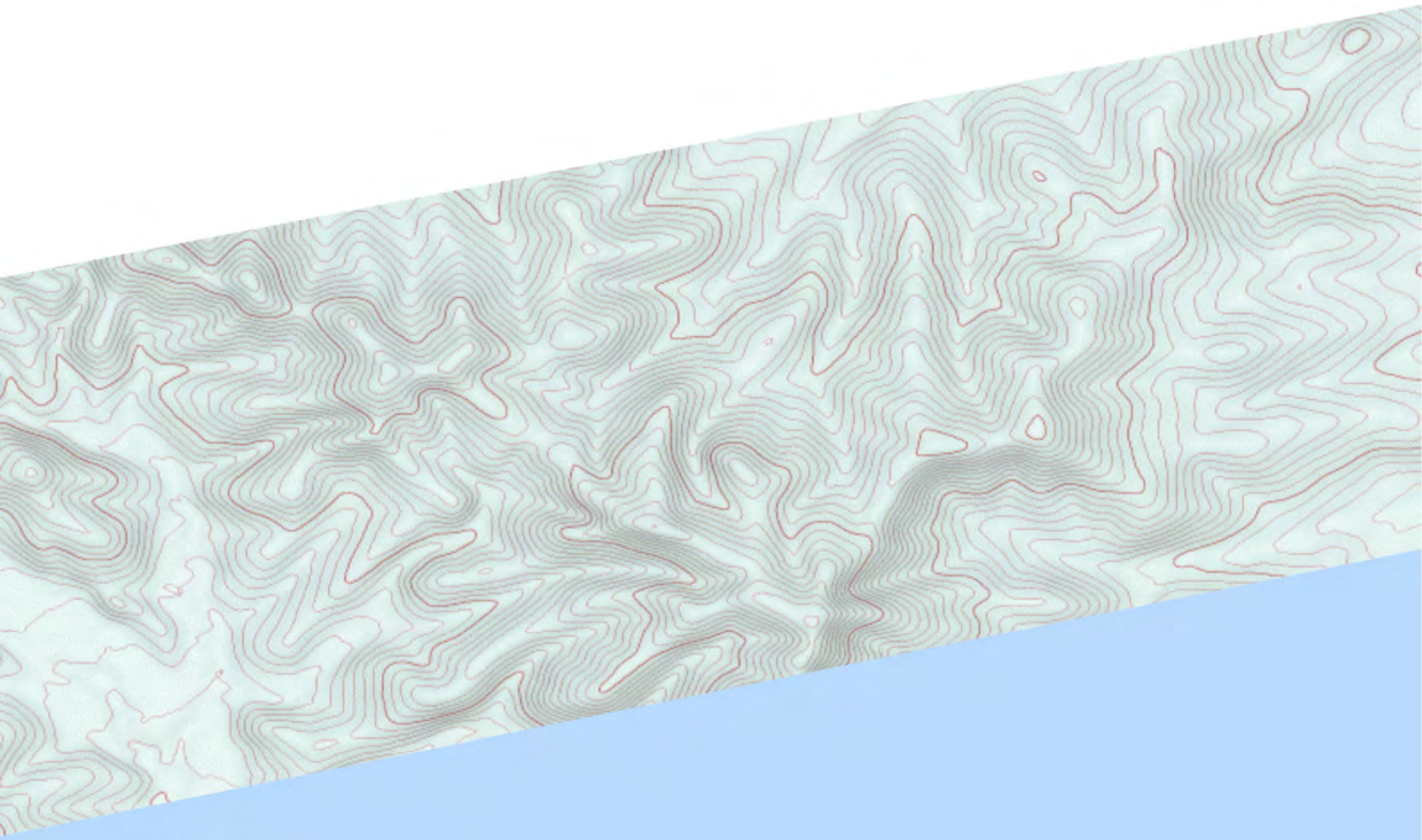
APPENDIX B

Groundwater Assessment



Illawarra Metallurgical Coal

Dendrobium Mine Extension Project (DMEP)

Groundwater Assessment

March 2022

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Quality Control

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Executive Summary

South32 Illawarra Metallurgical Coal (IMC) engaged Watershed HydroGeo Pty Ltd to undertake this Groundwater Assessment to inform IMC's Environmental Impact Statement for the Dendrobium Mine Extension Project (DMEP) which is to be submitted to the New South Wales (NSW) Government. The main feature of the proposed Project is the extraction of ten (10) longwalls in the Area 5 domain, located in the centre of the Southern Coalfield and within the Metropolitan Special Area. These are proposed to be extracted from the Bulli Coal seam during the period 2026-2034.

This work builds upon previously completed work for the Dendrobium Mine and includes a conceptual model of the impacts of this longwall project, both in the operational and post-closure phases. Numerical flow modelling and consideration of likely water quality effects on groundwater and connected surface waters are presented, along with recommendations for monitoring and a preliminary framework for assessing environmental performance, should the Project be approved.

The early phases of this study included data review and conceptualisation, incorporating reviews of:

- geotechnical and geological data and IMC's geological model;
- a significant database of pre-mining and post-mining hydraulic properties from packer testing and other methods;
- hydrological data related to groundwater:
  - groundwater levels;
  - groundwater inflow;
  - groundwater chemistry;
  - groundwater recharge; as well as
- surface water flow and water quality.

The main environmental risk pathway associated with longwall mining is subsidence and the associated fracturing and deformation of strata above and adjacent to longwall panels. Fracturing causes changes to hydraulic properties, mainly to hydraulic conductivity or permeability. This fracturing can cause connected fracturing or disconnected fracturing. Depending on the geometry of the longwall panel and depth of cover, this can potentially provide direct flow pathways from the surface to deeper fracture networks and the mine workings. Additionally, near-surface strata above longwall panels are very likely to be affected by tensile cracking ('surface cracking'), while deformation of strata outside the longwalls can also increase permeability, although this latter effect is not consistent.

A site-specific conceptual model is presented for fracturing above longwalls at Dendrobium, based on multiple lines of evidence, including IMC's recent and significant investigative drilling and borehole logging program. The need for this site-specific model was a recommendation of the Independent Advisory Panel for Underground Mining (IAPUM). The fracture model and the height of fracturing assessment for Area 5 presented in this report have been Peer Reviewed by Professor Bruce Hebblewhite.

In comparison to previously proposed mine plans, the Project targets areas of relatively higher depth of cover and lower cutting height in the Bulli Coal seam. These mining parameters imply a lower risk of seam-to-surface fracturing than in historical mining areas and compared to the Previous Application (the 2019 EIS). This finding is made irrespective of the method or empirical model used to assess height of fracturing.

The numerical groundwater model has been modified from previous assessments to incorporate findings from IMC's over-goaf and Avon shoreline drilling programs and the site-specific model of subsidence fracturing, as well as improved methods for simulating surface water and groundwater-surface water interaction. The model incorporates recharge estimates derived from a soil moisture model calibrated against independent estimates of recharge from literature and from the Bureau of Meteorology modelling, and model parameters for hydraulic conductivity are constrained by the significant database compiled for this site and for neighbouring mines.

