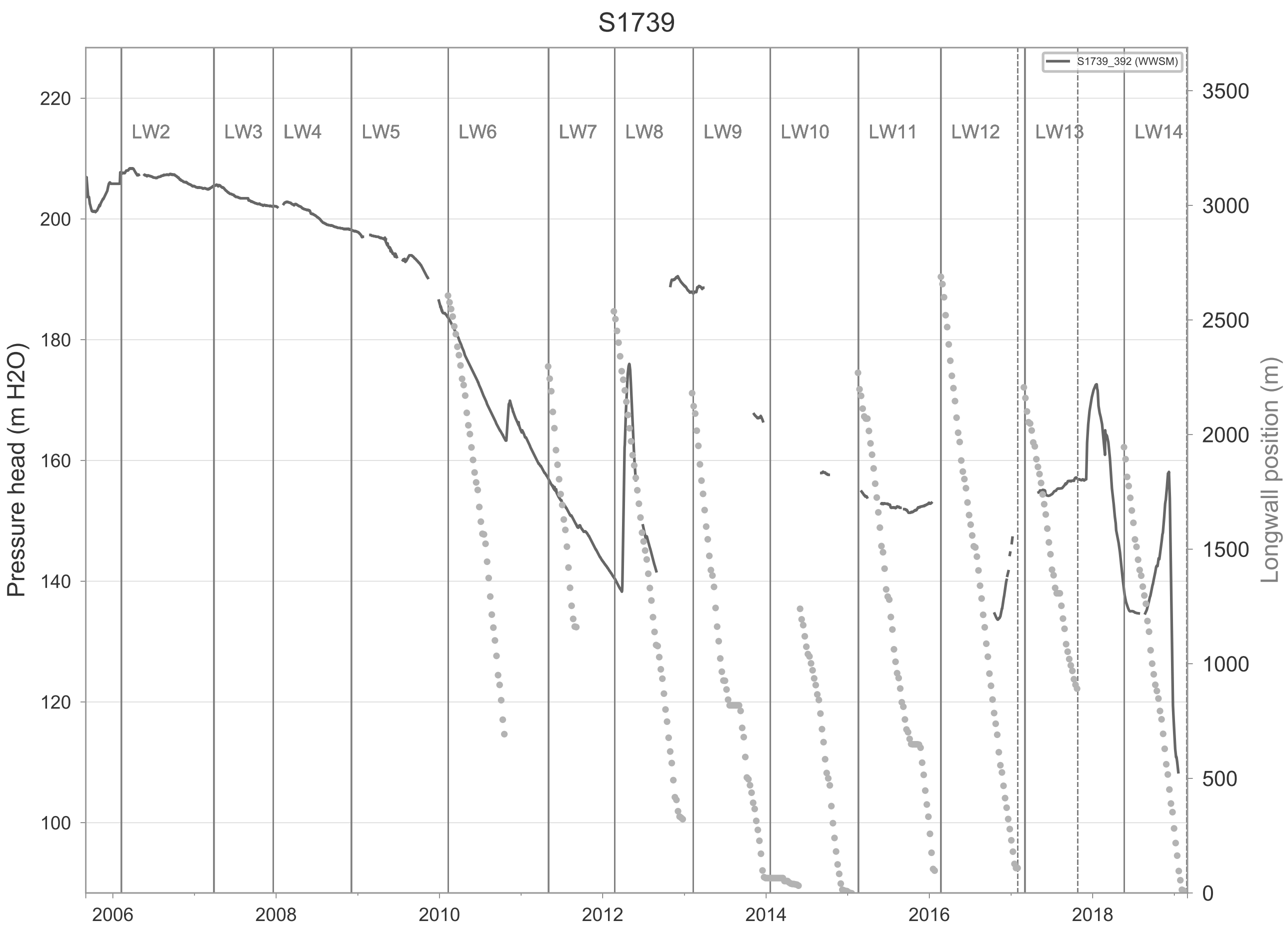
Groundwater hydrographs



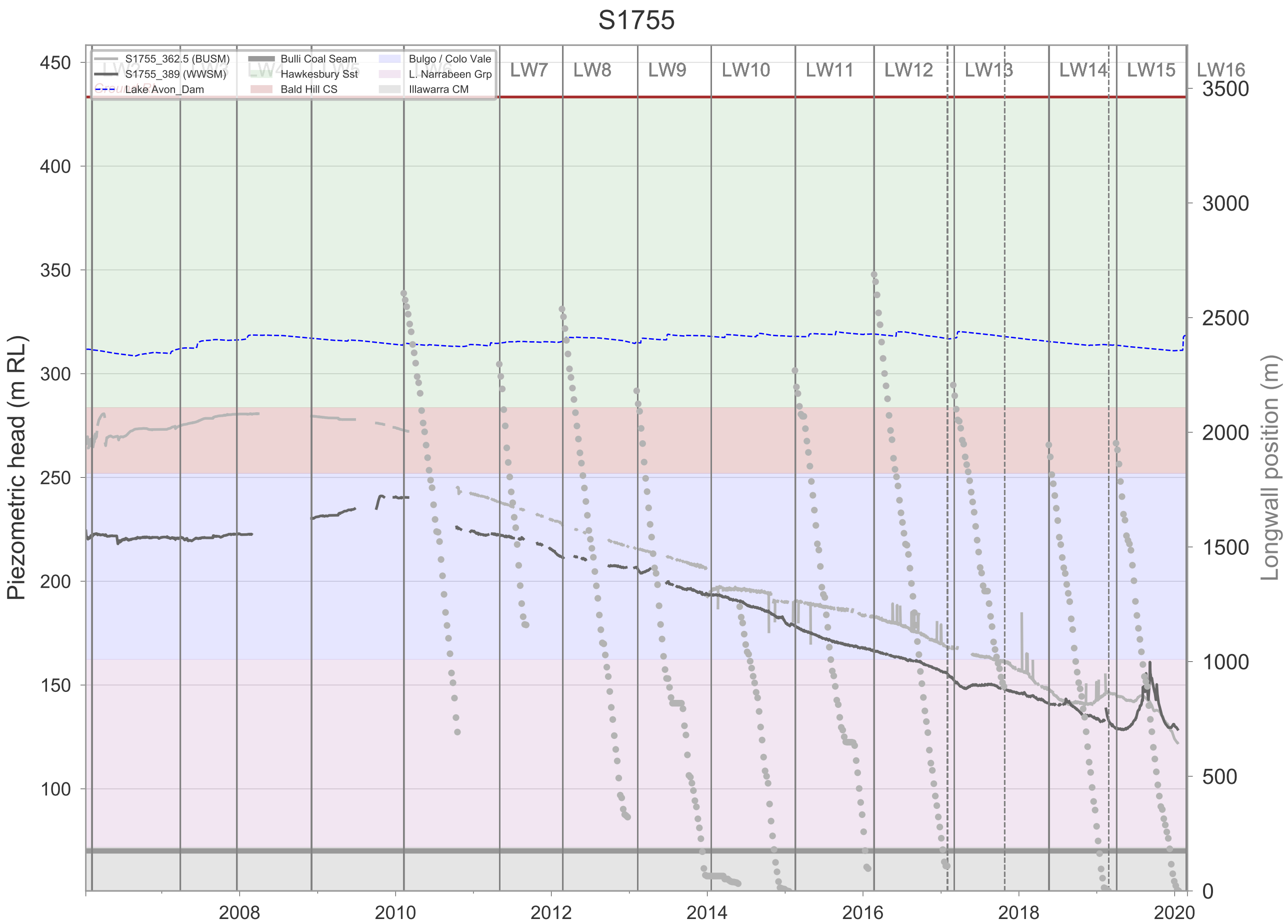


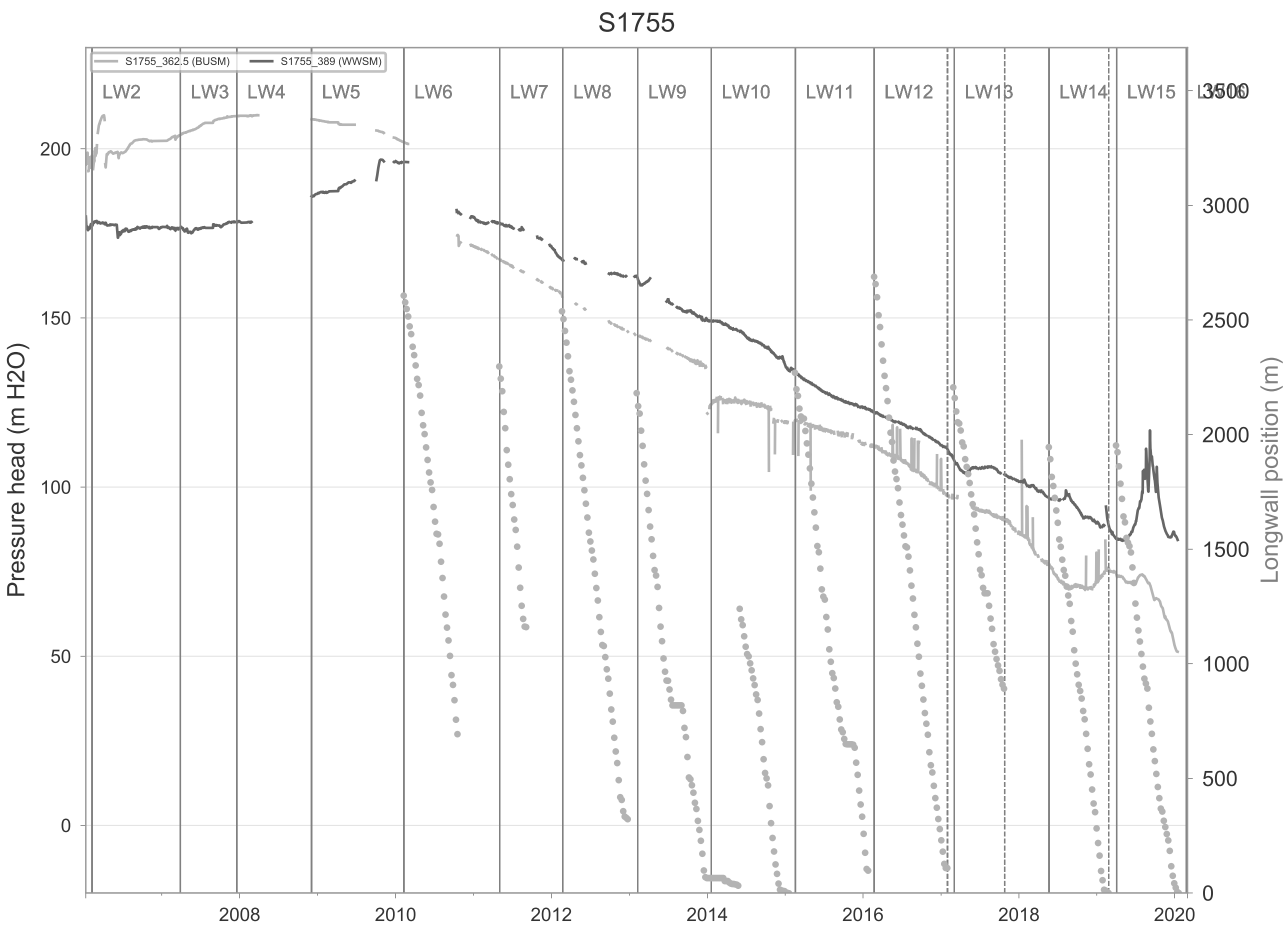
Groundwater hydrographs





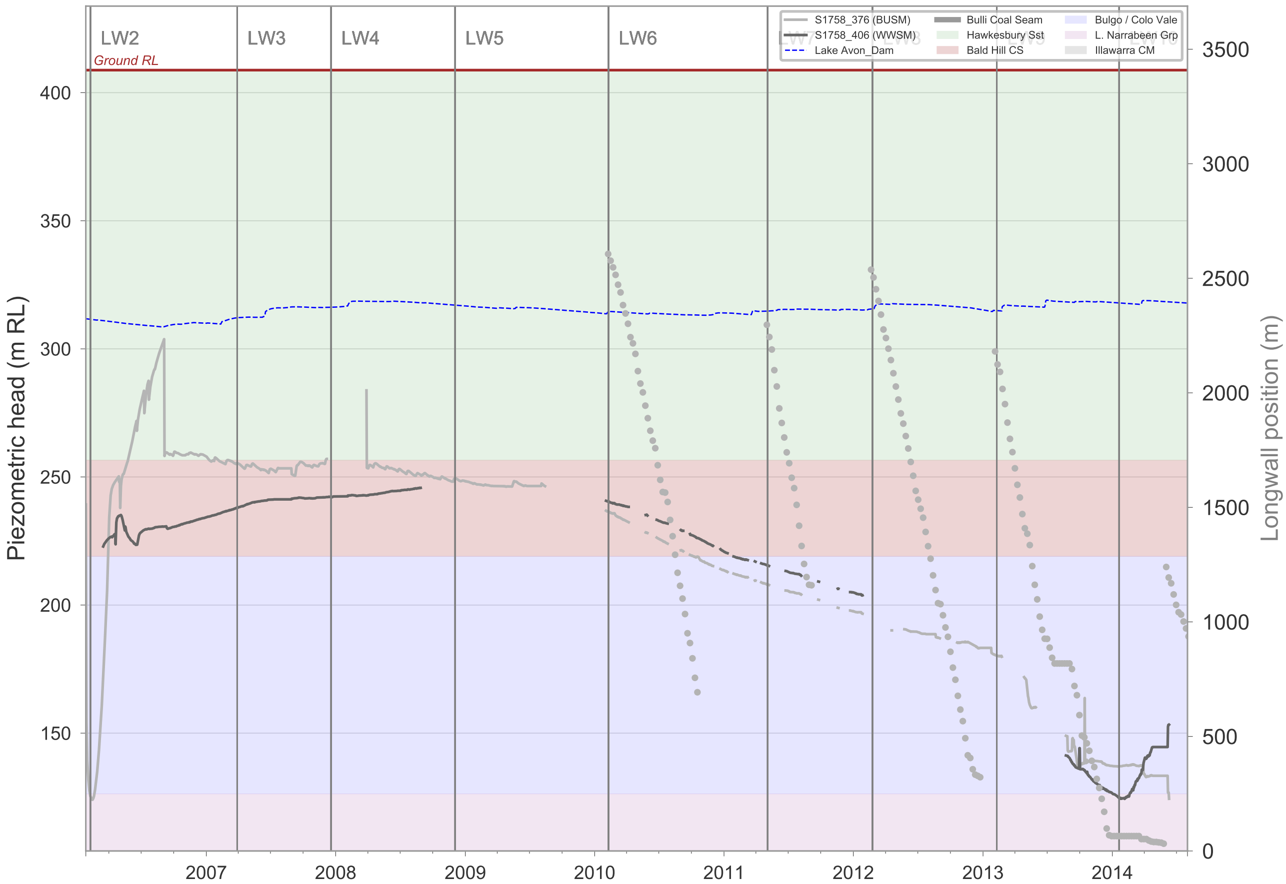
Groundwater hydrographs



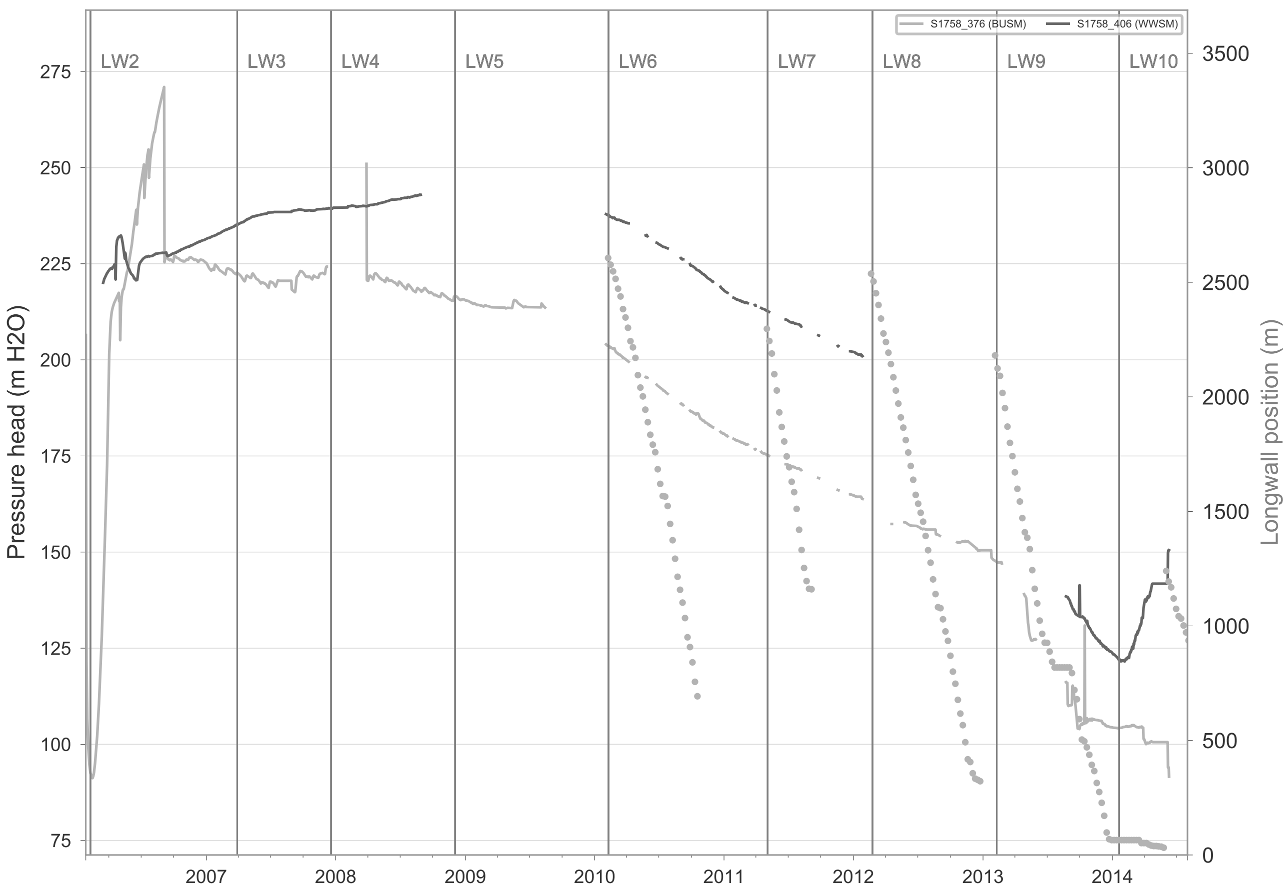


Groundwater hydrographs

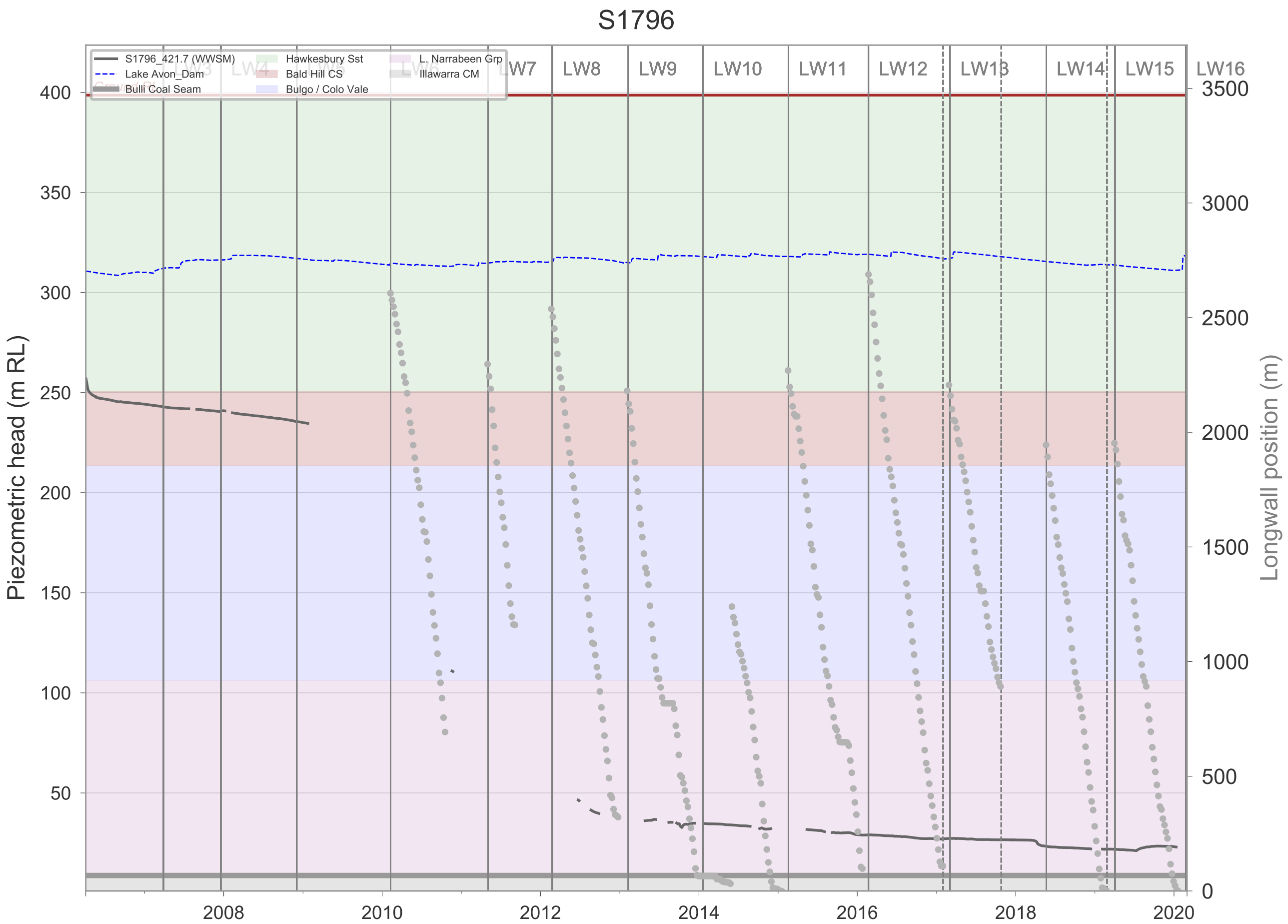
S1758

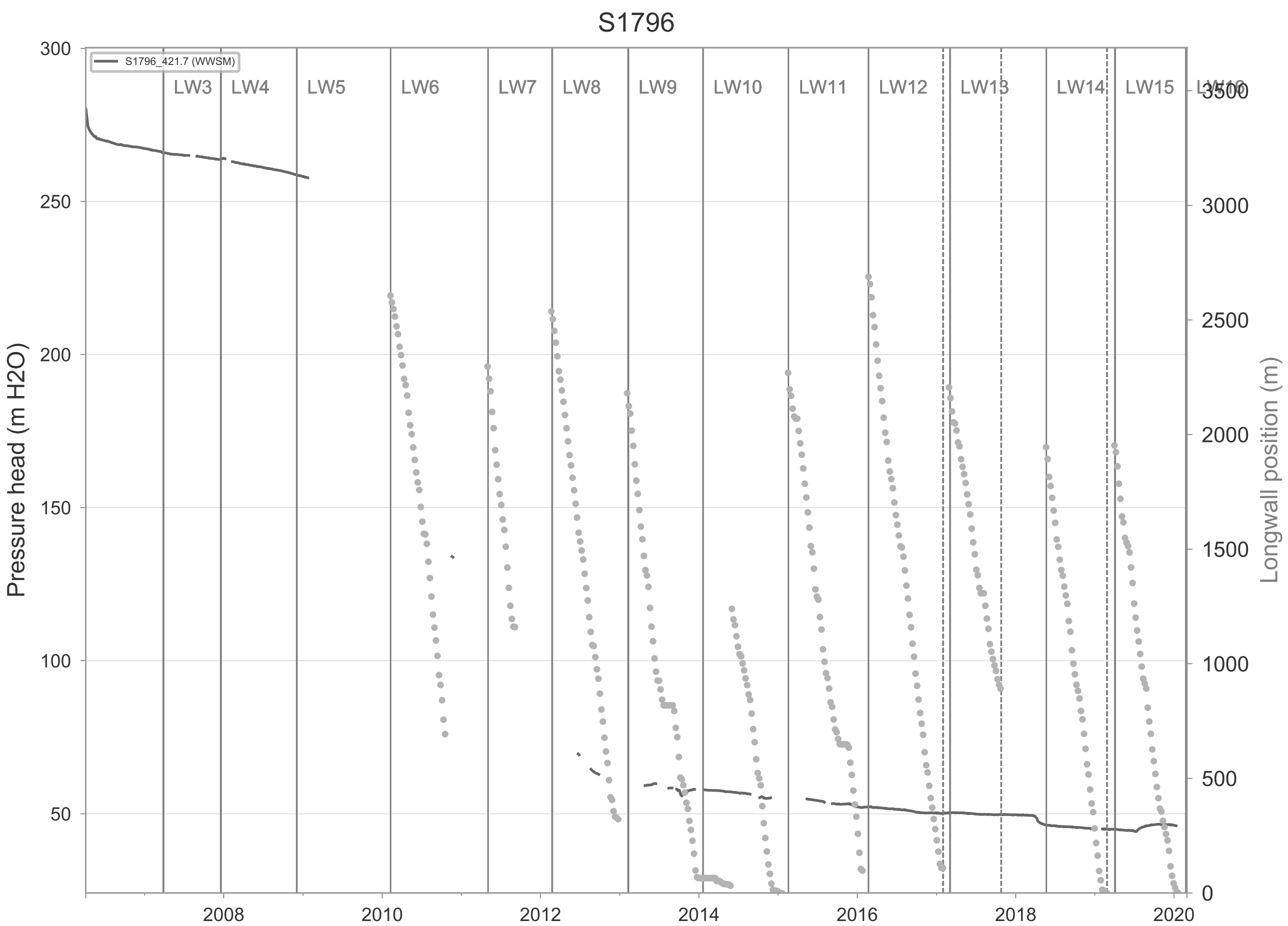


S1758

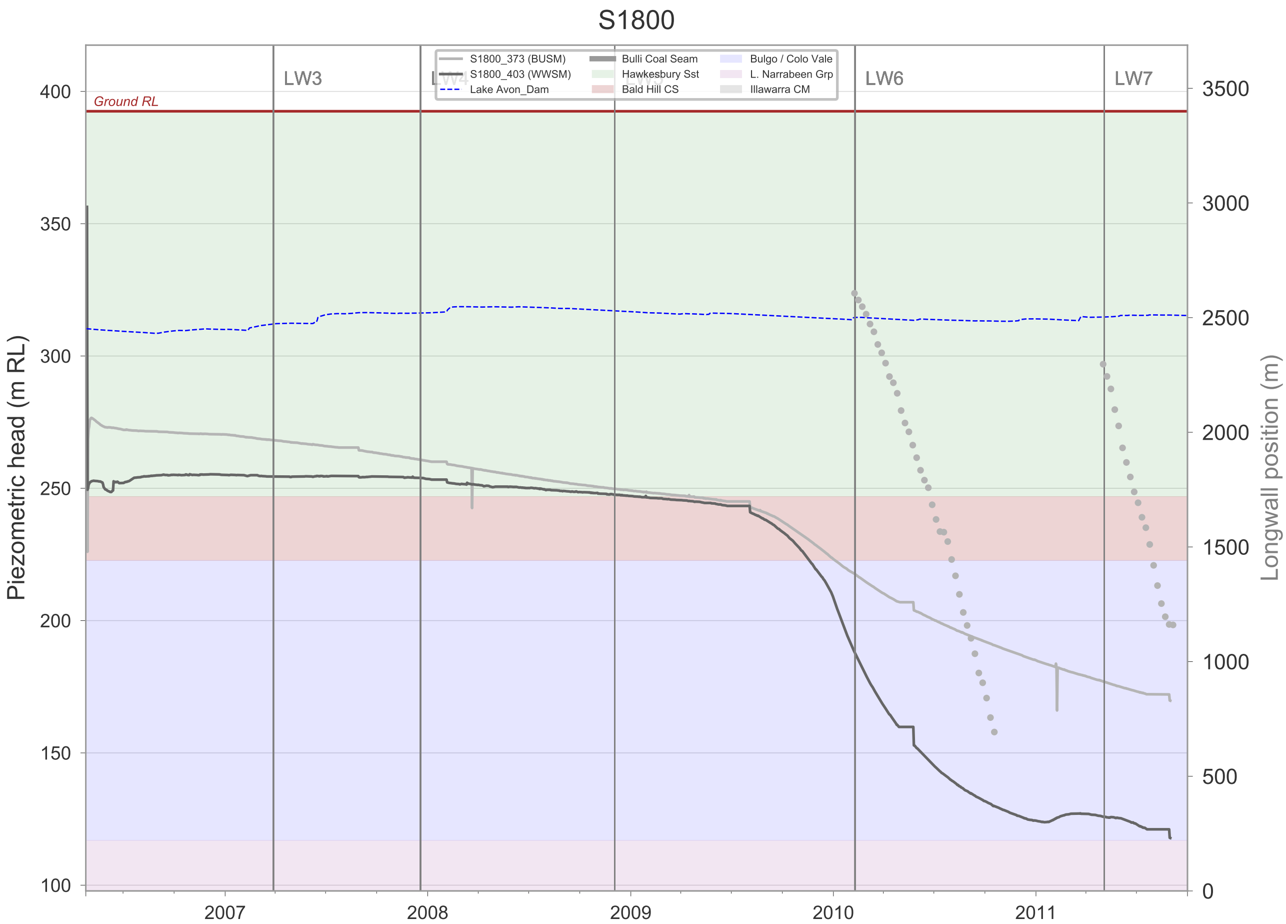


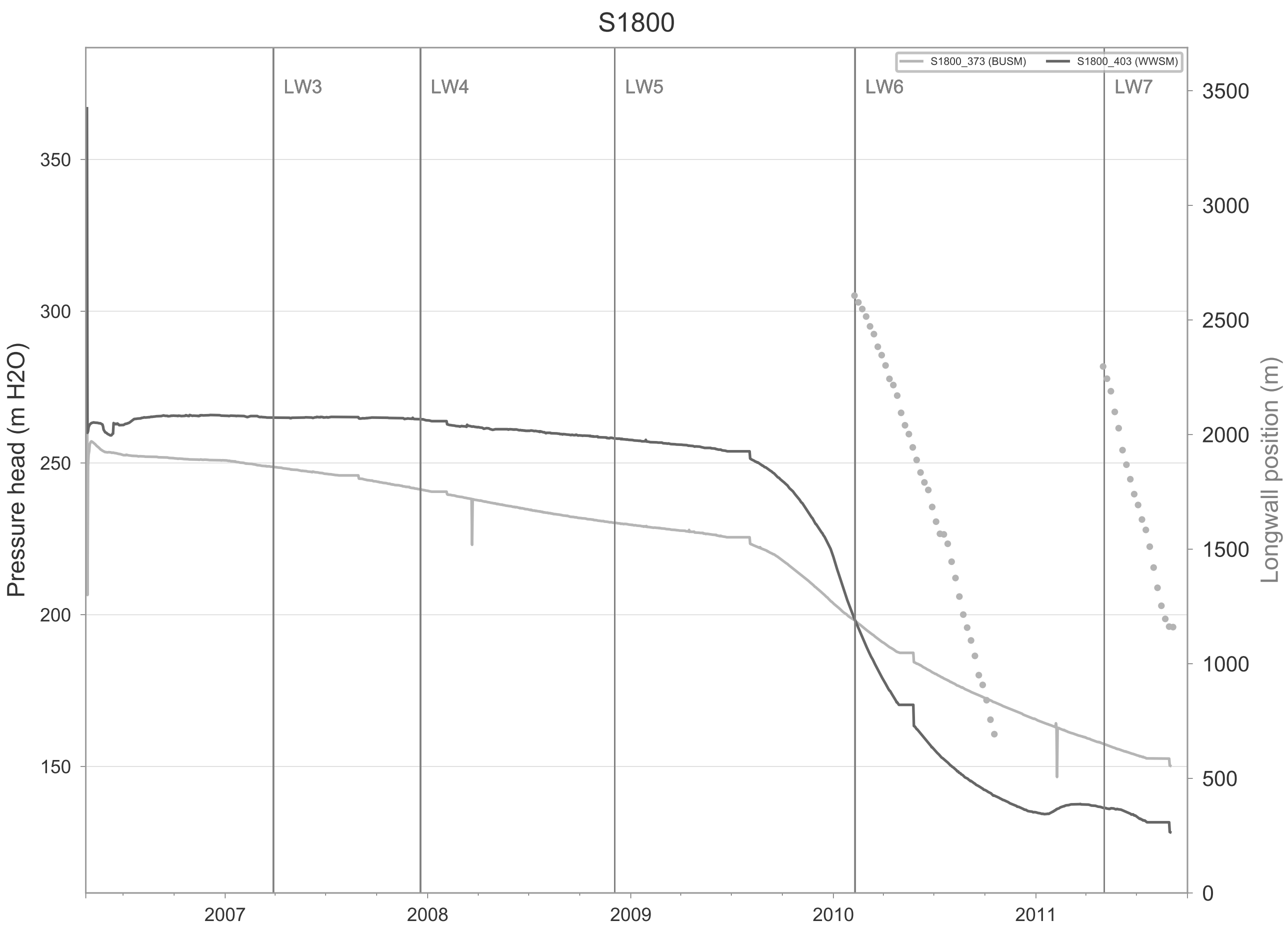
Groundwater hydrographs





Groundwater hydrographs





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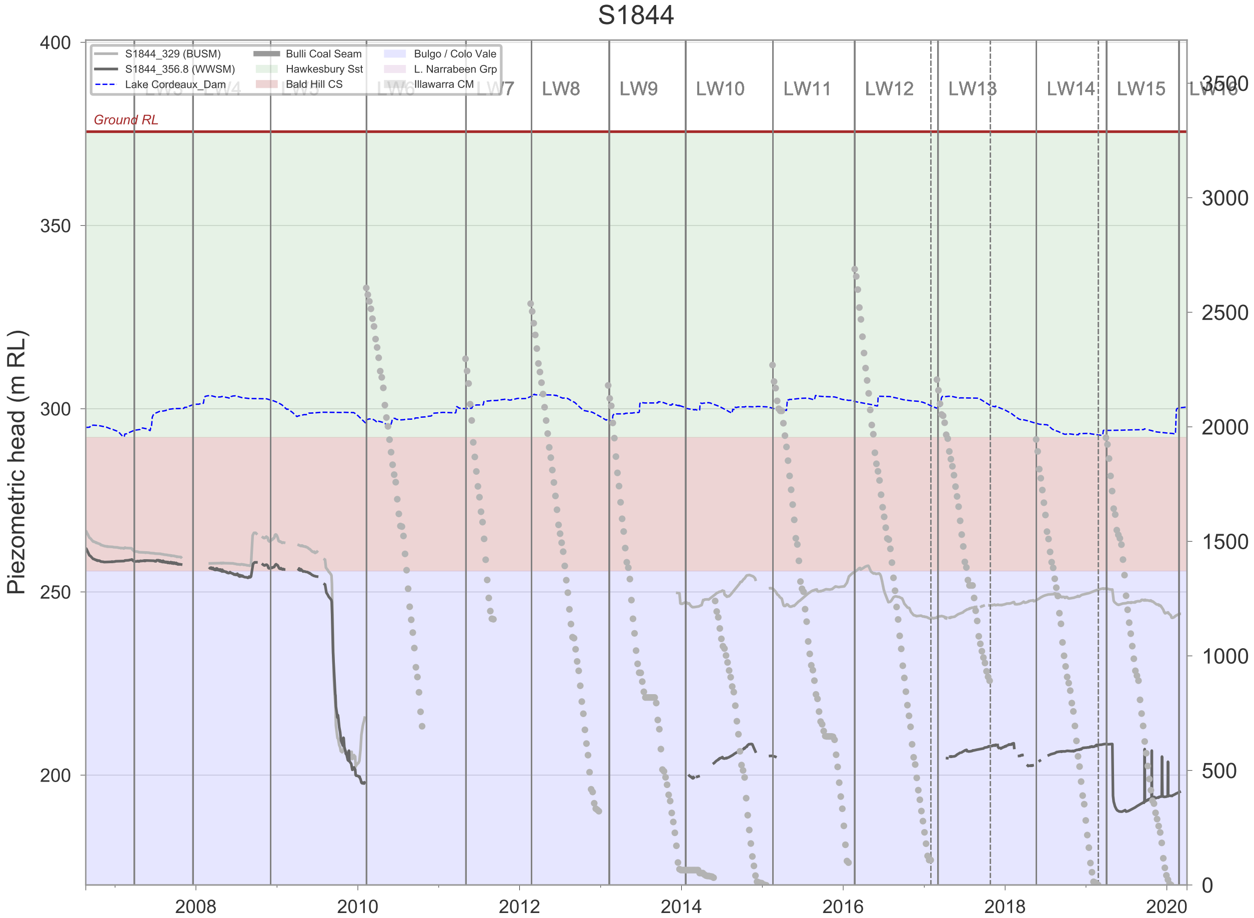

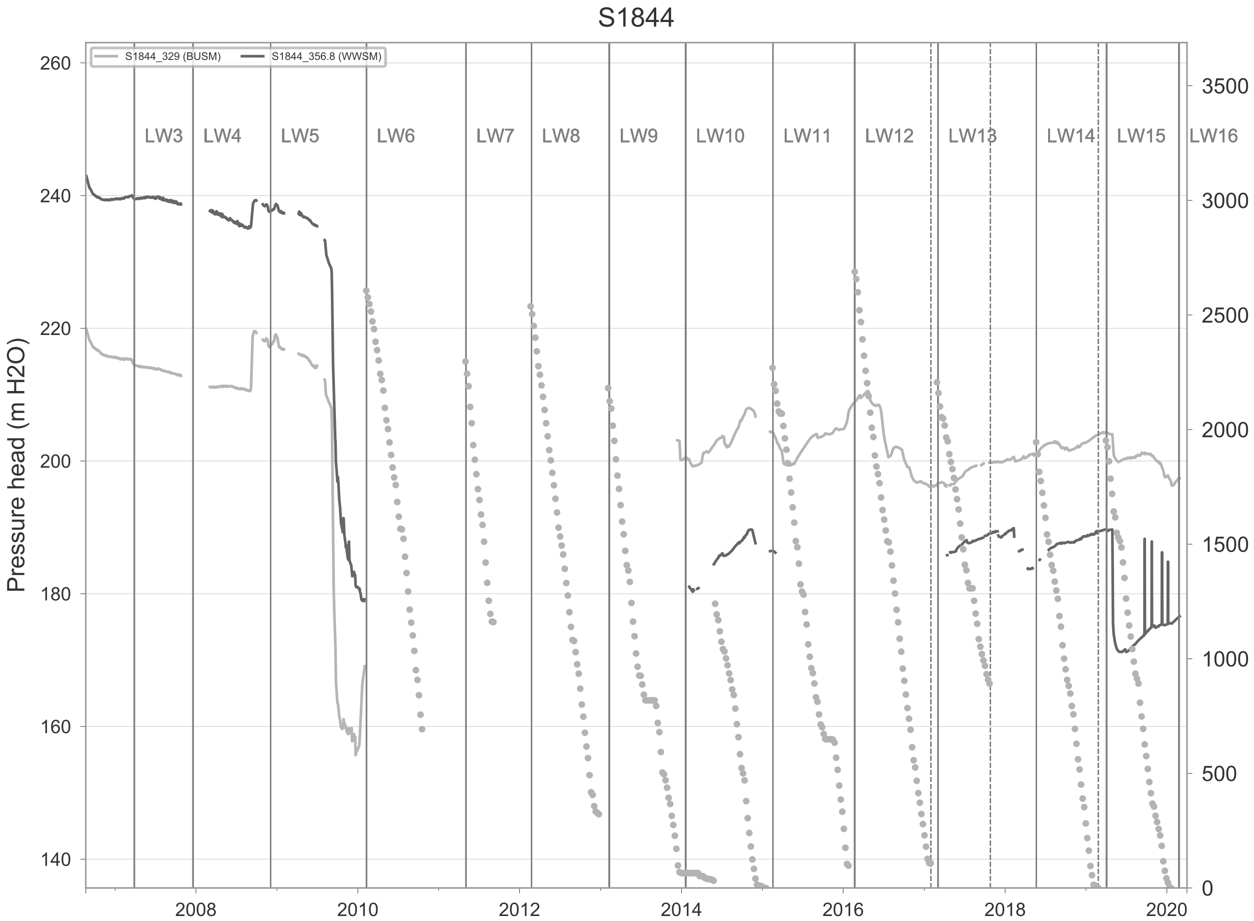

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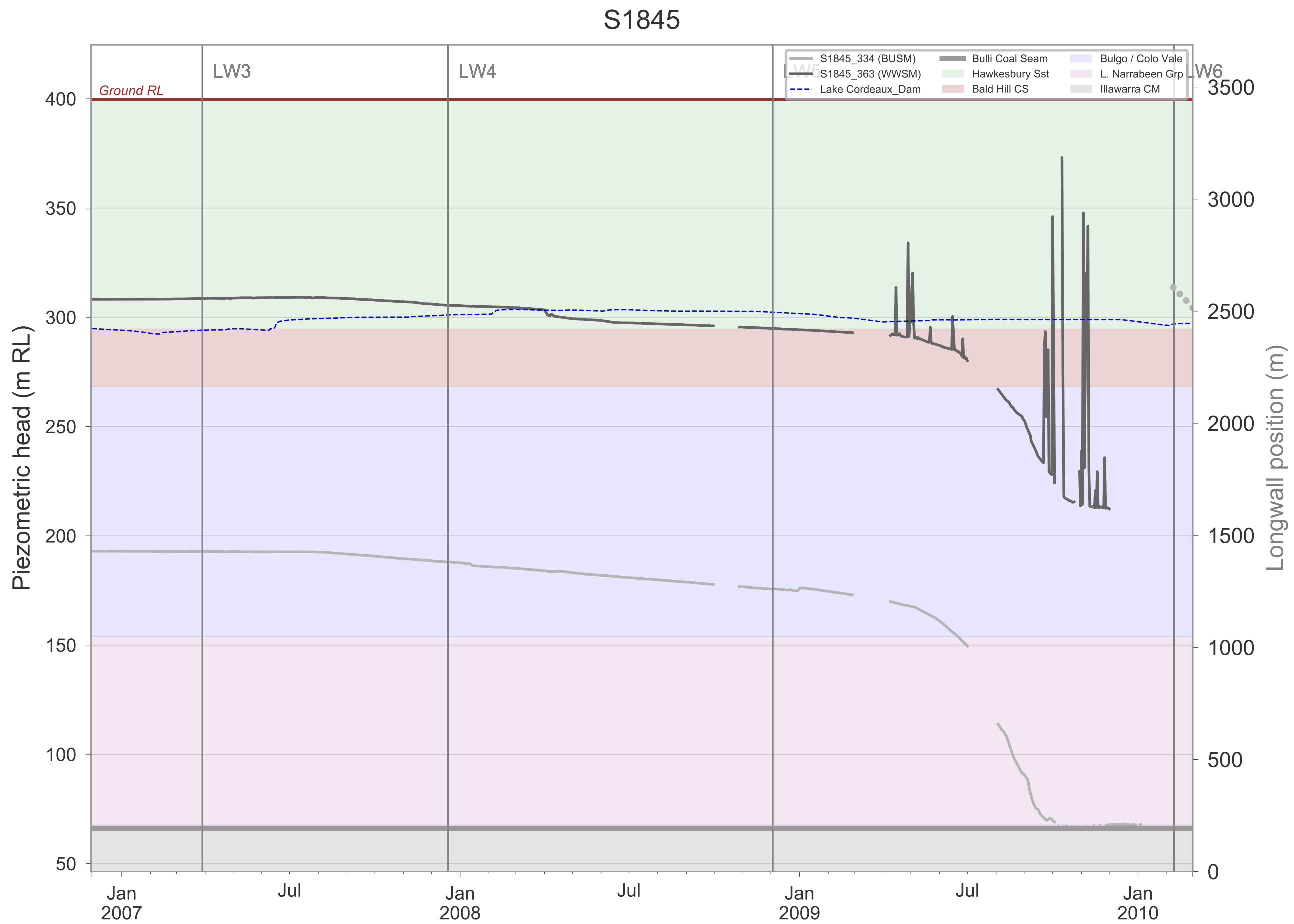

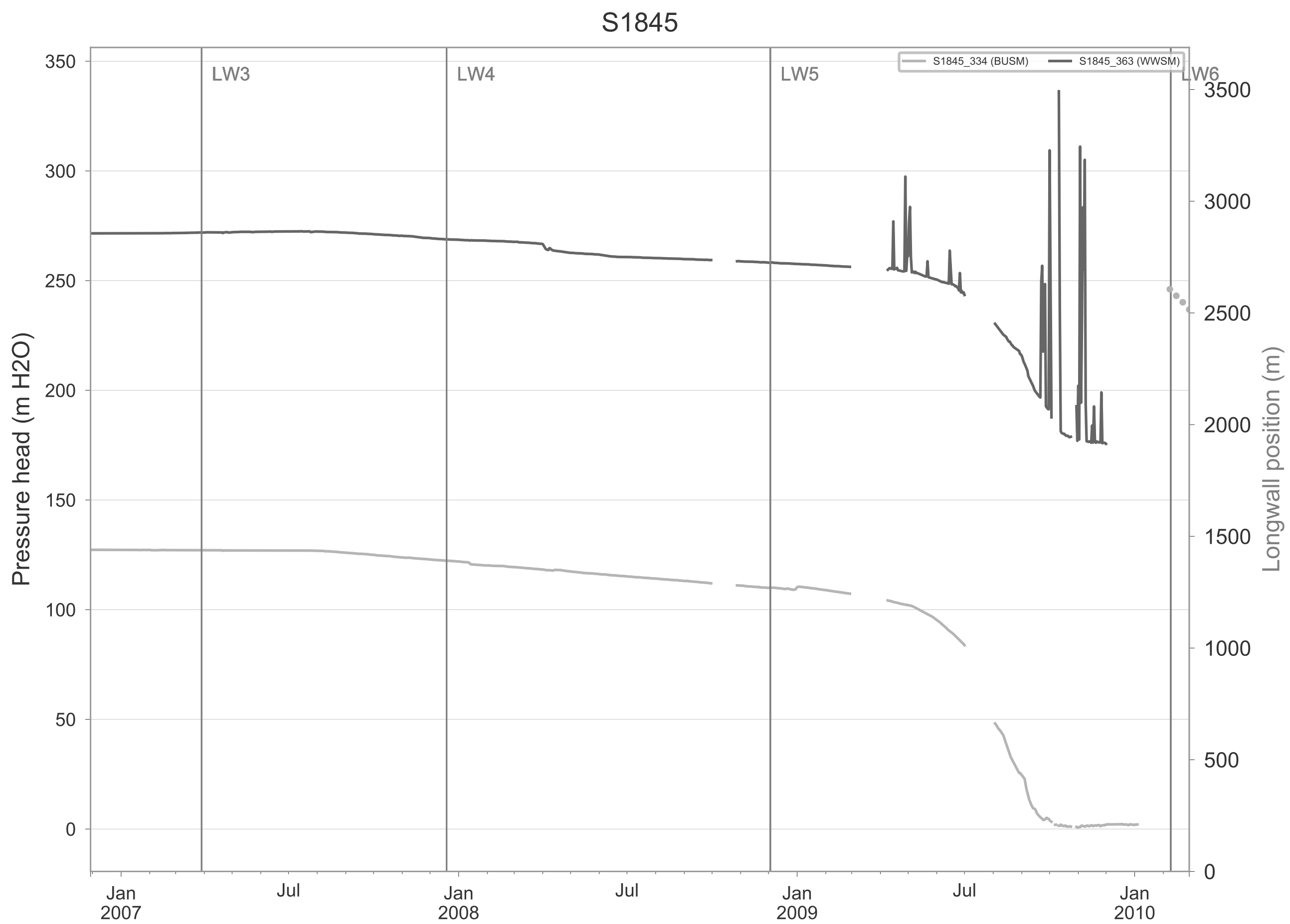

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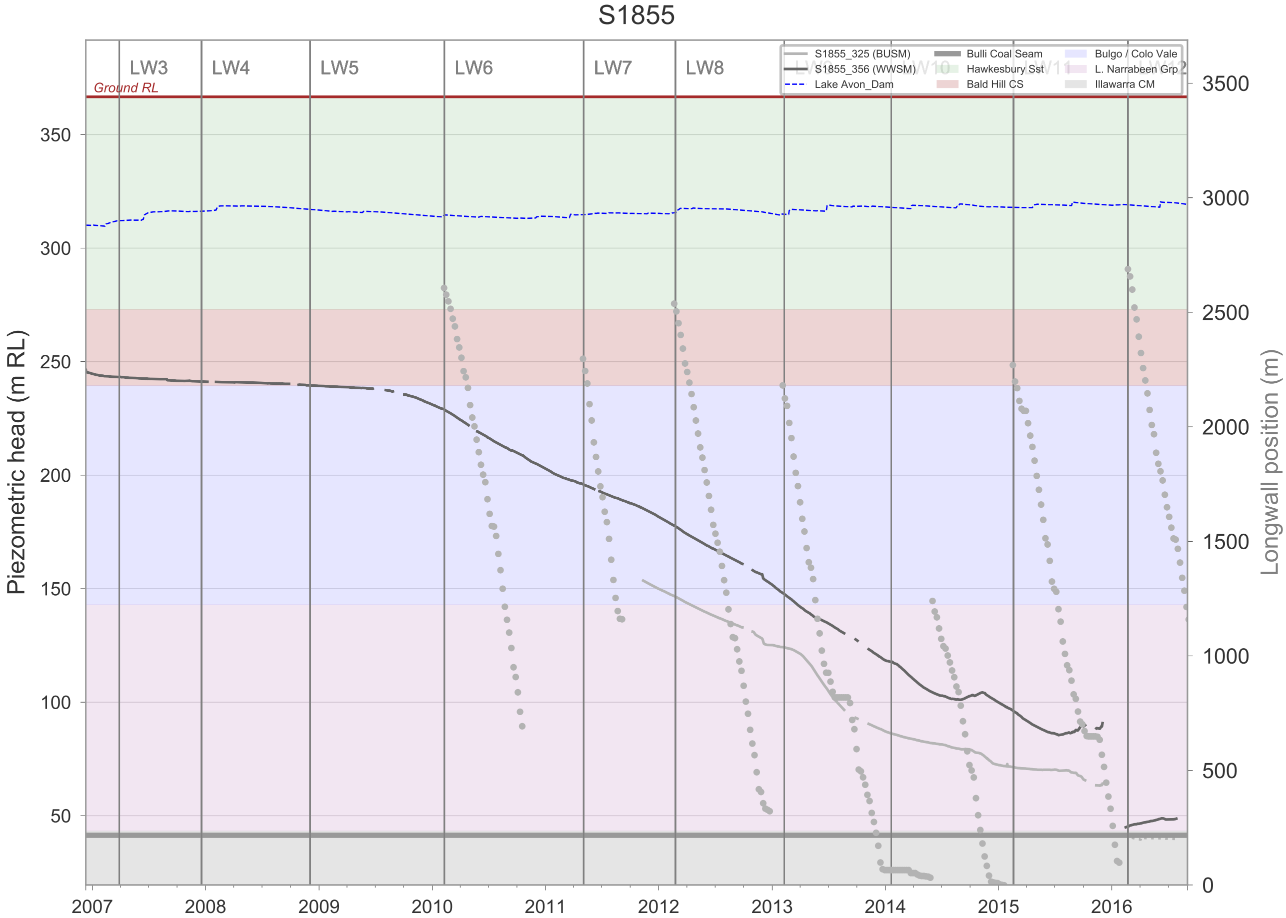

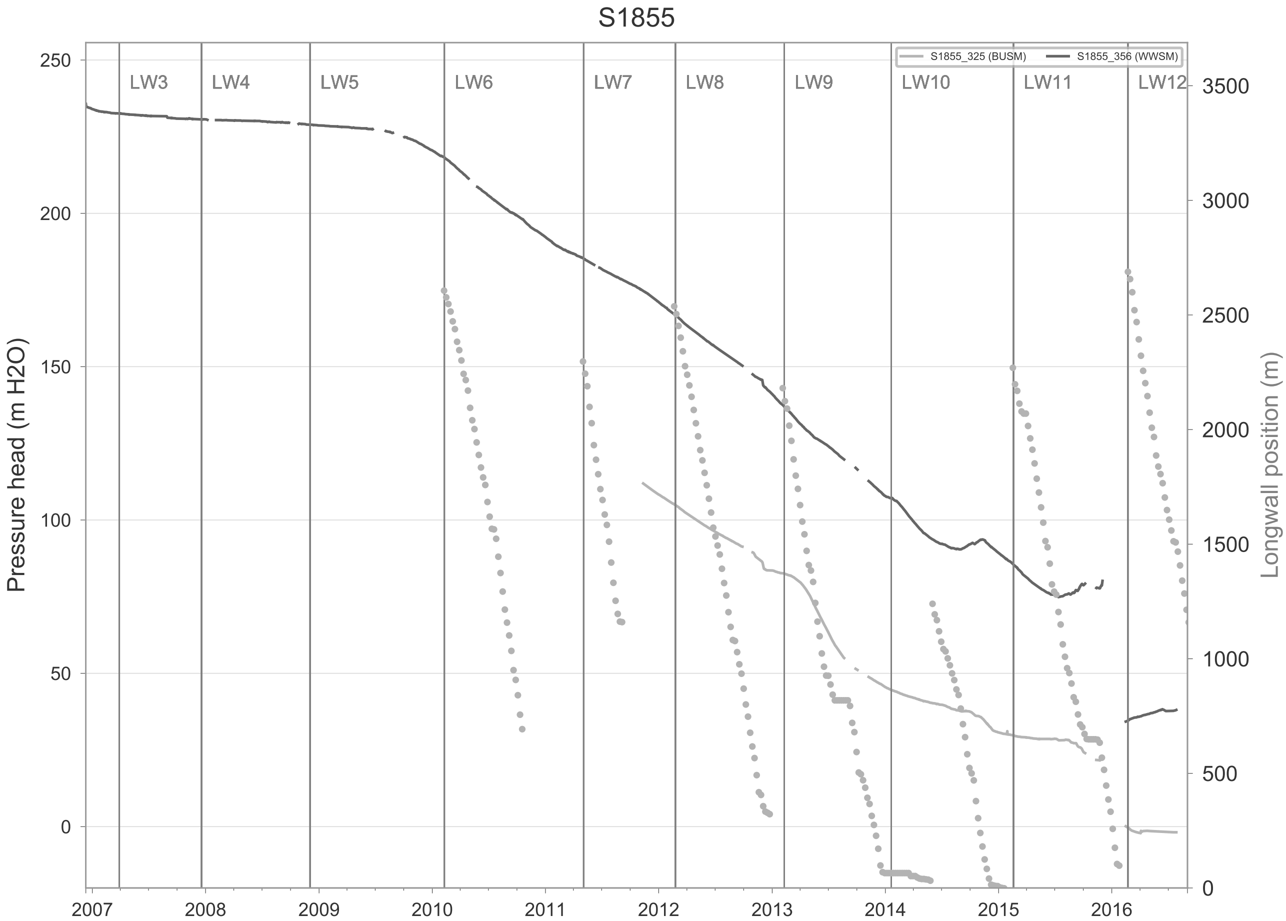

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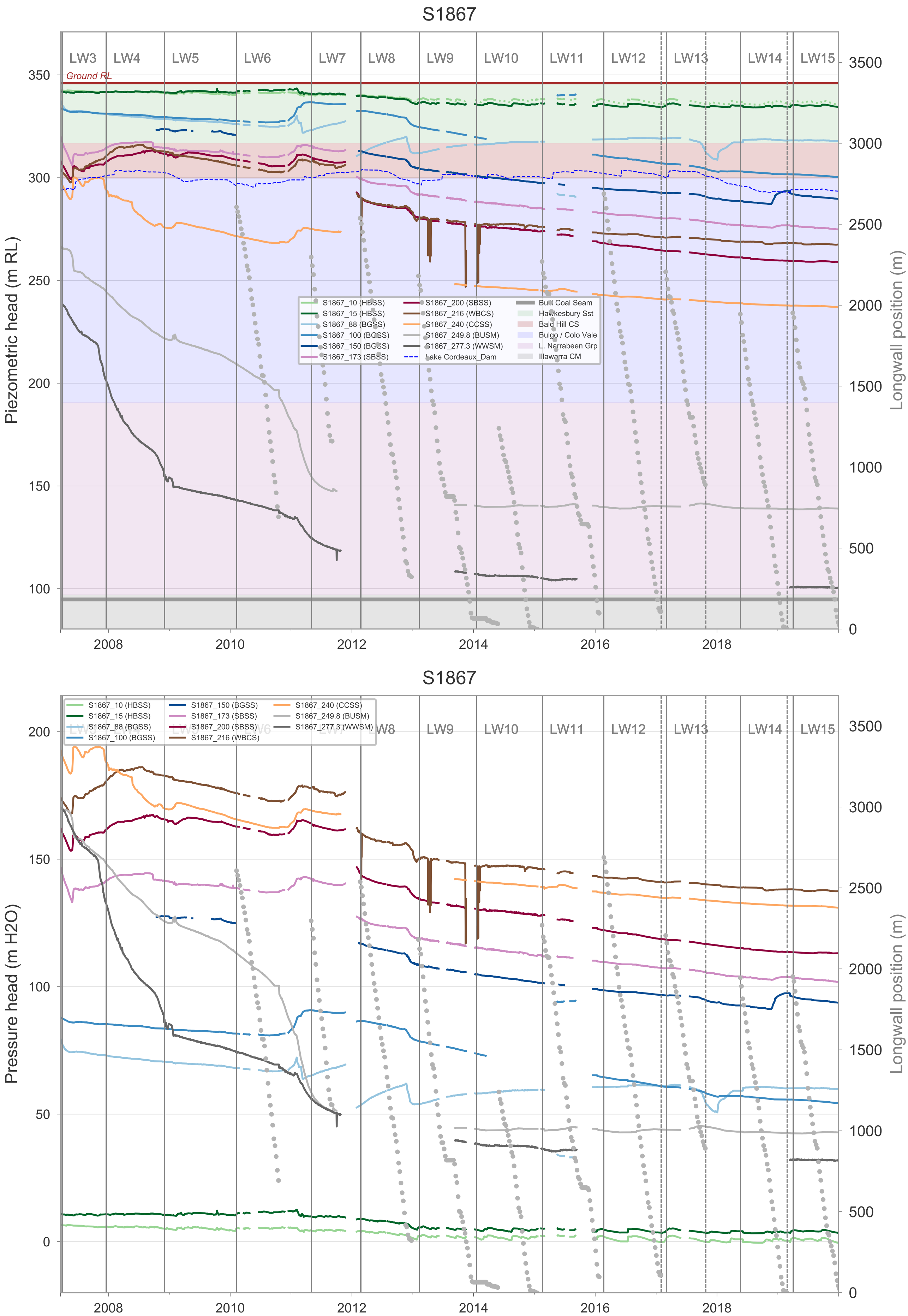

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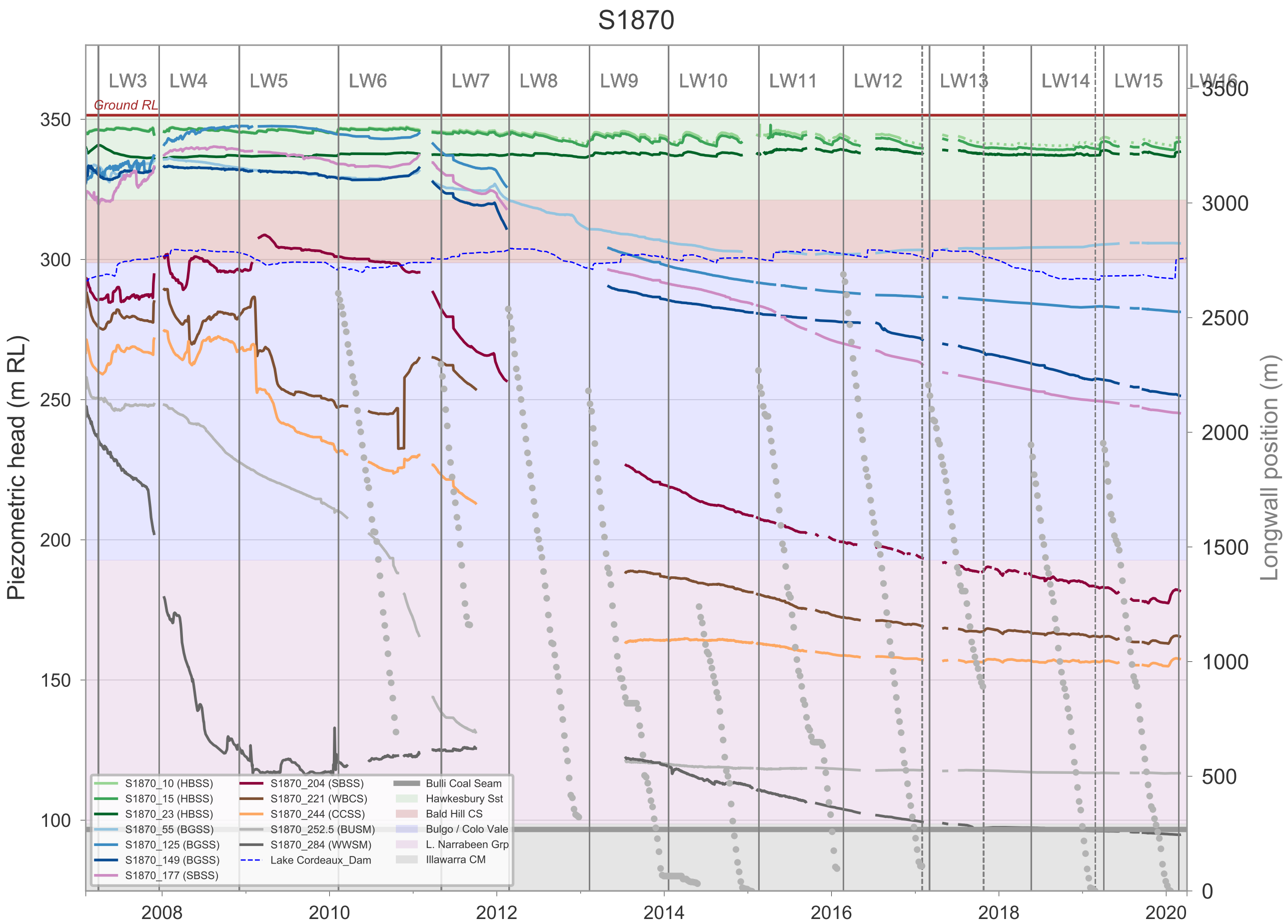

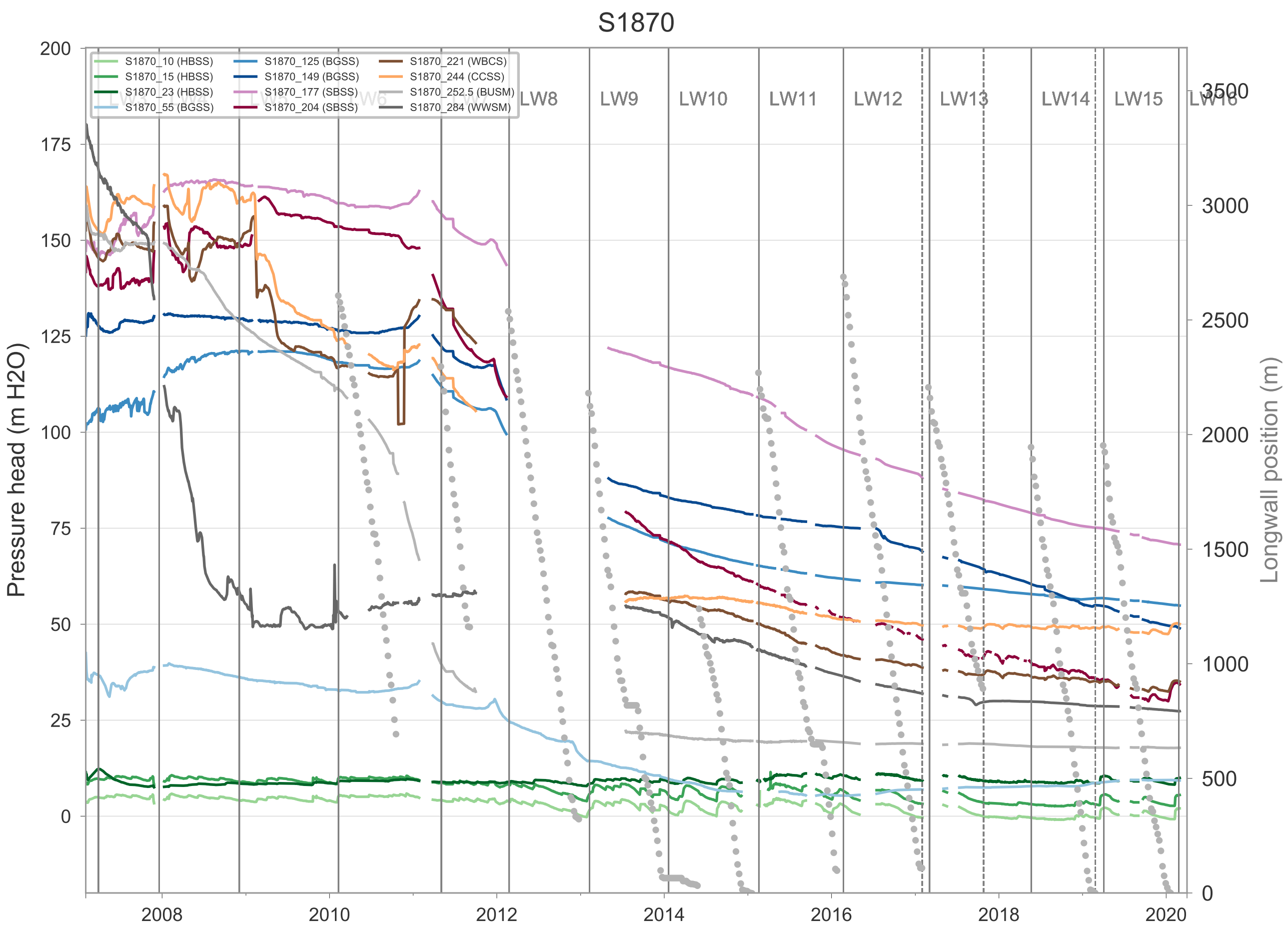

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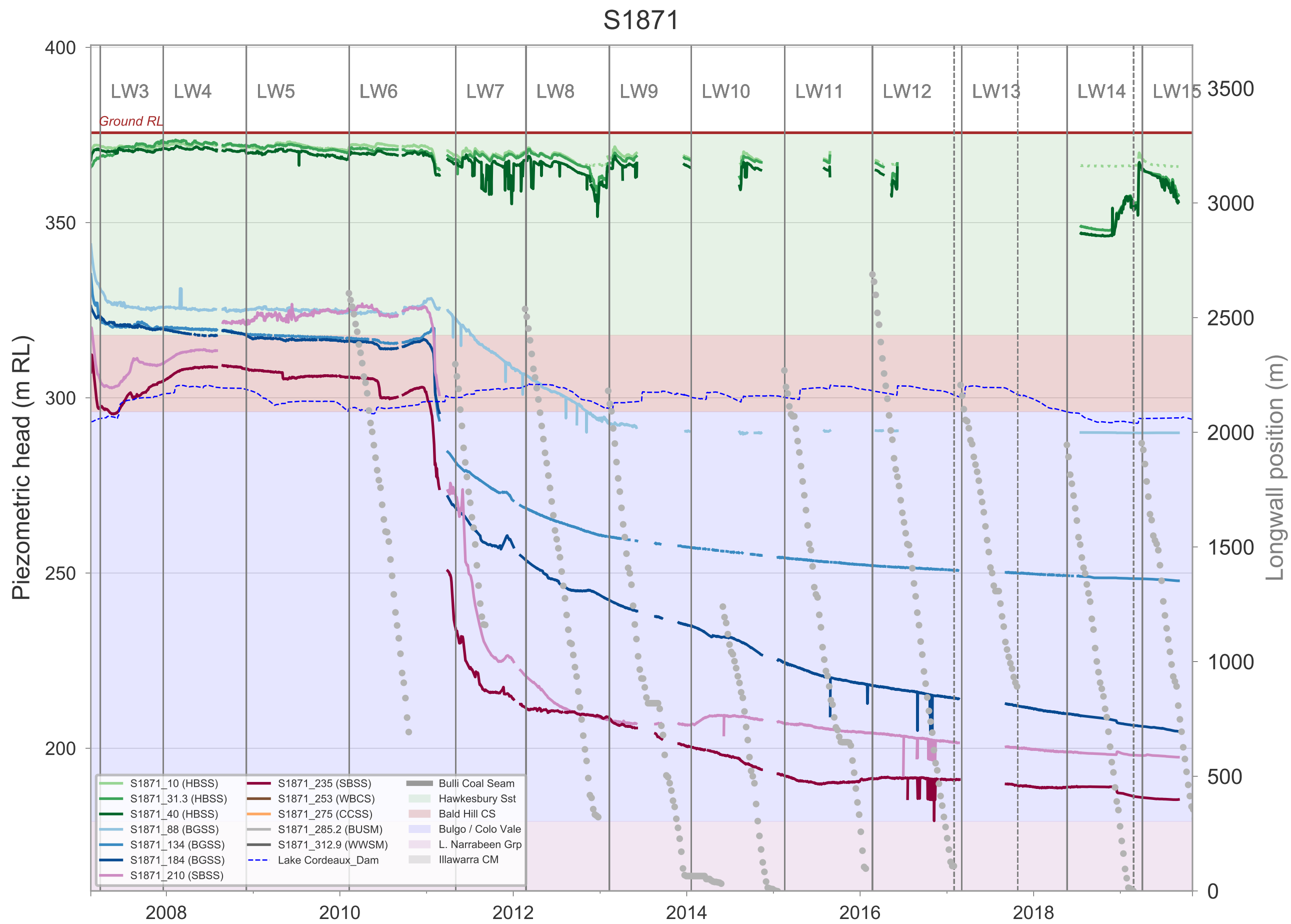

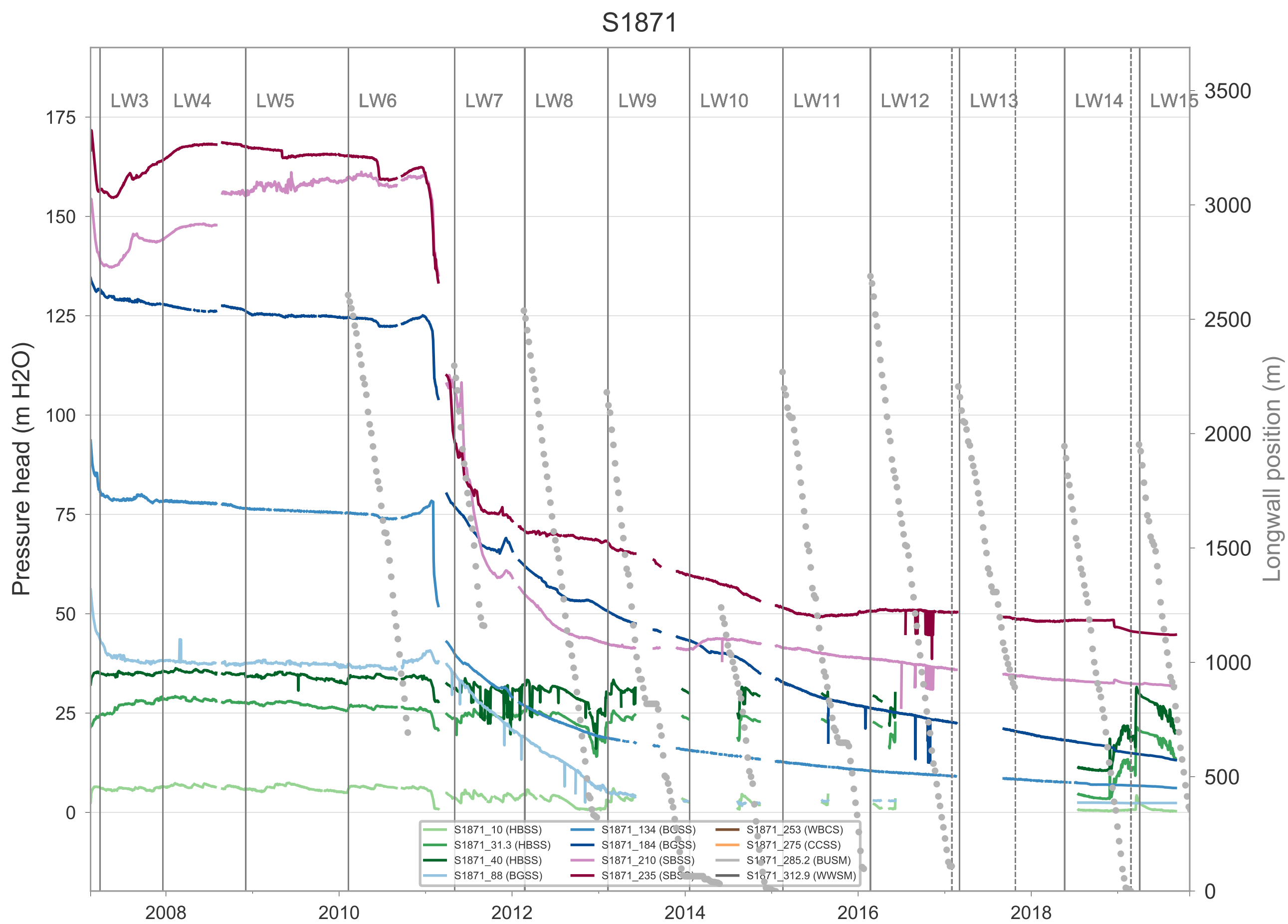

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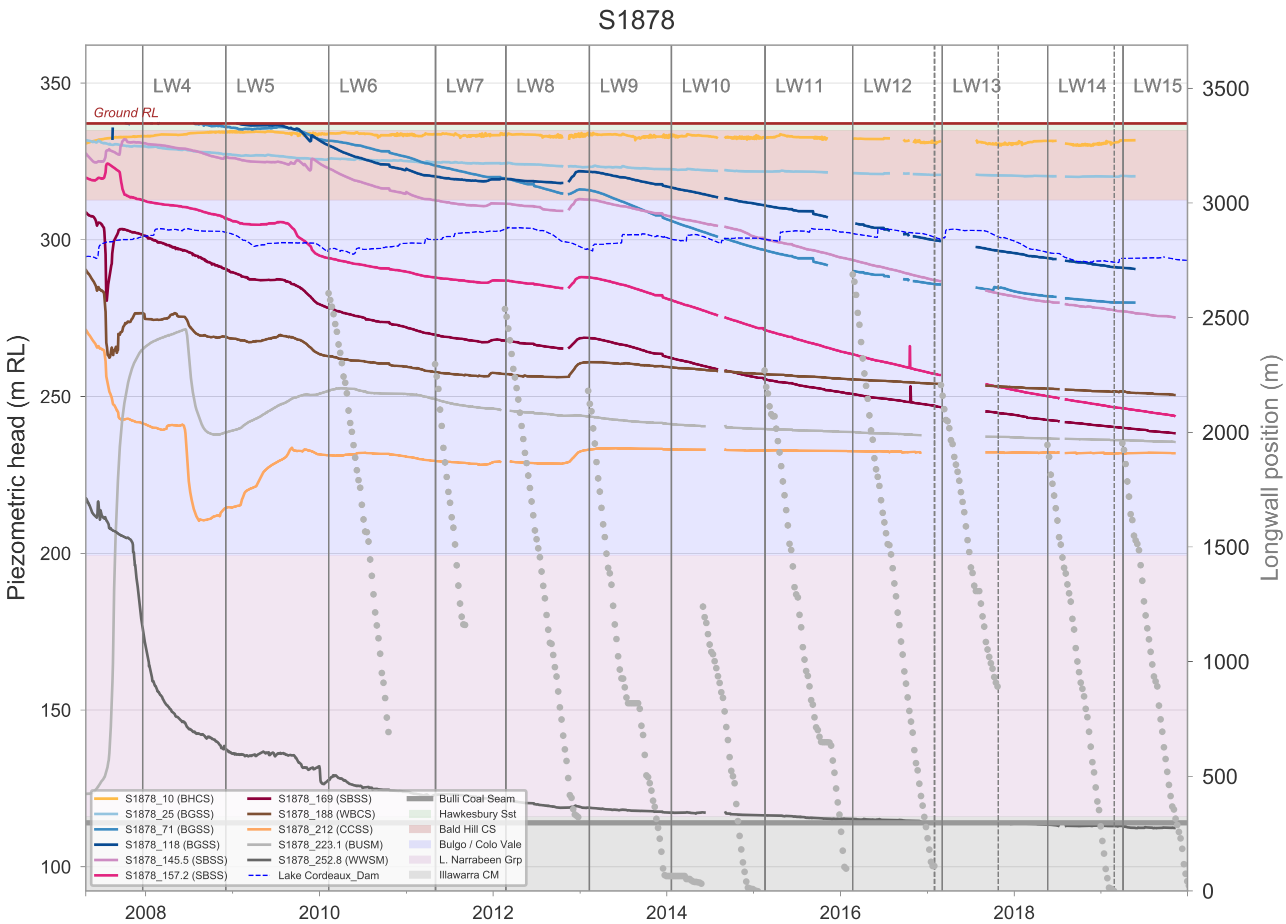

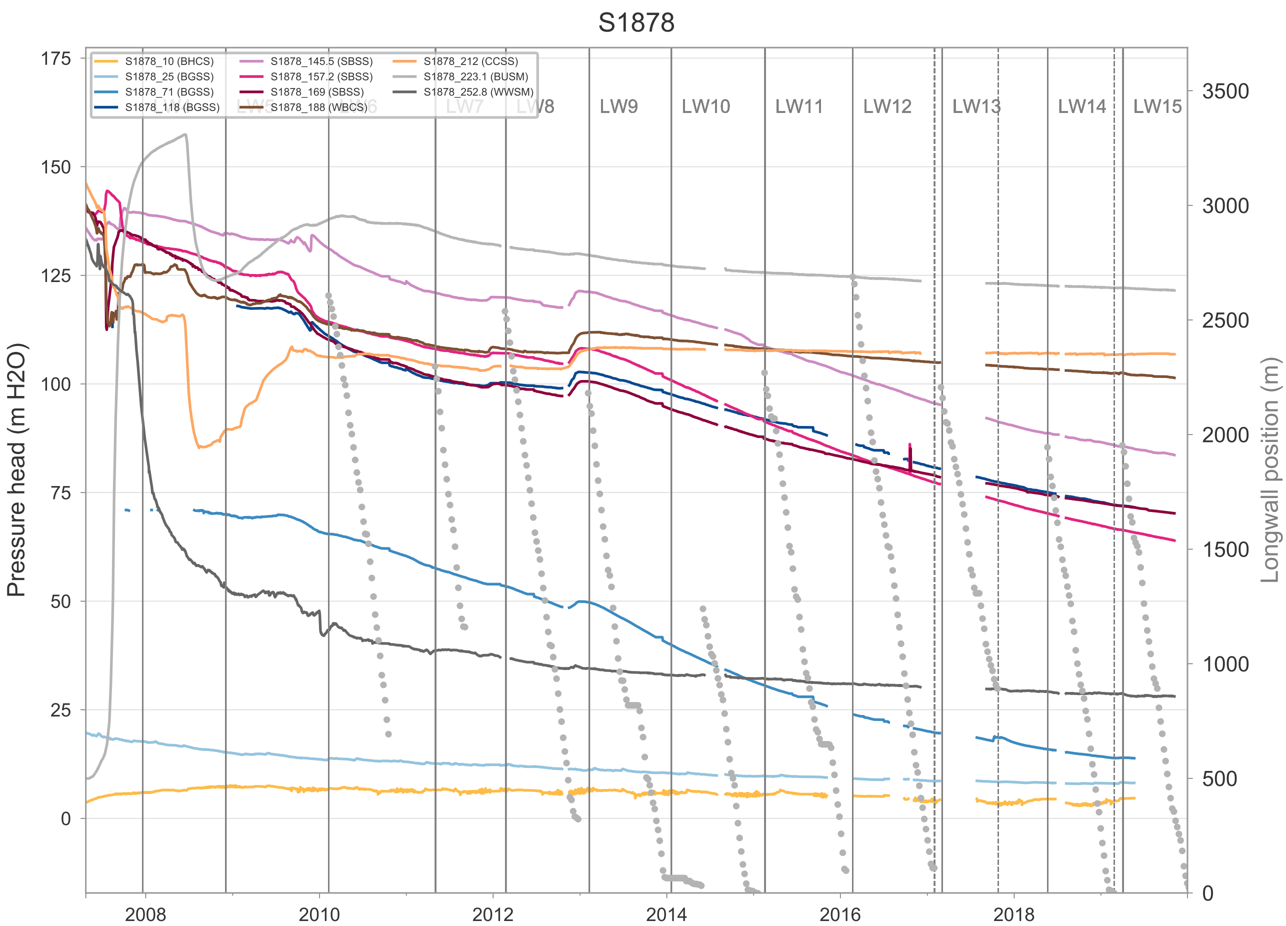

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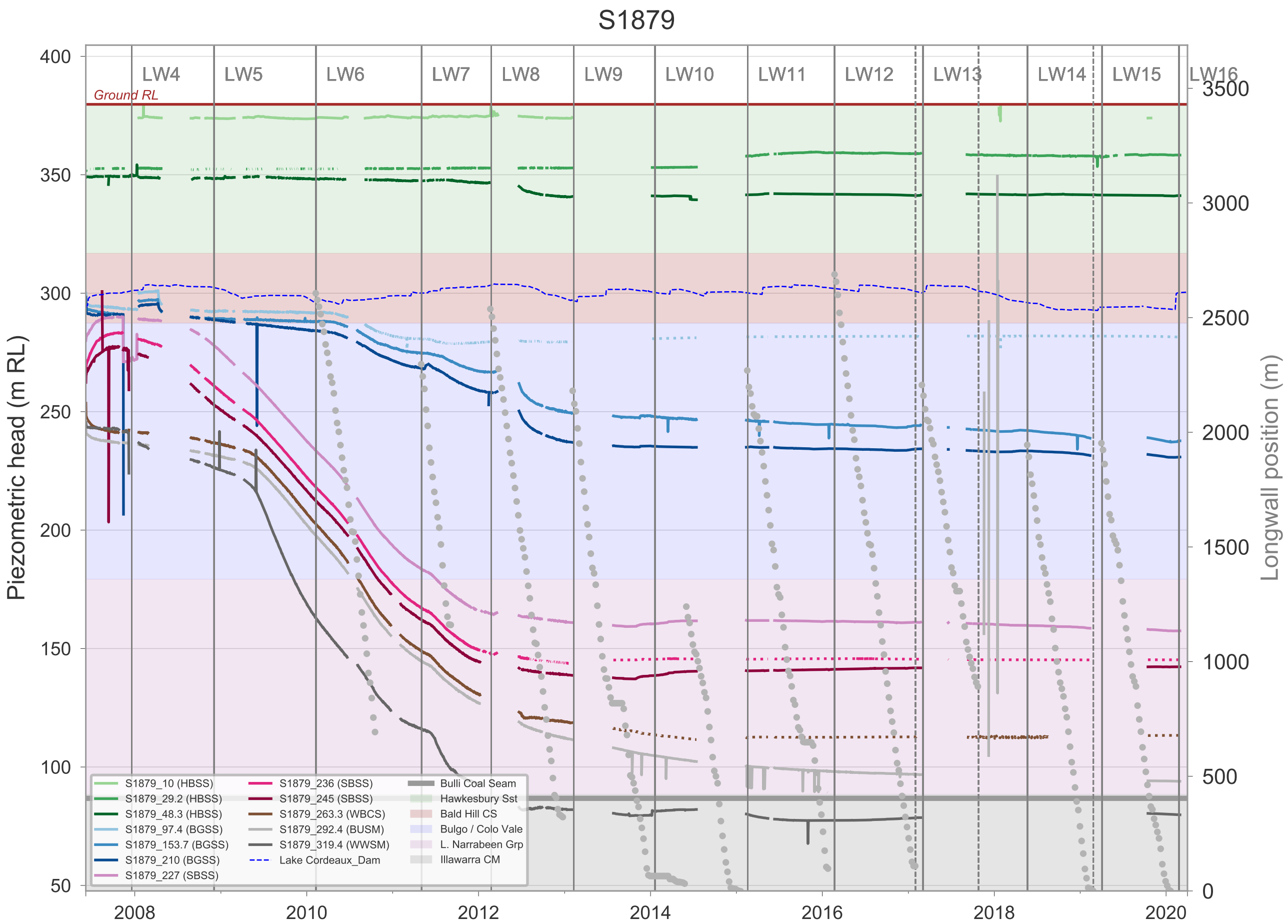

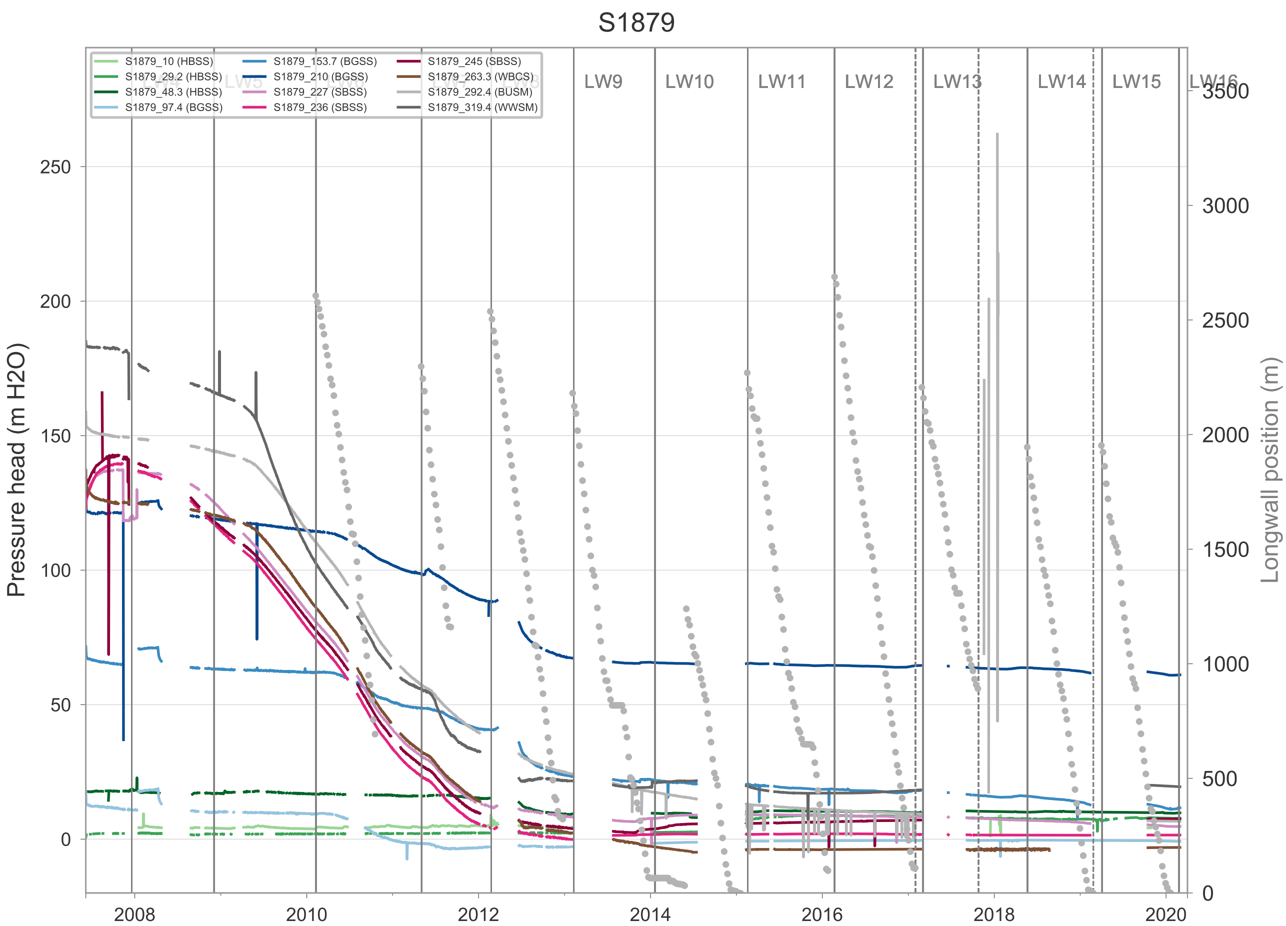

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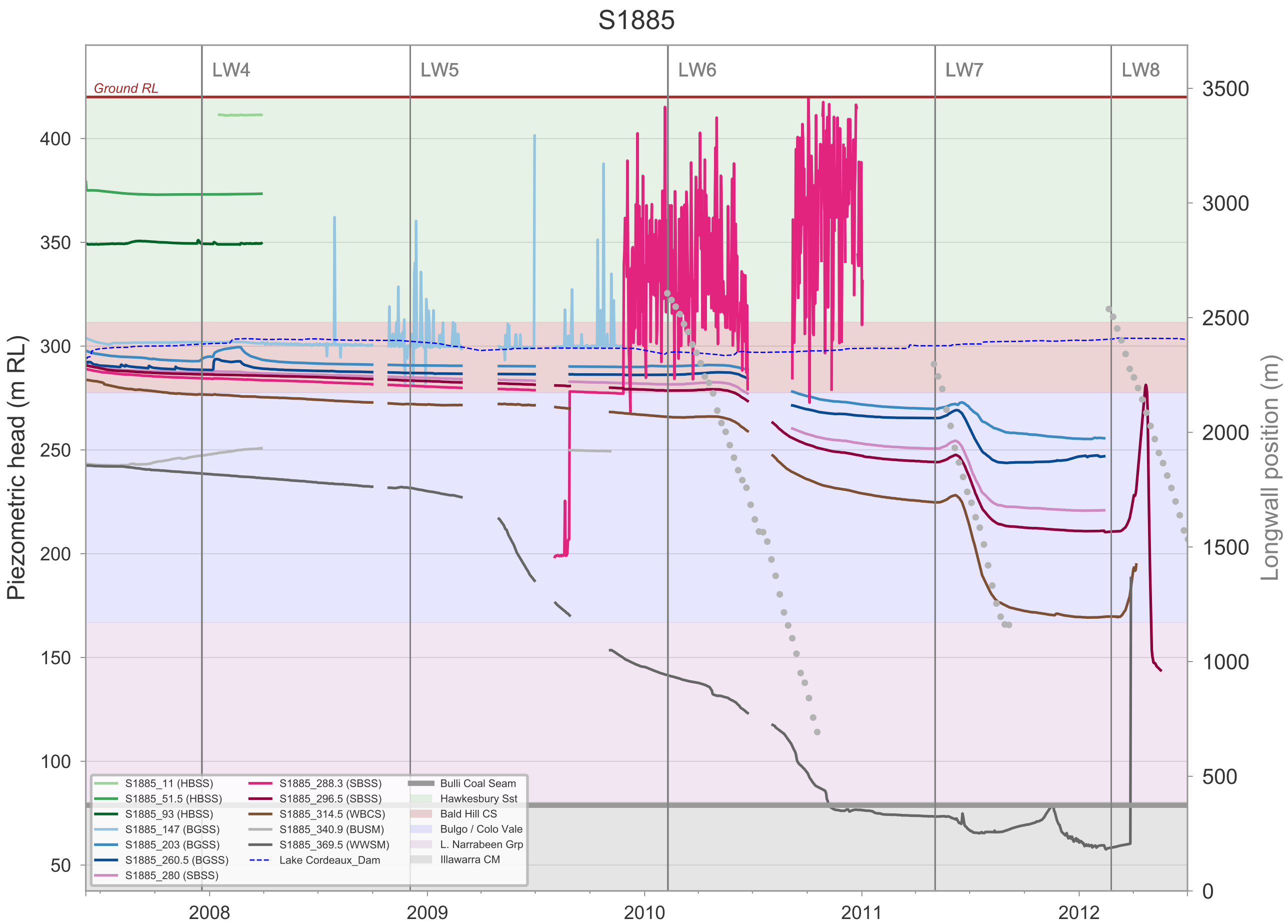

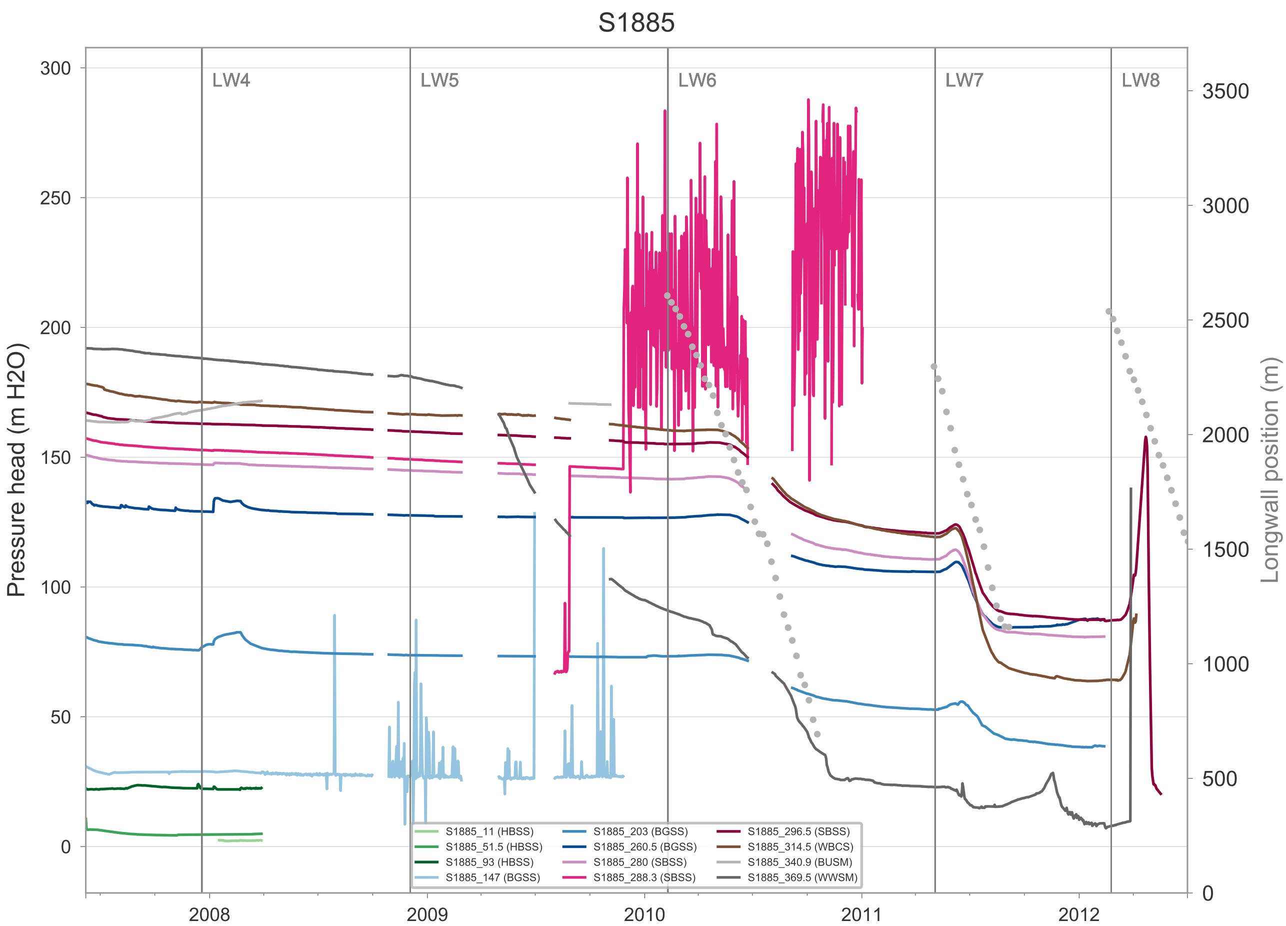

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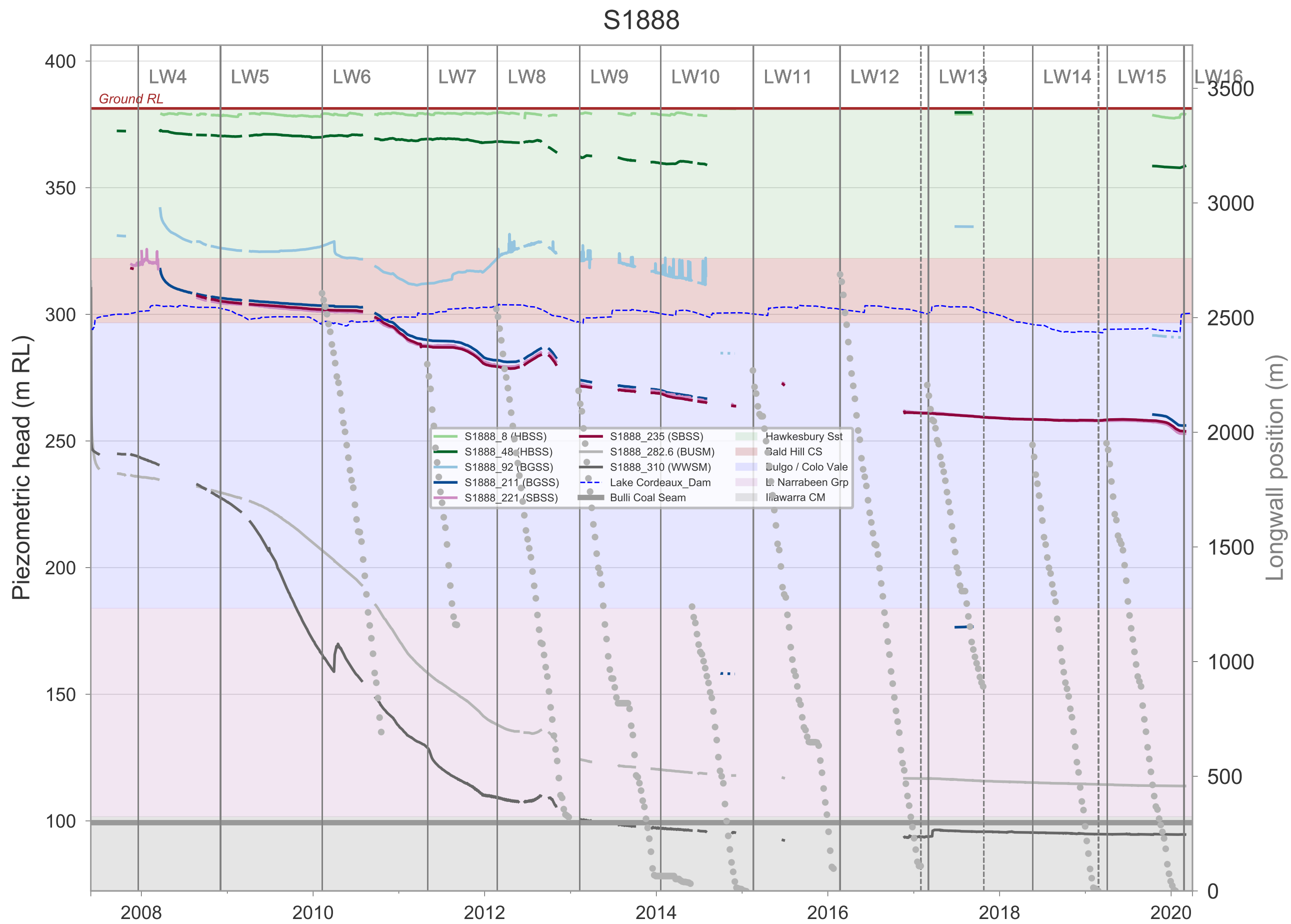

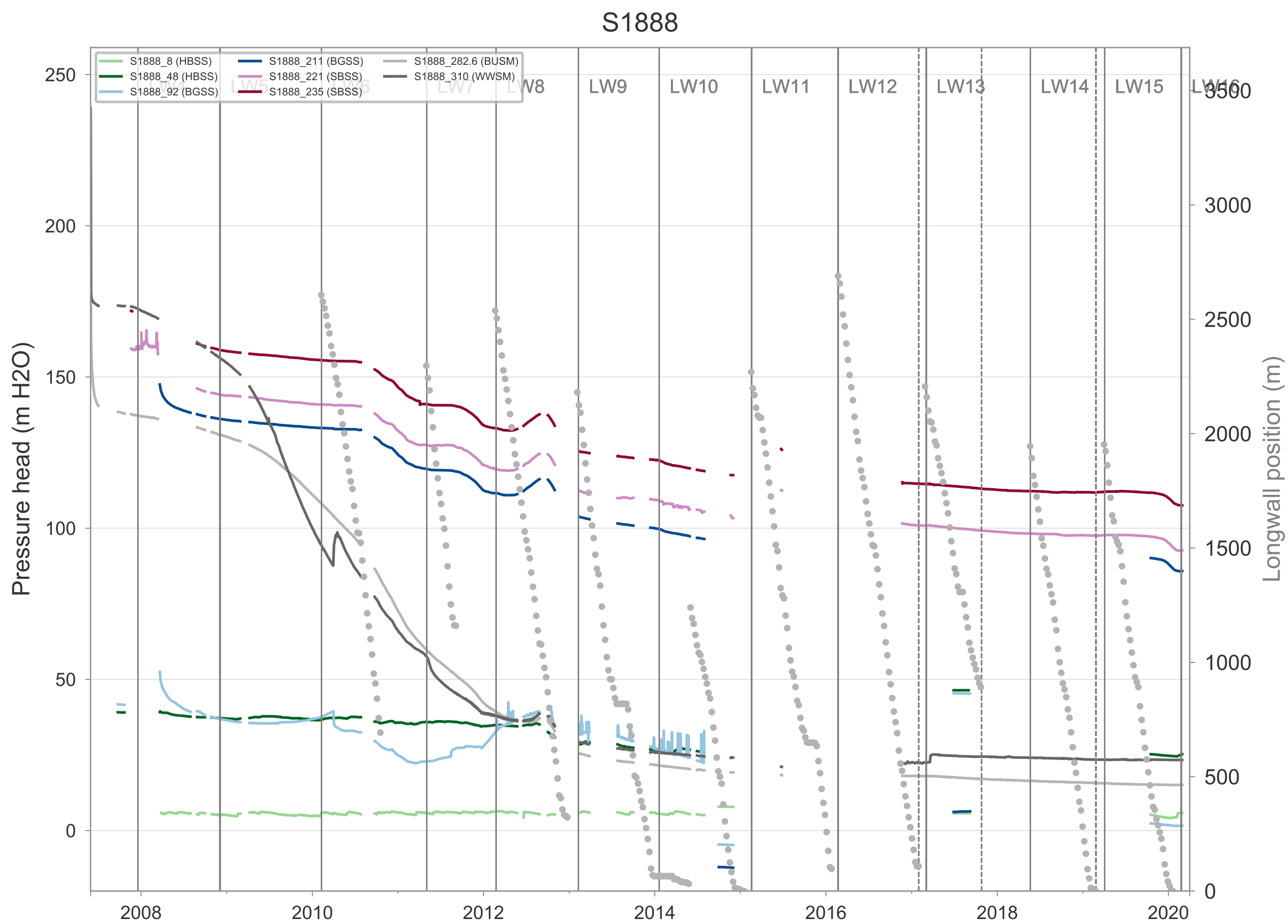

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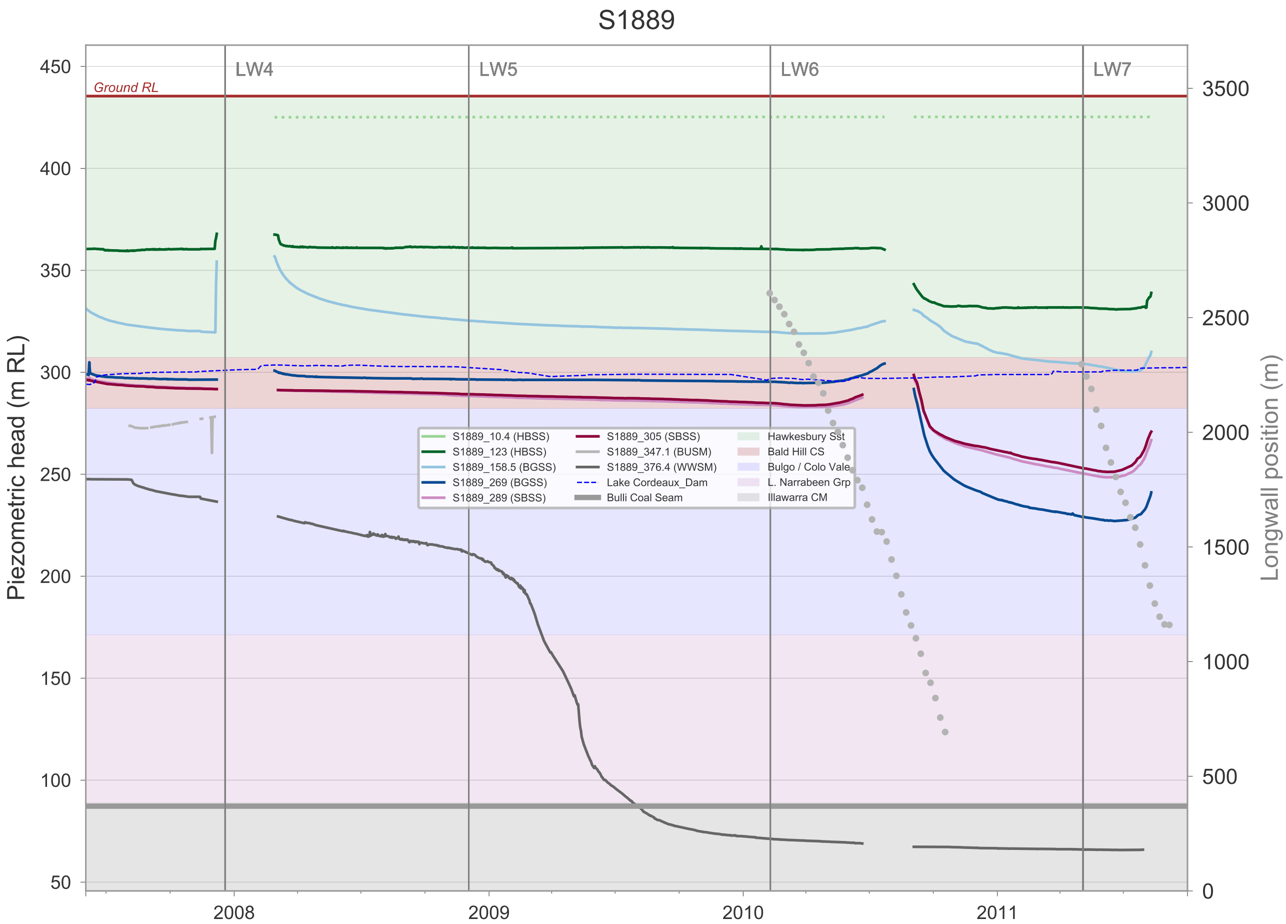