The numerical model is calibrated against transient groundwater levels, historical records of mine inflow, and, in an advance on the previous application, calibration against historical surface water flow reductions as determined from field data. This last point addresses comments by the Independent Planning Commission (IPC) and other agencies regarding the reliability of previous forecasts of the effect on water resources.

The modelling indicates that the peak groundwater inflow to the Project would be approximately 5.5 ML/day (ML/d), and would contribute to a peak groundwater inflow of approximately 16 ML/d in combination with inflow to other parts of Dendrobium Mine. The predicted peak groundwater 'take' to Dendrobium Mine (inclusive of the Project) of approximately 5,830 ML/year (ML/yr) [likely range 5,600-5,900 ML/yr] is less than the groundwater entitlement already held by IMC for the *Nepean Sandstone Groundwater Source* (Management Zone 2) that Dendrobium Mine and the Project are located within.

These projected whole-of-mine inflows represent an approximate reduction of 35-40% compared to the predictions in the Previous Application. This is primarily due to the significantly reduced longwall footprint, as well as the use of improved assumptions and parameters, including the incorporation of the site-specific fracturing model into the groundwater model and more realistic longwall cutting heights.

As a result of longwall extraction, groundwater drawdown will occur in strata above and around Area 5 longwalls. Reductions in surface water flow will occur, especially in areas affected by surface cracking. Groundwater drawdown caused by the dewatering and subsidence will be similar to drawdown observed in other parts of Dendrobium, with pressures declining 200-300 metres (m) in the Bulli Coal seam and adjacent strata, drawdowns of 50-100 m in the Bulgo Sandstone, and in the order of tens of metres or less in the Hawkesbury Sandstone. The nature of fracturing and deformation in the Hawkesbury Sandstone aquifer above Area 5 longwalls means that groundwater drawdown will likely be temporary, i.e. will recover, or partially recover.

As has been observed at Area 3A and 3B, following initial groundwater drawdown, recovery of groundwater waters within and then through near-surface fracture networks can cause discharge of poorer quality groundwater. Elevated concentrations of metals, such as iron, manganese, zinc and aluminium, are likely in groundwater and locally in watercourses, with concentrations declining with distance away from longwall areas, and for some of these species, this effect is probably temporary. The potential for impacts to long-term surface water quality as a result of groundwater recovery and upward migration groundwater from deep strata is very low.

An assessment of the Aquifer Interference Policy minimal harm considerations indicates that no High Priority Groundwater Dependent Ecosystems (GDEs) would be affected by drawdown from the Project, which is consistent with the large distance to such features. No registered 'water supply' bores are predicted to experience more than 2 m of drawdown due to the Project. This is due to the distance between the Project and registered bores. Other mines in the Southern Coalfield are closer to settled areas, and so cumulative drawdown impacts (>2 m) arising from mining might occur at registered bores, but these effects are not related to Dendrobium Mine.

The Project longwalls are setback at least 300 m from the Avon Reservoir Full Supply Level. Numerical modelling predicts that losses from the reservoir, caused by drawdown and possibly by deformation of strata between the Area 5 longwalls and the reservoir, would be 0.03-0.40 ML/d (mean 0.18 ML/d). The maximum loss due to Dendrobium Mine is predicted to be up to 0.58 ML/d, which is within Dams Safety NSW's threshold of 1 ML/d.

Incremental losses, due to the Project, from Cordeaux Reservoir and Nepean Reservoir, which are more distant from Area 5 have been assessed at 0.03 ML/d and 0.01 ML/d.

Projected losses from reservoirs are similar to those from the Previous Application, given that the minimum set-back distance is consistent and total frontage of the longwalls parallel to the shoreline is also relatively similar.

The predicted maximum reduction of surface water flow is predicted to be approximately 1.2 ML/d (428 ML/yr) as a result of the Project. This would take Dendrobium Mine's total predicted effect to a maximum of approximately 4 ML/d (1454 ML/yr). With respect to the Project, this represents an approximate reduction of 75-80% compared to the predictions in the Previous Application, related primarily to the reduction in the proposed mining footprint.

The model includes post-closure mitigation measures (installation of bulkheads) recommended by SLR (2022), and simulates groundwater response to that. The modelling suggests that the Project would have little effect on the volume of this discharge water from the mine portals following closure. IMC is currently carrying out chemical analysis of the waters discharging from old mine workings along the Illawarra Escarpment near to Dendrobium, and this will assist with closure planning related to the need for water treatment.

The potential for groundwater recovery in the long-term after mine closure in the presence of vertically-connected fracturing to act as a pathway for the upward migration of poor quality groundwater from the coal measures or other deep strata has been assessed as very minor. The flushing of shallower fracture networks (noted above) is more likely to cause water quality effects within the Special Area and would occur in a shorter timeframe after mining. However the magnitude of these effects would not affect WaterNSW's ability to meet the standards stated in raw water supply agreements. This, and the report by SLR, addresses the comments by the IPC and the IAPUM regarding the need for consideration of closure management and assessment of water quality impacts.

The Groundwater Assessment, specifically the numerical modelling, and its conclusions have been the subject of Peer Review by Brian Barnett (Jacobs).

IMC already operates a significant hydrological monitoring network in Area 5, with many monitoring bores in the Triassic and Permian aged strata, shallow piezometers in Upland Swamps, and surface water flow and water quality monitoring sites. This assessment provides some recommendations for further groundwater and surface water monitoring in the event that the Project be approved.

Abbreviations

Abbreviation	Meaning
AWRA-L	Australian Water Resources Assessment Landscape model. Model operated by BoM for estimating rainfall, soil moisture, runoff and recharge.
BCS	Biodiversity Conservation and Science Directorate (formerly Biodiversity and Conservation Division [BCD]) and Office of Environment and Heritage [OEH])
BoM	Bureau of Meteorology
DPE	NSW Department of Planning and Environment
EPA	NSW Environment Protection Authority
IAPUM	Independent Advisory Panel for Underground Mining (advising DPE), succeeding IEPMC)
IEPMC	Independent Expert Panel for Mining in the Catchment (advisors to DPE)
IESC	Independent Expert Scientific Committee (advising Federal and state governments)
IMC	Illawarra Metallurgical Coal
IMCEFT	Illawarra Metallurgical Coal Environmental Field Team
LTA	Long-term average
mAHD	metres above Australian Height Datum (effectively elevation as metres above sea level)
mBG	metres below ground
ML/d	megalitres per day
Q50	Median (50th percentile) flow at a gauge for a specified period
SFR	Streamflow Routing package (simulating stream flow and groundwater-surface water interaction in MODFLOW groundwater models).
USG	Unstructured Grids (version of MODFLOW numerical modelling software)
WaterNSW	Bulk water supply and source protection authority for Greater Sydney

1. Introduction

Illawarra Coal Holdings Pty Ltd (Illawarra Metallurgical Coal [IMC]), a wholly owned subsidiary of South32 Limited (South32), operates the underground Dendrobium Mine, in the Southern Coalfield of New South Wales (NSW) (Figure 1-1). Since the initial approval in 2001, underground mining has been carried out using longwall extraction within Areas 1, 2 and 3A, and is currently underway in Area 3B. IMC is seeking approval to expand mining into Area 5, located to the northwest of Dendrobium Area 3B, within Consolidated Coal Lease (CCL) 768. The development of this new area is referred to as the Dendrobium Mine Extension Project ("the Project").