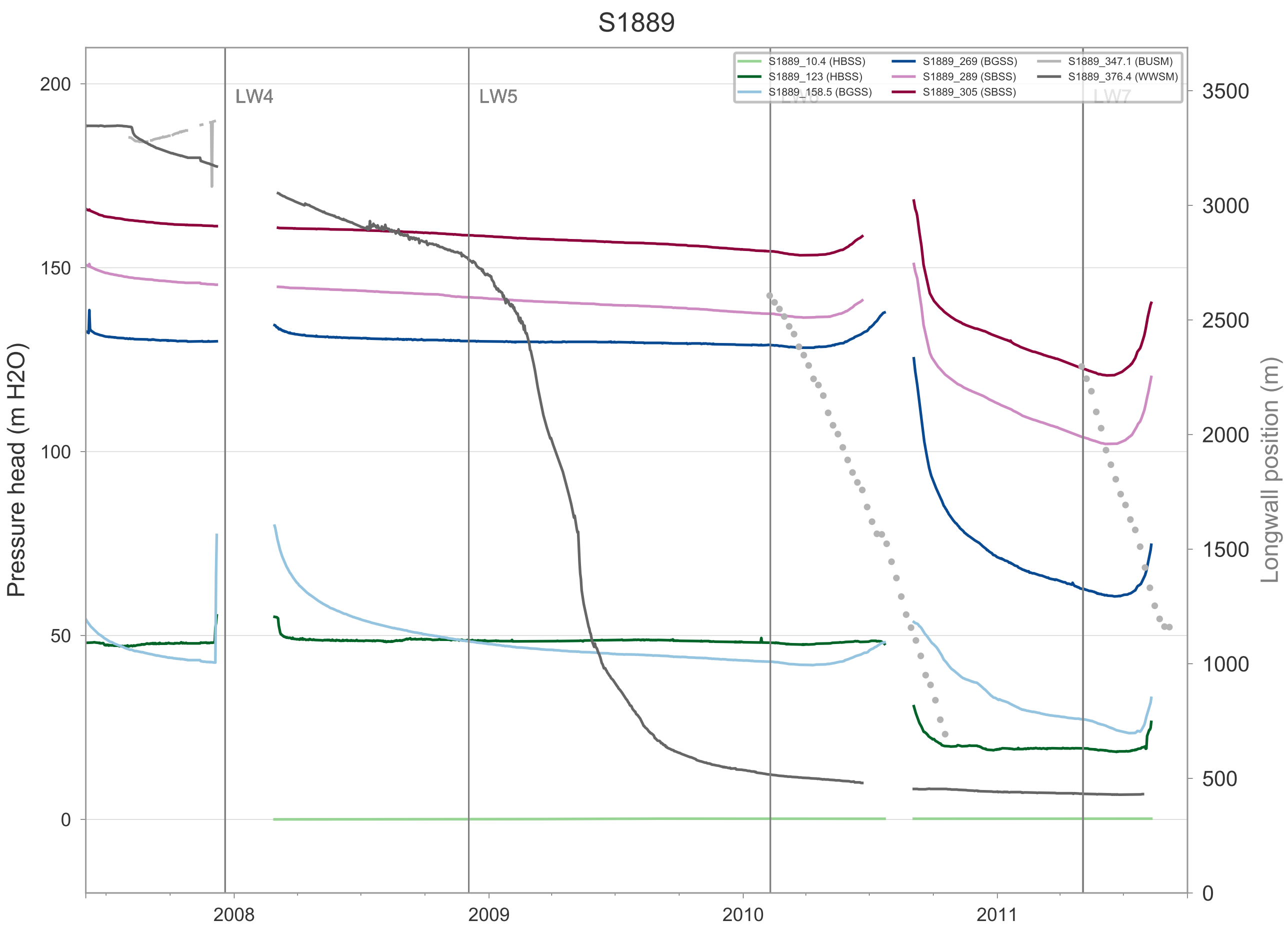

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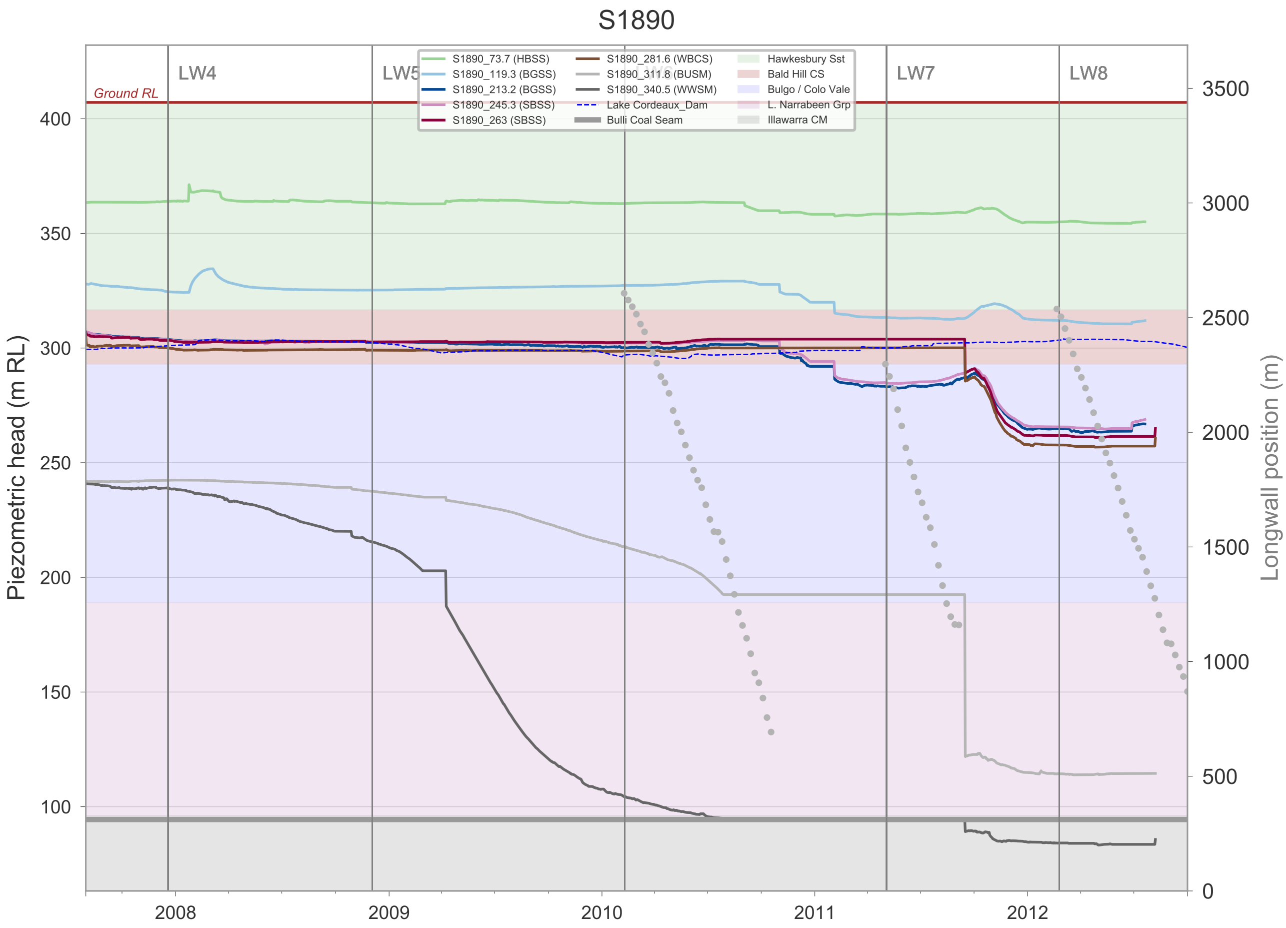

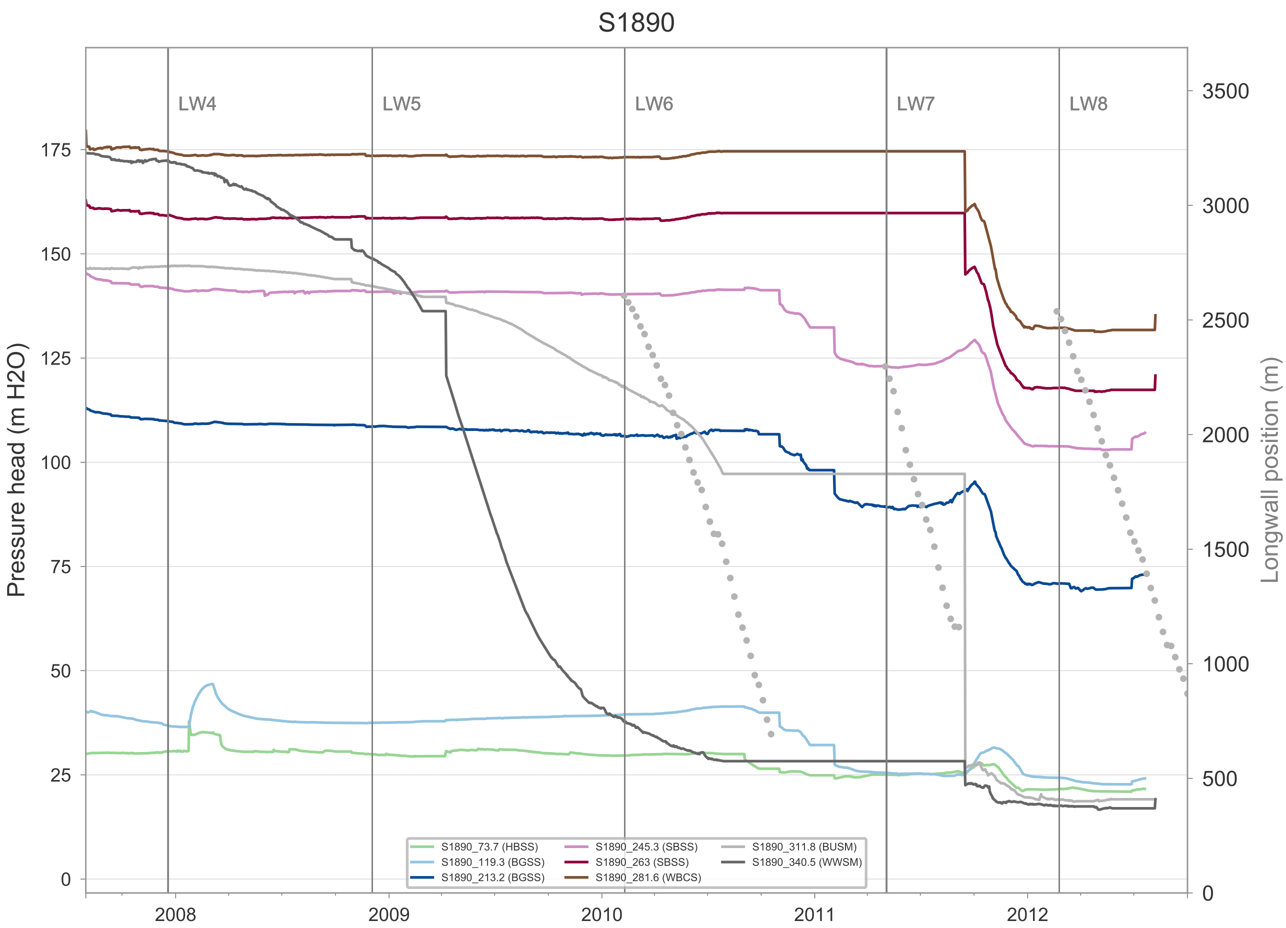

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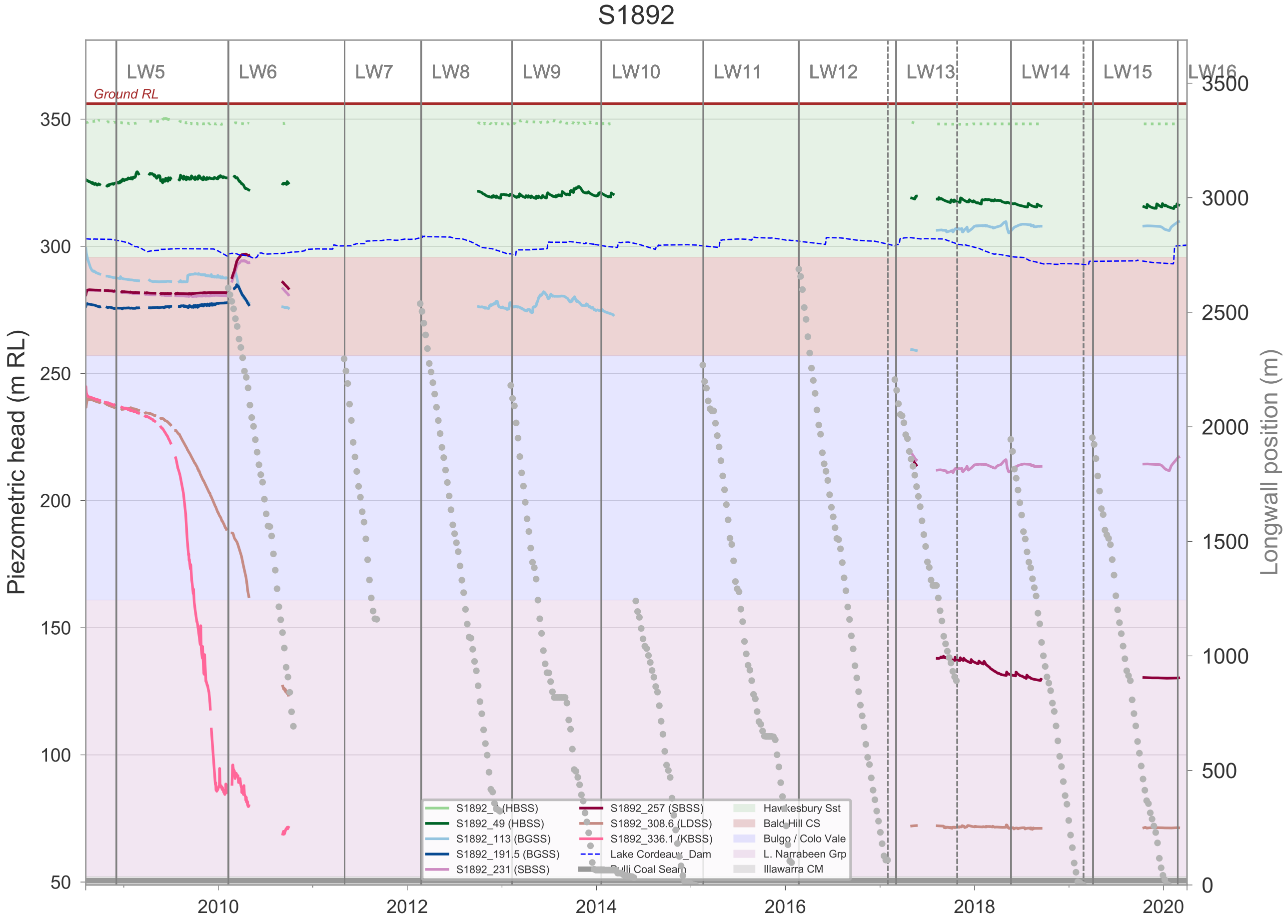

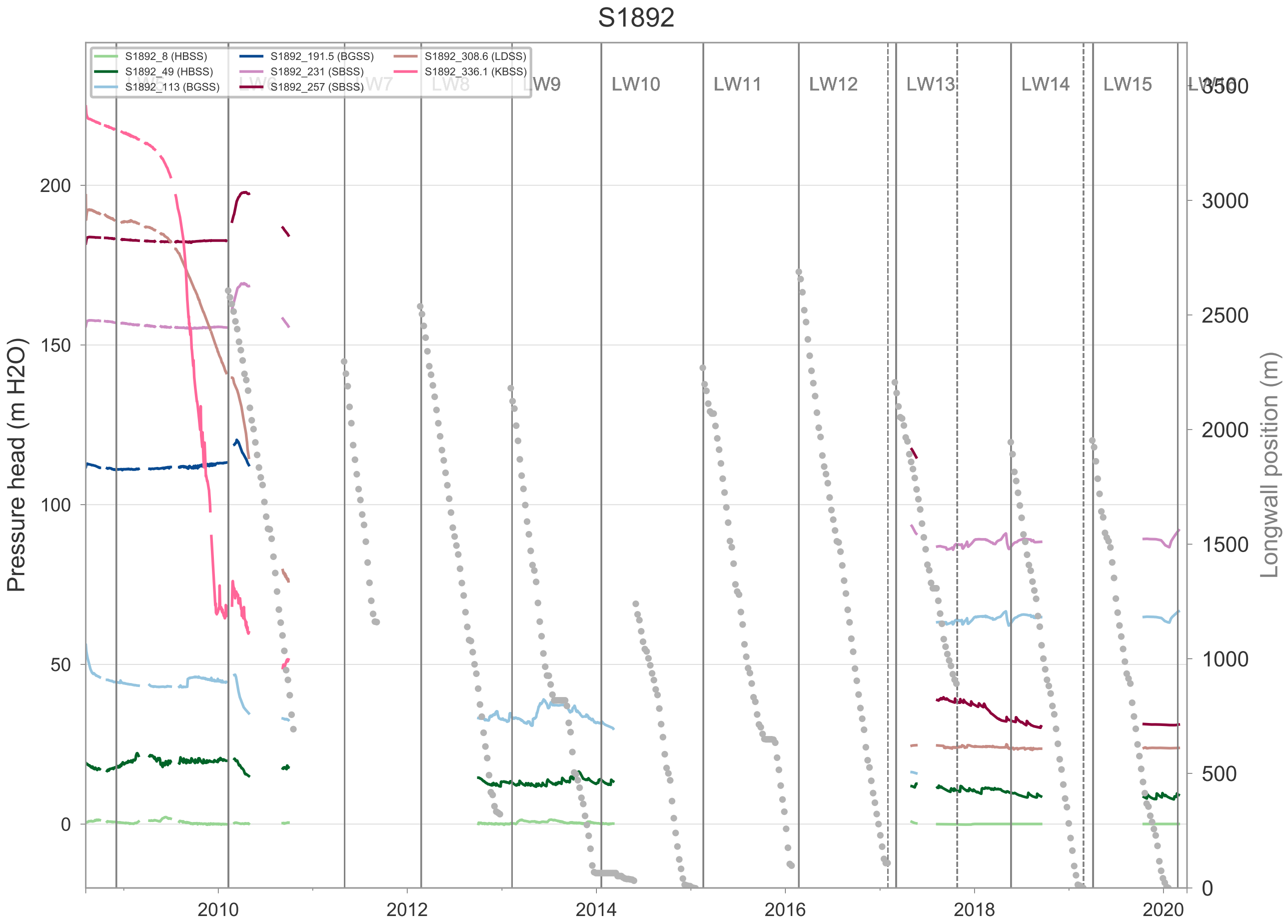

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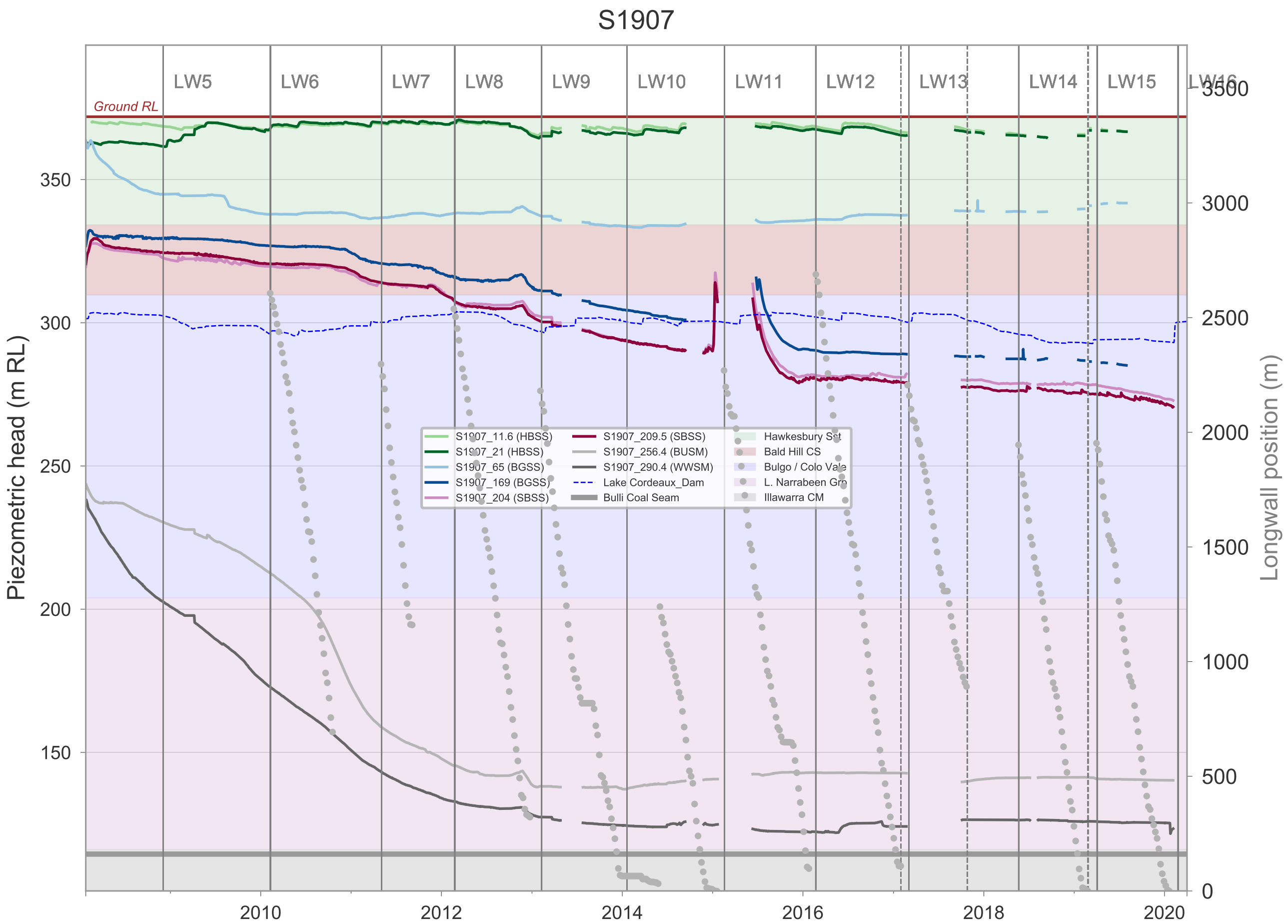
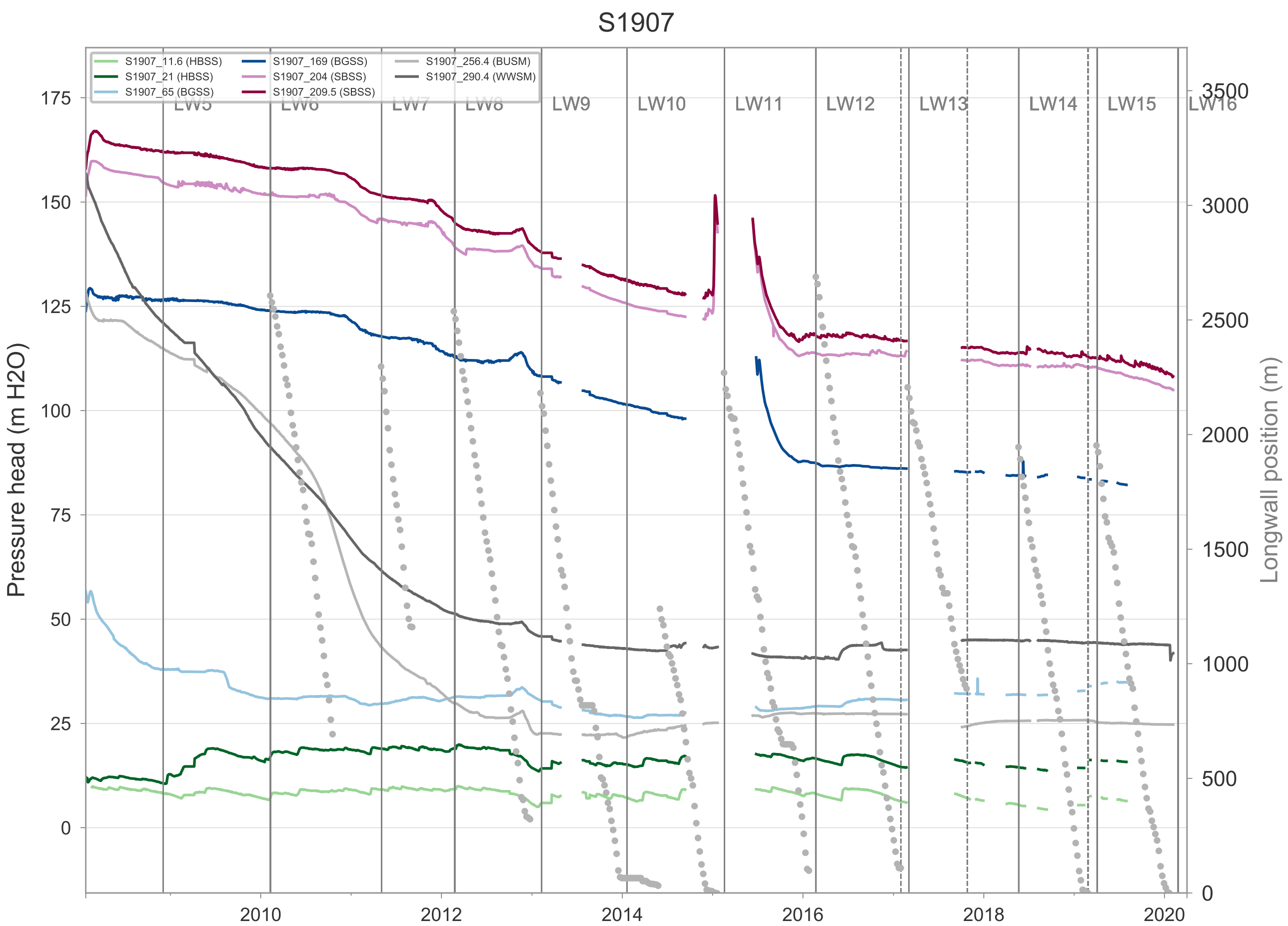
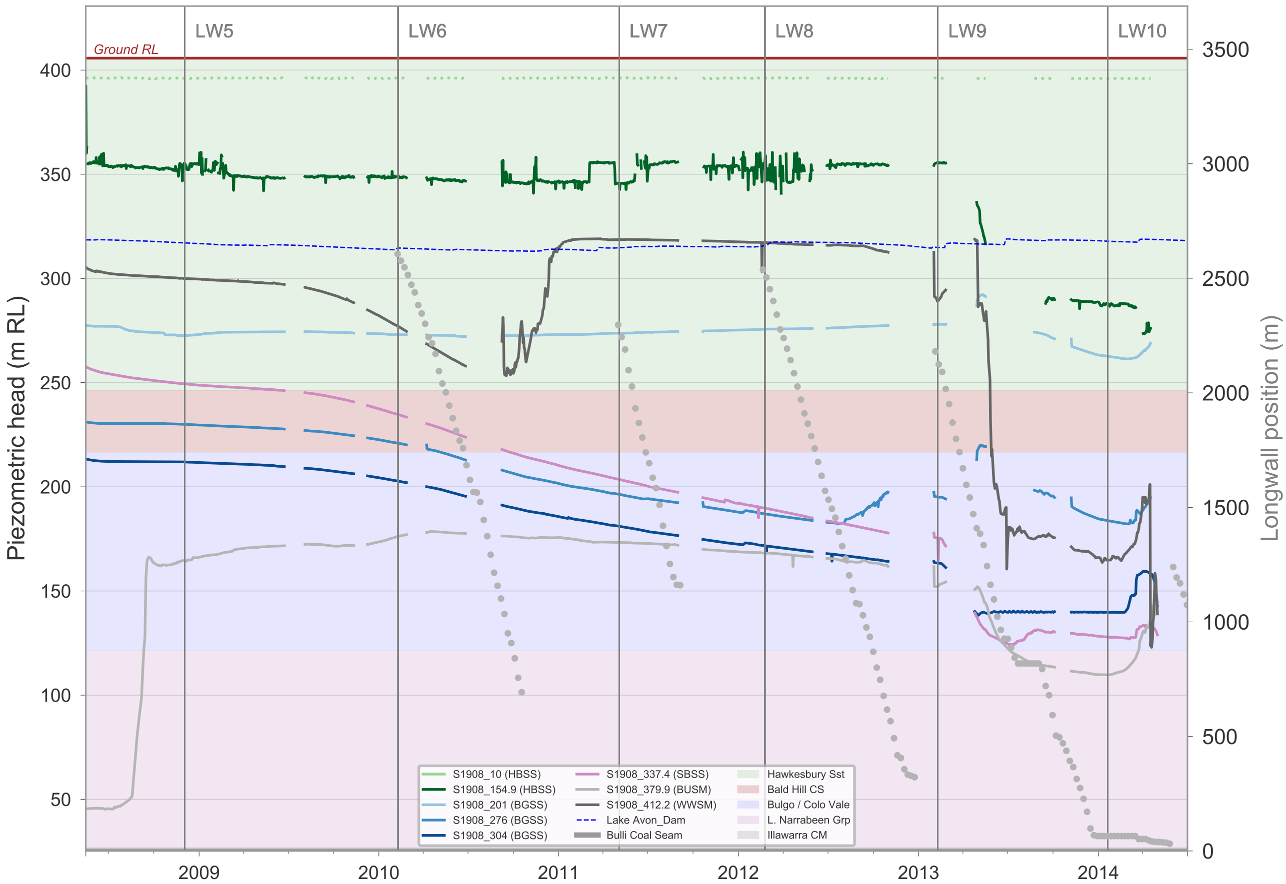




Groundwater hydrographs

S1908



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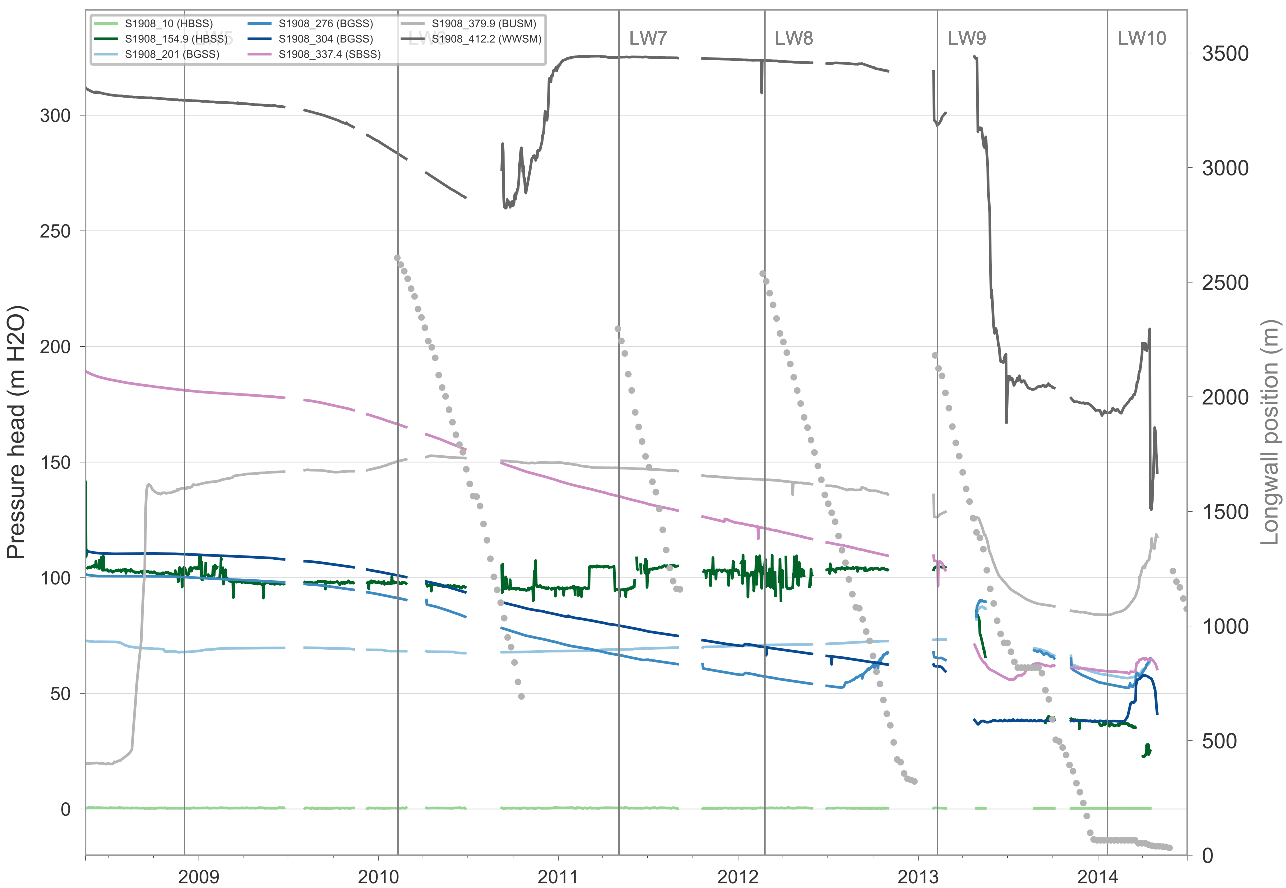
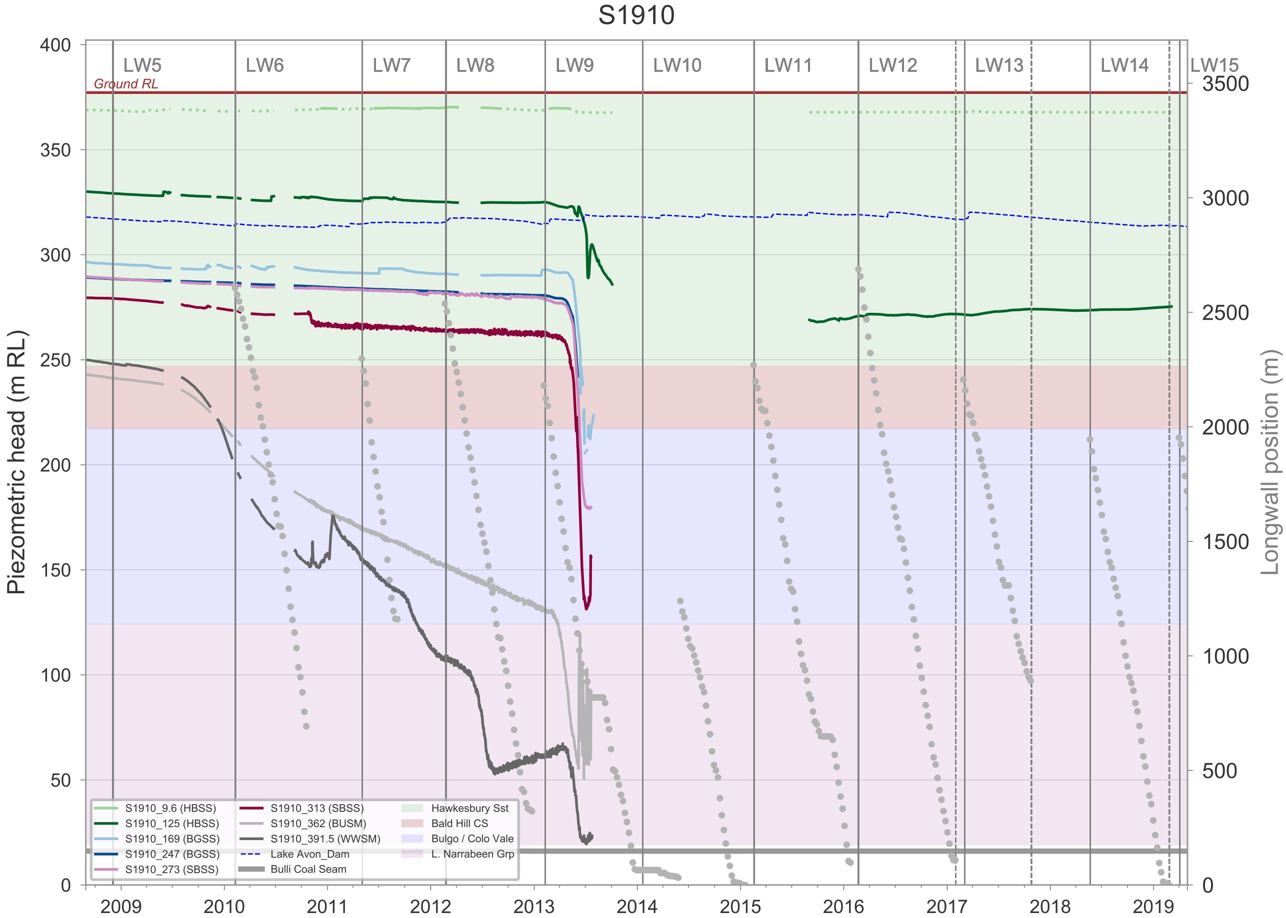
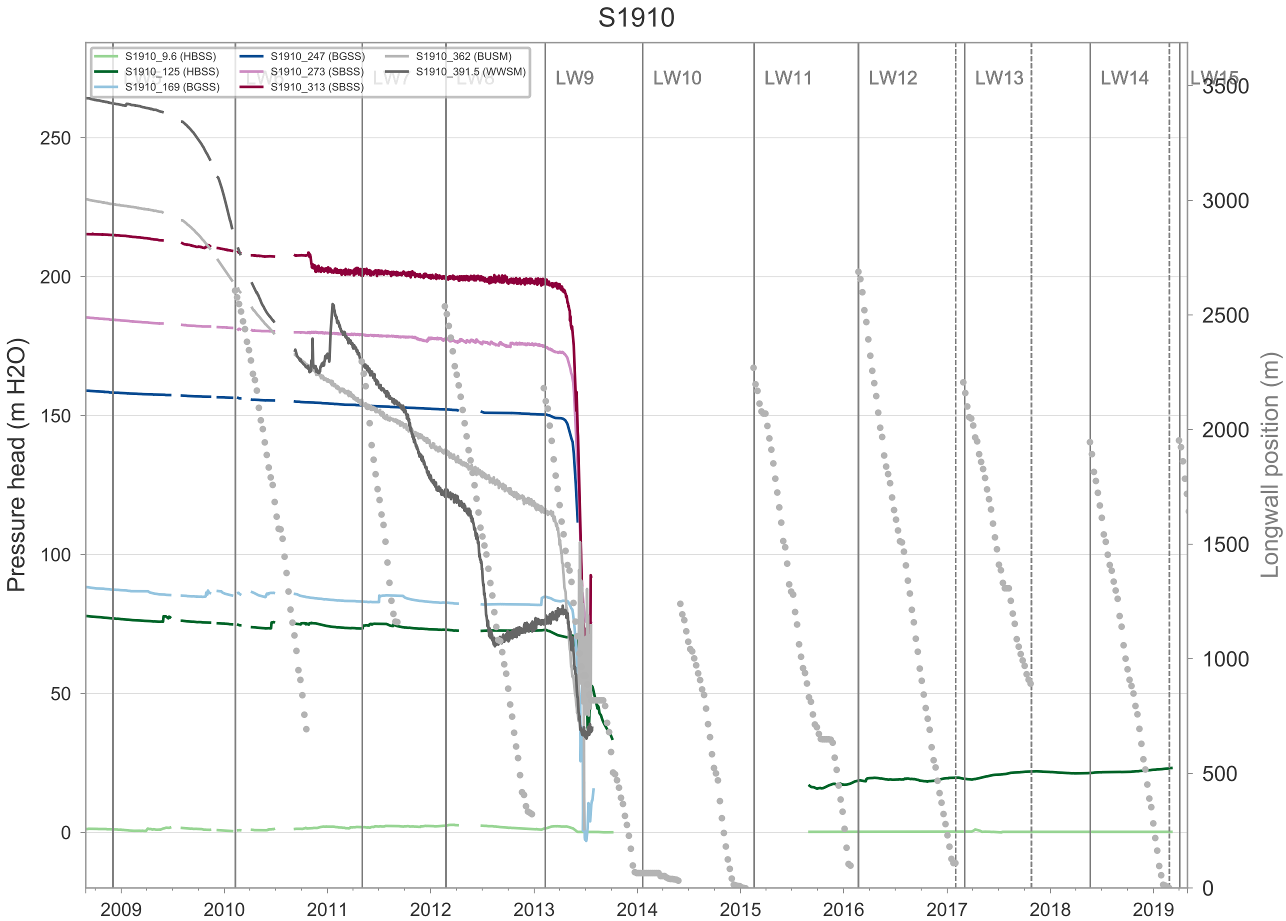
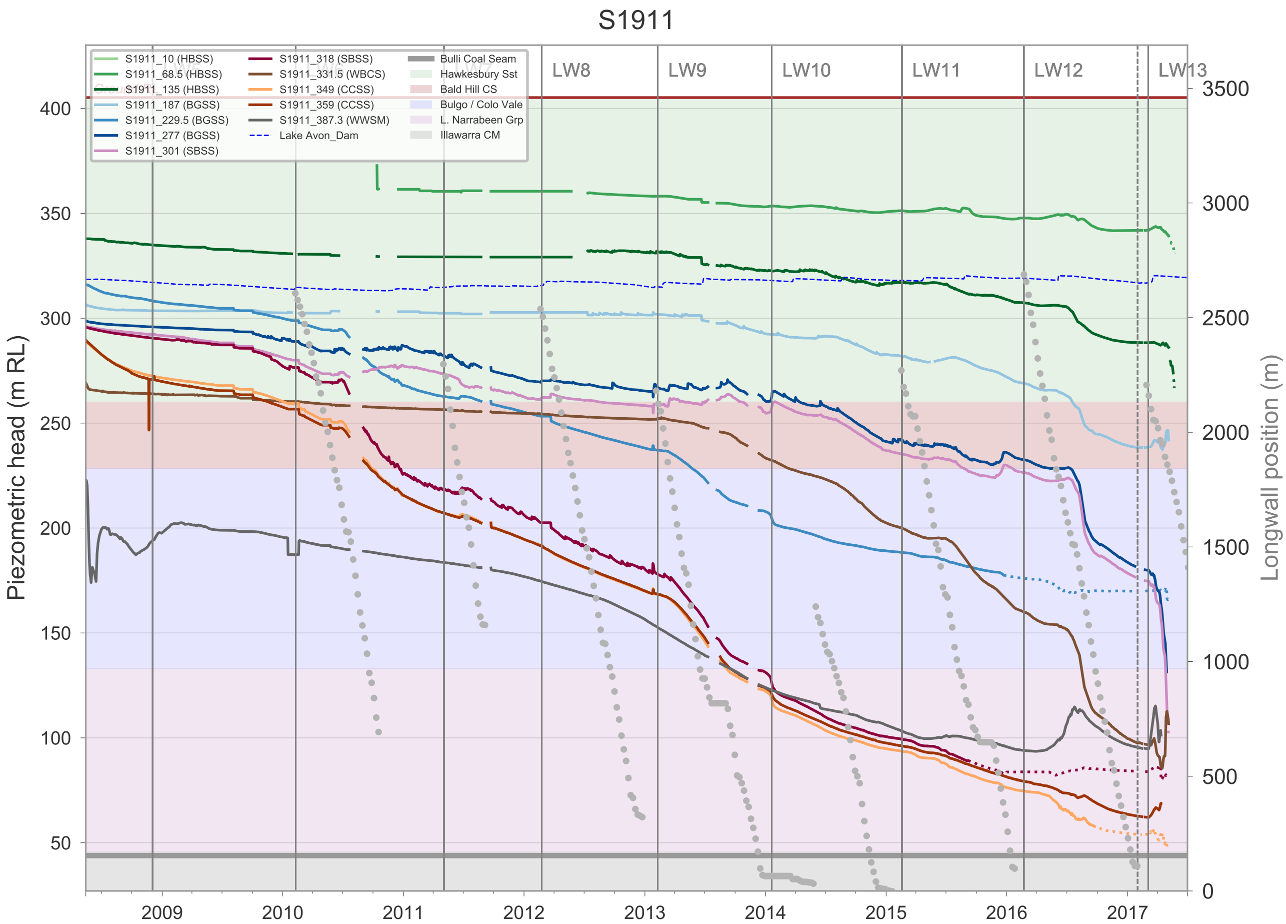


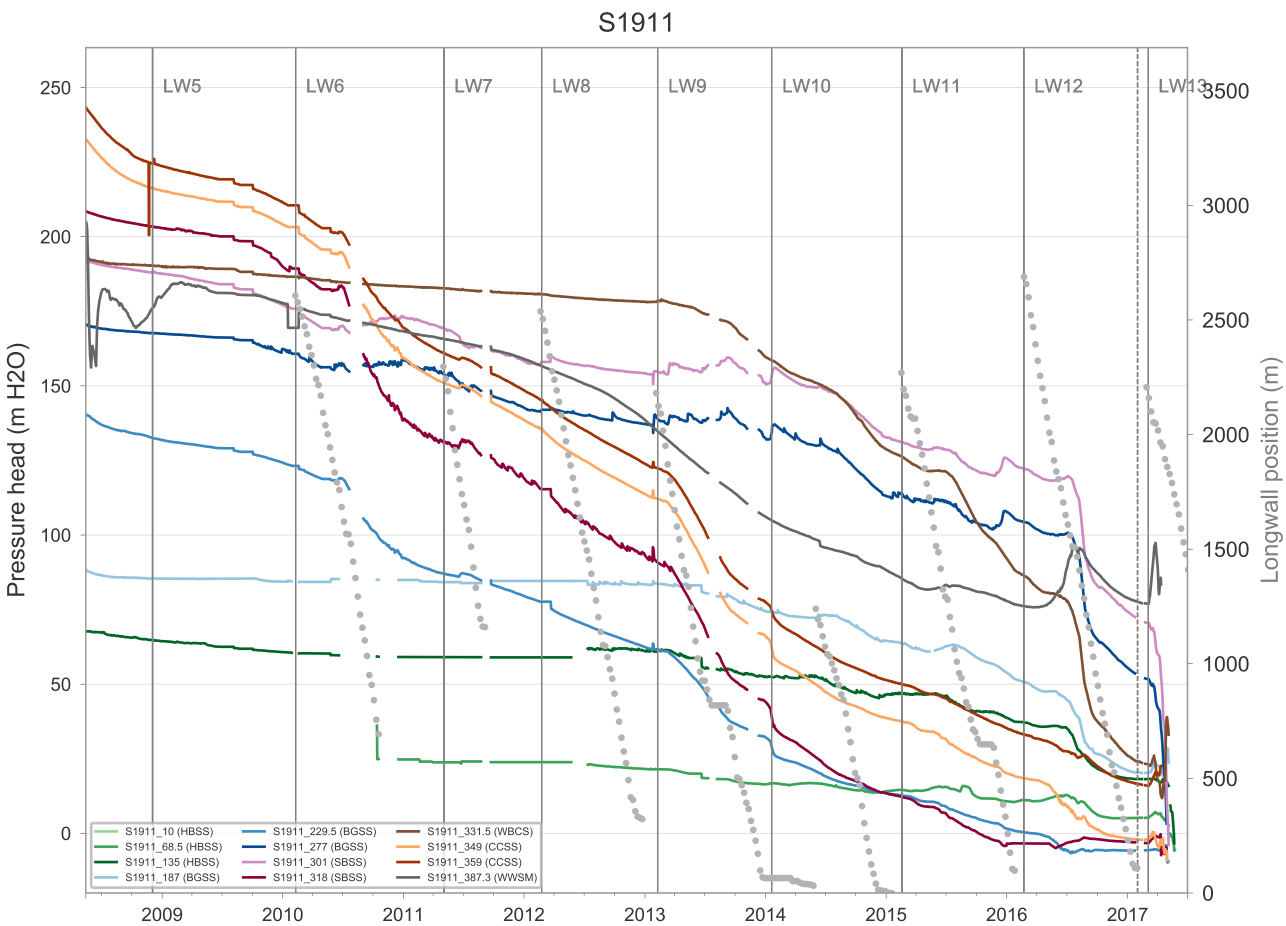
Groundwater hydrographs



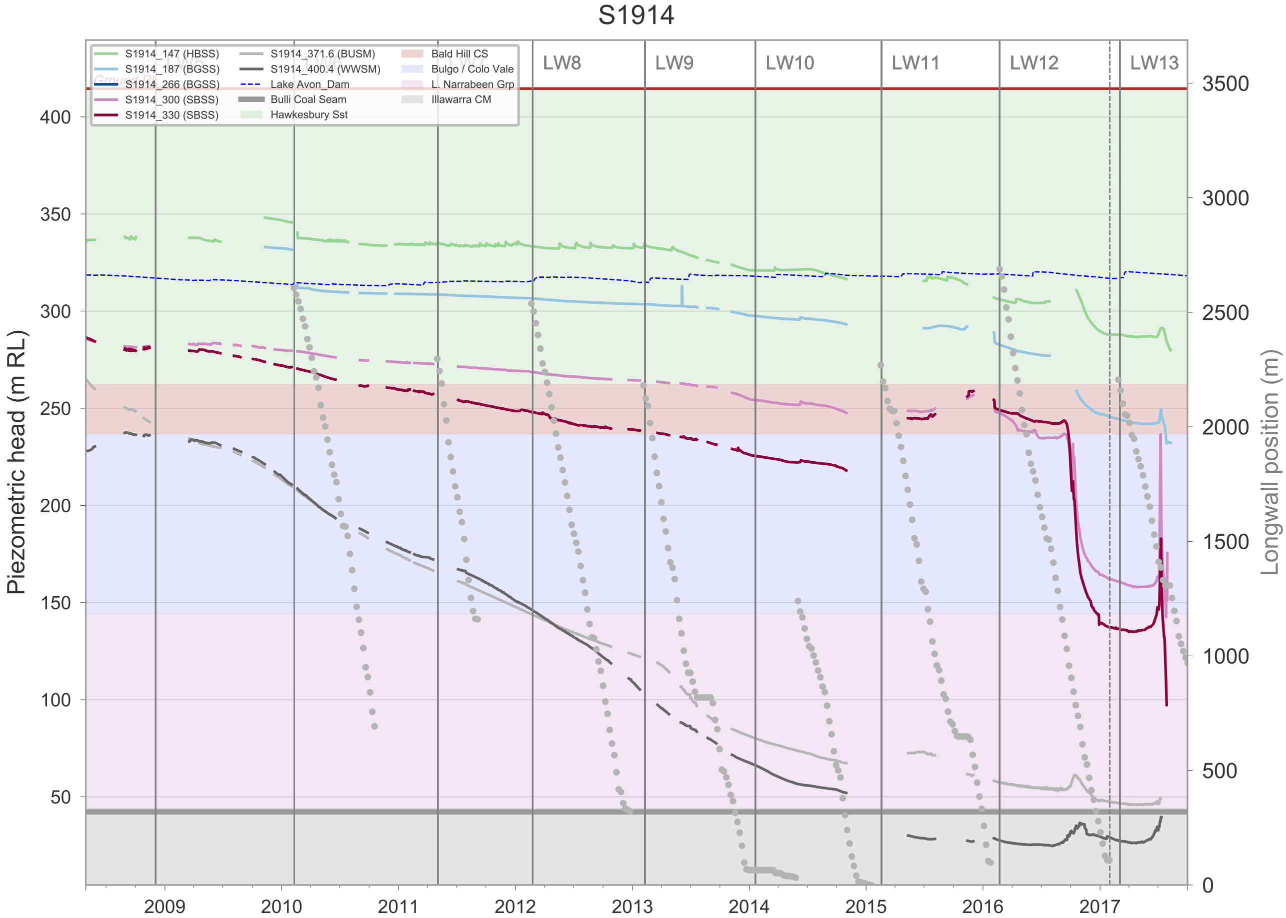


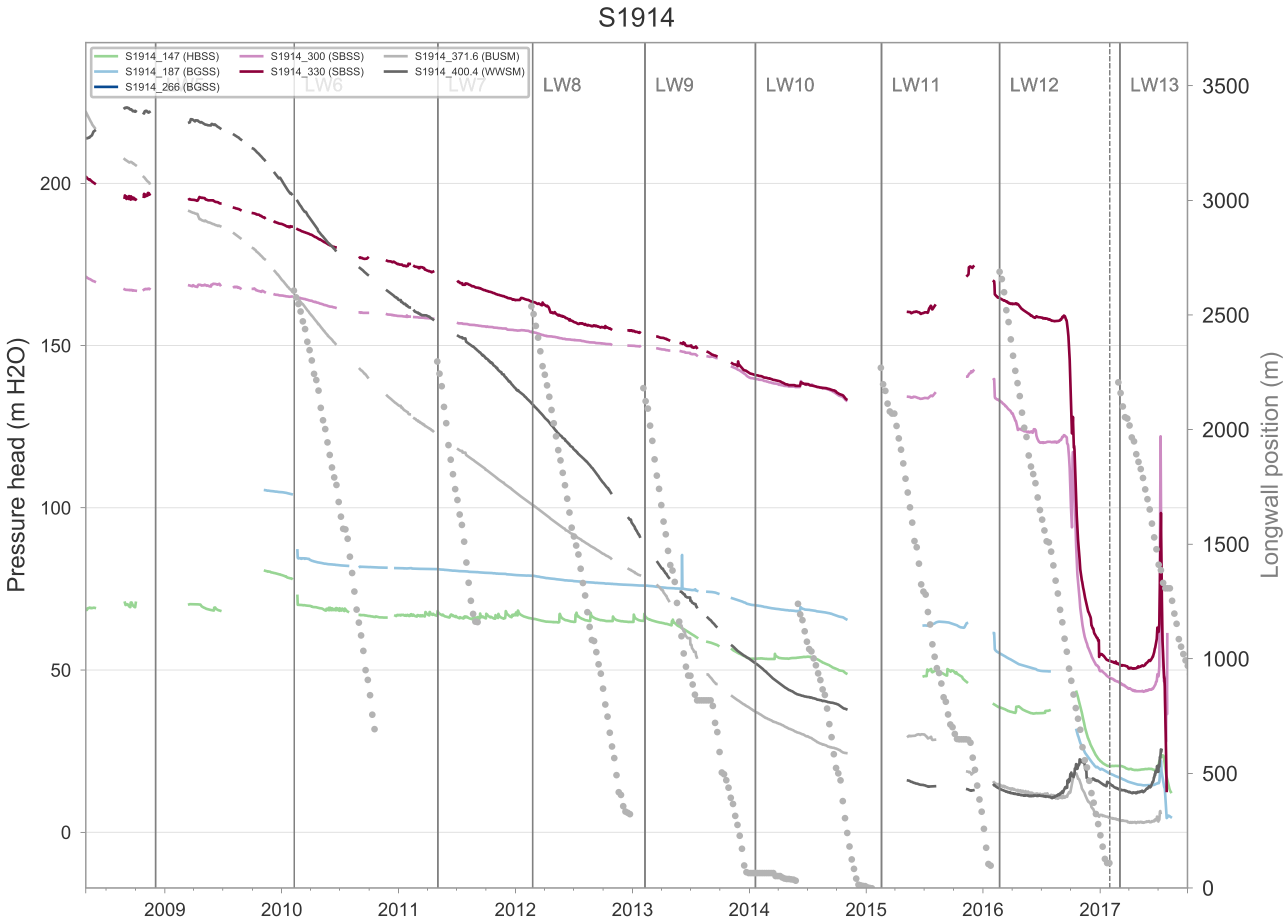
Groundwater hydrographs





Groundwater hydrographs





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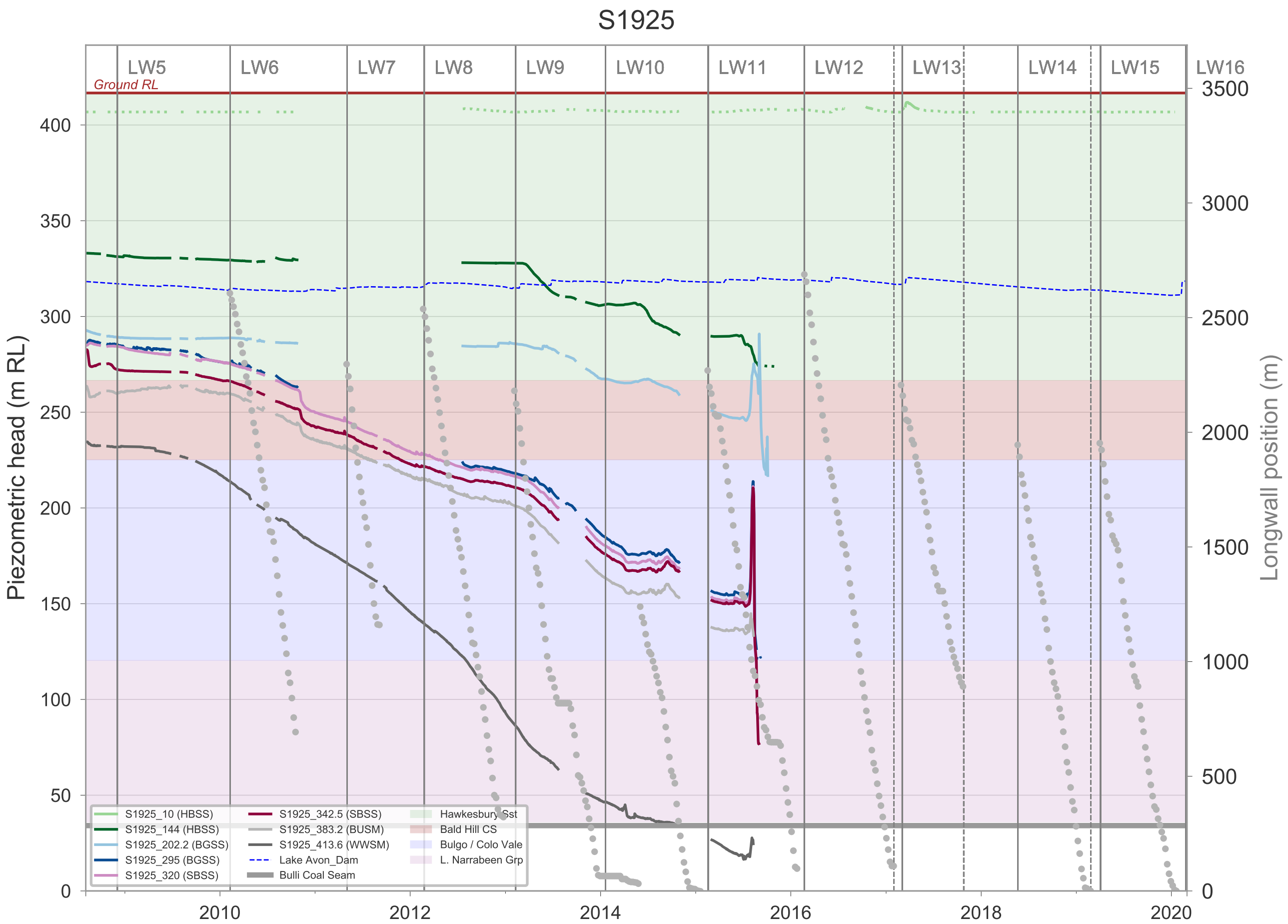

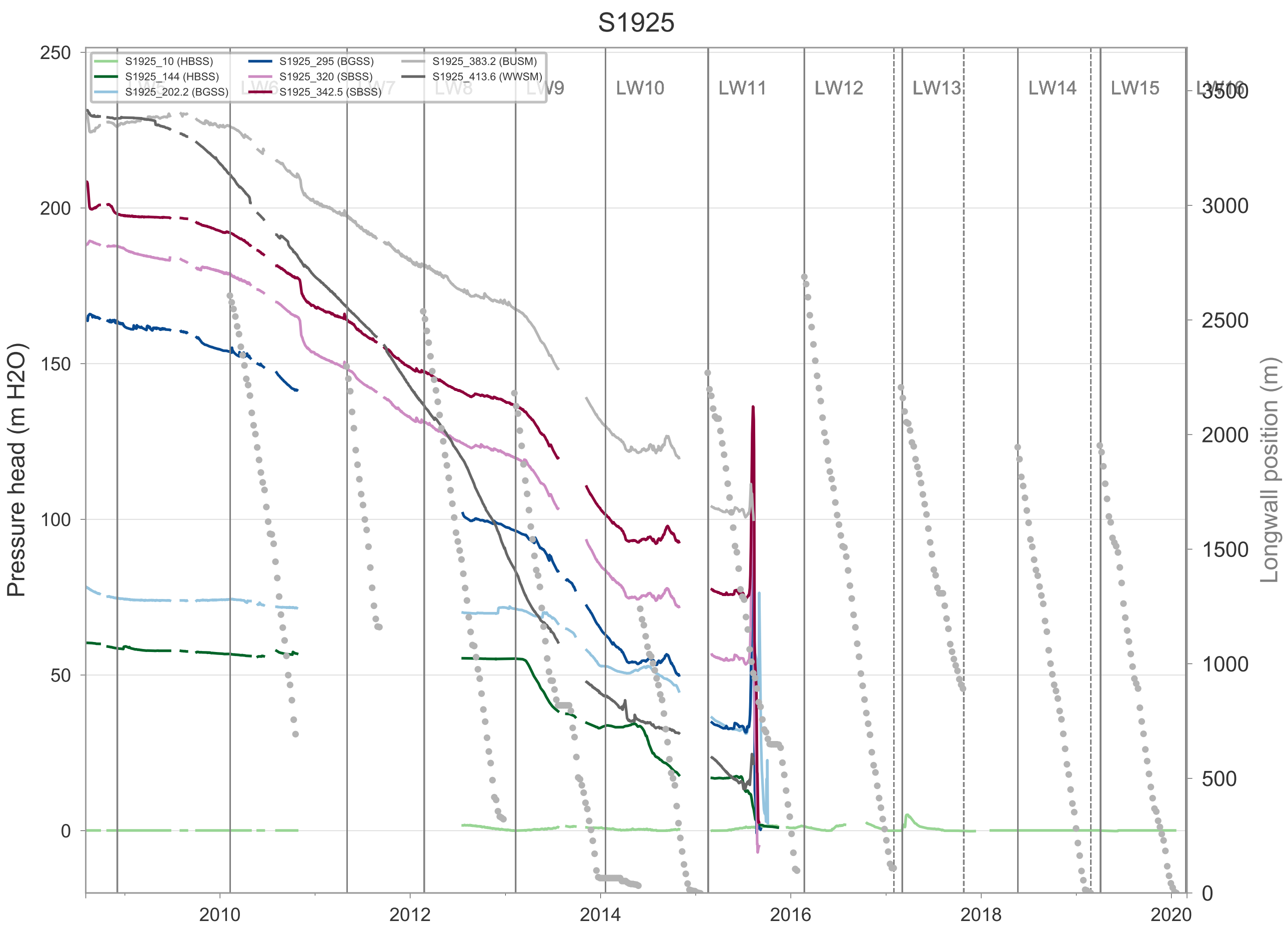

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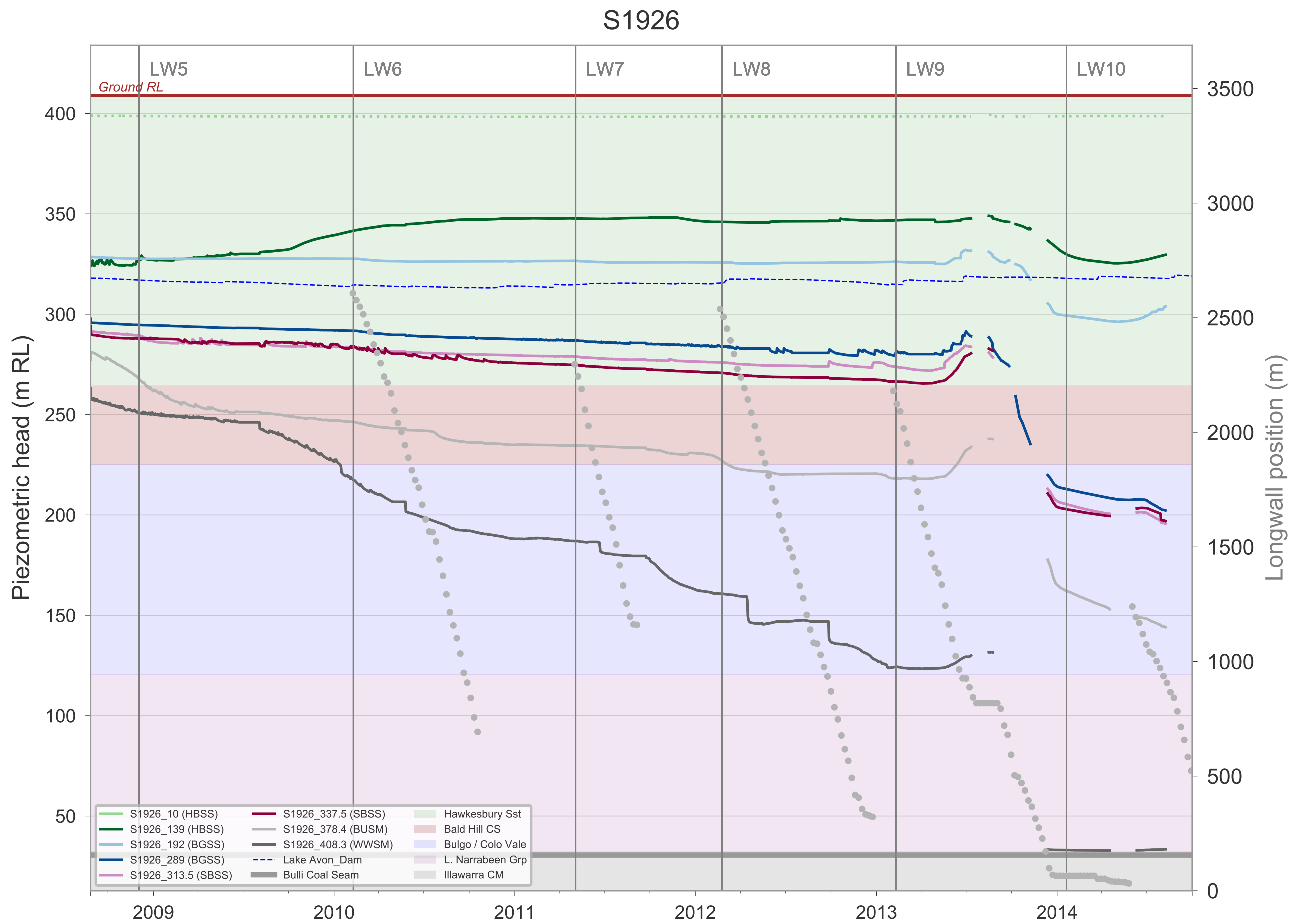

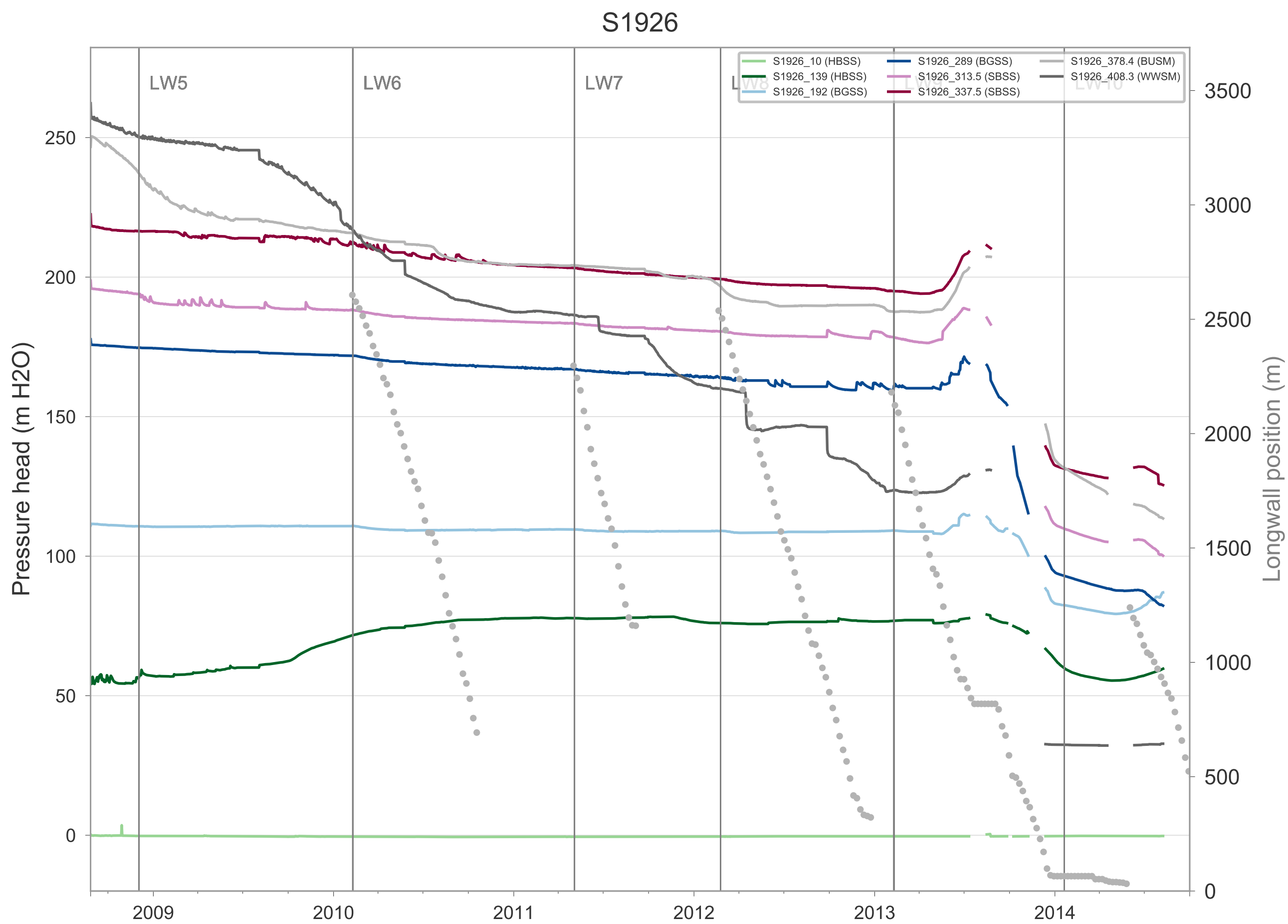

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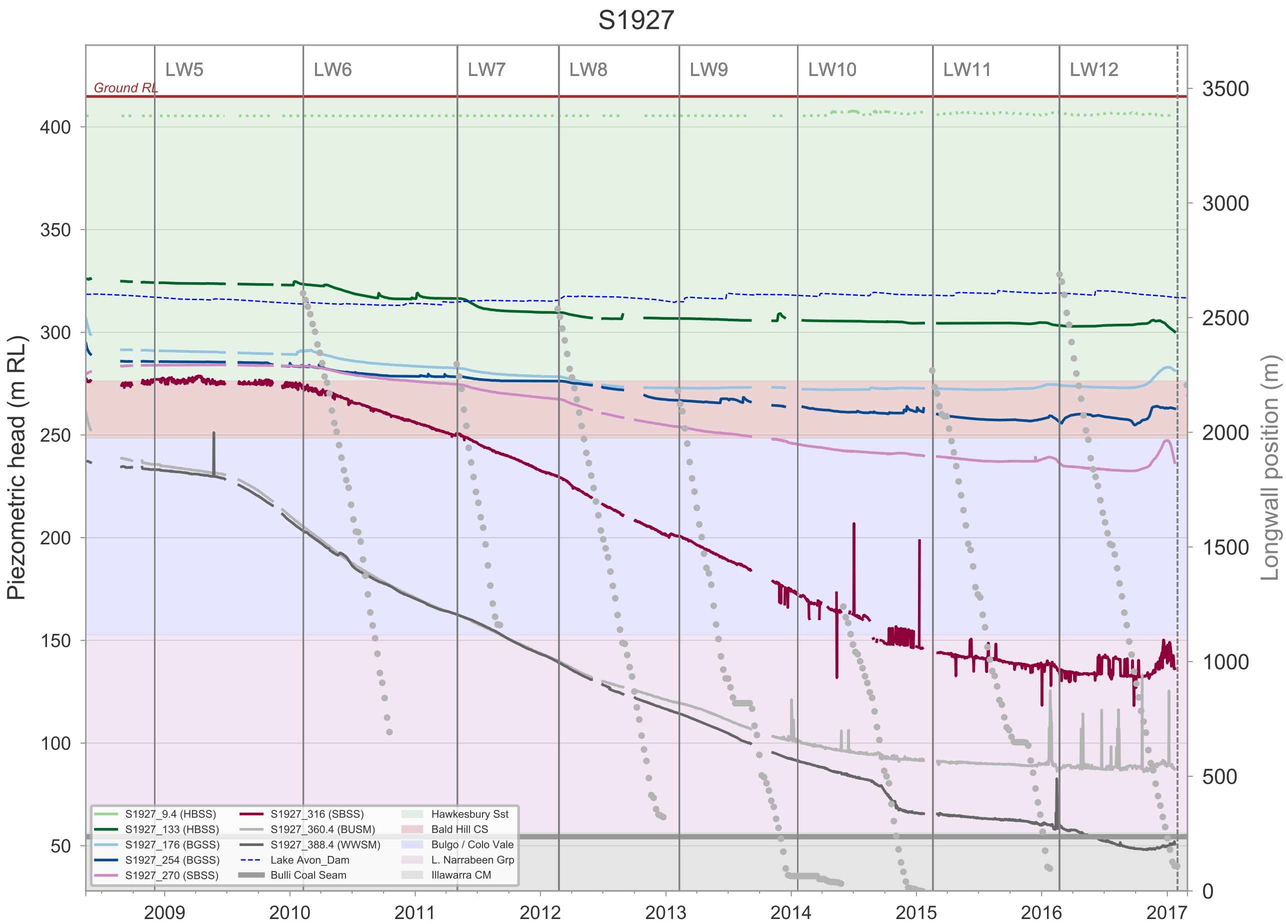

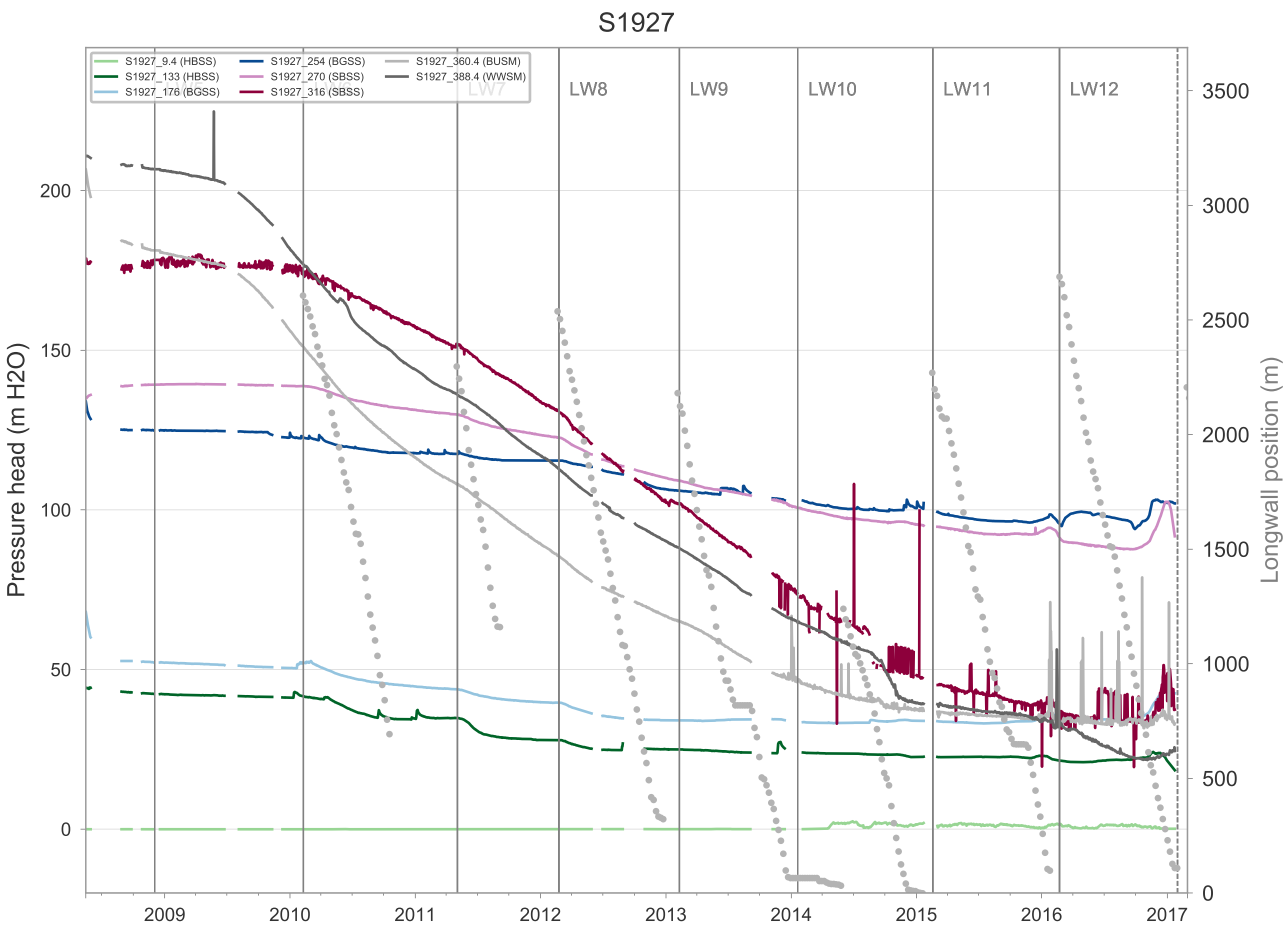

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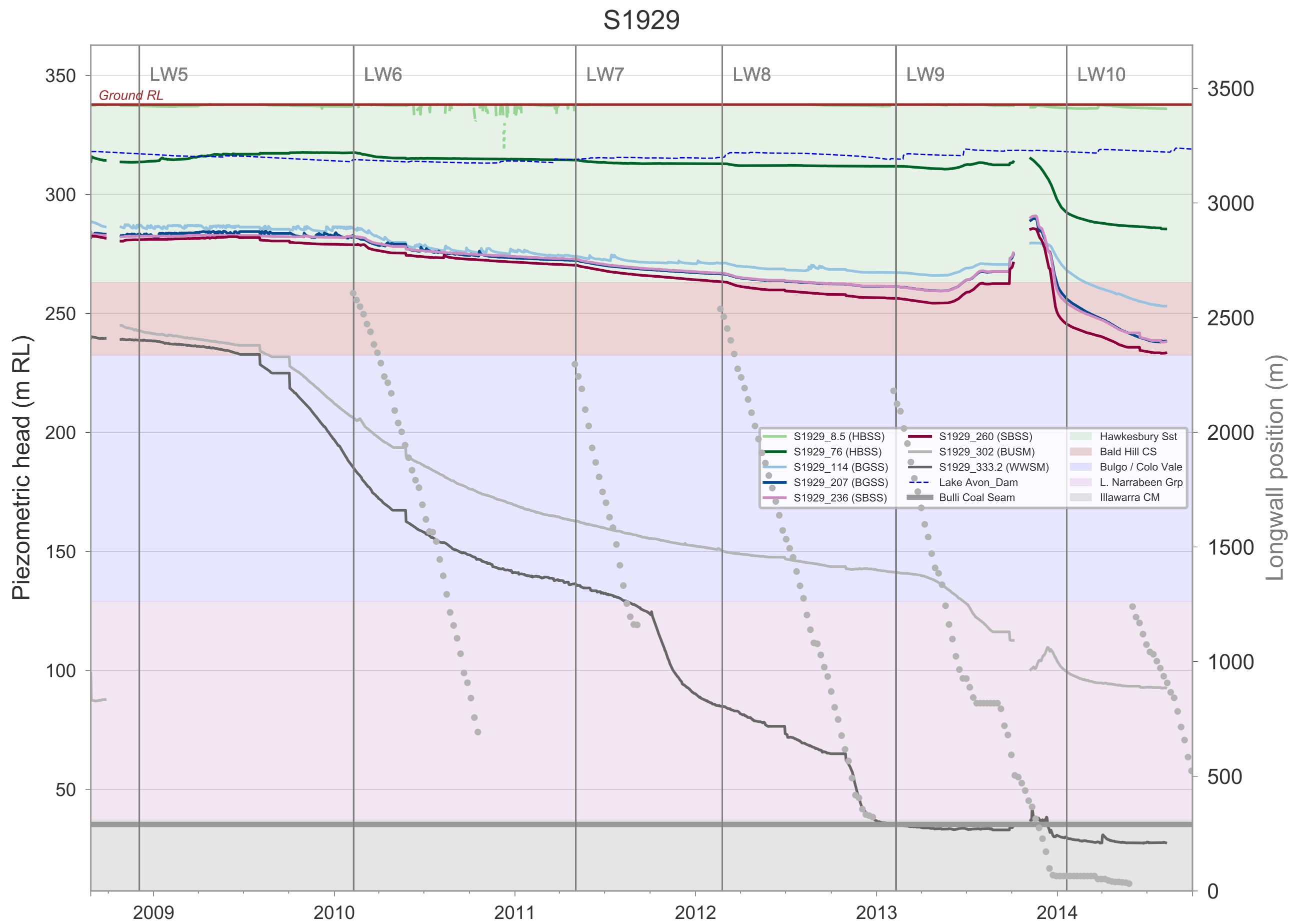
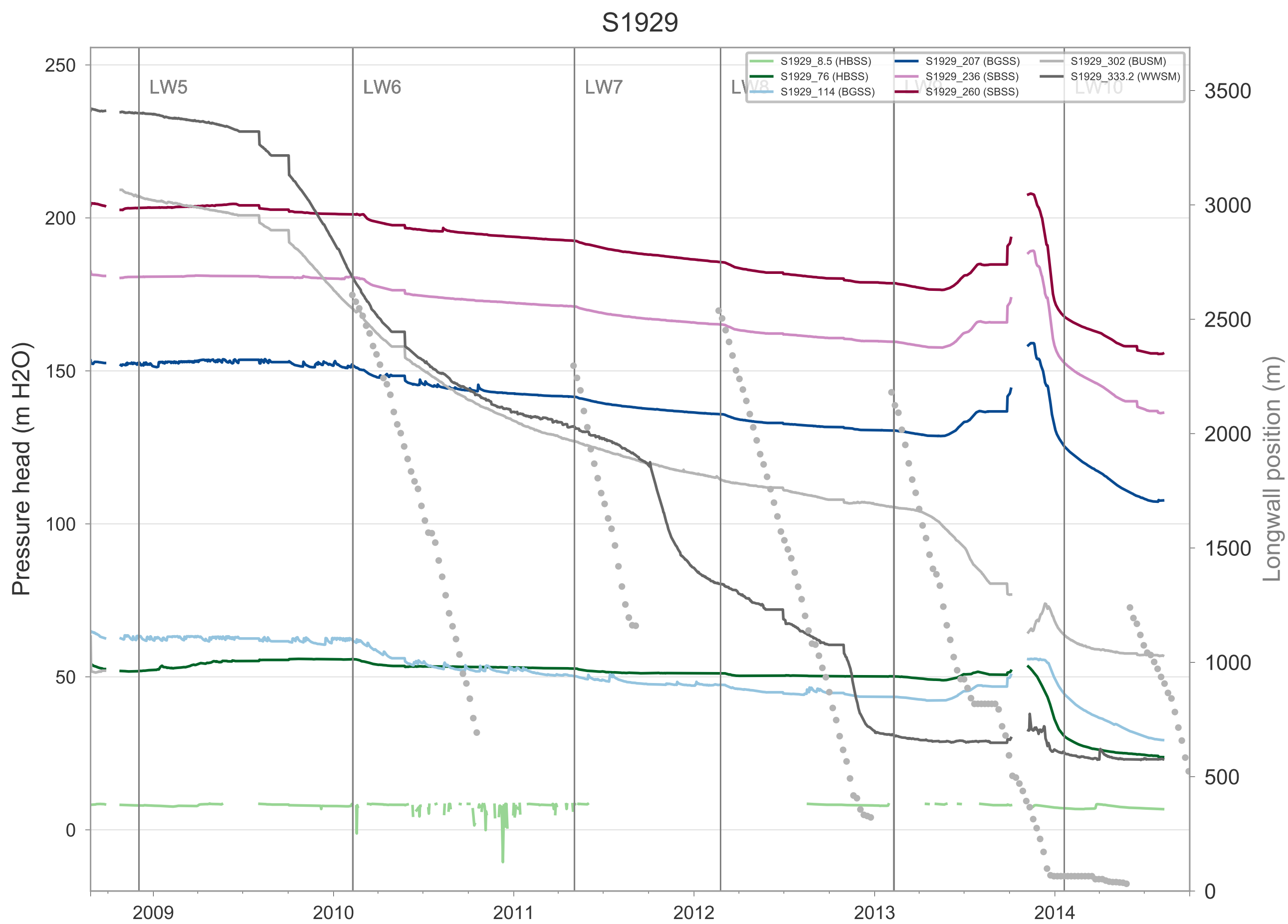
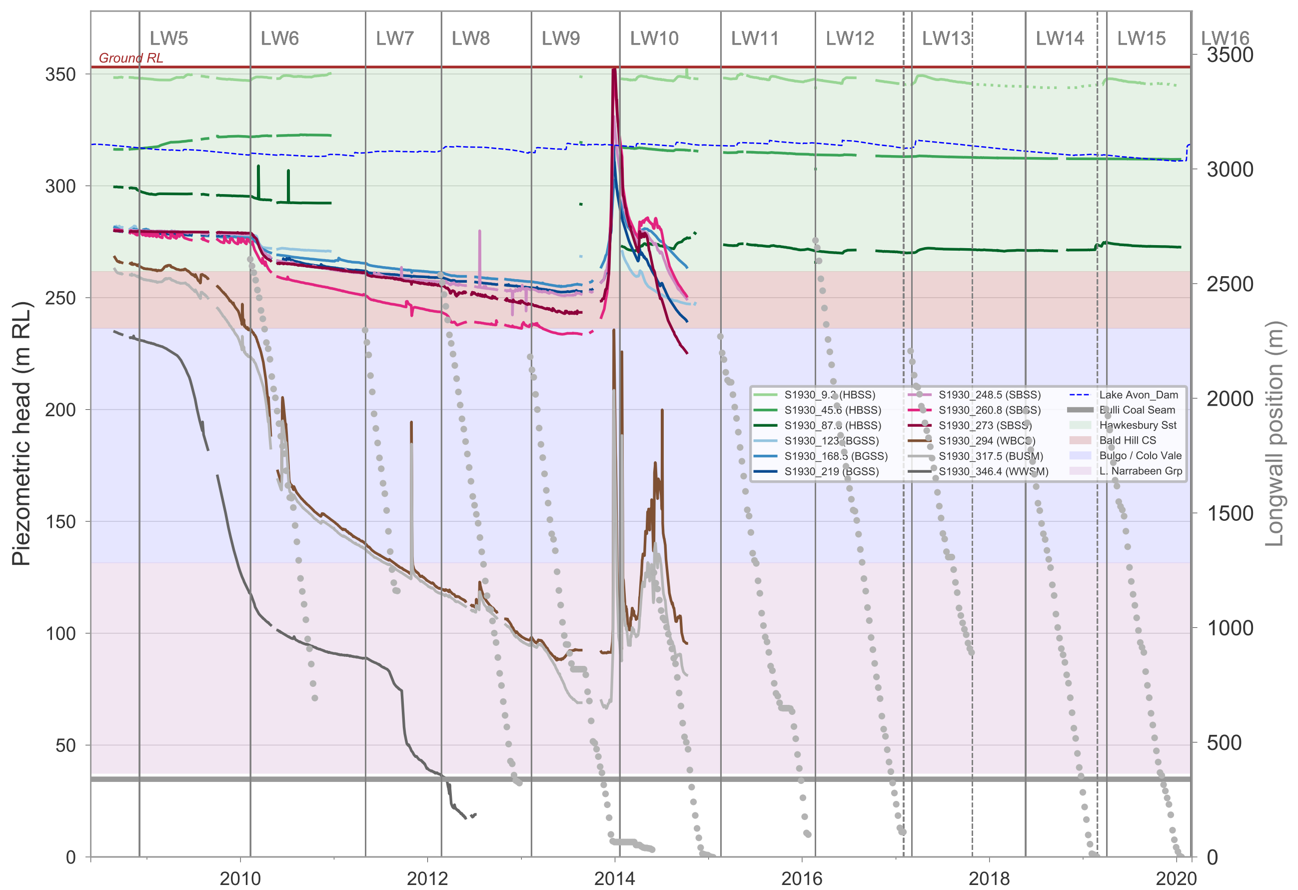




Groundwater hydrographs

S1930



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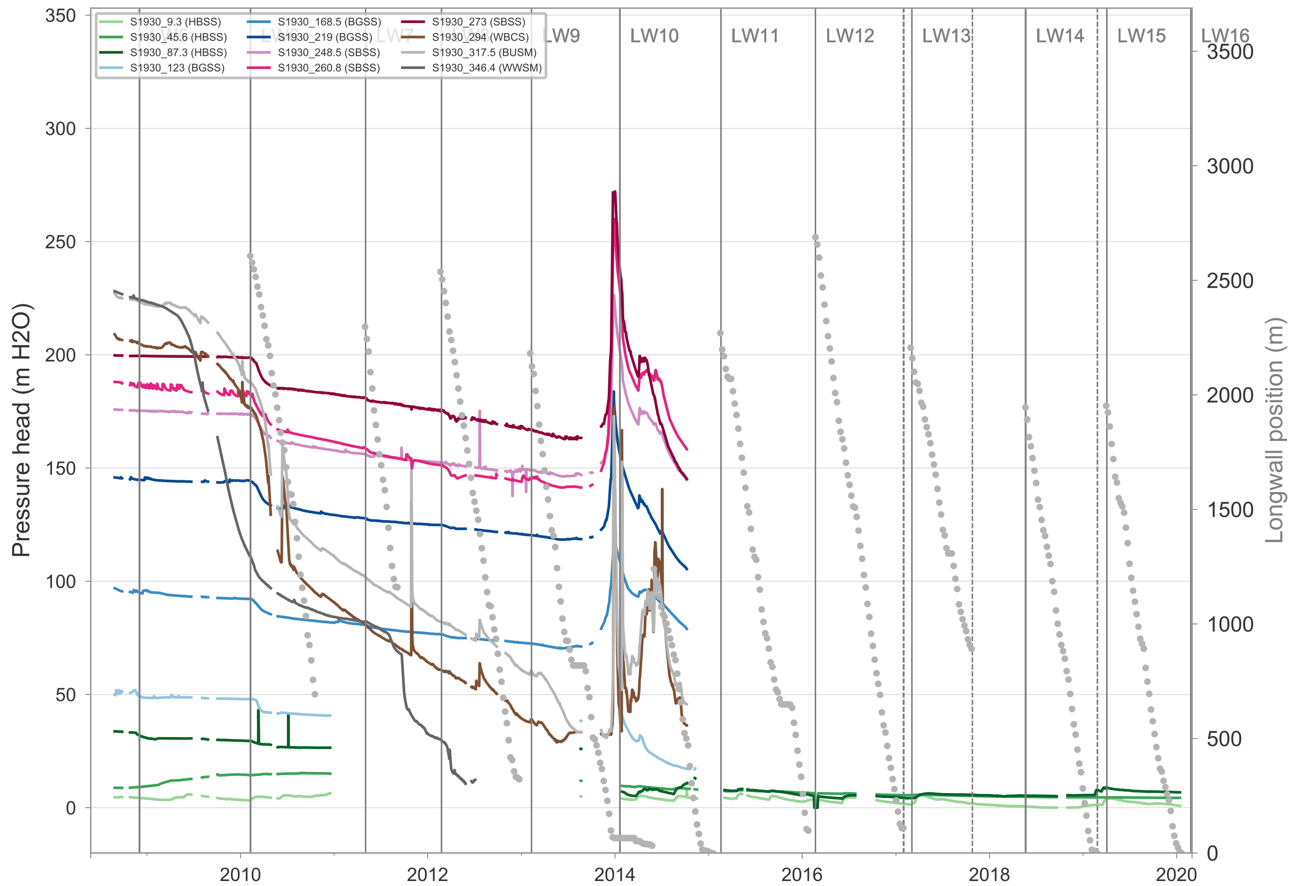
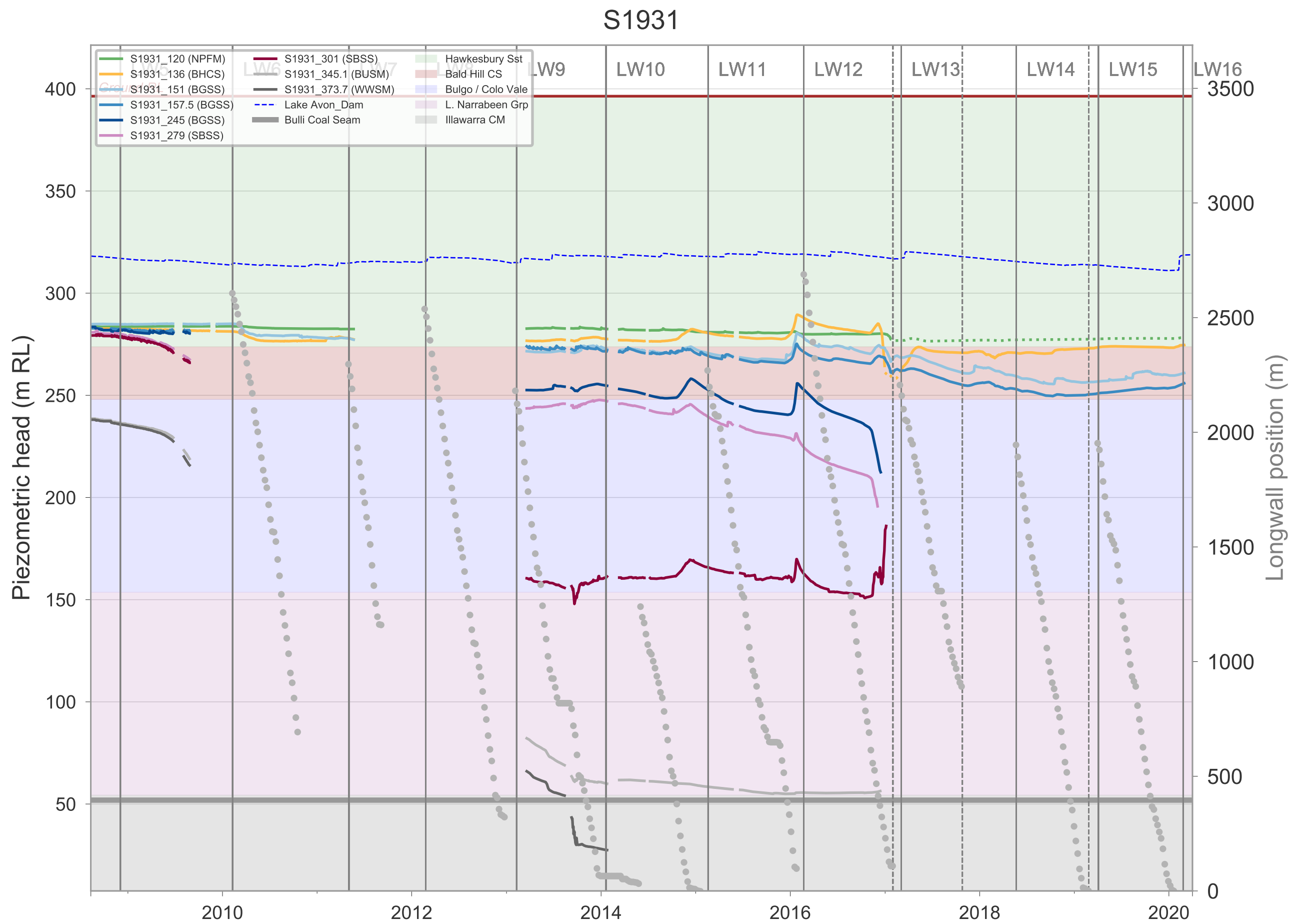
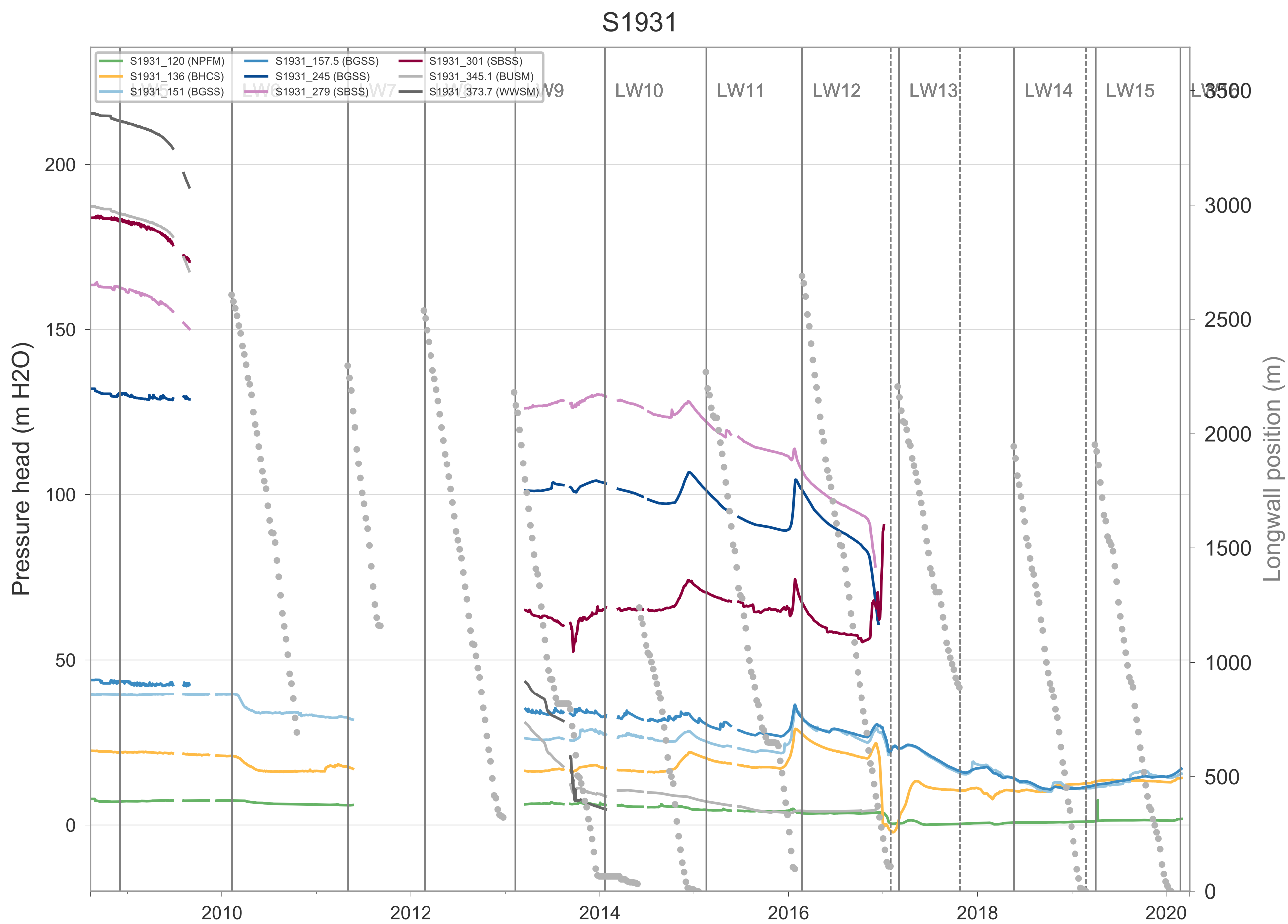


Groundwater hydrographs





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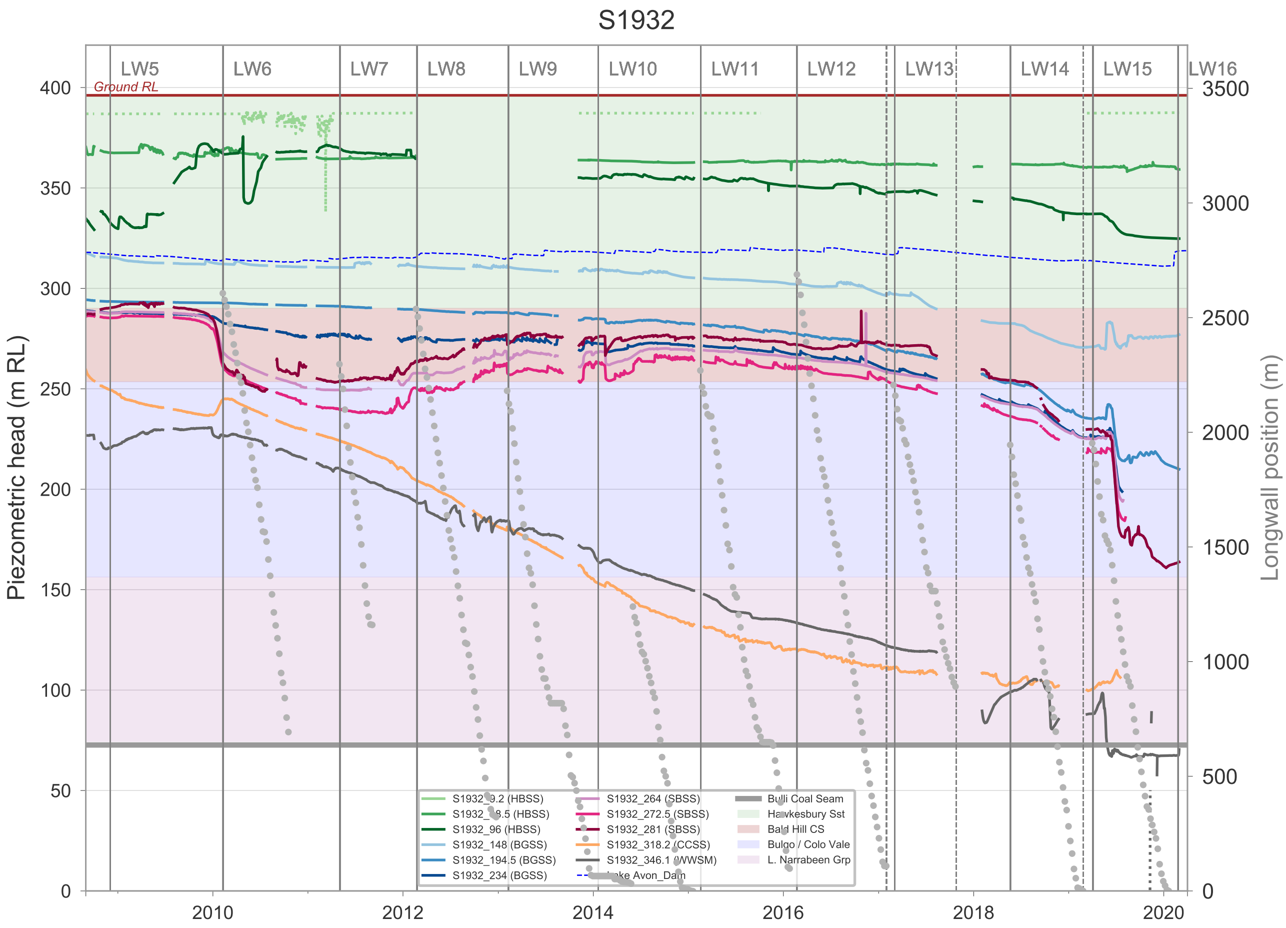