1.1 Previous assessments

A Groundwater Assessment (HydroSimulations, 2019) was presented as part of a previous EIS for the *Dendrobium Mine – Plan for the Future: Coal for Steelmaking* EIS (the previous application). The primary authors of this current report were the primary authors of that previous document. Some of the content in this report is the same, and is used with permission.

1.2 Scope

This assessment provides information about potential groundwater behaviour in response to longwall extraction and associated subsidence for consideration by the NSW Department of Planning and Environment (DPE). This assessment focuses on the potential impacts of the Project on groundwater, watercourses and reservoirs. The cumulative effects of all relevant operations at Dendrobium as well as those from neighbouring operations, in terms of historical and future effects, are considered.

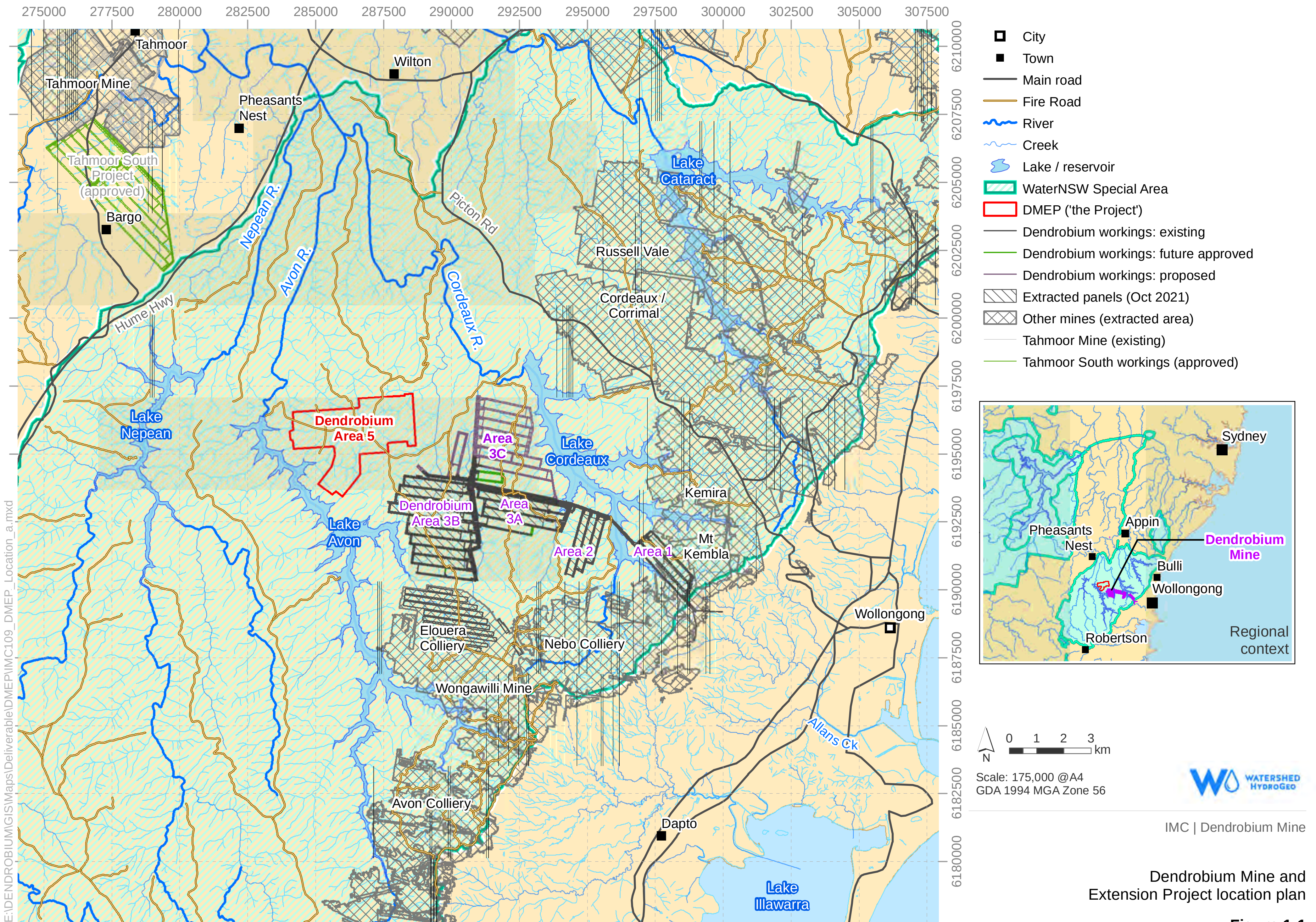
The assessment must meet requirements from a number of sources:

- NSW Aquifer Interference Policy 2012 ('AIP').
- Recommendations for licensing under the Water Management Act 2000.
- Estimates of loss from water supply reservoirs for Dams Safety NSW.
- Project SEARS set by DPE.
- Recommendations made by the Independent Expert Panel for Mining in the Catchment (IEPMC) and Independent Advisory Panel for Underground Mining (IAPUM) and other agencies or advisory groups.

Details of the various requirements are tabulated in Sections 1.2.1 and 1.2.2, including a reference to where these are addressed in this document.

As in previous groundwater assessments for Dendrobium Mine, numerical modelling is used here to inform IMC and regulators about the potential effects and impacts that longwall mining has or may have on water features around Dendrobium. Groundwater modelling for Dendrobium was initially completed in 2007 and has advanced, both in terms of complexity and the requirements, through the modelling of Areas 3A, 3B and 3C.

Th Dendrobium groundwater model developed for the previous application (HydroSimulations, 2019), is routinely updated for Subsidence Management Plan (SMP) requirements. A modified version of that model, incorporating new field data and some revised methods to better meet requirements by agencies, is presented in this report (Sections 4 to 6).



Dendrobium Mine and Extension Project location plan

Figure 1-1

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1.2.1 Secretary's Environmental Assessment Requirements (SEARS)

SEARs for the Project (application SSI-33143123) were issued by DPE on 23/12/2021. Items from the SEARs relevant to this Groundwater Assessment are listed in Table 1-1.

Table 1-1 Summary of DPIE SEARs (23/12/2021)

Ref. in SEARs	Issue		Reference
General requirements			
General Requirements, SEARs, p.2	The EIS must include… an assessment of the likely impacts of the development on the environment focusing on the specific issues identified below, including:		
General Requirements, SEARs, p.2	Existing environment	a description of the existing environment likely to be affected by the development, using sufficient baseline data;	Section 2 describes the existing environment.
General Requirements, SEARs, p.2	Likely impacts, including cumulative impacts	an assessment of the likely impacts of all stages of the development, including appropriate worst-case scenarios, consideration of any cumulative impacts, taking into consideration any relevant legislation, environmental planning instruments, guidelines, policies, plans and industry codes of practice and with consideration to advice provided by agencies in Attachment 2;	Subsidence Assessment (MSEC, 2022). Subsidence effects, with respect to hydrology and hydrogeology in Section 3. Section 6 presents modelled (quantified) estimates of drawdowns and changes in flux at key receptors. Consideration of agency advice in Section 1.2.2.
General Requirements, SEARs, p.2	Mitigation measures	a description of the measures that would be implemented to avoid, mitigate and/or offset the likely impacts of the development, and an assessment of:	Groundwater effects cannot be practically avoided for the longwall mine plan proposed. IMC's proposed mine plan considers setbacks from reservoirs and significant surface water features.
General Requirements, SEARs, p.2	Effectiveness of measures	the likely effectiveness of these measures, including performance measures where relevant;	Performance measures to be agreed pending approval. A framework and key hydrological behaviours are presented in Section 7.2.2.
General Requirements, SEARs, p.2	Contingency plans	whether contingency plans would be necessary to manage any residual risks; and	Section 7.2.2
General Requirements, SEARs, p.2	Monitoring and reporting	a description of the measures that would be implemented to monitor and report on the environmental performance of the development if it is approved;	The existing extensive monitoring network is described in Sections 2.4.1 and 2.6.1. Section 7.2.1 – recommendations for further monitoring. Section 7.2.2 – performance measures.

Ref. in SEARs	Issue		Reference
2 Subsidence			
Subsidence, SEARs, p.4.	Longwall height of fracturing	a scientifically robust assessment of predicted height of fracturing above longwall panels and the vertical distance separating the fracture zone from the surface cracking zone, including consideration and assessment of alternative mine design options to maximise the vertical distance separating the height of connective fracturing with the surface cracking zone and minimise surface water losses;	Section 3, including: • Literature review (Section 3.1), • data analysis (Section 3.2) and • site-specific model of fracturing at Dendrobium (Section 3.3). Consideration of alternative mine design provided in Attachment 11 to the EIS Main Text.
Subsidence, SEARs, p.4.	Subsidence, including height of fracturing	assessment of the potential consequences of subsidence-related effects and impacts on the natural and built environment, paying particular attention to those features that are considered to have significant ecological, economic, social, cultural or environmental value, taking into consideration connective fracturing above the longwall panels and recorded regional and historical subsidence;	Groundwater modelling incorporates site-specific model of fracturing (Section 3 and 4.6), leading to forecasts of effects on hydrological features in Sections 6.4-6.9.
Subsidence, SEARs, p.4.	Peer review of subsidence and height of fracturing assessments	an independent peer review of the subsidence and **height of fracturing assessment/s** prepared for the development.	Review of relevant sections of this document (i.e. Section 3) in separate document (Hebblewhite, 2022). The Subsidence Assessment is a separate document (MSEC, 2022).
3 Water			
Water, SEARs, p.5.	Impacts on water resources	an assessment of the likely impacts of the development on the quantity and quality of surface and groundwater resources, having regard to the NSW *Aquifer Interference* Policy and the advice of DPIE-Water, WaterNSW and the Environment Protection Authority (EPA) (see Attachment 2).	Conceptual model of likely effects in Section 3, specifically Sections 3.4, 3.5 and 3.6. Assessment against AIP in Section 7.1. Consideration of agency advice in Section 1.2.2.
		The assessment is to be supported by groundwater modelling and uncertainty analysis generally consistent with the *Australian Groundwater Modelling Guidelines*;	Sections 4, 5 and 6 document the groundwater modelling. Peer review of modelling and assessment by Brian Barnett of Jacobs (Jacobs, 2022).
Water, SEARs, p.5.	Impacts on water features	an assessment of the likely impacts of the development on aquifers, watercourses, swamps, riparian land, groundwater dependent ecosystems, water supply infrastructure and systems including Cordeaux Dam and Avon Dam, basic	Conceptual model of likely effects on groundwater and surface water features in Section 3, specifically Sections 3.4, 3.5 and 3.6.

Ref. in SEARs	Issue		Reference
		landholder rights and other water users. The significance of water-related features must be considered individually for the purpose of impact assessment;	Numerical model forecasts of effects are in Sections 6.5-6.9, including regional effects and effects on individual features.
Water, SEARs, p.5.	Mine closure	an assessment of post-mining groundwater recovery and the potential long-term impacts on water quality and quantity of post-closure groundwater discharges, including the proposed method for managing post-closure groundwater discharges. If sealing of mine entries is proposed as a management strategy, the EIS must present:	Conceptual model of post-mining effects in Section 3.5 and SLR (2022). SLR (2022) documents the closure management strategies.
		evidence to support the feasibility and likely success of this strategy in mitigating ongoing water losses; and	Mine Closure Concepts report by SLR (2022)
		detailed assessment of the long-term effects, impacts and consequences of mine sealing on neighbouring mines, the environment, water quantity and quality in the catchment and public safety;	Forecasts of long-term (post-closure) behaviour in Sections 6.4, 6.6 and 6.10, and in SLR (2022). Modelling includes voids at Nebo, Kemira and Mt Kembla.
Water, SEARs, p.5.	Water licensing	demonstration that water can be obtained from an appropriately authorised supply in accordance with the operating rules of any relevant Water Sharing Plans (WSP) or any alternative mechanisms agreed following consultation with the relevant NSW government agencies/ statutory authorities;	IMC already hold sufficient Groundwater Entitlement for the Project (Section 1.7).
Water, SEARs, p.6.	Surface water and groundwater monitoring	a description of proposed surface and groundwater monitoring activities and methodologies;	Surface water: Sections 2.4.1 (existing), 7.2.1 (recommendations) and Surface Water Assessment (HEC, 2022). Groundwater: Sections 2.6.1 (existing), 7.2.1 (recommendations), as well as Mine Closure Concepts report (SLR, 2022).
Water, SEARs, p.6.	Cumulative impacts	An assessment of any potential cumulative impacts on water resources, and any proposed options to manage the cumulative impacts;	Potential cumulative drawdown and effects on surface water features described in Sections 6.6, 6.8 and 6.9. There are no options to manage cumulative impacts.
Water, SEARs, p.6.	Mitigation and management of effects on water	a description of the reasonable and feasible mitigation and management measures proposed to prevent pollution of waters and to avoid or mitigate impacts to the quality or quantity of surface and groundwater	Bulkheads between A1-A2 for closure, and water treatment at portals as

Ref. in SEARs	Issue		Reference
		resources, including assessment of the predicted effectiveness and cost of the mitigation measures; and	described by SLR (SLR, 2022).
Water, SEARs, p.6.	Peer review of Groundwater Assessment	an independent peer review of the groundwater model and the assessment of groundwater impacts prepared for the development.	Review of the Groundwater Assessment by Brian Barnett of Jacobs (Jacobs, 2022).

Agency advice (including from WaterNSW, DPIE-Water, Biodiversity and Conservation Division [BCD] and others) to DPIE and provided along with the SEARs is referred to in Section 1.2.2.