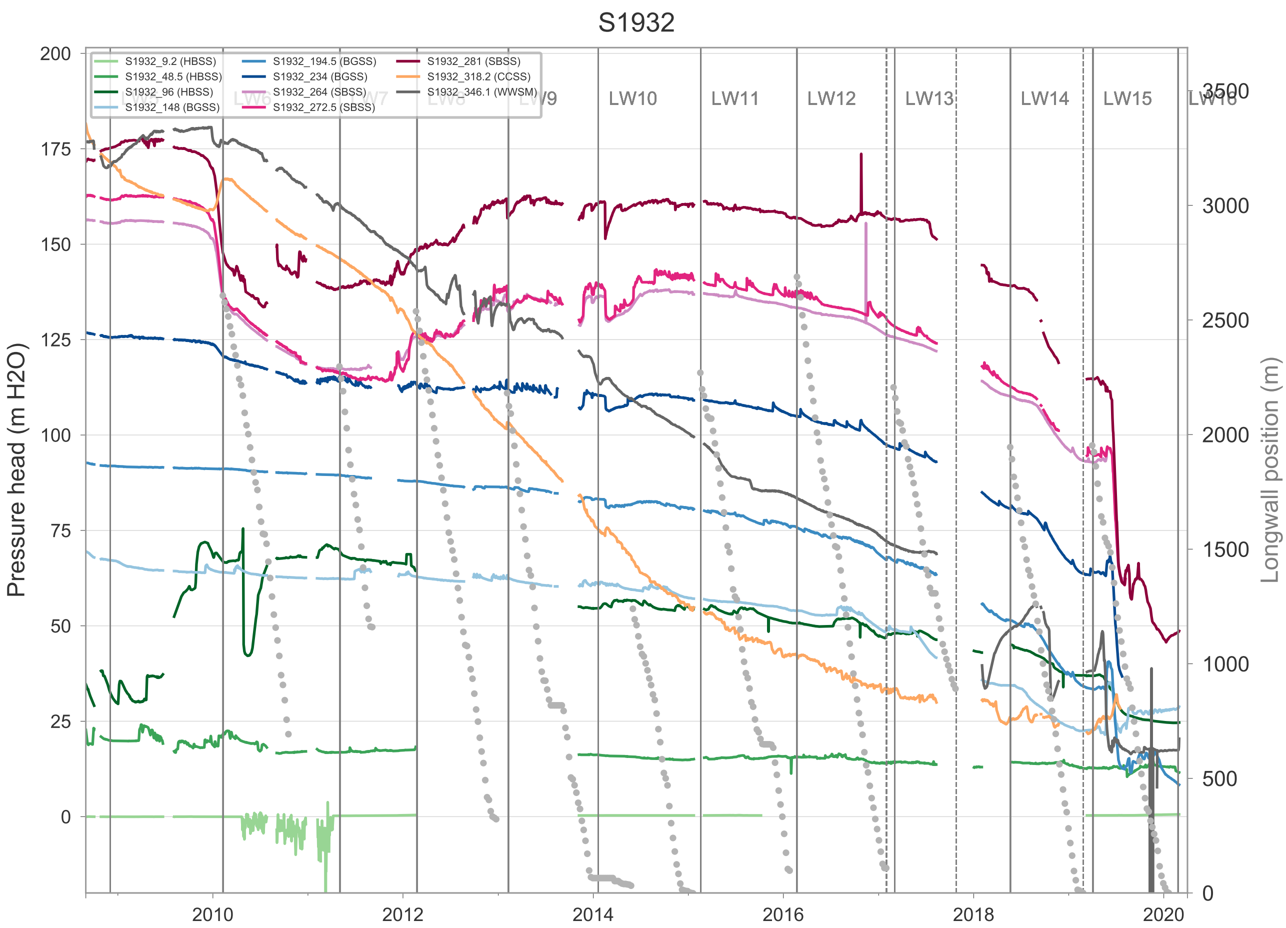

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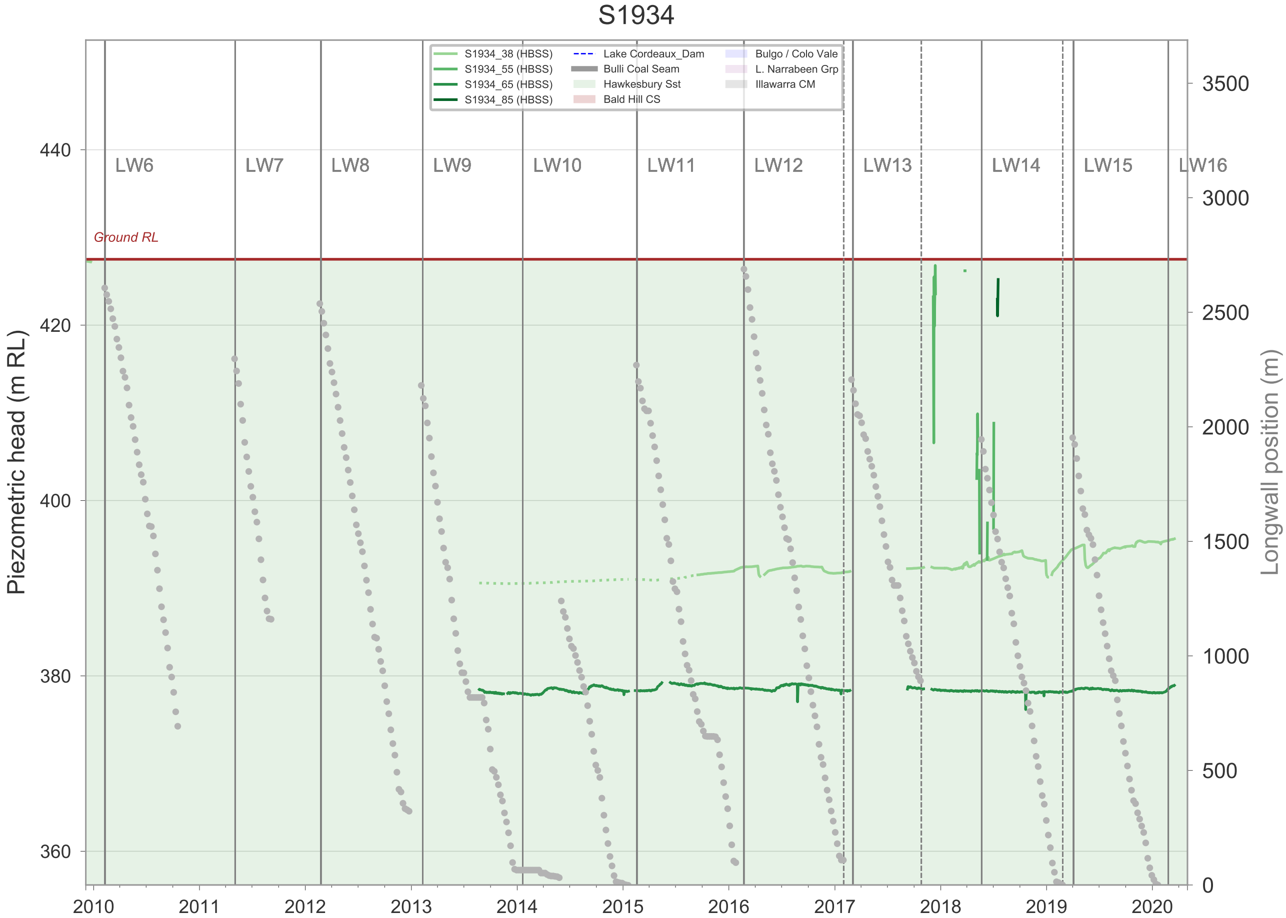

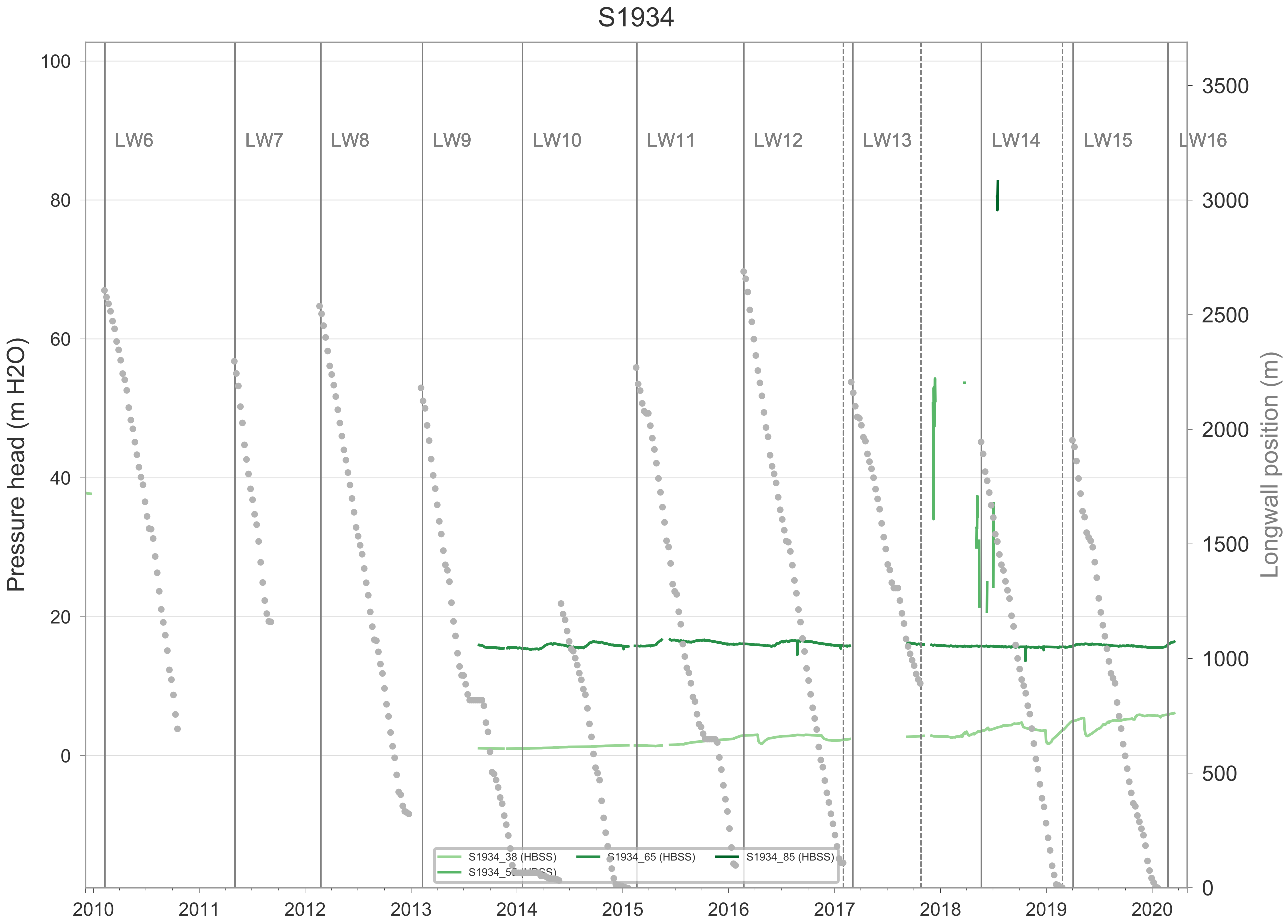

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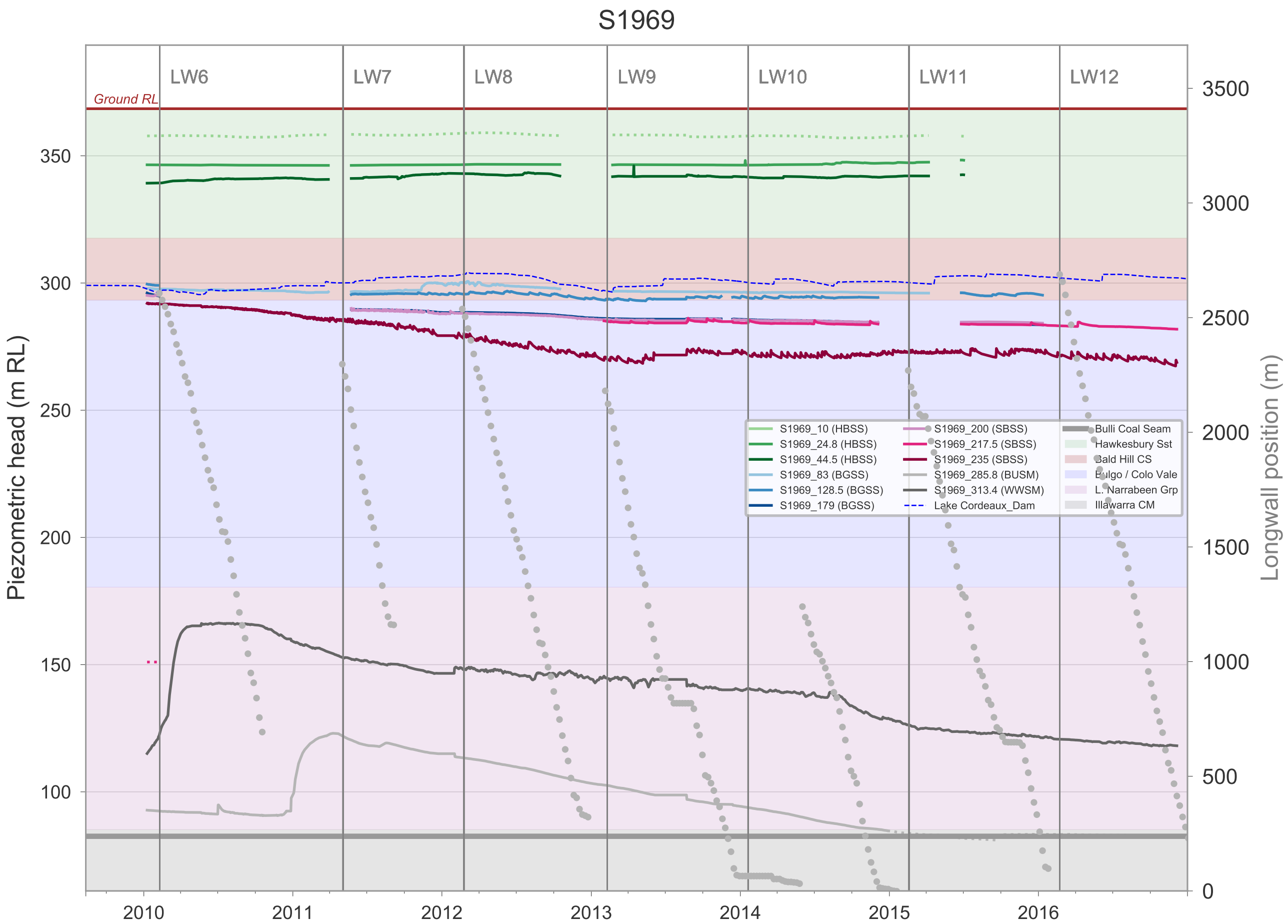

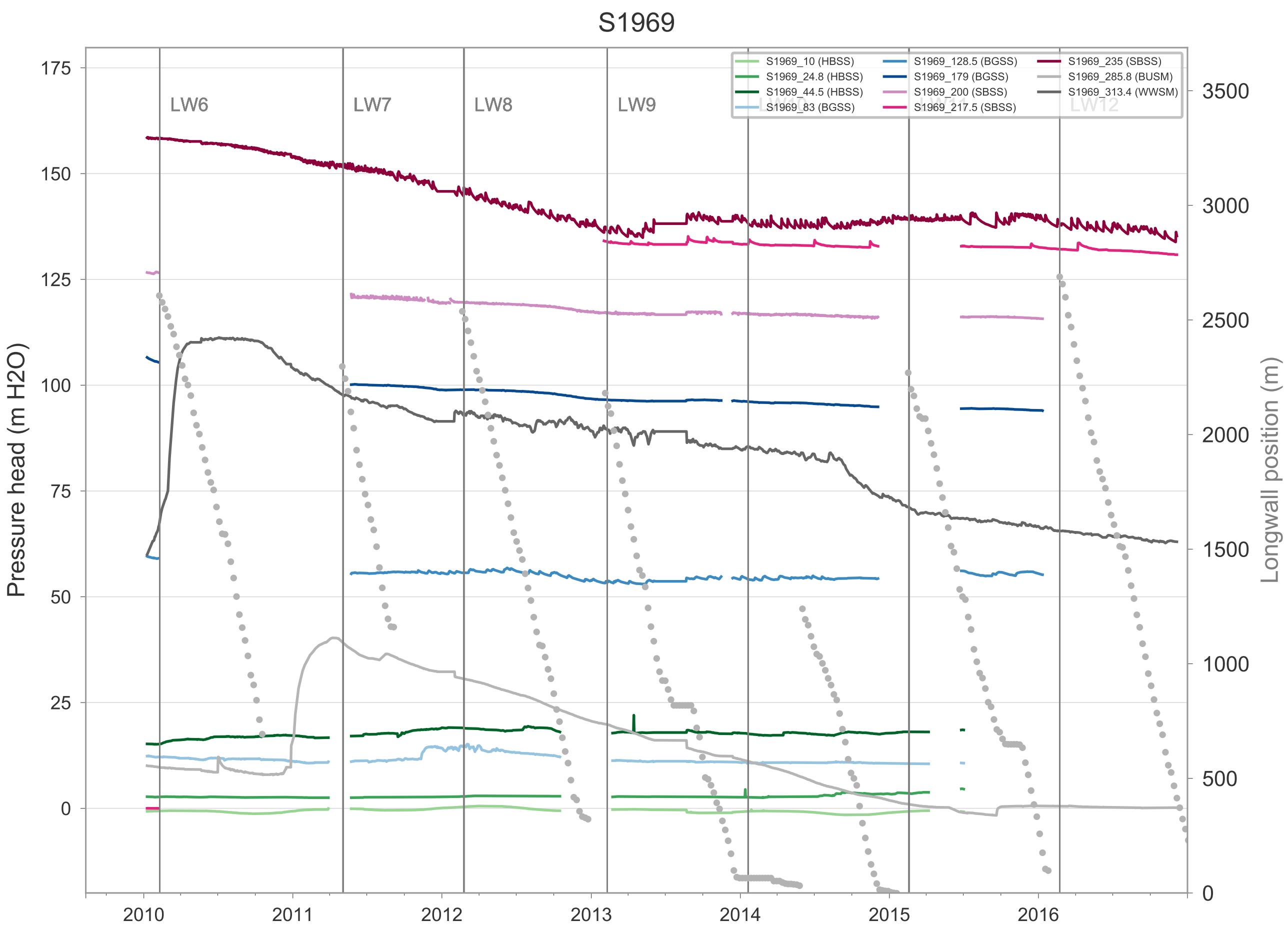

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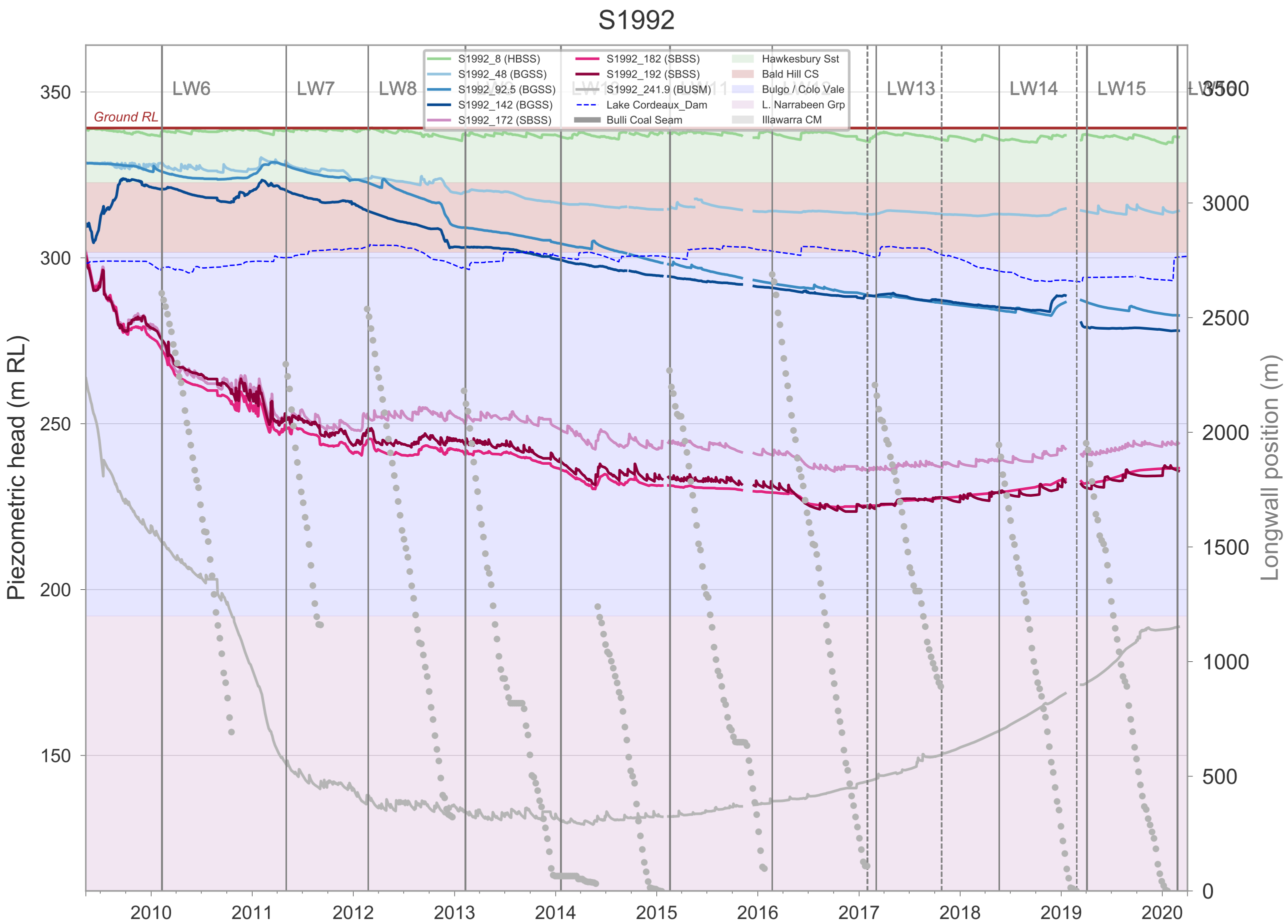

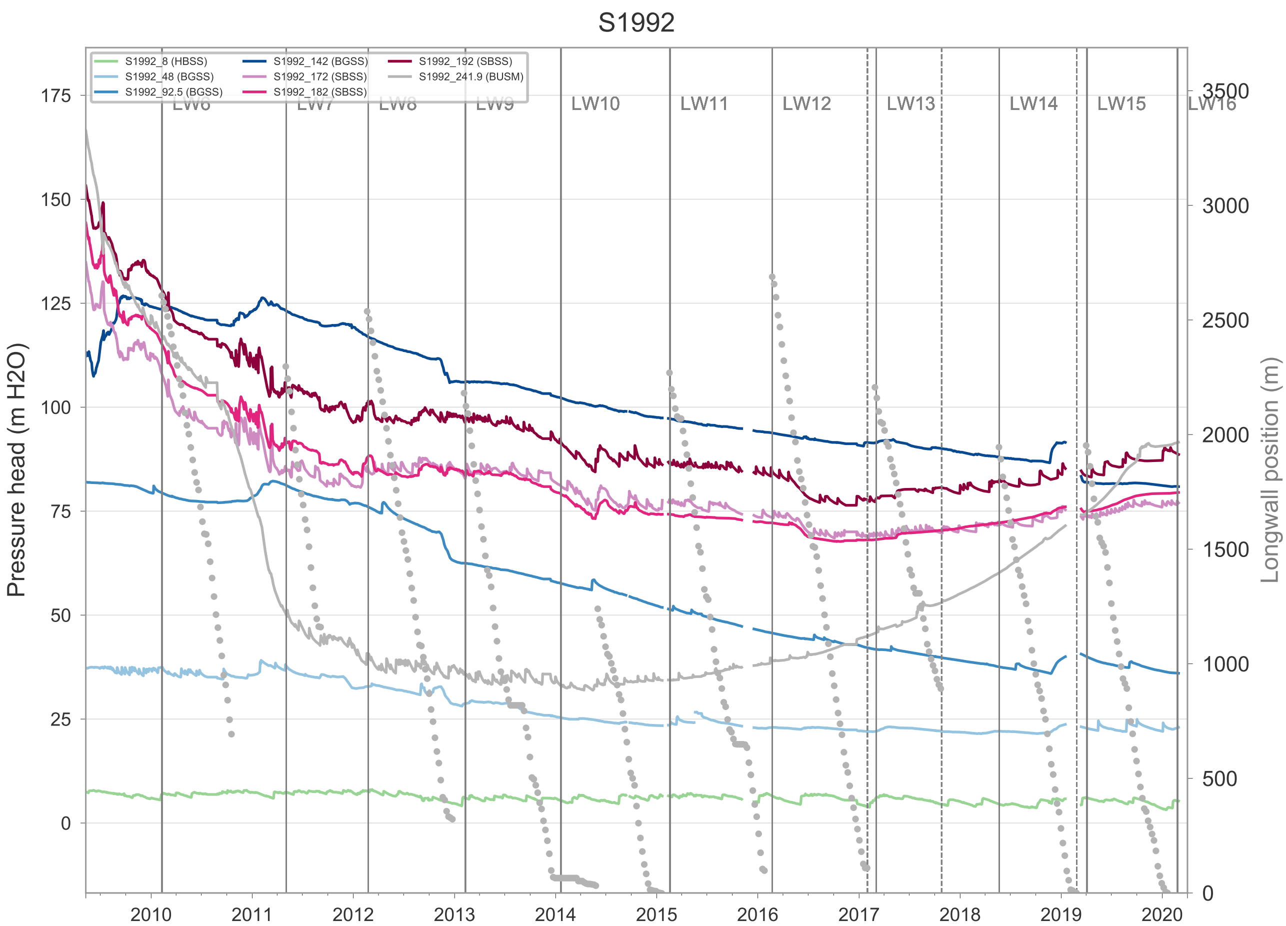

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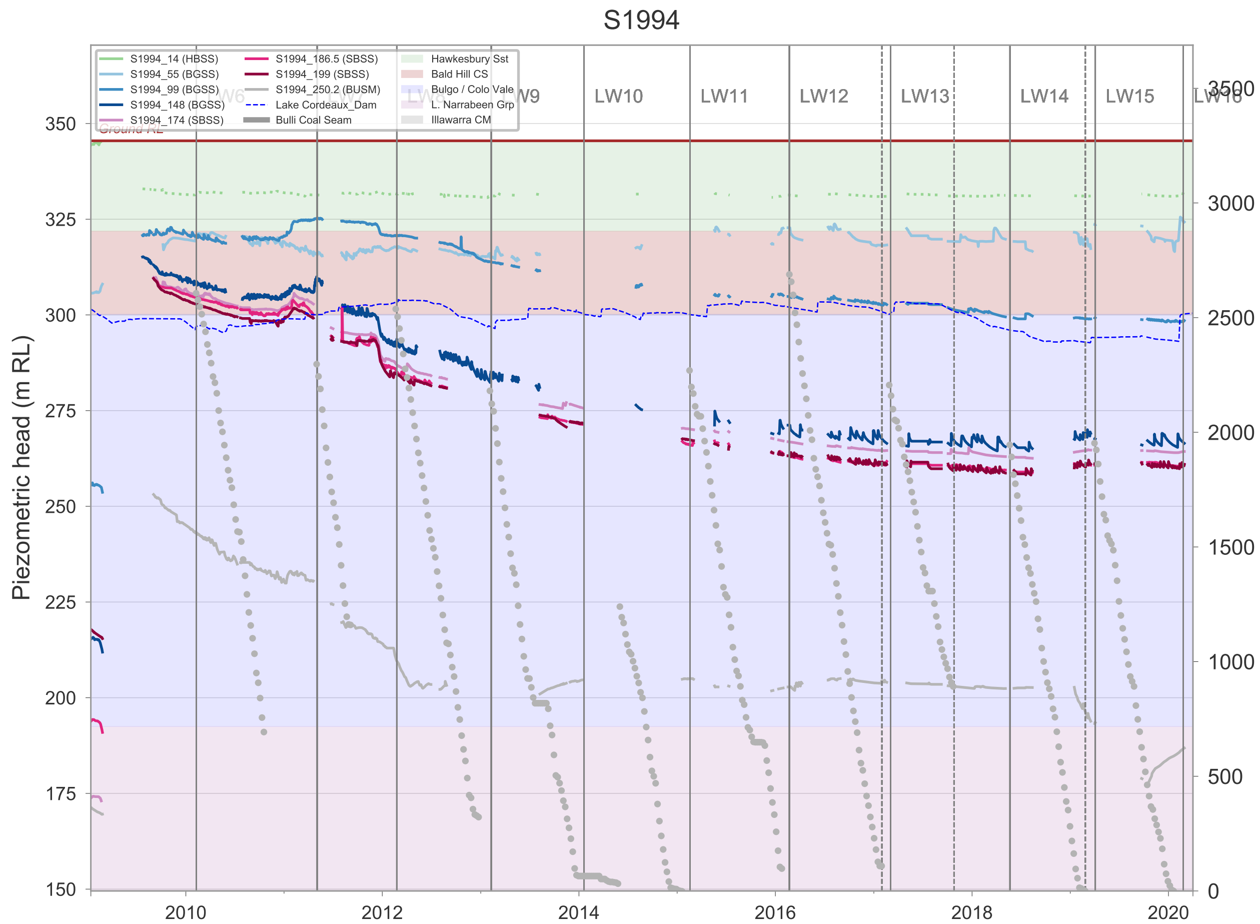
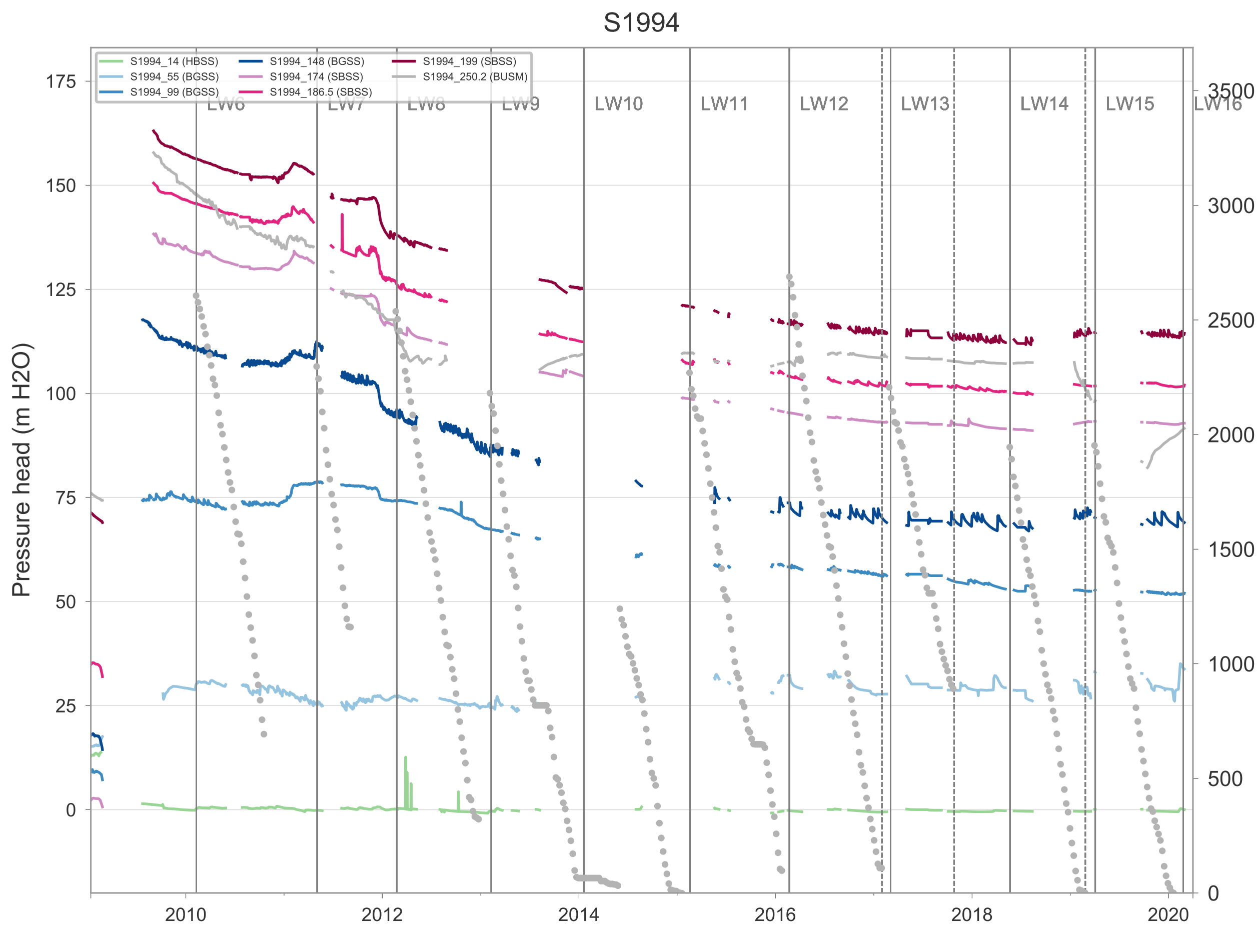
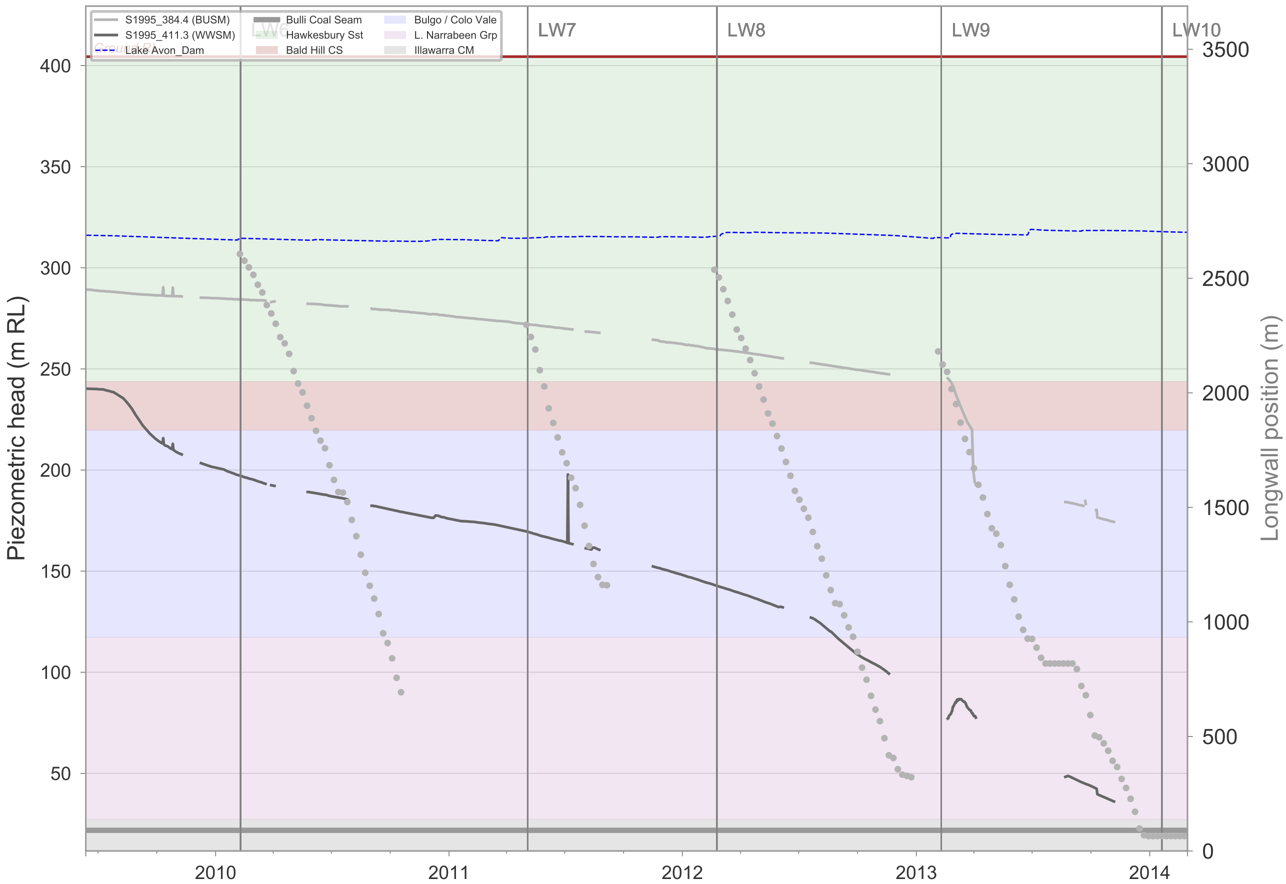




Groundwater hydrographs

S1995



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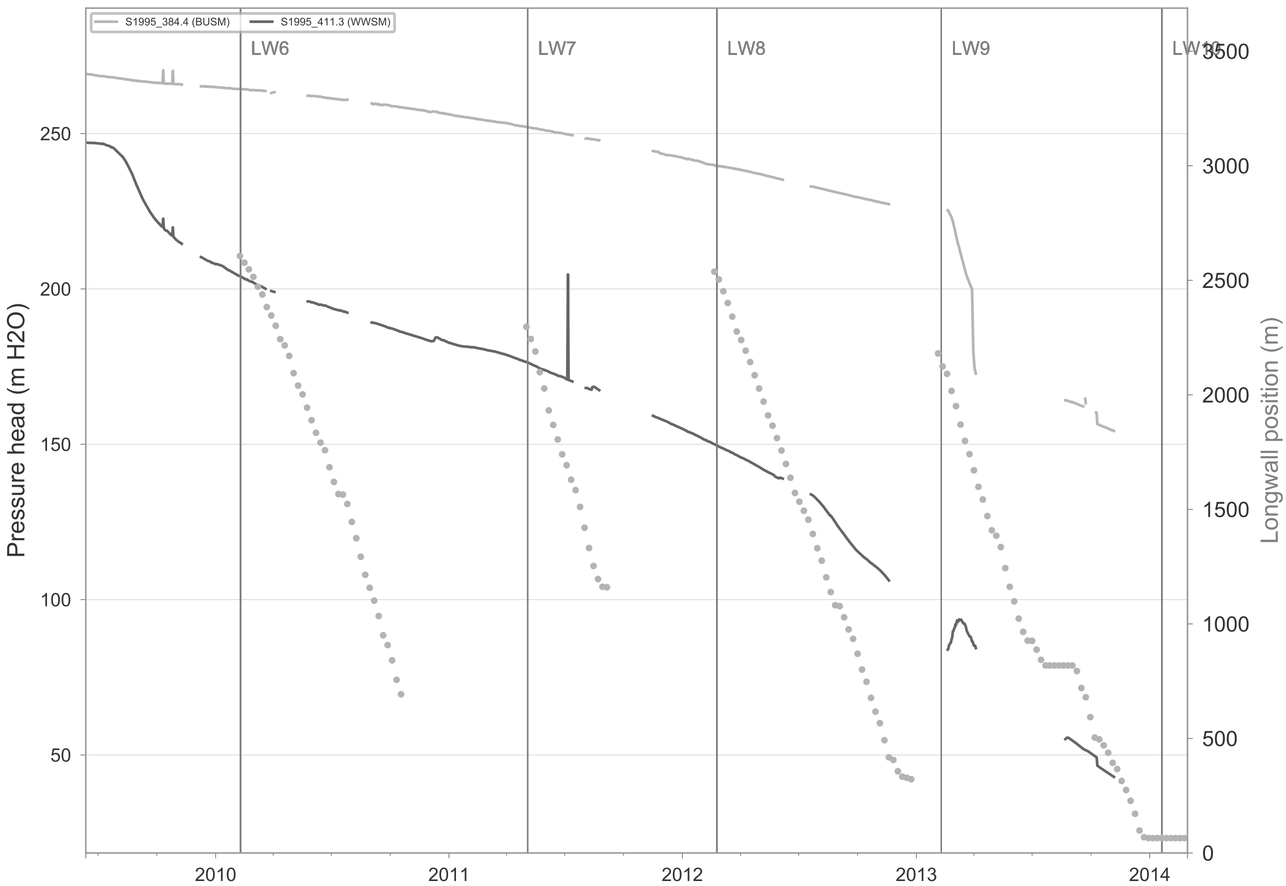
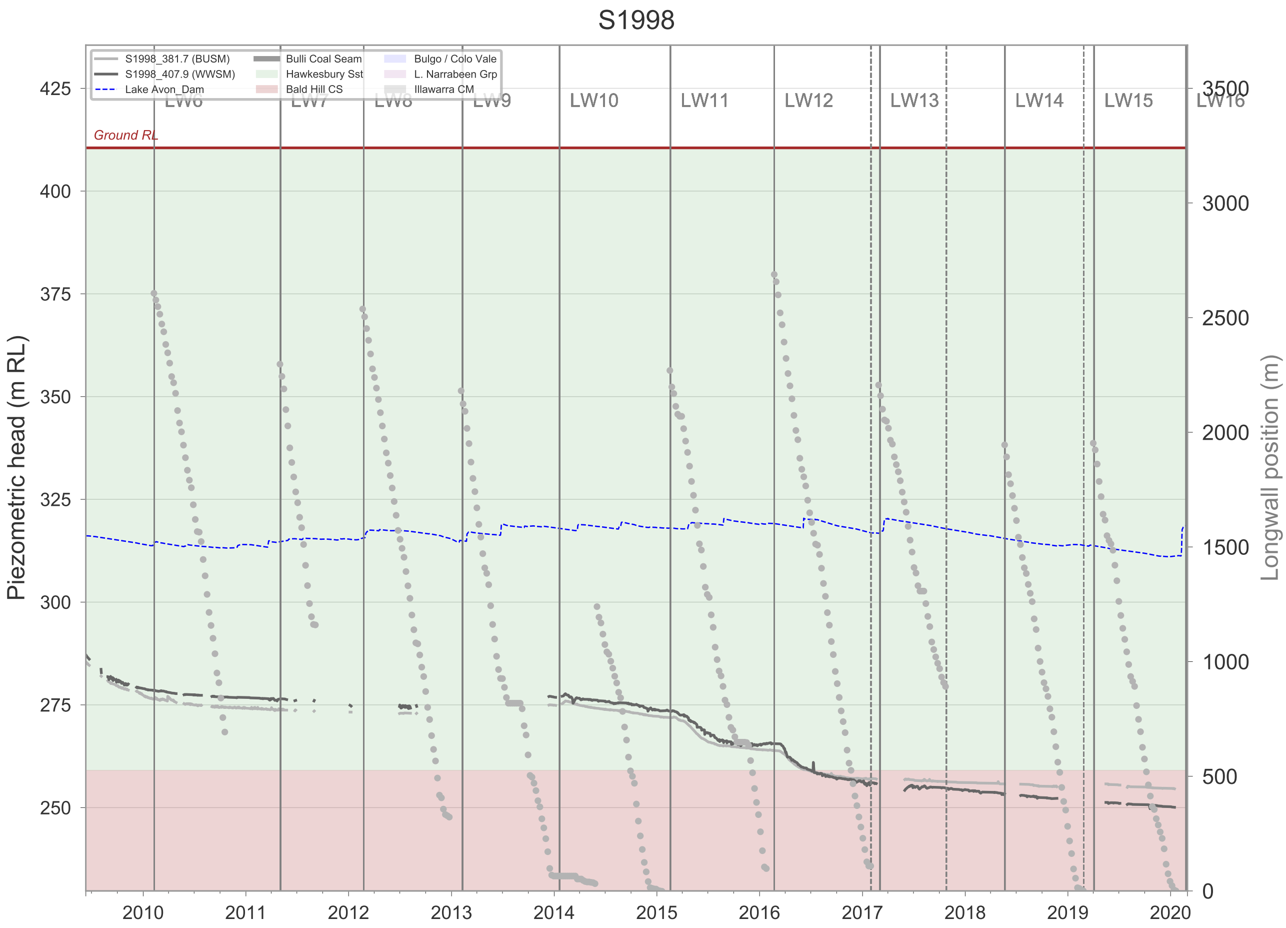
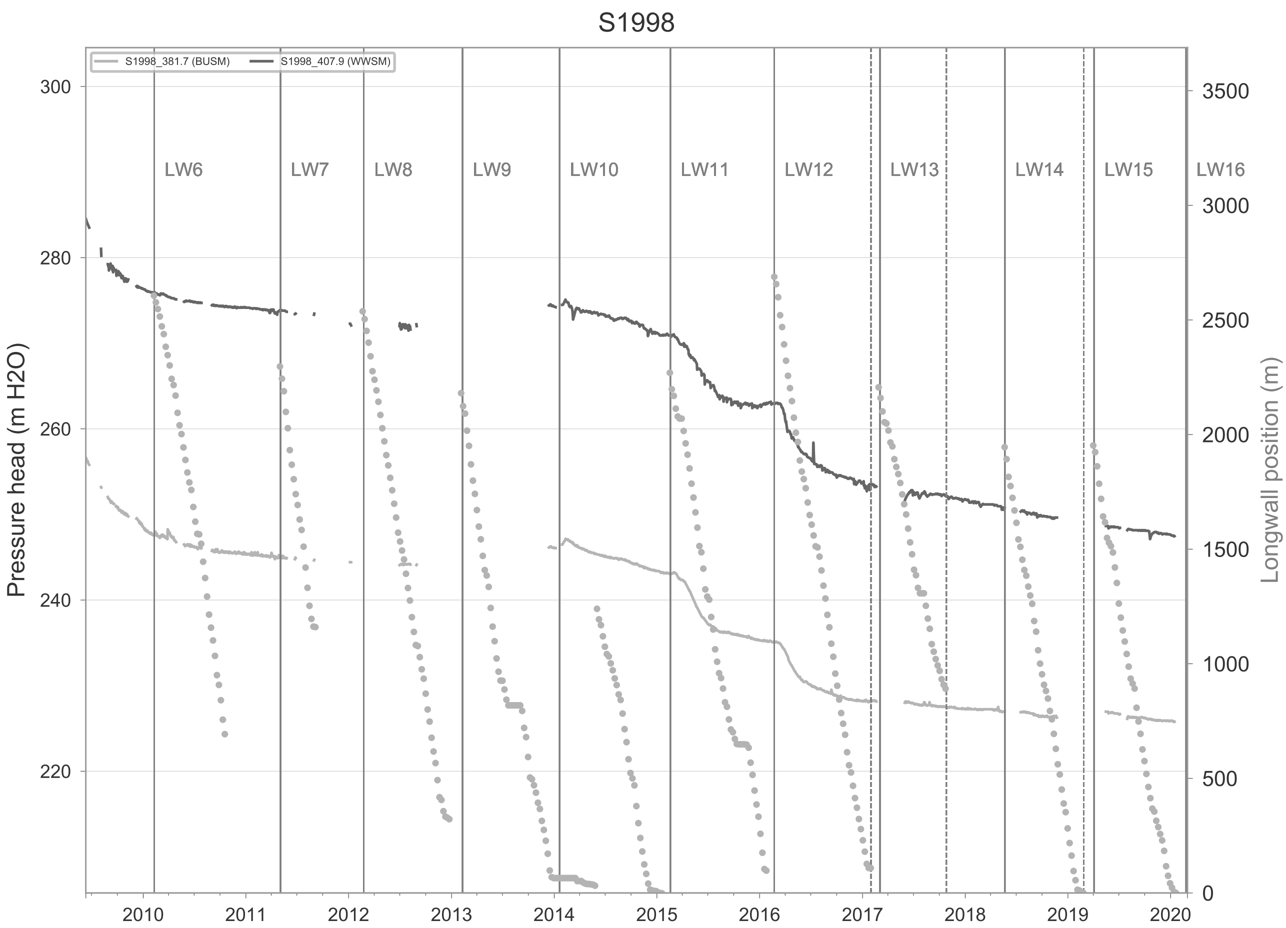


Groundwater hydrographs





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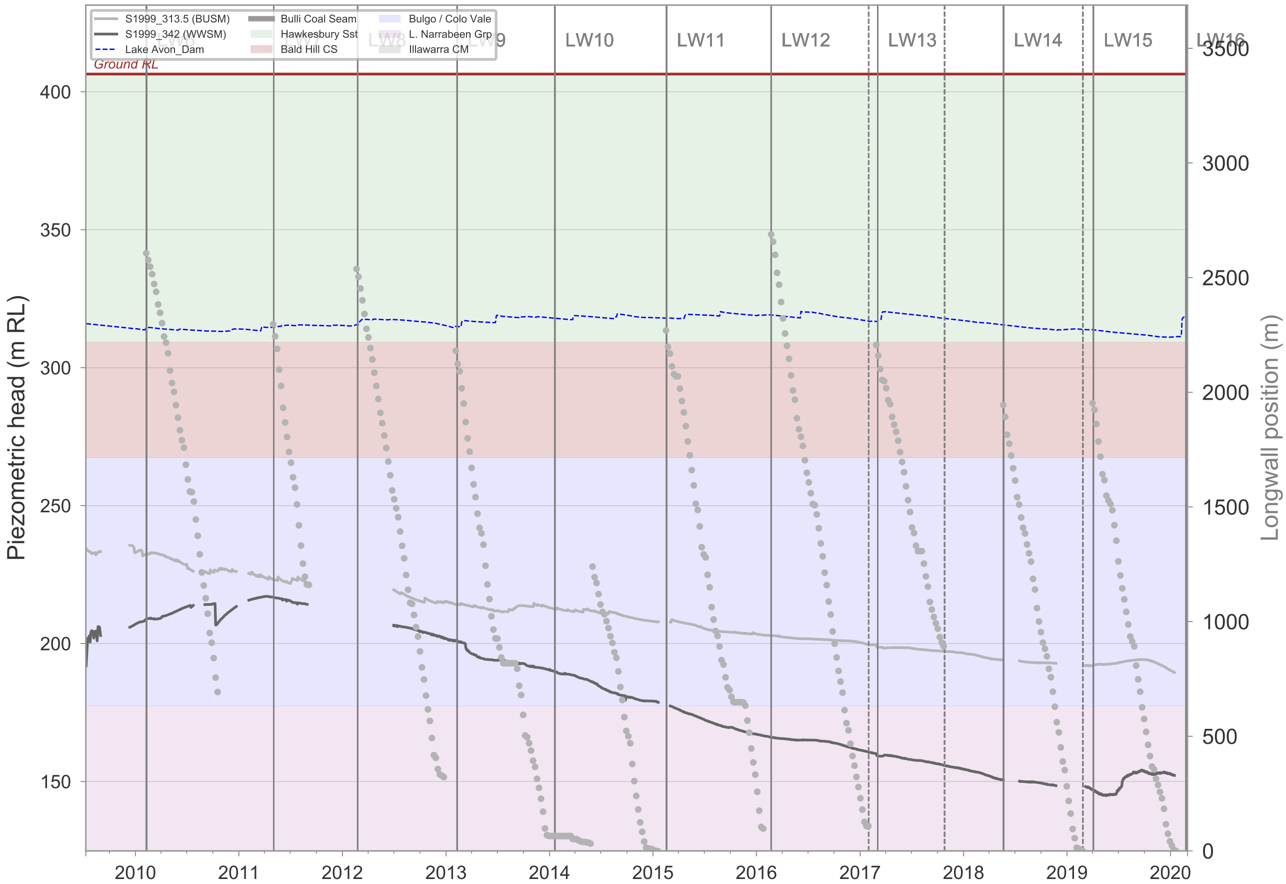

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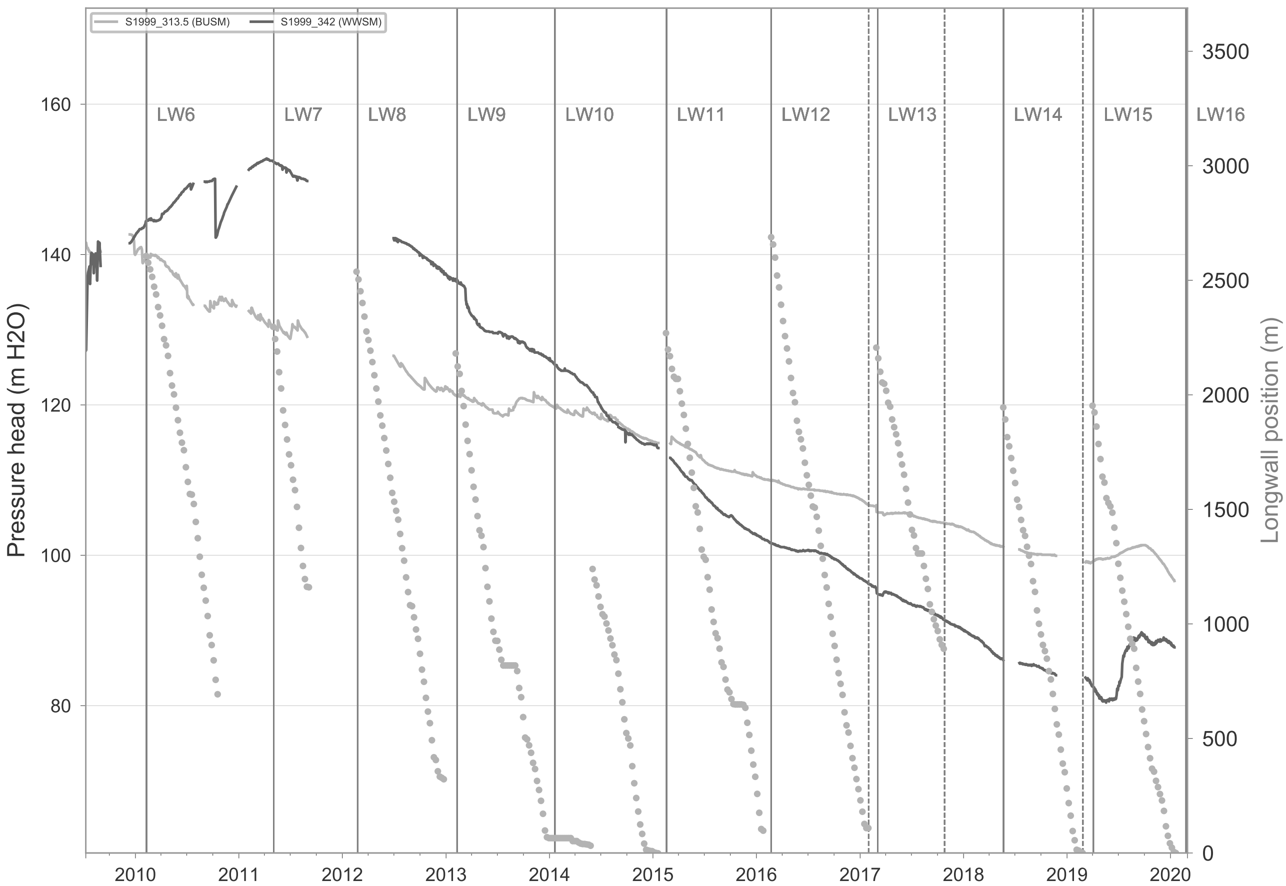

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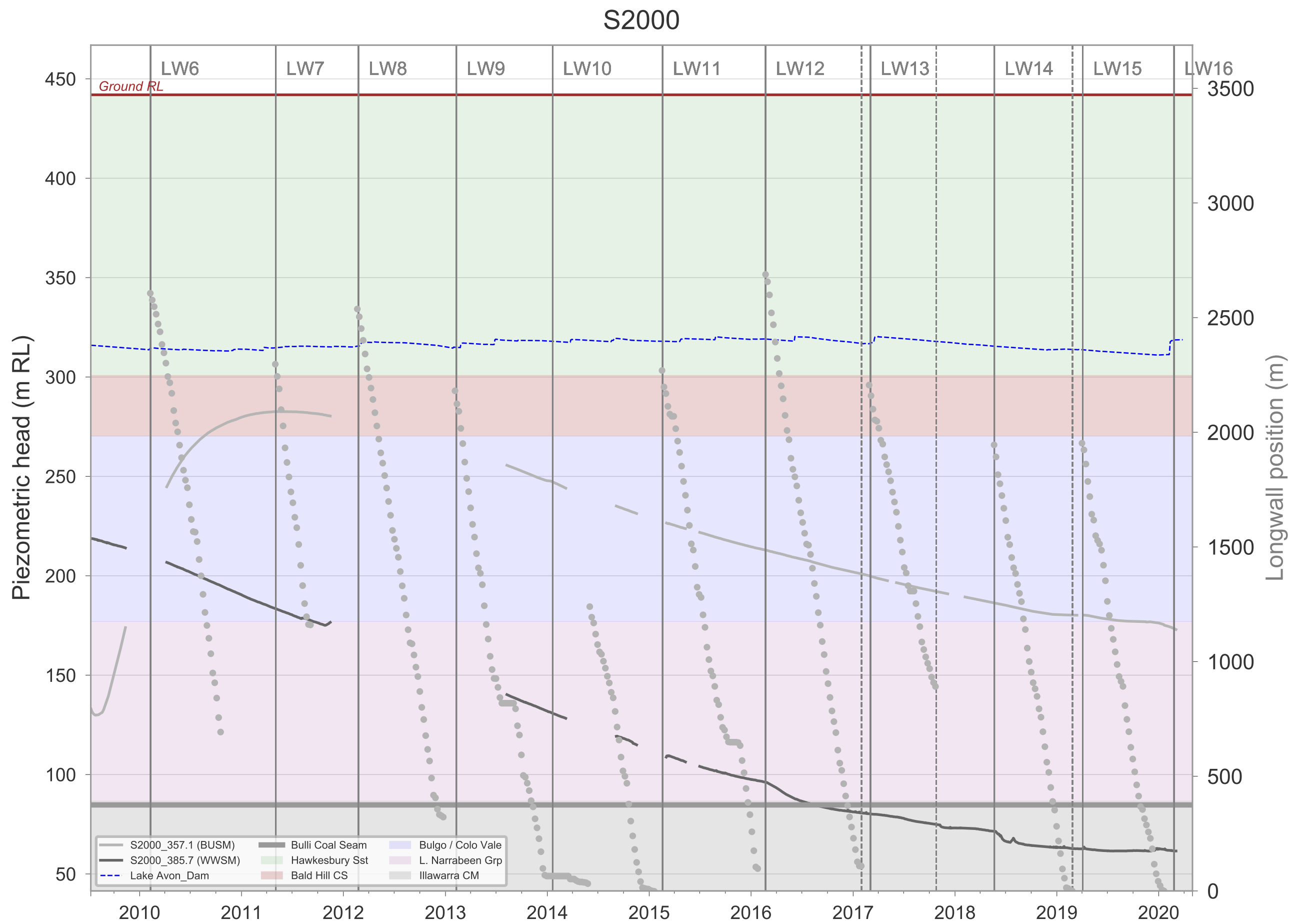
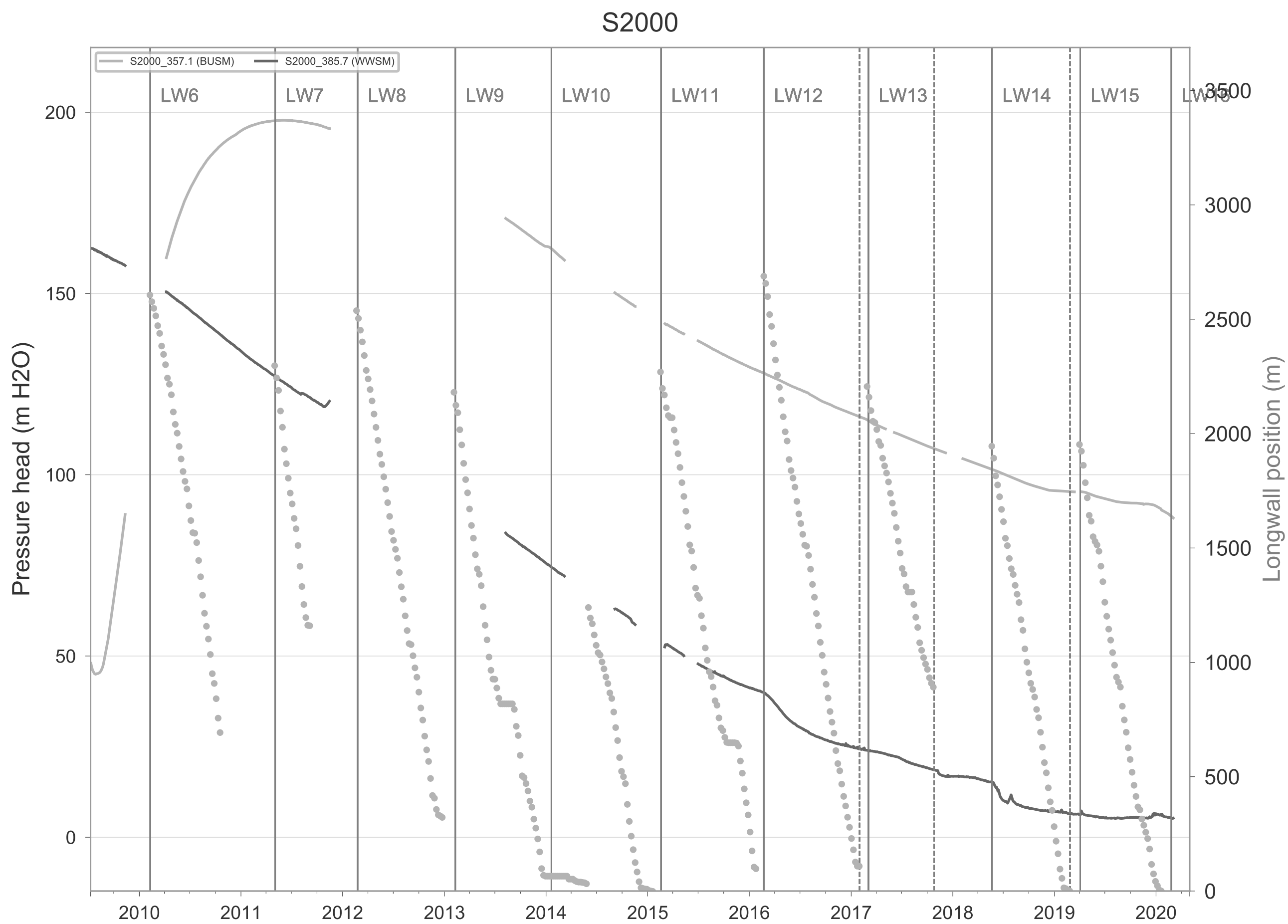
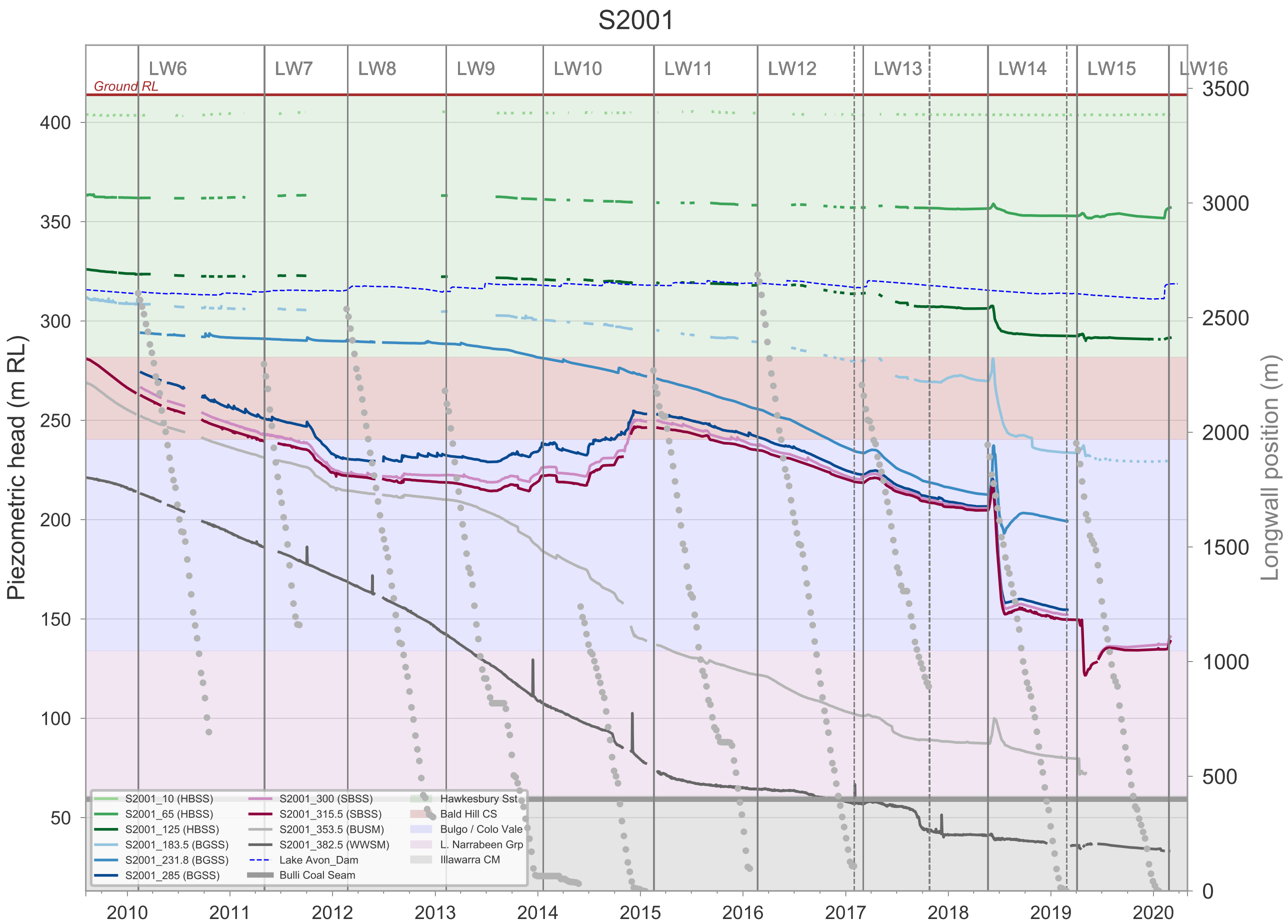
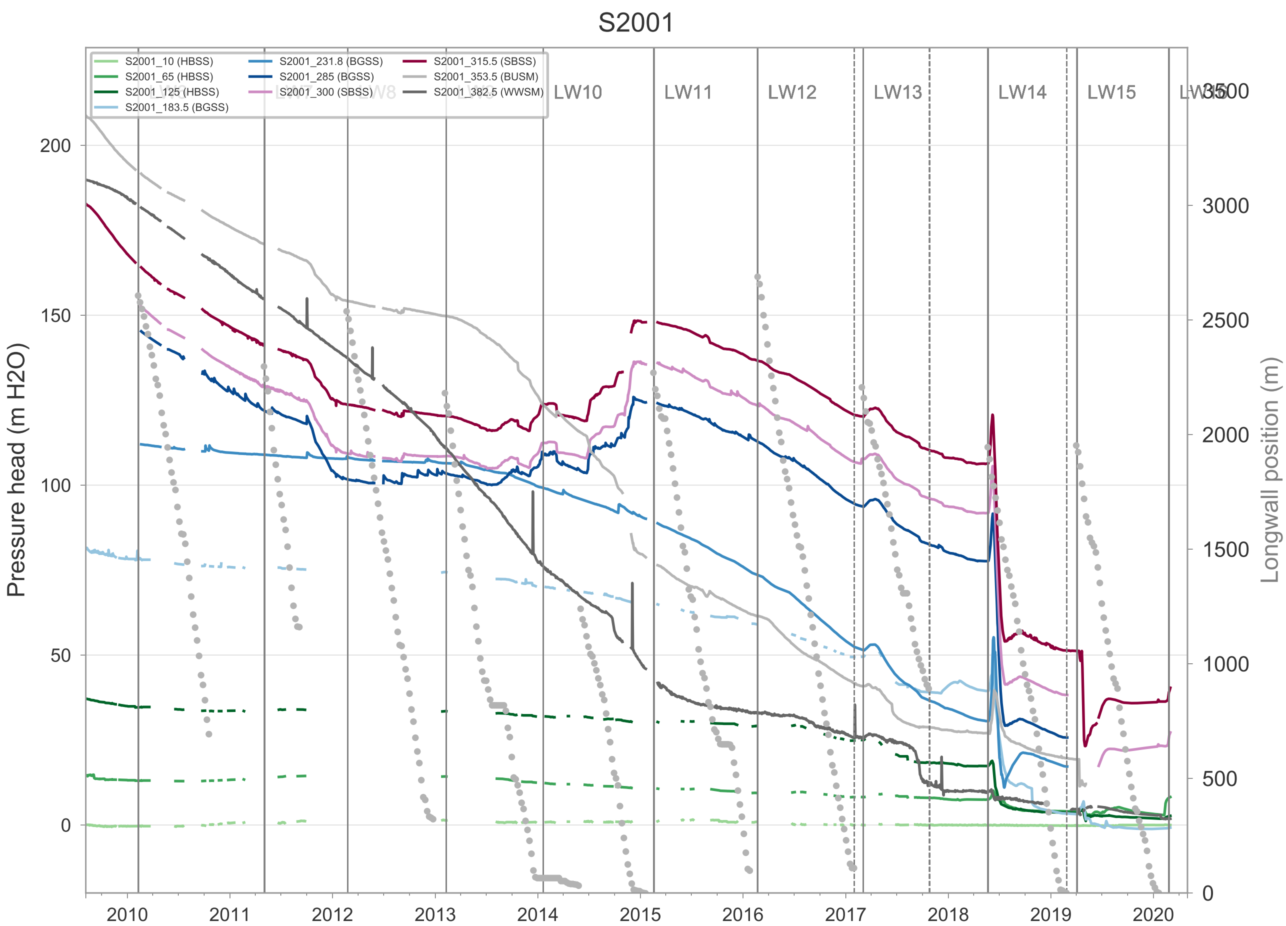




Groundwater hydrographs





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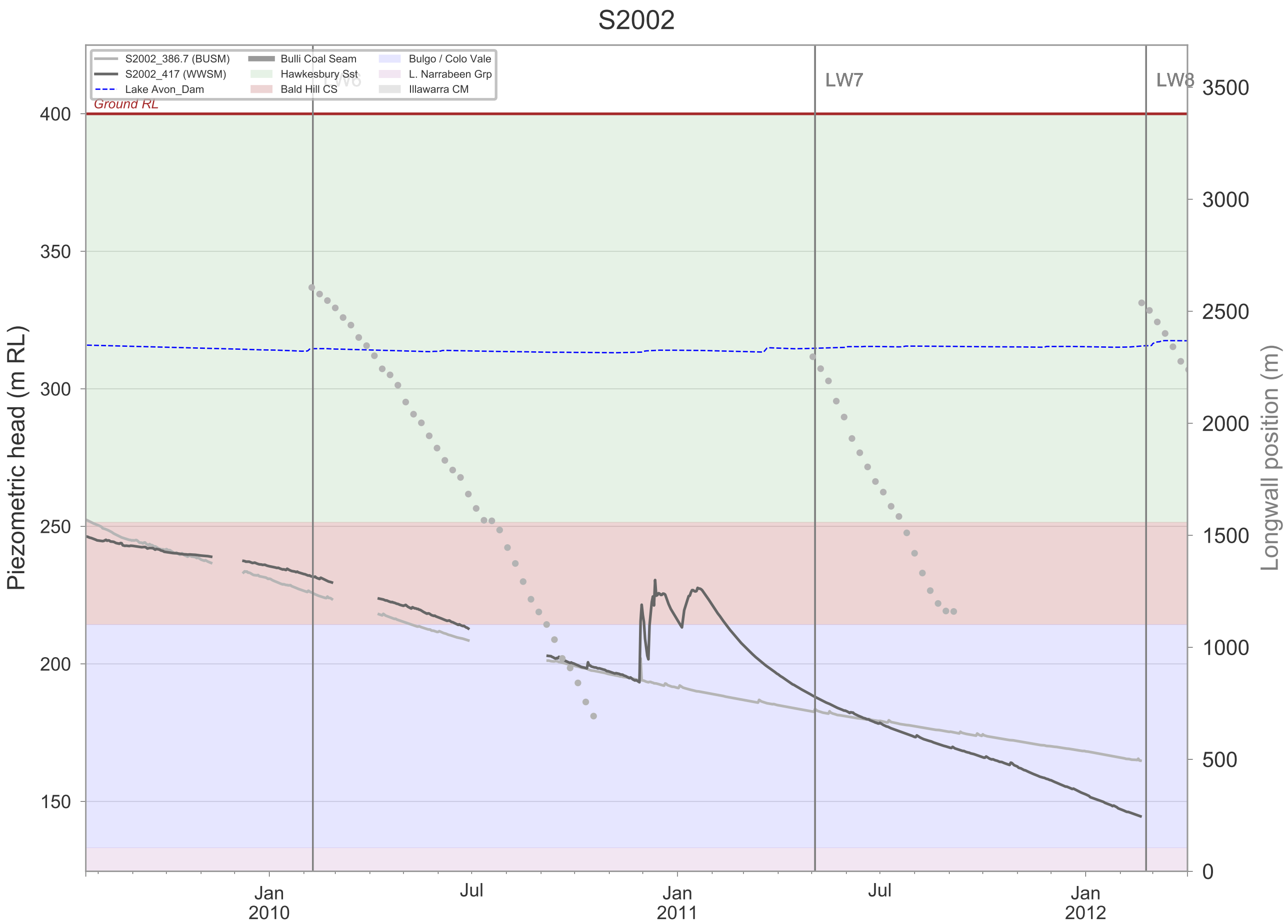

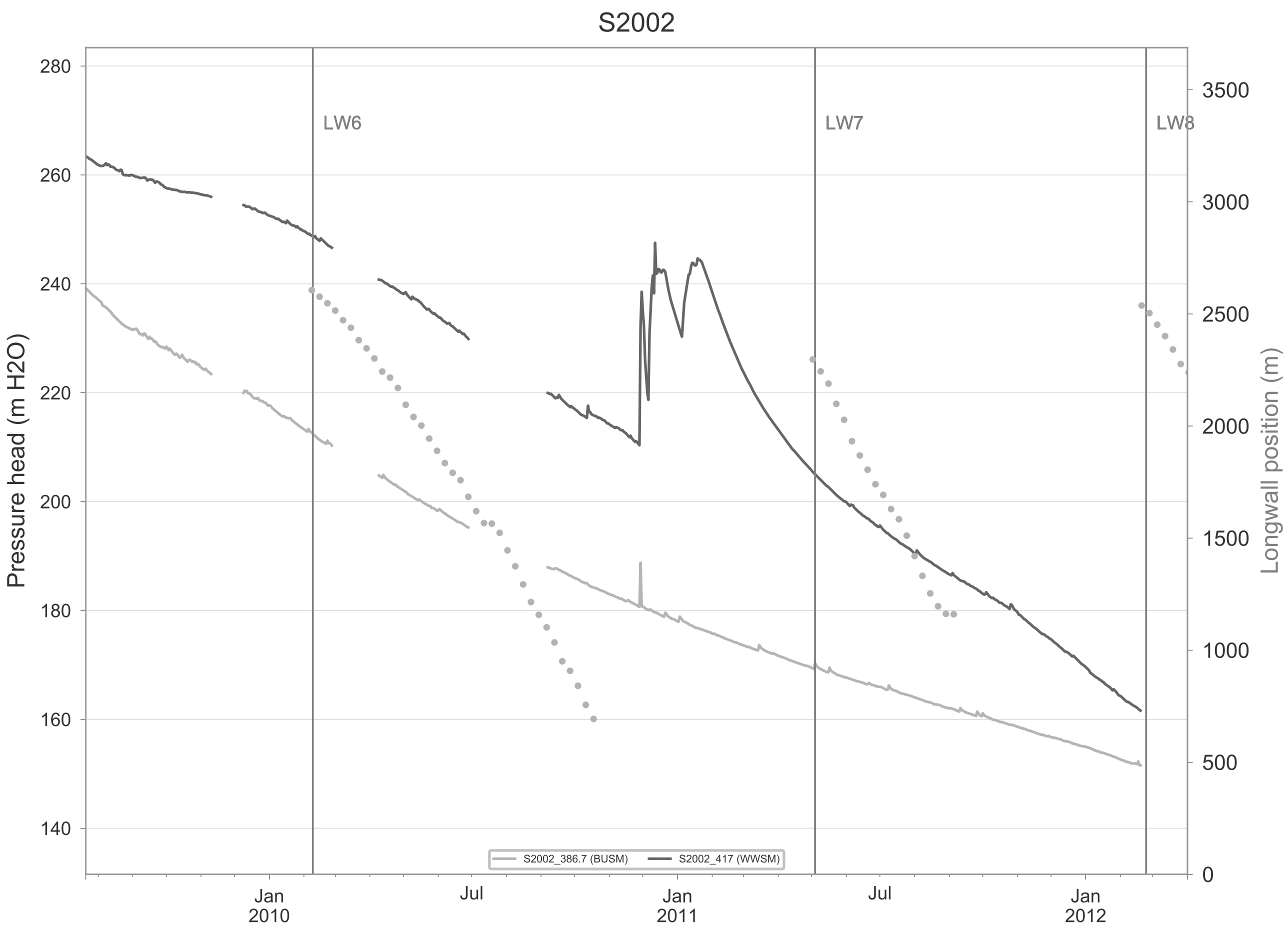

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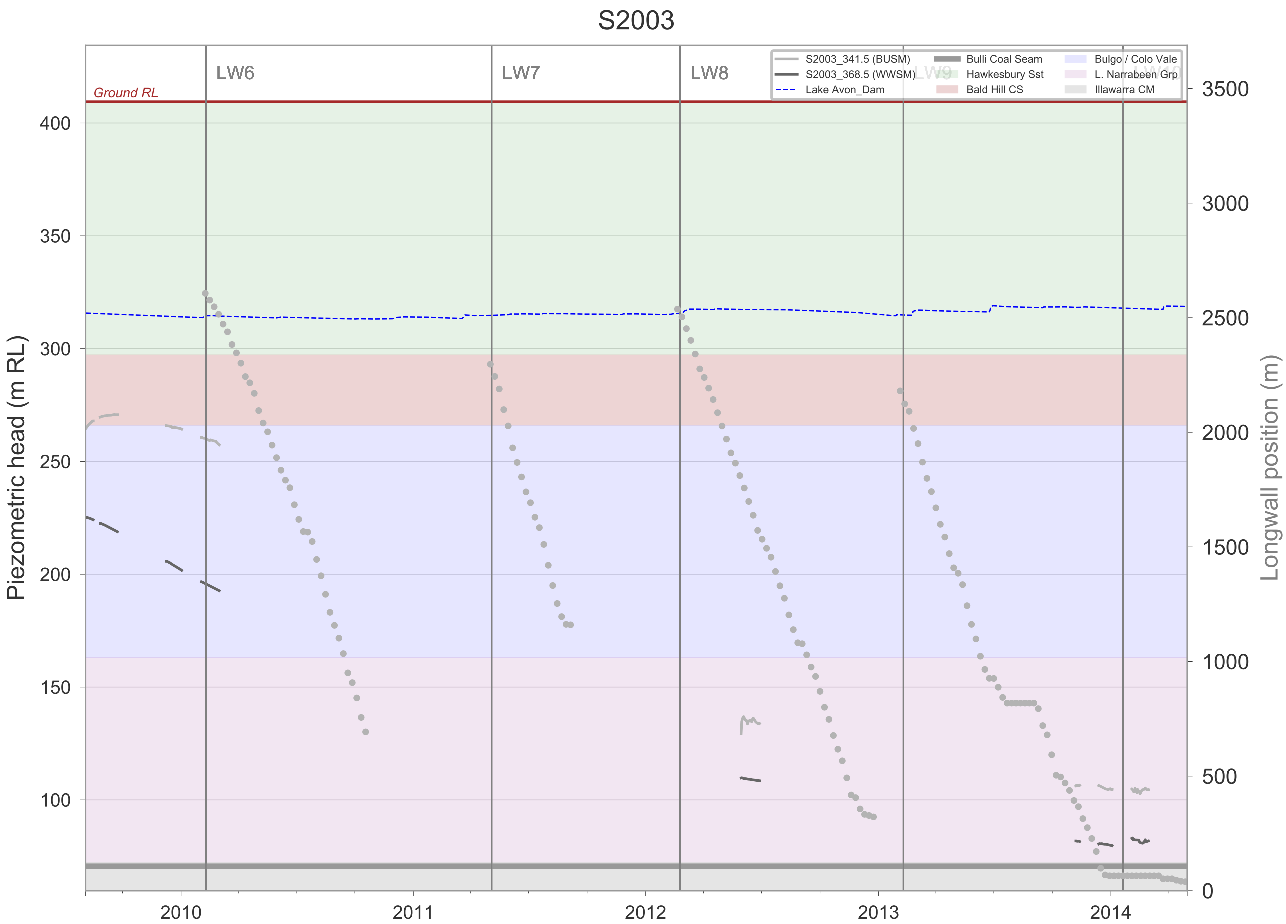
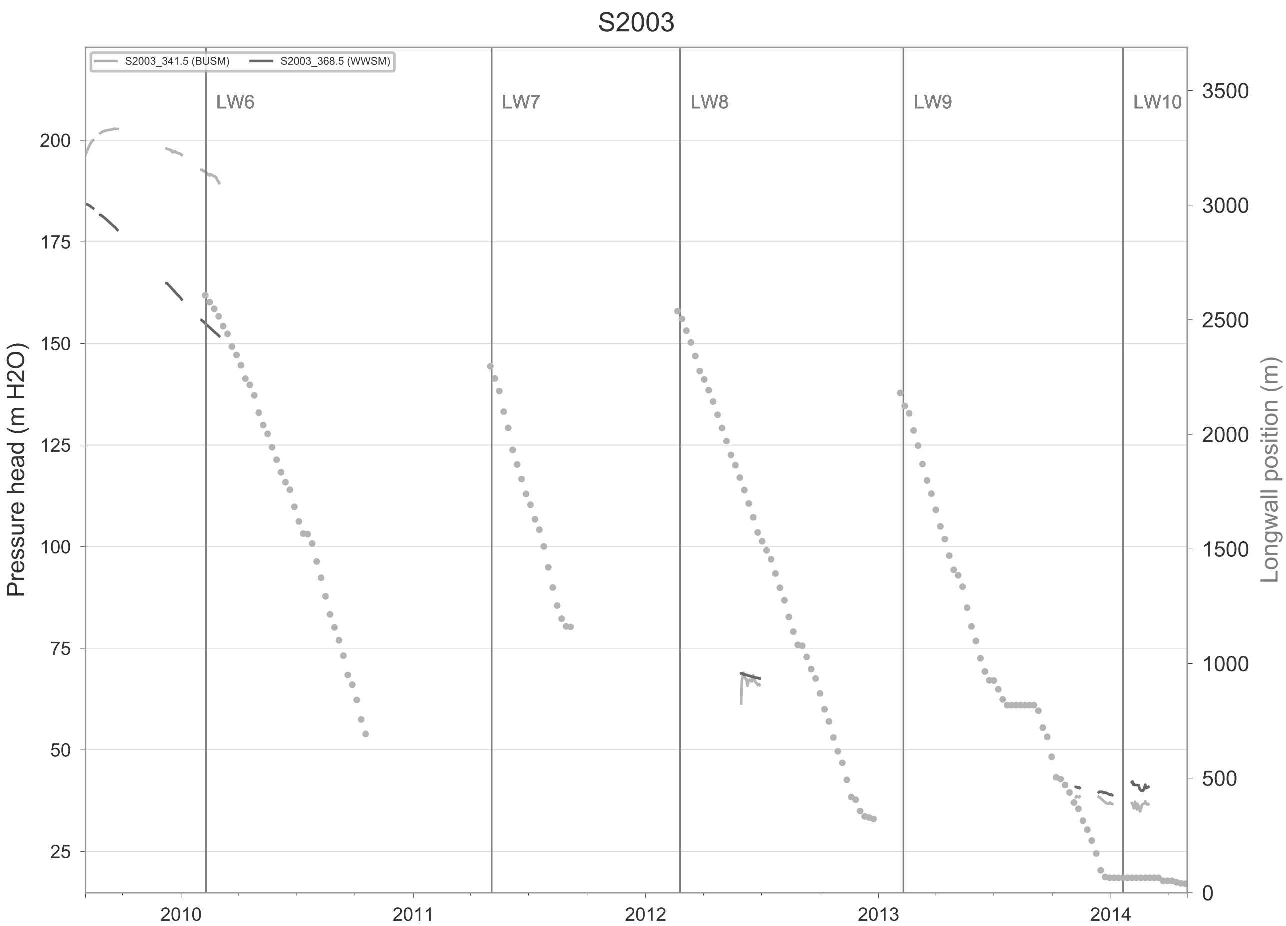
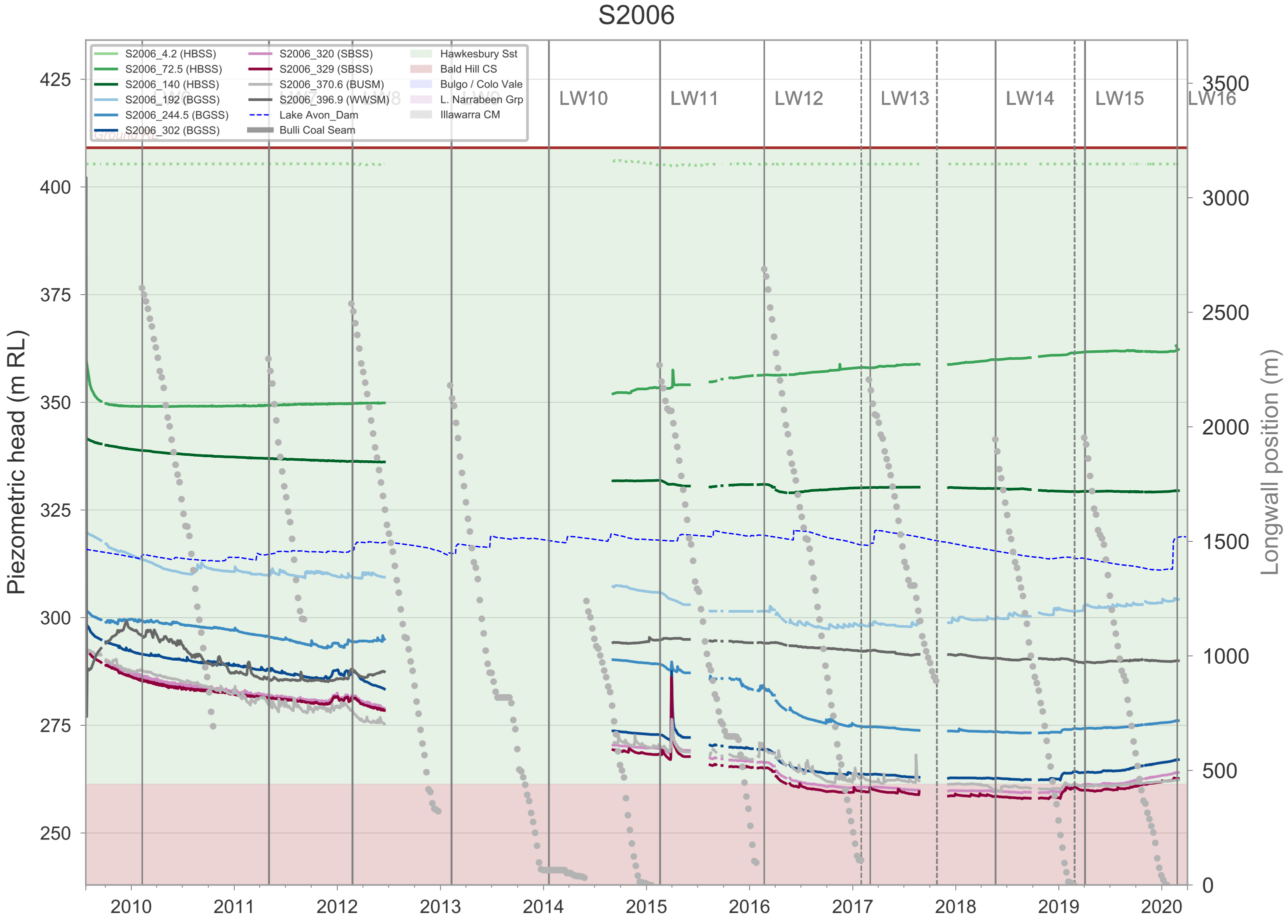
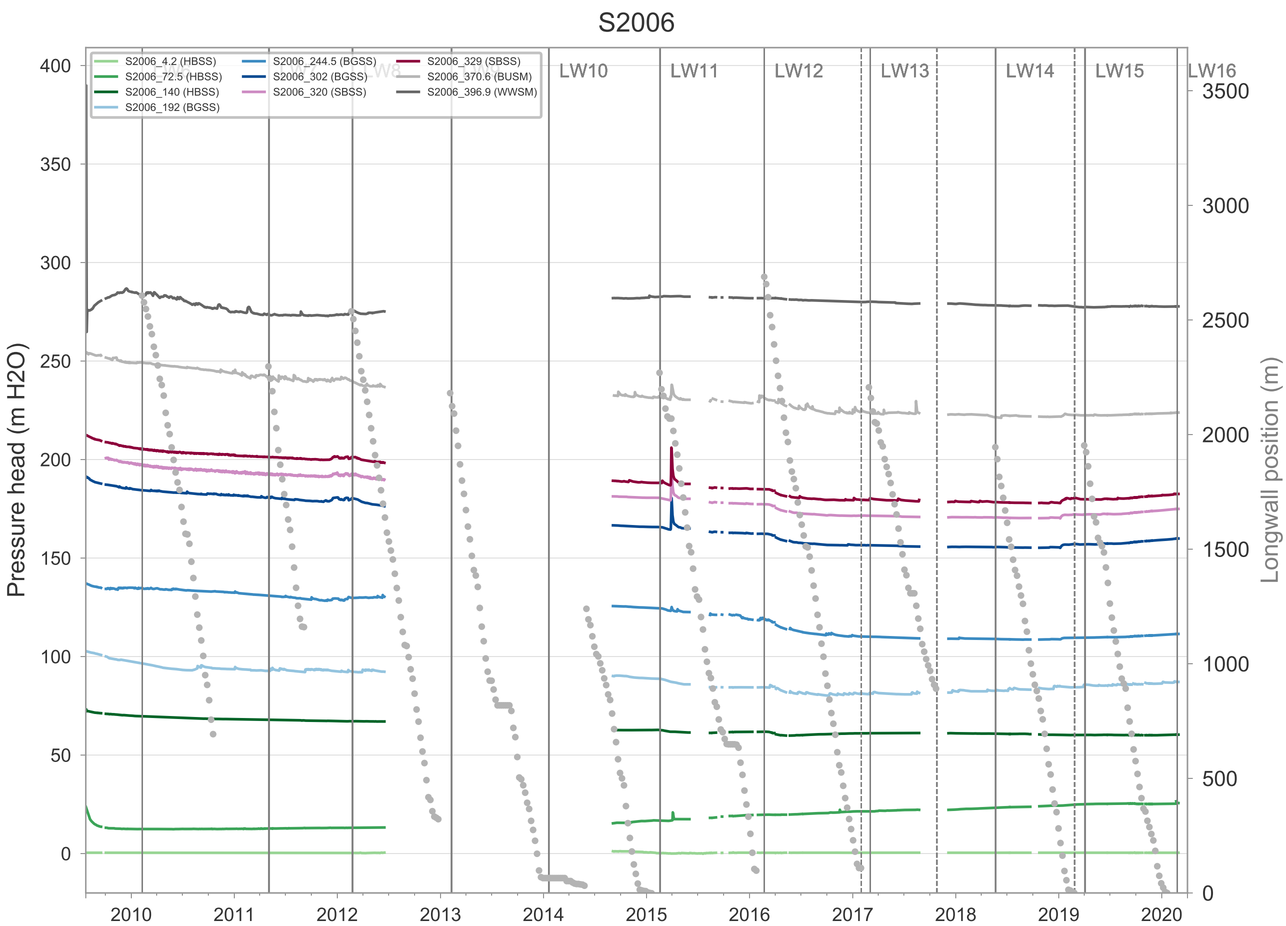


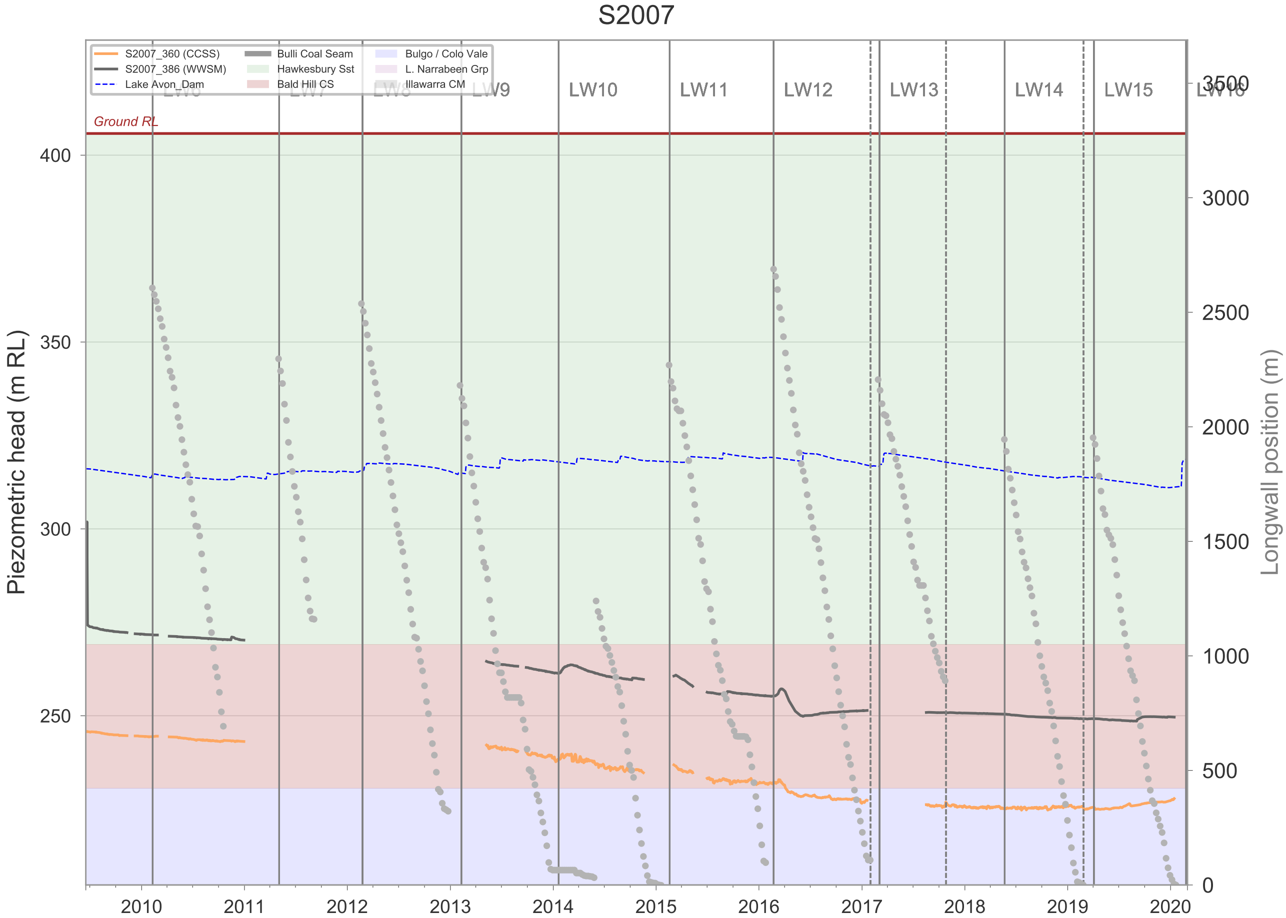


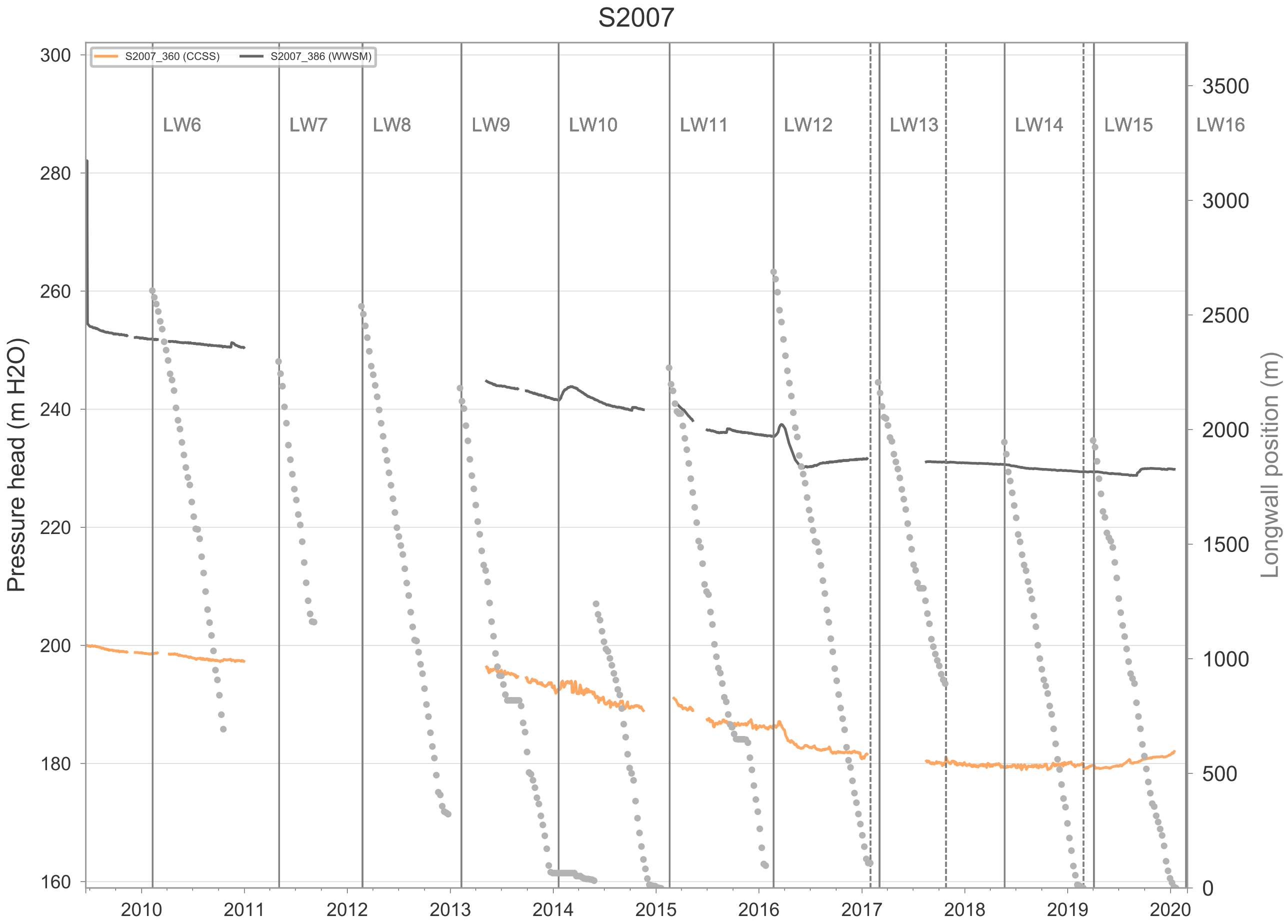
Groundwater hydrographs



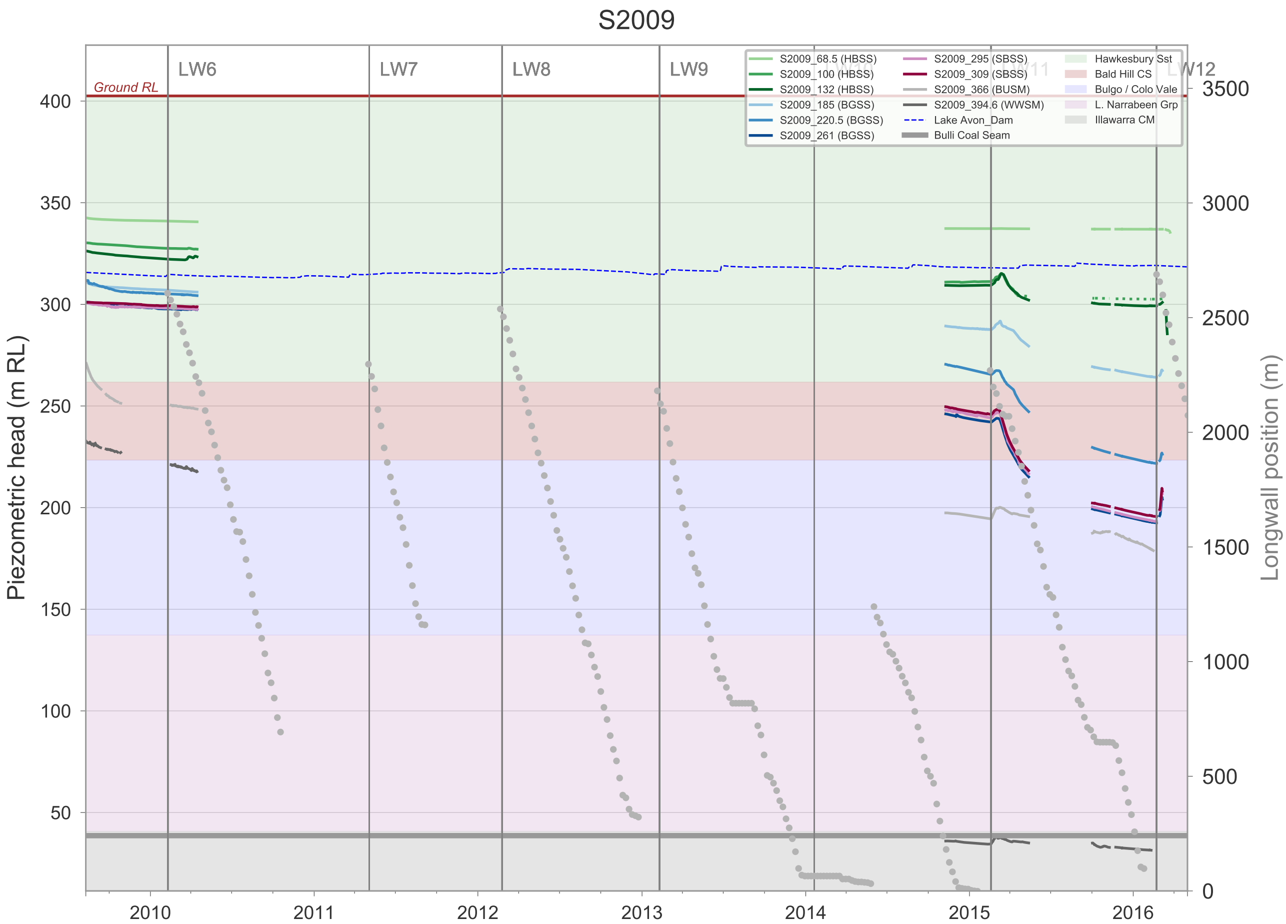


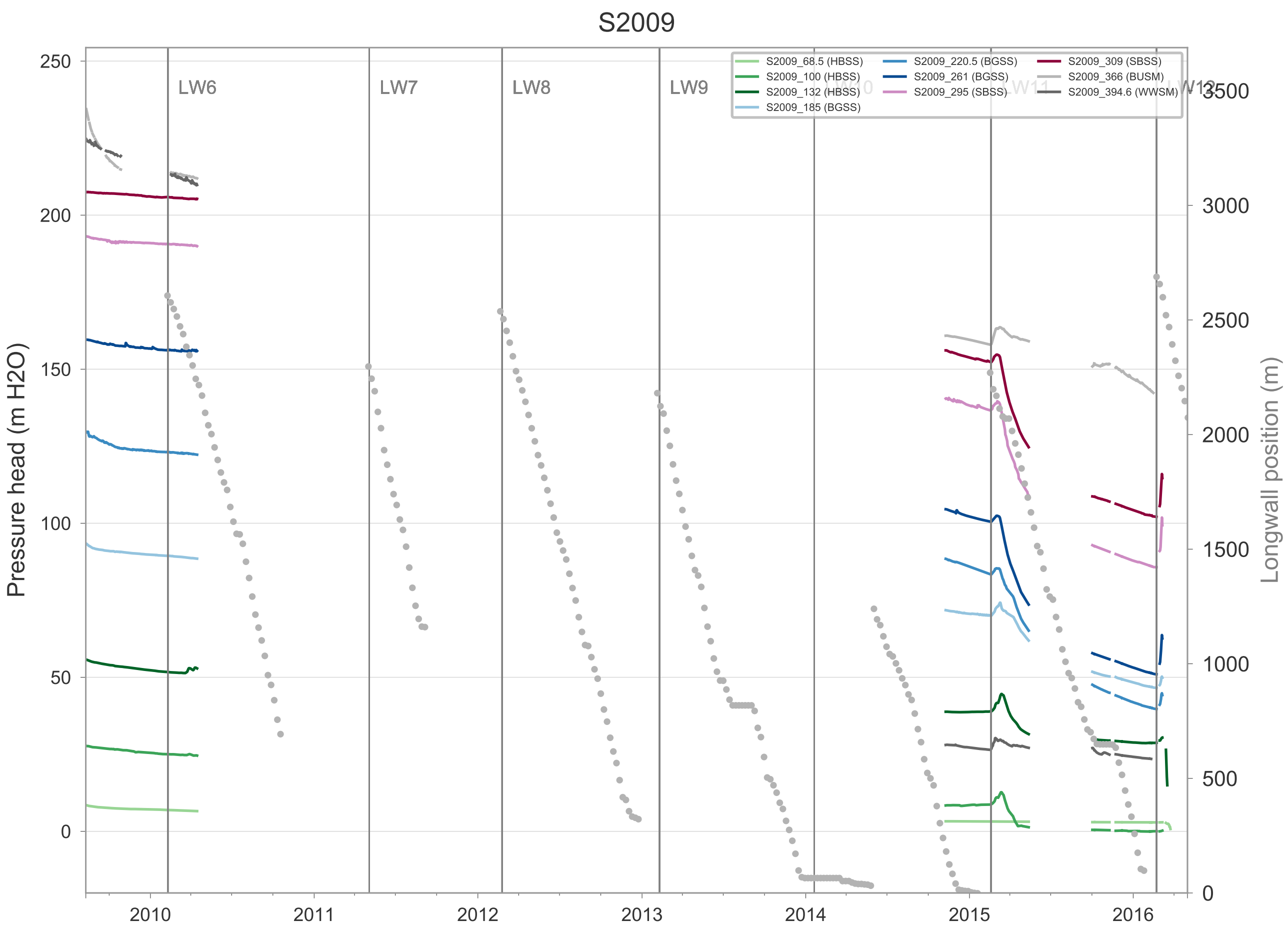
Groundwater hydrographs





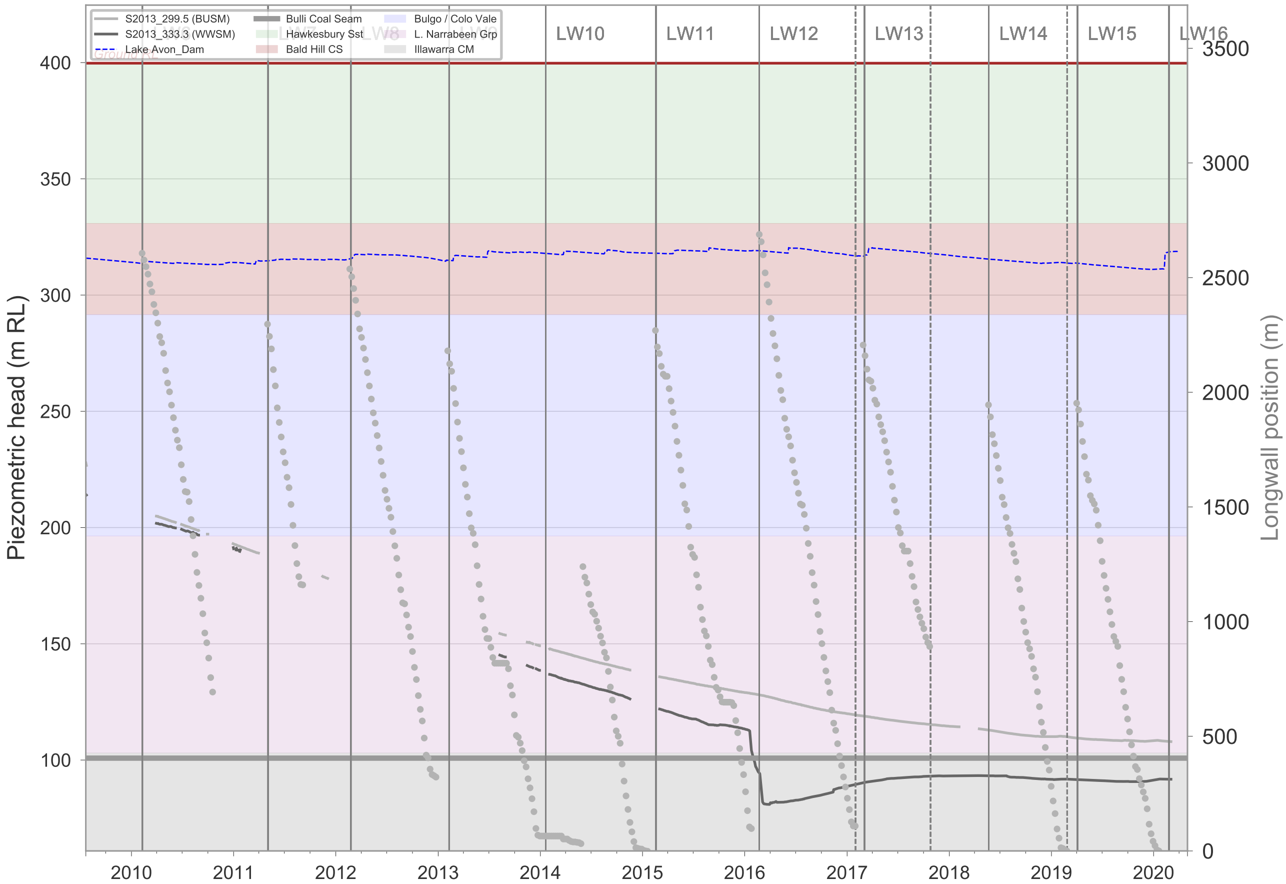
Groundwater hydrographs





Groundwater hydrographs

S2013



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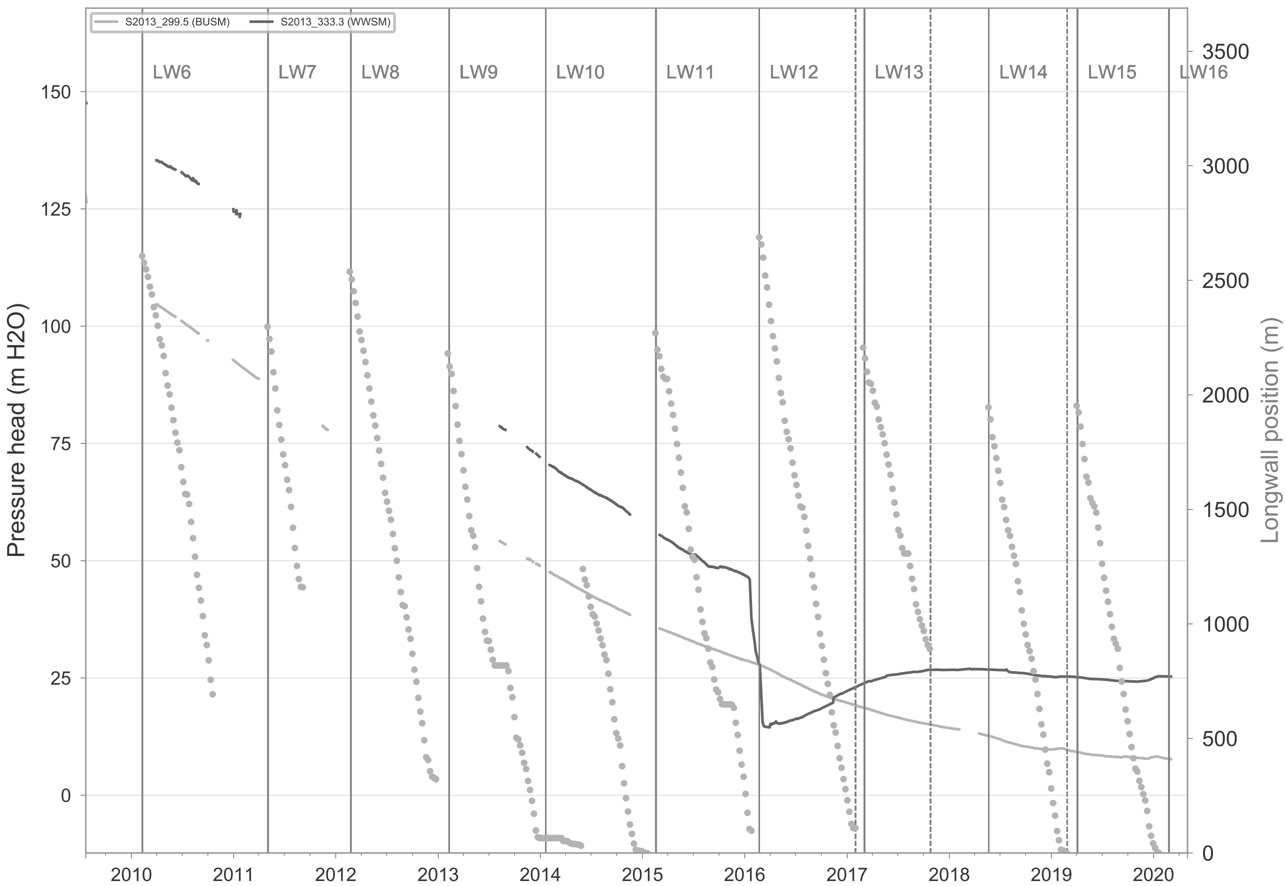
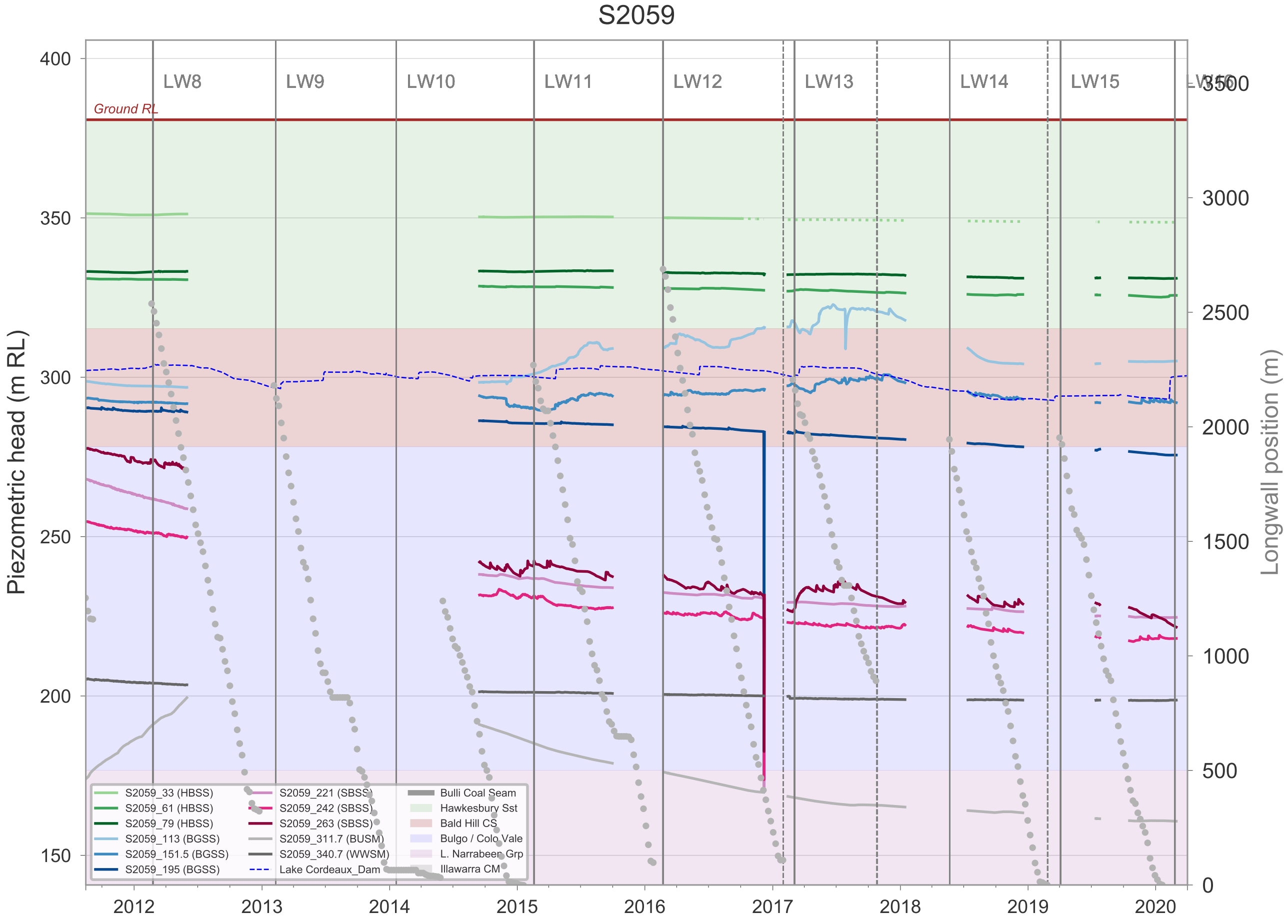
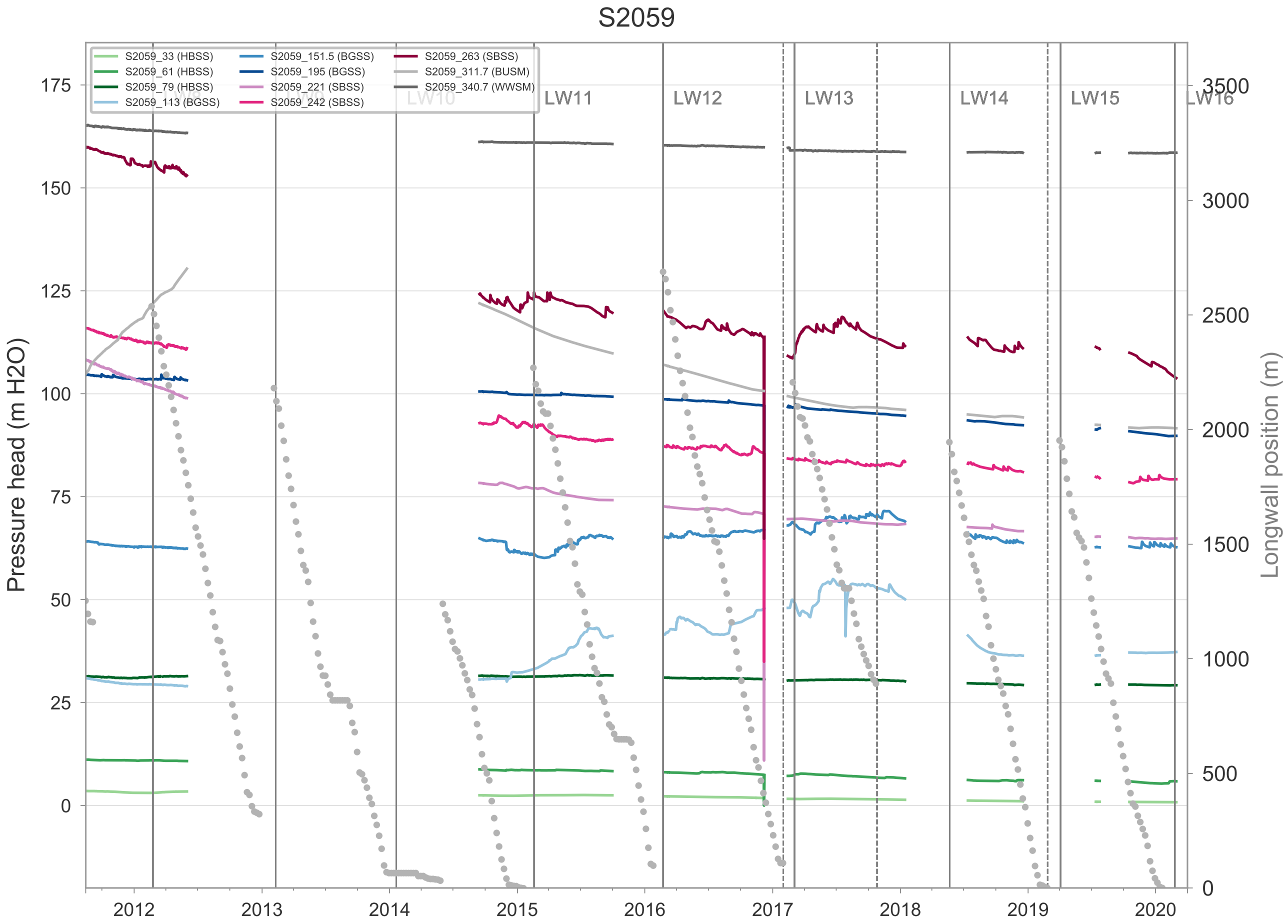
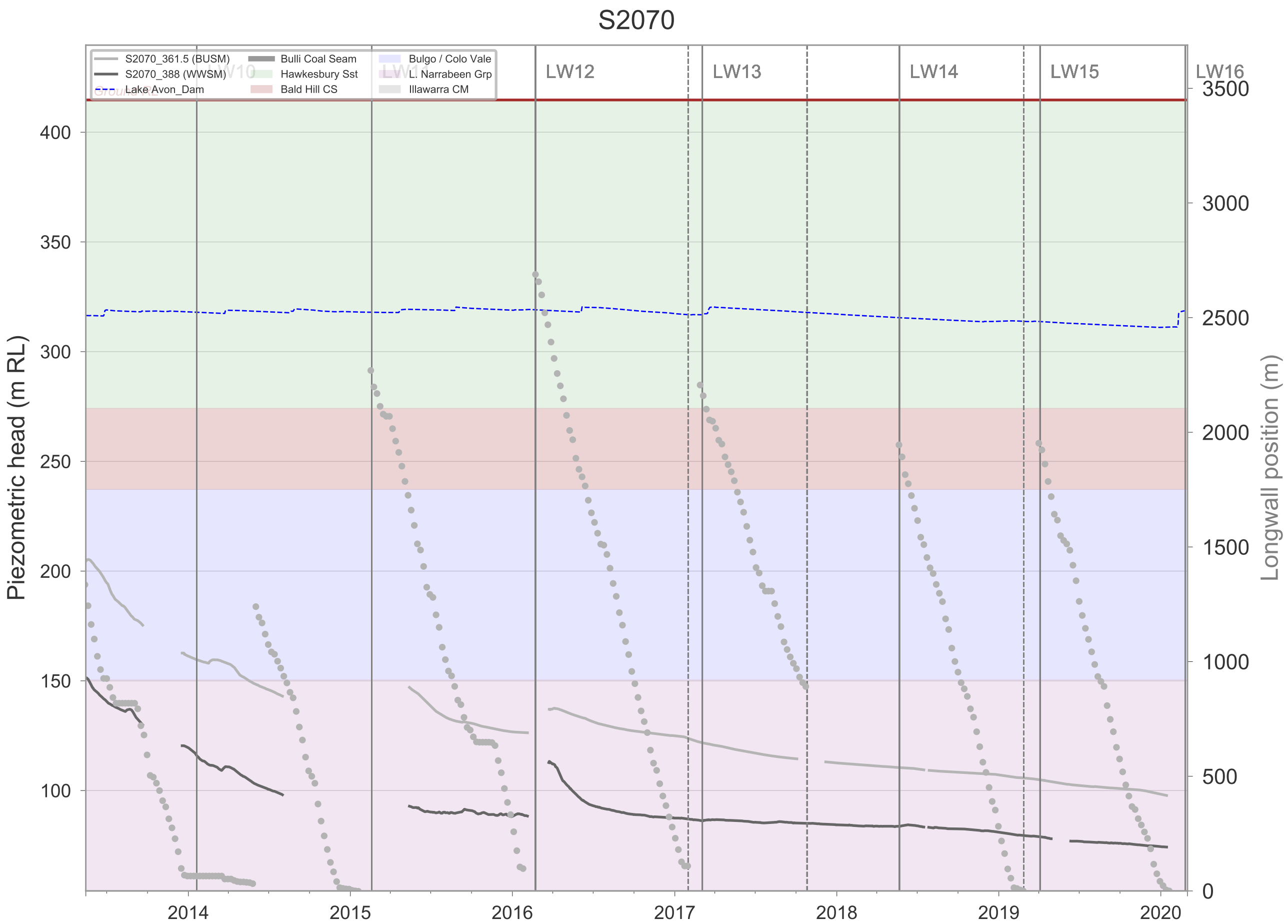


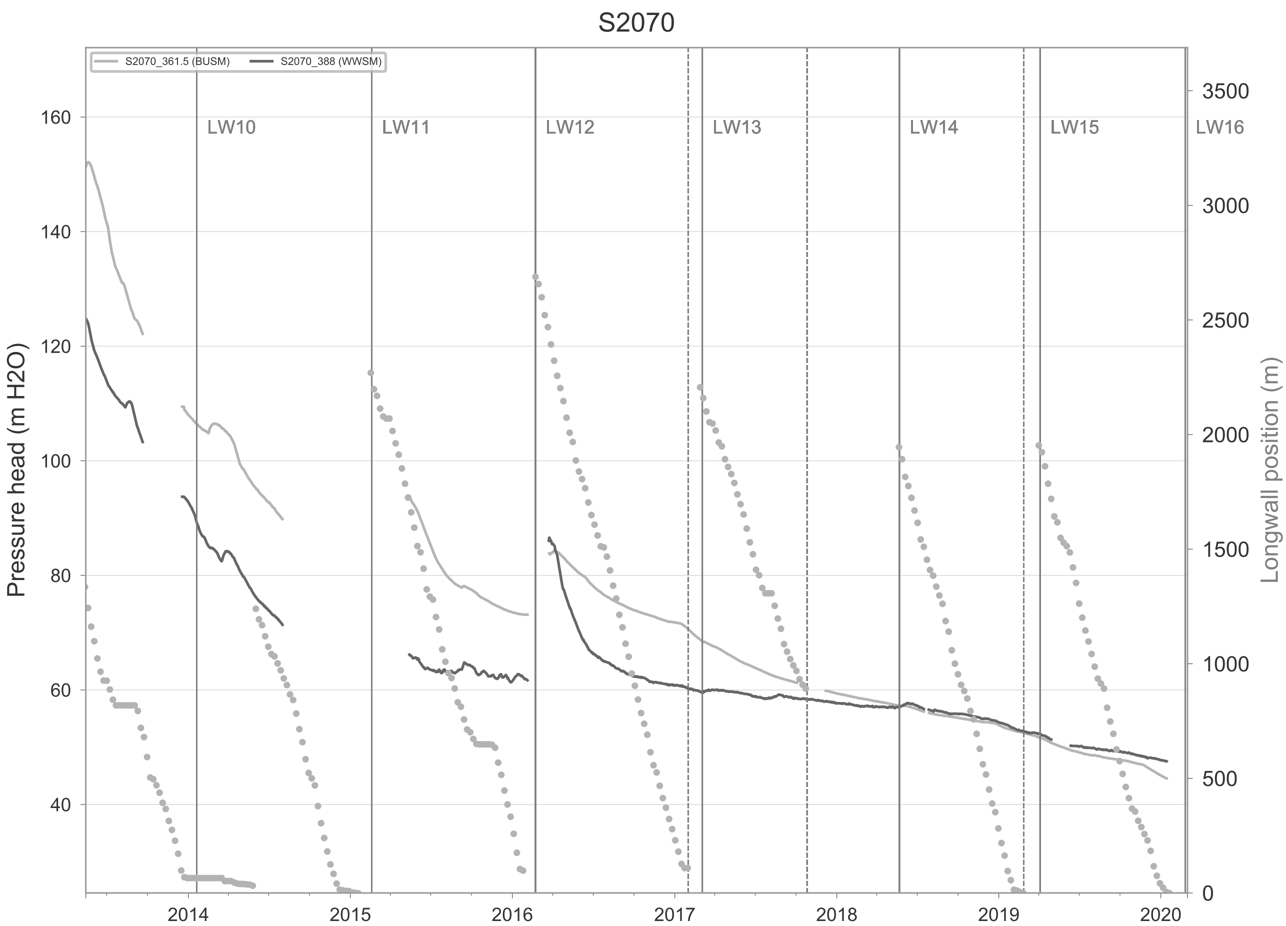
Groundwater hydrographs



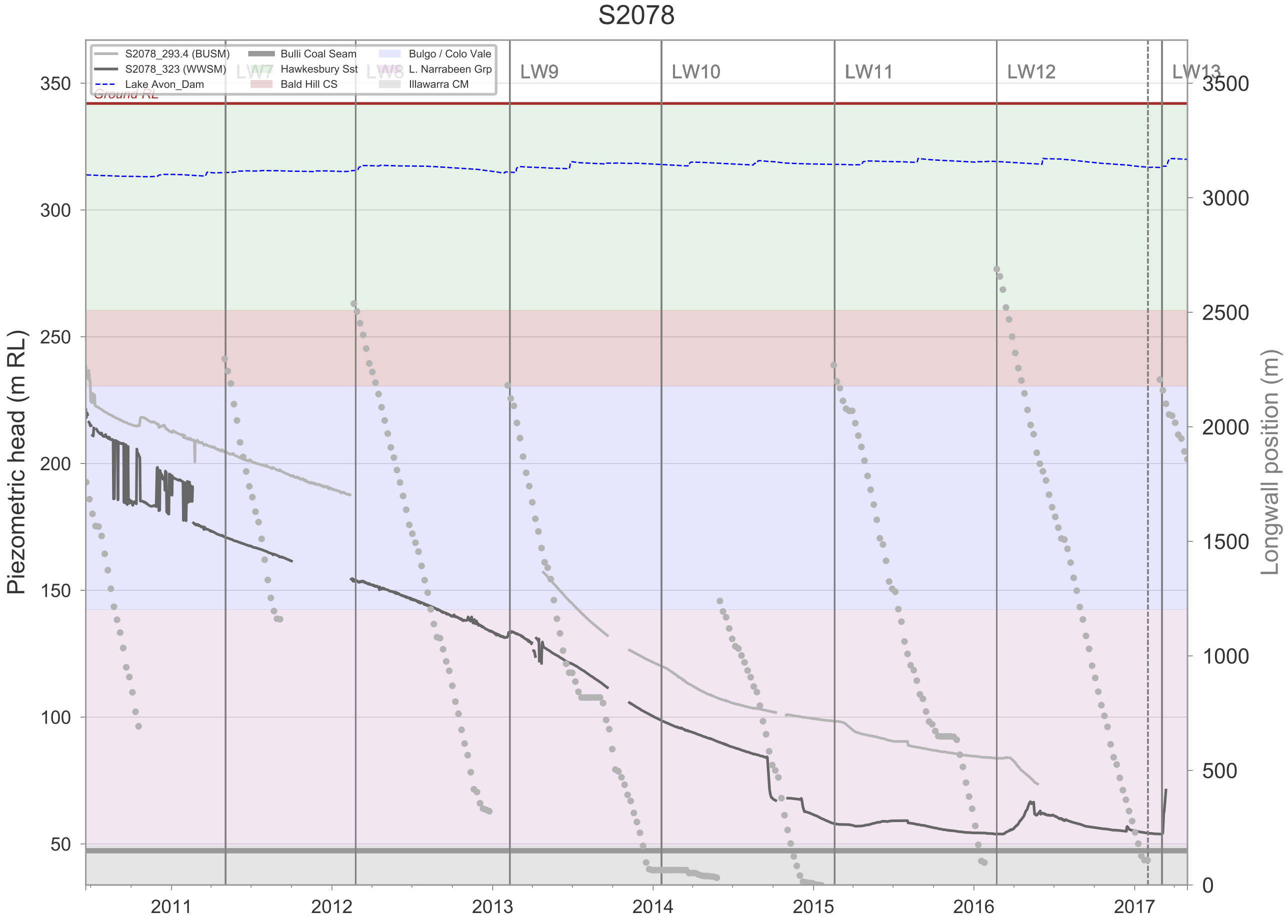


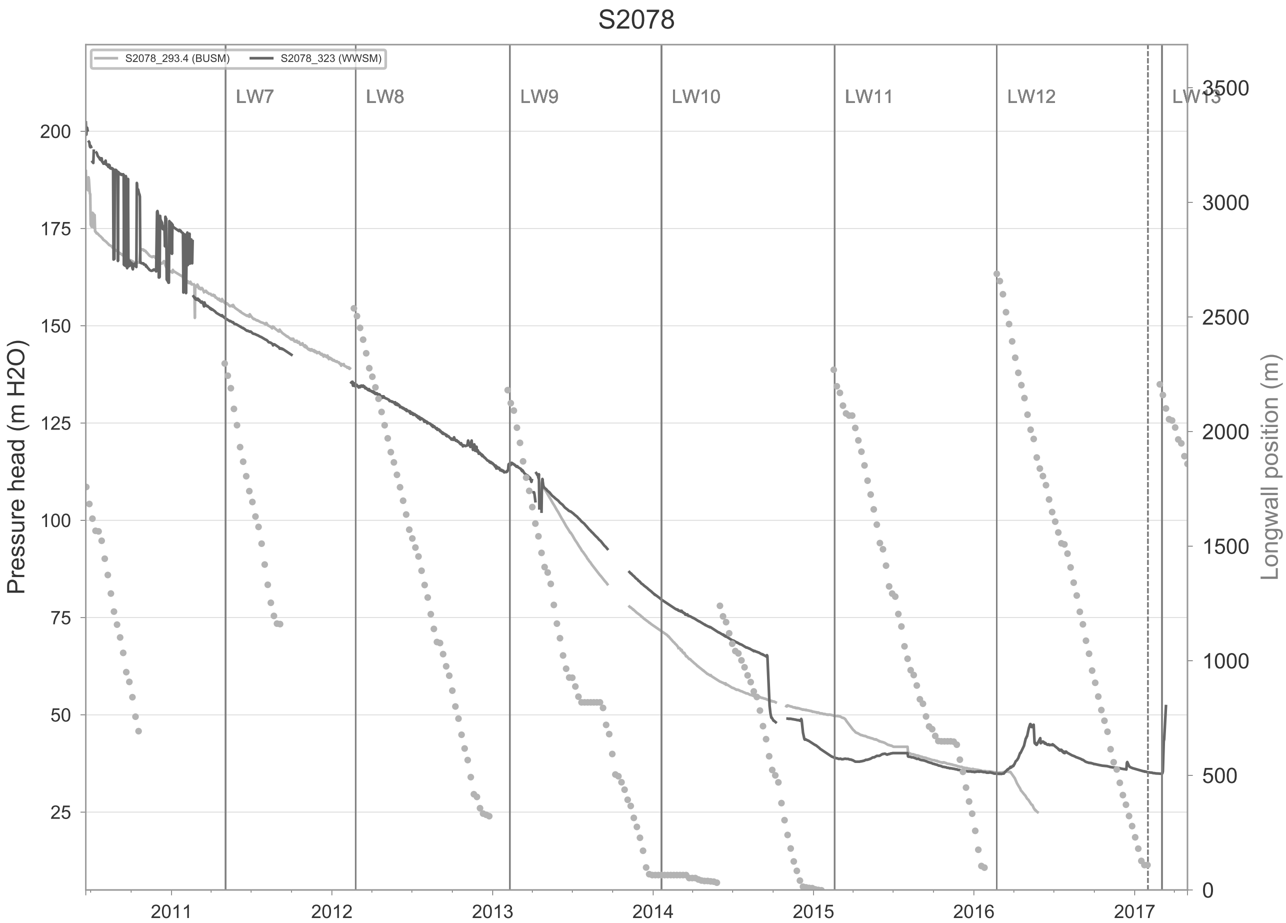
Groundwater hydrographs





Groundwater hydrographs





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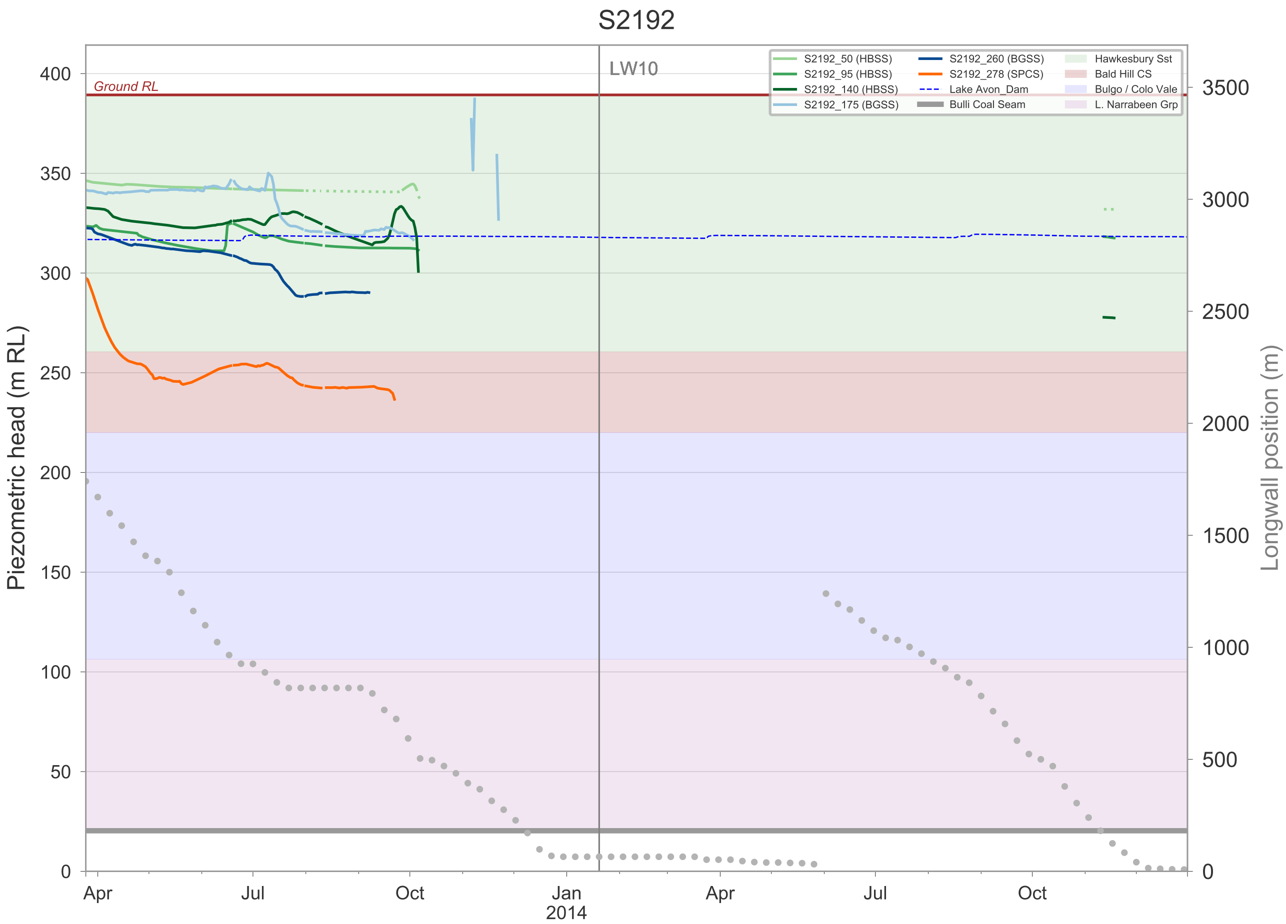

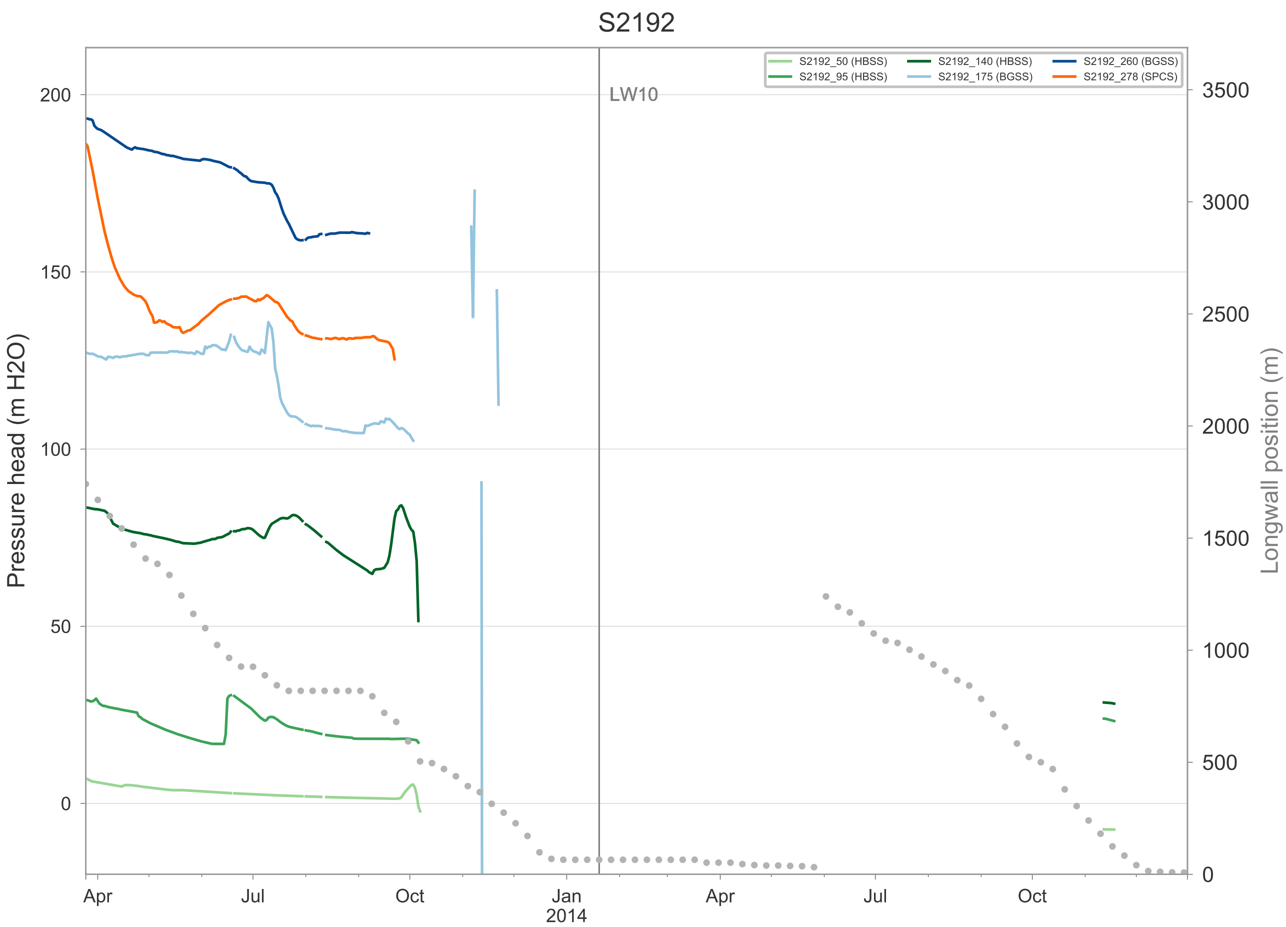

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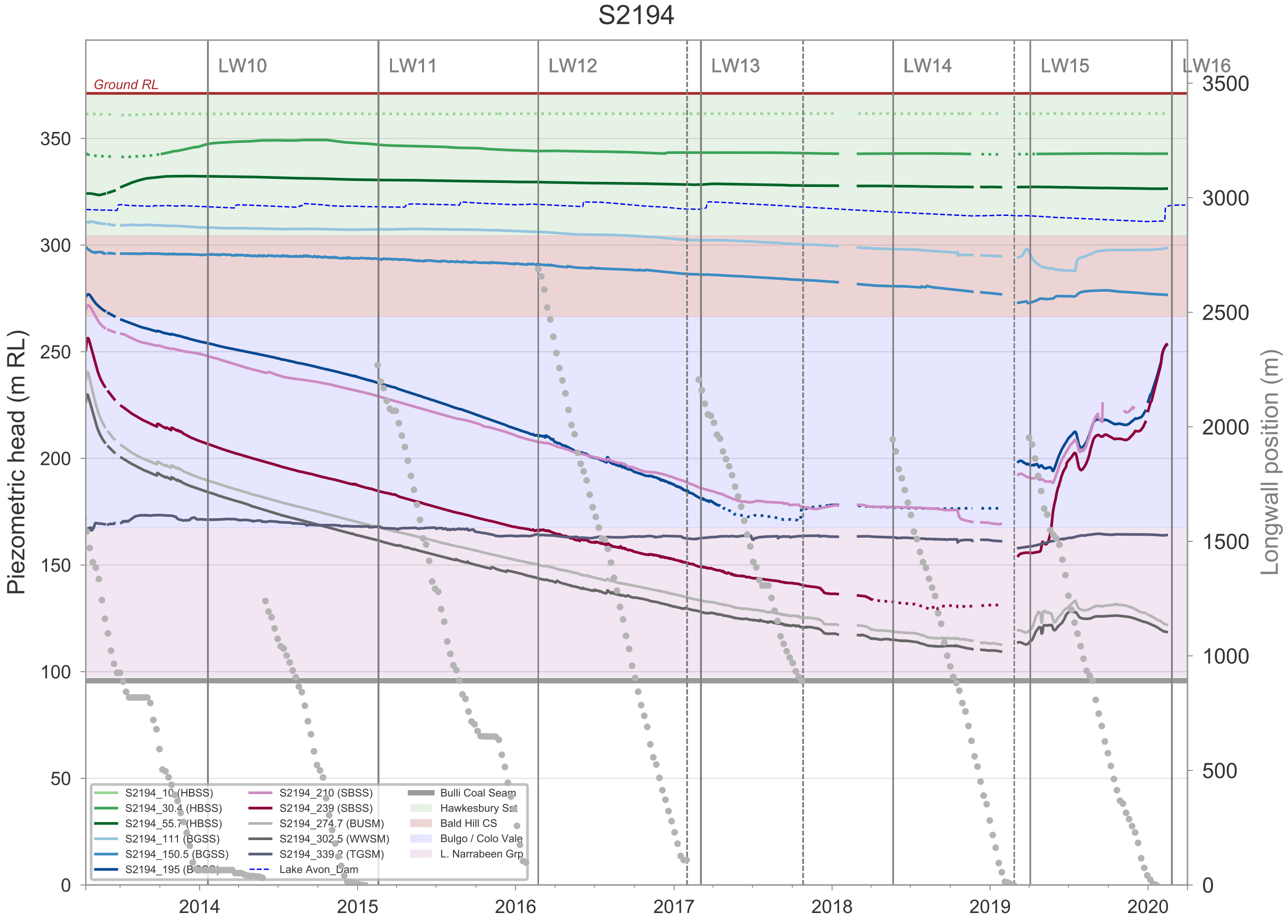
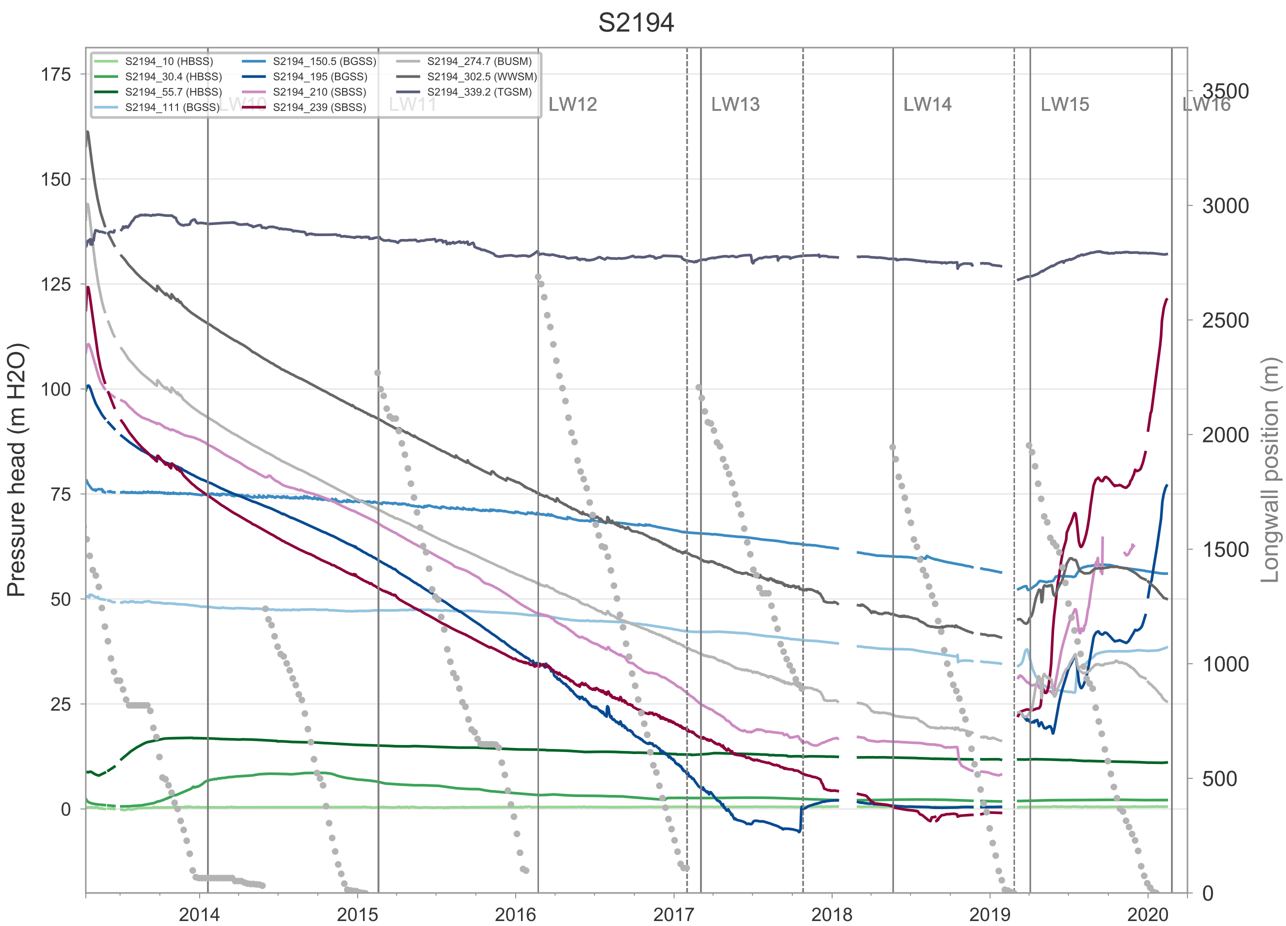
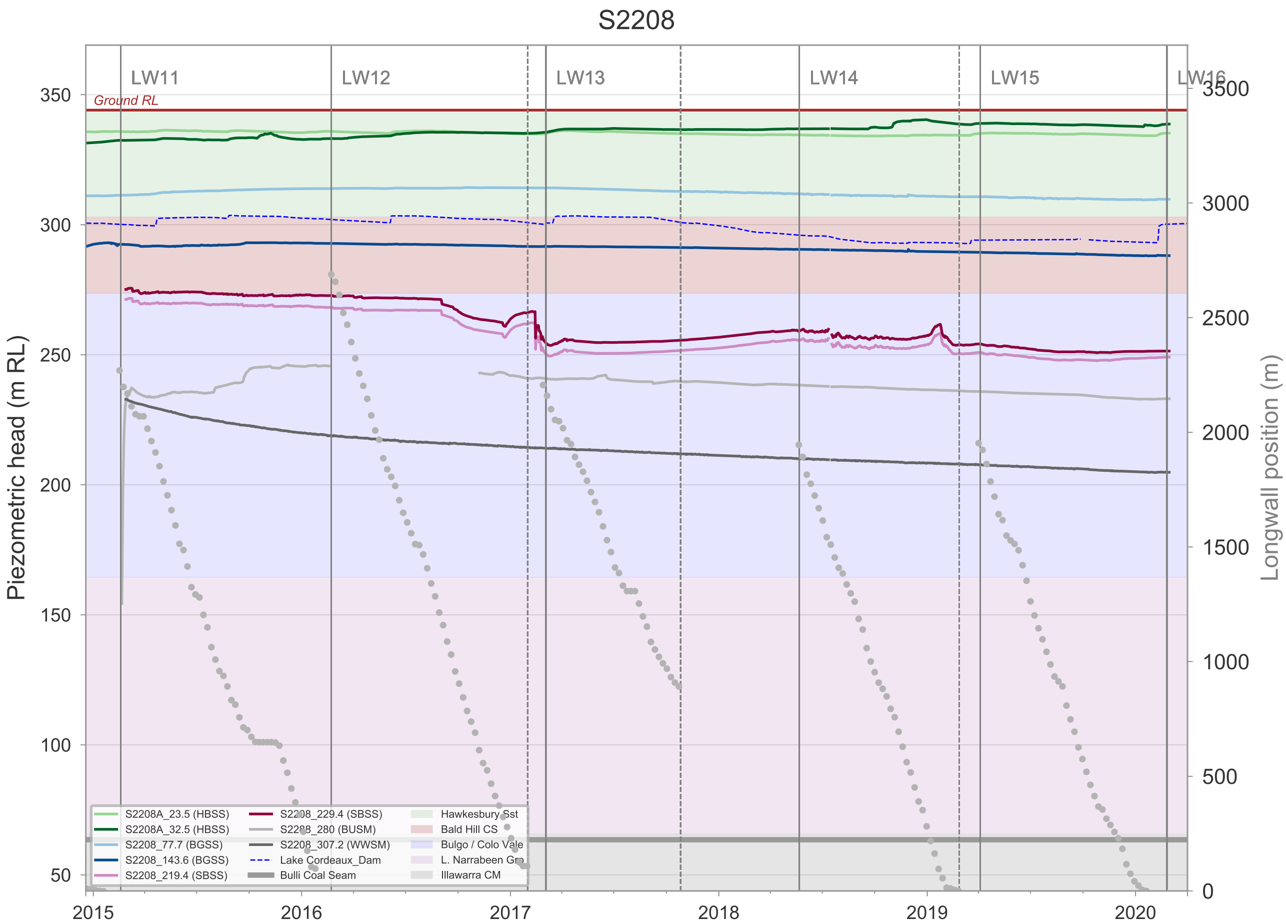
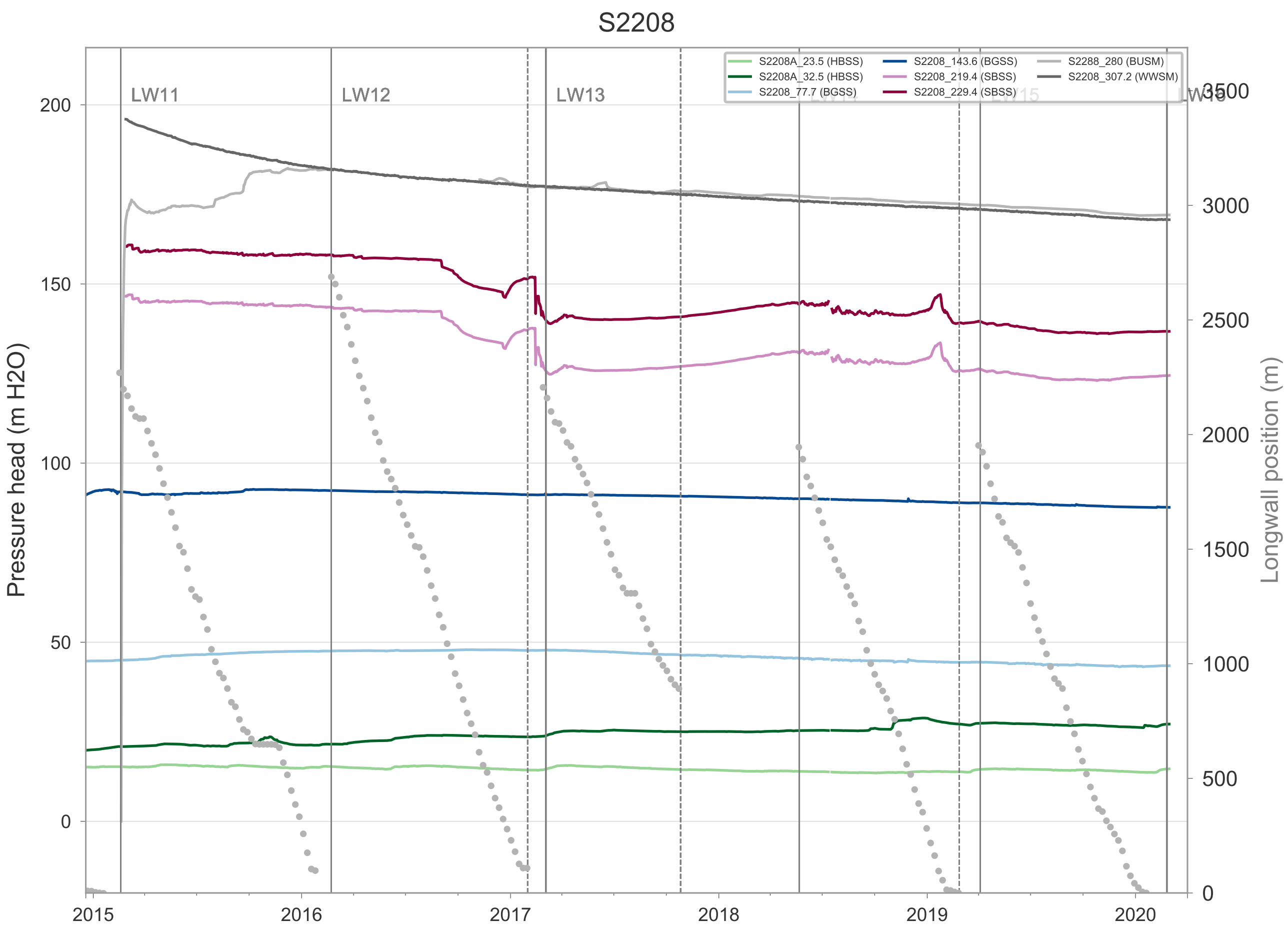




Groundwater hydrographs





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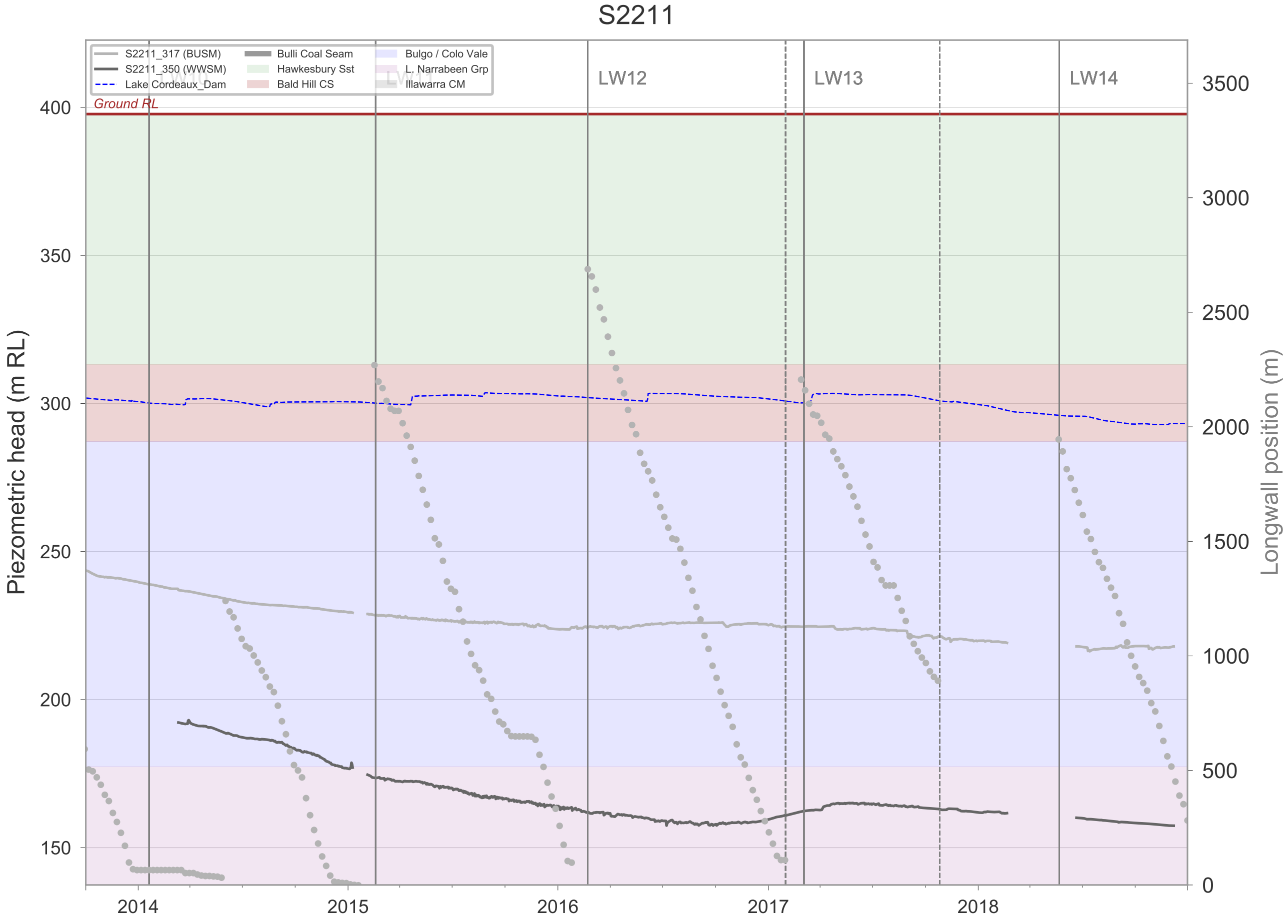
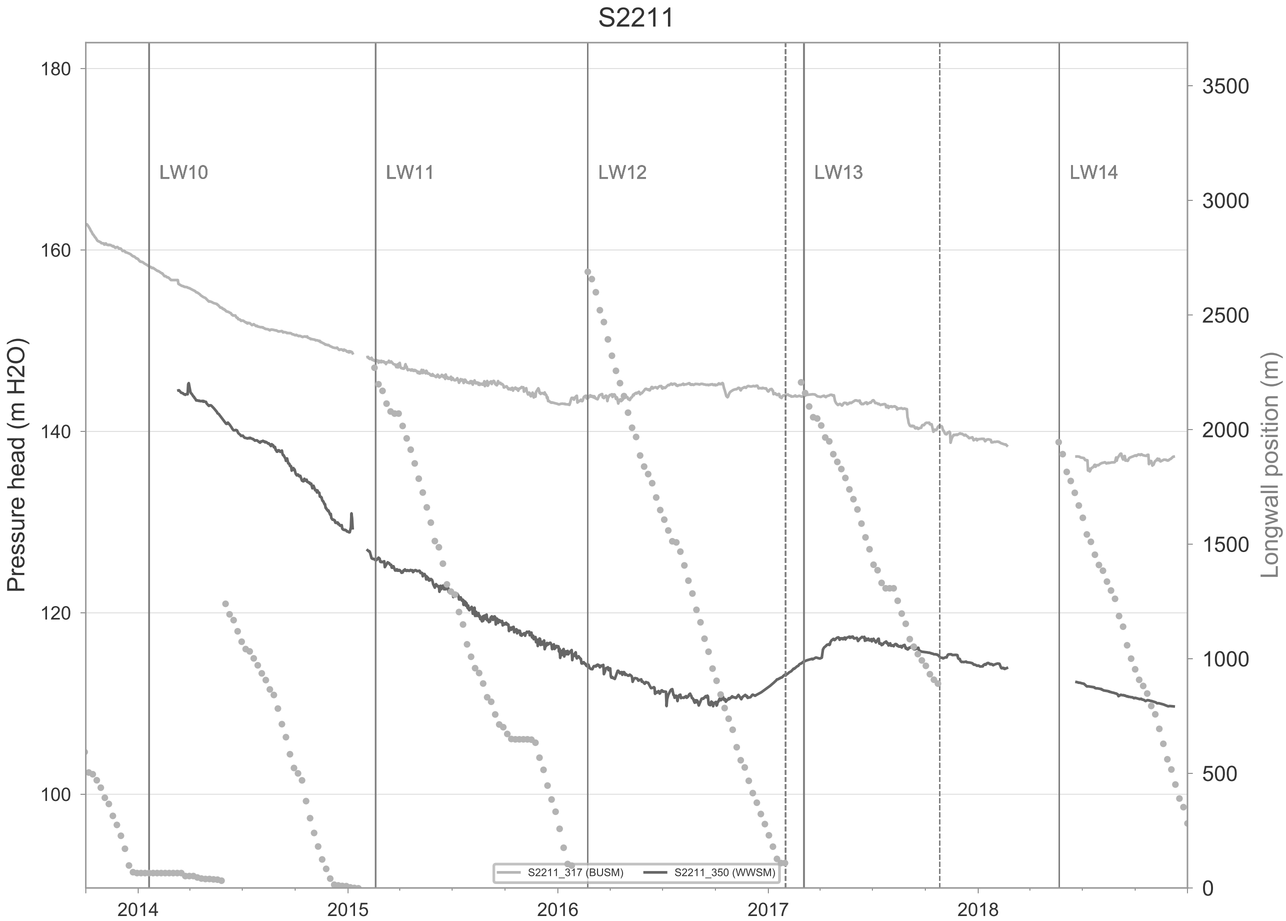
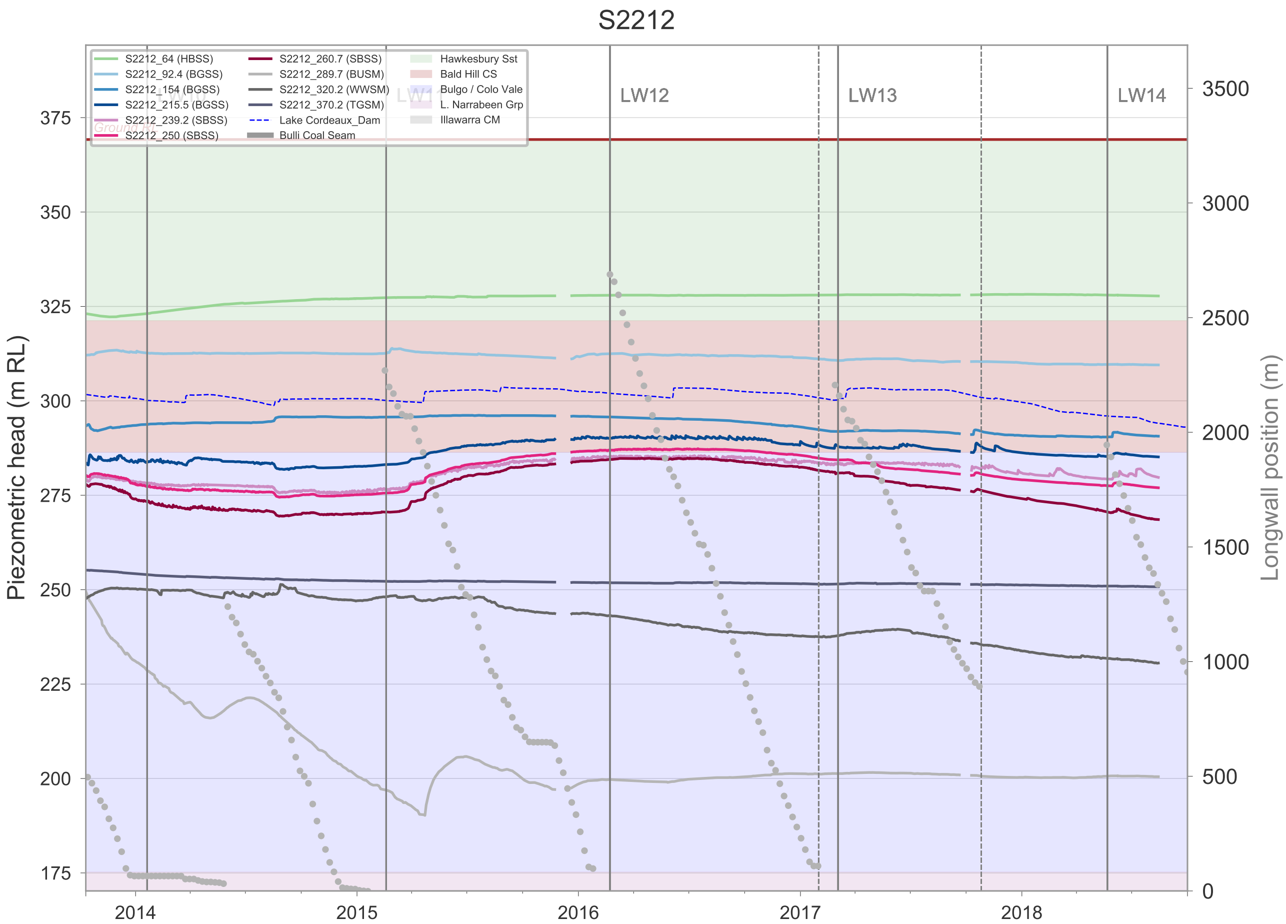
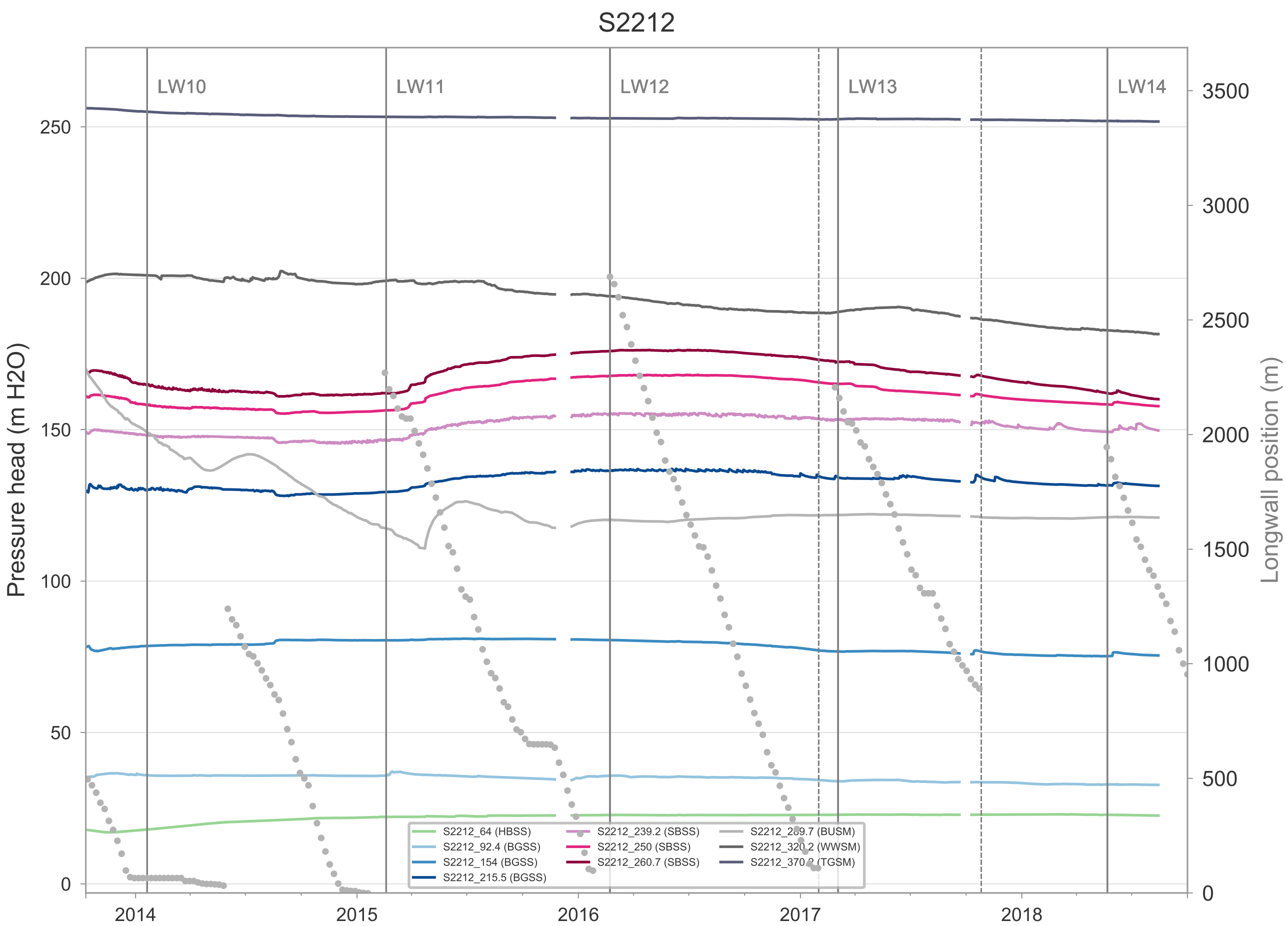


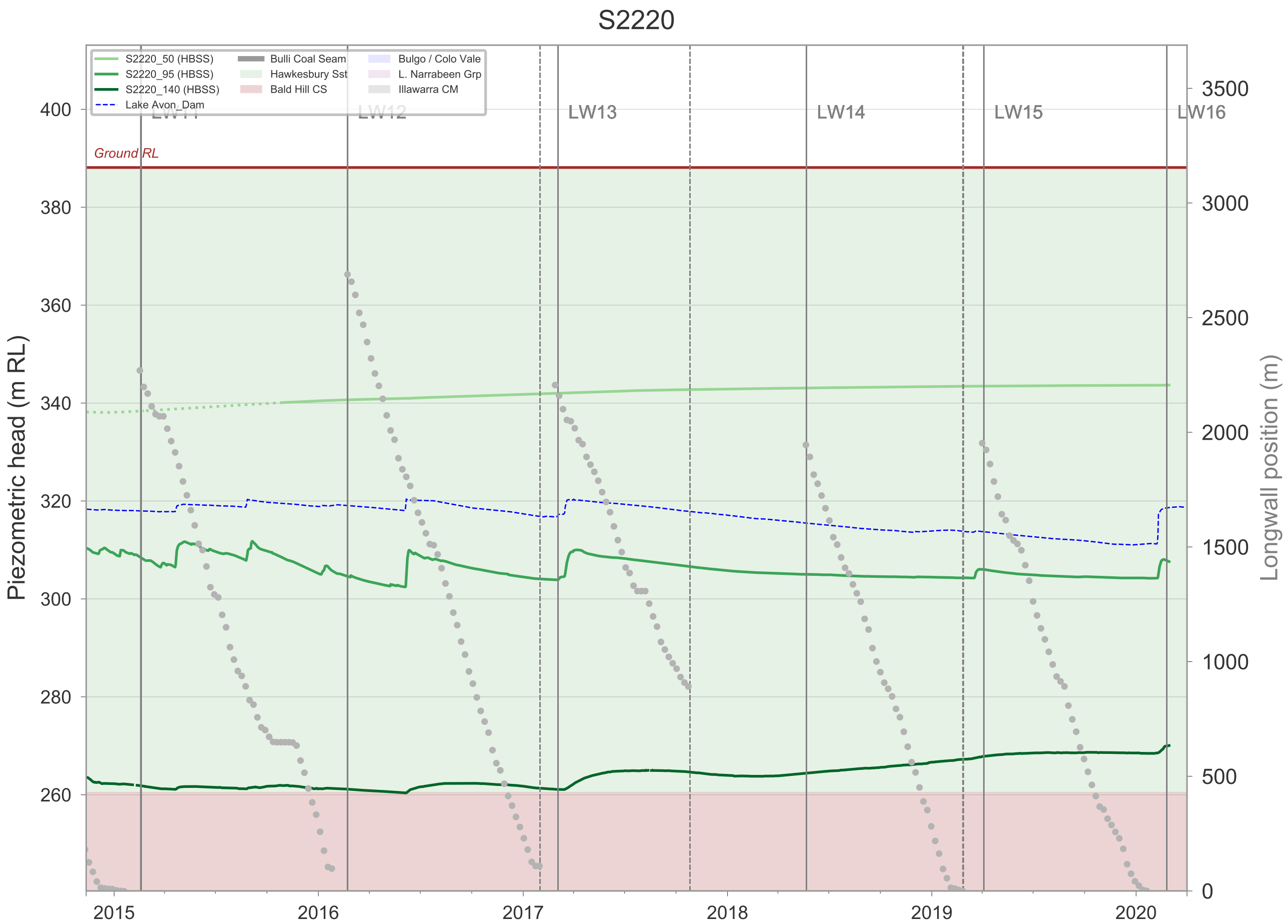


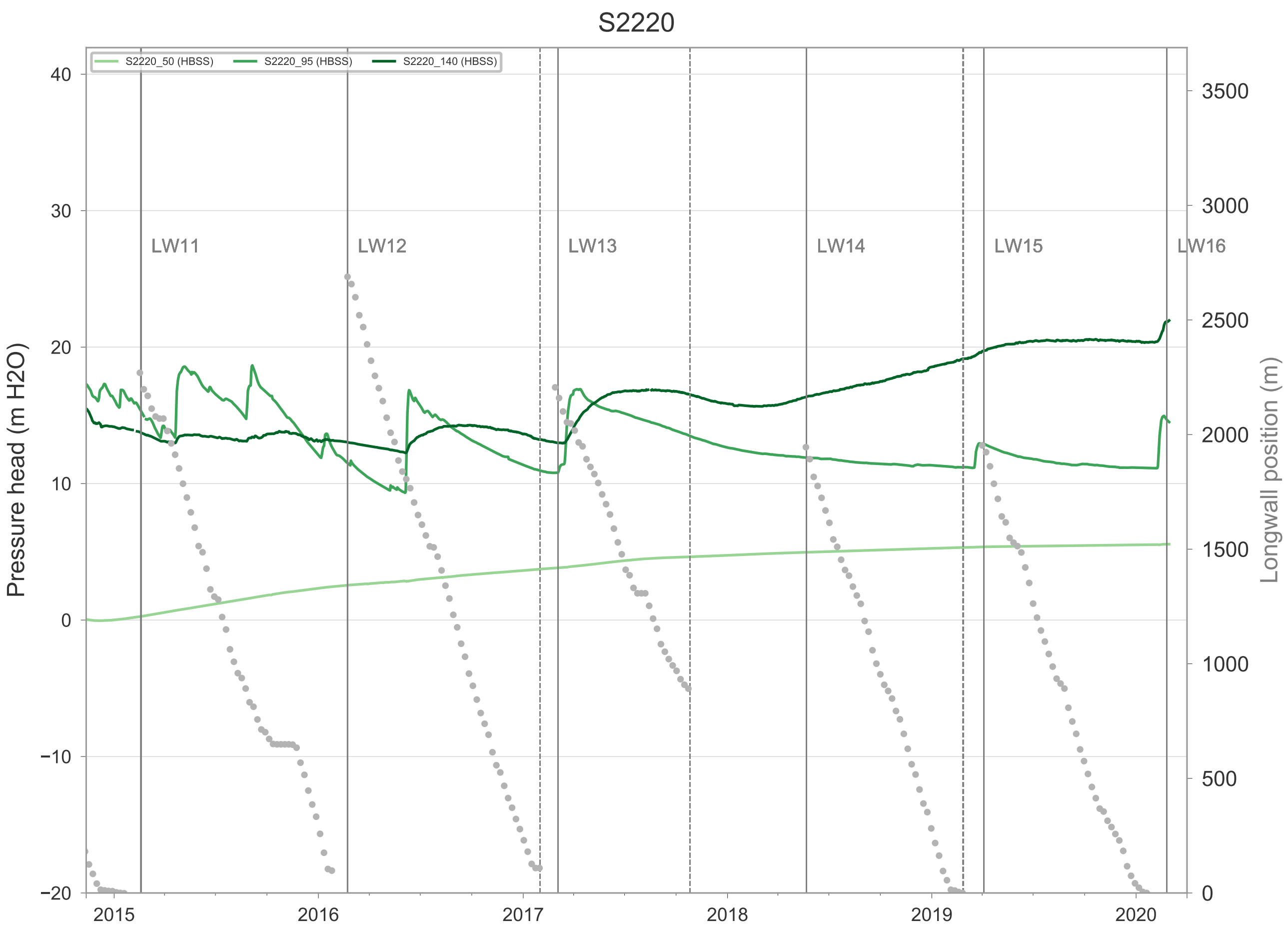
Groundwater hydrographs



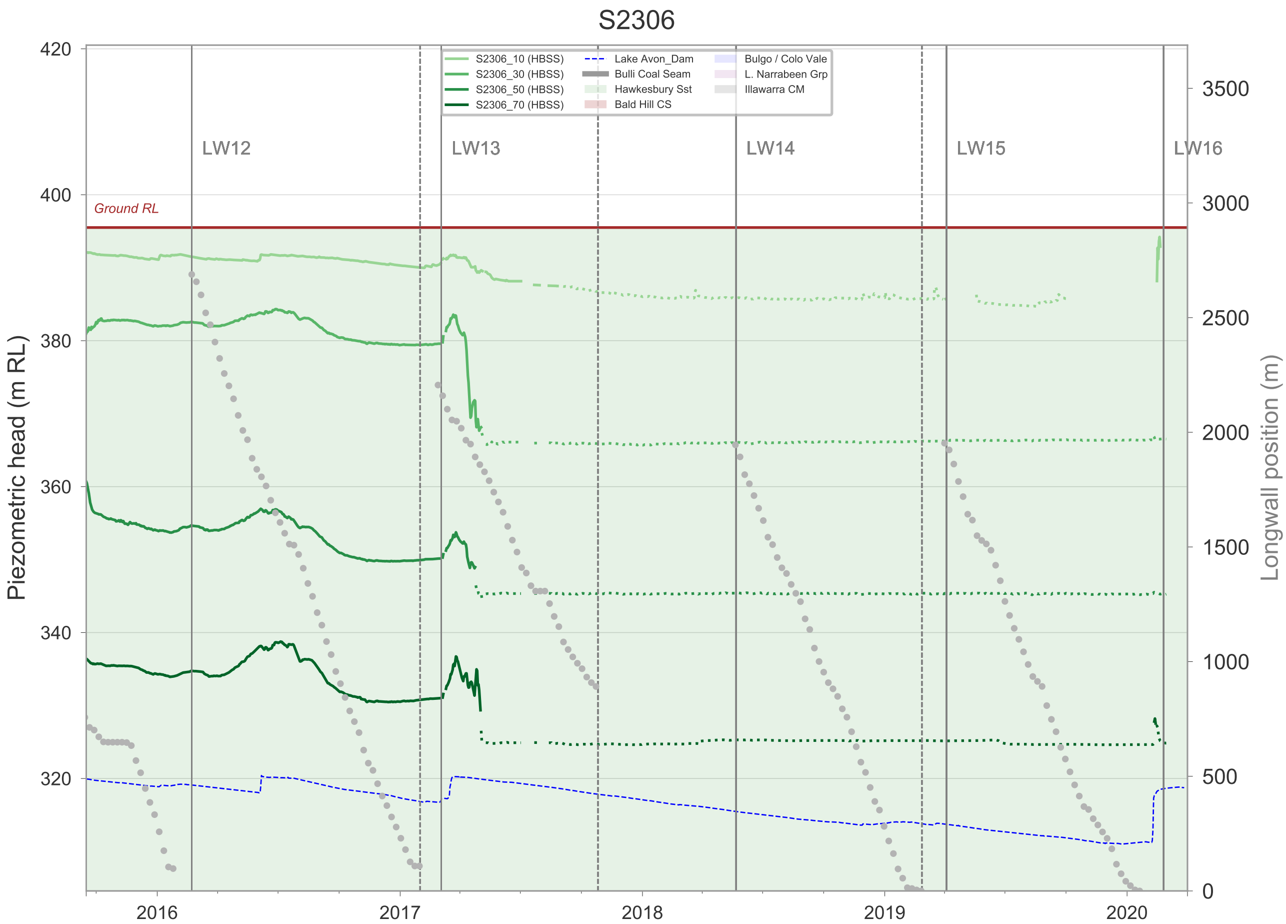


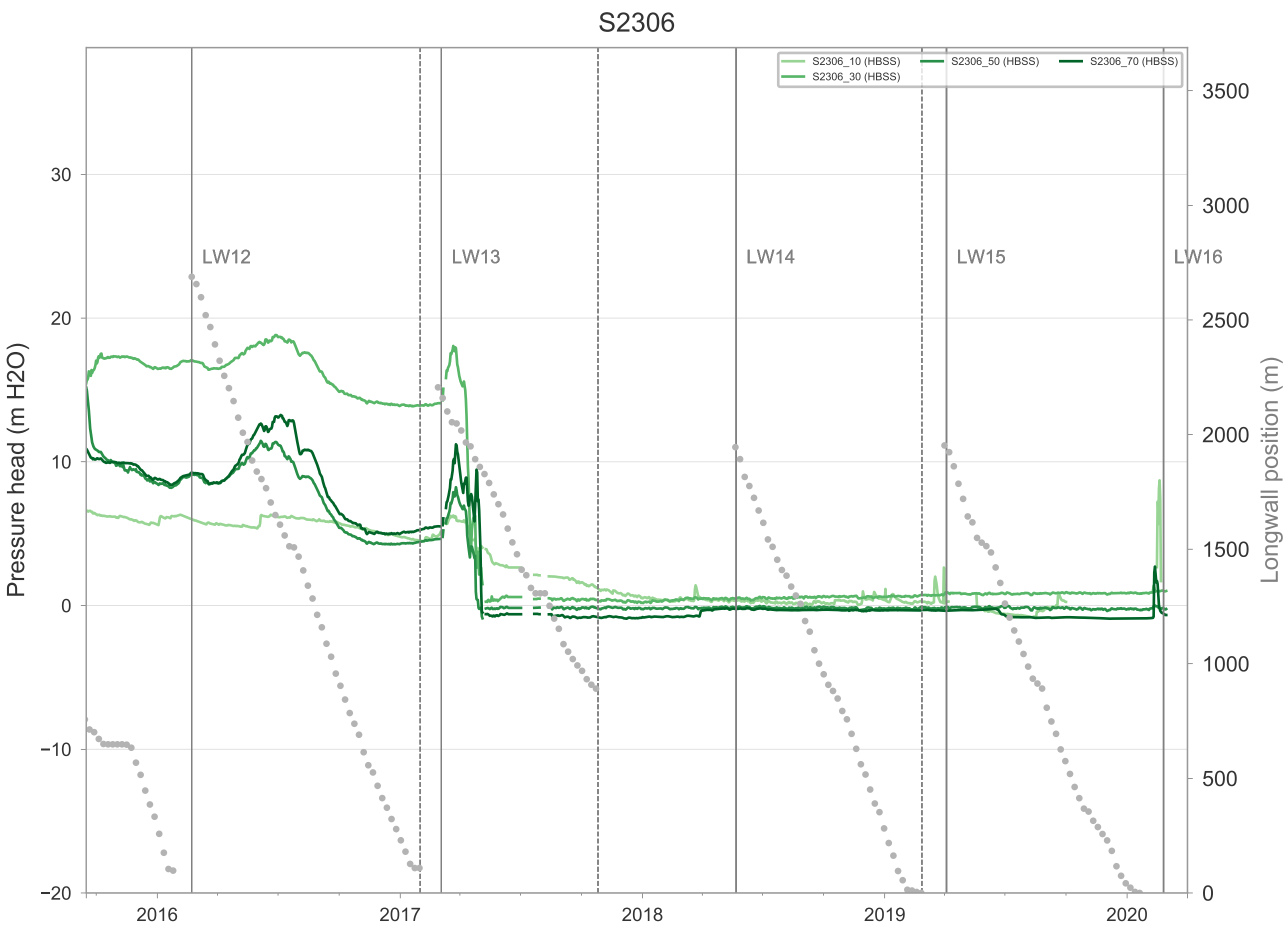
Groundwater hydrographs





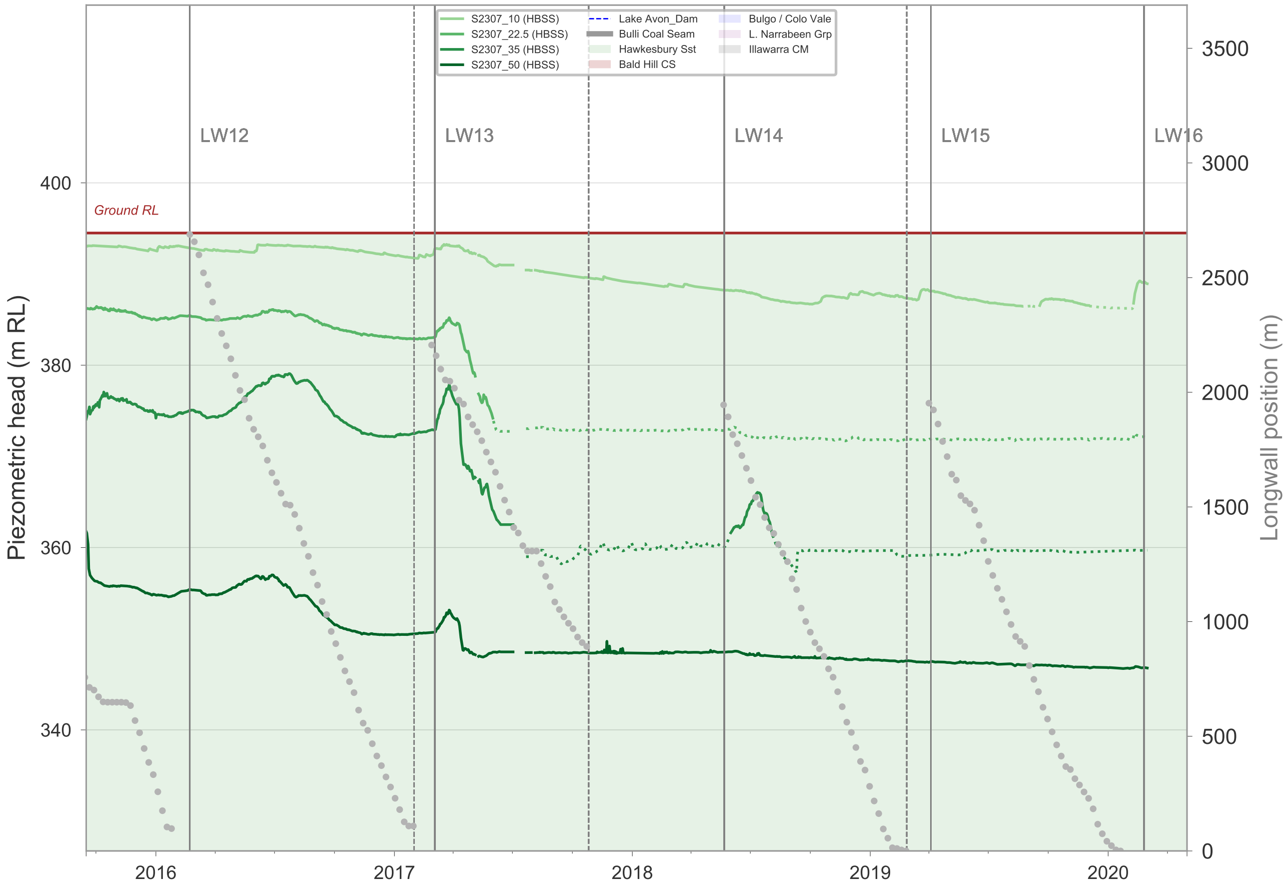
Groundwater hydrographs





Groundwater hydrographs

S2307



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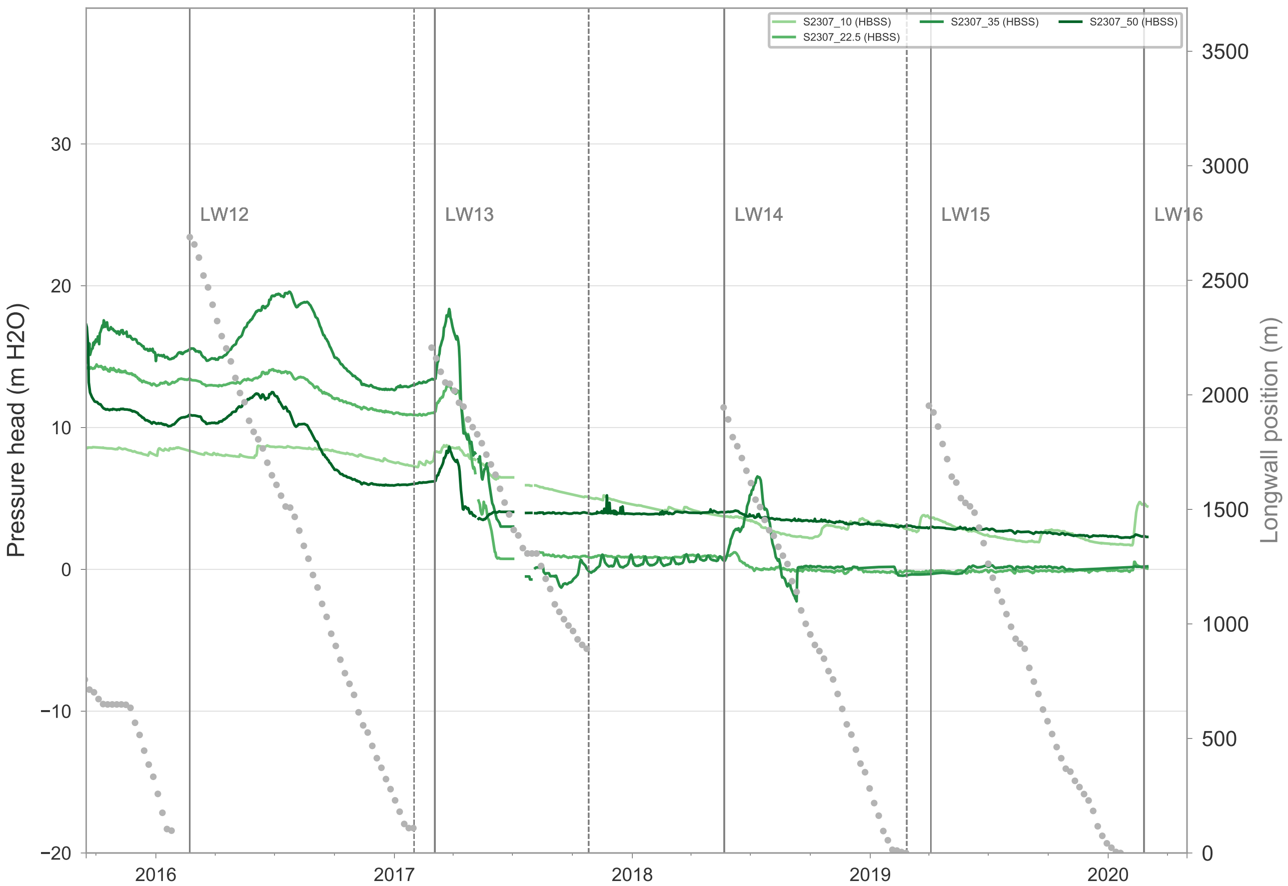
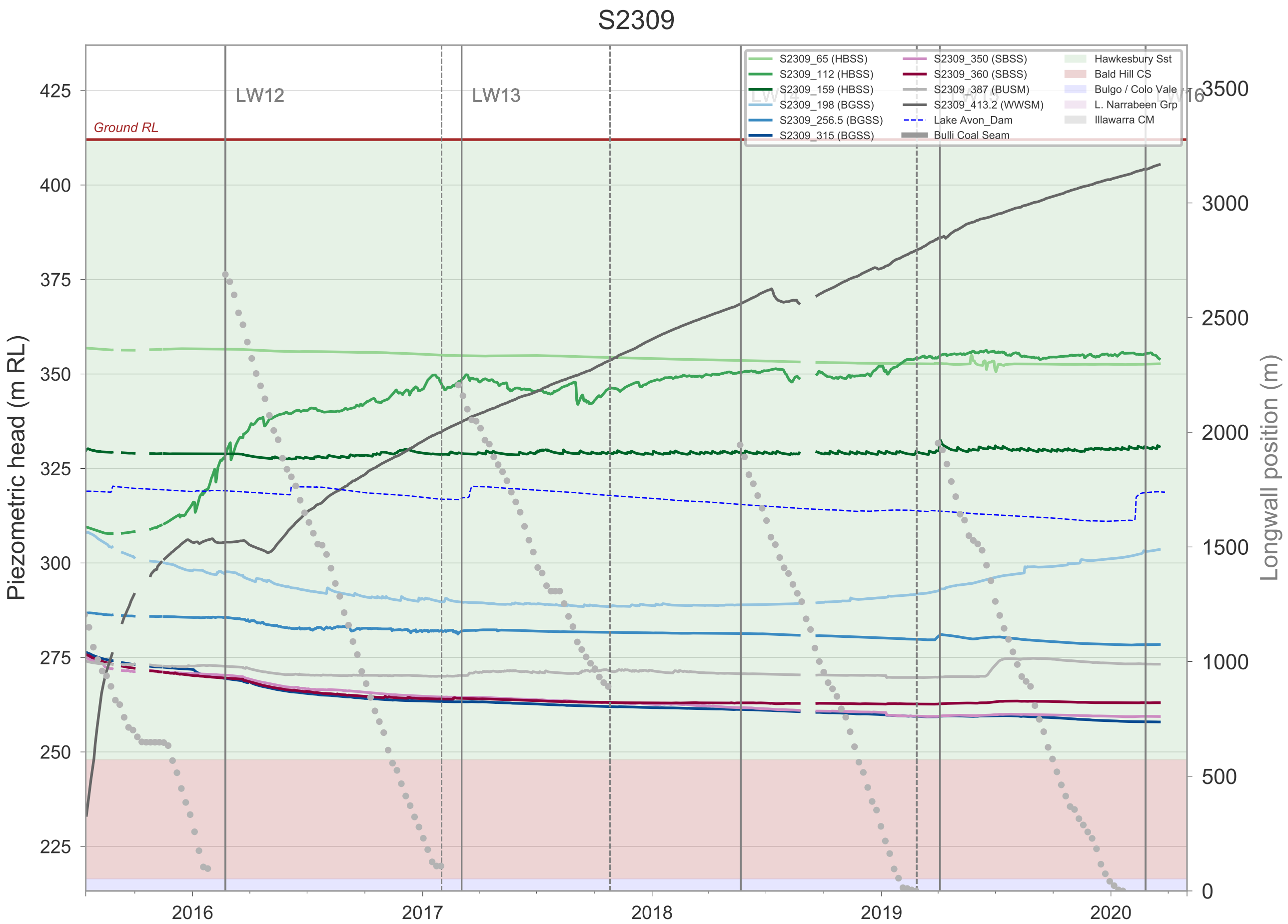
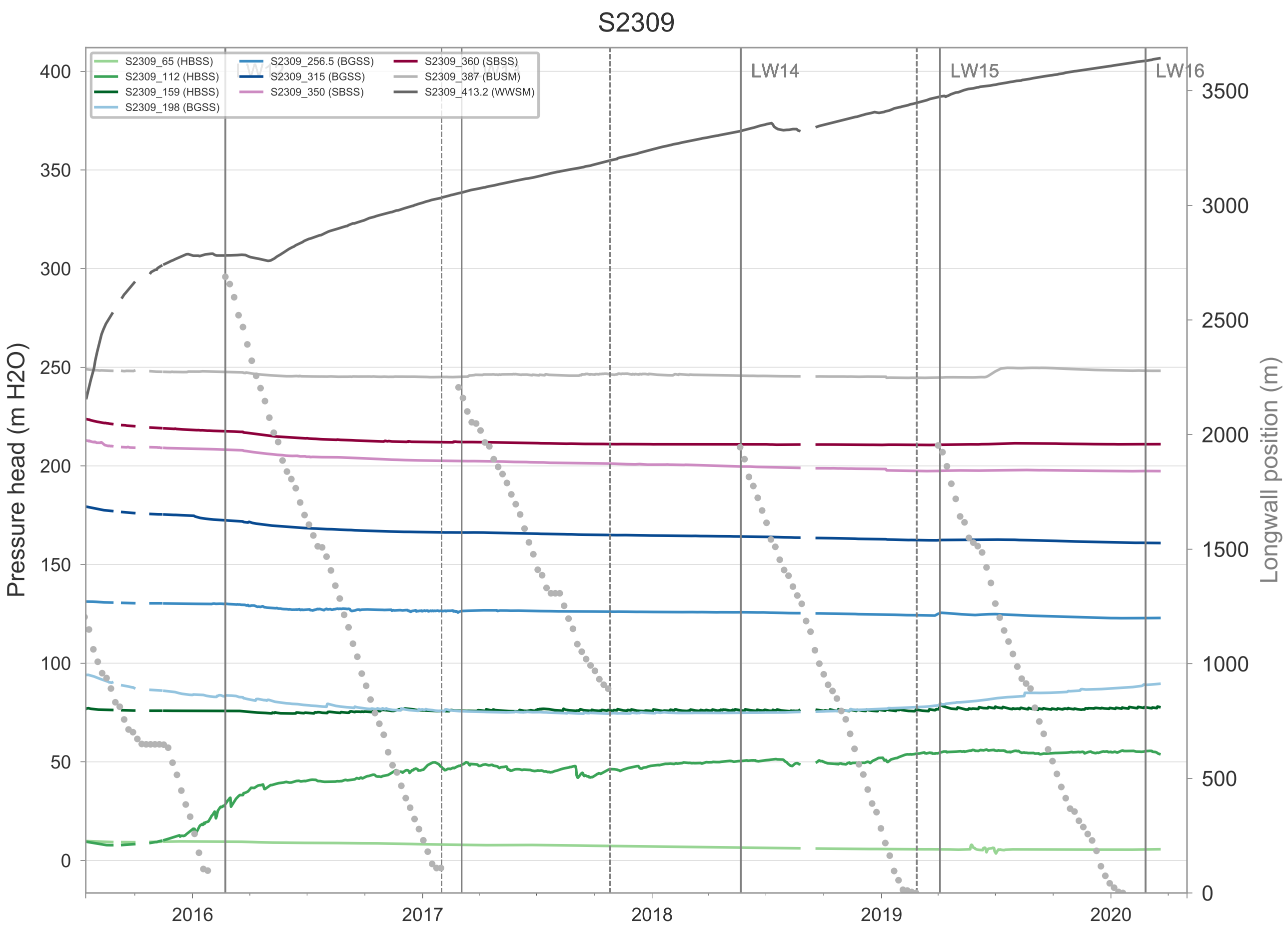
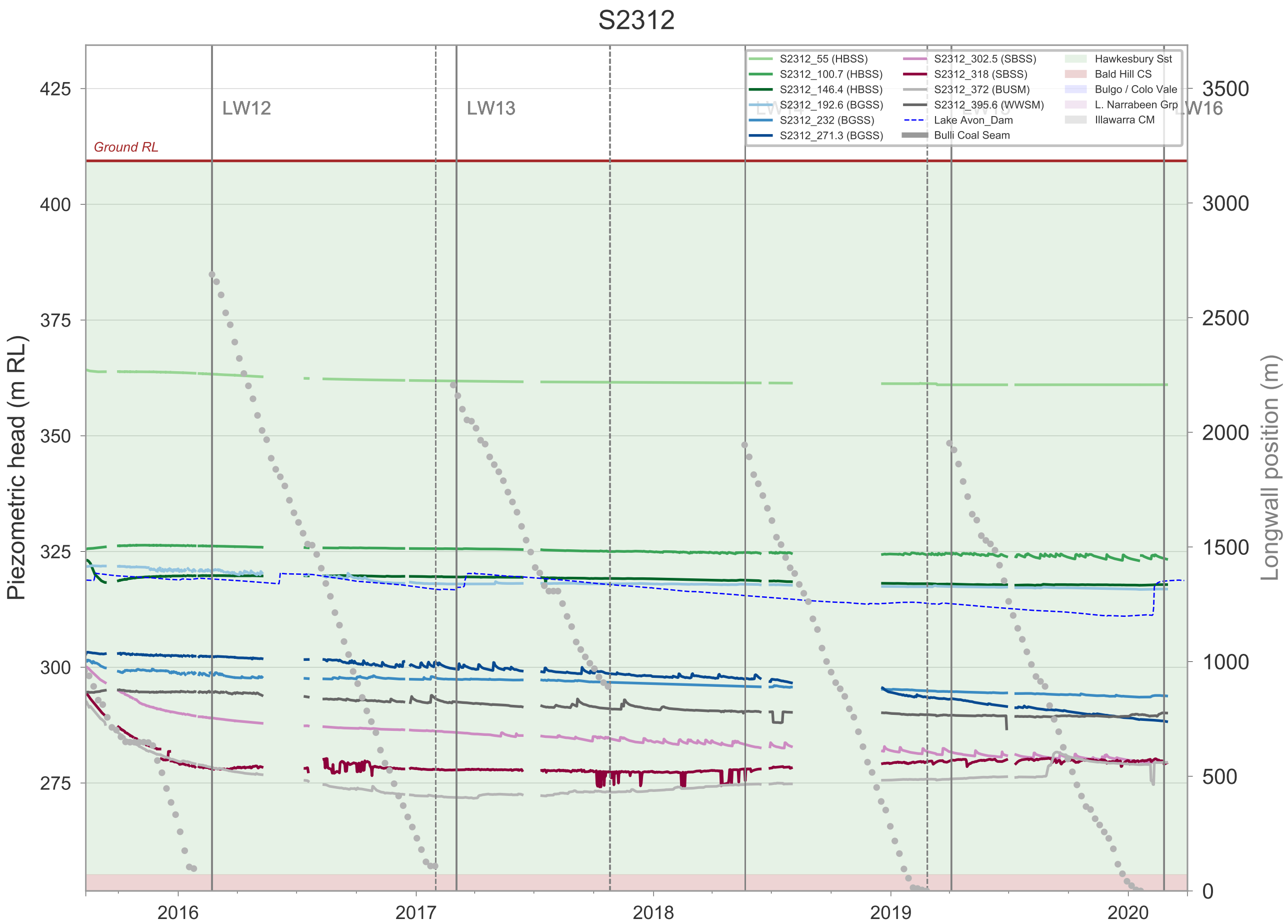