1.2.2 Agency requirements and comments on previous assessments

A summary of specific requirements is included in the following table, however some items are not included if they are included in the SEARs (Section 1.2.1).

Table 1-2 Summary of Agency advice accompanying the SEARs

Agency	Ref. in source	Issue	Reference
WaterNSW			
D2021/130215, Attachment A	Key issues (p.4)	Water quantity: There has been insufficient consideration of an alternative mine design that would prevent the height of free drainage from extending to the surface. Such an alternative mine design would likely result in a reduction in the surface water losses of the project.	Attachment 11 of the Main Text of the EIS.
Attachment A	Key issues (p.4)	Water quality: Uncertainty remains about whether the project would meet the NorBE test for water quality, particularly in relation to post-closure groundwater recovery.	Sections 6.10.1 and 6.10.2 assess potential for groundwater recovery and discharge into the catchment. NorBE assessment in HEC (2022)
Attachment A	Key issues (p.4)	Stream Impacts: The project would cause significant environmental impacts in various significant watercourses, including nine major streams (third order or above).	Predicted flow losses for watercourses in Section 6.8.1. More discussion on effects in Surface Water Assessment (HEC, 2022).
Attachment A	Residual questions (p.4)	1. Are the predicted catchment water losses accurate and reliable?	Section 2.4.4 describes recent estimates of surface water losses. Forecasts of the Project's effects on watercourses and catchment-wide are presented in Sections 6.8.1 and 6.8.2 respectively. Assessment of the likely reliability of these estimates is presented in Section 5.3.4.
Attachment A	Residual questions (p.5)	5. What are the catchment water losses post-mining?	Forecasts of the Project's effects on watercourses and catchment-wide are presented in Sections 6.8.1 and 6.8.2 respectively, and these include potential post-mining effects.

Agency	Ref. in source	Issue	Reference
Attachment A	Residual questions (p.5)	6. What are post-mining impacts on water quality?	Section 6.10
Attachment A	Residual questions (p.5)	8. What is the worst-case scenario for swamps?	EIS Appendix D – Development Assessment Report (BDAR) (Niche, 2022).
Attachment A	Seam to Surface Connectivity (p.5)	WaterNSW considers "…there is still a lack of clarity with regards to the vertical distance separating the zone of free drainage (i.e. the fracture zone upwards from the seam towards the surface) from the surface cracking zone, and the geological formations intersected."	Section 3, including: - Literature review (Section 3.1), - data analysis (Section 3.2); and - site-specific model of fracturing at Dendrobium (Section 3.3).
Attachment A	Surface water losses and water offsets	Any lost surface water due to the proposed mining means a loss to WaterNSW for use as a drinking water supply and distribution.	Effects on surface water flow described in Sections 2.4.4, 3.4.1 and 3.4.2. Forecasts of losses in Sections 6.4.2, 6.8.1 and 6.9.
Attachment A	Groundwater	There is a knowledge gap and inadequate studies done with regards to groundwater recharge rates. This and has been noted in several groundwater assessment reports. The investigation of groundwater recharge rates over subsided areas is necessary in both past and future Dendrobium mining areas.	This is a plausible mechanism as discussed previously, but changes to both permeability and storage properties, and water quality, means that practical methods to assess this are difficult to implement. Current approach of not assuming higher post-mining recharge rates is conservative with respect to forecasts of surface water losses and post-mining groundwater recovery.
Attachment A		As recommended by the IEPMC future swamp monitoring and modelling programs should be designed to provide a hydrological balance for representative swamps, sufficient to identify any mining-induced changes in soil moisture and in baseflow down the exit stream; and to provide vertical leakage rates as inputs to groundwater models, in order to quantify how much of the leakage is diverted back into the catchment or elsewhere.	Swamp monitoring and modelling in HEC (2022) Ongoing studies by UNSW/WRL are focussed on water balances for specific Upland Swamps at Dendrobium.
Attachment A	Mine closure	There is a need to include detailed consideration of the potential long term water quality and quantity implications for rehabilitation and mine closure planning.	Refer to the Mine Closure Concepts report (SLR, 2022). IMC have commissioned water quality sampling at disused portals near to Dendrobium Mine (Section 2.8.2).
Attachment B	Groundwater	16. Establish and detail a reporting regime for outcomes of groundwater modelling that provide insights into simulated processes and allows to quantify surface water impacts of Dendrobium mine and	The groundwater model includes all mines within the area of groundwater influence (Section 1.6). Modelling considers cumulative impacts where some component of that is due to Dendrobium Mine. Beyond that,

Agency	Ref. in source	Issue	Reference
		cumulative impacts of all mining in the Sydney drinking water catchment.	cumulative effects of mining may occur, but unrelated to Dendrobium and so not considered here.
DPIE-Water			
OUT21/17836	p.1	Details of all water take for the life of the project and post closure. This is to include water taken directly and indirectly and itemised to quantify the contributions from each relevant water source where water entitlements are required to account for the water take.	Water take is presented in Section 6.5 (groundwater) and Section 6.8.1 (surface water). A summary is provided in Section 6.9.
OUT21/17836	p.1	Details of Water Access Licences (WALs) held to account for any take of water where required, or demonstration that WALs can be obtained prior to take of water occurring.	IMC already hold sufficient Groundwater Entitlement for the Project (Sections 1.7 and 6.9).
OUT21/17836	p.1	Assessment of impacts on surface and ground water sources (both quality and quantity), related infrastructure, adjacent licensed water users, basic landholder rights, watercourses, riparian land, and groundwater dependent ecosystems, and measures proposed to reduce and mitigate these impacts.	This Report, as well as: - EIS Appendix A – Subsidence Assessment (MSEC, 2022), - EIS Appendix C – Surface Water Assessment (HEC, 2022), and - EIS Appendix D – BDAR (Niche, 2022).
OUT21/17836	p.2	Full technical details and data of all surface and groundwater modelling and an independent peer review of the groundwater model having regard to DPIE Water guidelines. The groundwater modelling advice should take into account concerns raised in DPIE Water RTS advice (OUT20/8971).	Details of modelling methods are presented in Section 4, with model performance described in Section 5 and forecasts in Section 6.
OUT21/17836	p.2	Proposed surface and groundwater monitoring activities and methodologies including details and timing of specific studies which demonstrate accuracy and resolution of the above methods.	Groundwater monitoring: Sections 2.6.1 (existing), 7.2.1 (recommendations). IMC are in the process of commissioning a comparative study of grouted VWPs and other monitoring installation types.
OUT21/17836	p.2	Consideration of relevant legislation, policies and guidelines, including the NSW Aquifer Interference Policy (2012), … and the relevant Water Sharing Plans.	Water Sharing Plans (WSPs) in Section 1.7. AIP assessment in Section 7.1.
BCD			
Attachment A	1 Biodiversity (p.3)	7. The additional loss of swamp aquifer water, surface water and baseflow due to longwall mining from the Dendrobium mining proposal needs to be properly quantified	Forecasts of Surface water and baseflow effects in Section 6.8.1.