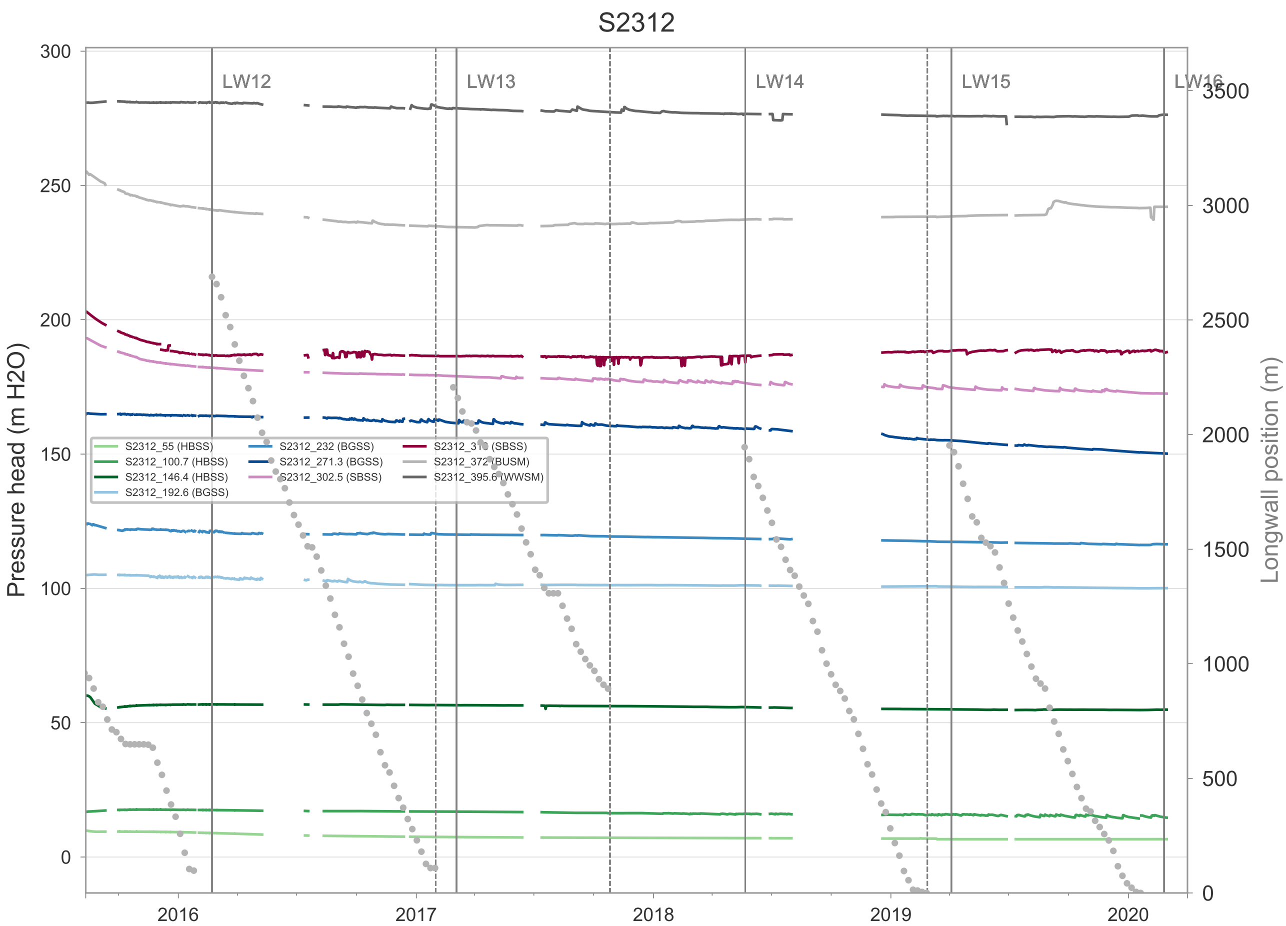
Groundwater hydrographs





Groundwater hydrographs





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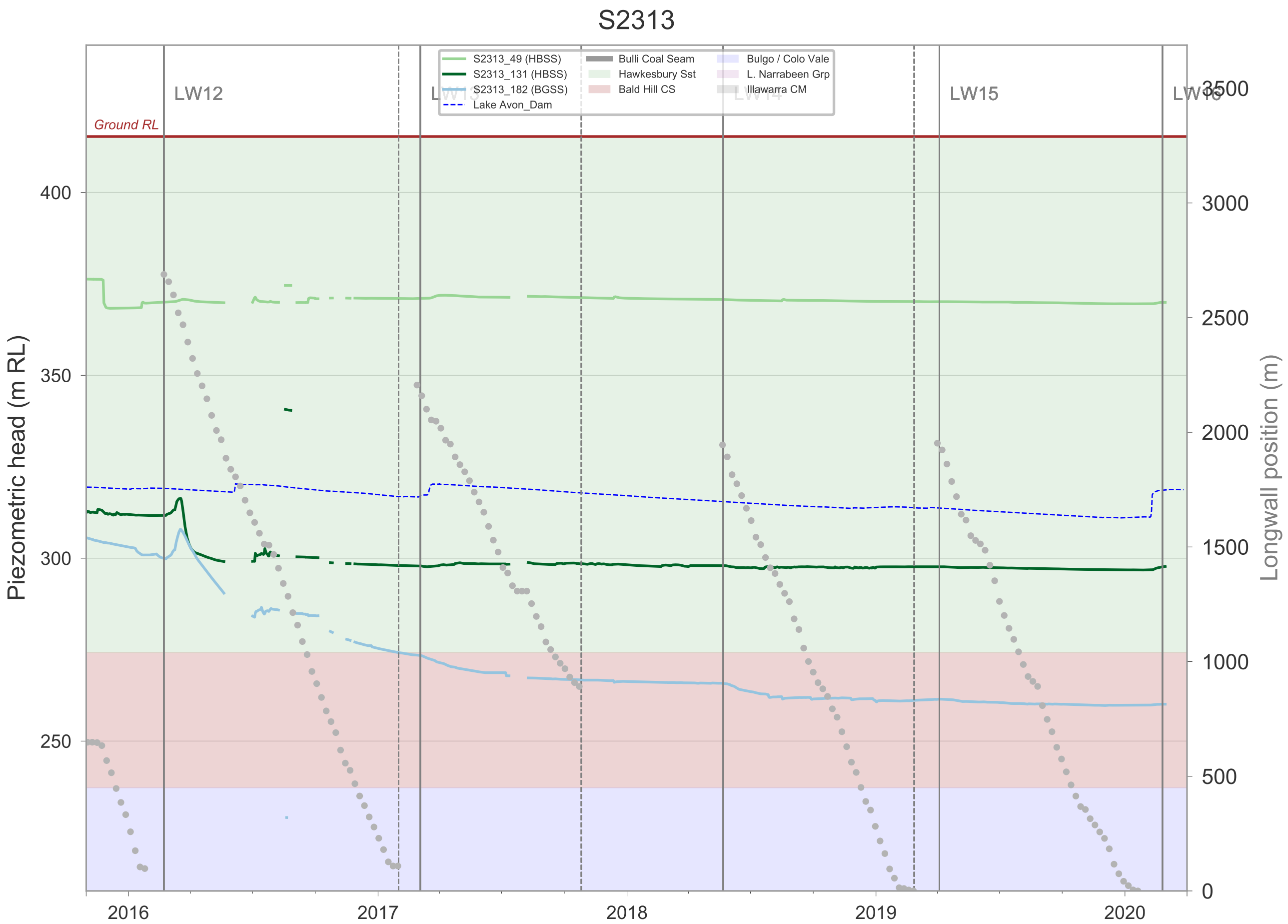

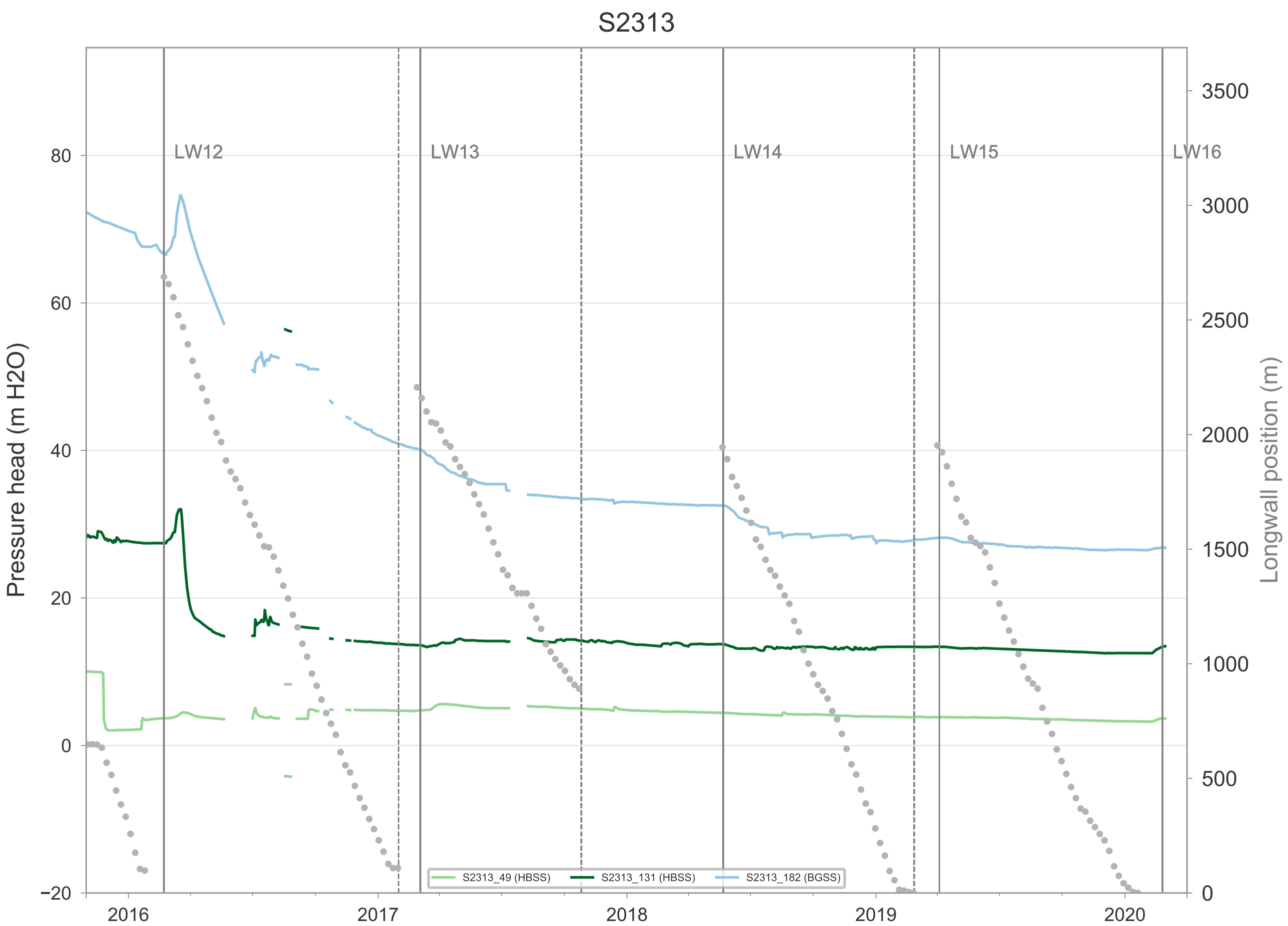

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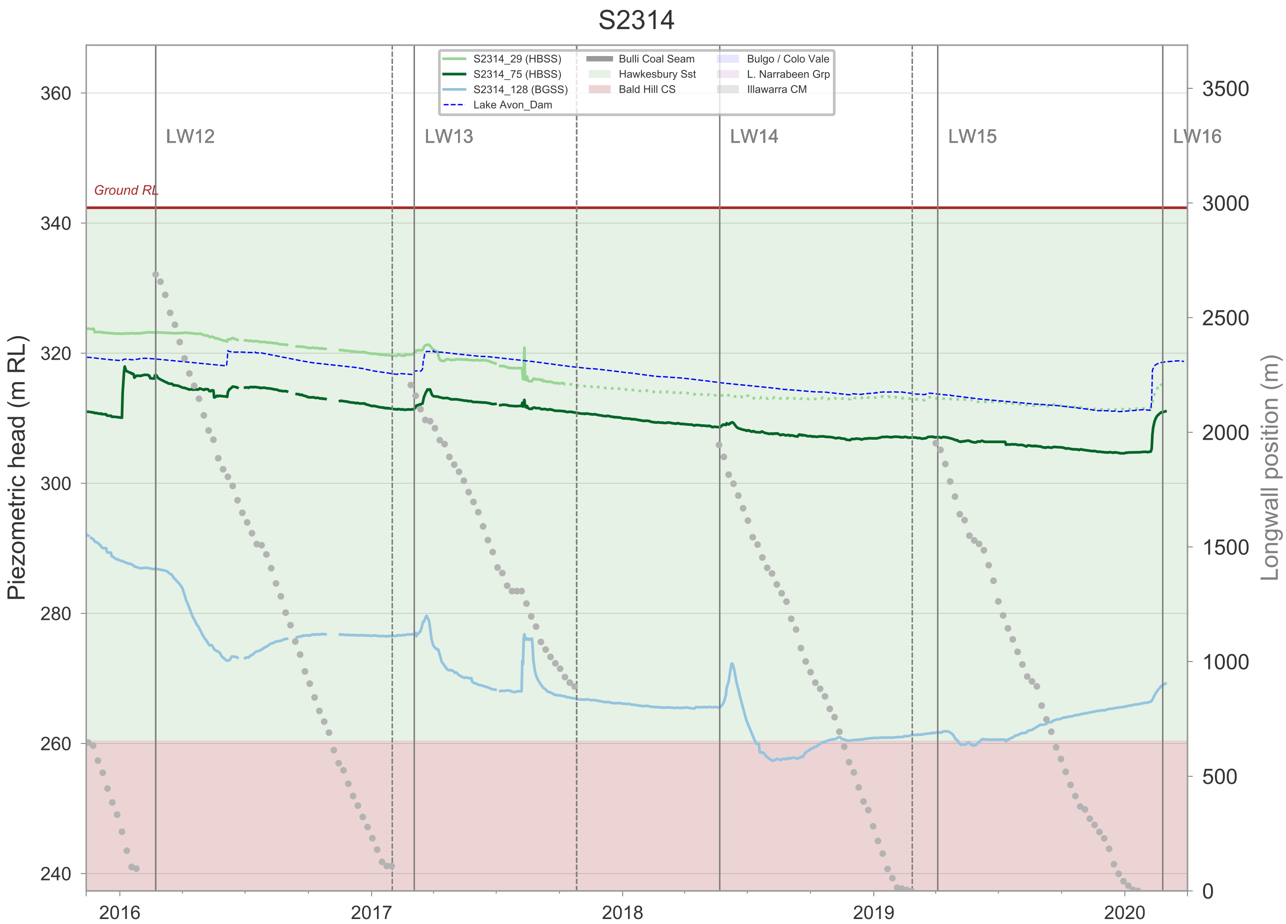

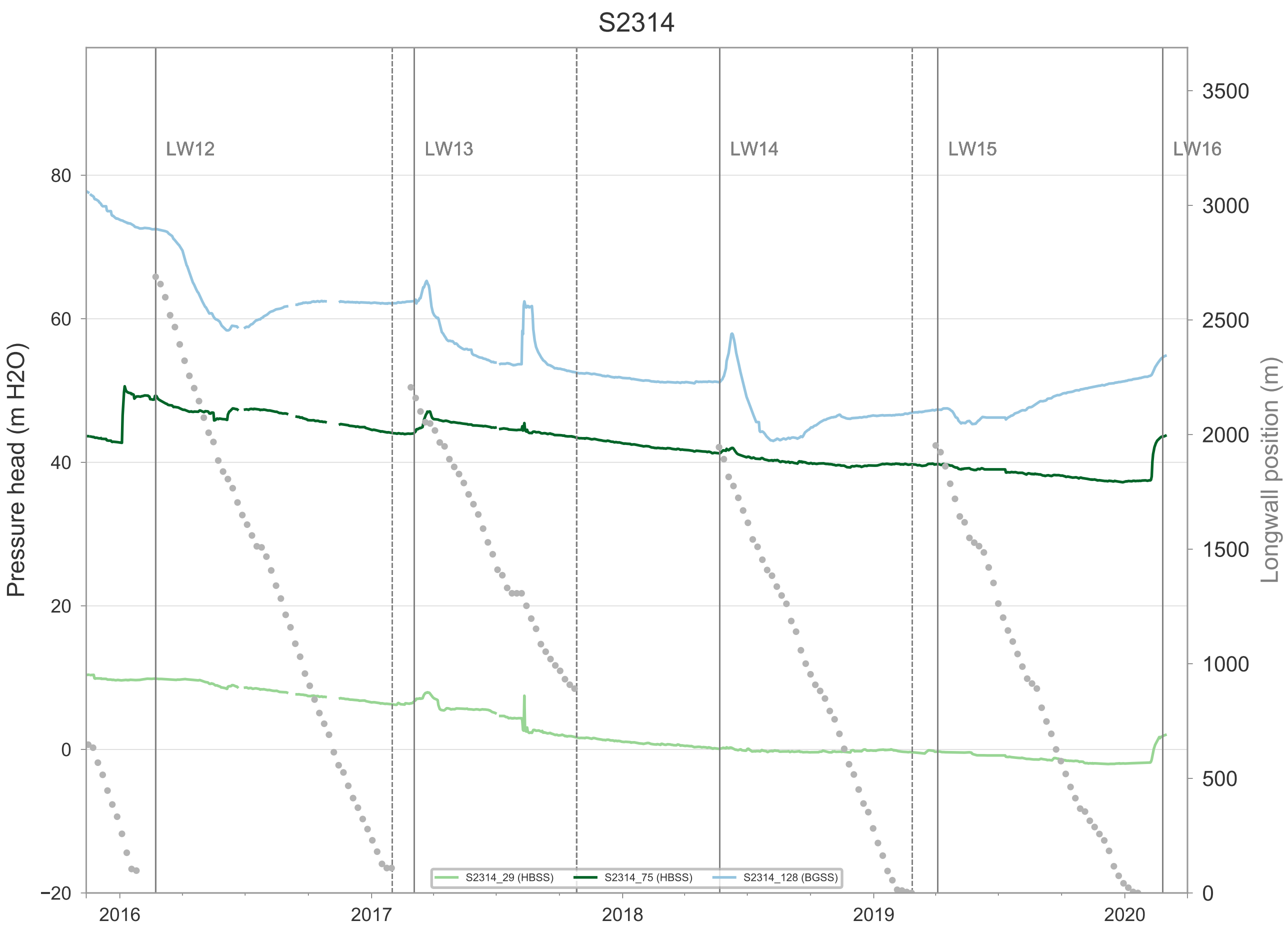

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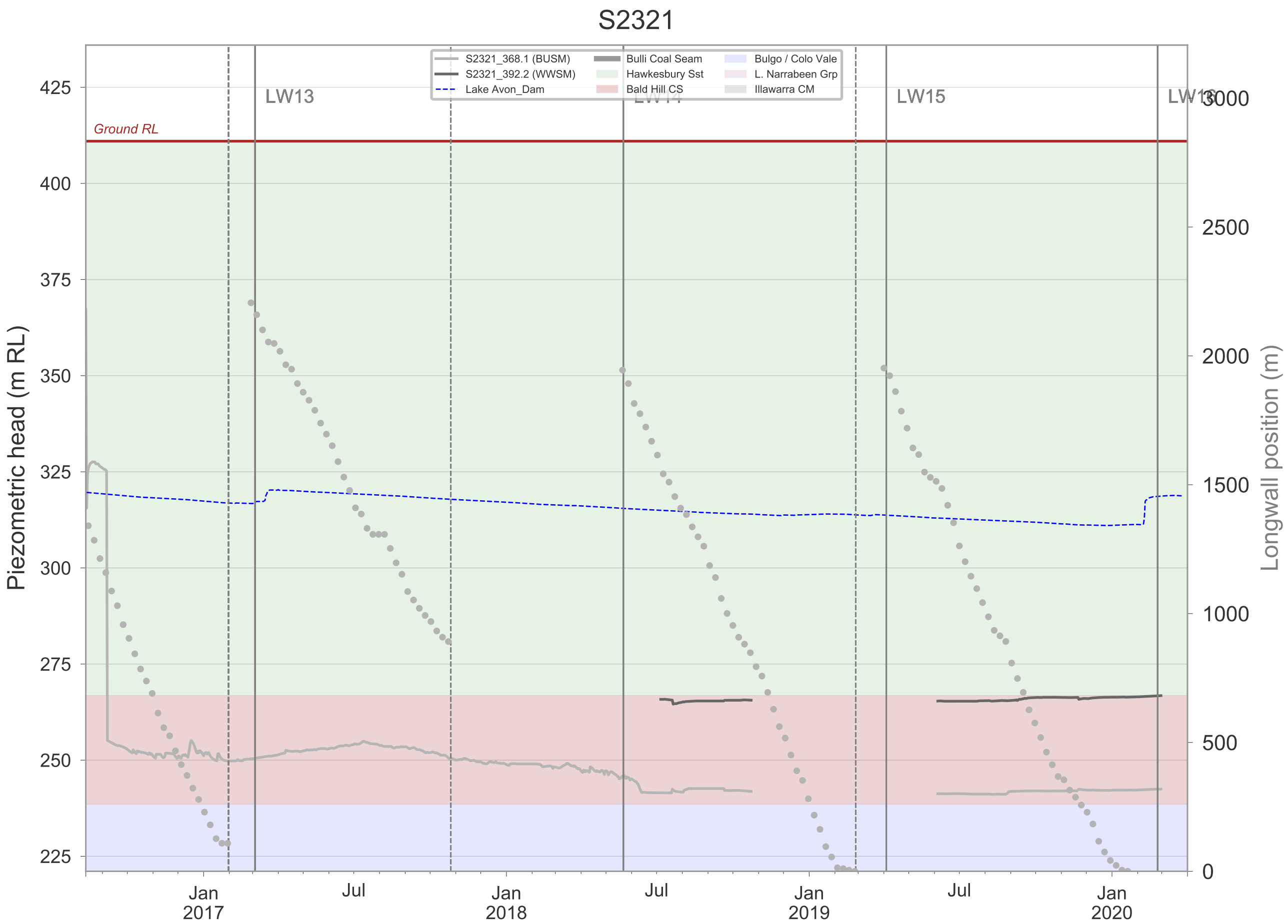

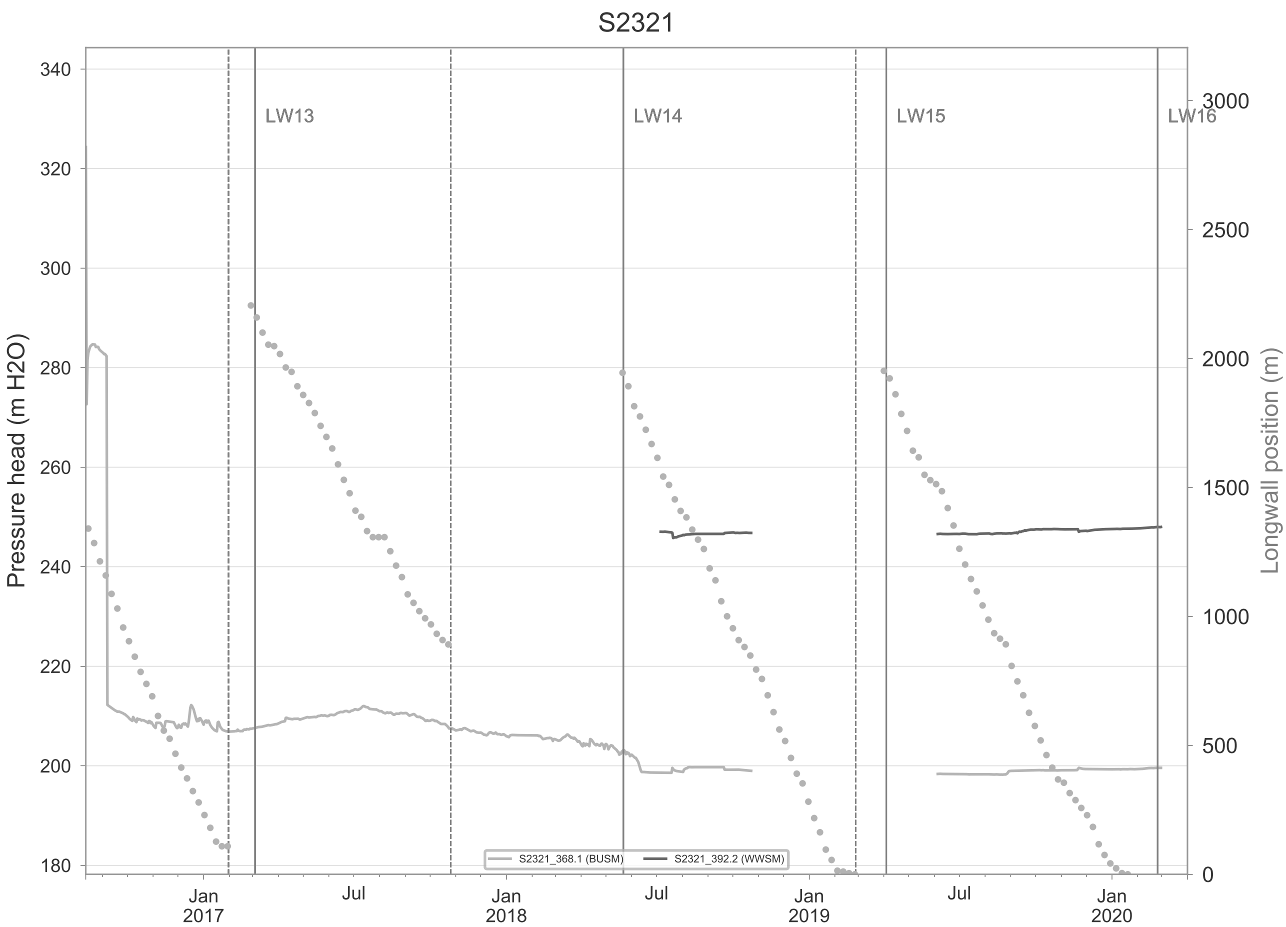

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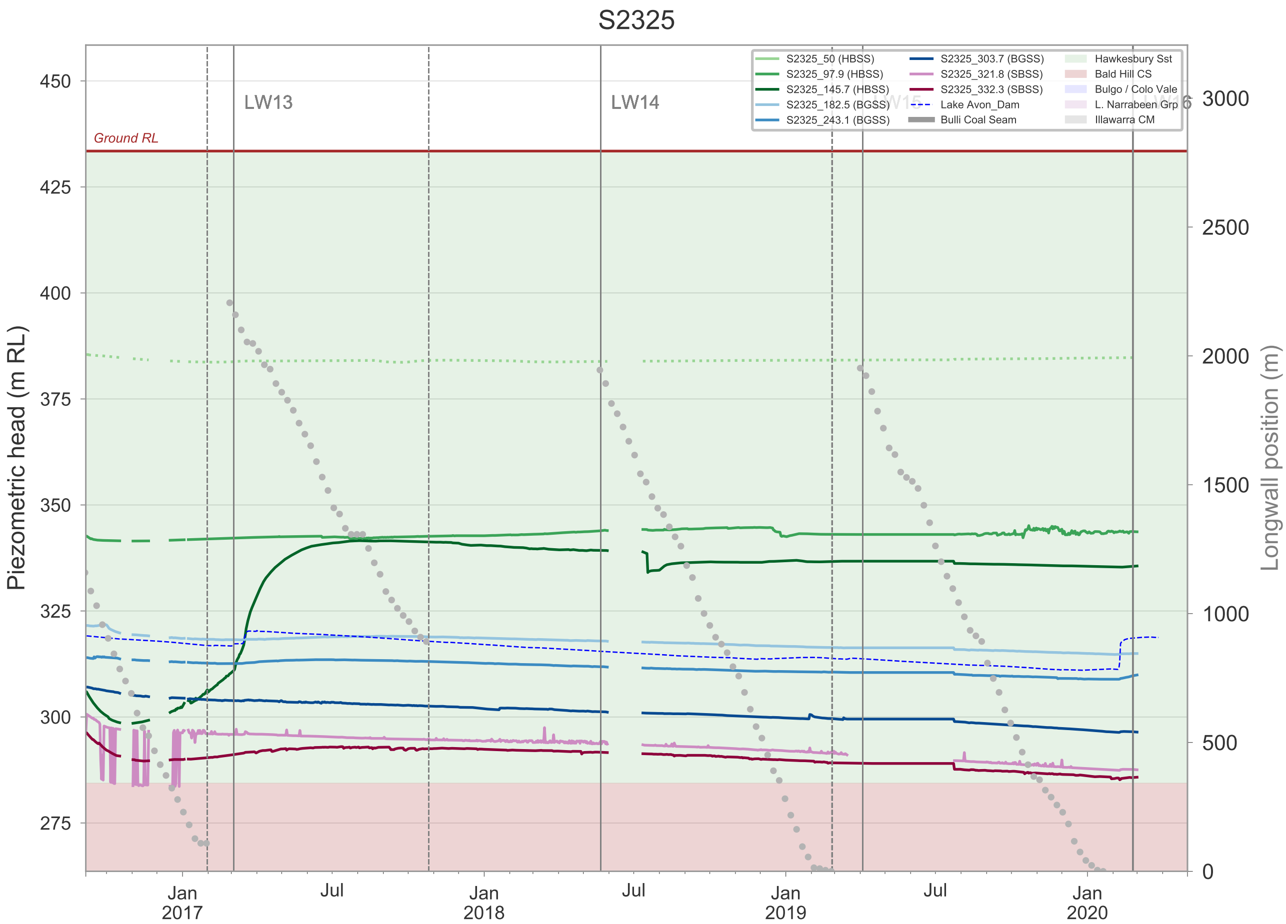

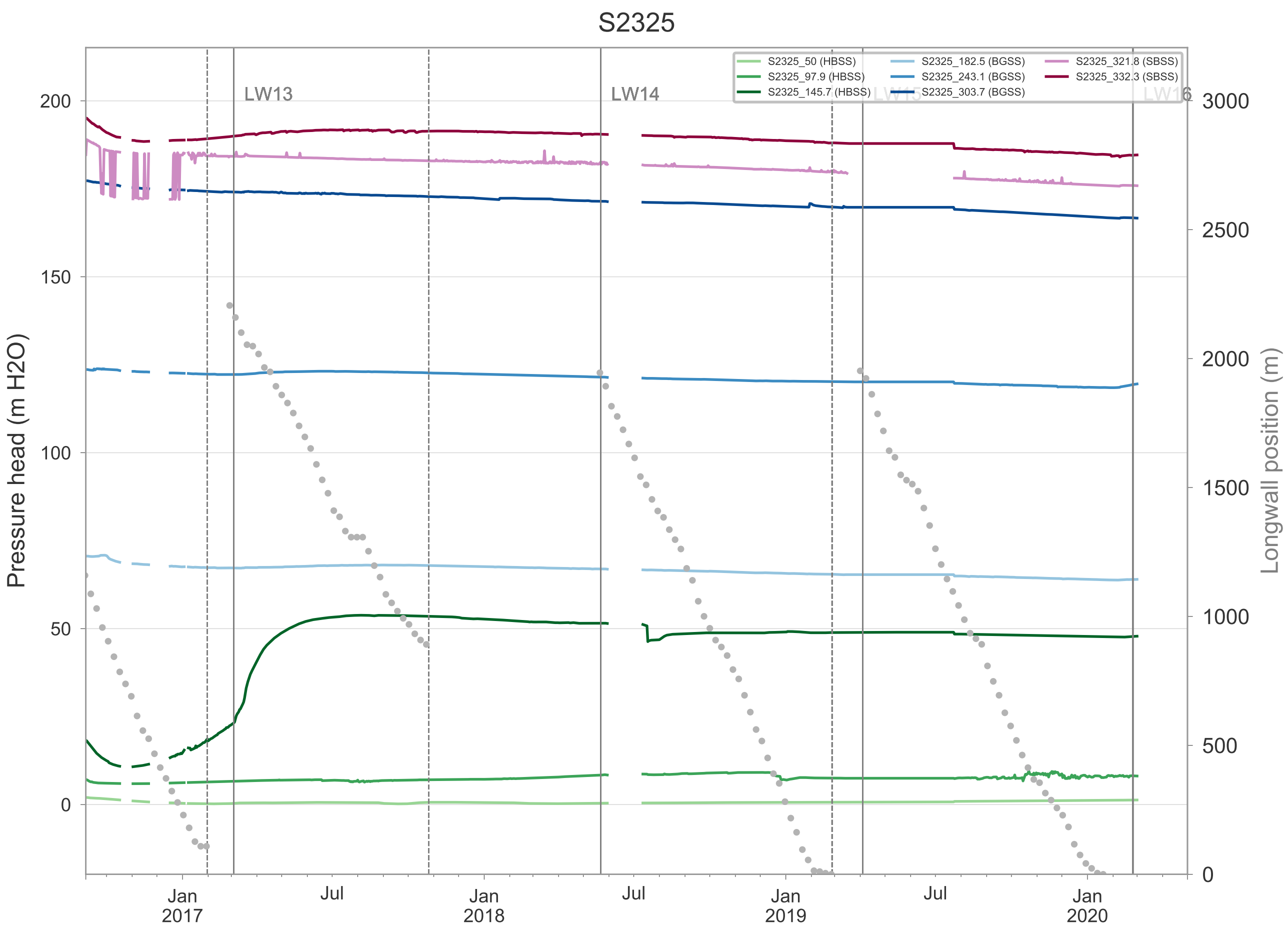

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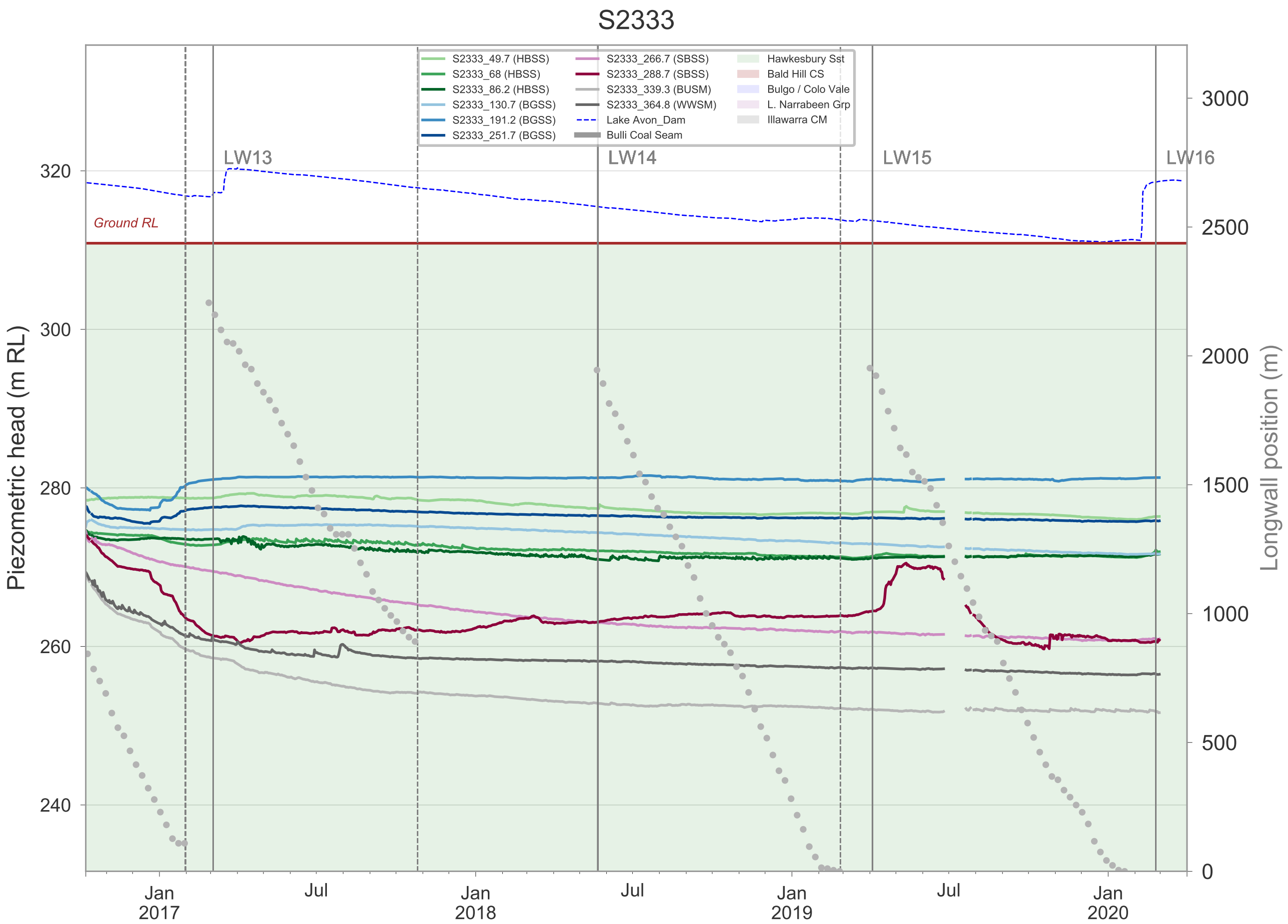

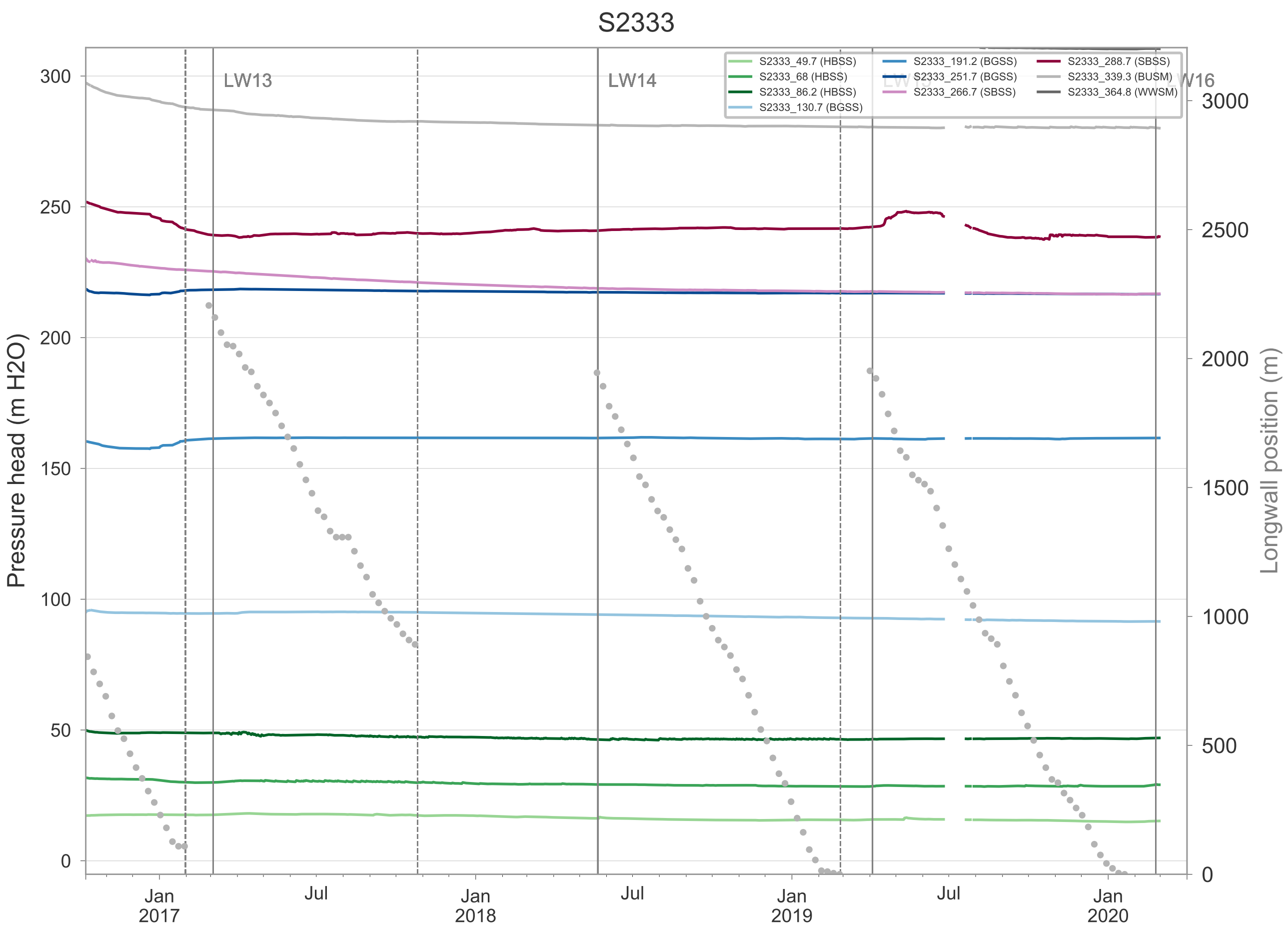

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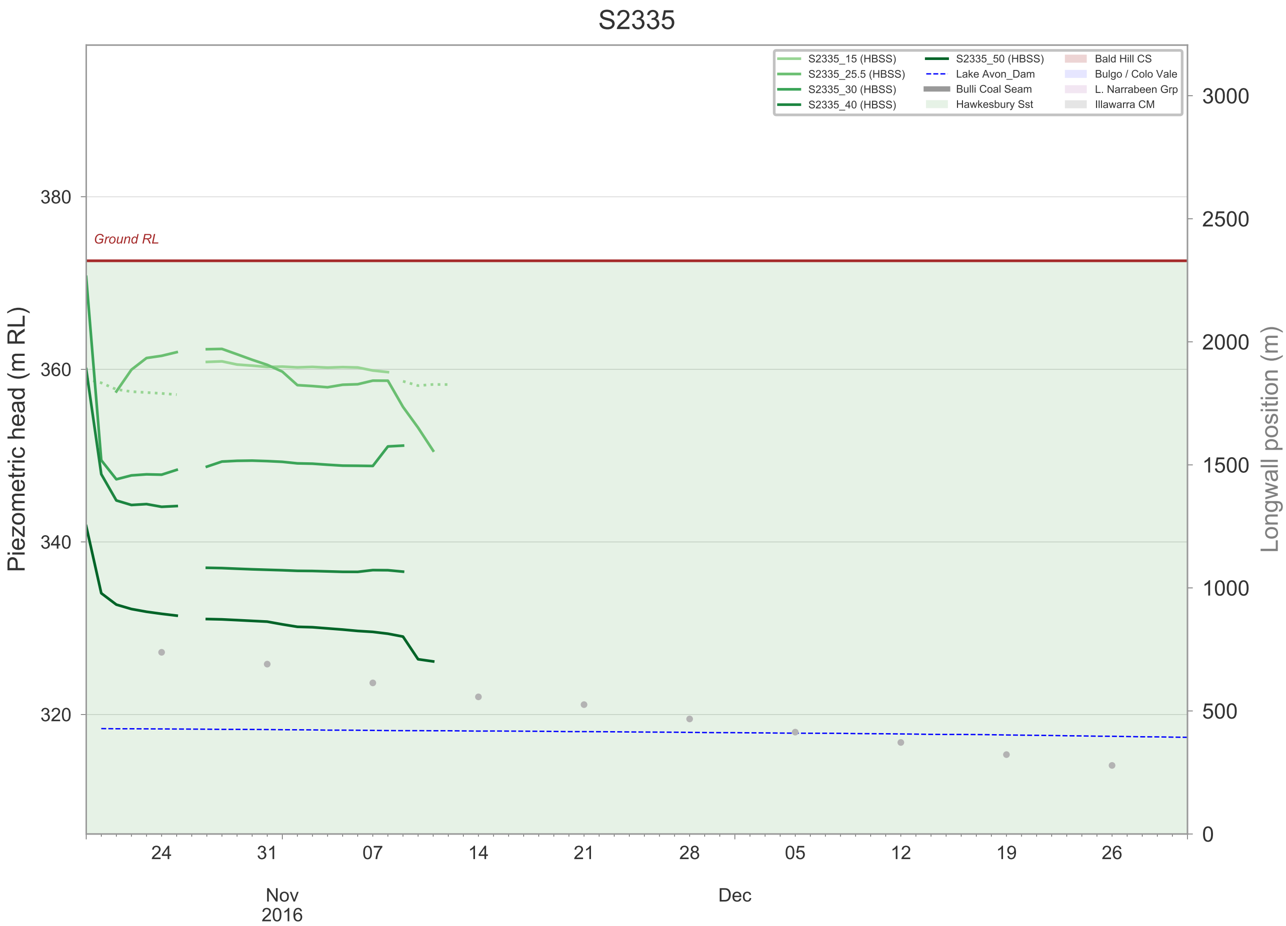

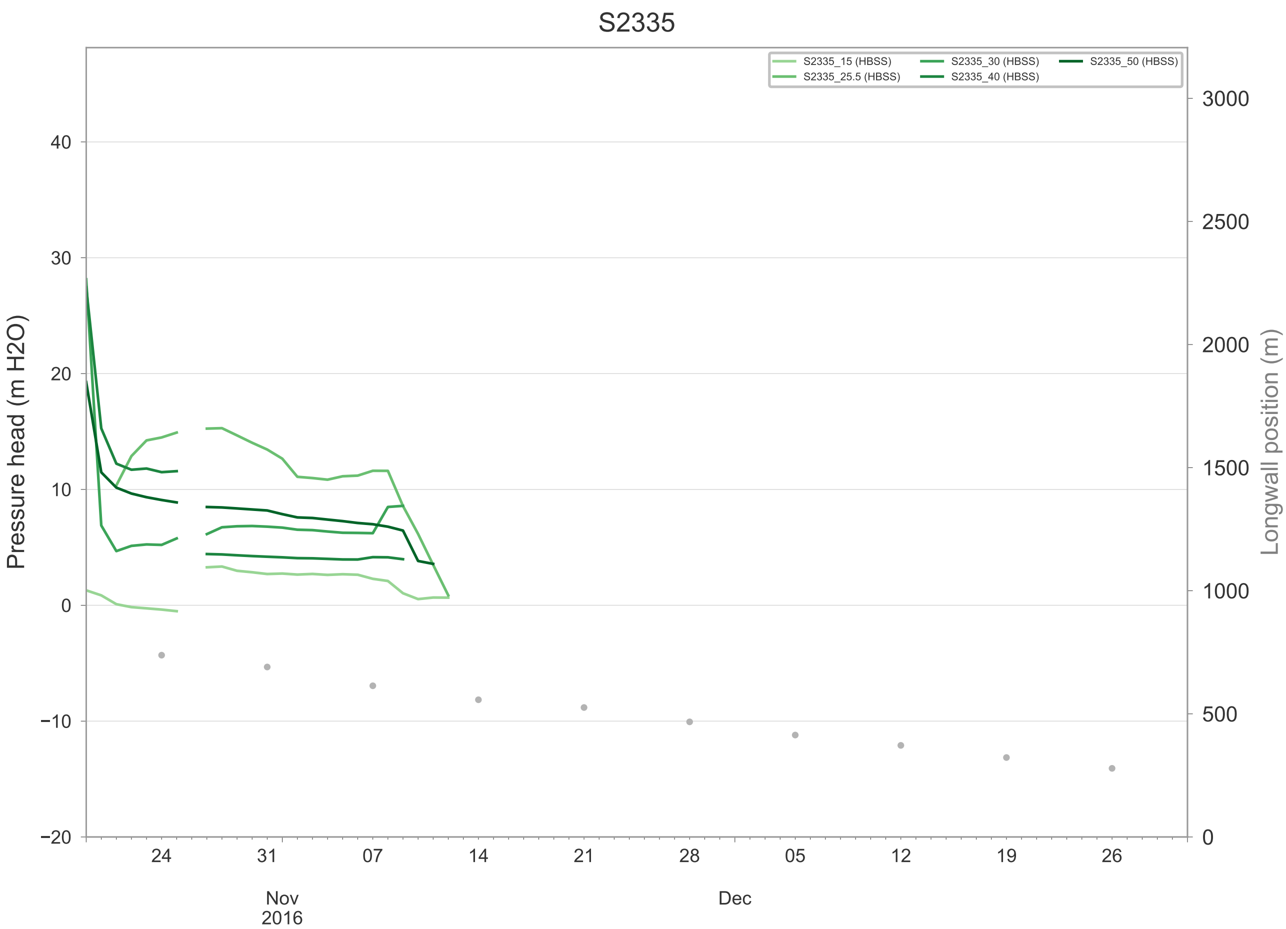

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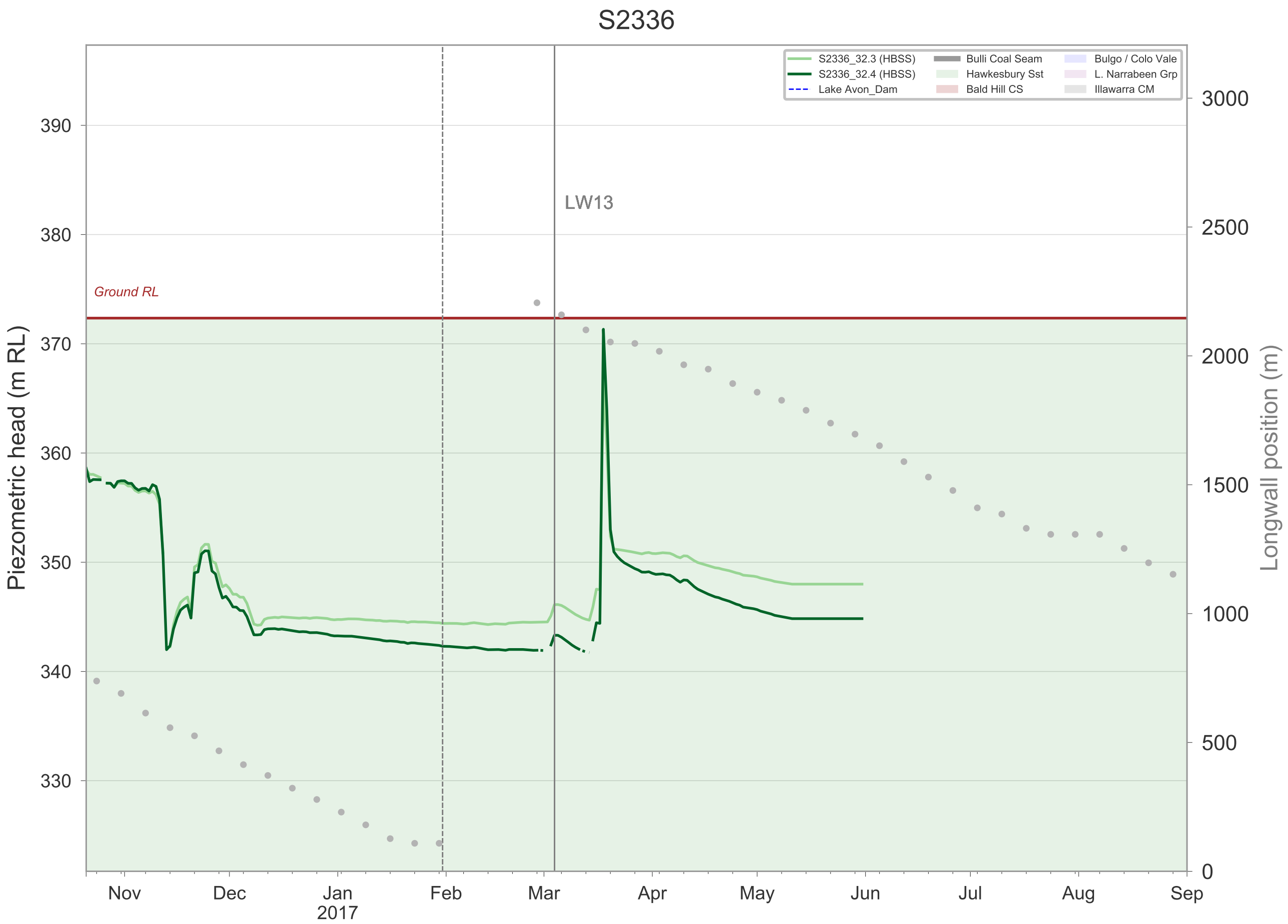

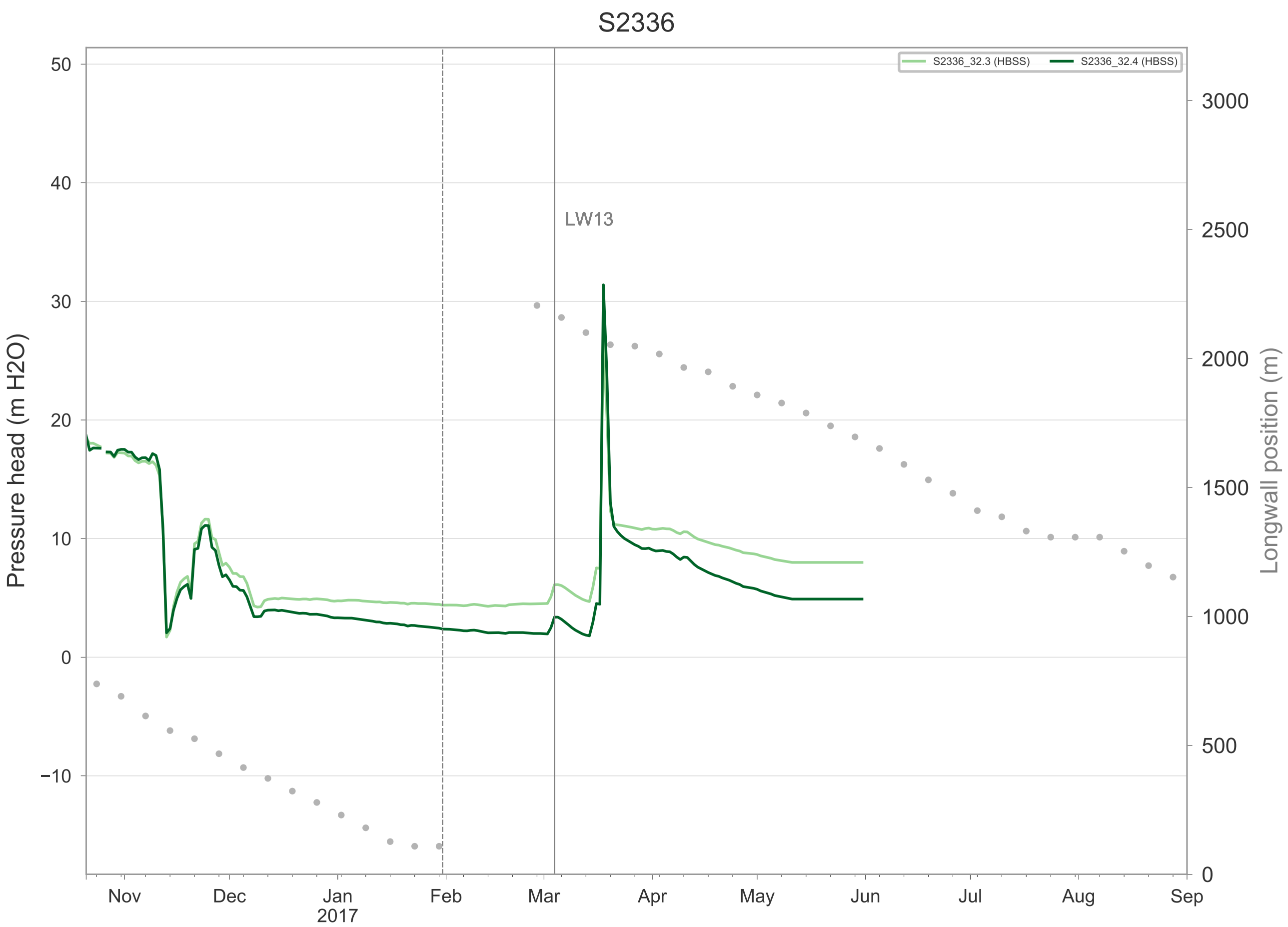

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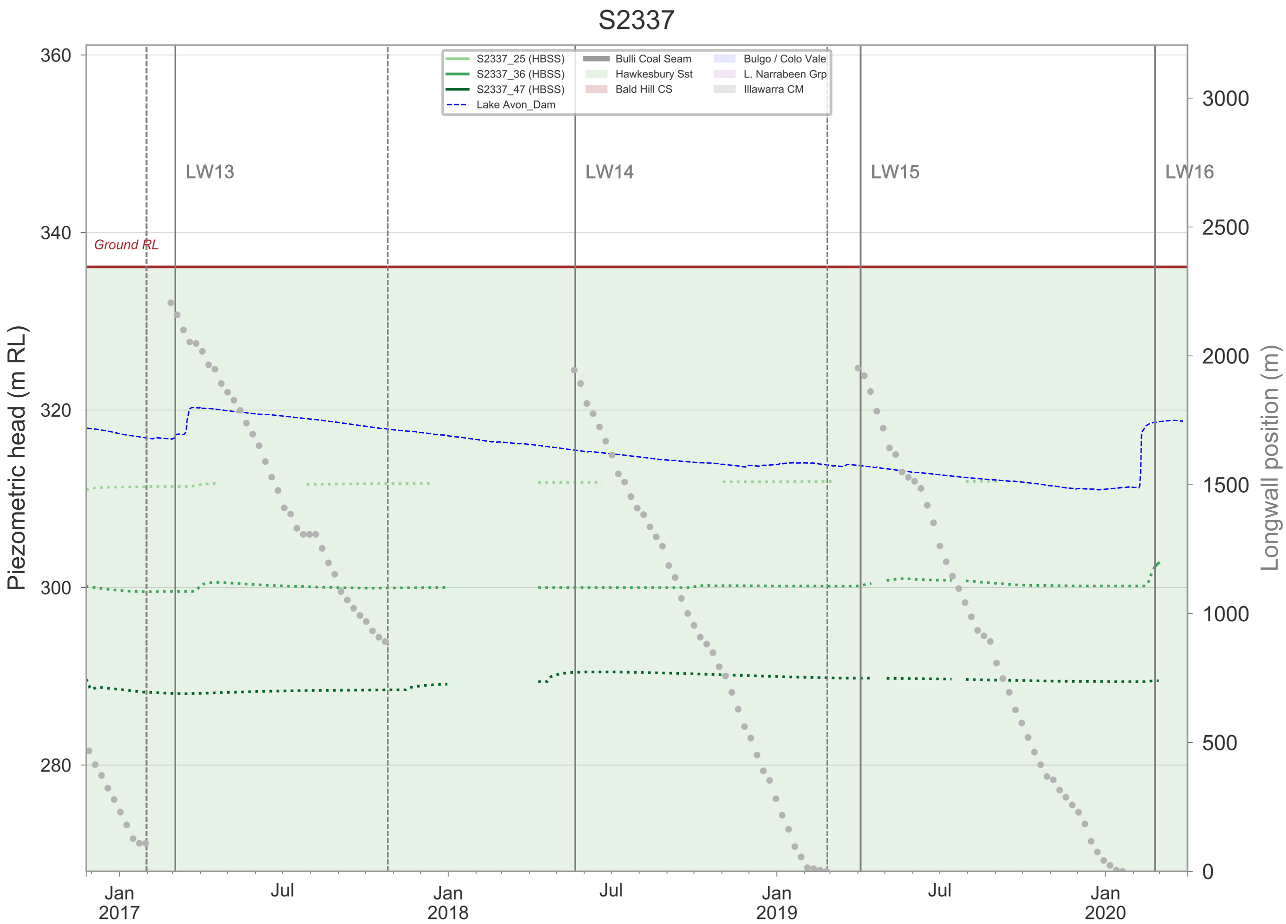
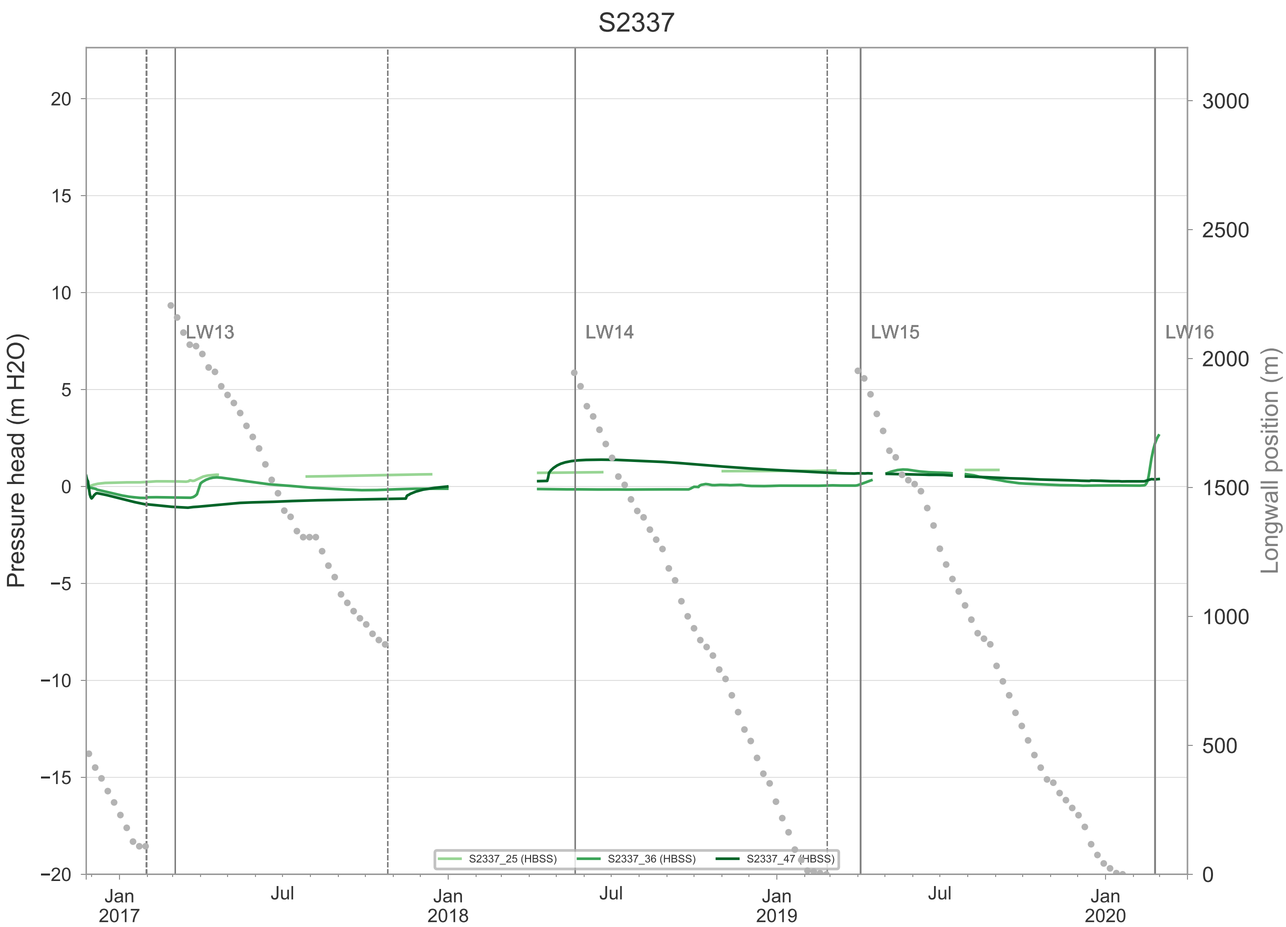
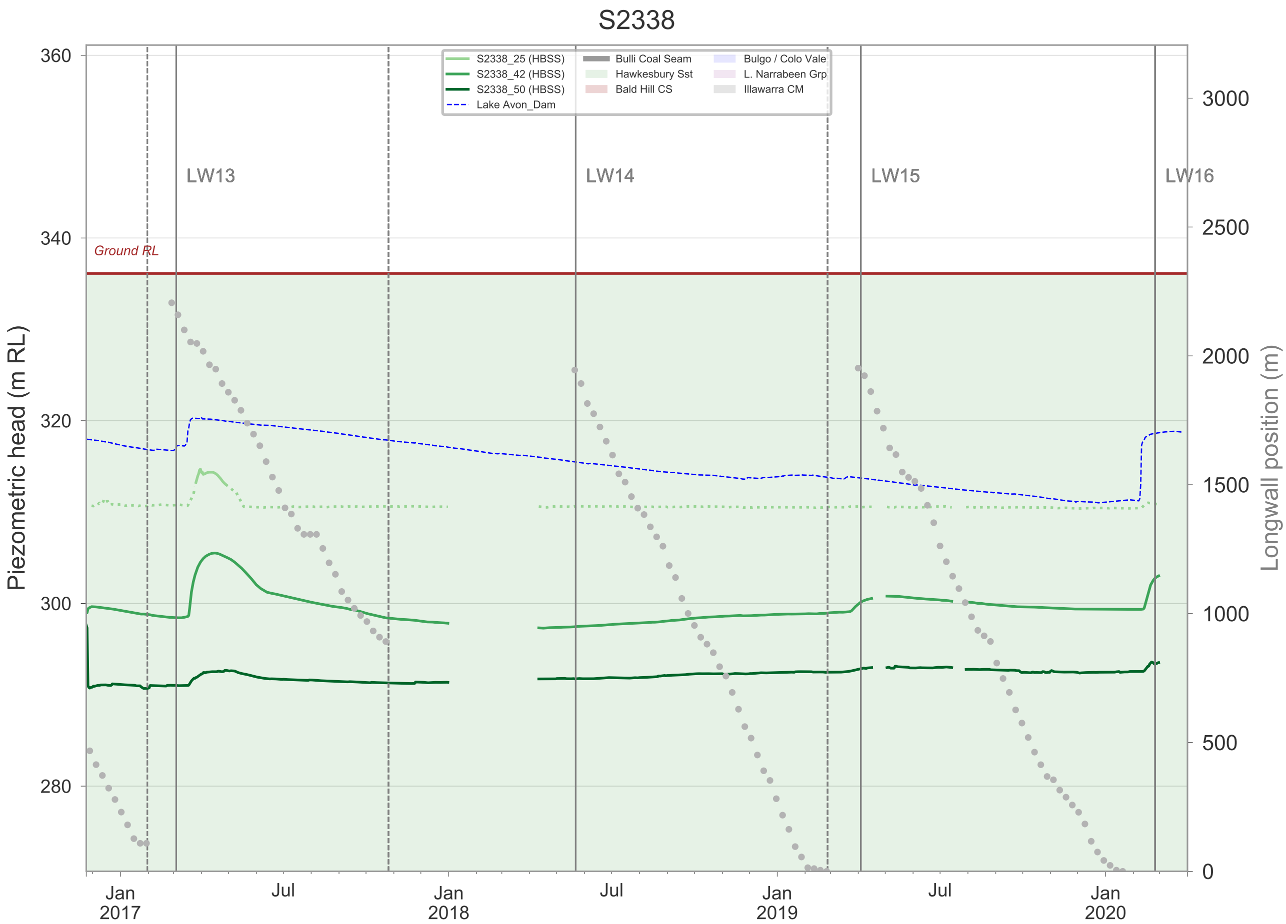
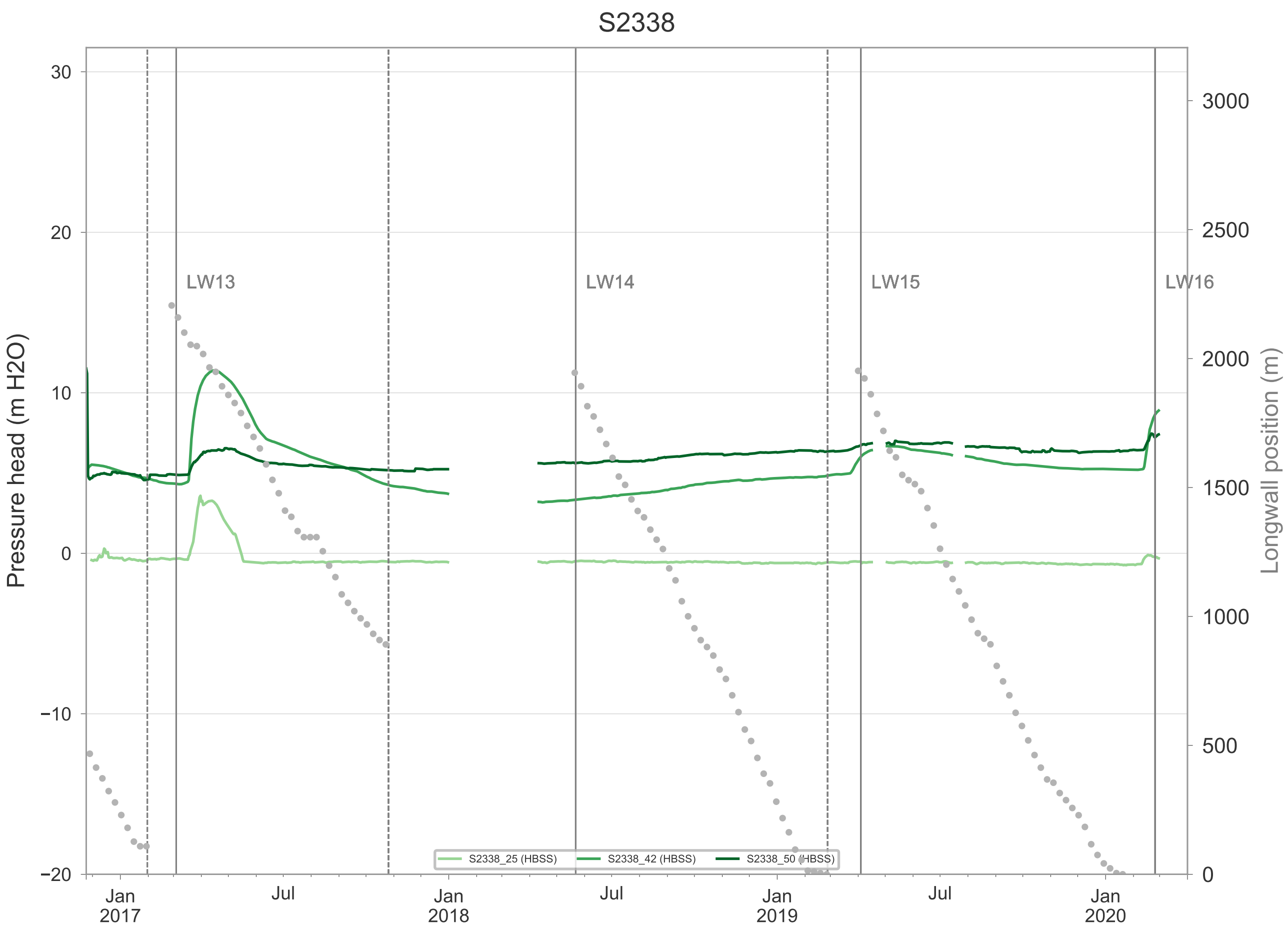


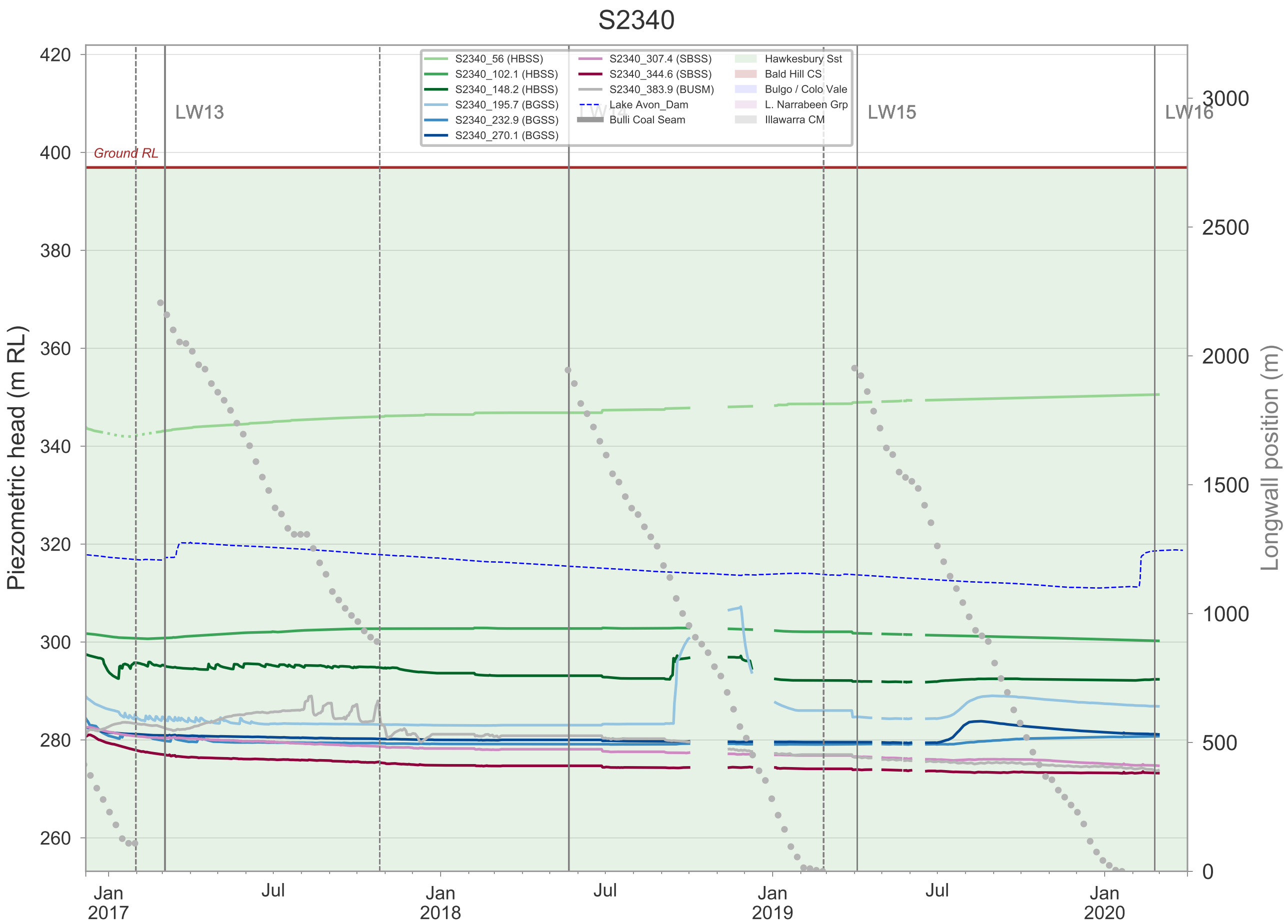


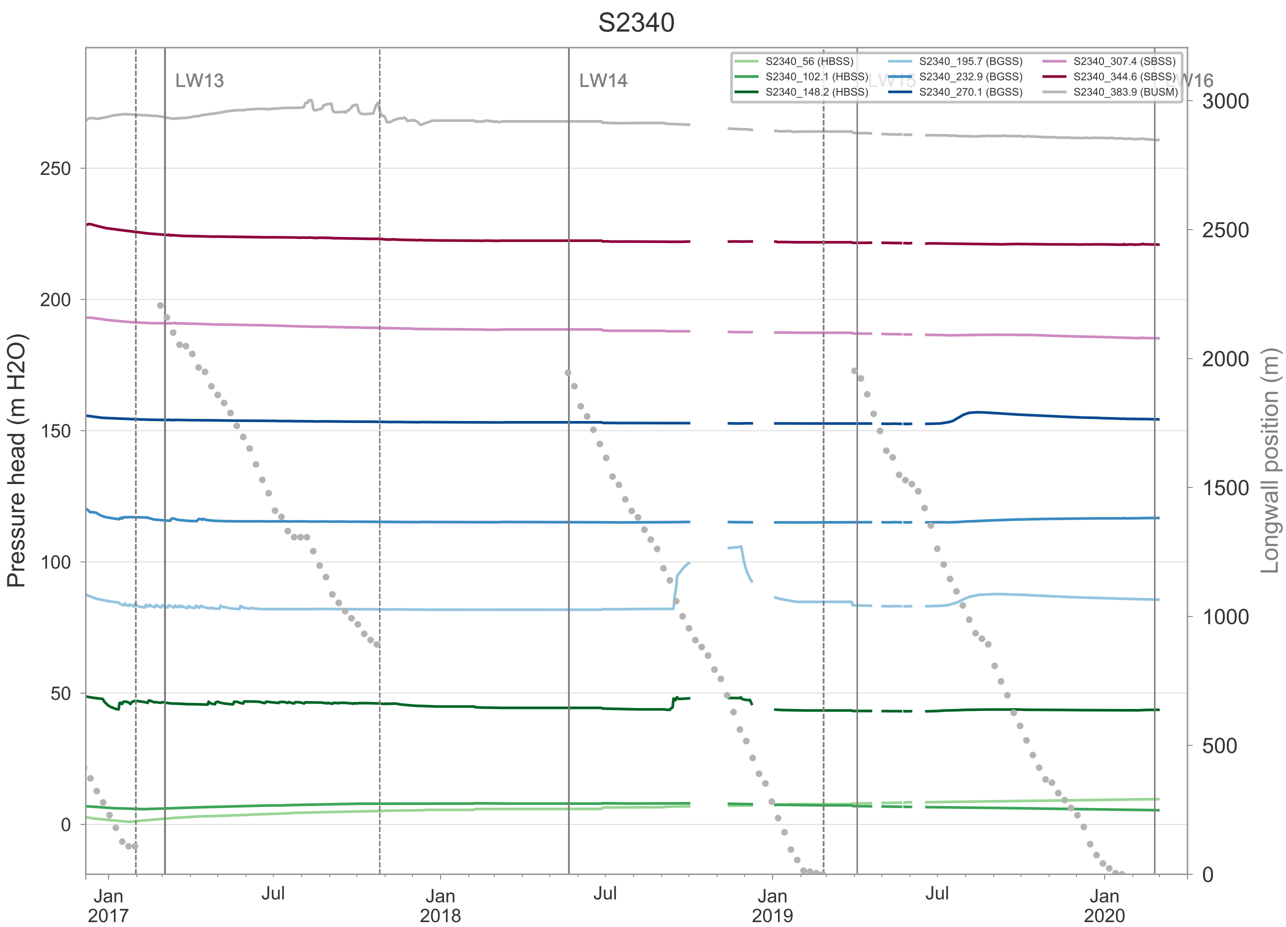
Groundwater hydrographs



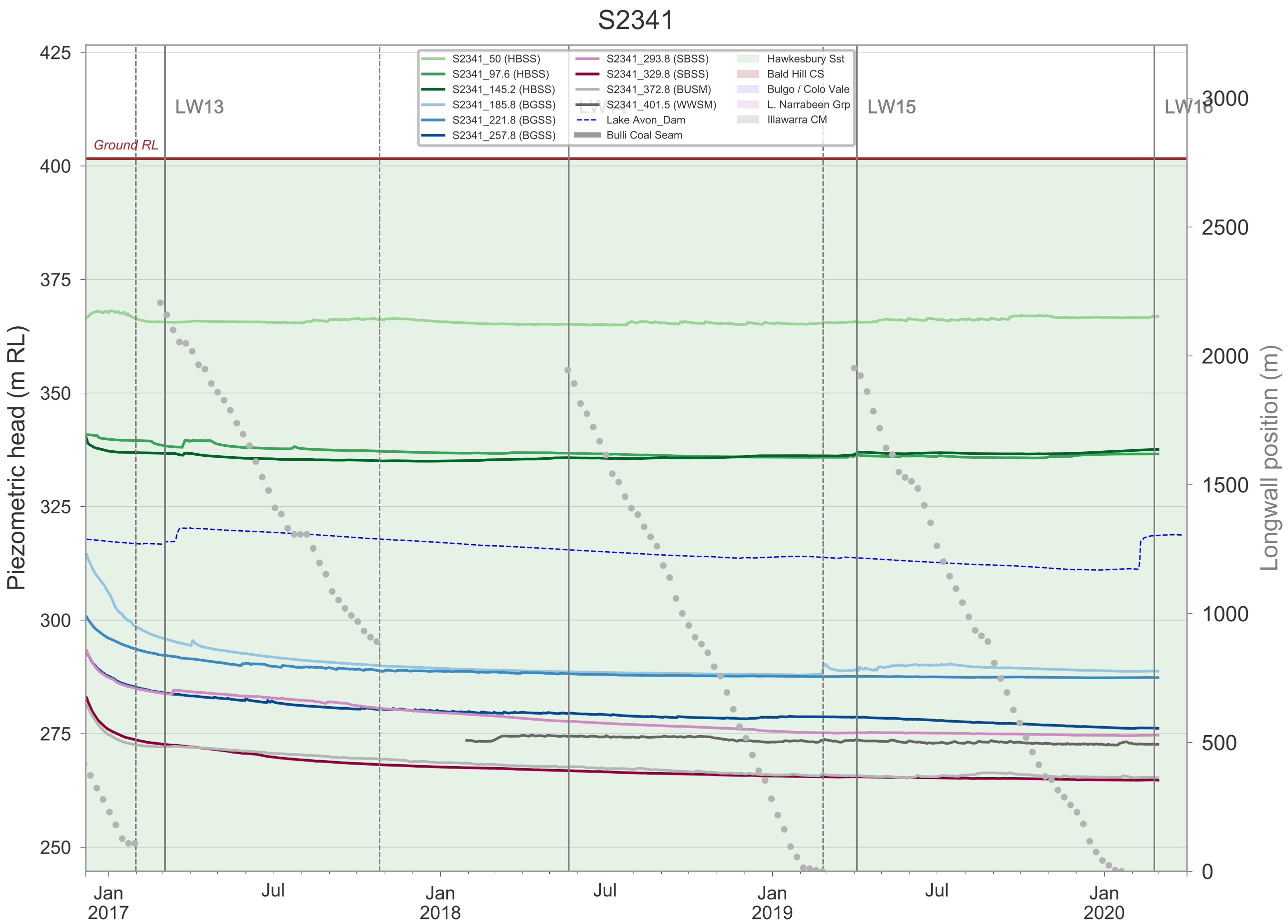


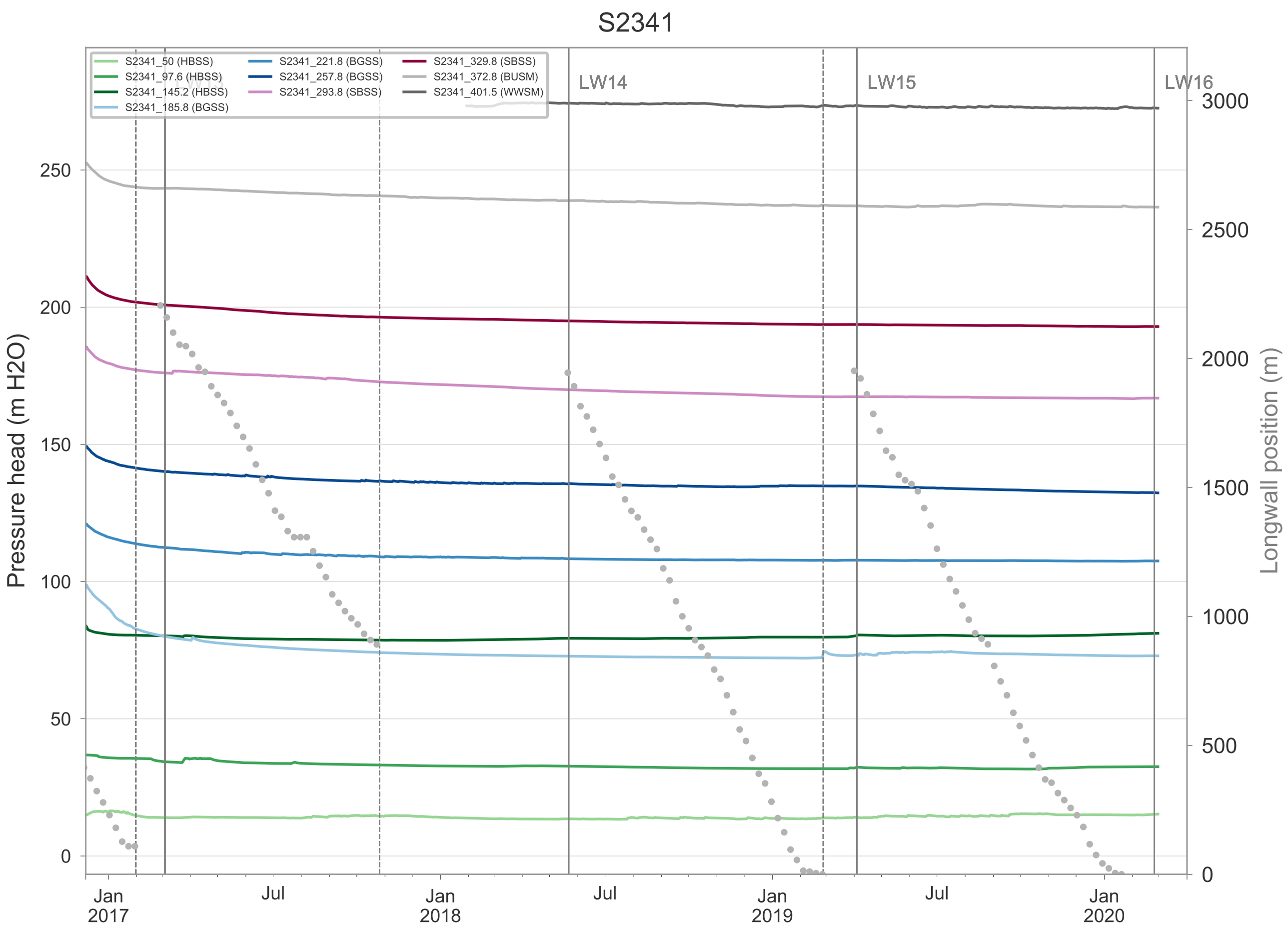
Groundwater hydrographs





Groundwater hydrographs





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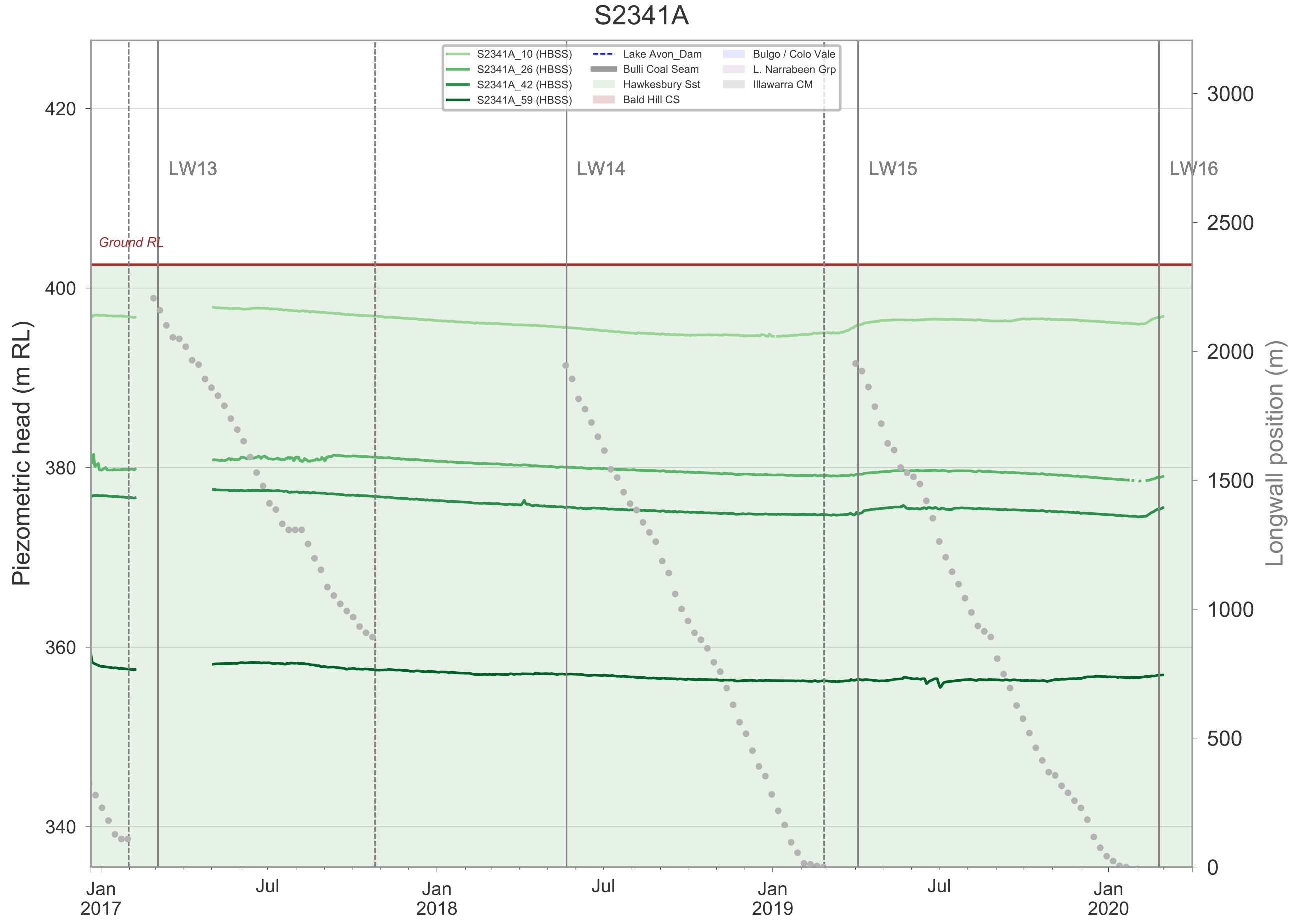
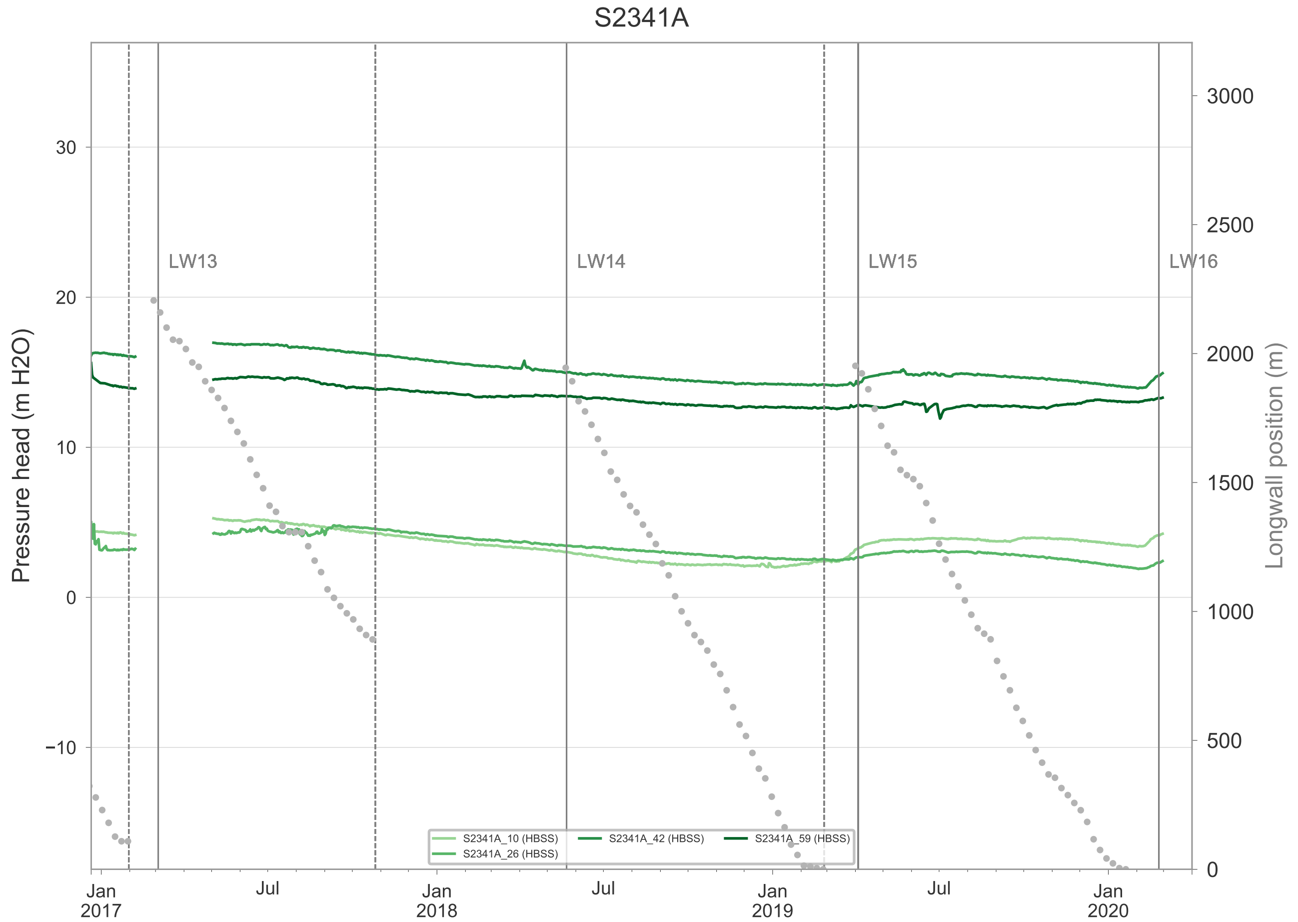
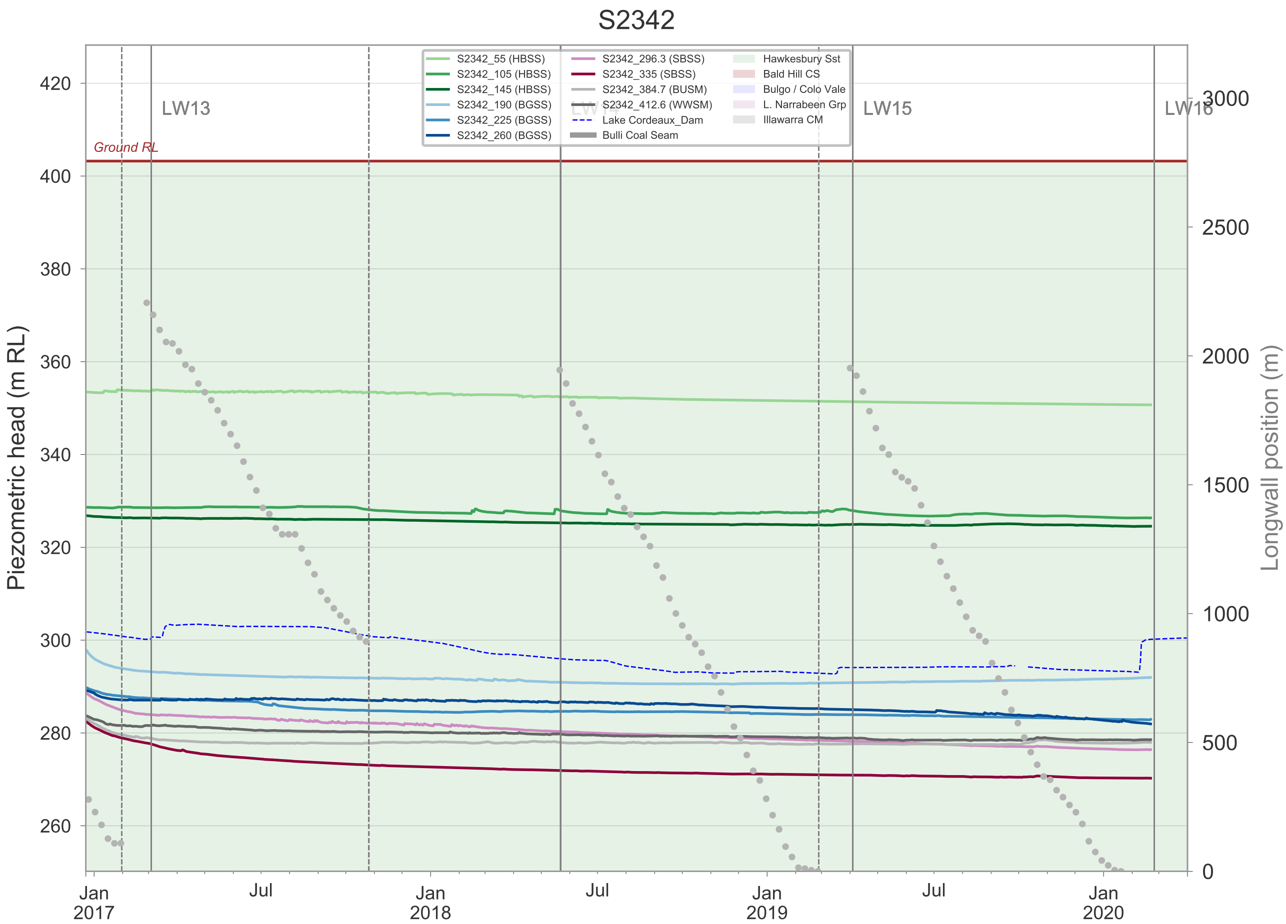
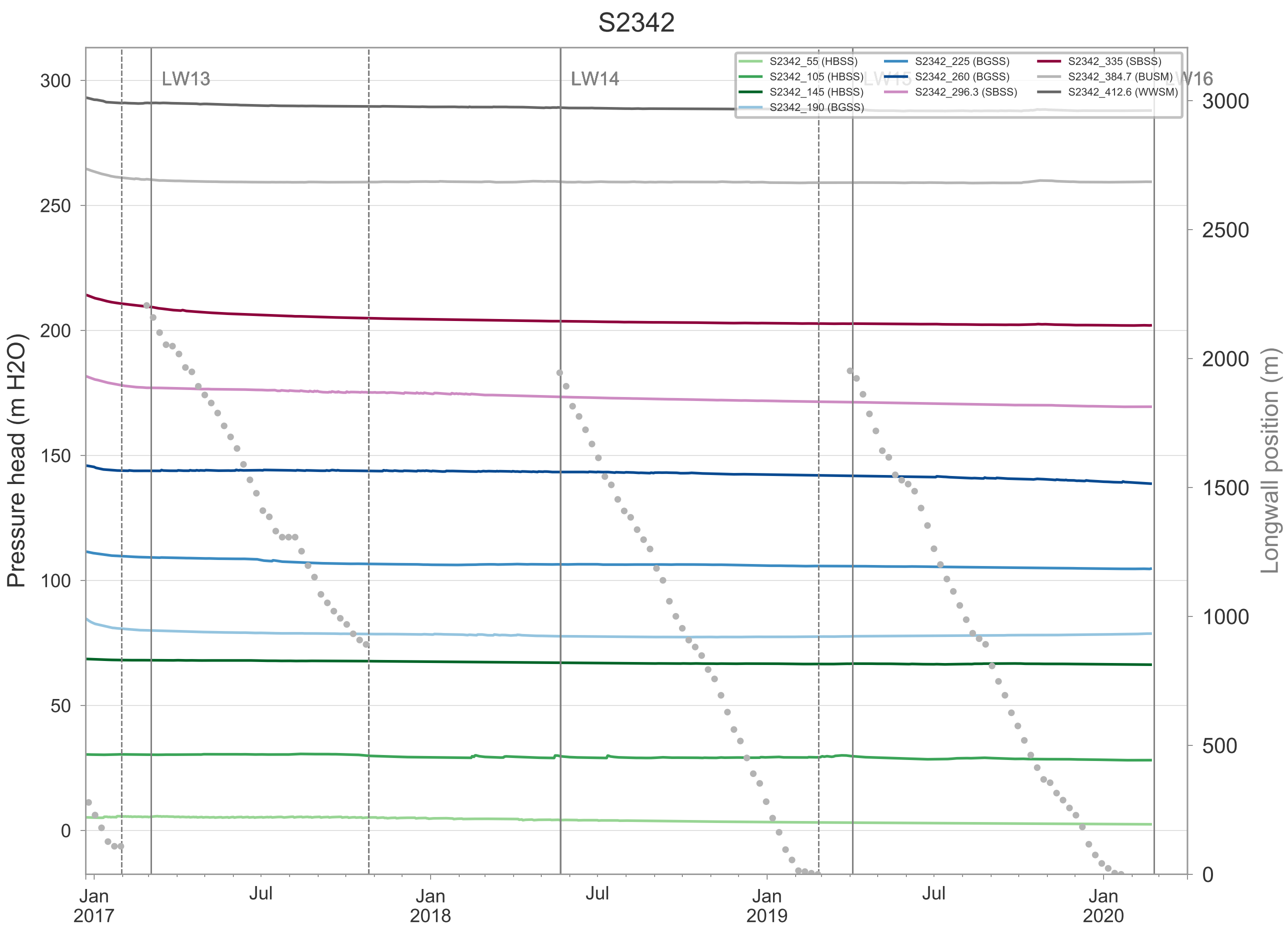




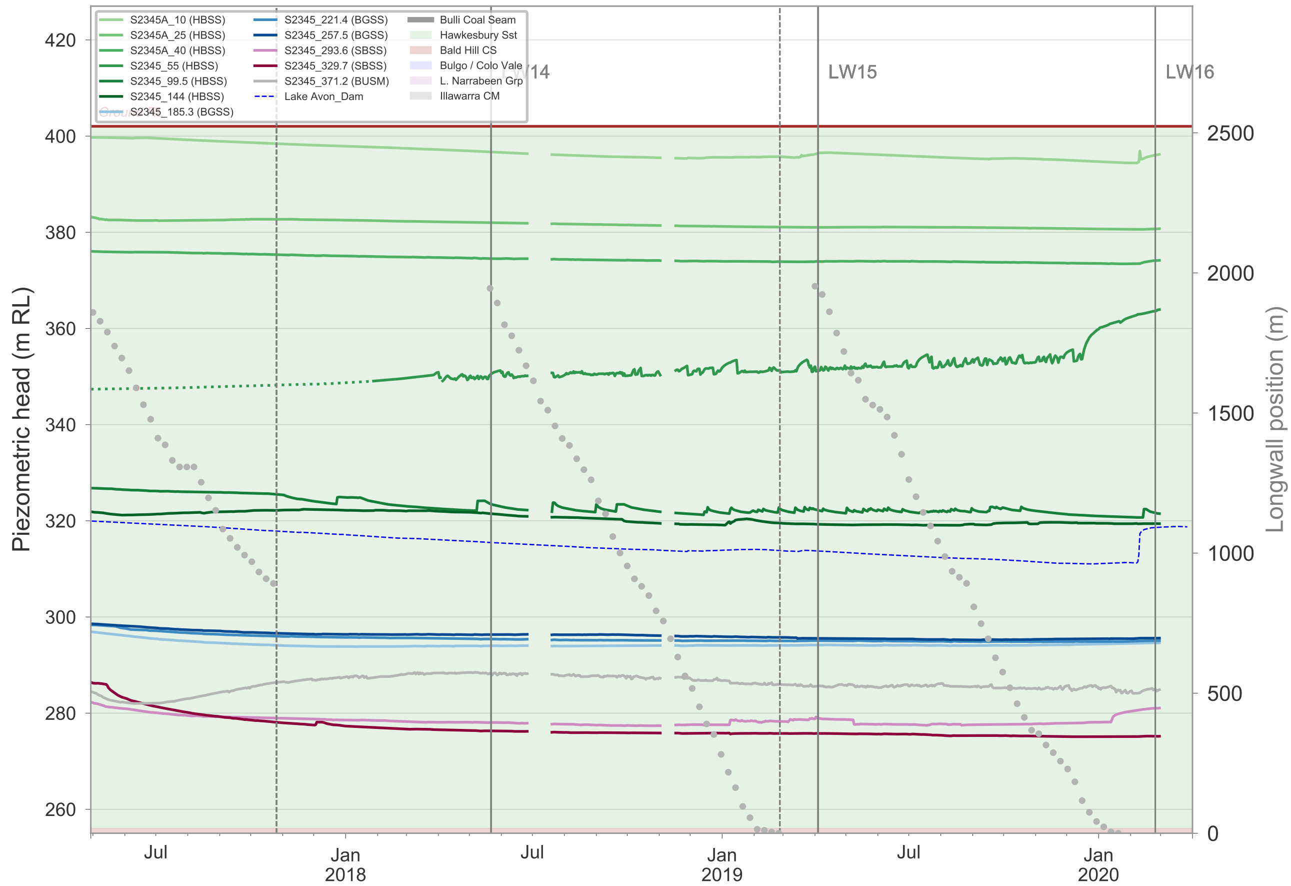
Groundwater hydrographs





Groundwater hydrographs

S2345



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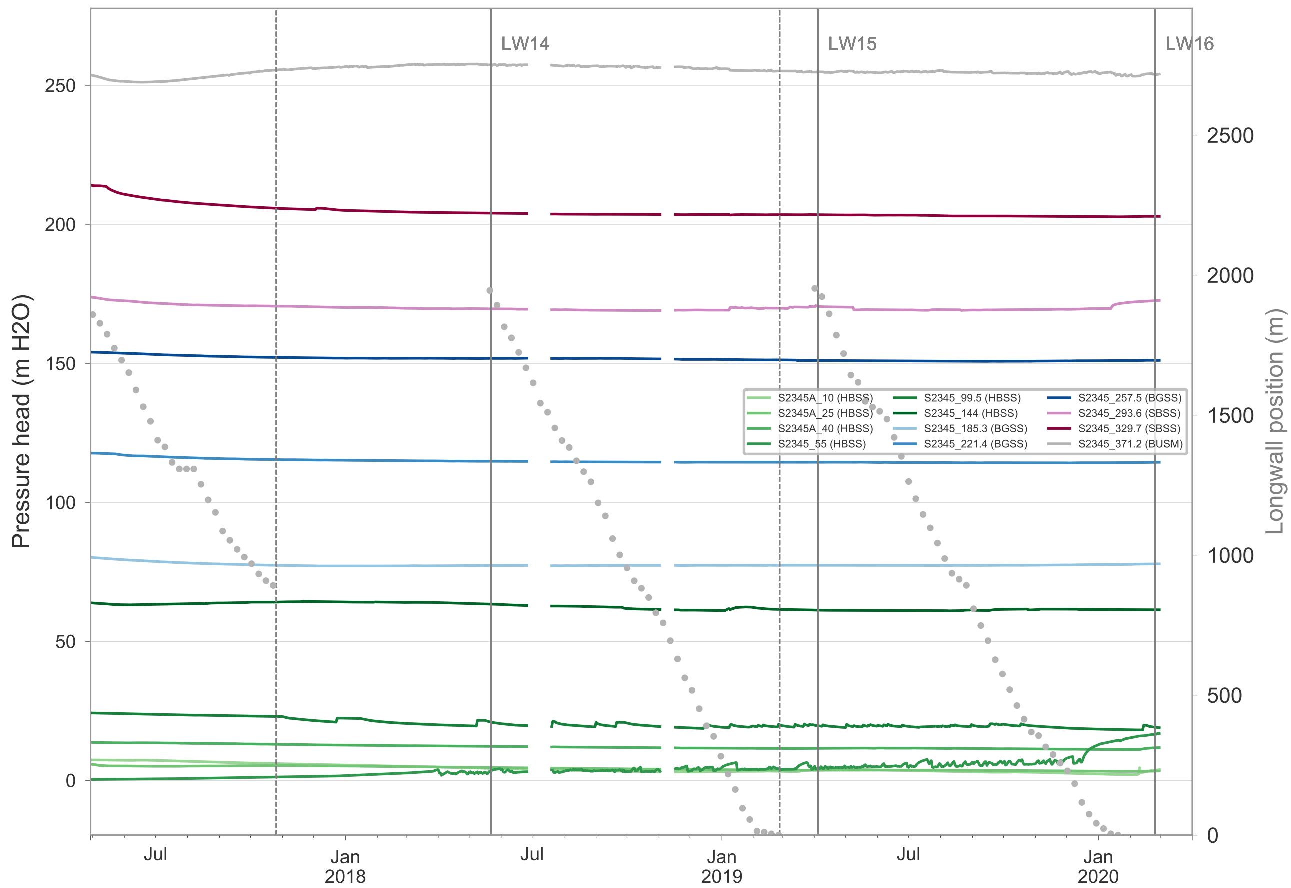
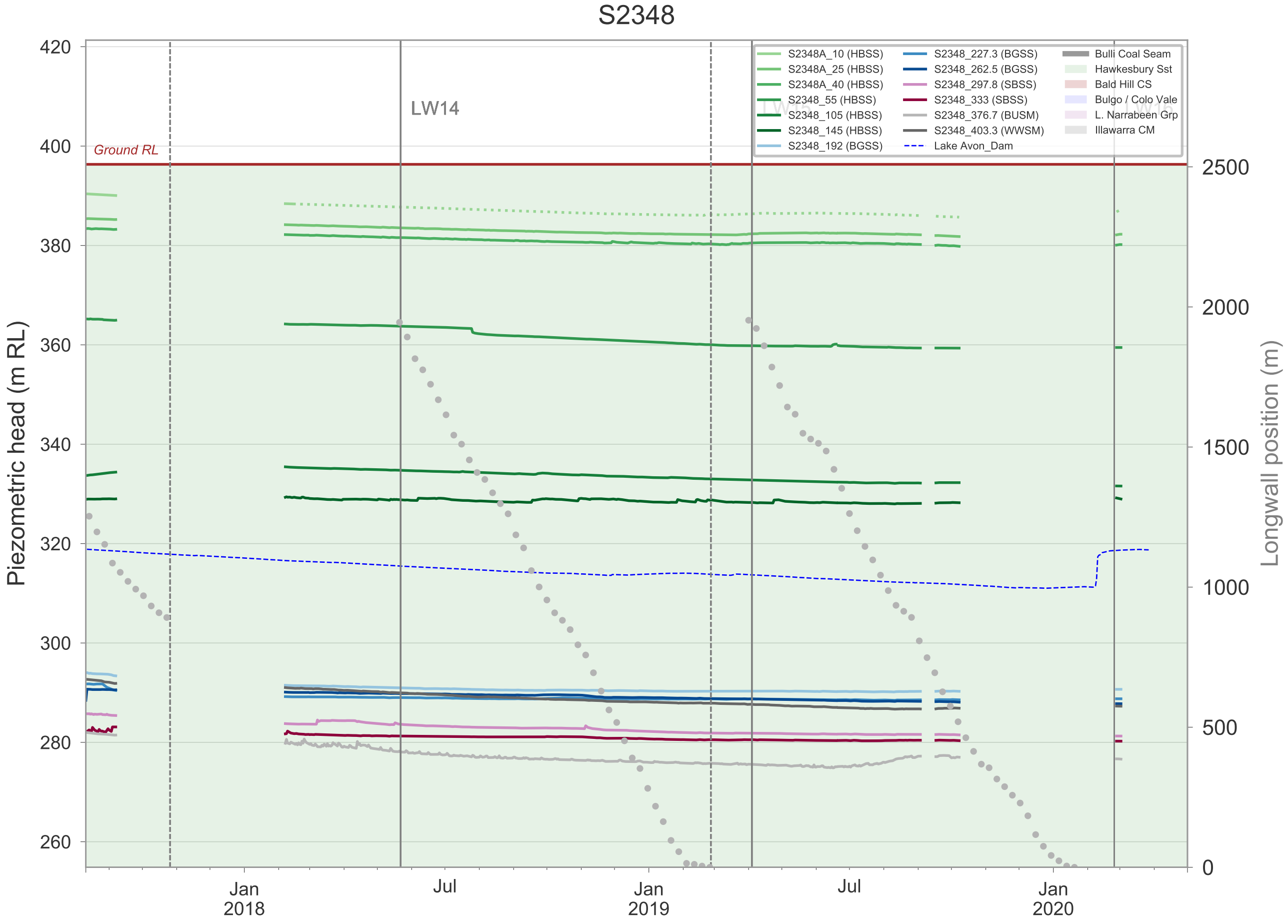
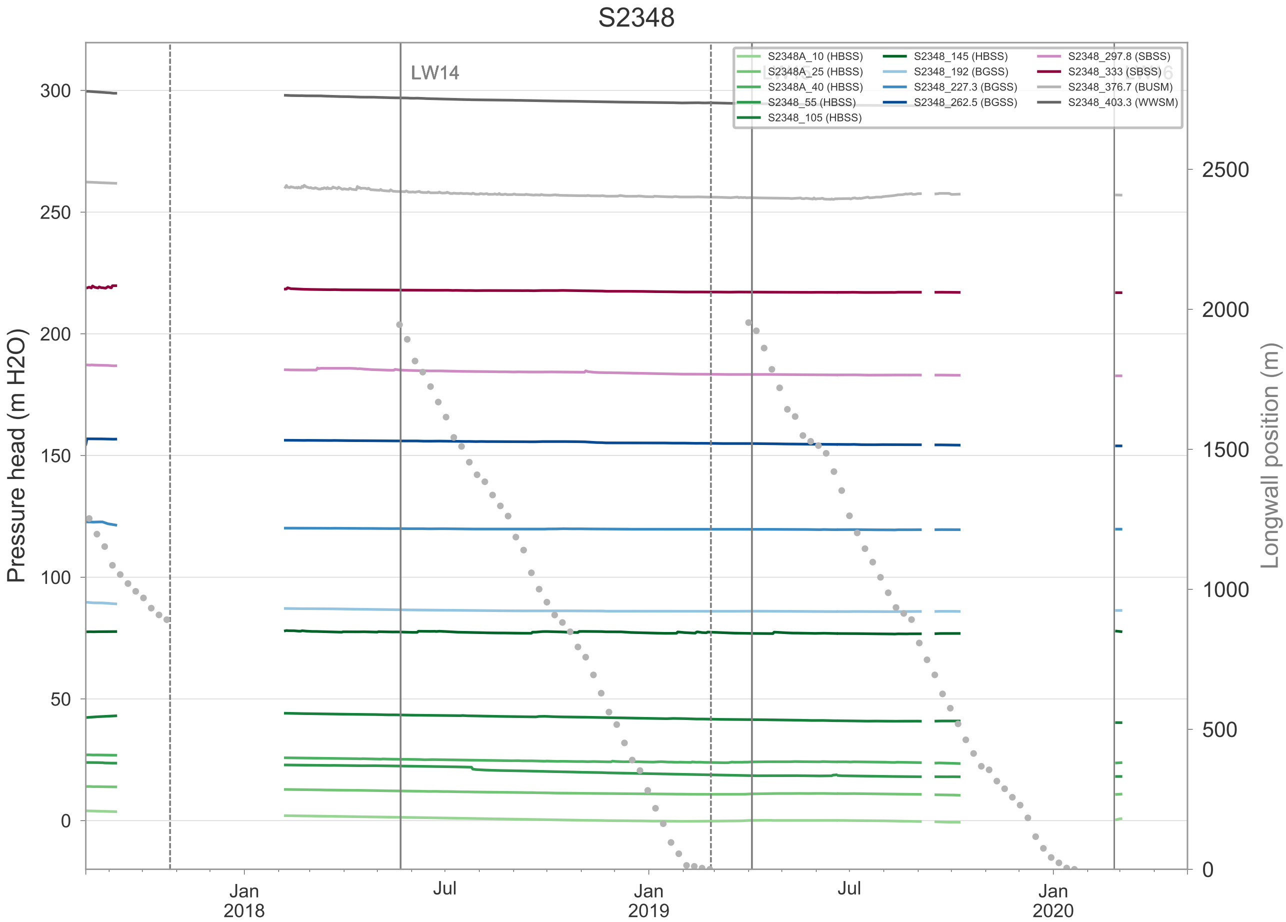
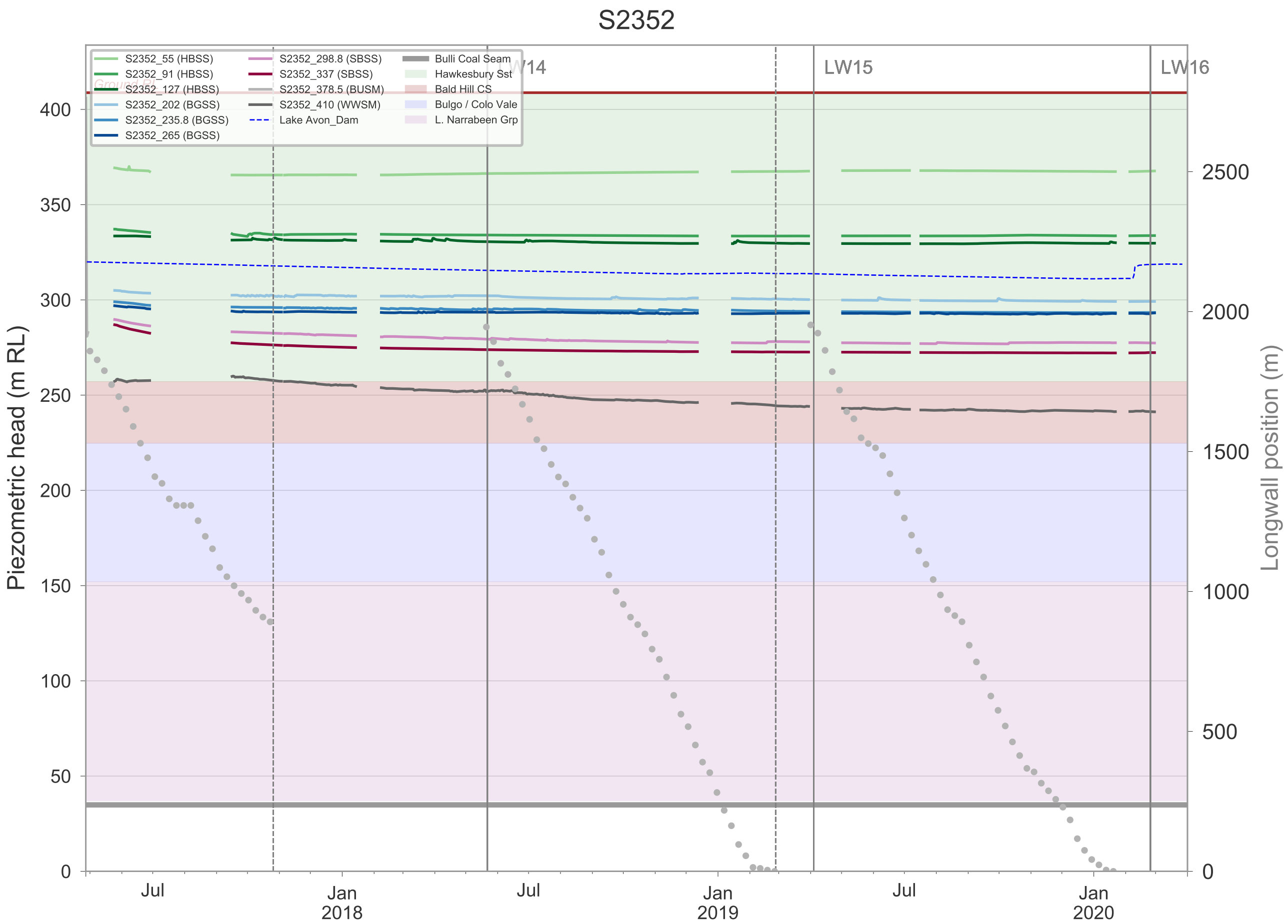


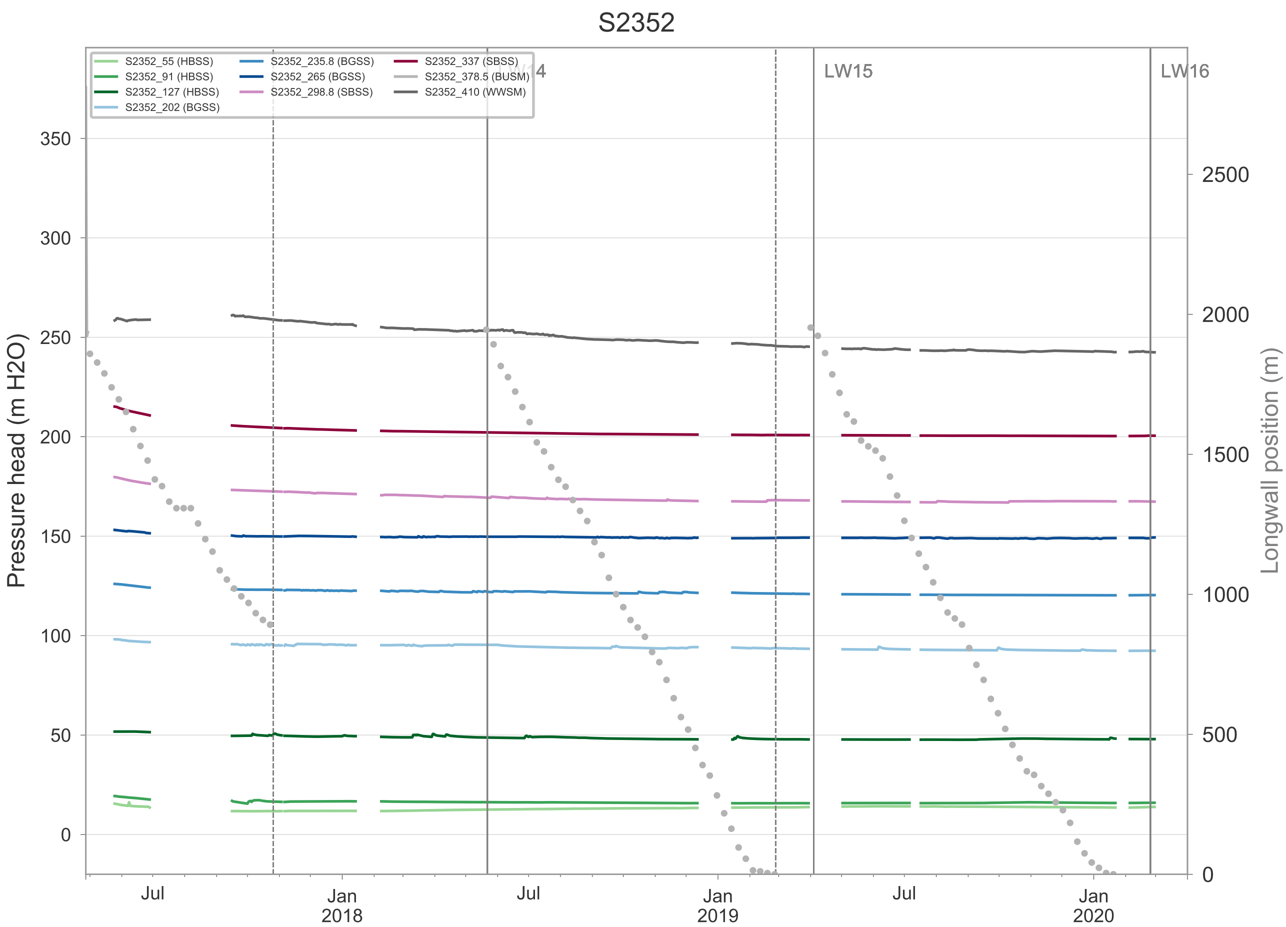
Groundwater hydrographs



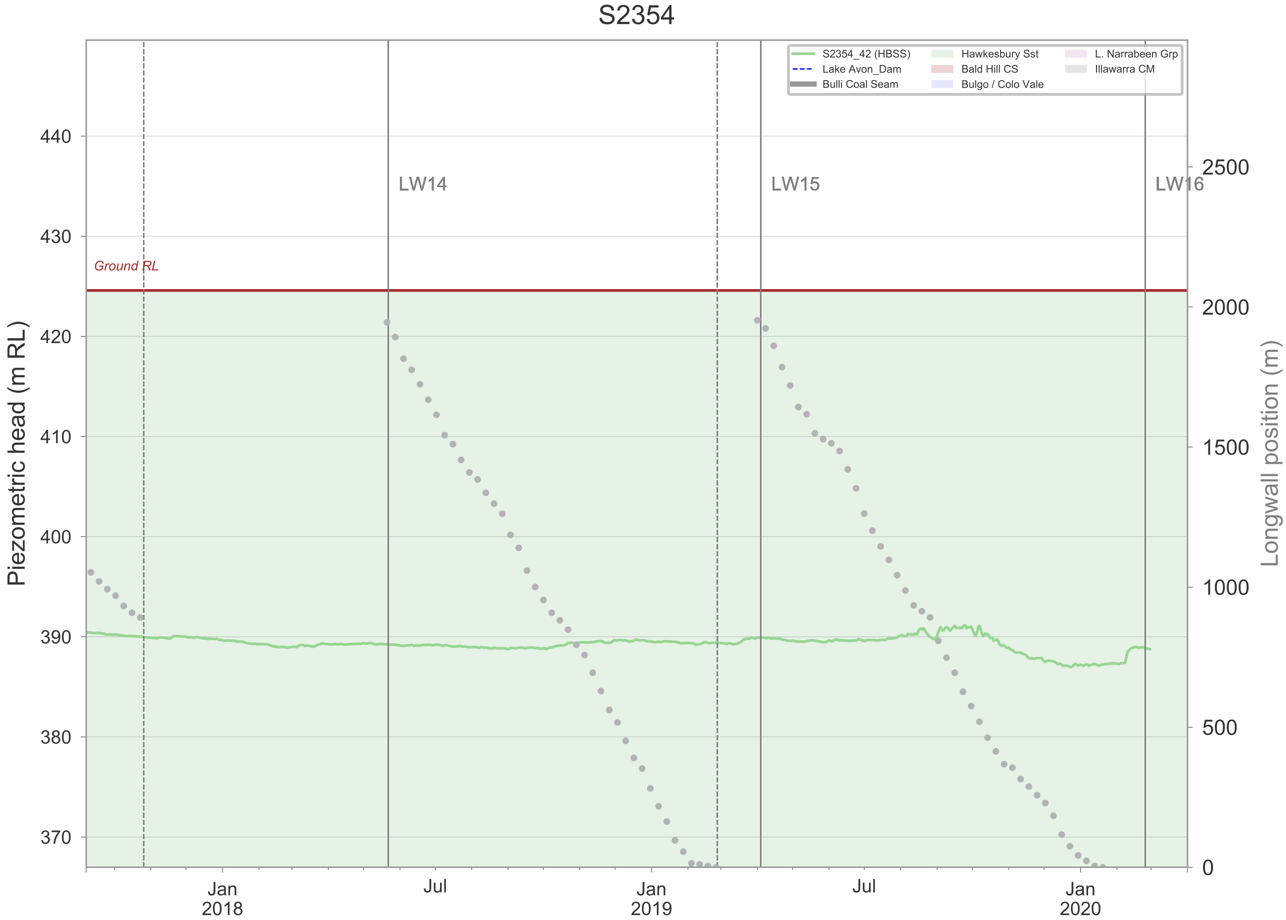


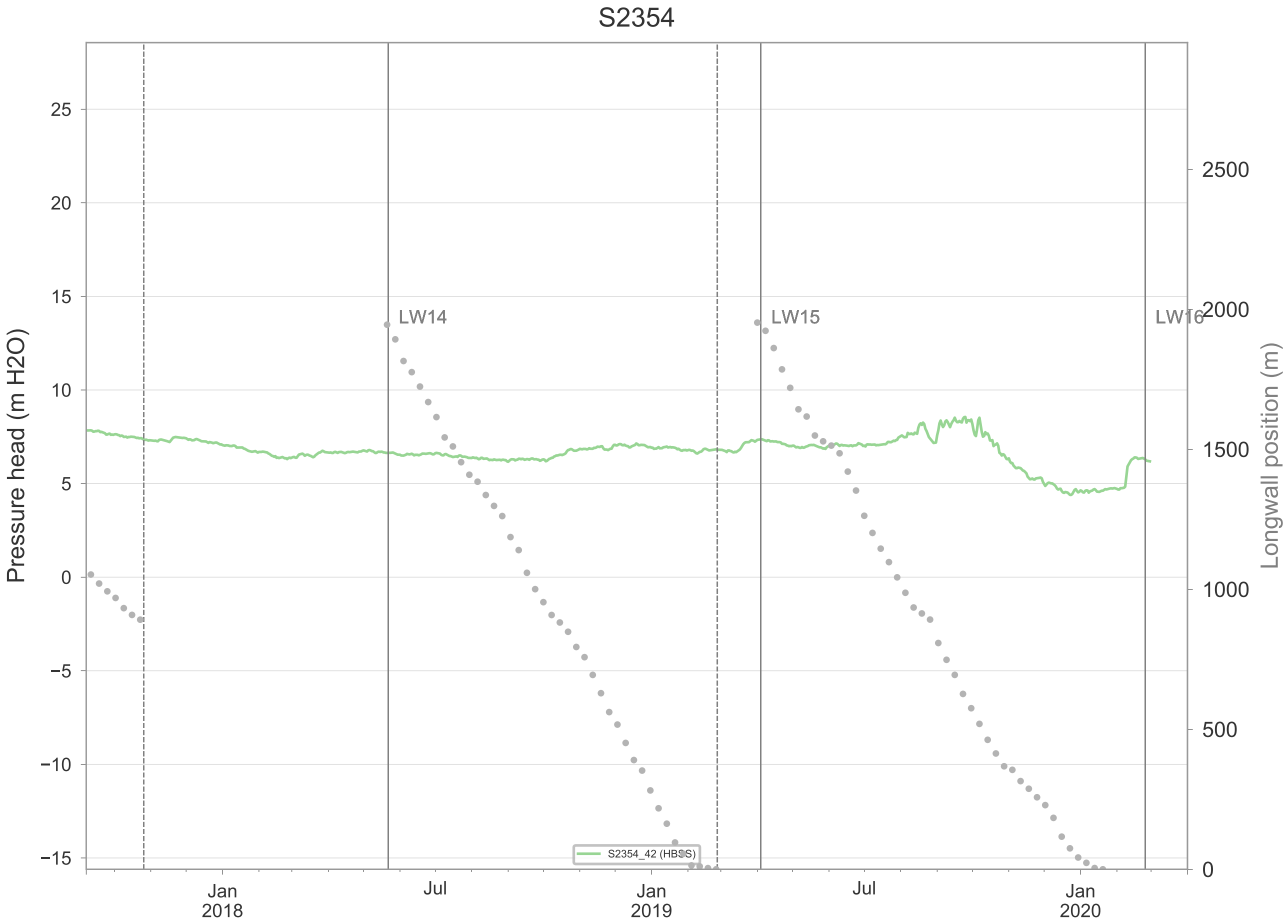
Groundwater hydrographs



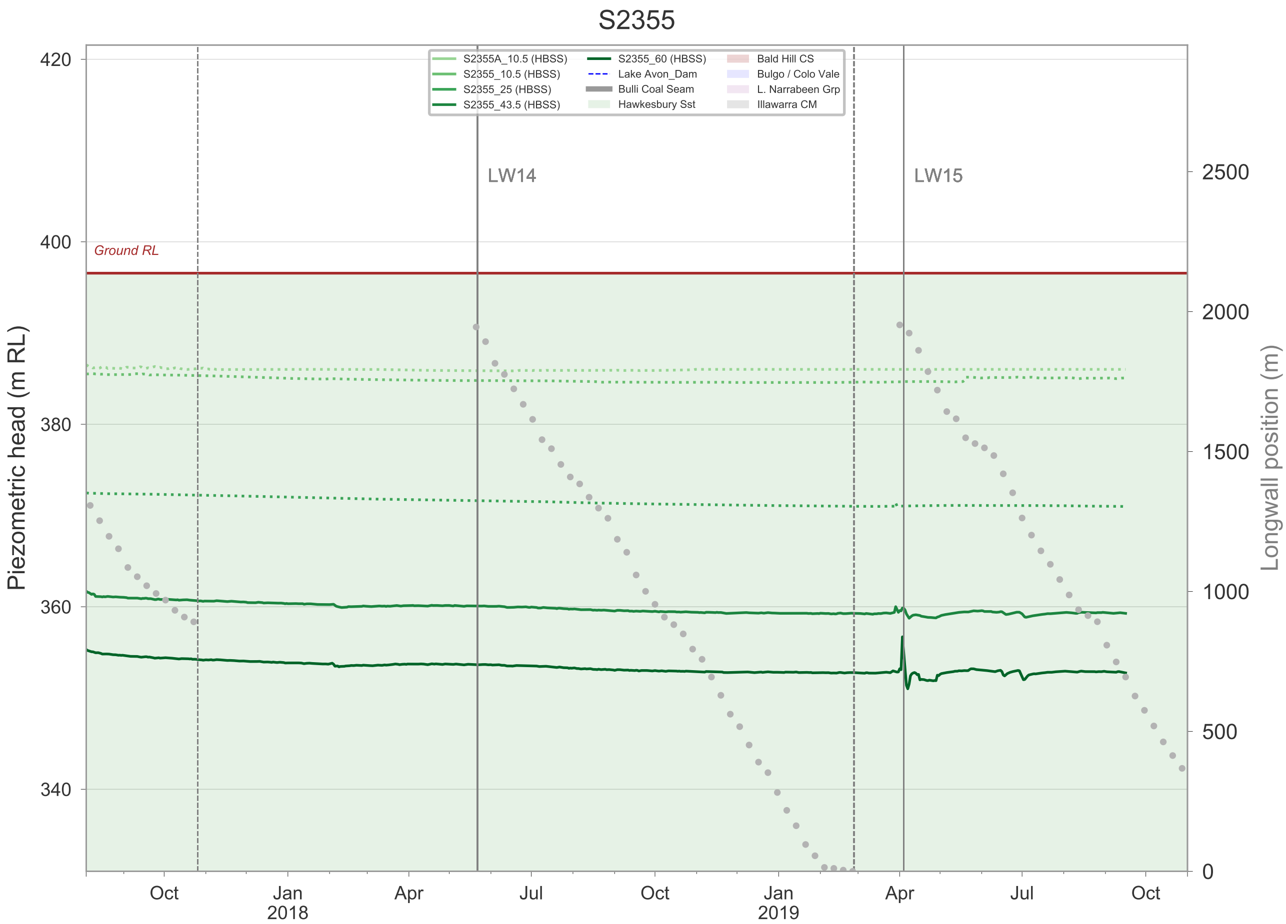


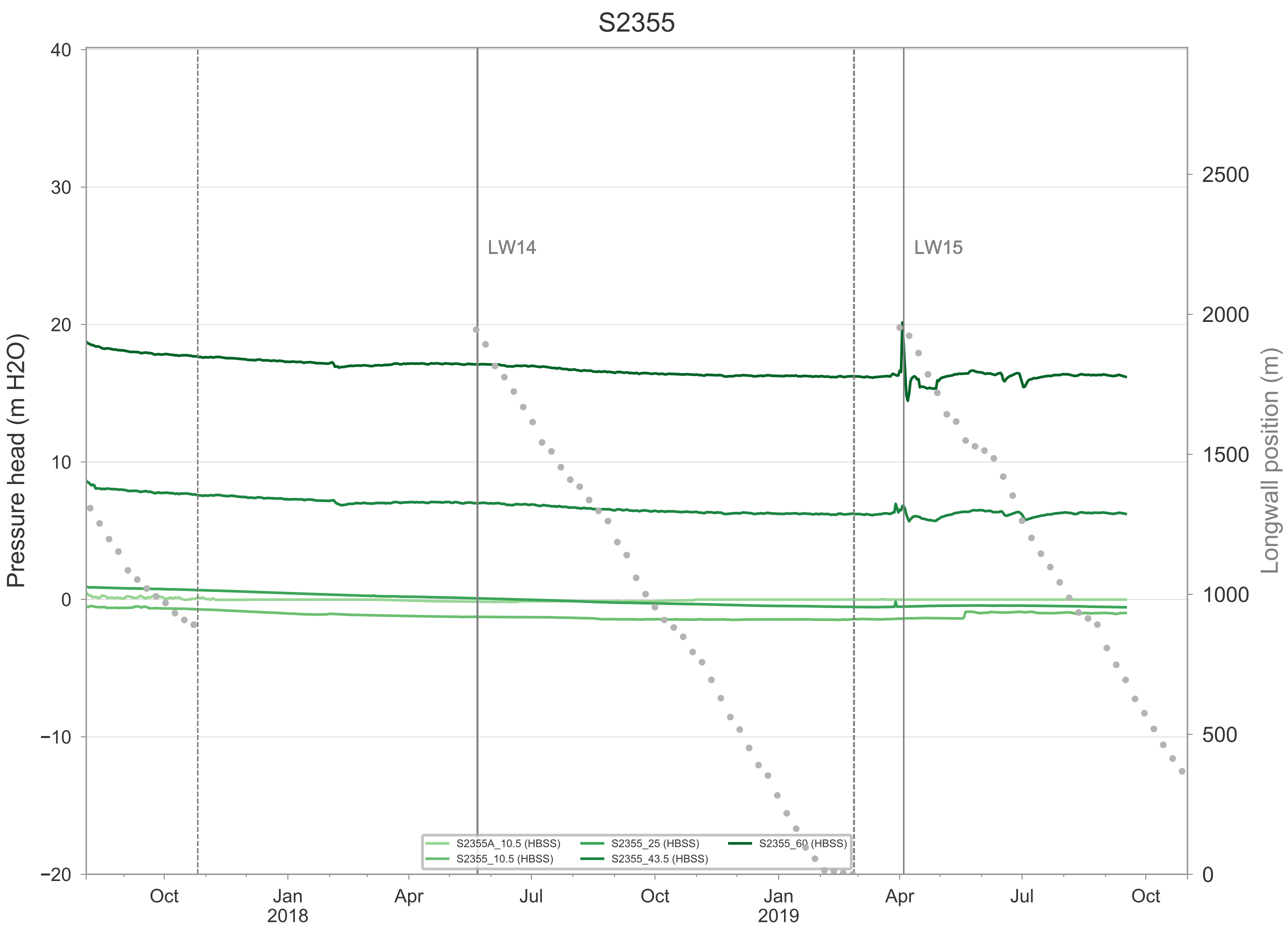
Groundwater hydrographs



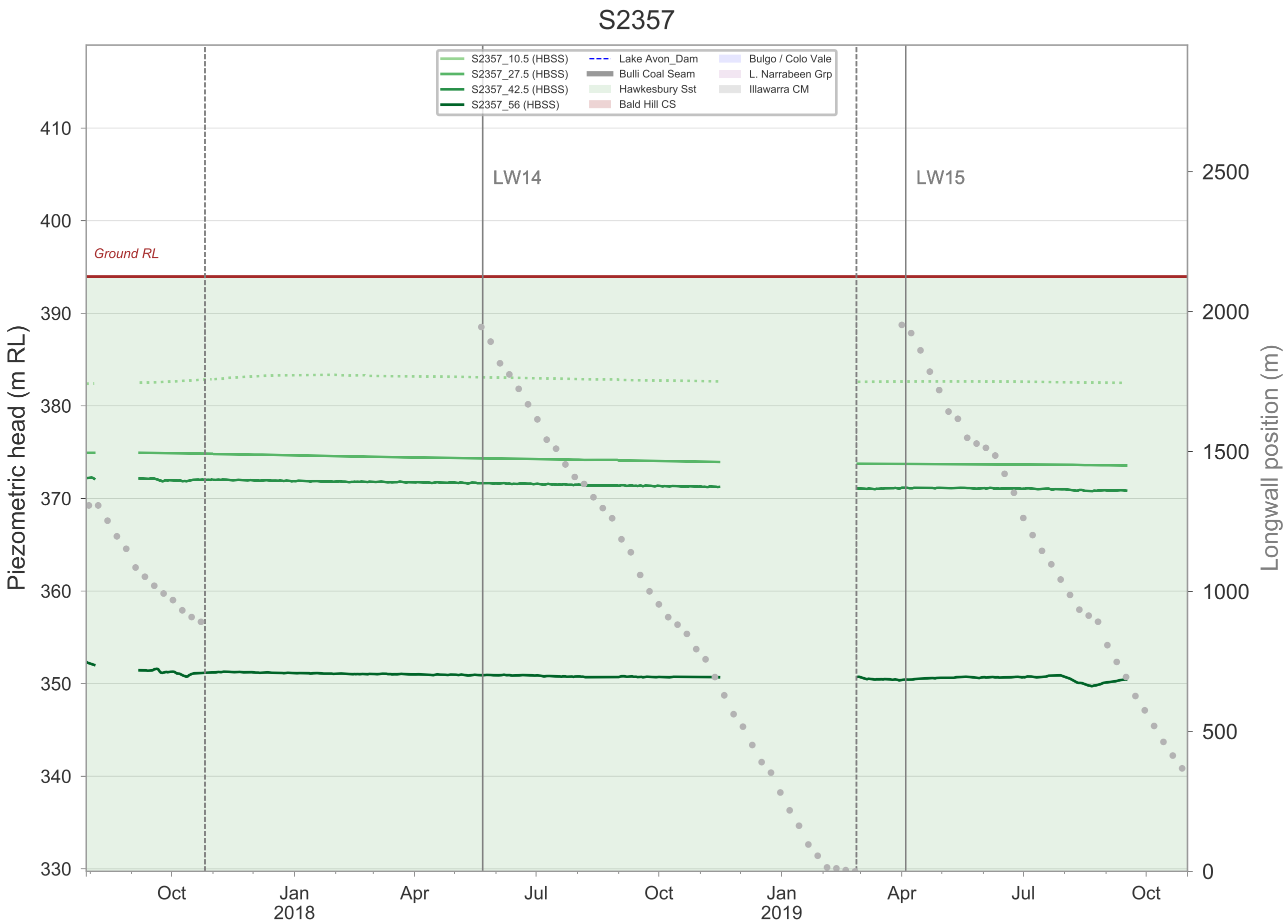


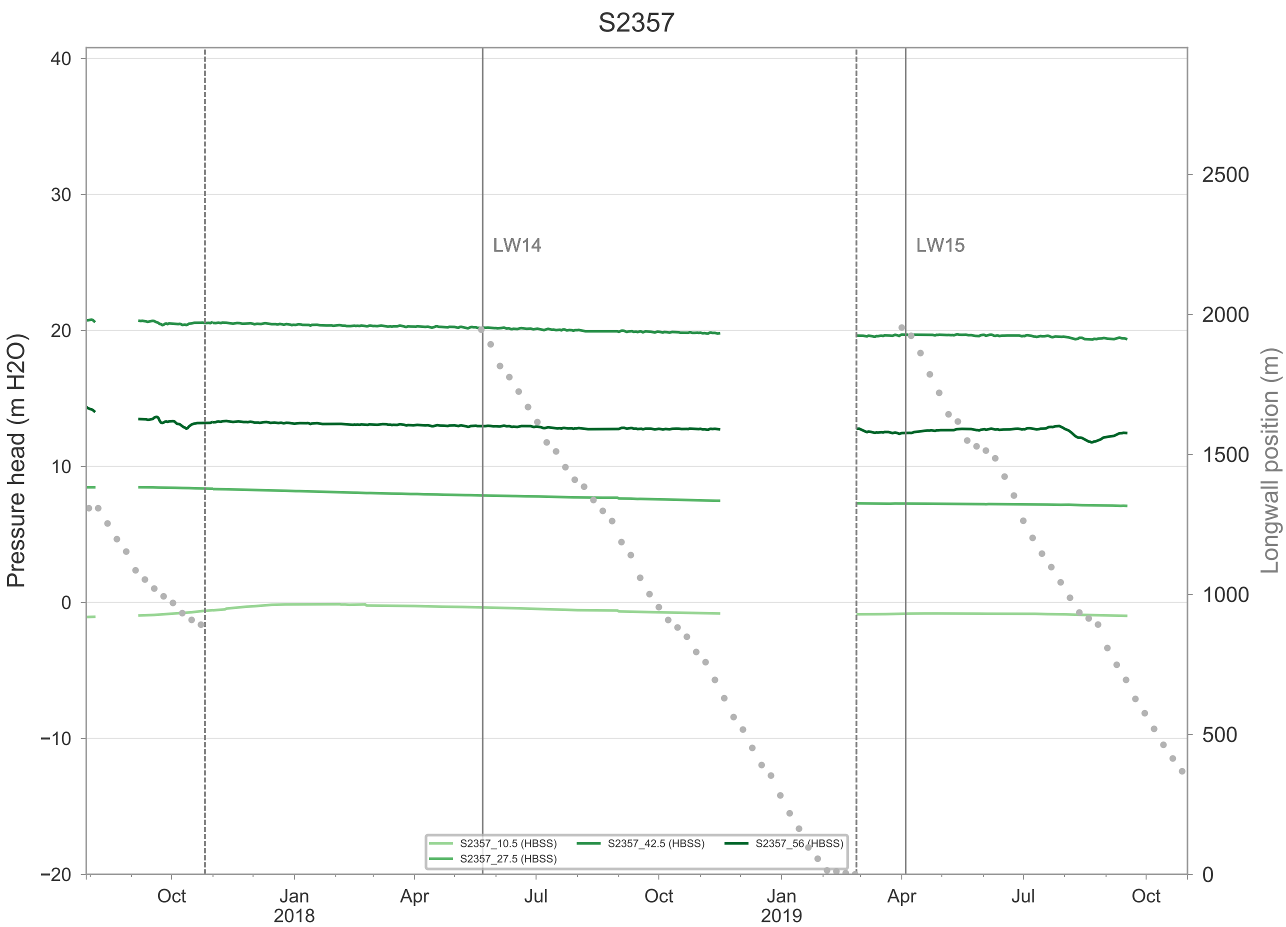
Groundwater hydrographs



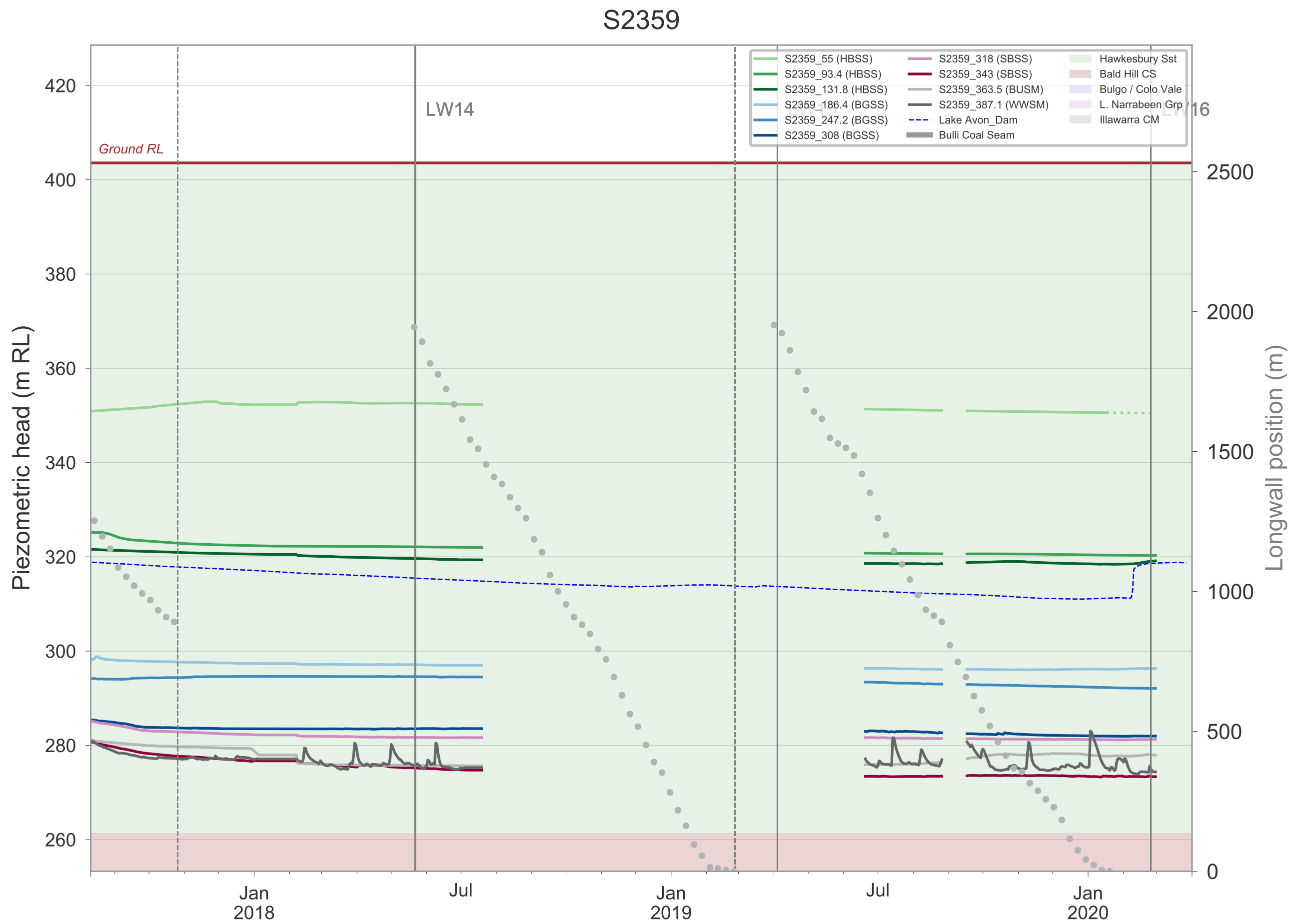


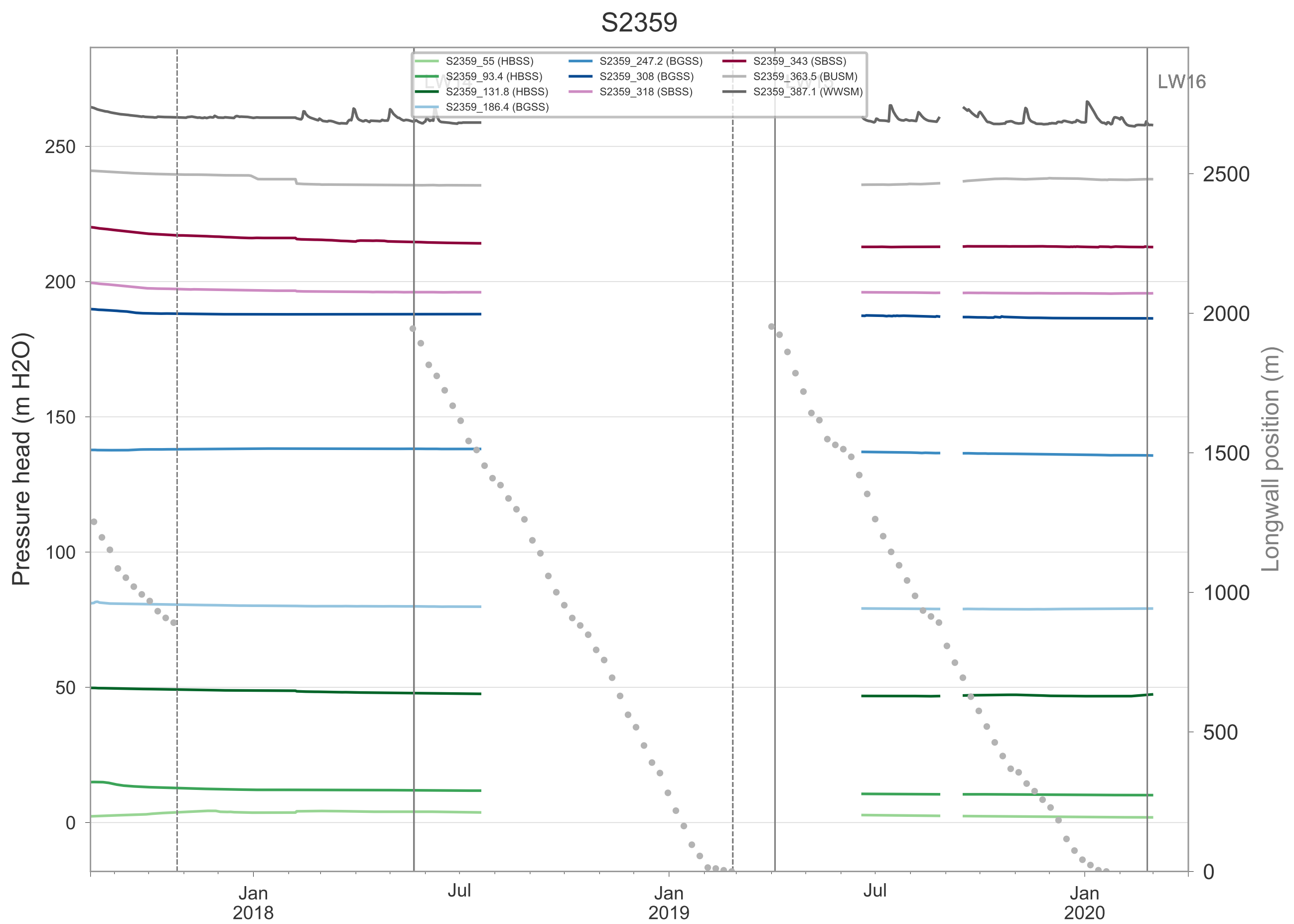
Groundwater hydrographs





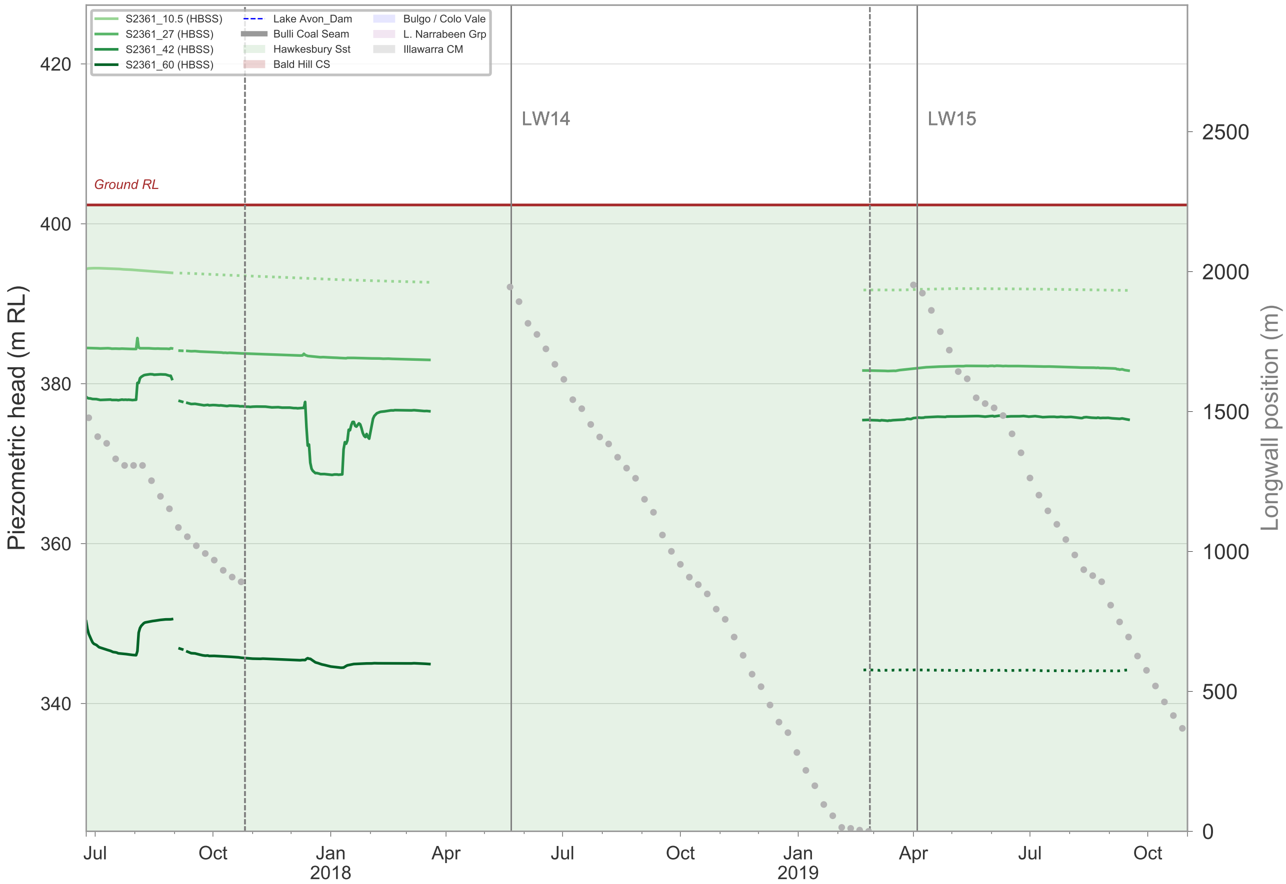
Groundwater hydrographs



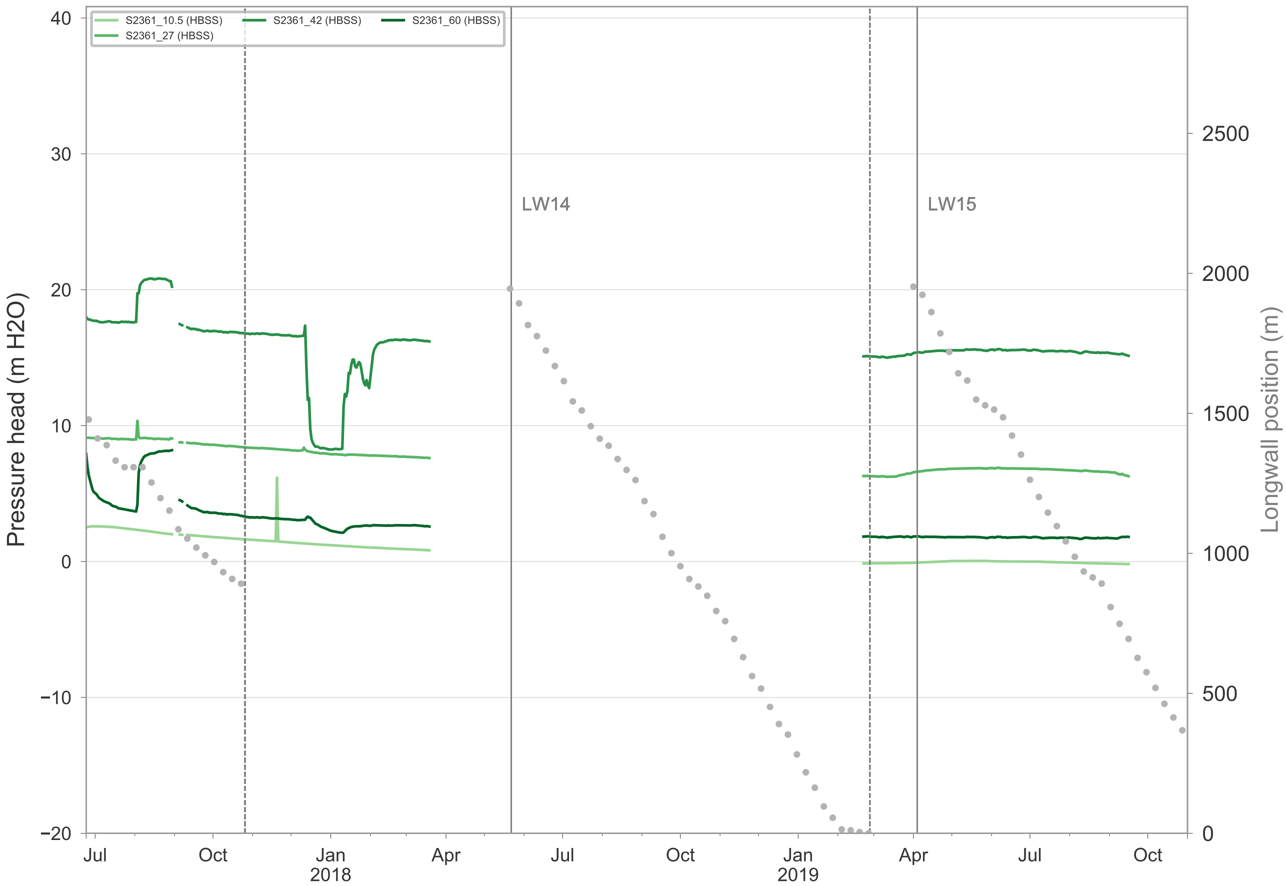


Groundwater hydrographs

S2361



S2361



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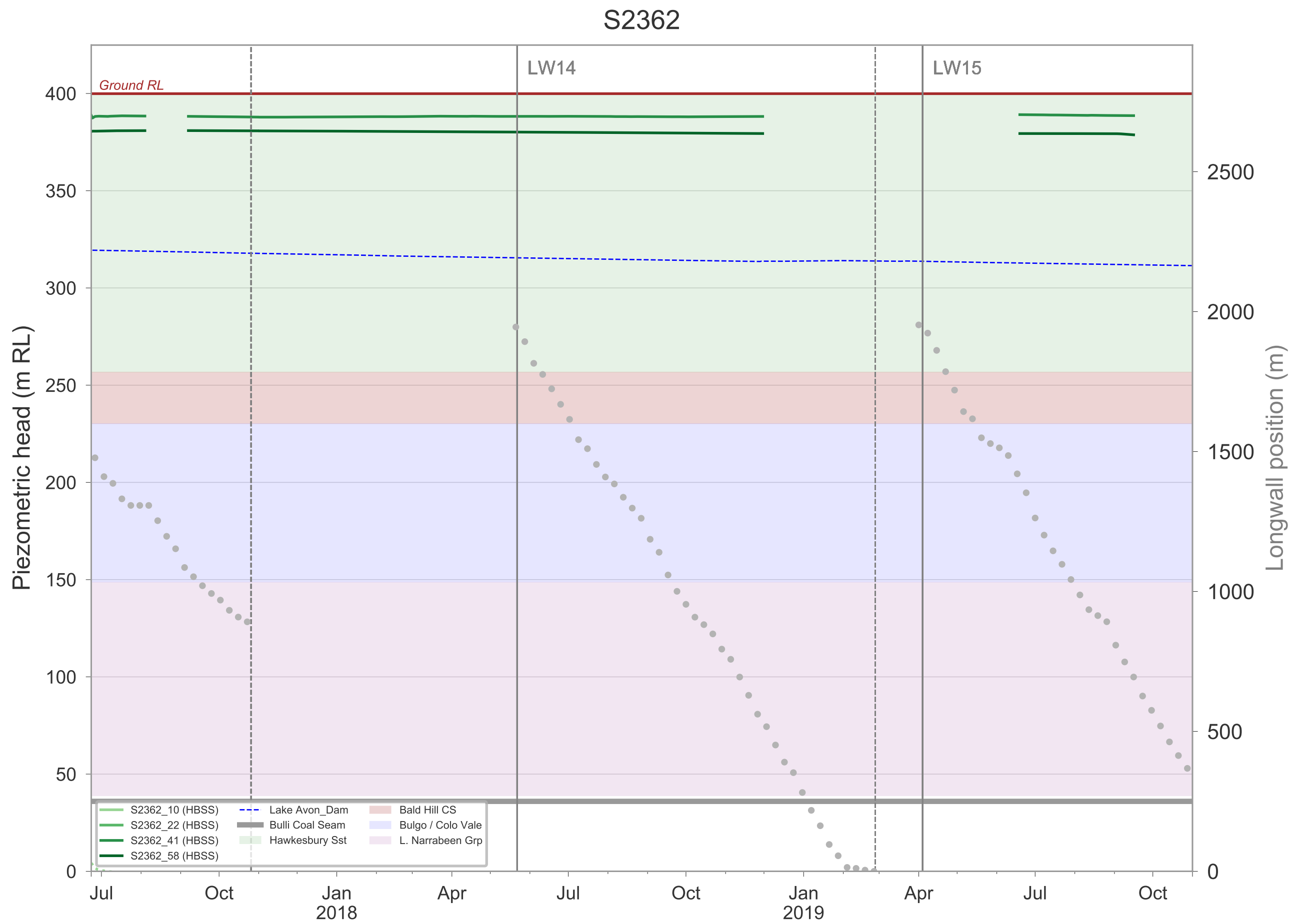

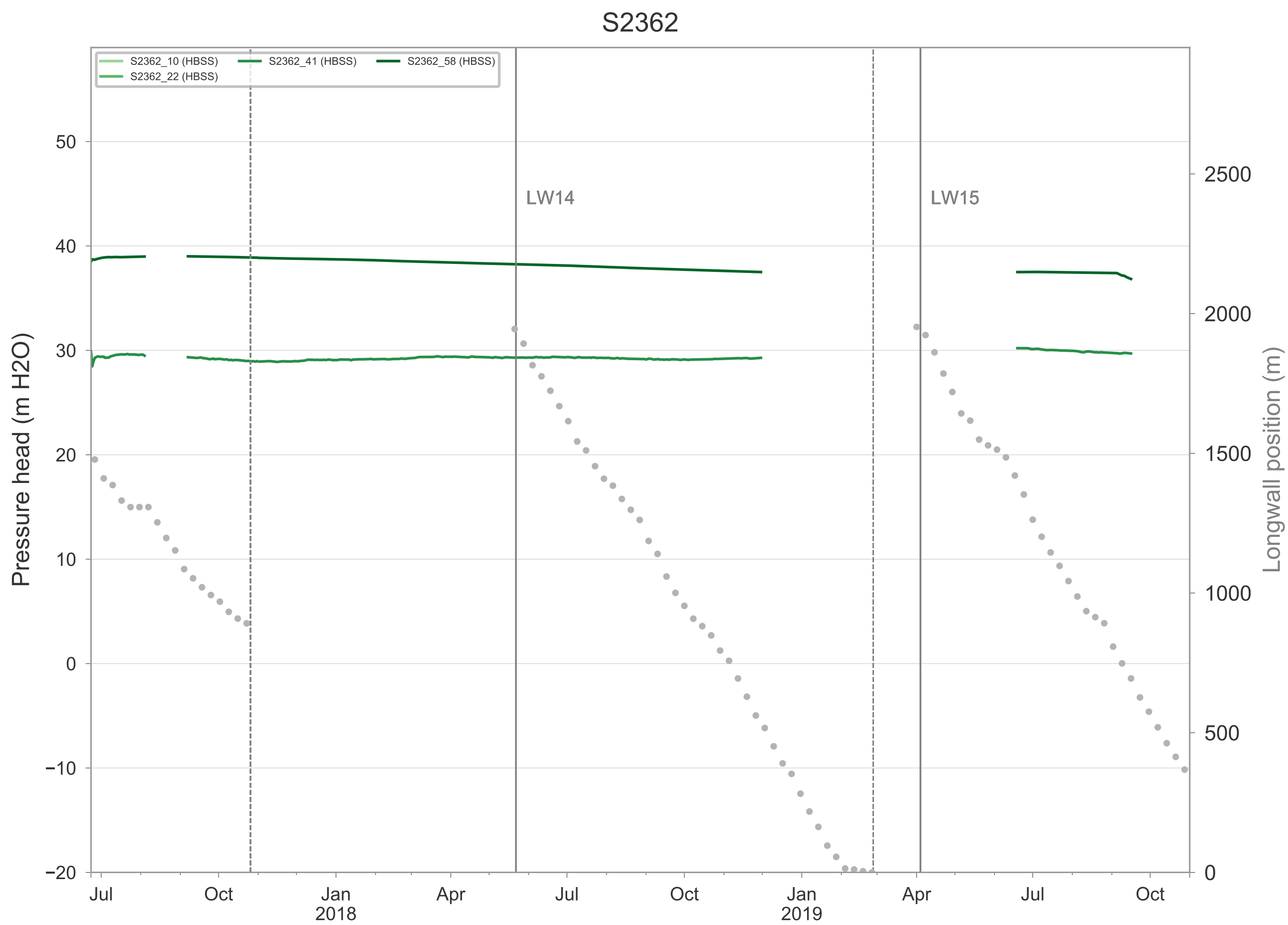

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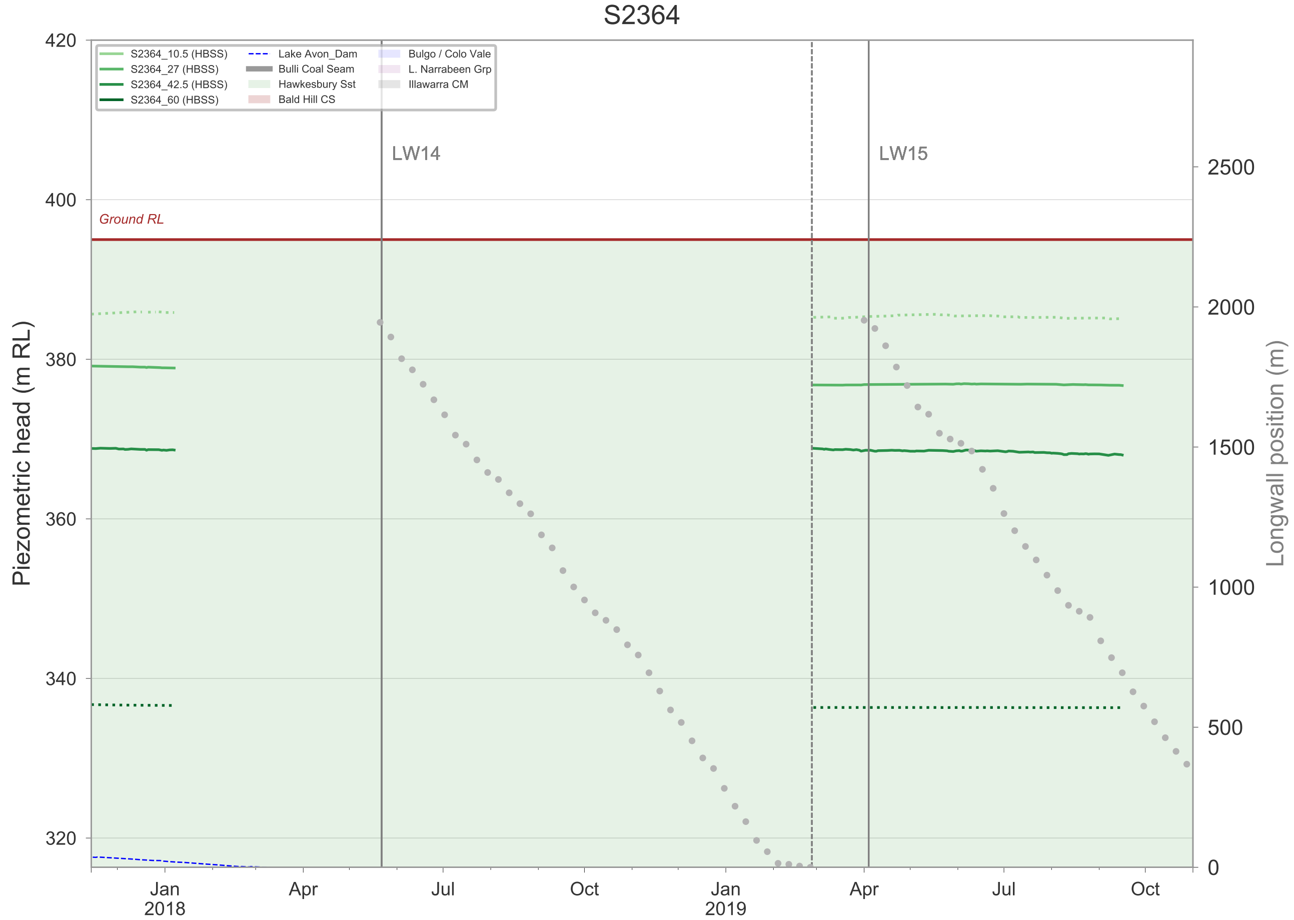

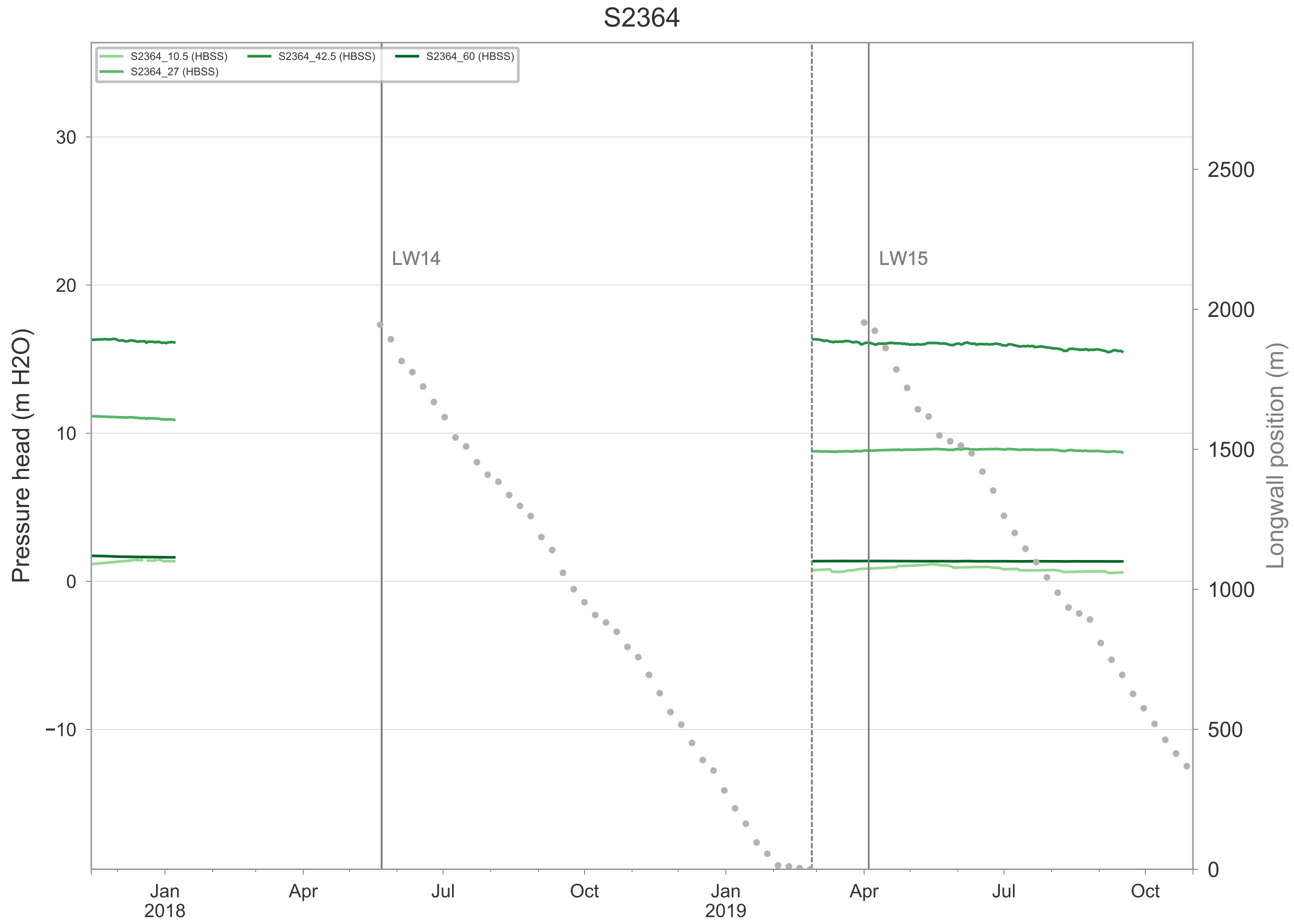

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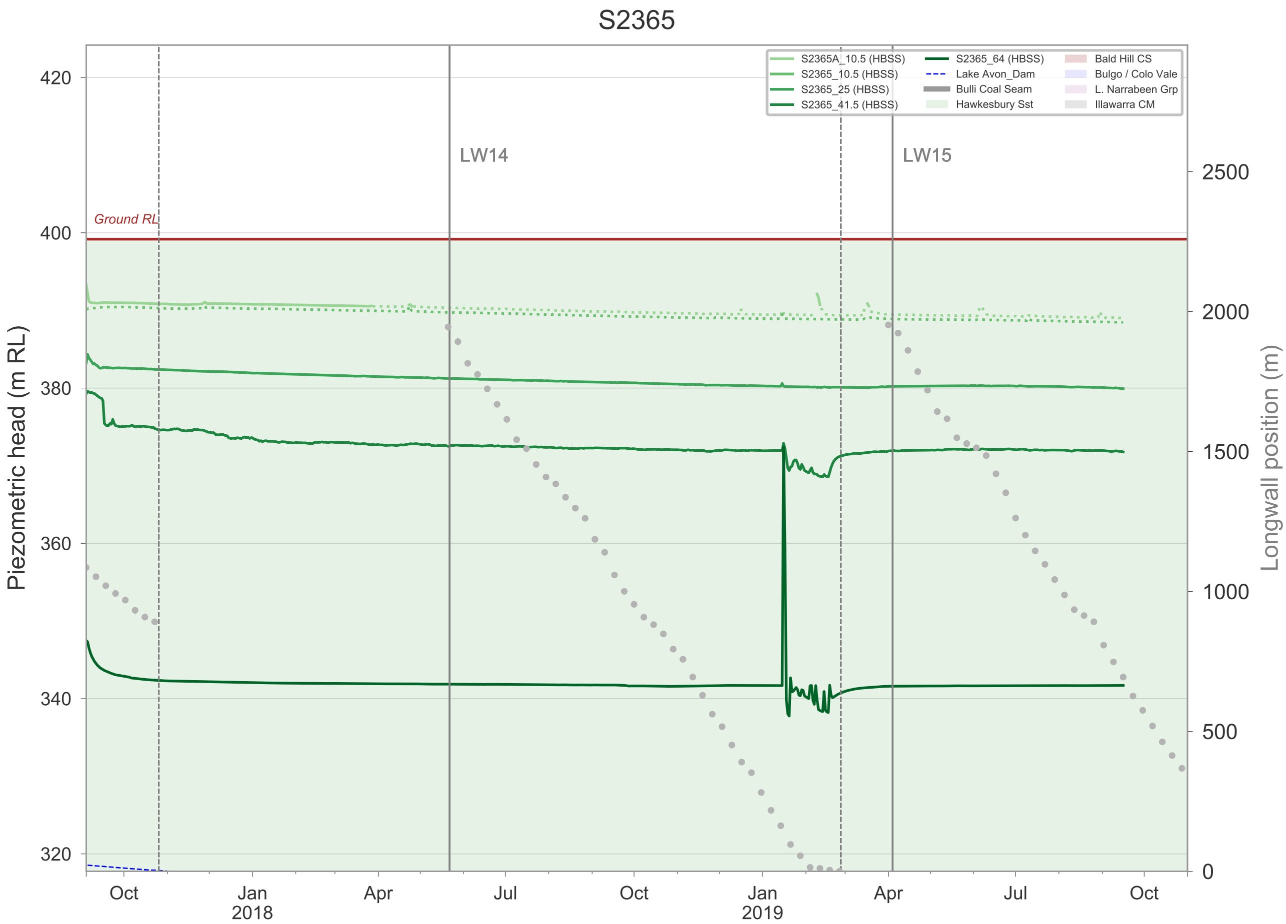

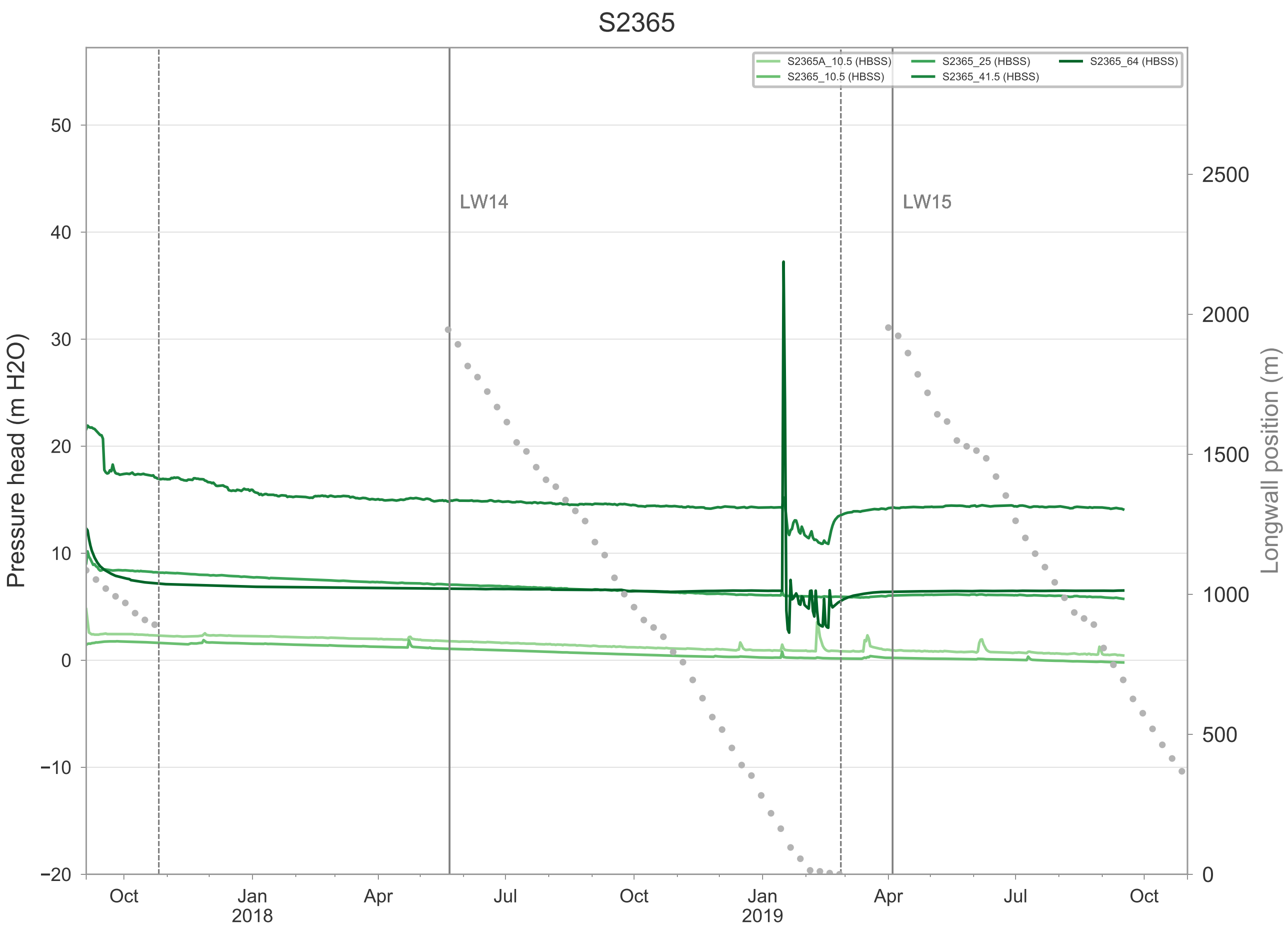

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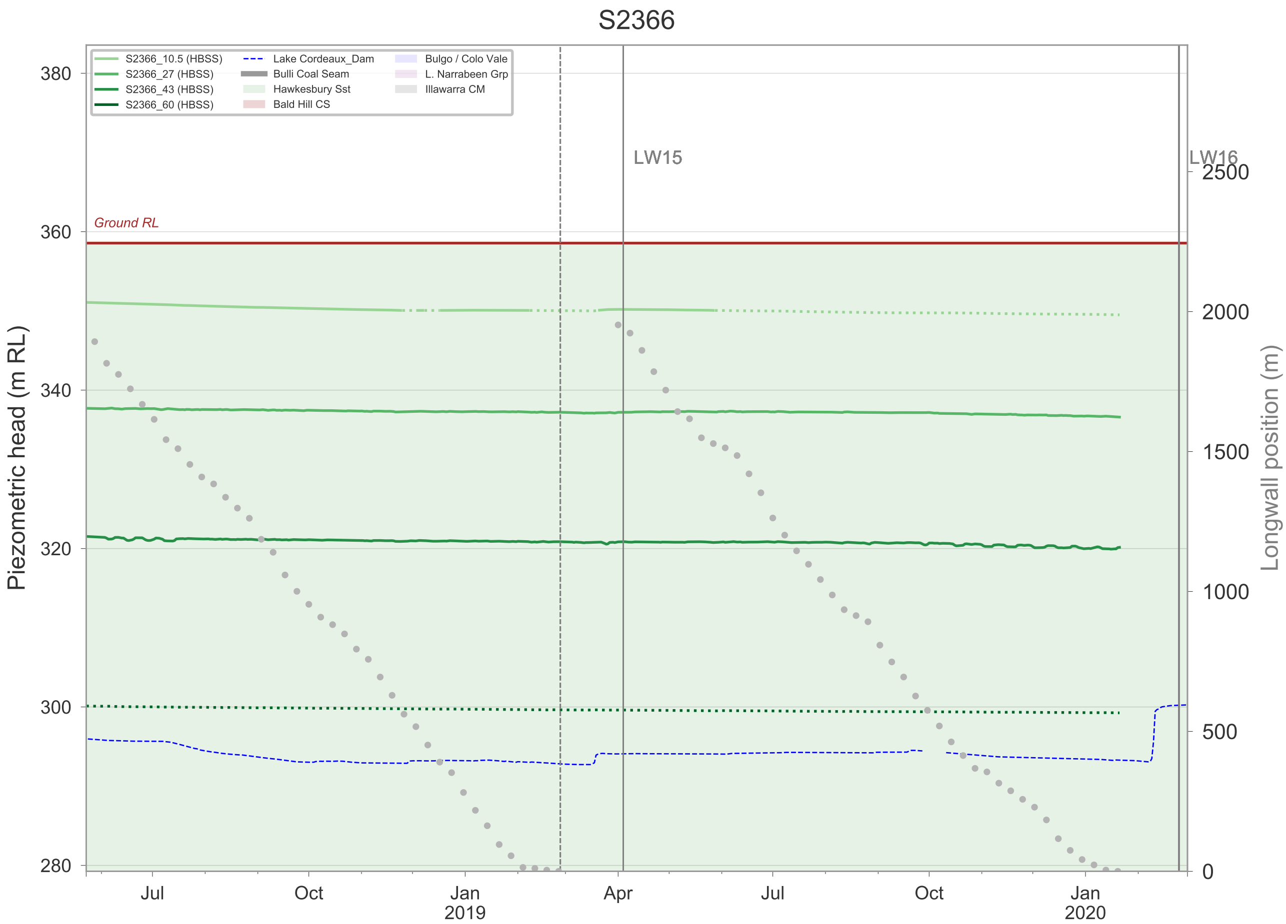

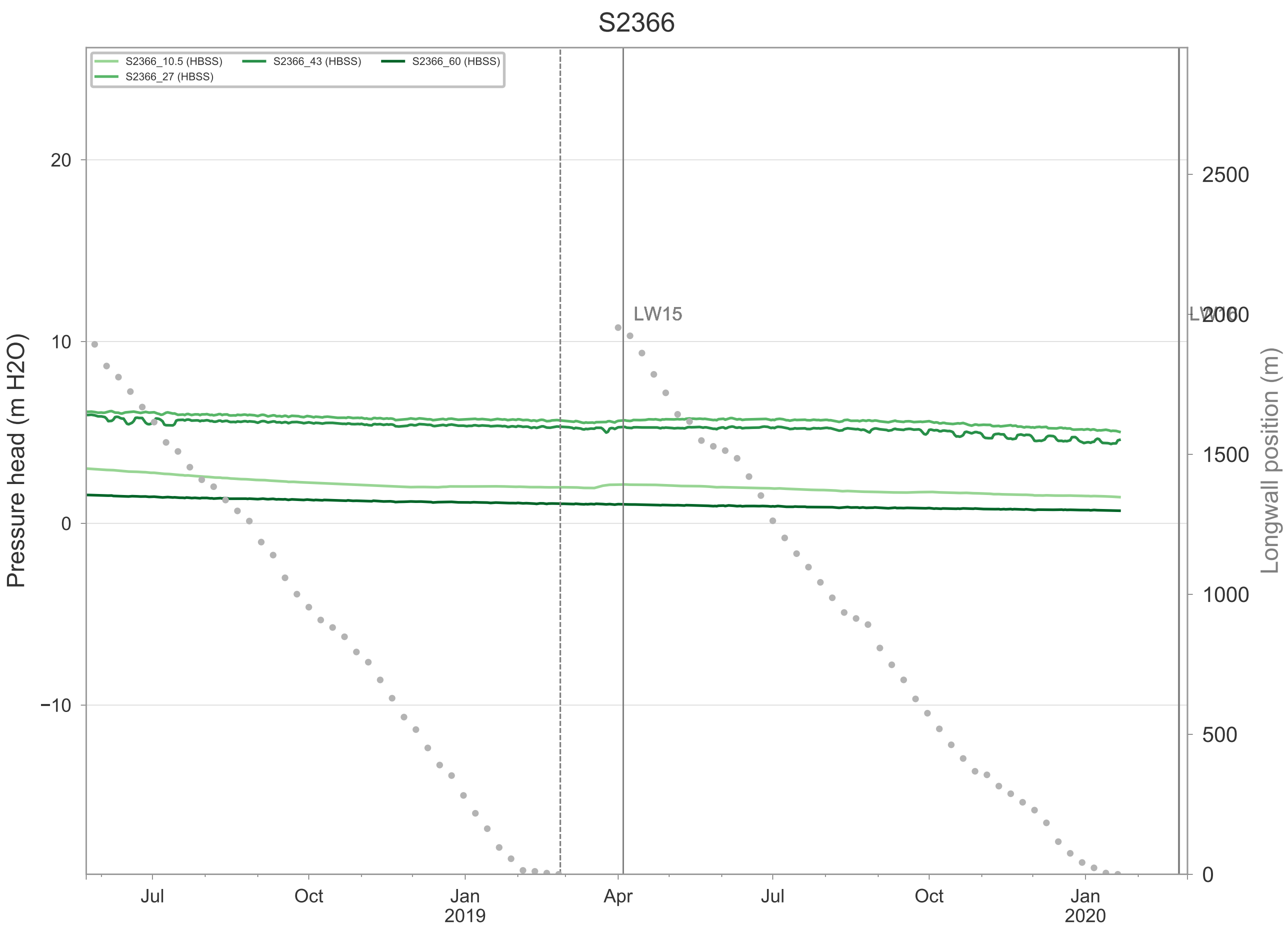

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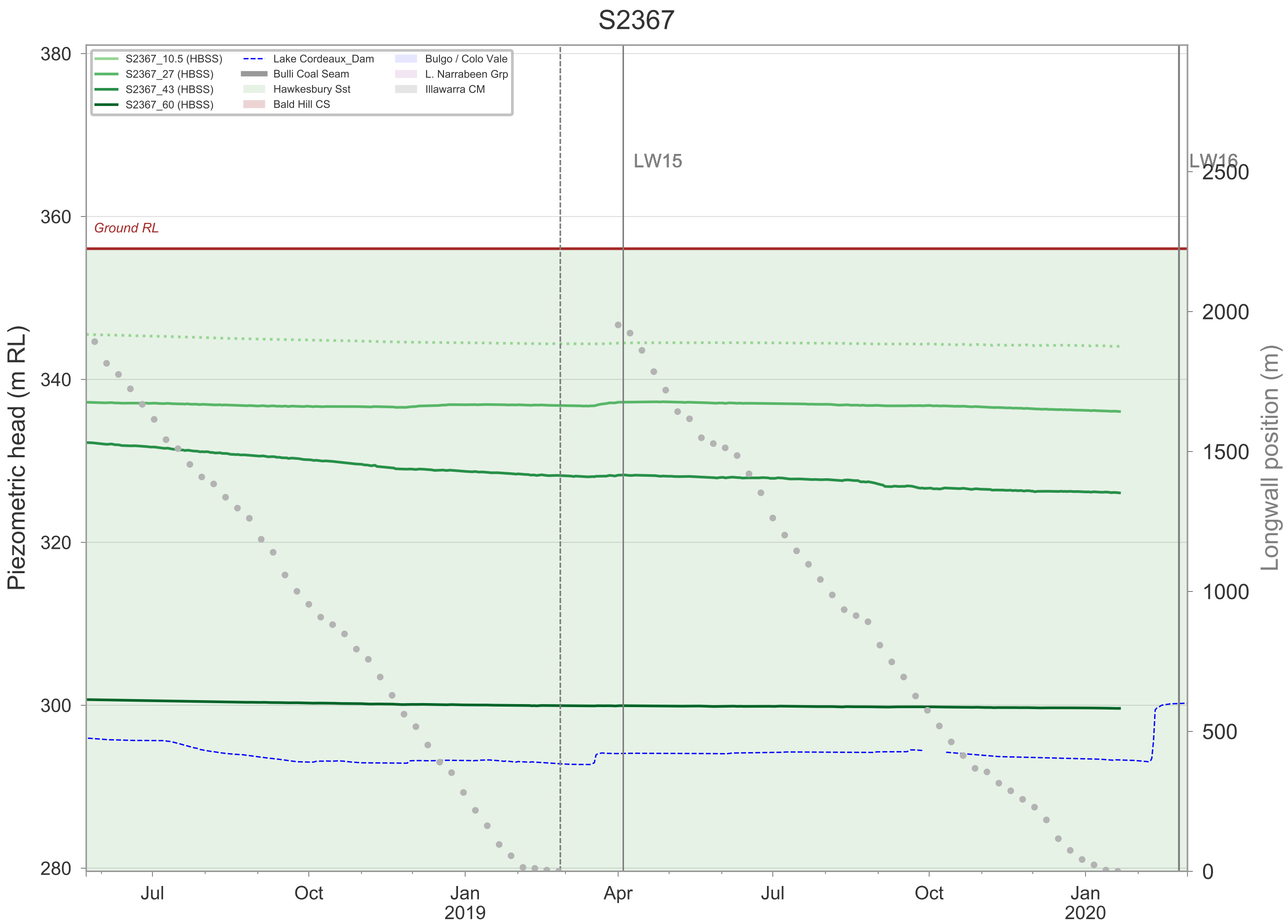

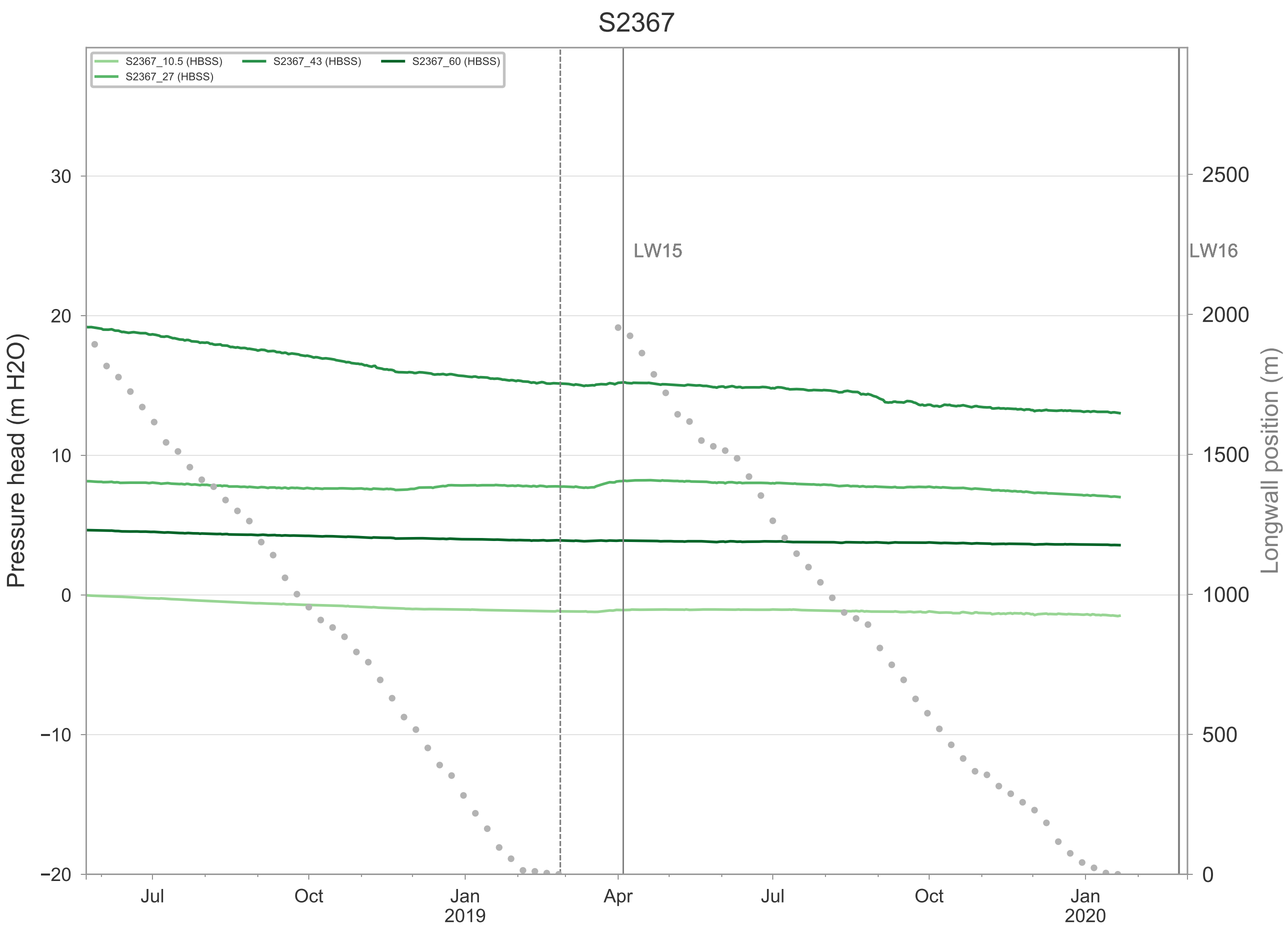

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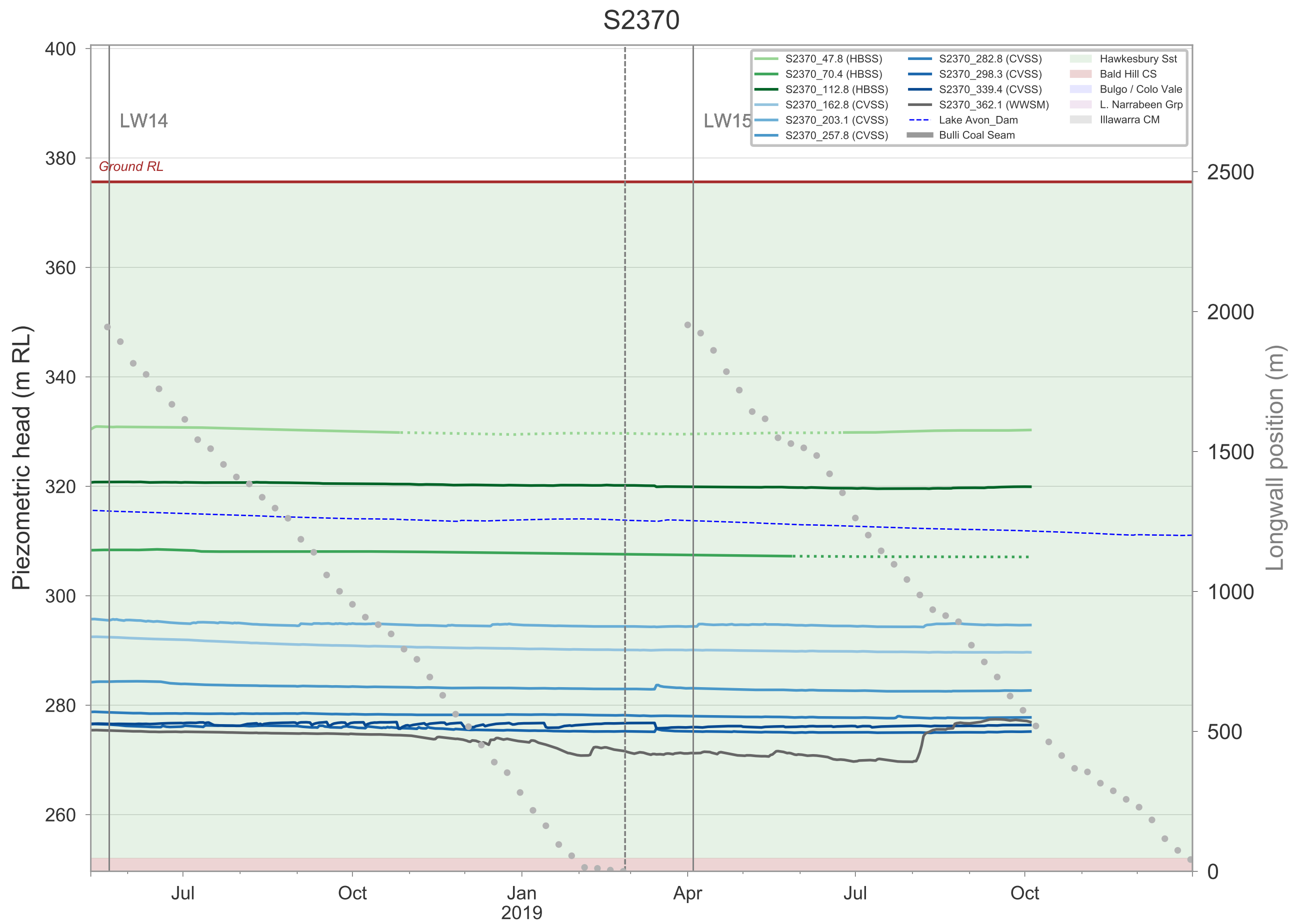

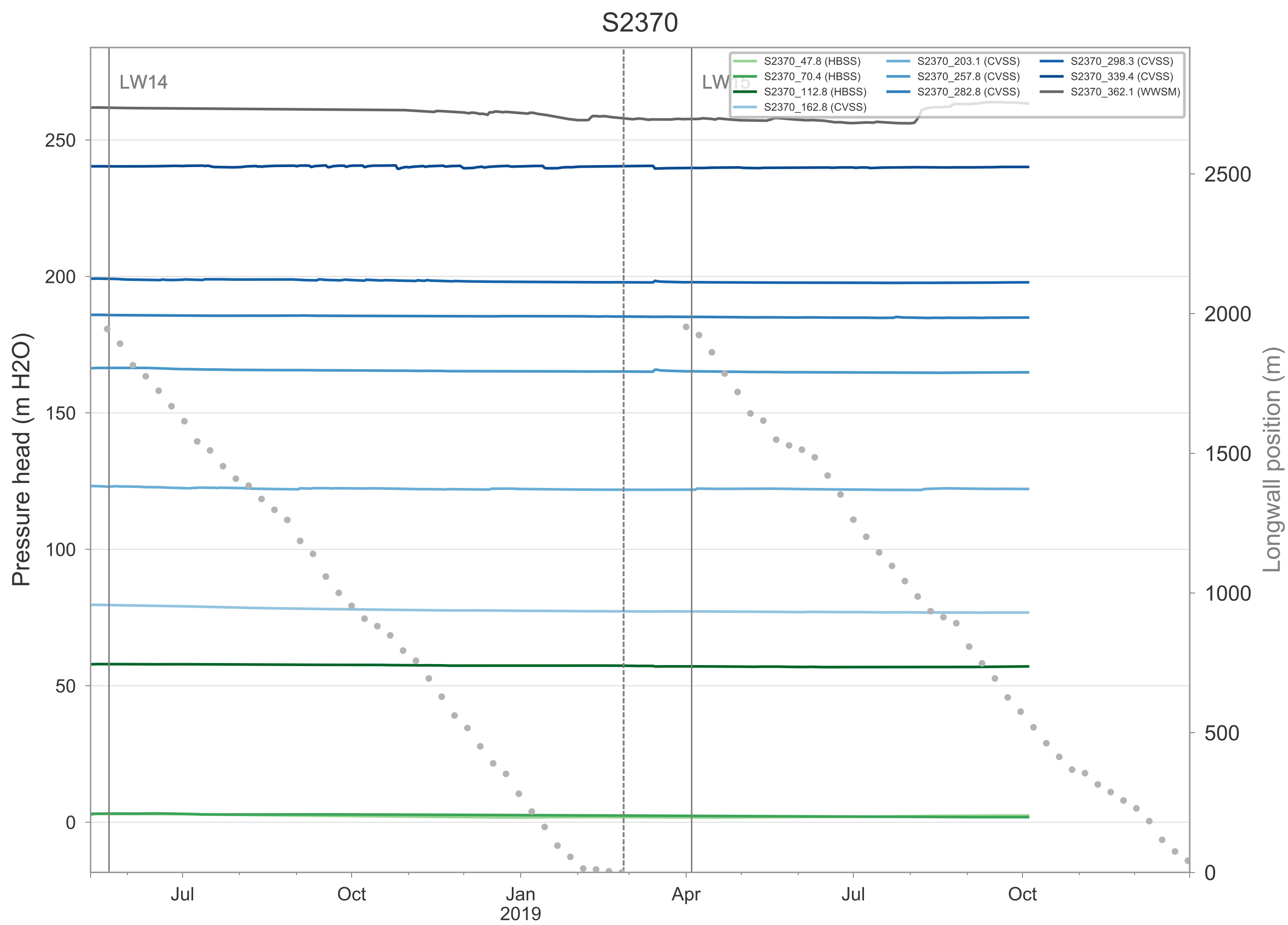

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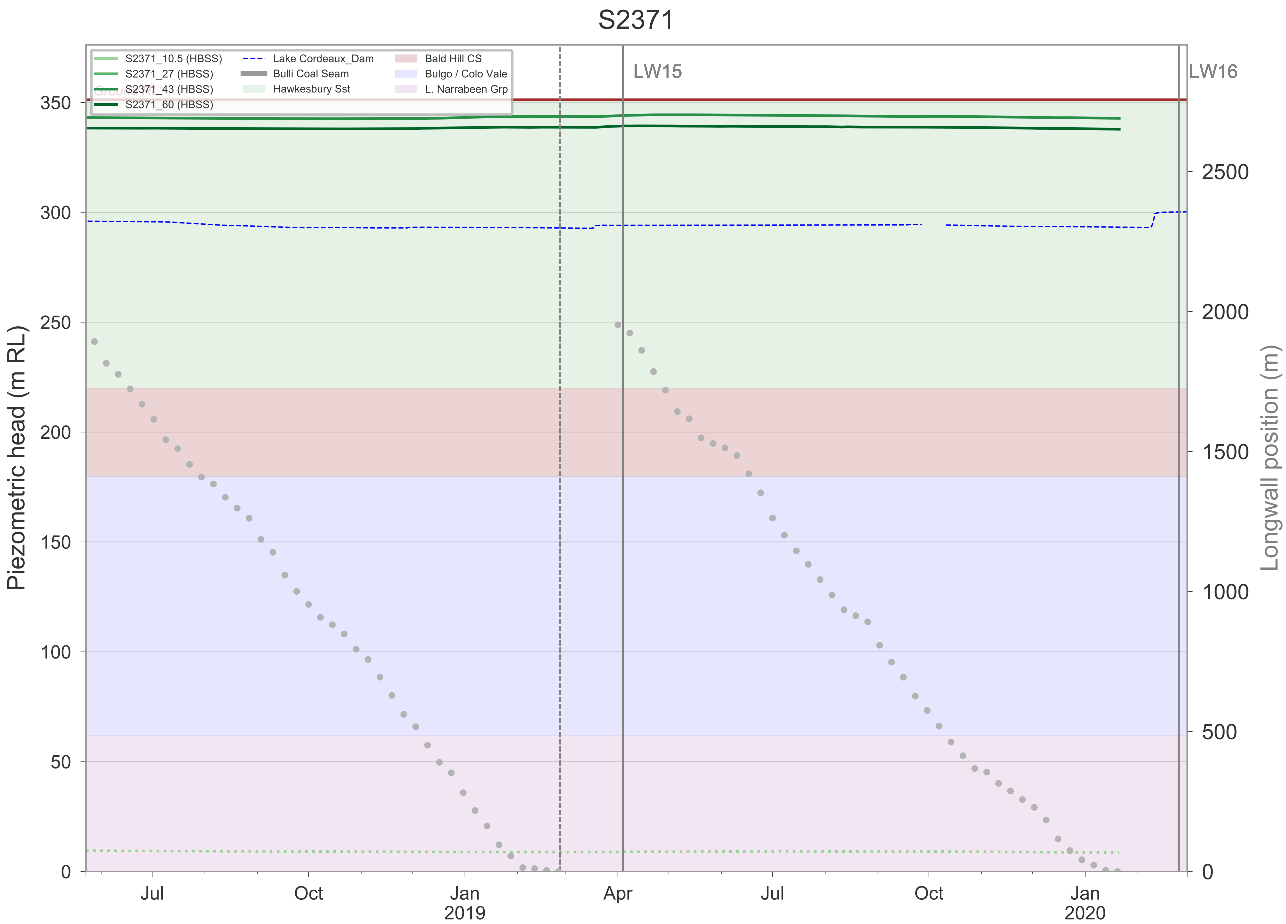