Agency	Ref. in source	Issue	Reference
Attachment A	1 Biodiversity (p.3)	9. A scientifically robust assessment of surface to seam fracturing based on IEPMC findings is required.	Seam-to-surface connective fracturing is unlikely for the Project. See Section 3 in this document, and peer review in separate document (Hebblewhite, 2022).
Attachment A	2 Water and Soils (p.4)	1 The Environmental Impact Statement (EIS) must map the following features as relevant to water and soils including: - Groundwater. - Groundwater dependent ecosystems.	Groundwater system described in Sections 2.5 and 2.6. GDEs (and potential GDEs) in Sections 2.4, 2.5.4 and 2.6.
Attachment A	2 Water and Soils (p.5)	2. The EIS must describe background conditions for any water resource likely to be affected by the project, including: - a) existing surface water and groundwater.	Aquifers (groundwater system) described in Sections 2.5 and 2.6. Surface water features described in Section 2.4 and the Surface Water Assessment (HEC, 2022).
Attachment A	2 Water and Soils (p.6)	1. The description of existing water quality/hydrology in the EIS must be based on… - h. An outline of baseline groundwater information, including, for example, depth to watertable, flow direction and gradient, groundwater quality, reliance on groundwater by surrounding users and by the environment.	Section 2.6 includes descriptions of groundwater levels and flow directions, groundwater quality and likely groundwater dependence.
Wollondilly Council			
1148-3#2023	p.2	Impacts to surface waters and groundwater	Effects to surface water and groundwater are described in the conceptual model (Sections 3.4-3.6)and forecasts of effects due to the Project are presented in Section 6.
1148-3#2023	p.2	Groundwater Assessment is to contain "demonstrated consistency with the information Guidelines Explanatory Note: Characterisation and modelling of geological fault zones."	Fault zones in Area 5 are not yet mapped with sufficient detail. However it is agreed that approaches to mapping and modelling be consistent with such literature when conducted at the Subsidence Management Plan/Extraction Plan phase (as done for Area 3B Longwall 18 and the Elouera Fault).

The determination of the previous application EIS identified a number of key groundwater-related issues as reasons for rejection of that application. A summary of those issues, and how they are addressed in this or related documents is presented in Table 1-3.

Table 1-3 Key items from previous assessment (2019 EIS)

Issue raised		Response	Reference
IAPUM	No clear description of mine sealing	IMC commissioned SLR develop clear strategy and approach to mine closure and associated groundwater effects.	Mine Closure Concepts report (SLR, 2022).
IAPUM	Uncertainty regarding post closure groundwater recovery, mine outflow, sealing regardless of whether the Project is approved.	As above.	SLR (2022) documents the plan for post-closure management, including bulkheads to modulate outflow. Model forecasts in Sections 6.6 and 6.10.
IAPUM	Uncertainty in estimated surface water losses and effects on water resource	Height of fracturing studies, further analysis of groundwater and surface water data supports the concept that seam-to-surface connection is unlikely for much of Dendrobium (including the Project), with the exception of Area 2. Recent efforts have focussed on improving the groundwater model with respect to reliability of estimating surface water losses.	Historical effects on watercourses documented in Section 2.4.4. Conceptual model of effects on hydrology in Section 3.4. Numerical model calibrated to historical surface water losses (Section 5.3.4). Forecasts of effects on water resources in Sections 6.8.1-6.9
IAPUM	Uncertainty regarding long-term potential for deep groundwater to migrate upward and result in water quality effects within the Special Area.	Seam-to-surface connection unlikely to occur in Area 5, meaning that a pathway for upward migration is not present. However, subsidence effects on shallow strata are likely to result in some water quality effects in the catchment (iron-staining and other changes, similar to those observed in Areas 3A, 3B and elsewhere).	Water quality effects described in Section 2.8 and 3.4.3, and Mine Closure Concepts report (SLR, 2022). Data analysis, model simulation of post-mining groundwater behaviour presented in Sections 6.10.1 and 6.10.2.

1.2.3 Report structure

The structure of this report is outlined in Table 1-4. Data presented in this report is available on request.

Table 1-4 Outline of report structure

Section		Contents
1	Introduction	Description of study requirements and objective (scope of work). Description of operations at Dendrobium Mine, including works proposed as part of the Project.
2	Hydrogeological setting	Describes the environmental context for the area where Dendrobium Mine is located. A summary and discussion of key facets of the groundwater system, including discussion of mining effects.
3	Effects of mining: review and conceptual model	Summarises the literature, data and analysis in order to develop a site-specific model of fracturing at Dendrobium. This leads to the conceptual model of likely impacts during and following mining. The conceptual model is the basis for the design and operation of the numerical model in the following sections.
4	Numerical model development	Describes changes to the groundwater model to meet relevant conditions and requirements, as well as other modifications.
5	Model performance and history-matching	Outlines the procedure and the results of model history-matching phase of work, focussing on observations and data that are most relevant to the predictions required.
6	Forecasting of effects	Presents output from the updated model, including predicted groundwater inflow, groundwater level and pressure hydrographs/maps/profiles, and incidental take from surface water features.
7	Conclusions	Summarises the assessment of the Project and Dendrobium Mine against relevant requirements. Recommendations regarding monitoring, further analysis, and management measures.
8	References	List of documents referred to in this report

The following reports provide similar descriptions and conceptualisations for previous groundwater modelling assessments:

- Coffey, 2012a and 2012b;
- HydroSimulations (2014, 2016, 2018, and 2019);
- SLR, 2020a;
- Watershed HydroGeo (WatershedHG), 2020 and 2021.

Specific analysis of groundwater and surface water effects are provided in multiple End of Panel reports:

- Groundwater: e.g. HydroSimulations 2012-2016 and HGEO, 2017-2022; and
- Surface Water and Shallow Groundwater, e.g. HGEO, 2017-2022.

1.3 Objectives of this assessment

The objectives of this assessment are to present an assessment of the Project on the hydrogeological environment, and relevant surface water features, at Dendrobium Mine. Dewatering and subsidence associated with the Project will cause perturbations to groundwater pressures and levels and to fluxes, as will be described in the conceptual model. Numerical modelling will be used to quantify these potential impacts that may be caused by the proposed development of Area 5, as well as considering cumulative impacts with other mining.

The modelling to quantify the effects will be consistent with the conceptual model and observational data to enable forecasting of mining effects from past and proposed operations, including mine closure scenarios on groundwater and connected surface water systems.

Specifically, the forecasts of groundwater and surface water effects from the Project, including estimates of uncertainty; will include:

- Estimated groundwater inflow to mine workings.
- Estimate the extent and rate of drawdown at specific locations including at private bores in the region.
- Estimate the magnitude and timing of changes to surface water flows in watercourses.
- Estimate the magnitude and timing of changes to leakage from water supply reservoirs as a result of subsidence and drawdown effects.
- Estimate the duration of drawdown and recovery in groundwater levels following closure of the mine.

Following that, recommendations will be provided related to:

- Areas of potential risk where groundwater impact mitigation/monitoring measures may be necessary.
- Water supply or assets that may be affected by groundwater drawdown and may require mitigation or future compensation.
- Potential losses from water supply catchments and/or storage reservoirs and implications for groundwater and surface water licence allocations.

1.4 Numerical modelling approach

The approach to groundwater modelling in this study is based on key principles outlined in the Australian Groundwater Modelling Guidelines ['AGMG'] (Barnett et al., 2012a) and the Independent Expert Scientific Committee (IESC) guidelines for uncertainty analysis (Middlemis and Peeters (2018). The overall scope of the model and the choice of uncertainty analysis method should be appropriate to the environmental risks and project scope.

Groundwater modelling is typically carried out to support or inform management decisions. Models provide better support for environmental decisions if they are developed with the aim of assessing a specific question or testing a hypothesis, rather than with the aim of replicating all (or many) elements of the hydrological system (Doherty and Moore, 2019). Based on this view, Doherty and Moore (2019) recommend that modelling is carried out using the following approach (which is similar to the uncertainty-driven workflow of Middlemis and Peeters (2018), and implicit in the Planning phase of modelling as described in the AGMG):

- Identify the decision-critical prediction required of the numerical model (agreed by stakeholders).

- Conceptualise the systems and identify properties that contribute most to uncertainty of that prediction.
- Identify existing data (and/or collect new data) that can inform relevant parameters and reduce uncertainty through an appropriate data assimilation process (i.e. history matching).
- Use the model to calculate forecast values and uncertainty.

The above approach has implications for the design of the numerical model. In particular, the adoption of automated methods for parameter estimation and uncertainty analyses such as those in PEST/PEST++ require that the model is numerically stable and has a relatively short runtime (ideally < 60minutes, if not shorter).

The details of the modelling carried out for this study are presented in Sections 4 to 6.

1.5 Project overview

1.5.1 Dendrobium Mine

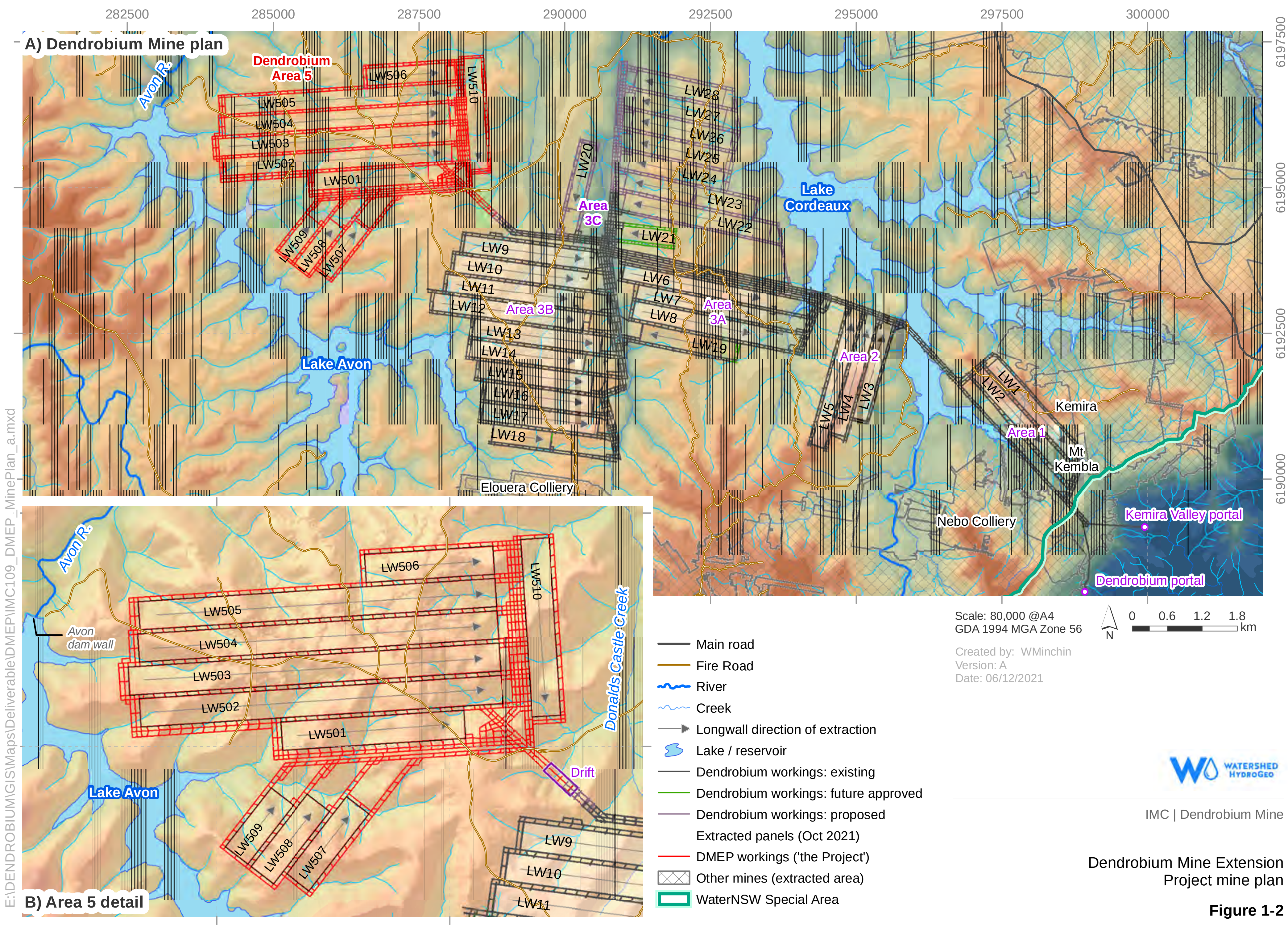
IMC has carried out longwall mining at Dendrobium Mine since 2005 (Table 1-5). Figure 1-2A shows the location of the Dendrobium mining areas including longwalls, location of watercourses and water supply reservoirs.

Access to the mine is via two portals, Kemira Valley Portal and Dendrobium Portal, at the eastern end of the mine on the Illawarra Escarpment (Figure 1-2A).

In order of when they were mined, and also from east to west (moving inland from the portals):

- Area 1 (Longwalls 1 and 2) completed in 2007.
- Area 2 (Longwalls 3, 4, and 5) completed in 2009.
- Area 3A (Longwalls 6, 7 and 8) extracted between 2010 and 2012. Longwall 19 has SMP approval and will be extracted following Area 3B.
- Area 3B has been active since February 2013. Nine longwalls have been completed (Longwalls 9, 10, 11, 12, 13, 14, 15, 16 and 17), and Longwall 18 is currently being extracted.

All historical and proposed extraction in Areas 1, 2, 3A, 3B and 3C is from the Wongawilli Coal seam. Longwall dimensions, i.e. widths and seam cutting heights, have generally increased from Area 1 to Area 3B (Table 1-5). Maximum cutting heights were approximately 3.7 m in Area 1, and up to 3.9 m in Areas 2 and 3A. Area 3B longwalls up to Longwall 13 had maximum cutting heights between 3.95-4.5 m, while subsequent SMP approvals require that recent longwalls (from Longwall 14) have a maximum cutting height of no more than 3.9 m.