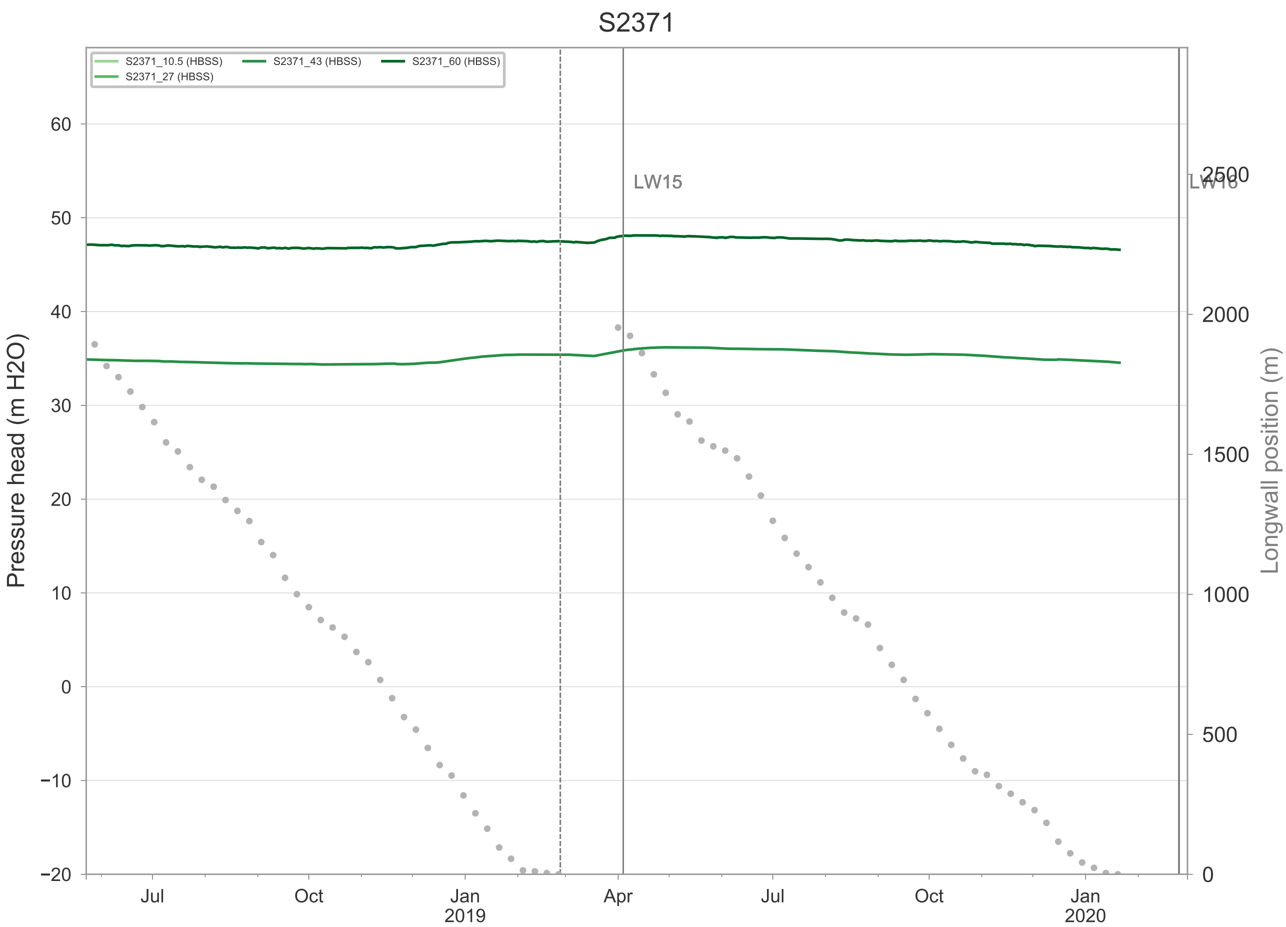

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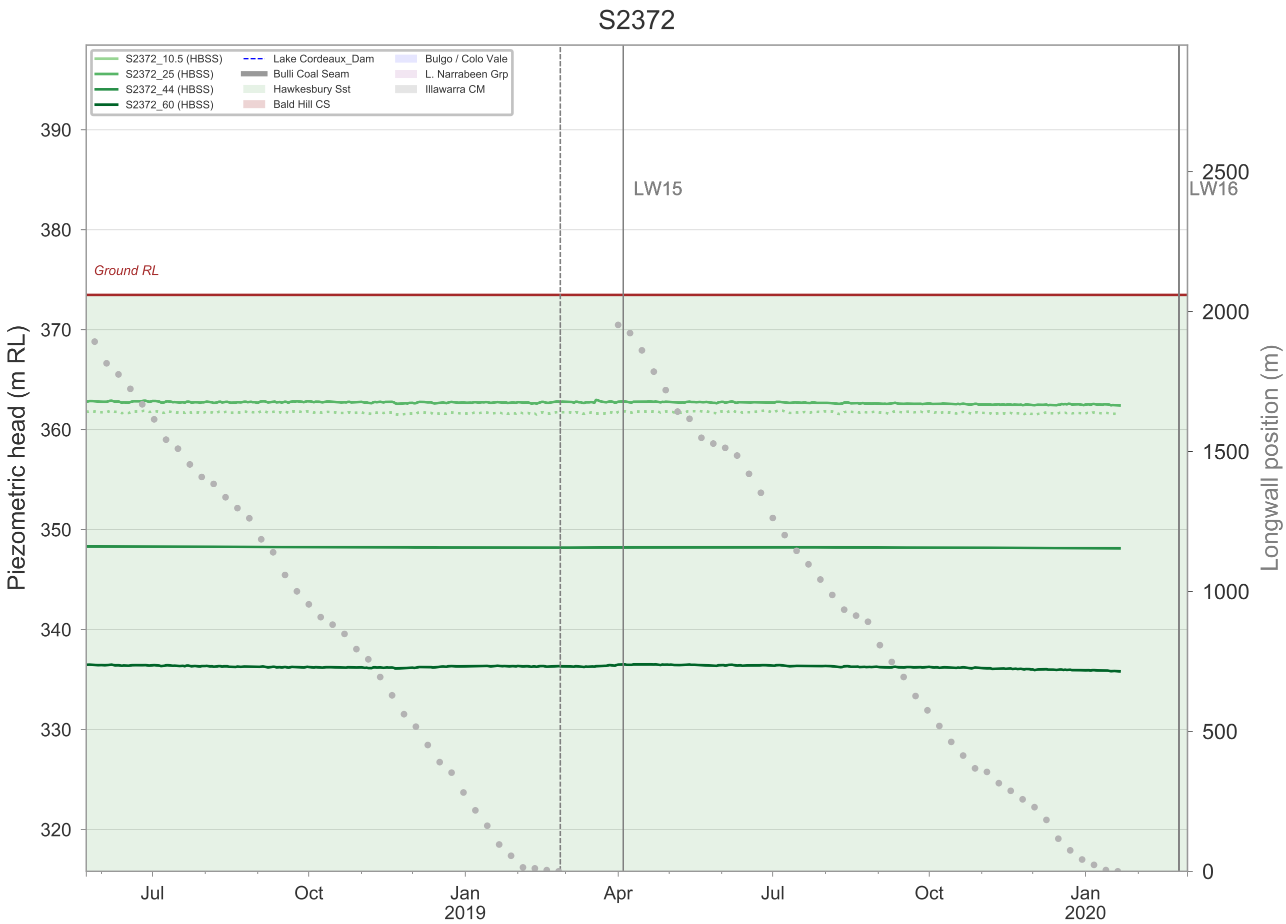

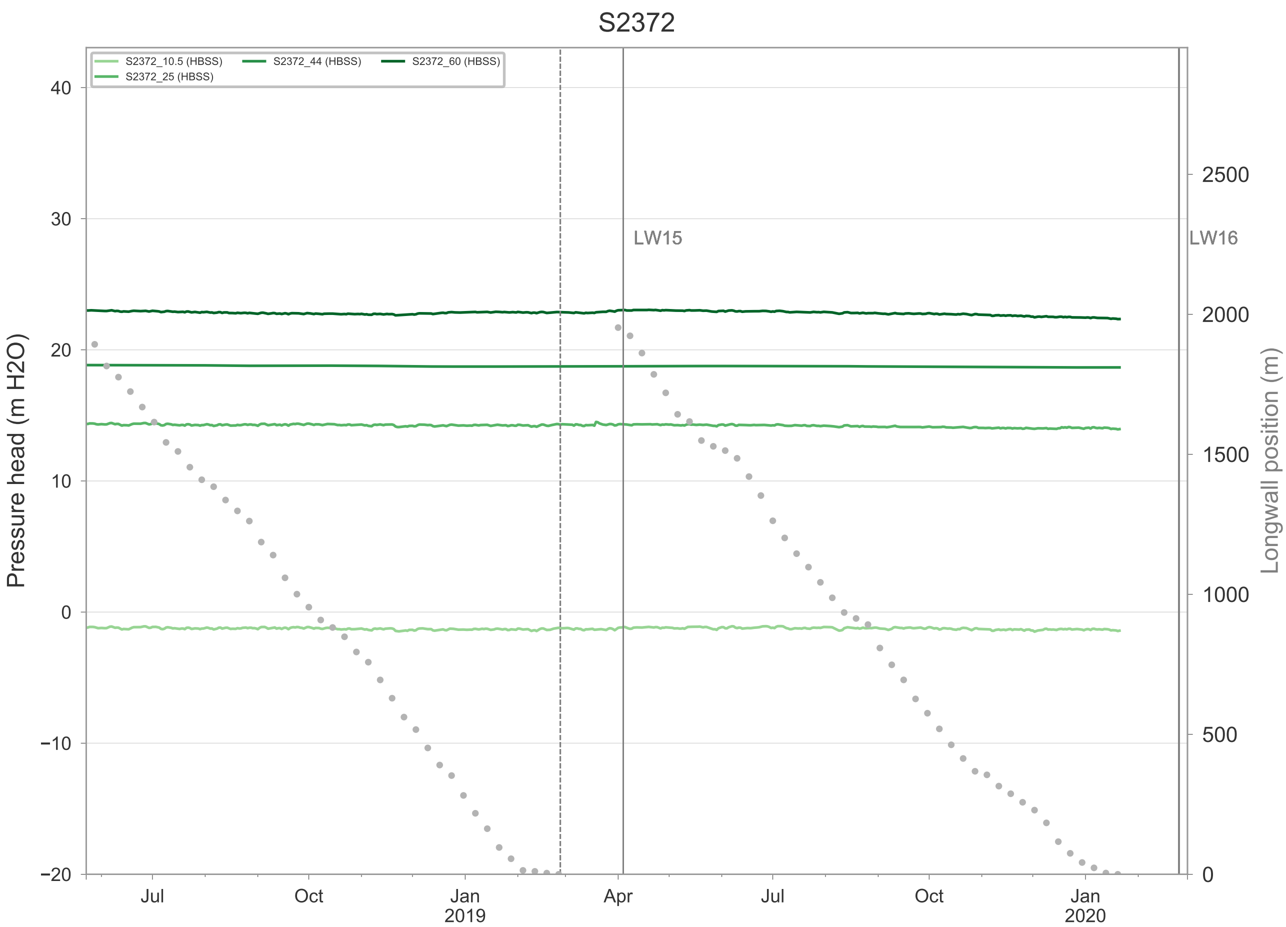

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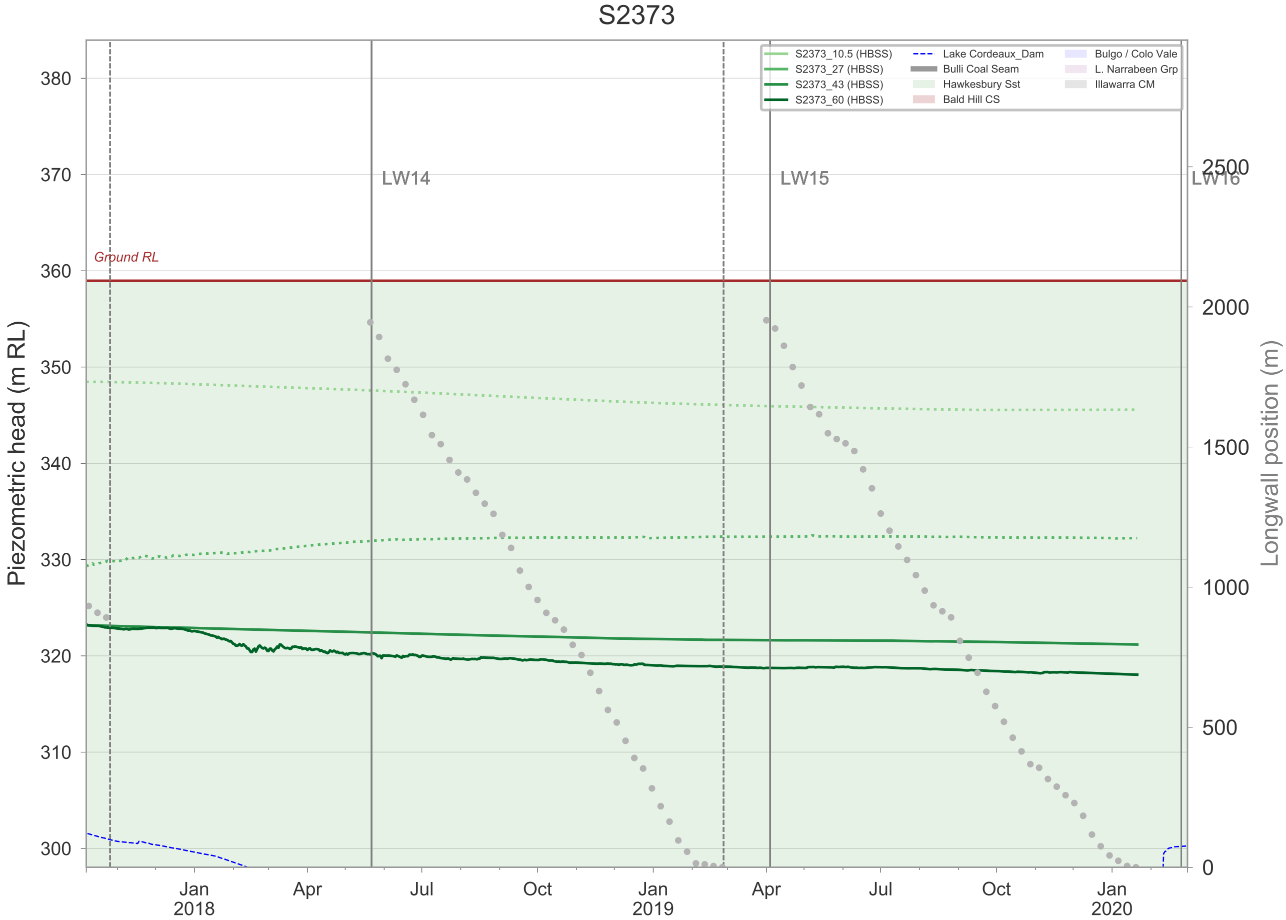

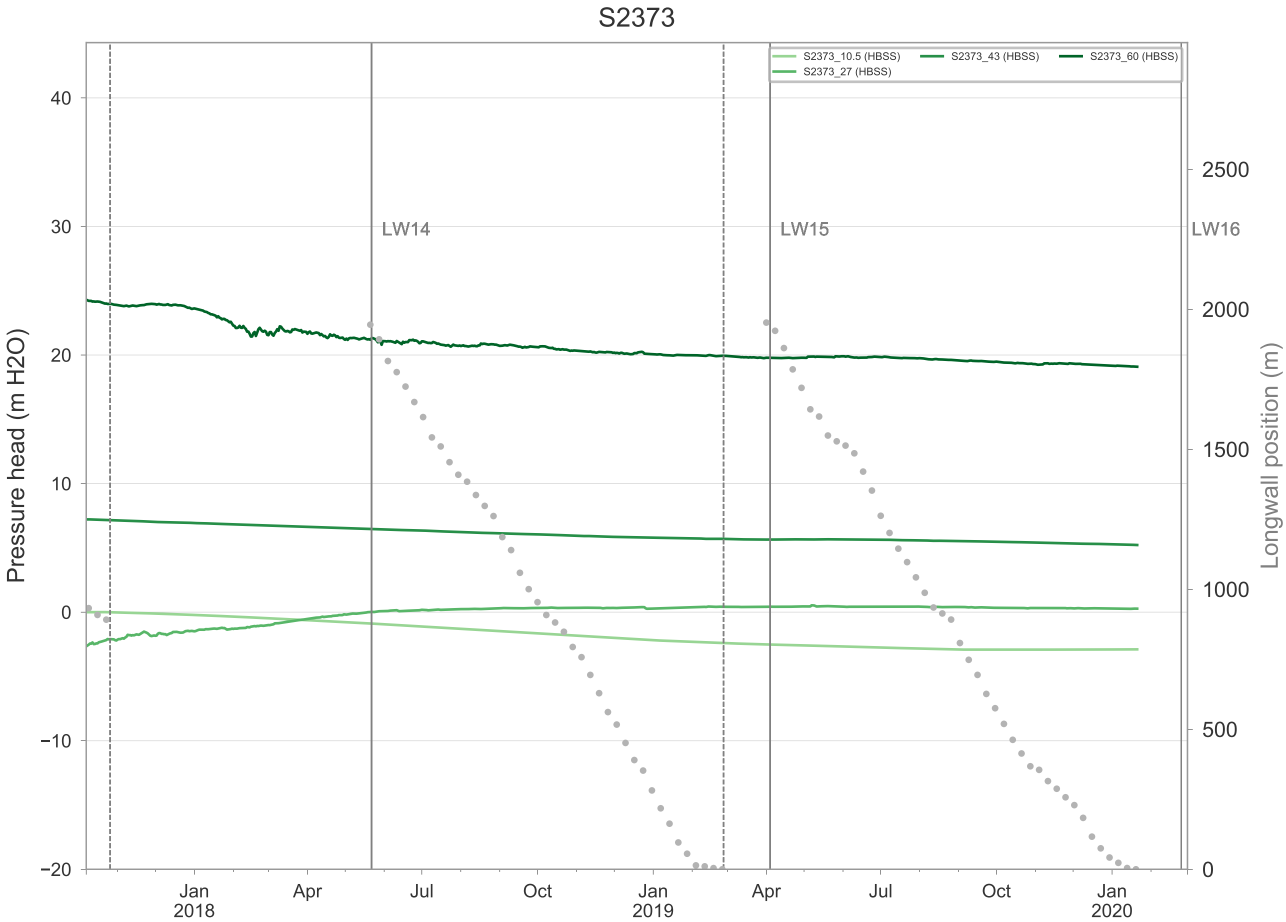

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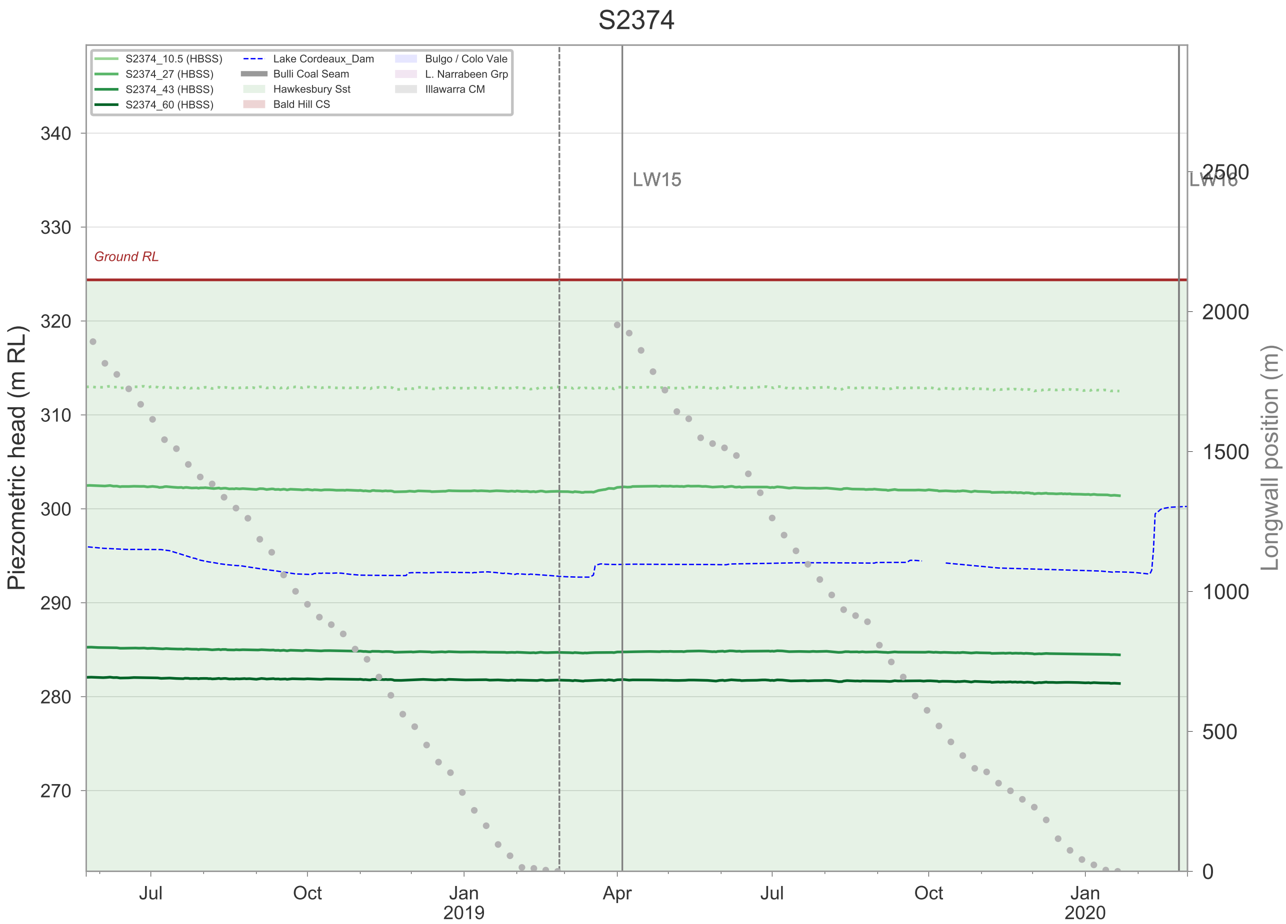

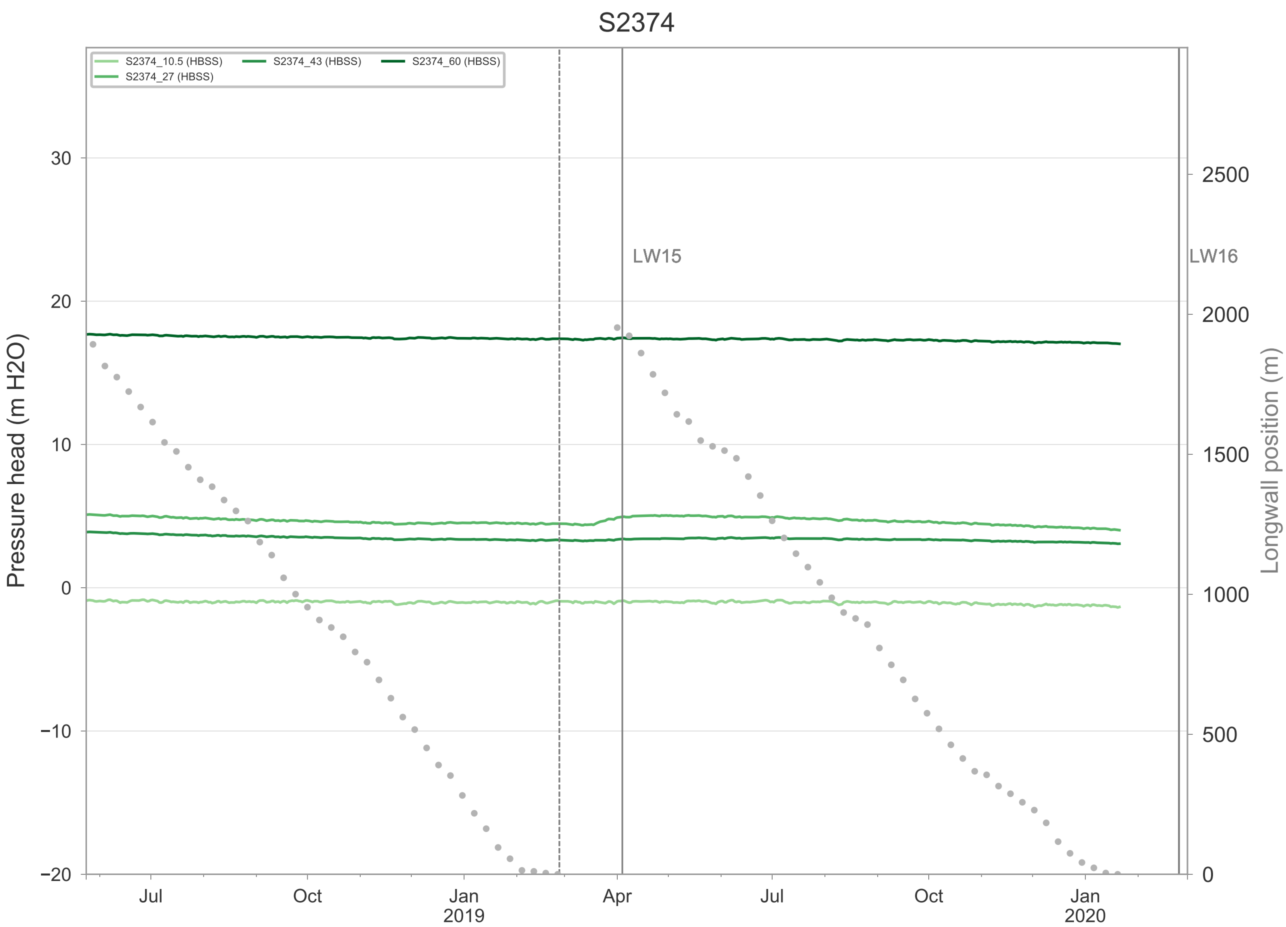

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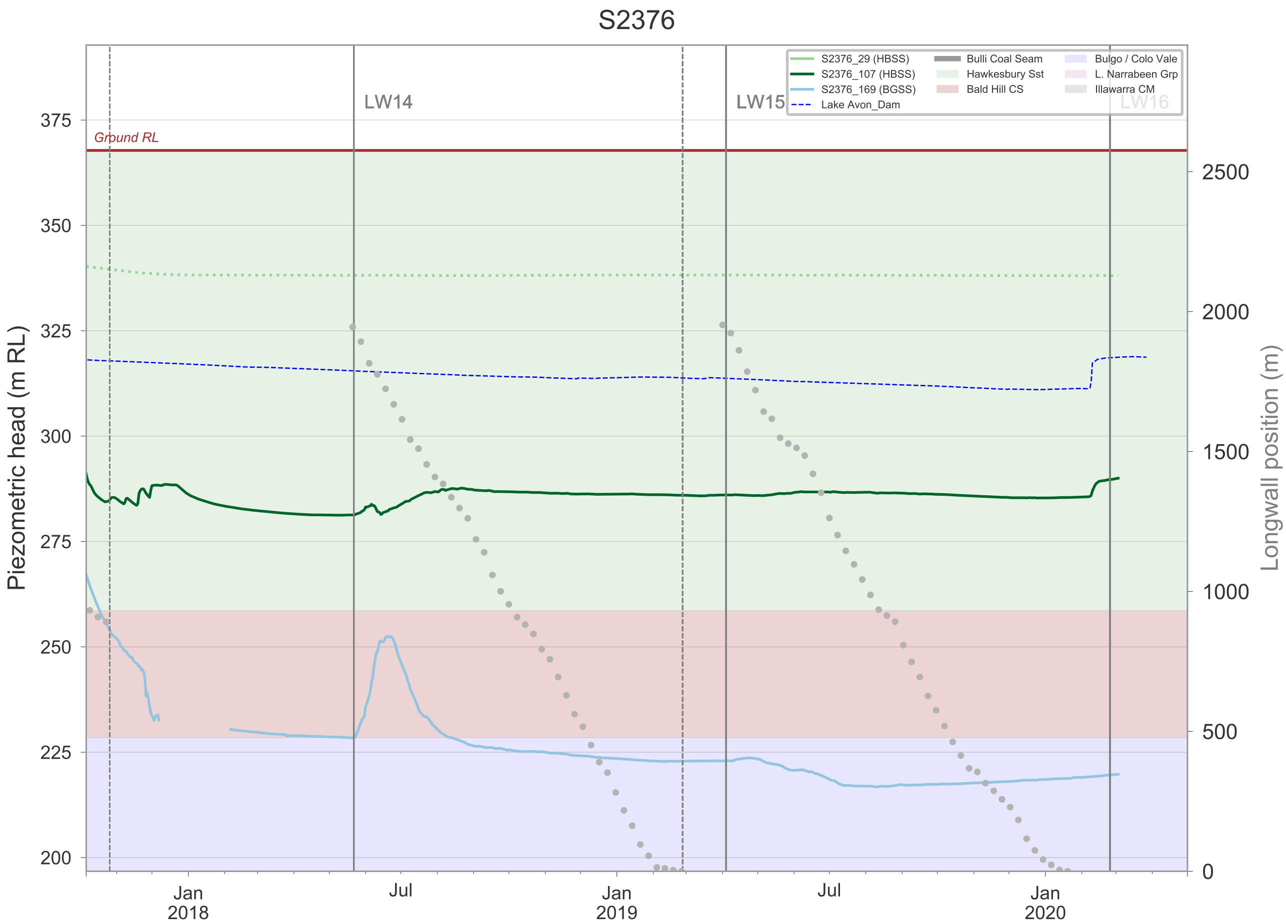

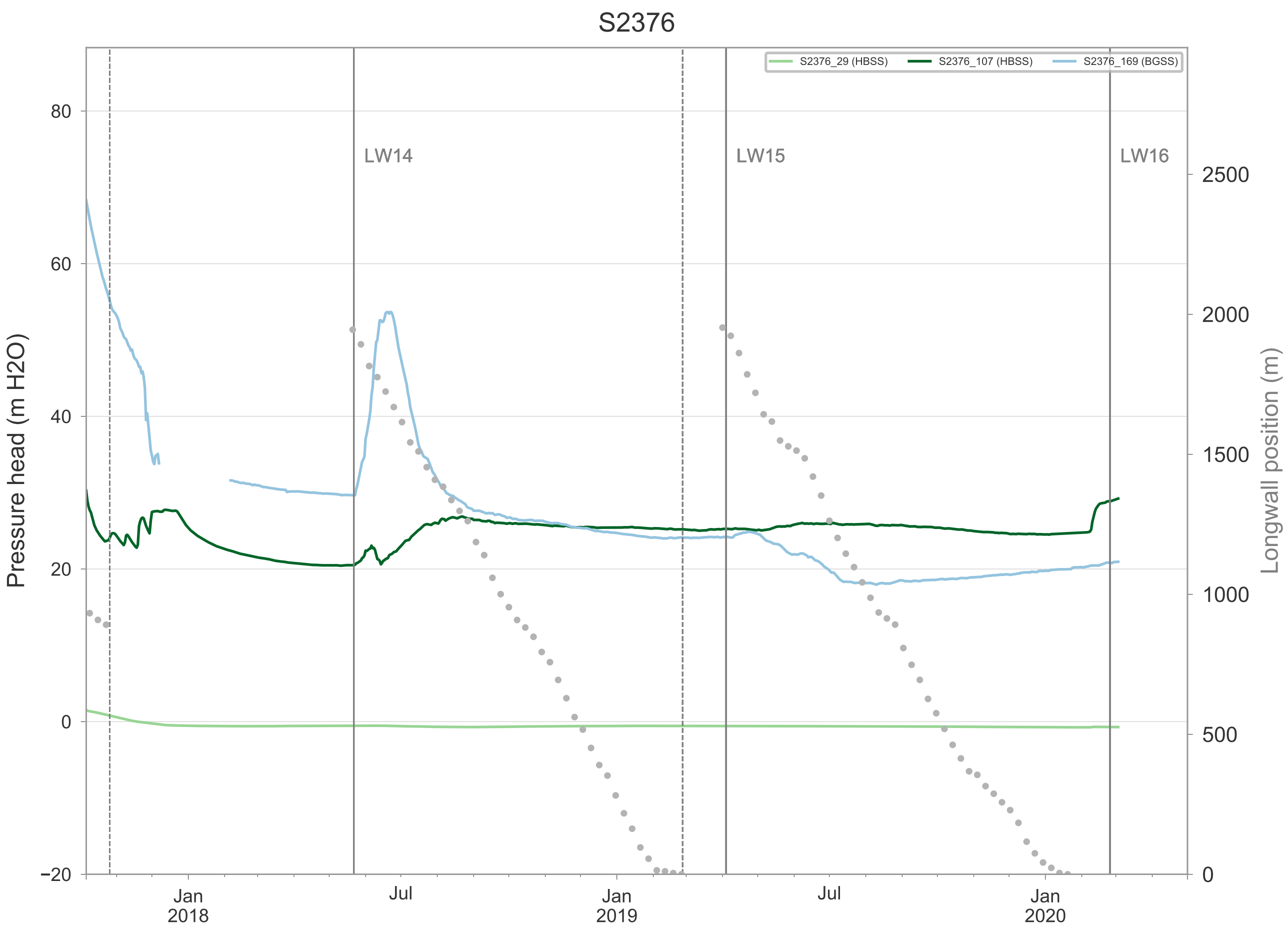

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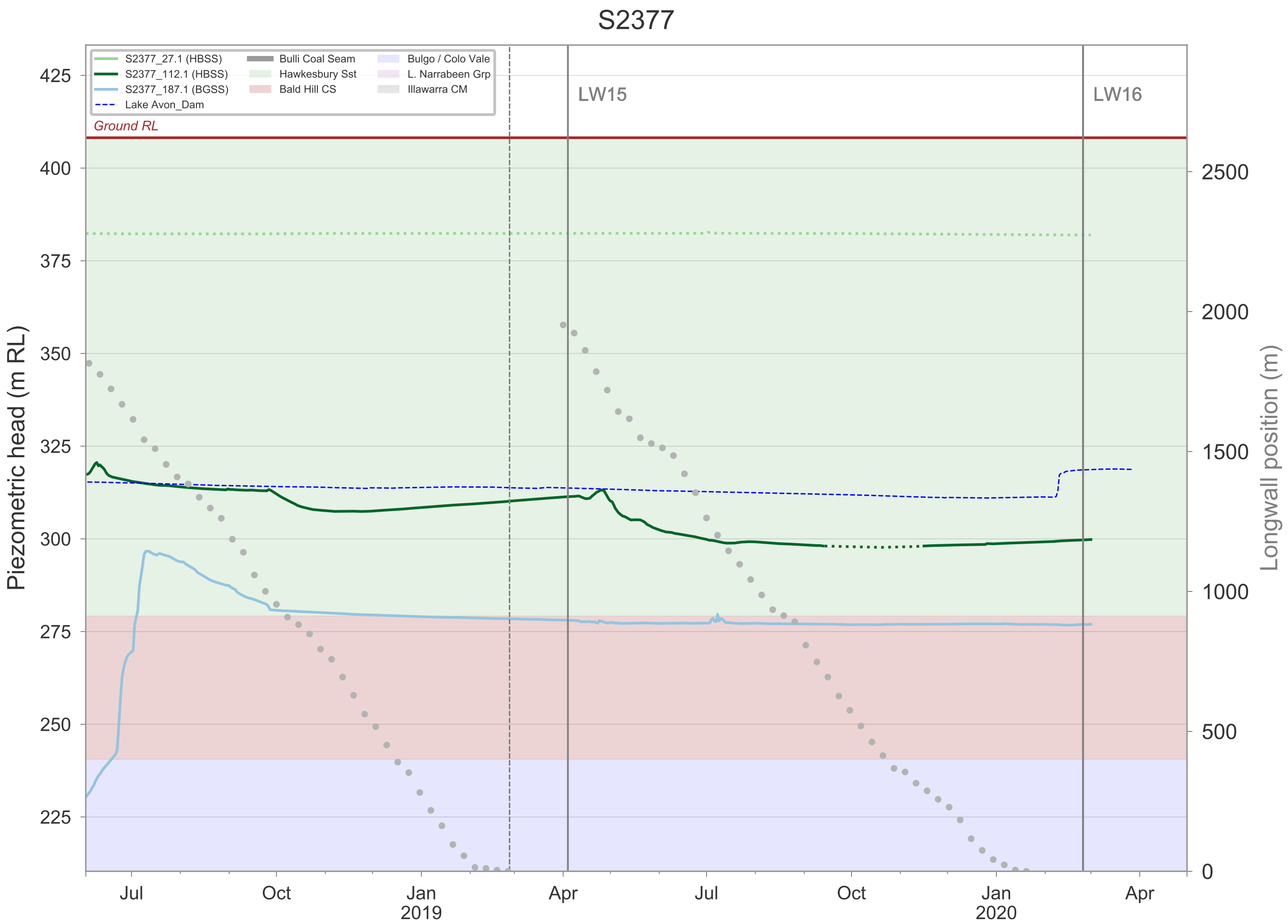

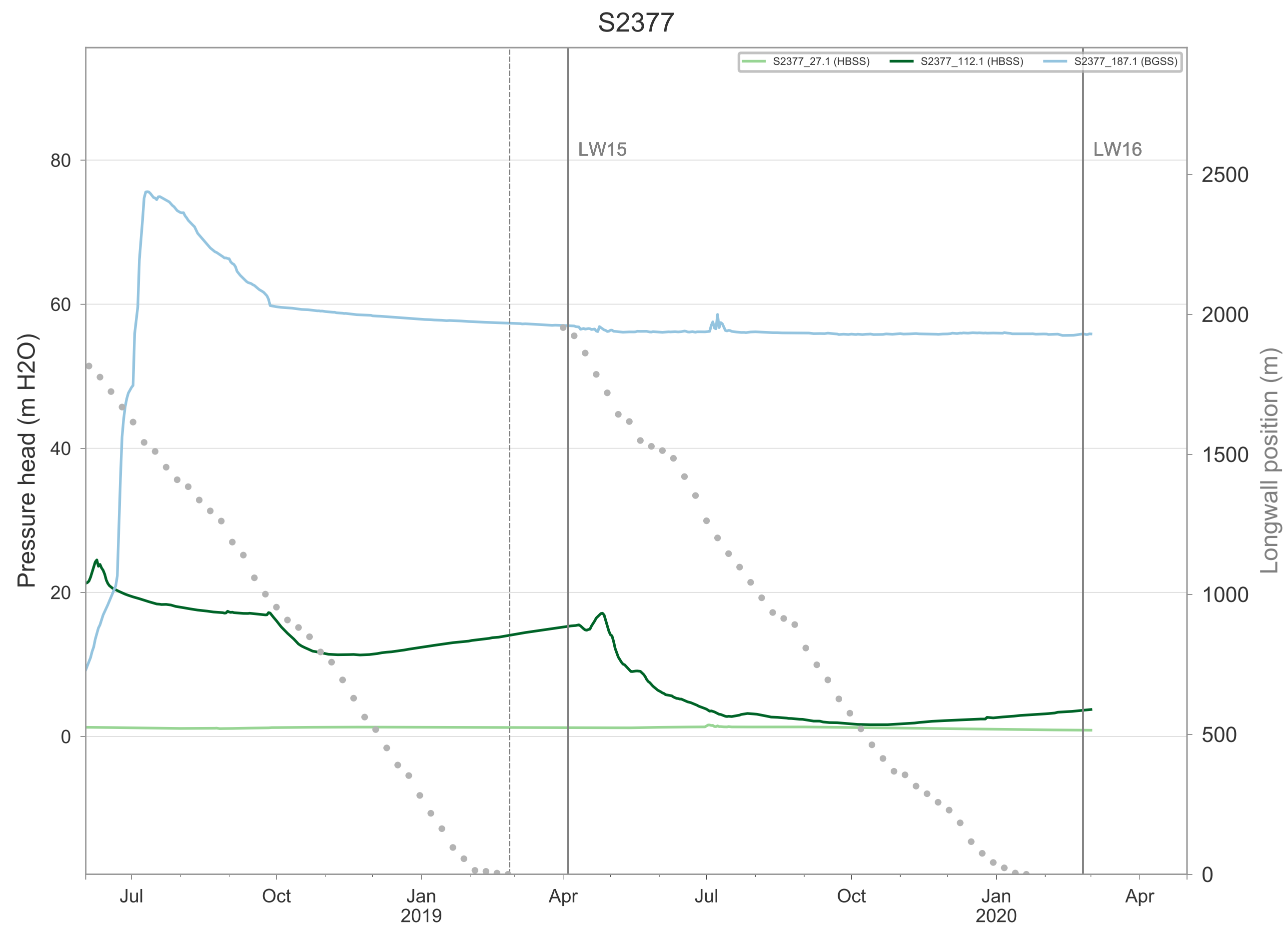

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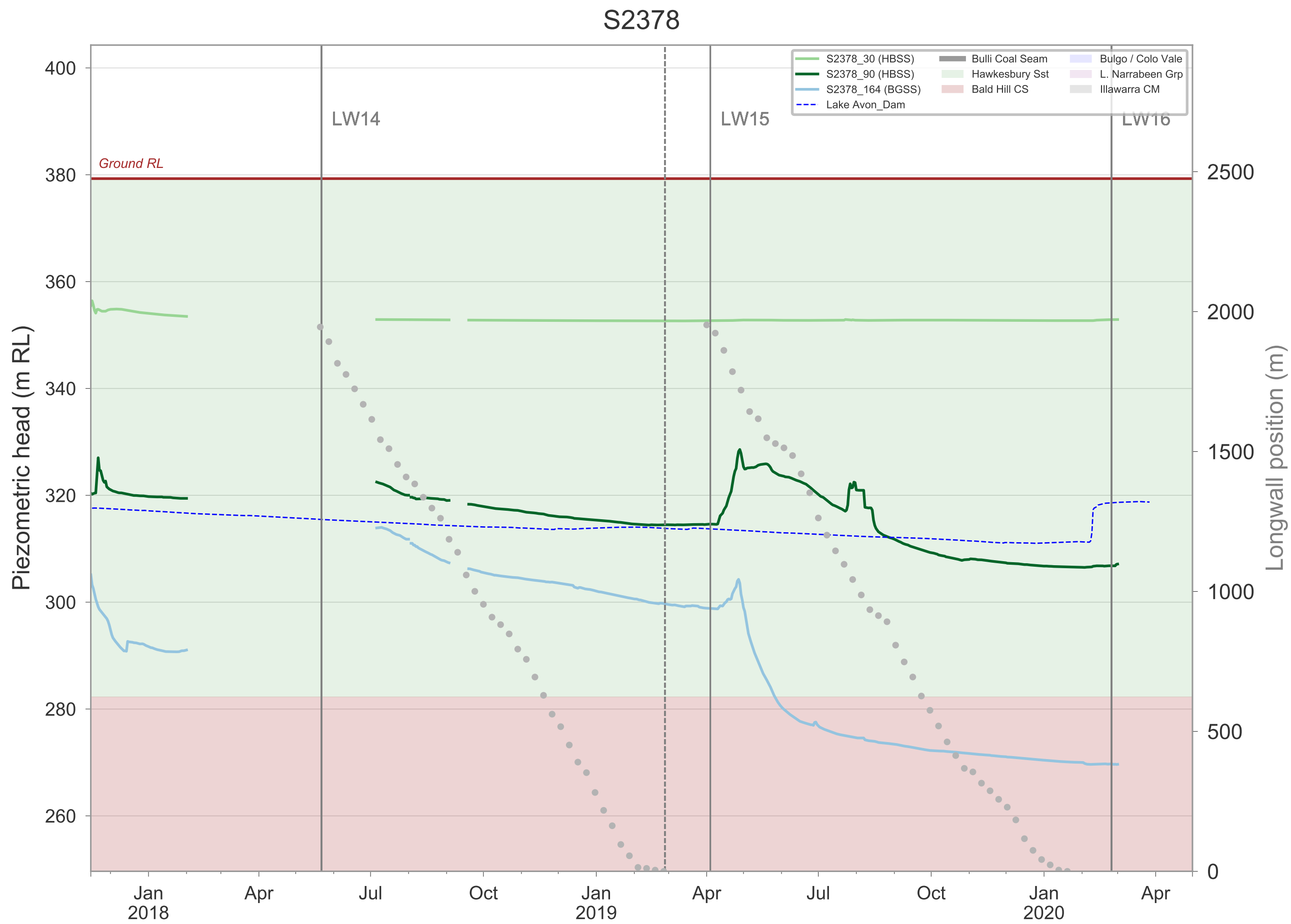

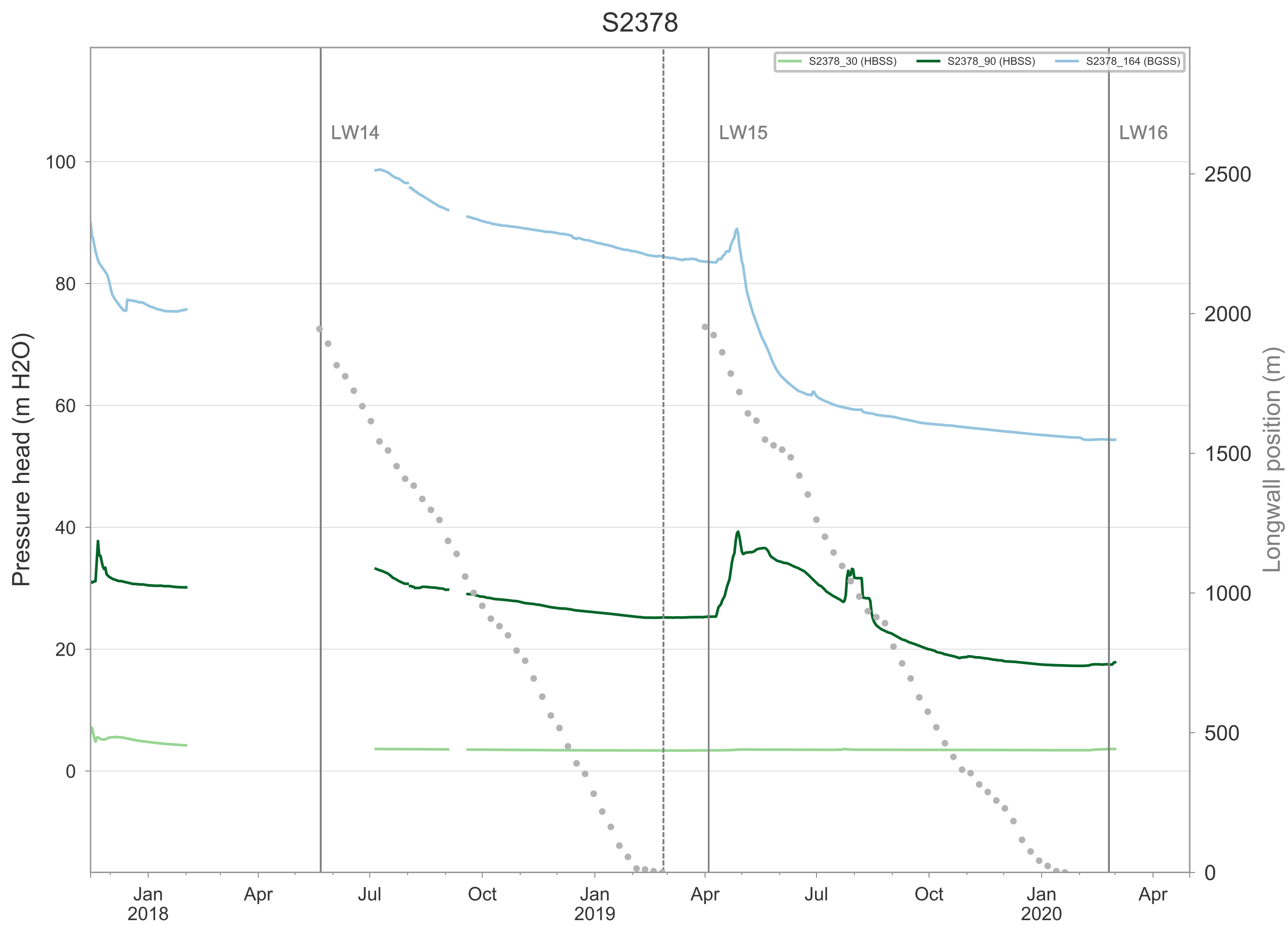

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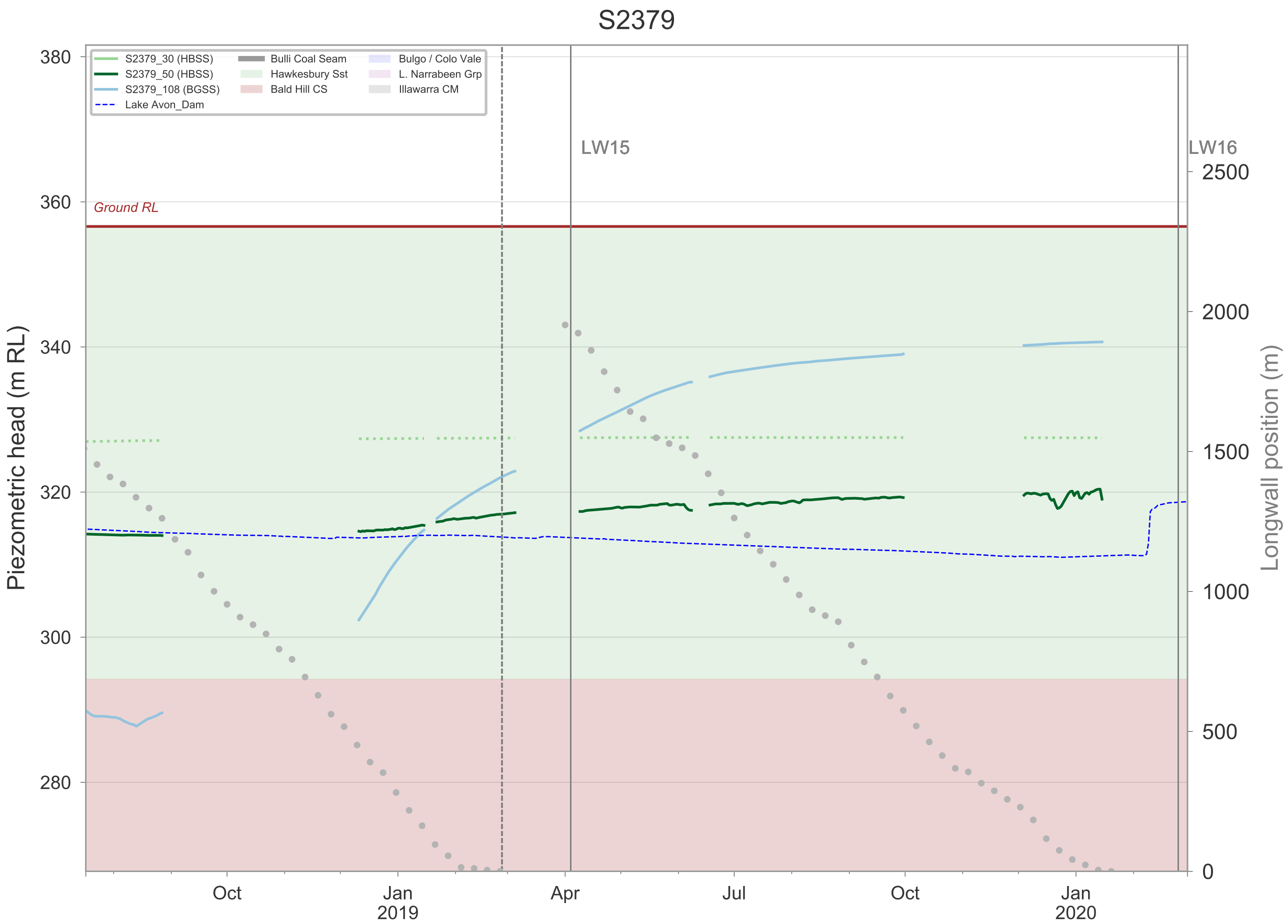

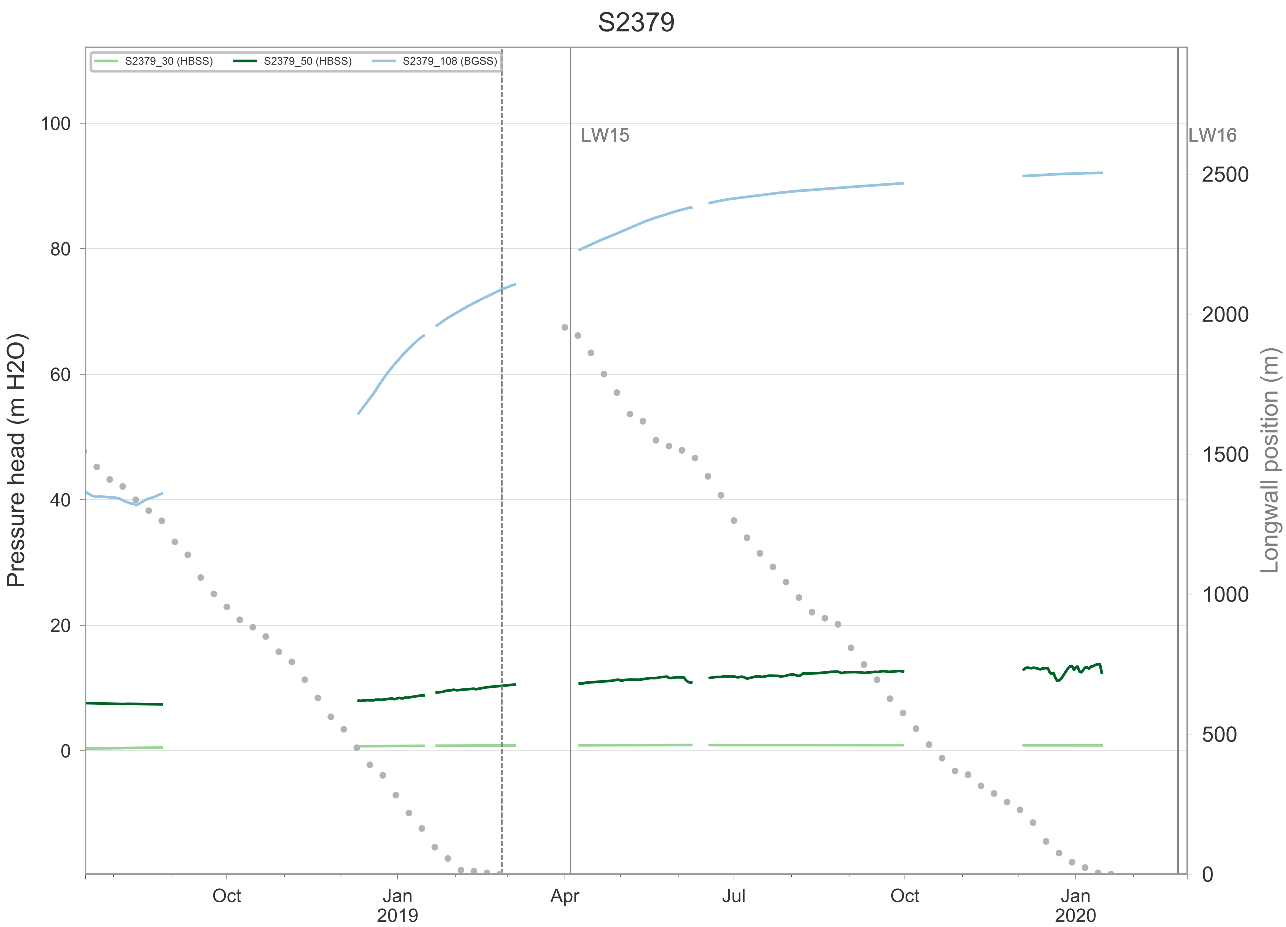

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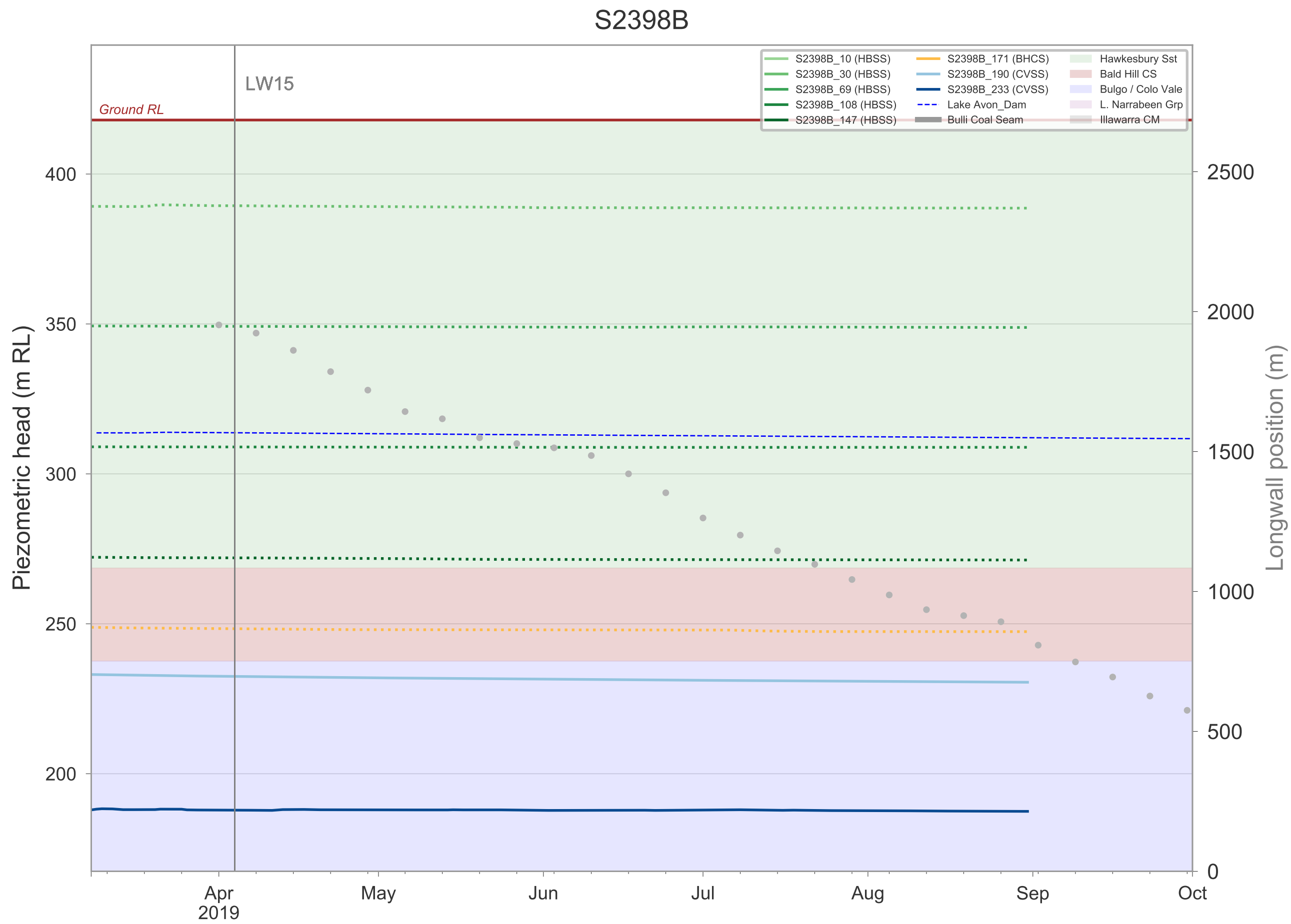

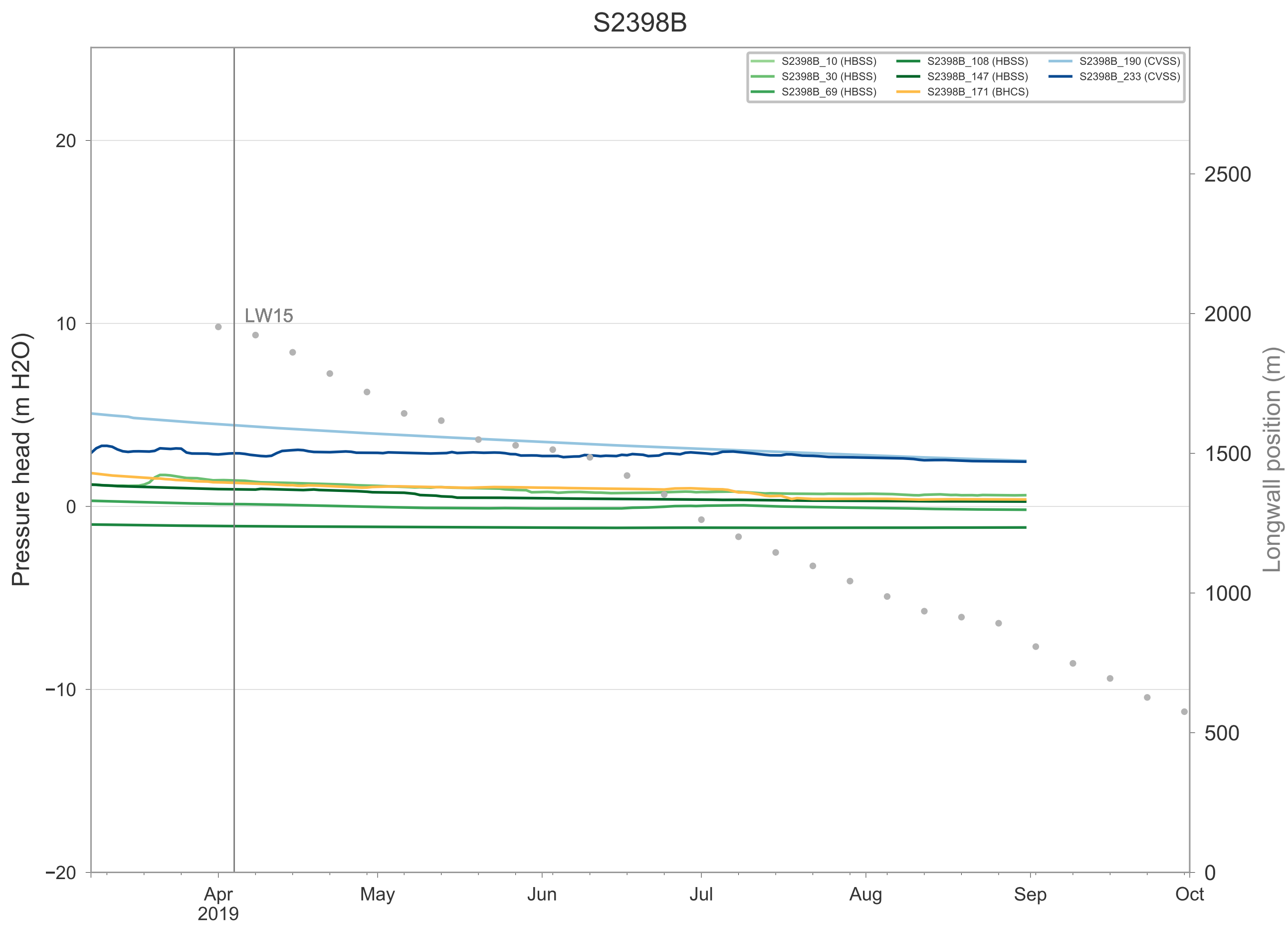

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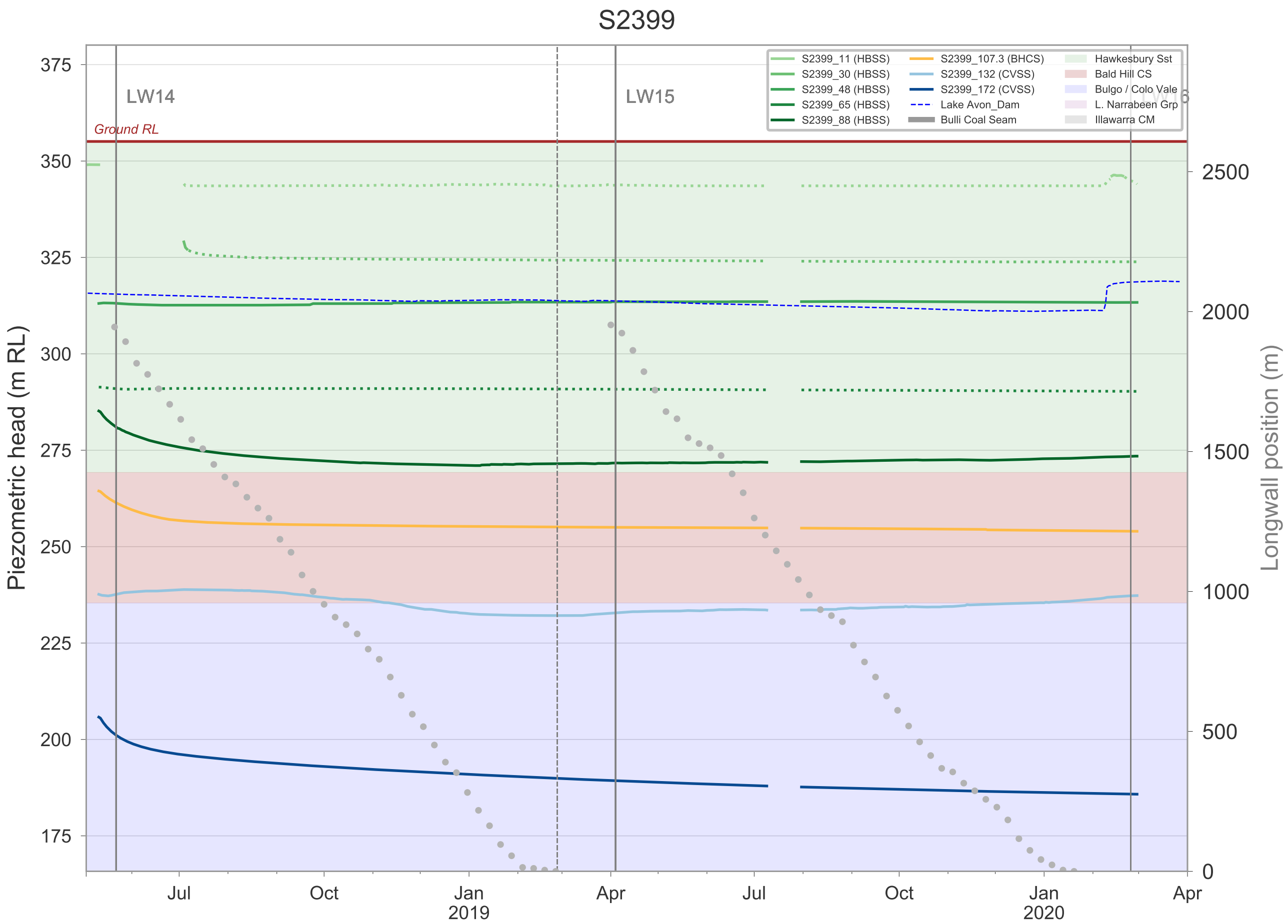

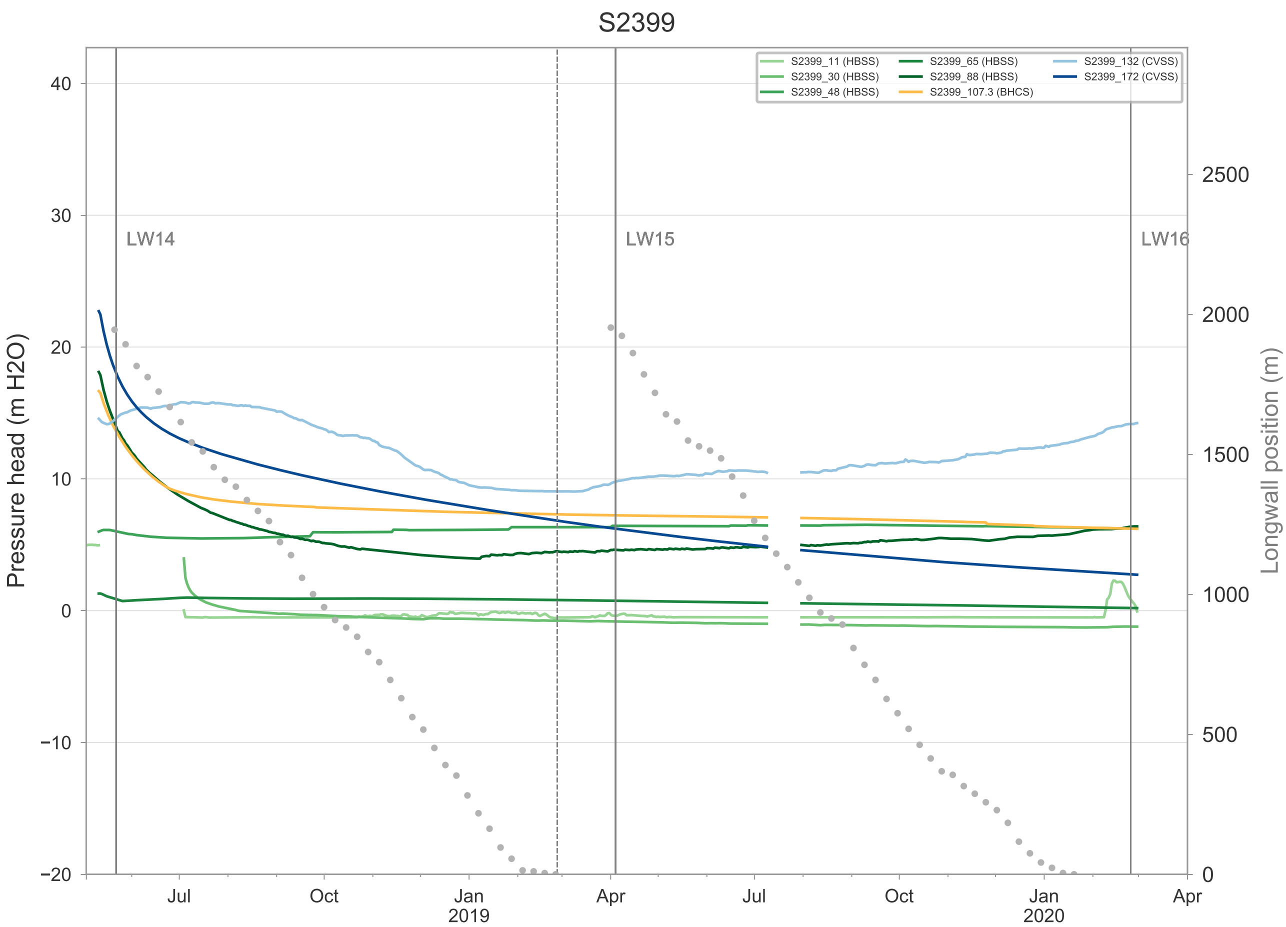

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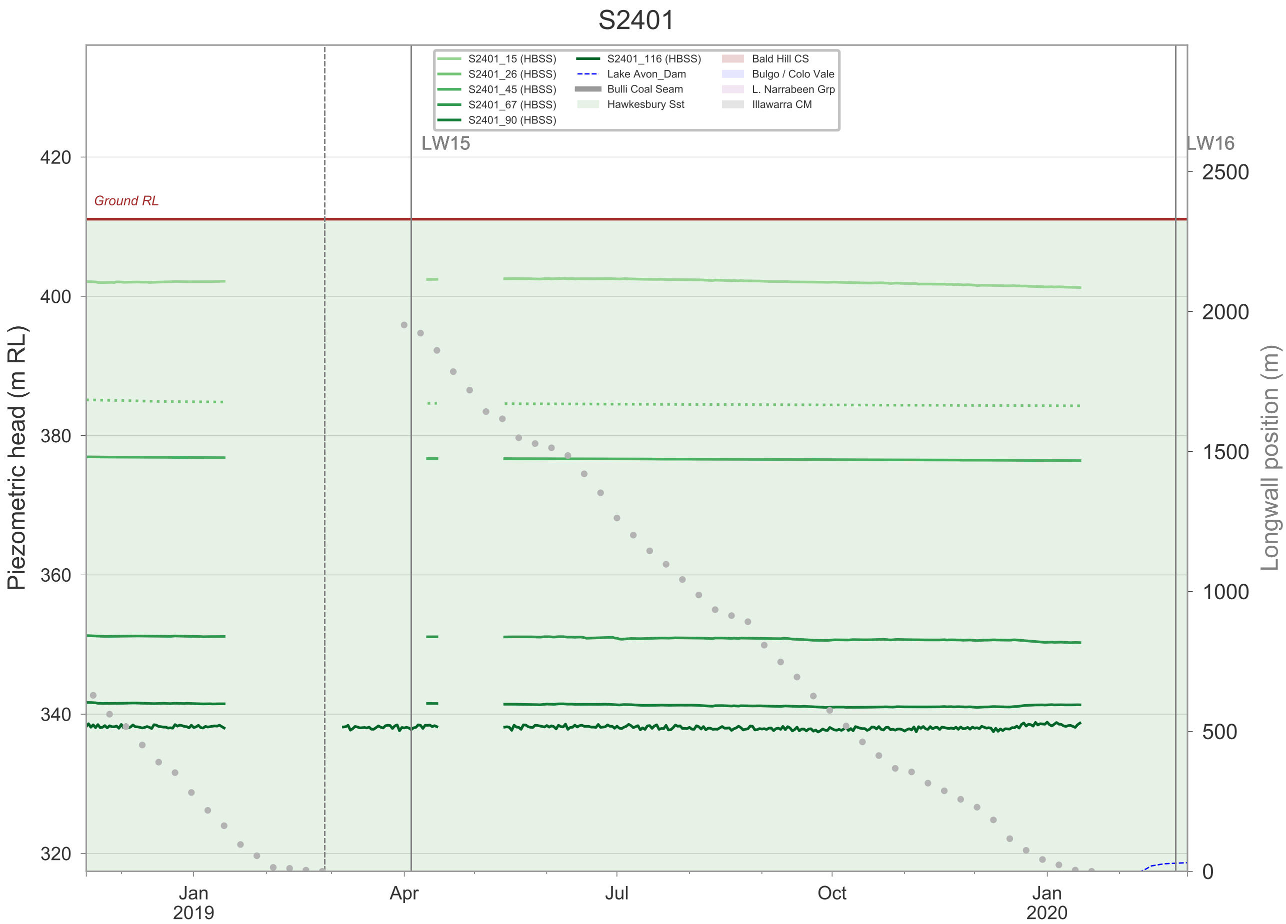

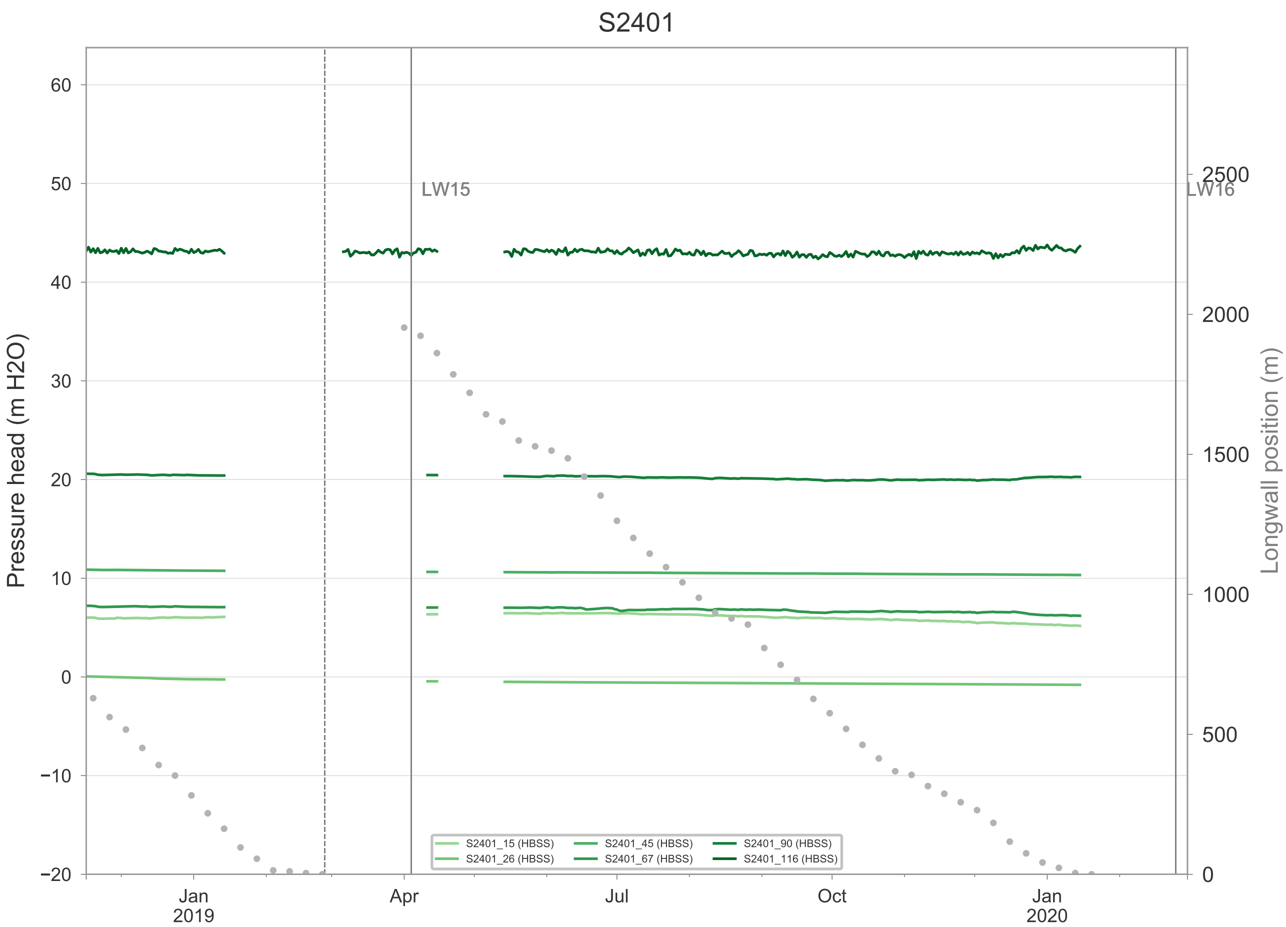

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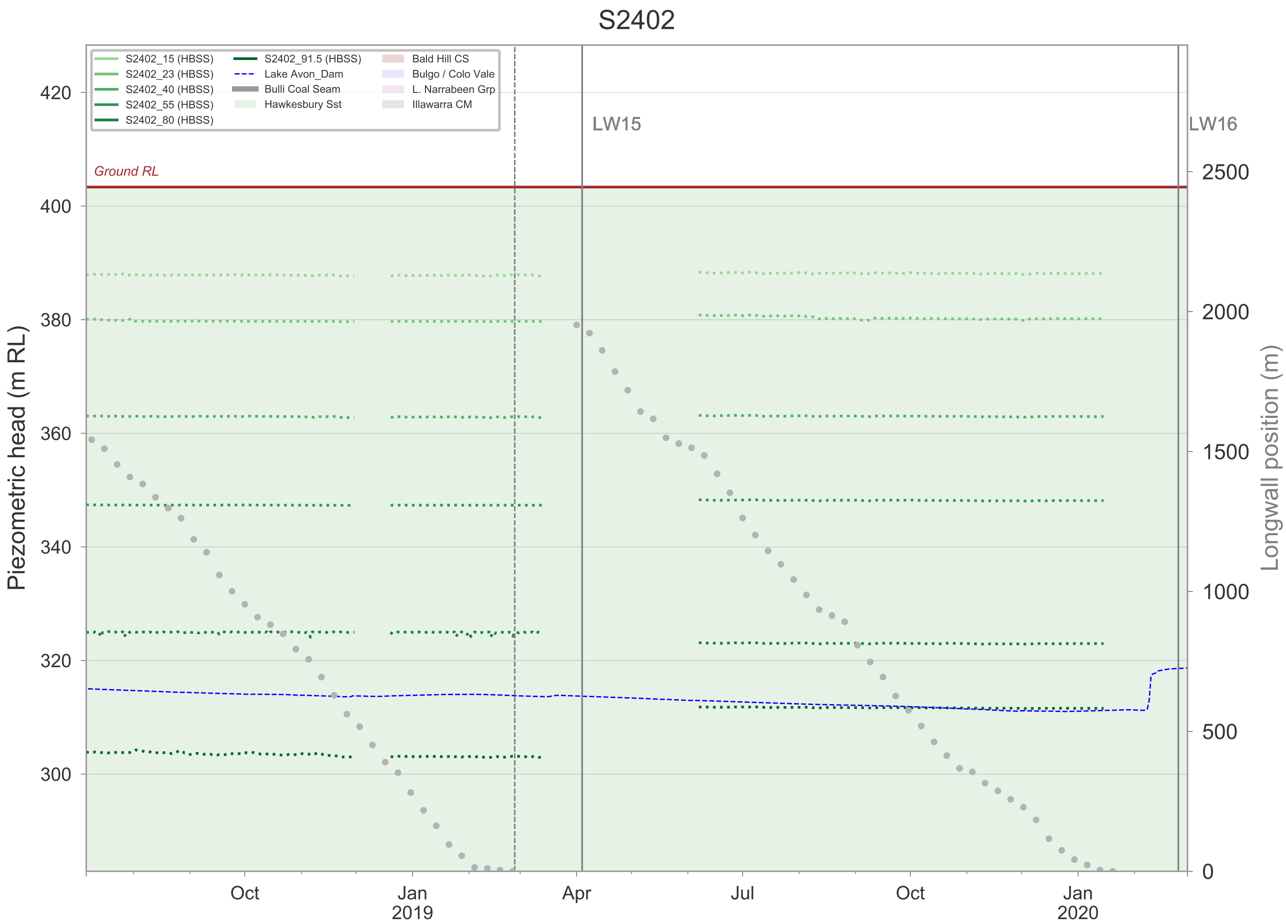

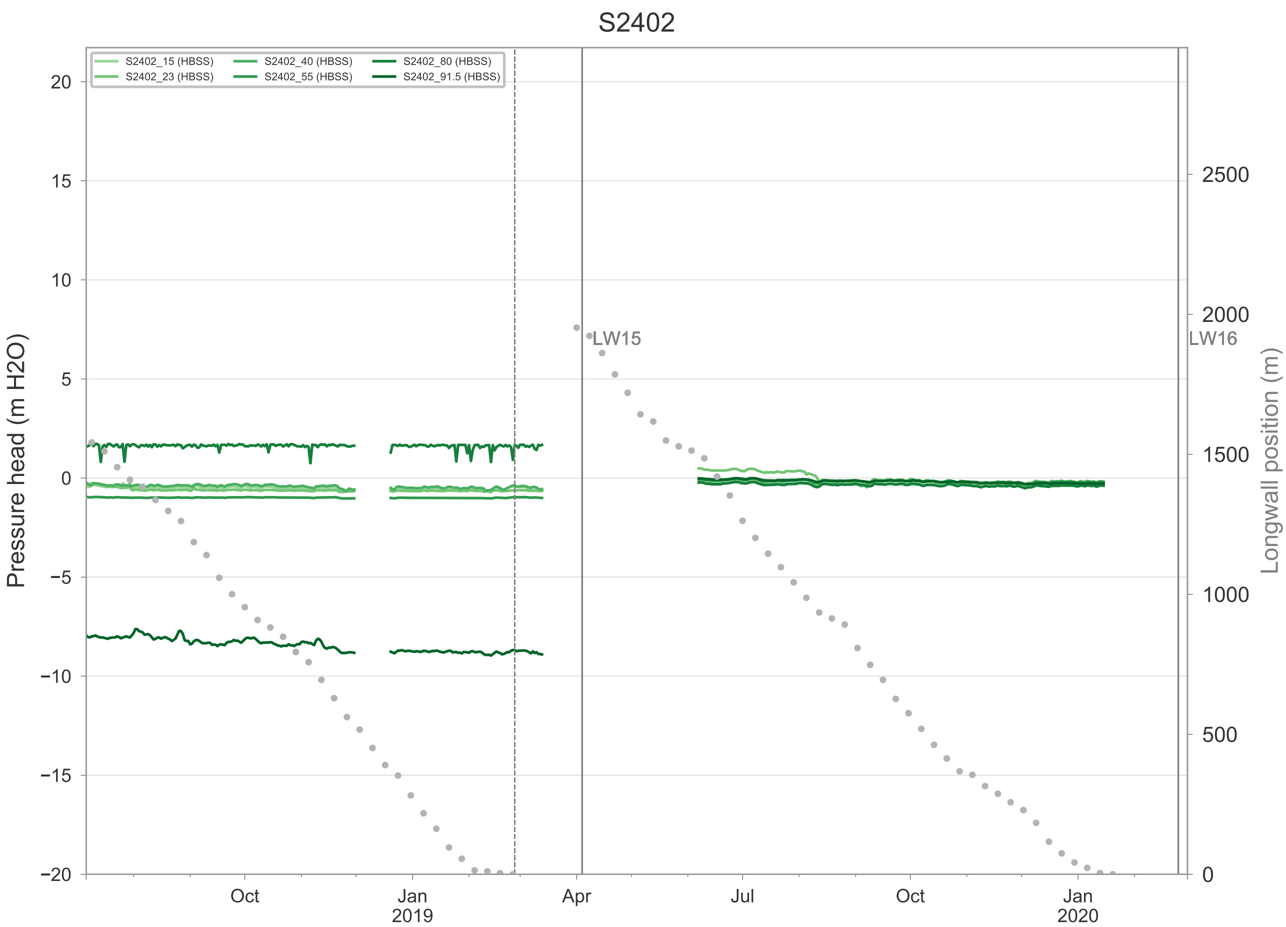

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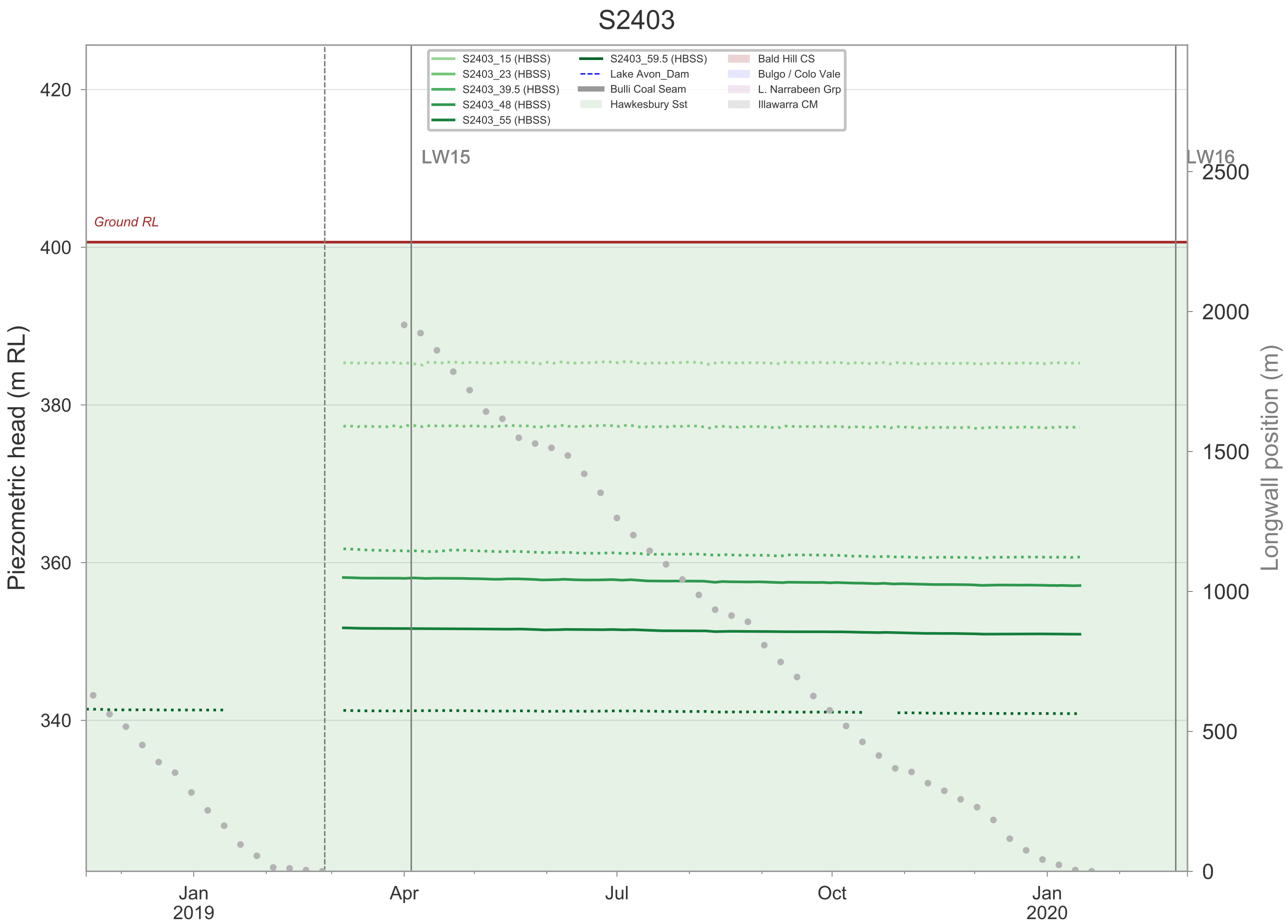

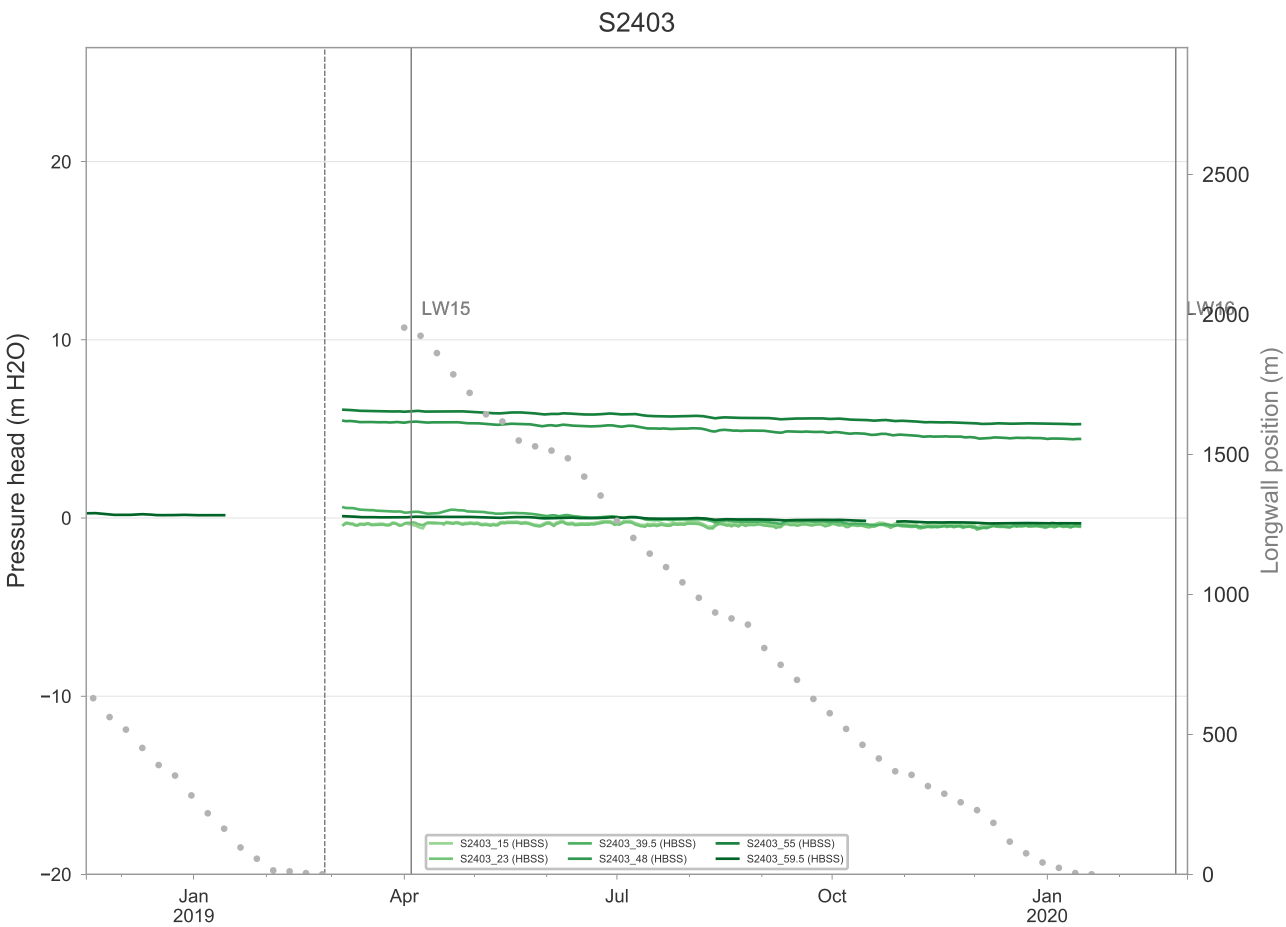

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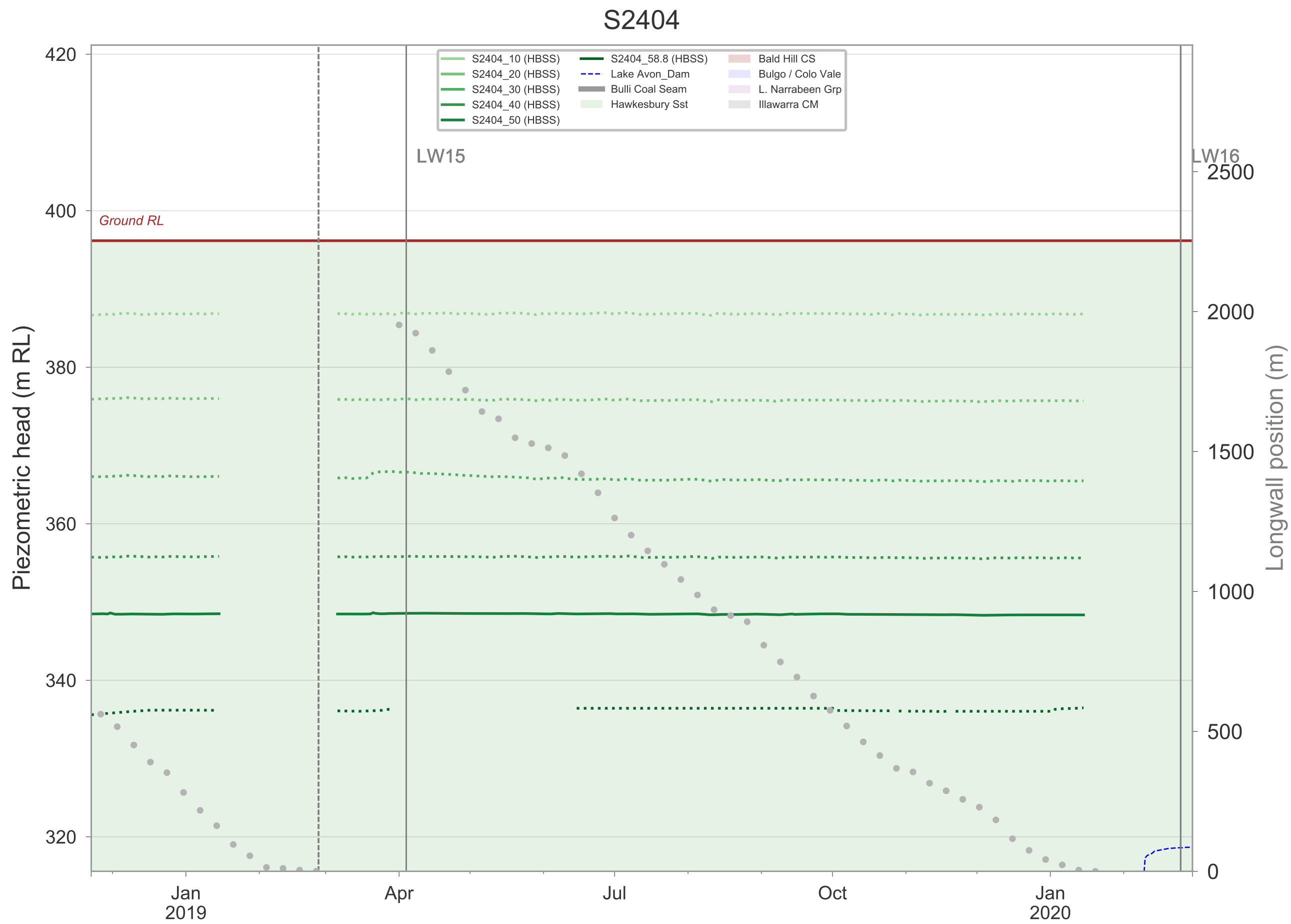

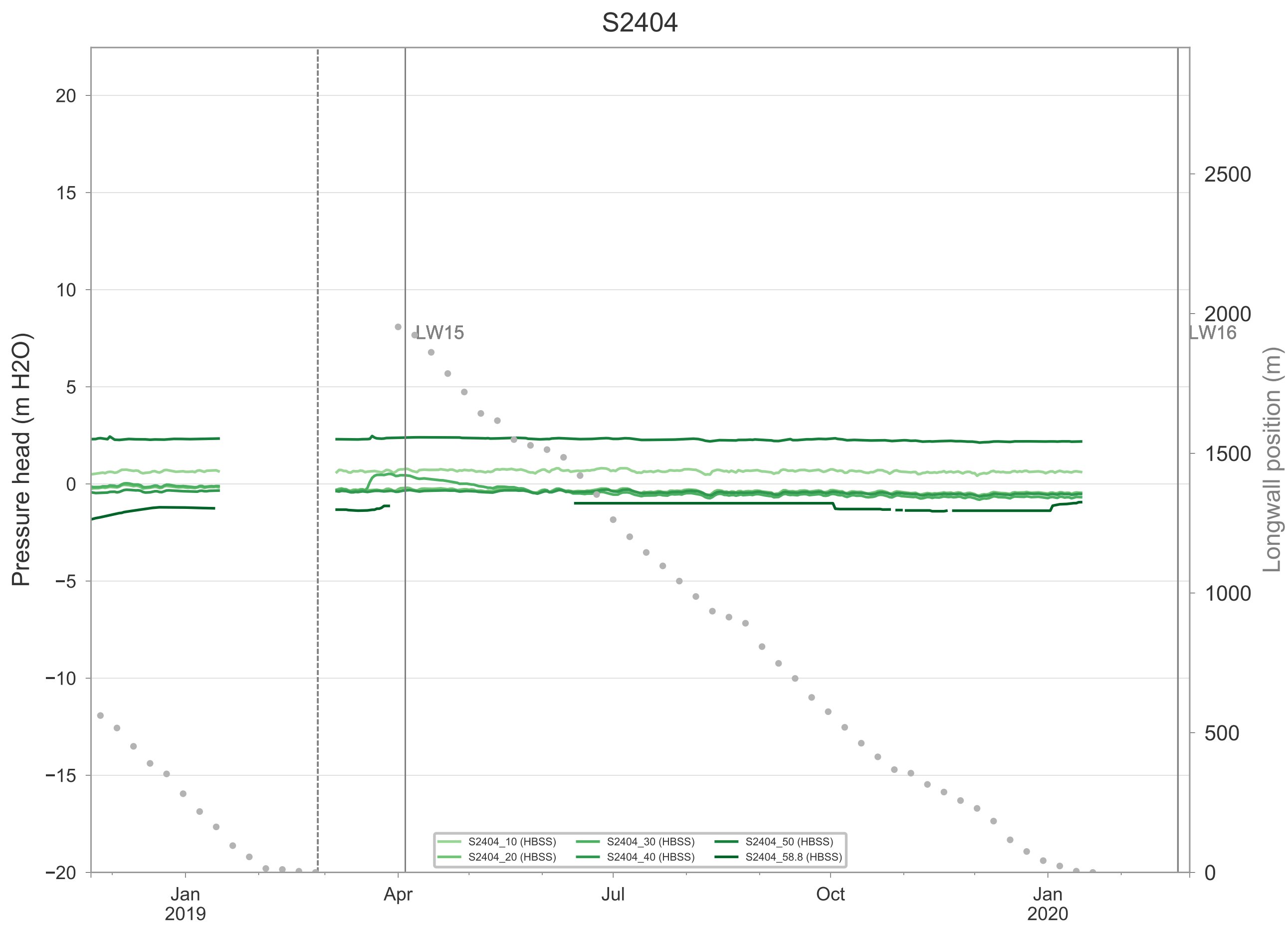

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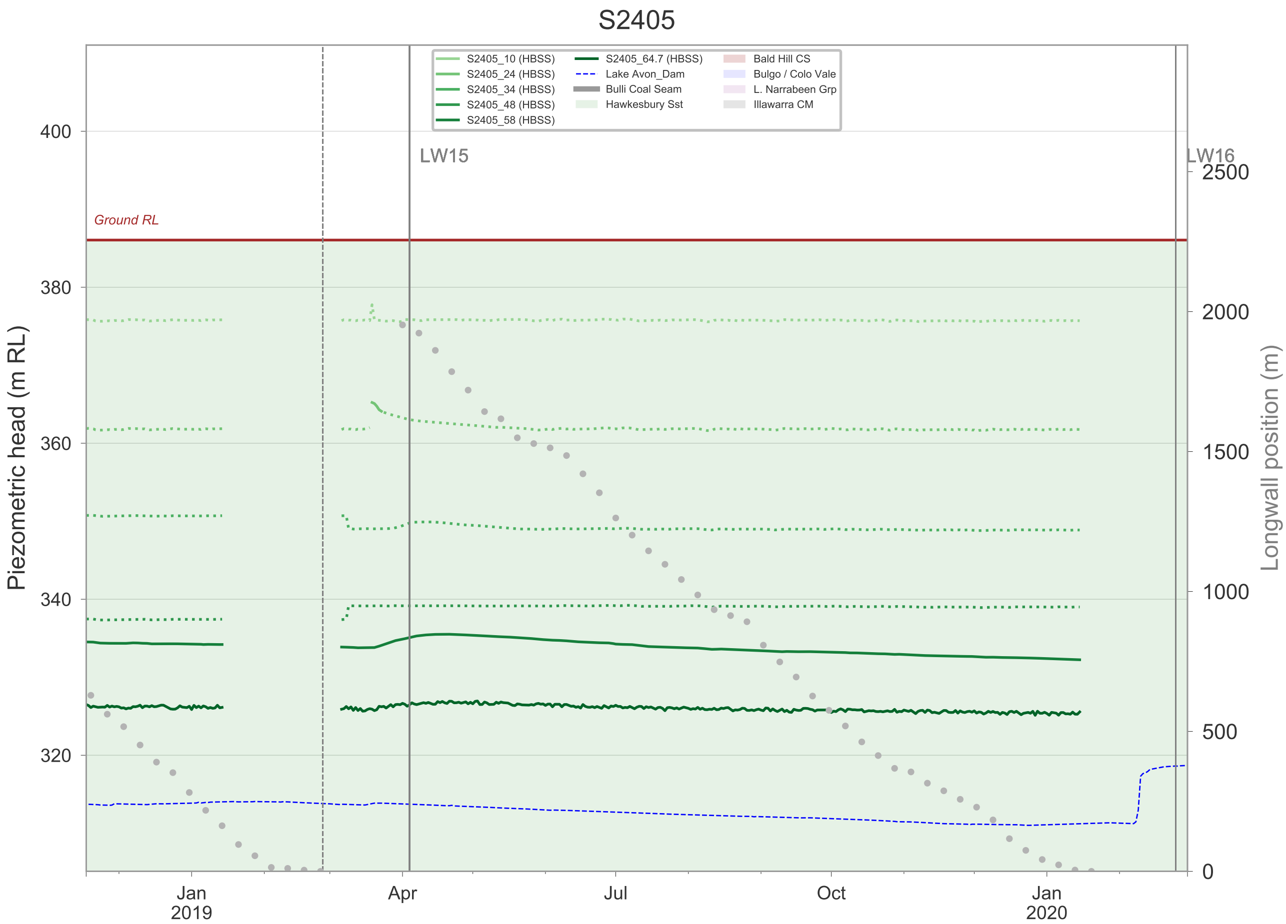

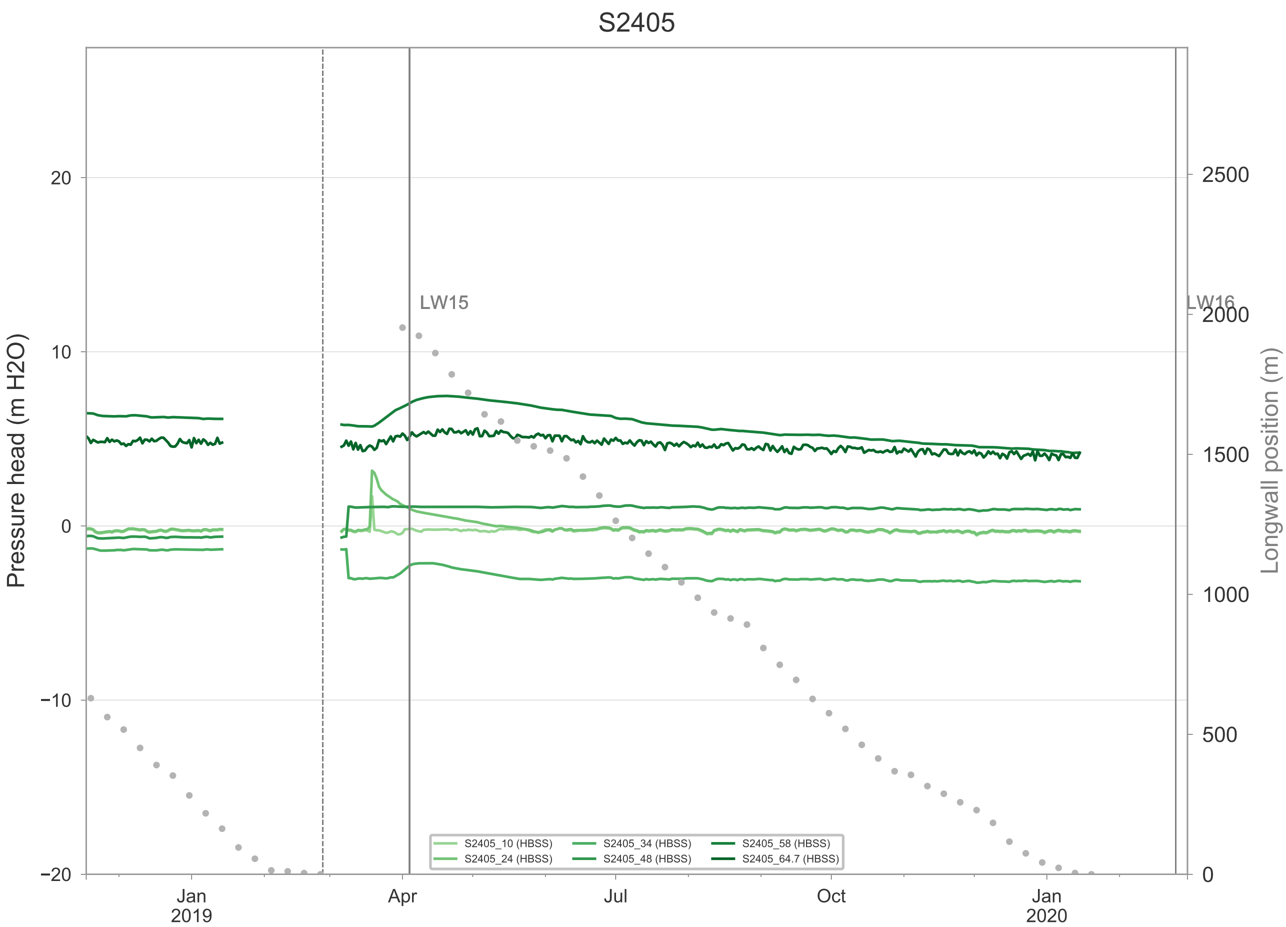

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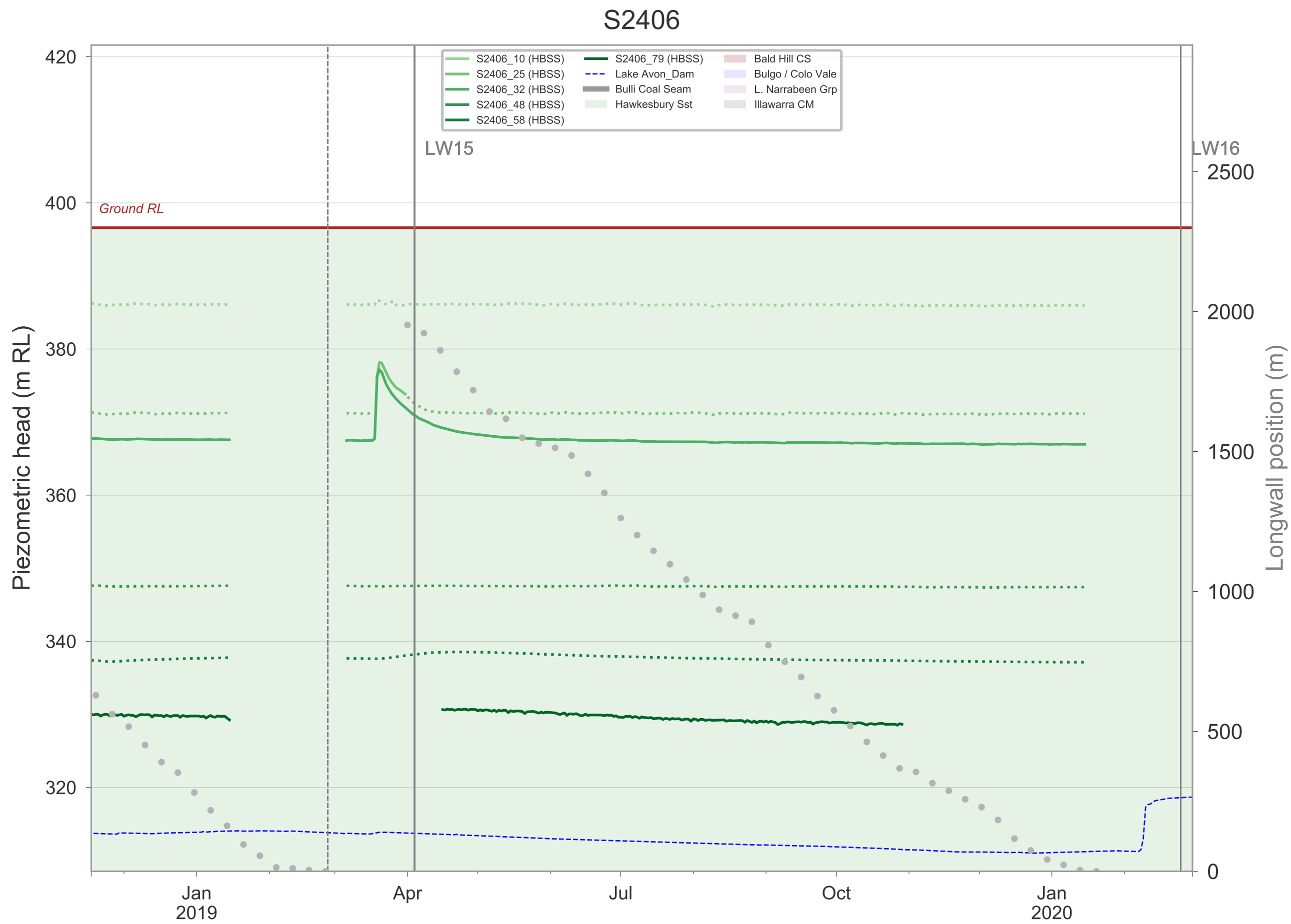

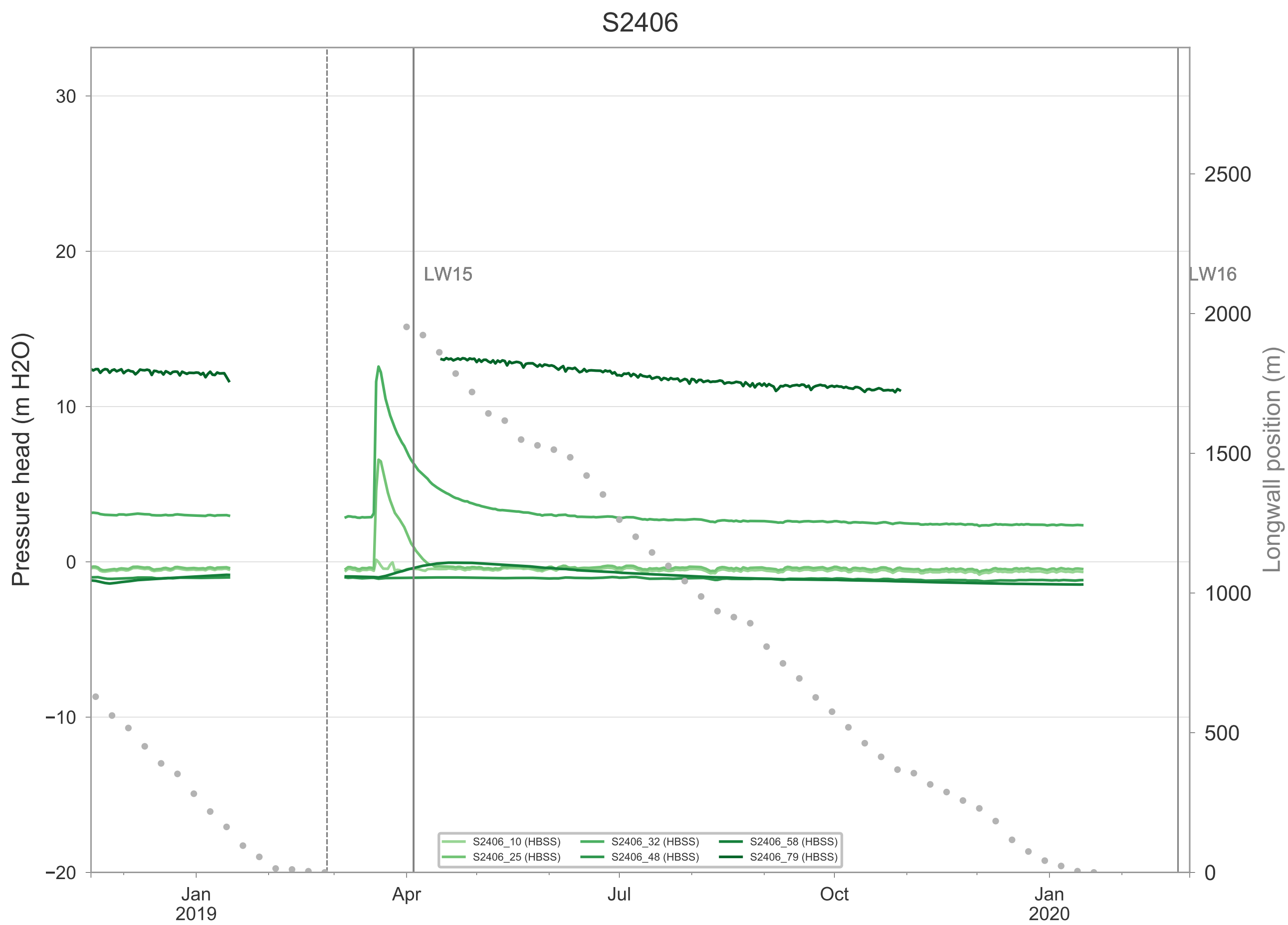

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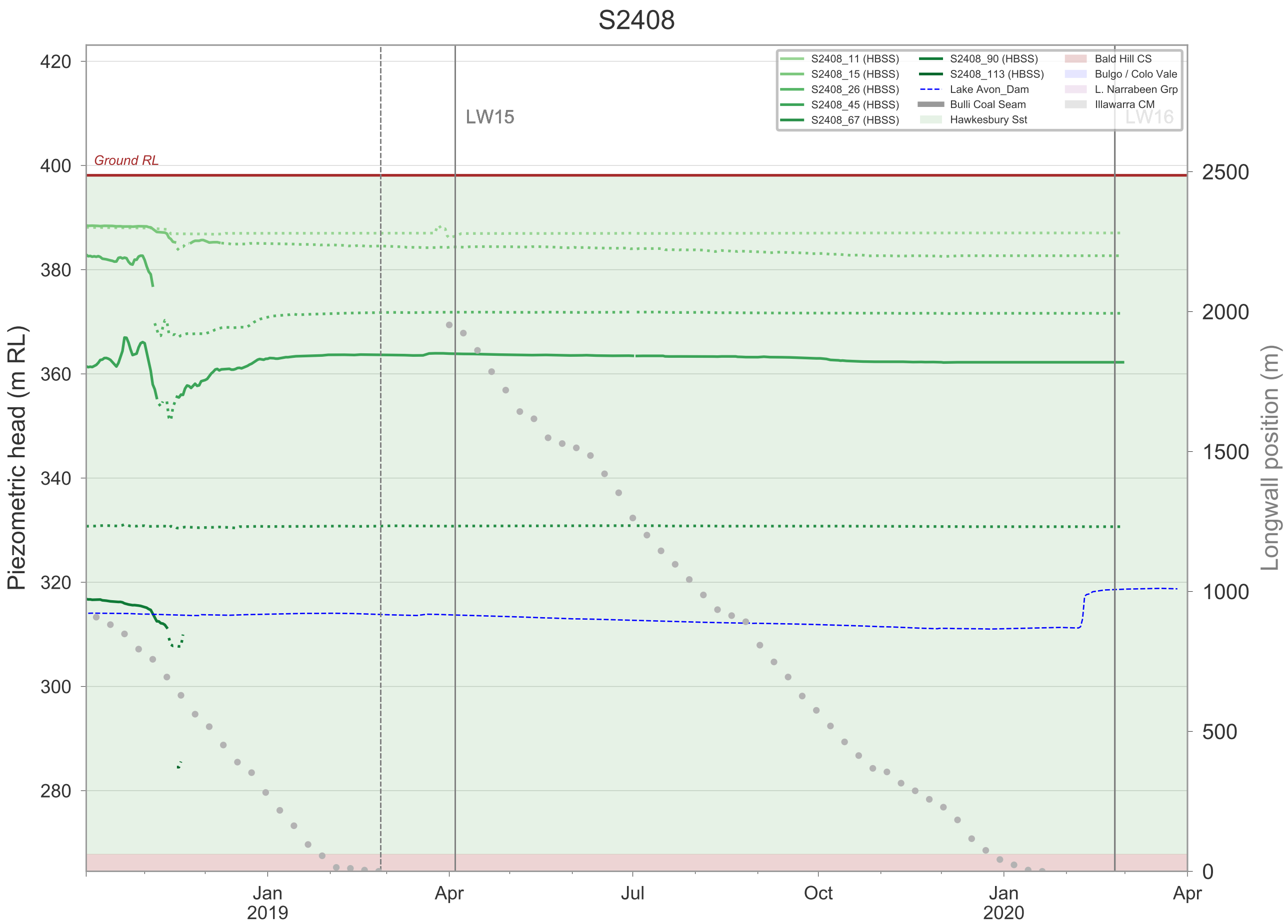

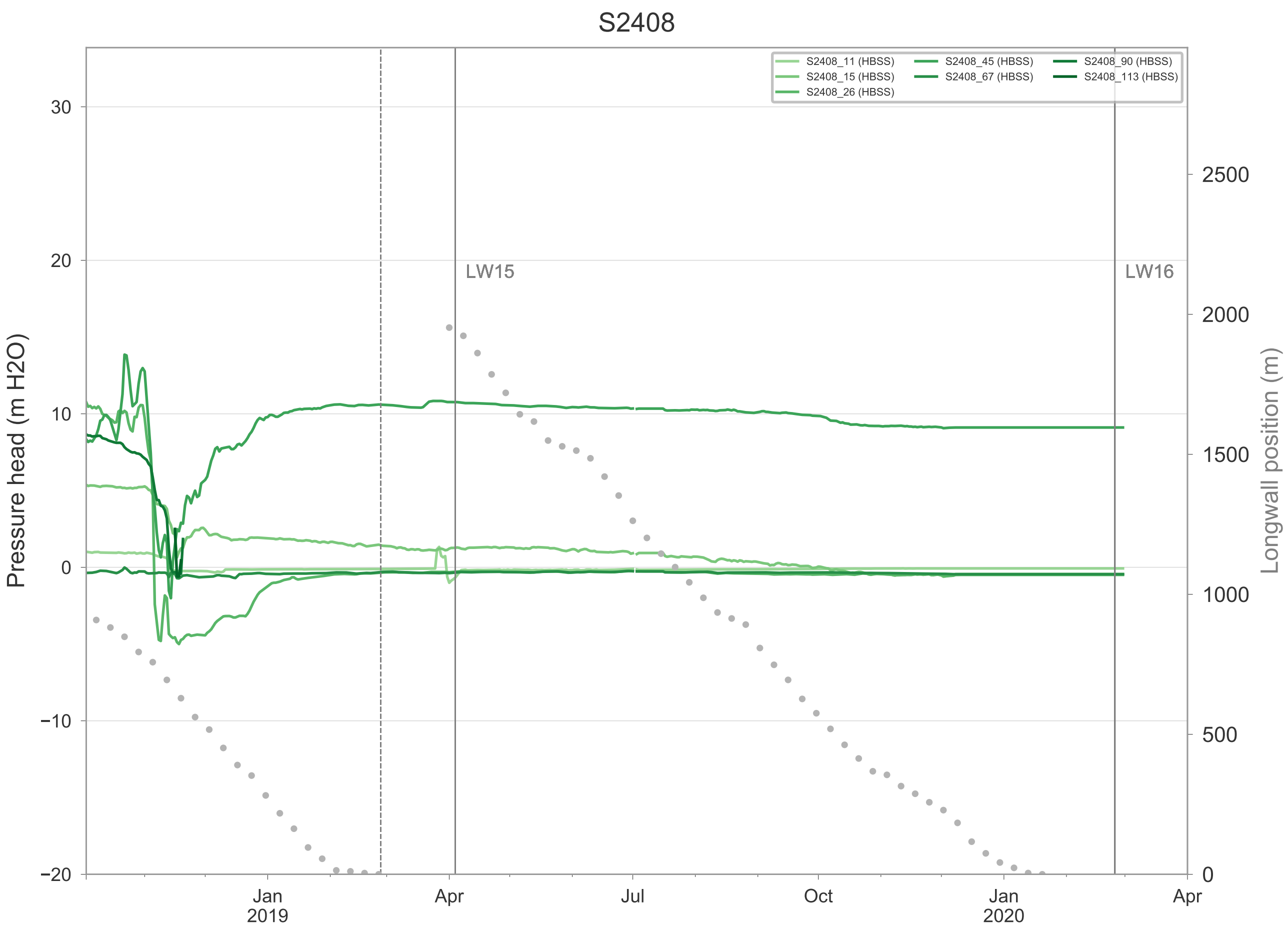

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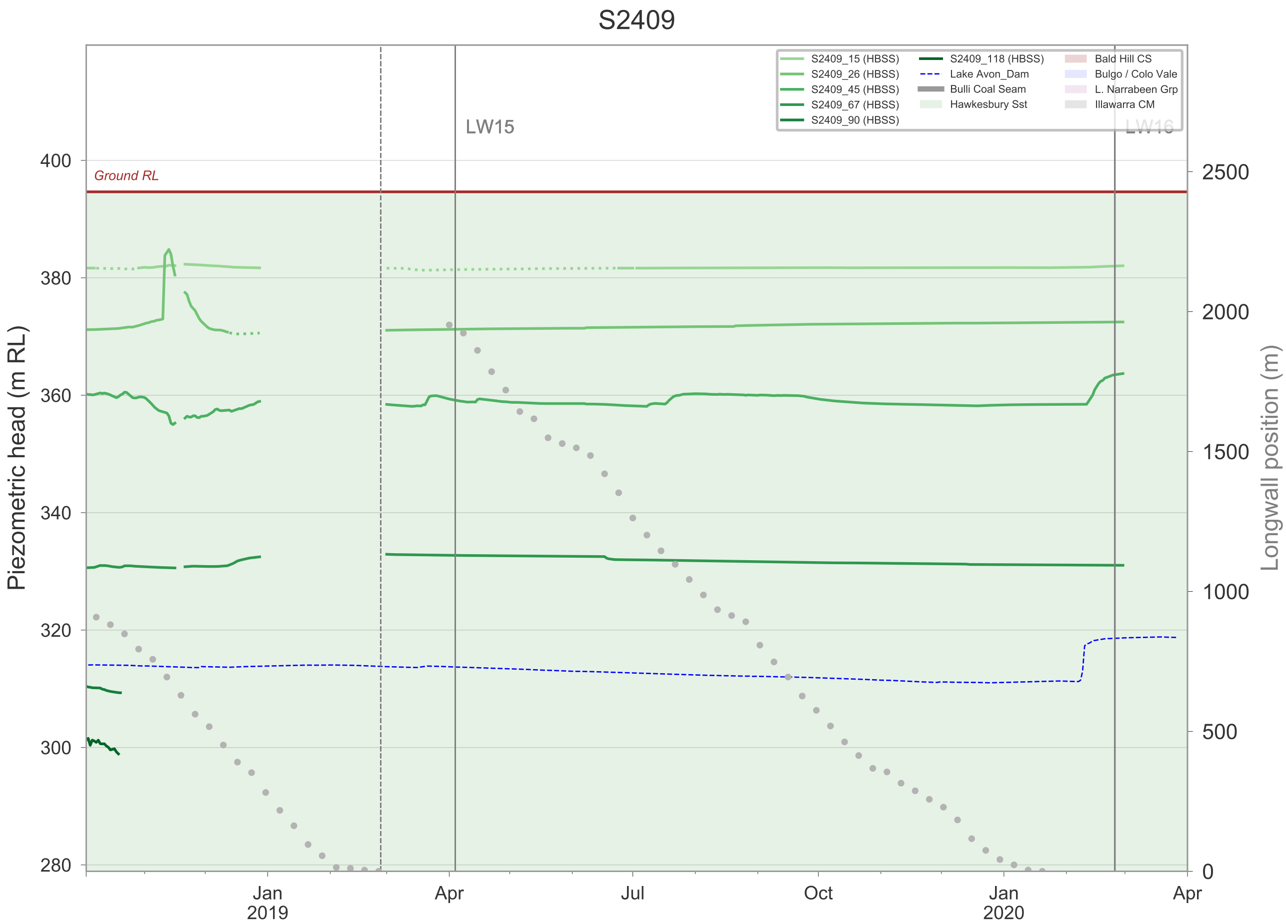

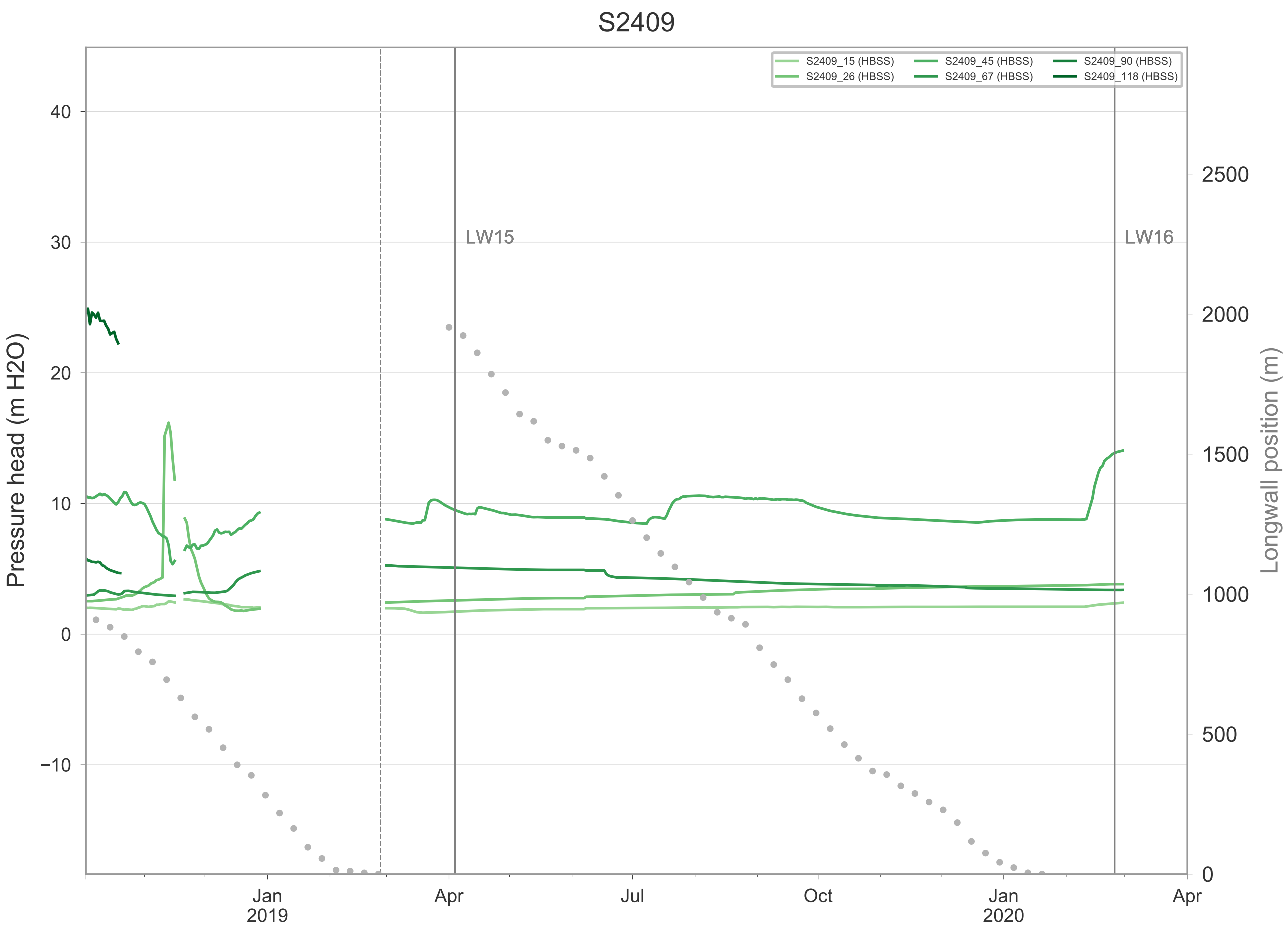

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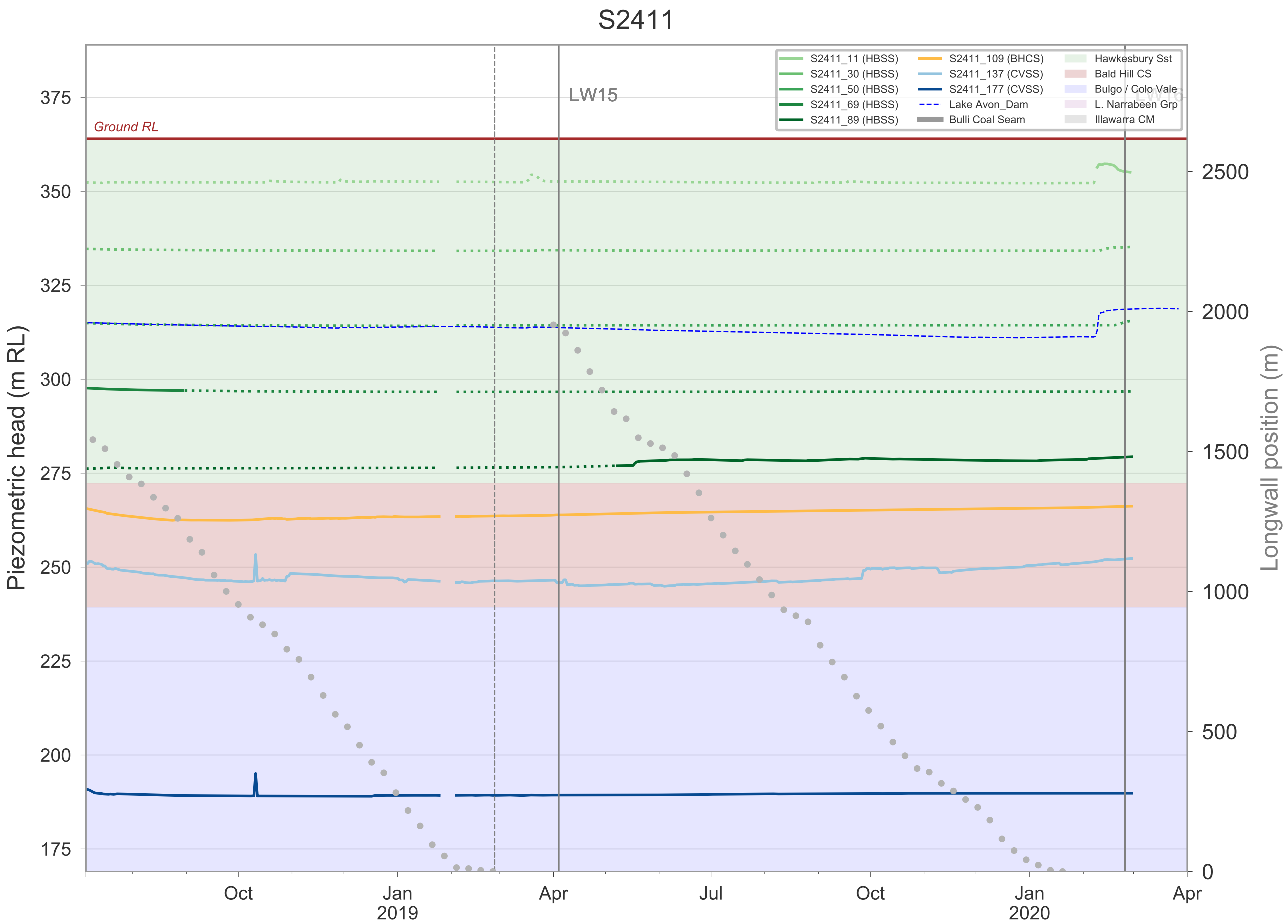

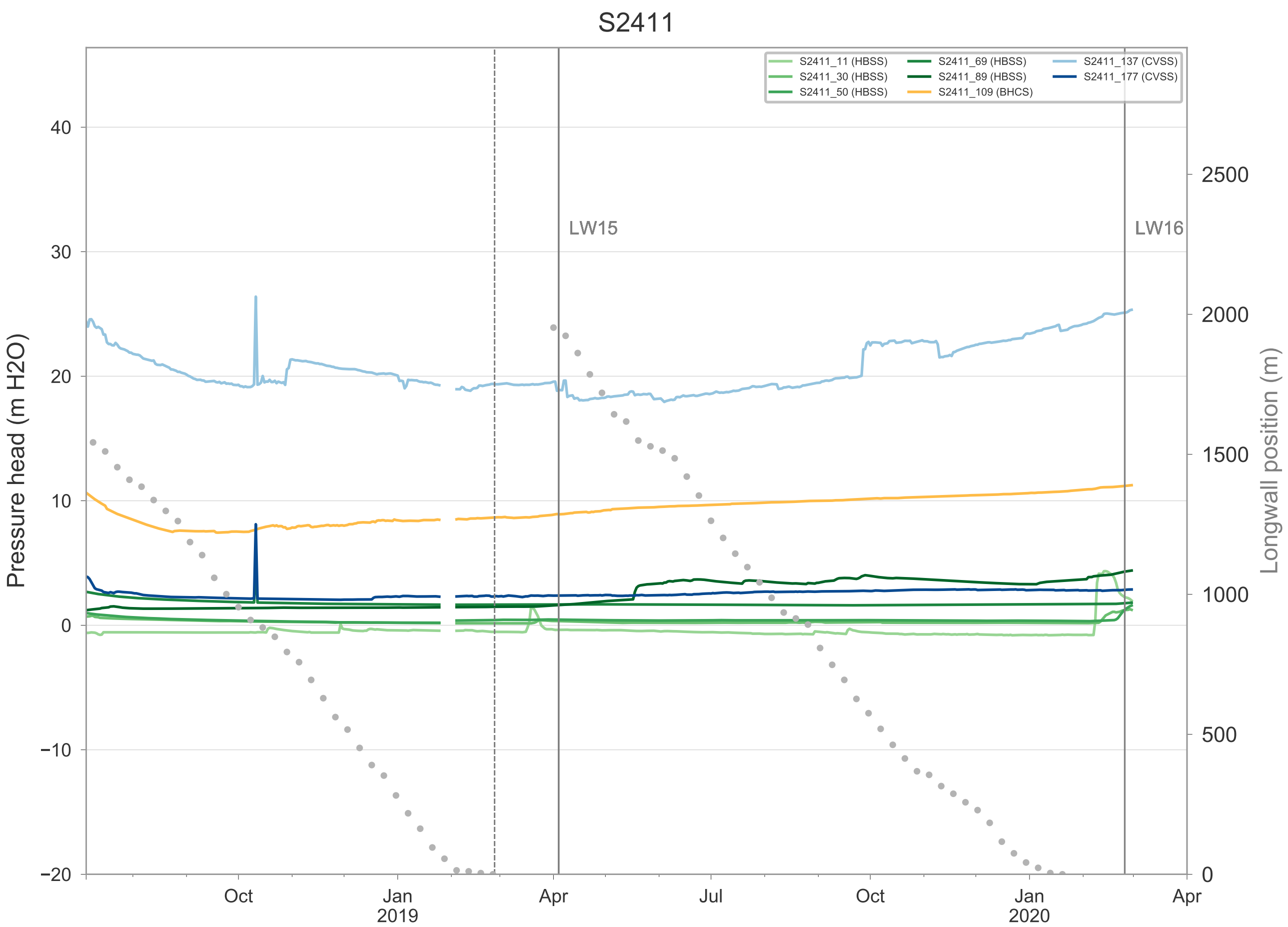

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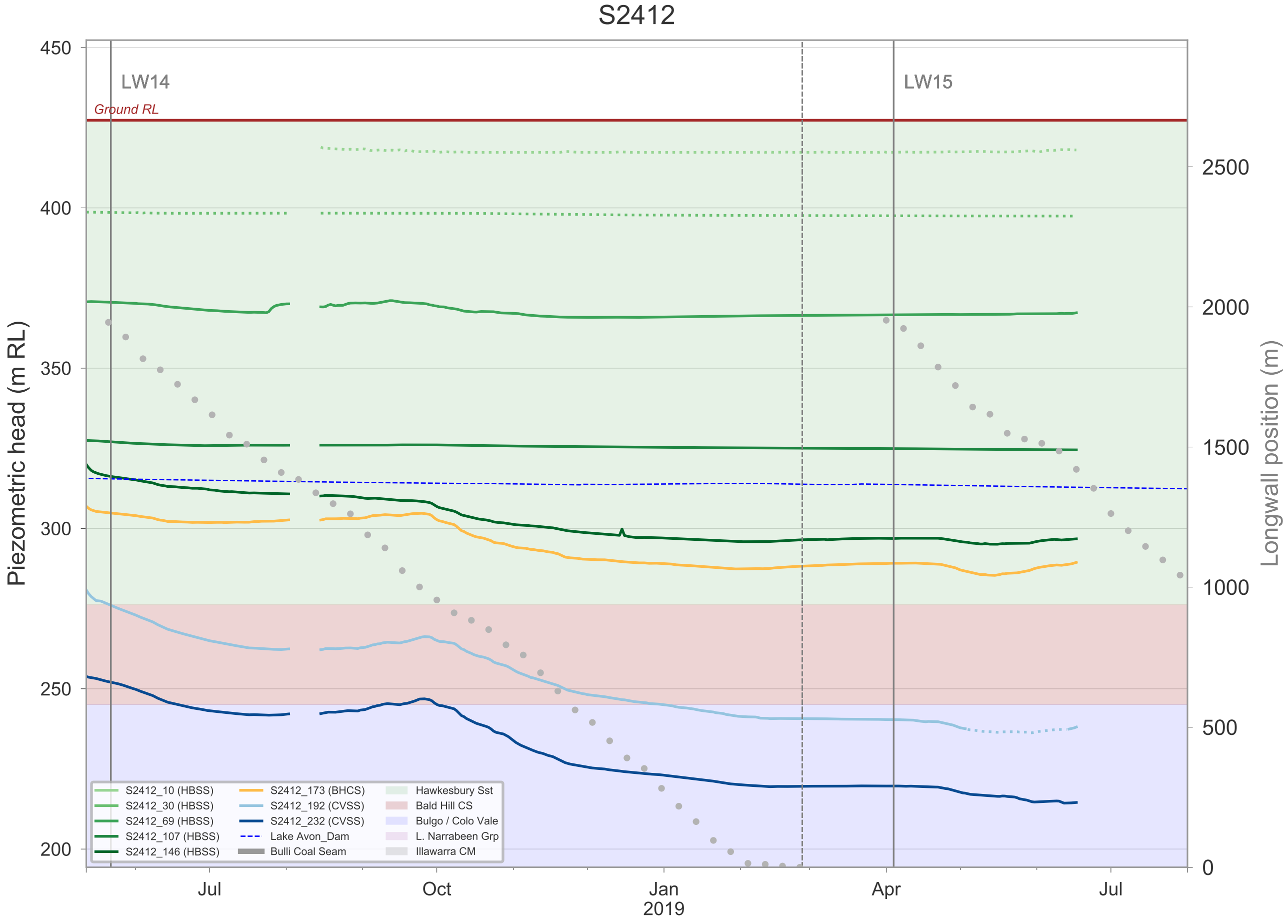

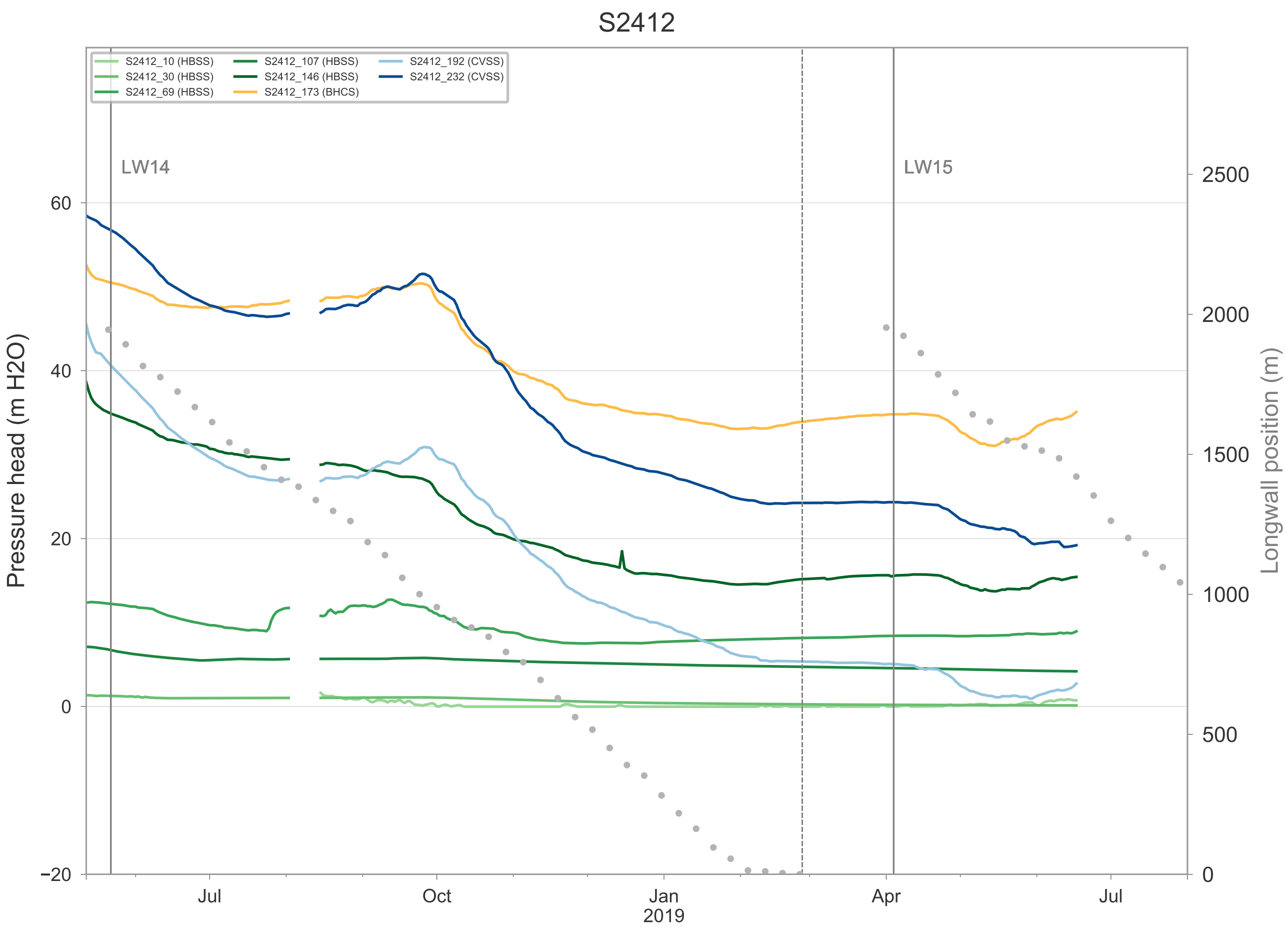

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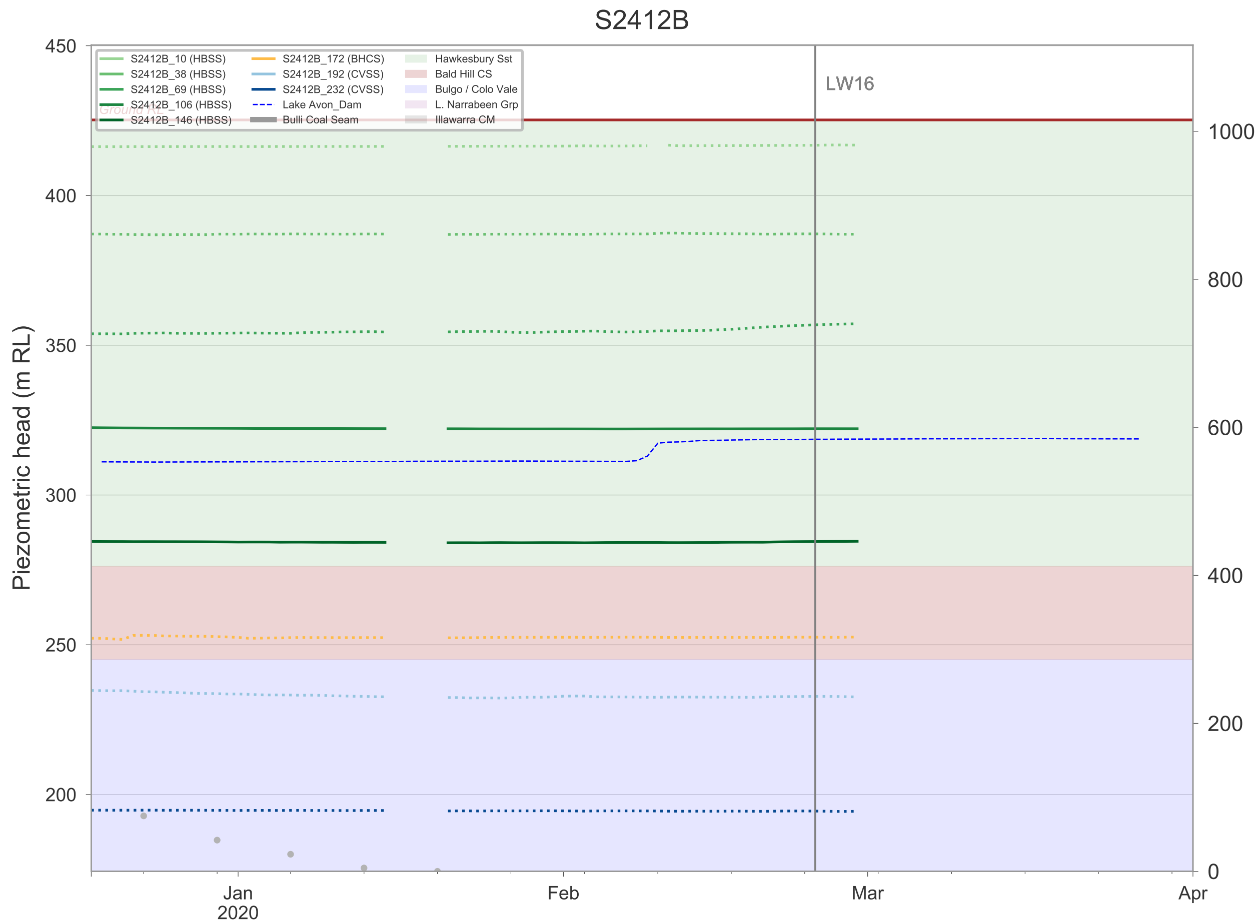

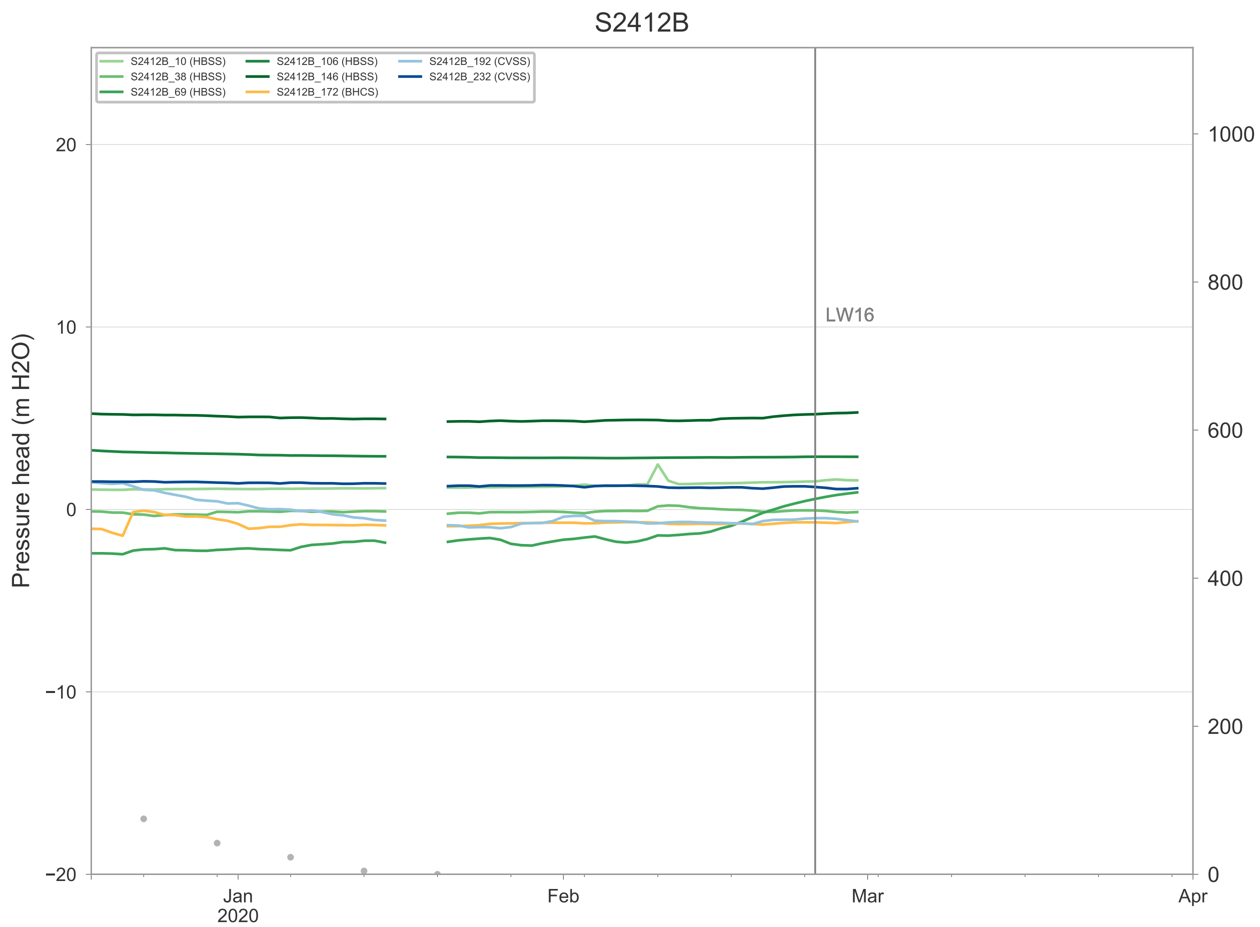

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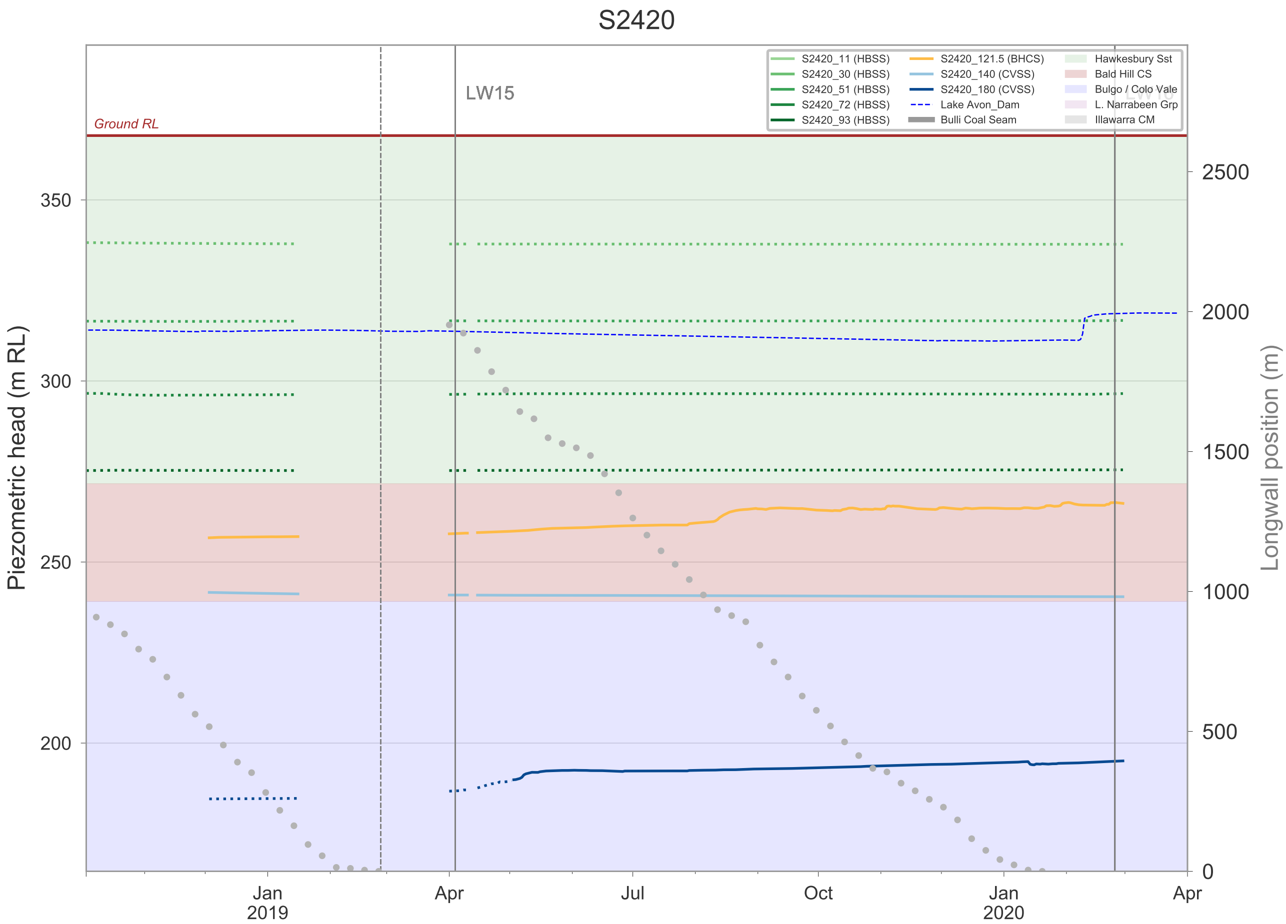

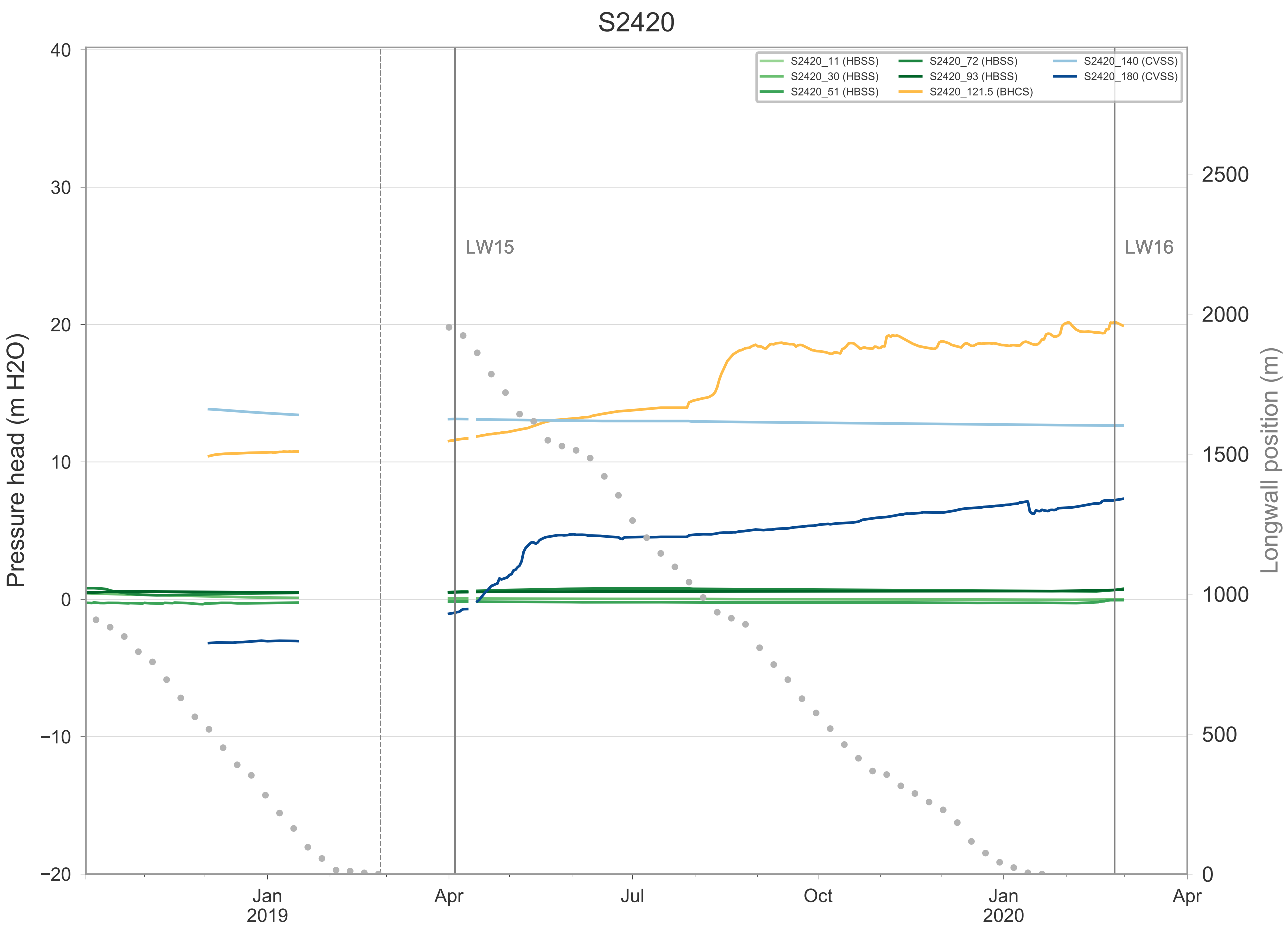

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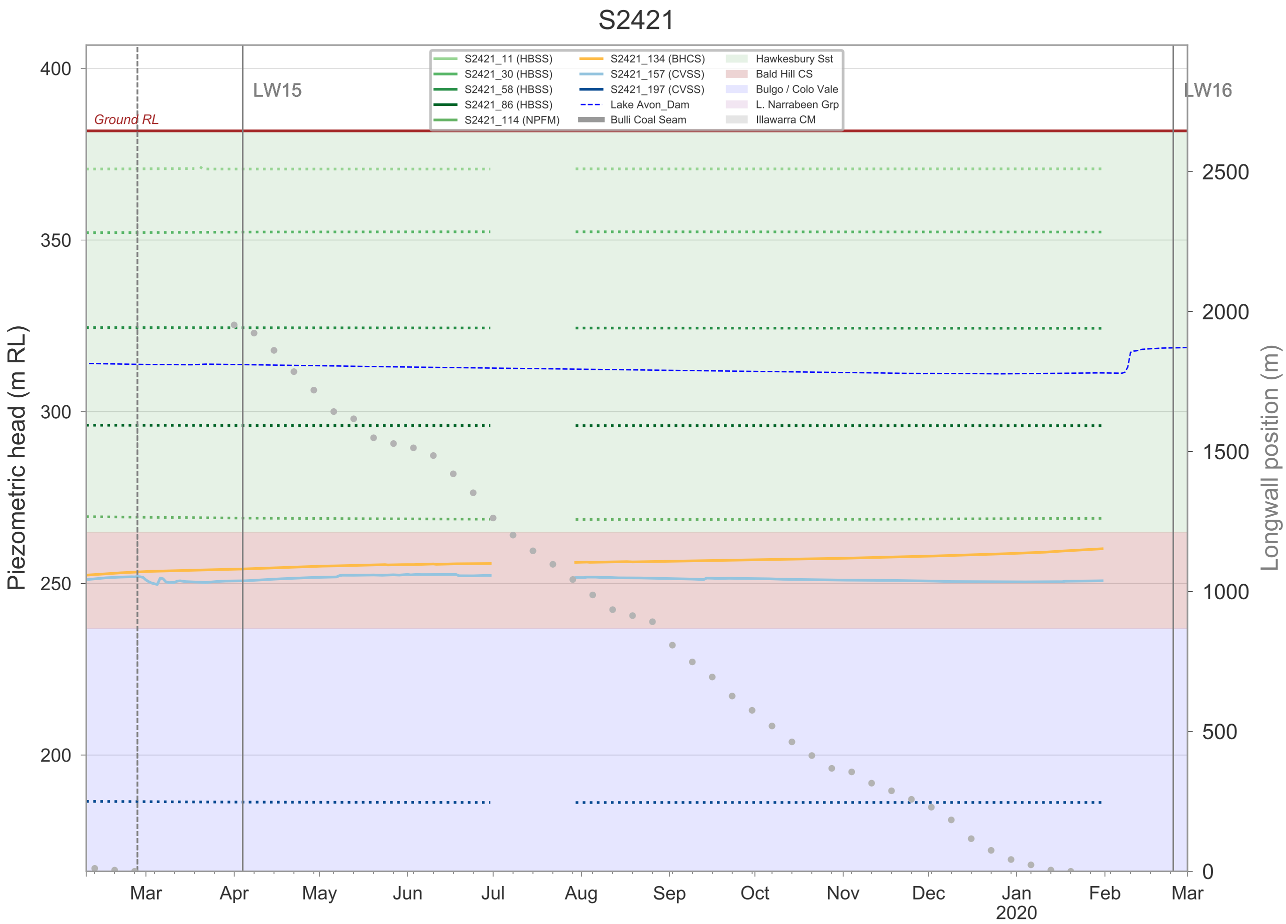

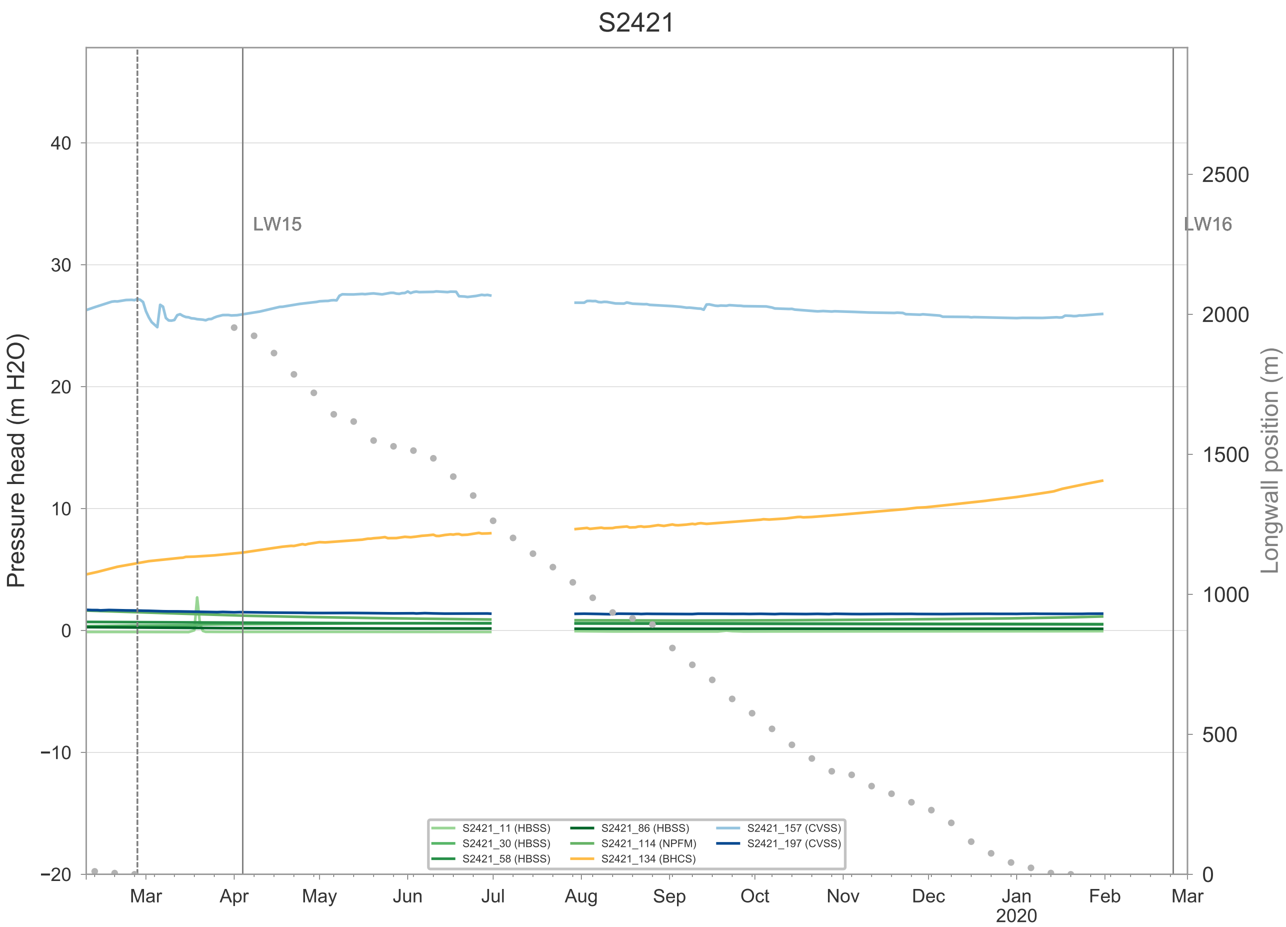

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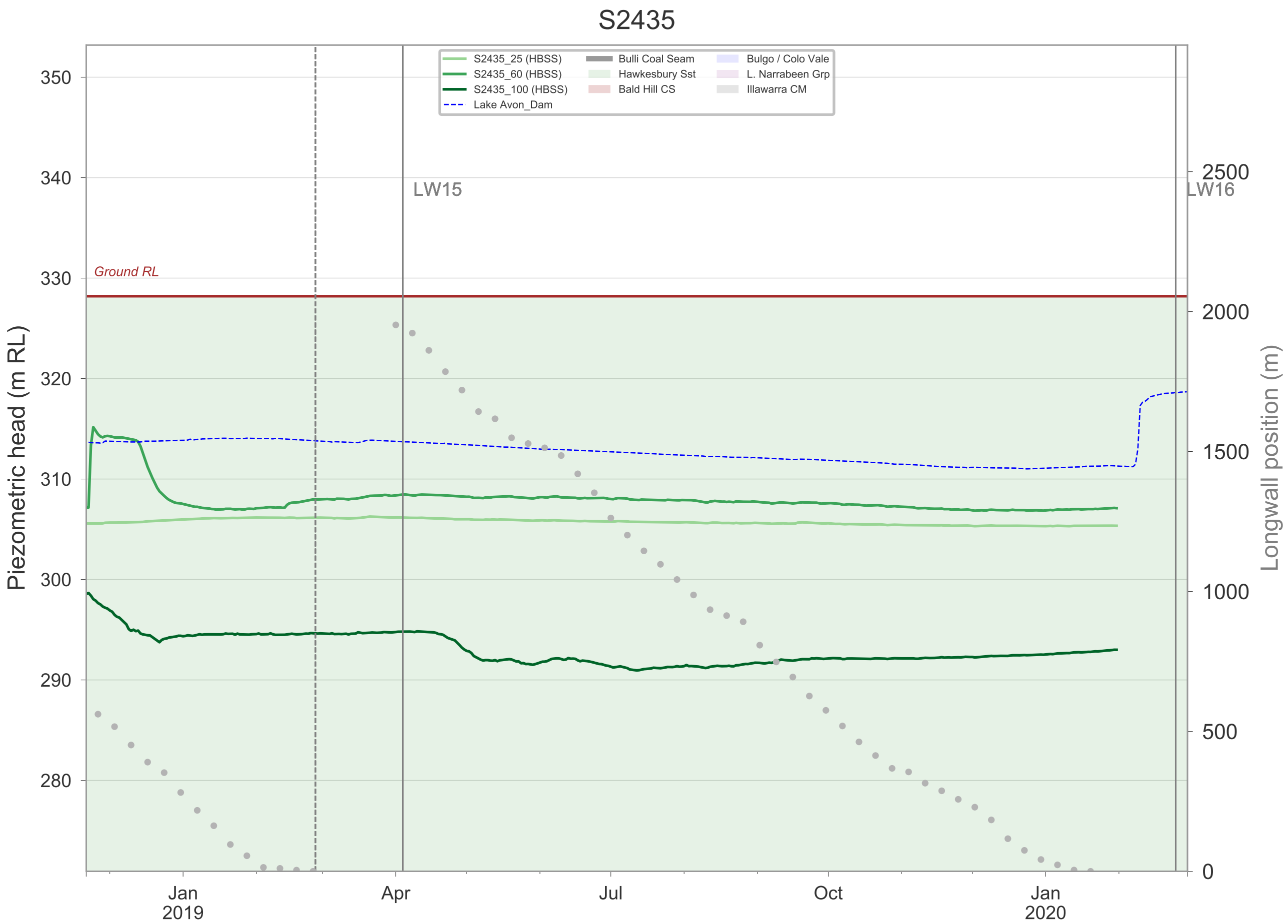

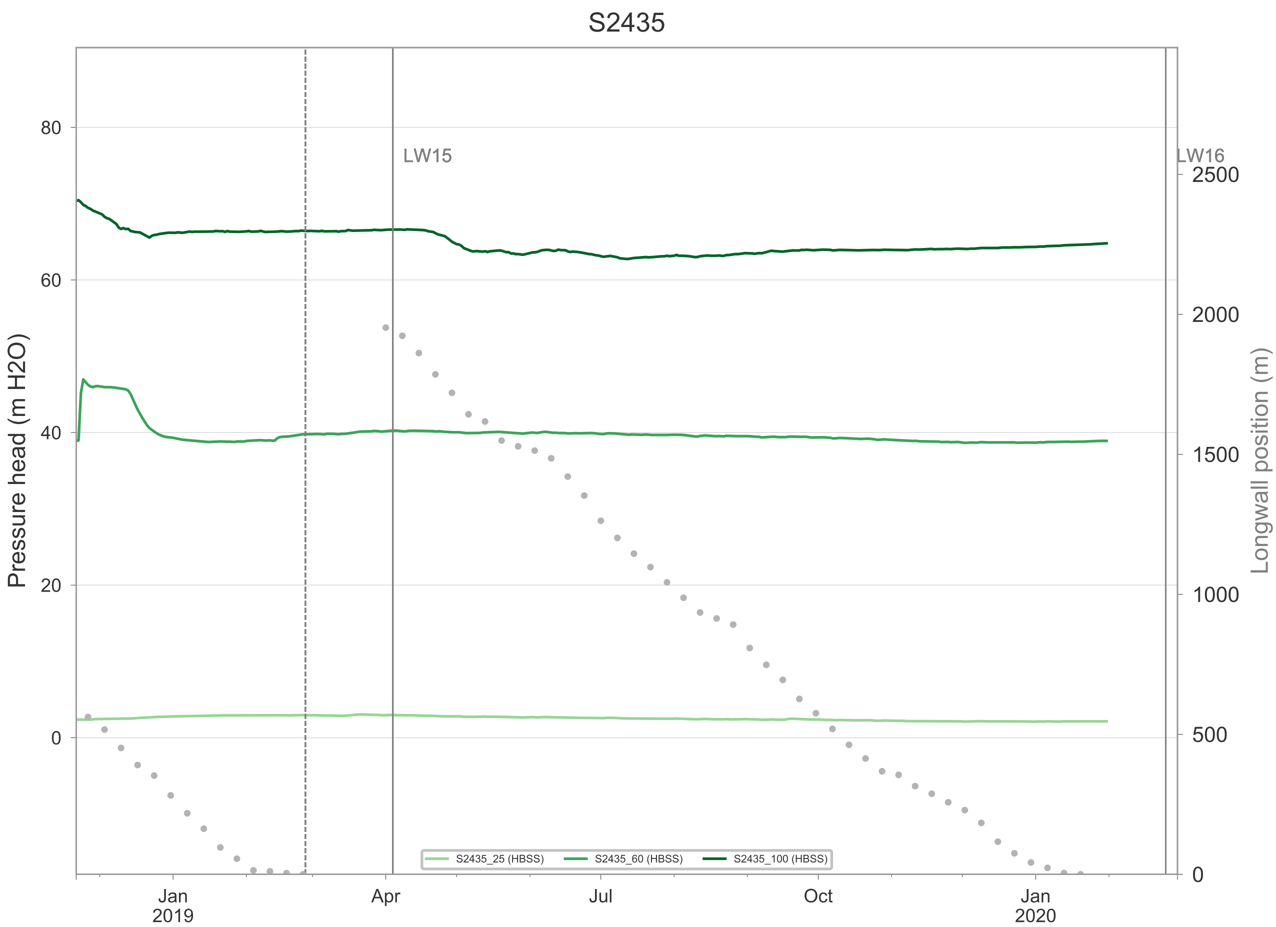

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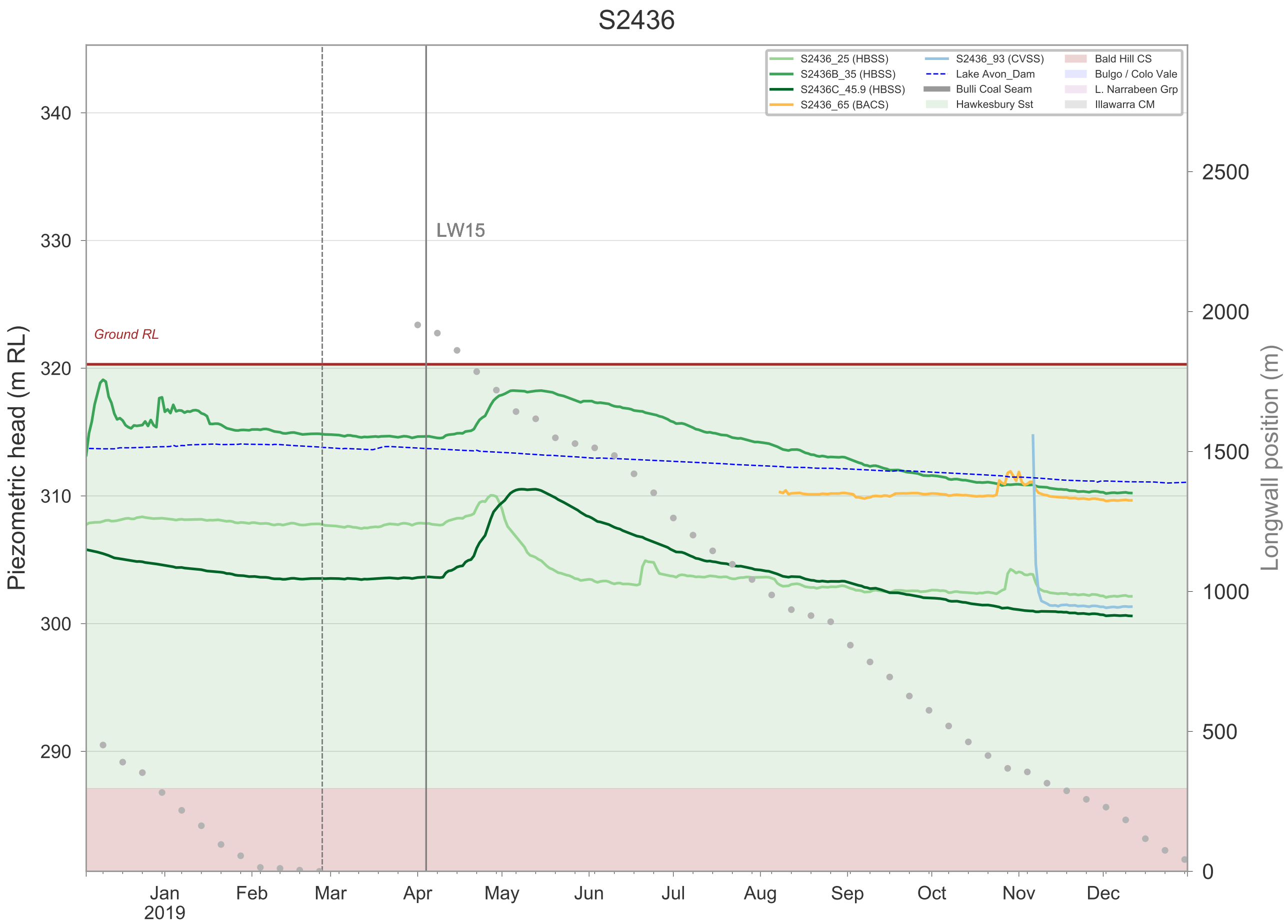

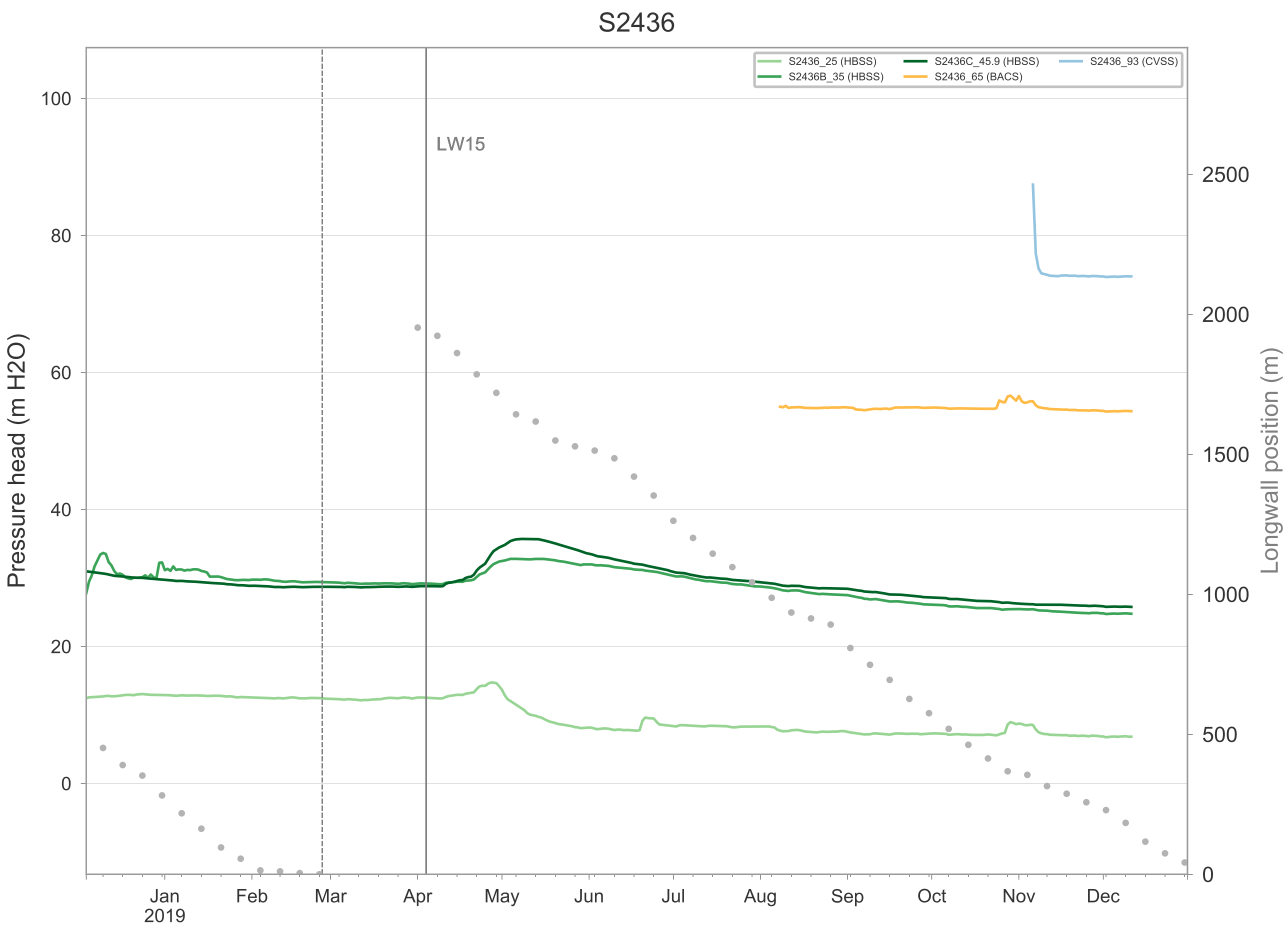

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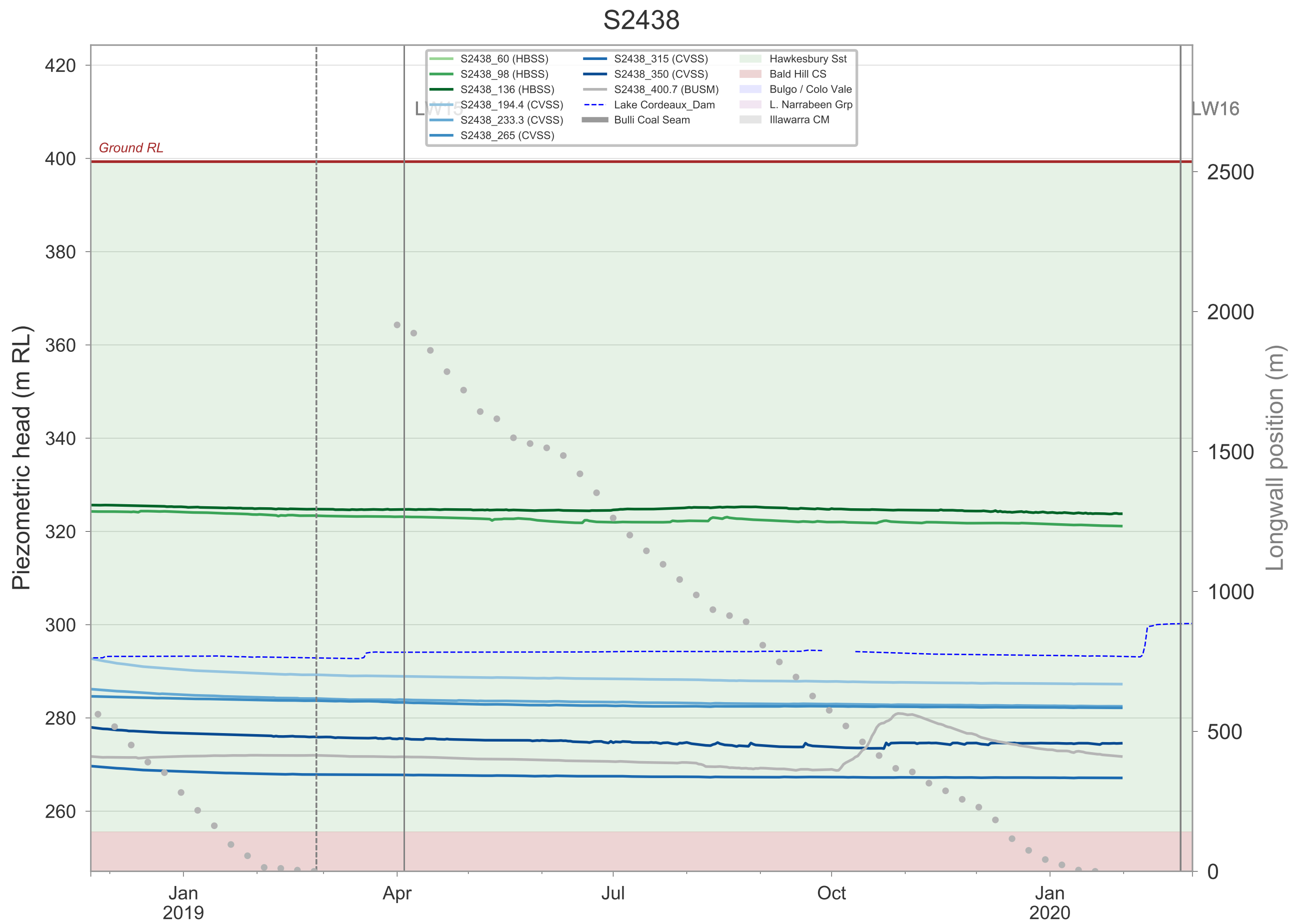

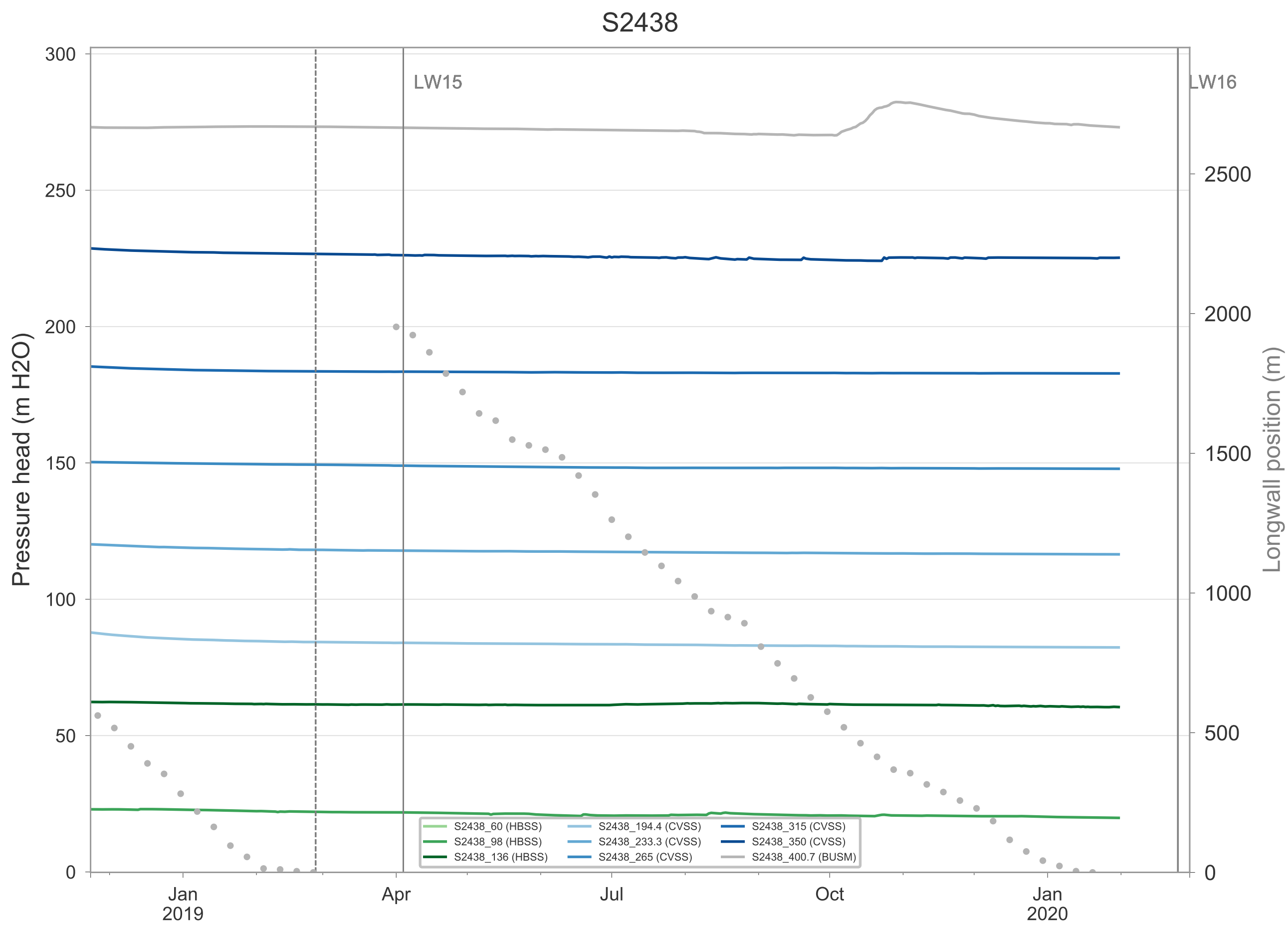

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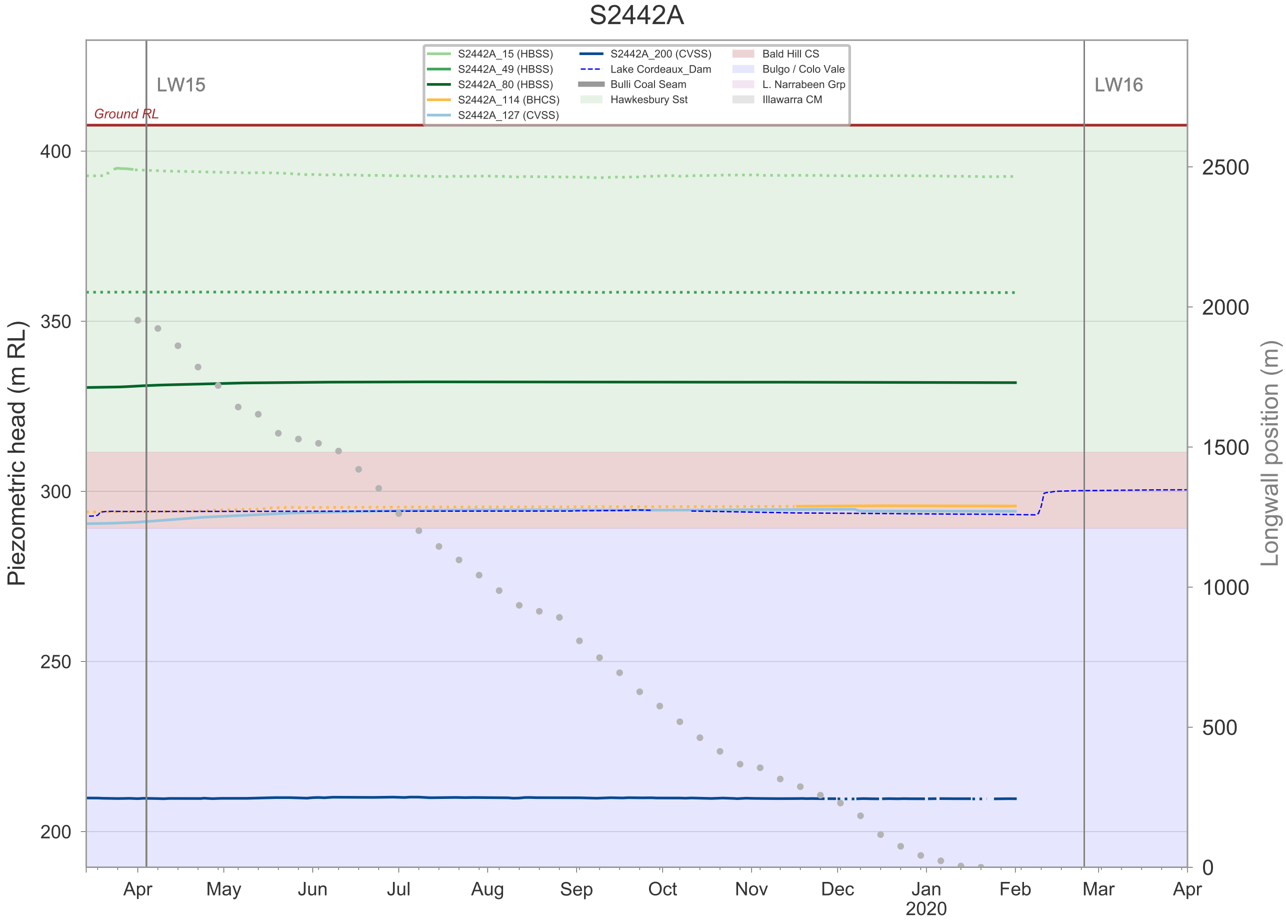

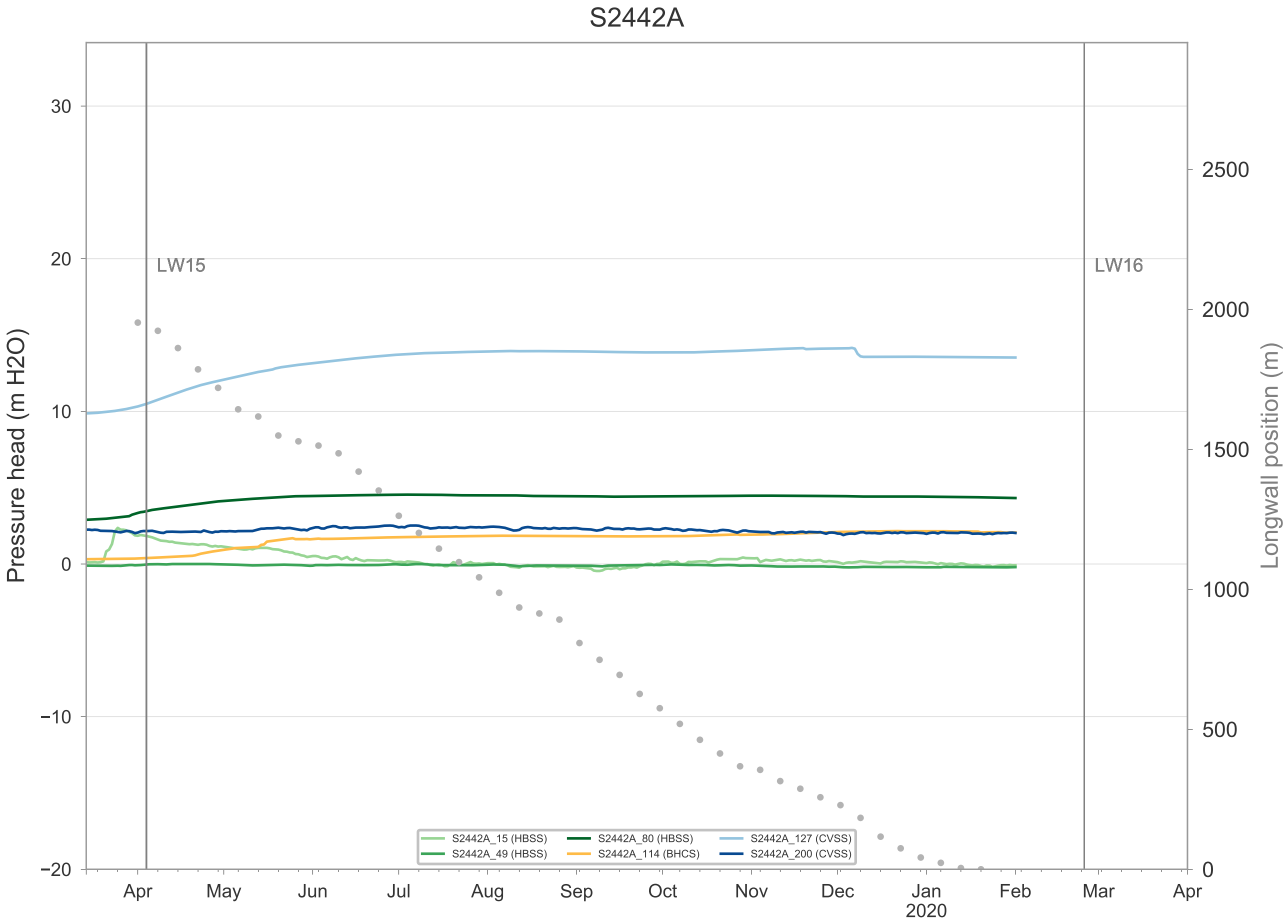

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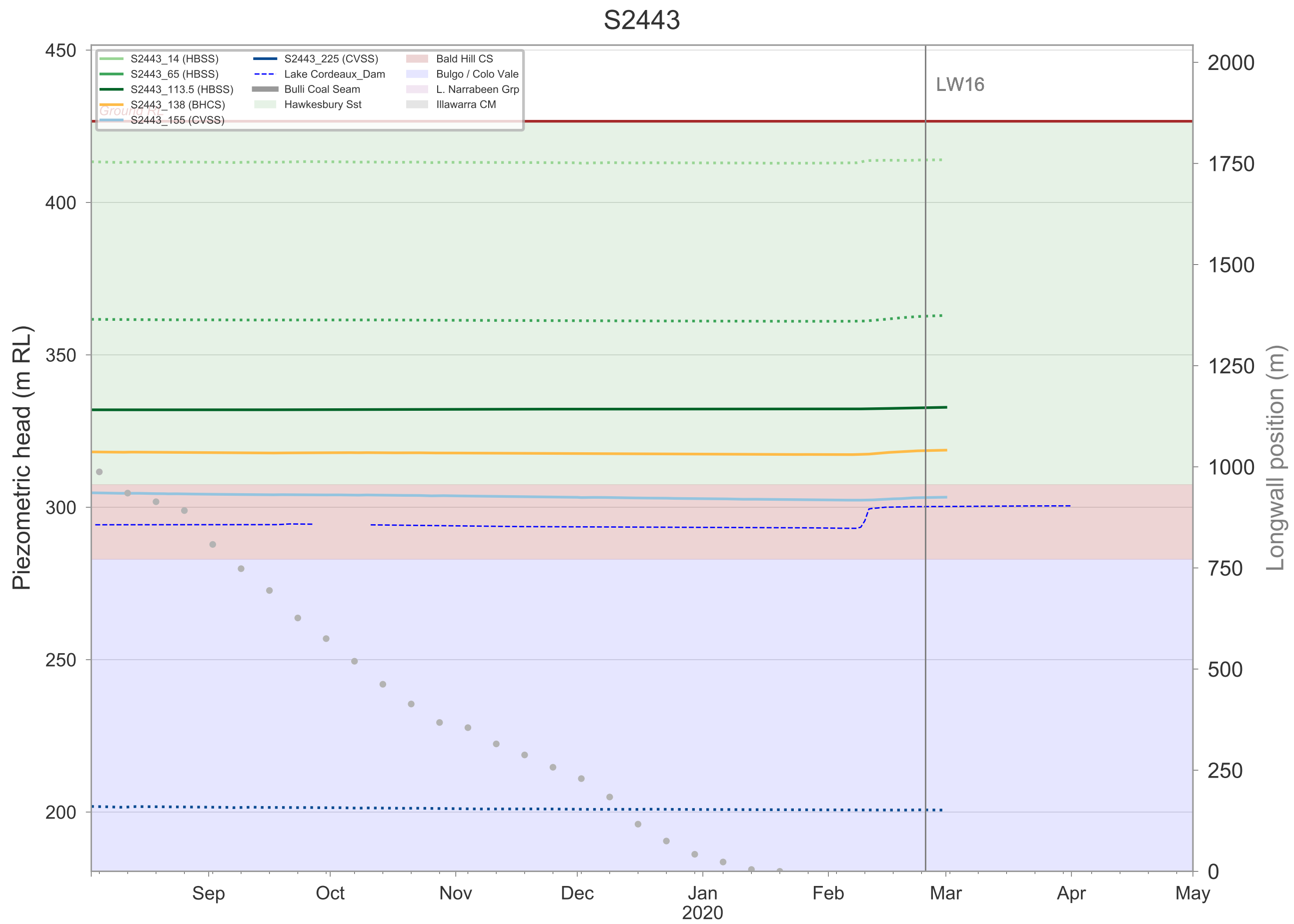

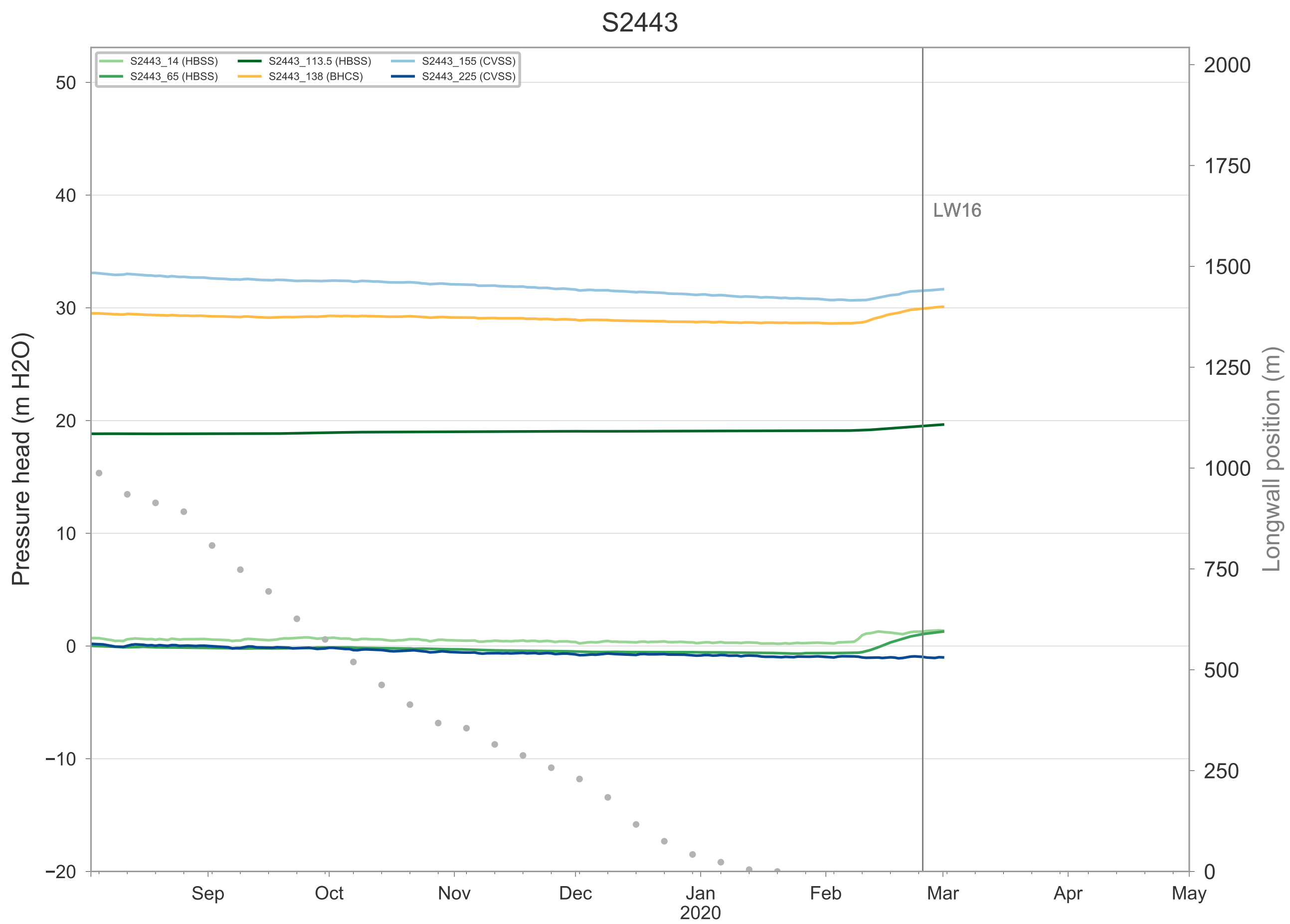

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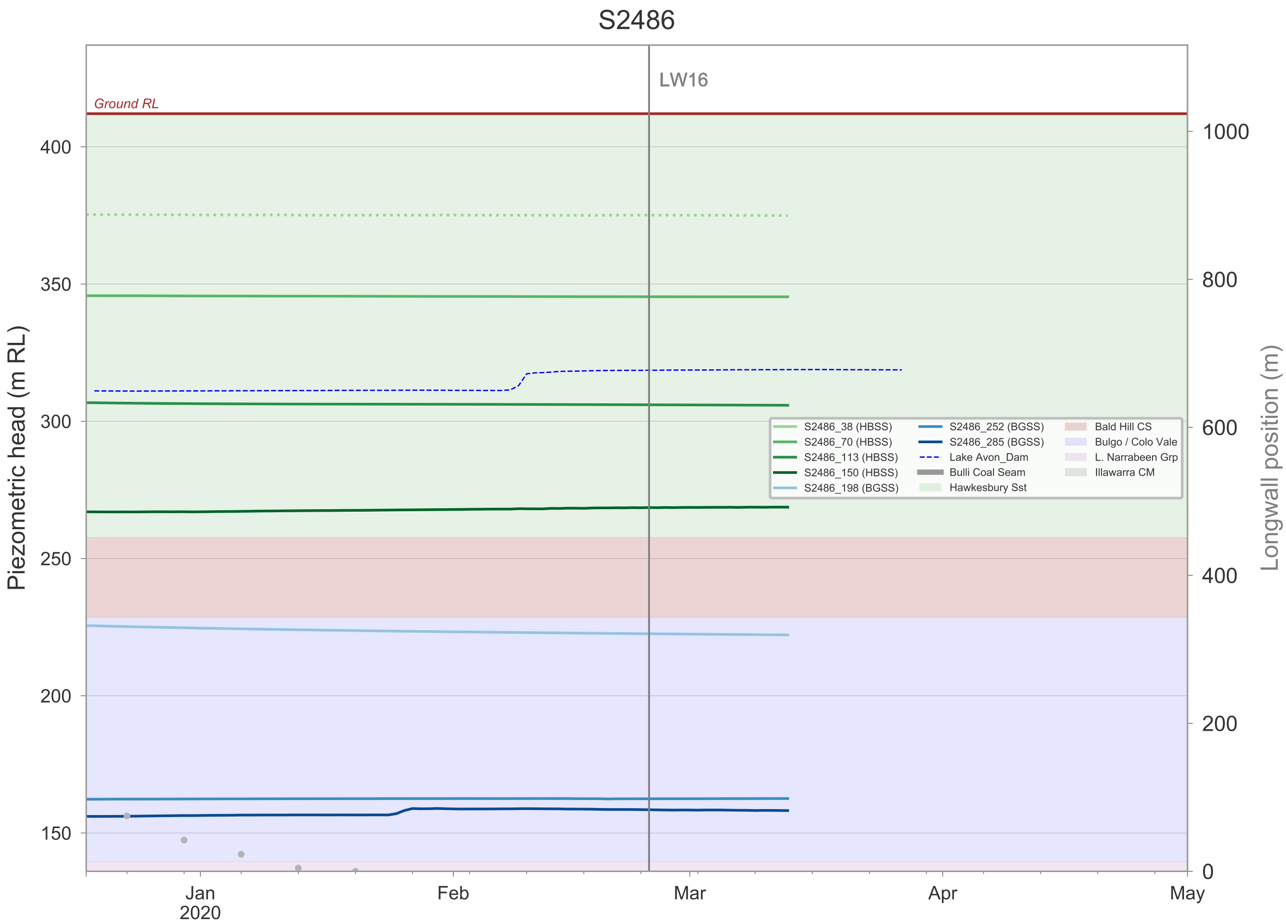

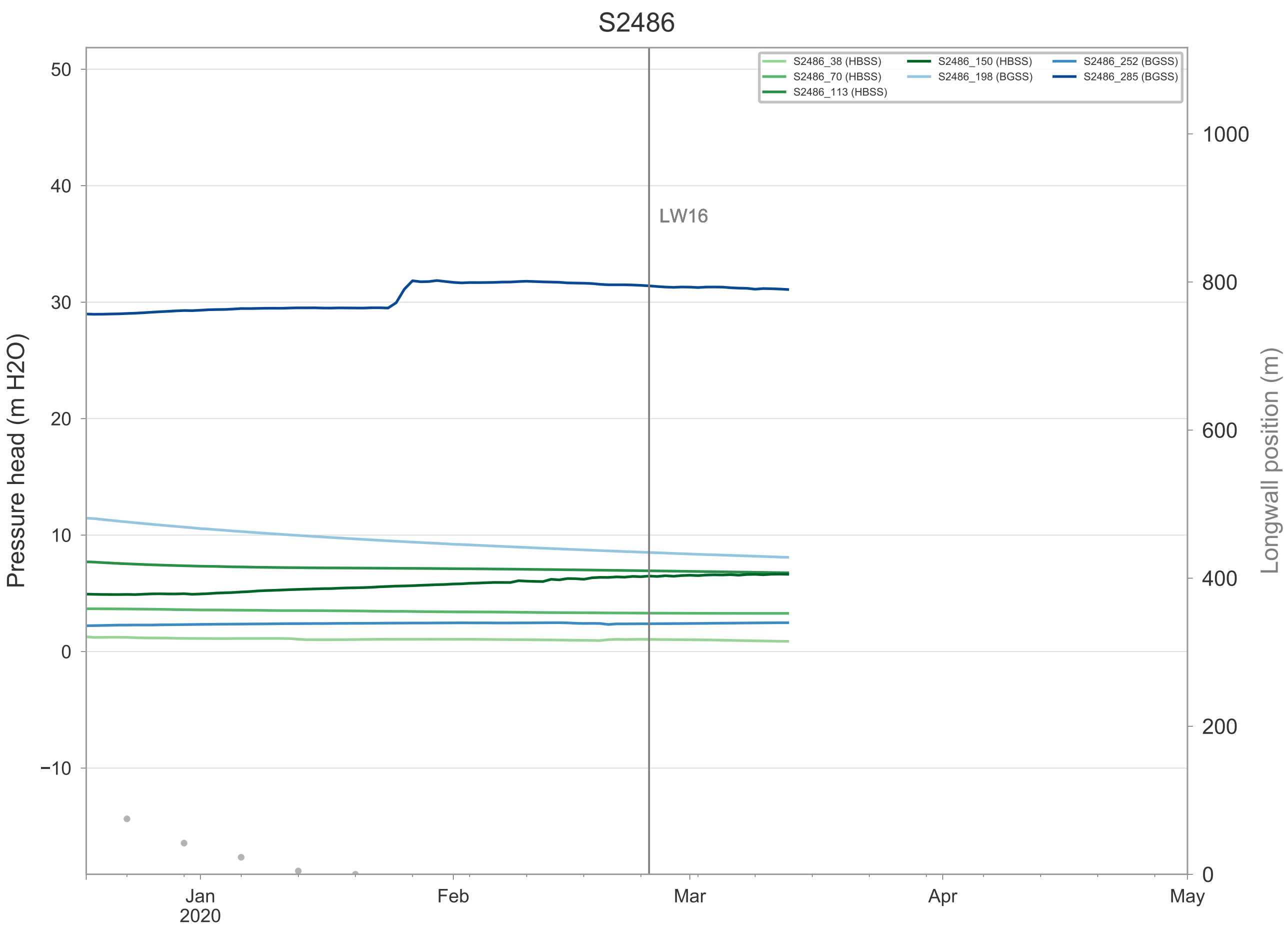

Groundwater hydrographs