IMC | Dendrobium Mine

Dendrobium Mine Extension Project mine plan

Figure 1-2

Table 1-5 Details of Historical and Approved Longwalls – Areas 1-3C

Mine Domain	Long-wall	Status	Date		Days	Panel length (m)	Width [m]		Cutting height [m]		Depth of cover [m]		
			Start	End			Panel	Void	Mean	Max	Min	Mean	Max
Area 1	1	Historical	30/03/2005	15/12/2005	261	1750	237	247	3.2	3.7	170	262	316
	2	Historical	09/02/2006	22/01/2007	348	2000	237	247	3.24	3.70	162	264	320
Area 2	3	Historical	30/03/2007	22/11/2007	238	1560	235	245	3.34	3.66	138	211	282
	4	Historical	17/12/2007	30/09/2008	289	1950	235	245	3.65	3.75	159	249	310
	5	Historical	04/12/2008	18/12/2009	380	2300	235	245	3.57	3.80	213	252	293
Area 3A	6	Historical	09/02/2010	28/03/2011	413	2610	238.5	248.5	3.7	3.90	287	345	389
	7	Historical	04/05/2011	23/01/2012	265	2220	238.5	248.5	3.46	3.60	288	338	379
	8	Historical	24/02/2012	29/12/2012	310	2220	295	305	3.38	3.50	261	321	373
Area 3B	9	Historical	09/02/2013	02/06/2014	479	2150	295	305	3.45	3.70	314	381	409
	10	Historical	20/01/2014	20/01/2015	366	2200	295	305	3.93	4.50	325	383	406
	11	Historical	18/02/2015	05/01/2016	322	2190	295	305	3.86	3.95	327	381	404
	12	Historical	22/01/2016	31/01/2017	377	2590	295	305	3.93	3.95	329	376	404
	13	Historical	04/03/2017	19/04/2018	411	2210	295	305	3.86	3.95	299	375	400
	14	Historical	22/05/2018	26/02/2019	223	1980	295	305	3.89	3.90	325	378	395
	15	Historical	08/04/2019	22/01/2020	243	1963	295	305	3.89	3.90	324	370	390
	16	Historical	20/02/2020	04/11/2020	244	1874	295	305	3.89	3.90	280	350	390
	17	Historical	12/12/2020	13/10/2021	306	1909	295	305	n/a	3.9	278	345	385
	18	Current	02/12/2021	*Apr-2022	155	1018	295	305	n/a	3.9	300	332	370
Area 3A	19	Approved	*May-2022	*Jan-2023	220	1500	295	305	n/a	3.9	287	331	369
Area 3C	21	Approved	*Feb-2023	*May-2023	100	872	245	256	n/a	3.9	310	340	382
	22	SMP approval sought	*Jun-2023	*Jun-2024	330	2561	295	305	n/a	3.9	305	345	380
	23		*July-2024	*July-2025	300	2283	295	305	n/a	3.9	290	340	395
	20	Proposed	*Sep-2025	*Jan-2026	180	1154	245	256	n/a	3.9	338	340	405

Dimensions are all in metres [m]. * proposed start and end dates.

Table 1-6 Details of Proposed and Planned Longwalls – Area 3C and 'the Project' (Area 5)

Mine Domain	Long-wall	Status	Date		Days	Panel length (m)	Width [m]		Cutting height [m]		Depth of cover [m]		
			Start	End			Panel	Void	Mean	Max	Min	Mean	Max
Area 5 ('the Project)													
Area 5	501	Proposed	1/04/2026	28/02/2027	330	1967	295	305	2.6	2.78	300	357	386
Area 5	502	Proposed	1/04/2027	31/05/2028	430	3890	295	305	2.7	2.89	286	342	373
Area 5	503	Proposed	1/07/2028	31/05/2029	330	3988	295	305	2.8	3.03	314	355	377
Area 5	504	Proposed	1/07/2029	31/05/2030	330	3860	295	305	2.9	3.20	313	363	386
Area 5	505	Proposed	1/07/2030	31/08/2031	425	3834	295	305	2.9	3.20	325	365	392
Area 5	506	Proposed	1/10/2031	29/02/2032	150	1378	295	305	2.8	3.06	365	389	398
Area 5	507	Proposed	1/04/2032	30/06/2032	90	1048	295	305	2.4#	2.46	255	320	358
Area 5	508	Proposed	1/08/2032	30/11/2032	120	984	295	305	2.4#	2.49	282	318	345
Area 5	509	Proposed	1/01/2033	31/03/2033	90	799	295	305	2.4#	2.54	272	288	318
Area 5	510	Proposed	1/05/2033	31/12/2033	240	1910	295	305	2.5	2.60	319	361	388
Area 3C													
Area 3C	24	Planned	1/01/2034	30/09/2034	270	1620	295	305	n/a	3.9	301	360	401
Area 3C	25	Planned	1/11/2034	31/09/2035	330	1673	295	305	n/a	3.9	327	357	393
Area 3C	26	Planned	1/11/2035	31/12/2036	420	1725	295	305	n/a	3.9	308	346	392
Area 3C	27	Planned	1/02/2037	31/10/2037	270	1592	295	305	n/a	3.9	319	354	401
Area 3C	28	Planned	1/12/2037	30/10/2038	330	1558	295	305	n/a	3.9	318	353	379

Dimensions are all in metres [m]. * proposed start and end dates. # minimum seam thickness <2.4 m, but equipment limitation enforces minimum cutting height of 2.4 m.

1.5.2 The Project

IMC is seeking the necessary approvals to allow for mining within Area 5, the location of which is shown on Figure 1-2A. This involves the preparation of an Environmental Impact Statement (EIS) for the Project and associated documents required to secure approval under the EP&A Act and EPBC Act. Area 5 would target the Bulli Coal seam[1] ('Bulli seam'). It is proposed that development of roadways would begin in 2022, with extraction of ten longwall panels through years 2027-2034, i.e. essentially 8-years of longwall extraction in Area 5.

The proposed mine plan is shown on Figure 1-2B, with details of the longwall panels provided in Table 1-6. Surface infrastructure, such as ventilation shafts, would be required within Area 5 or near roadways.

As noted in the tables, the longwall geometry is similar to previous areas. Area 5 has a smaller mining or cutting height (being in the Bulli seam) but a generally similar depth of cover to Areas 3A and 3B – in general, it is slightly shallower than longwalls in Area 3B (typically 94-98% of Area 3B depth of over) but deeper than those in Area 3A (99-108% of Area 3A depth of cover).

1.6 Neighbouring mines

Figure 1-1 shows the extent of historical and recent mining around Dendrobium. Many of these mines undertook partial extraction, with a move to longwalls in about the 1970s. The major mines currently or recently operating around Dendrobium Mine are listed in Table 1-7.

Other than Metropolitan Mine (which is distant from Dendrobium), the other operations listed in Table 1-7 are simulated in subsequent model scenarios the purpose of model calibration and cumulative impact assessment.

Of note, Mt Kembla workings, which are in the Bulli seam, overlie almost half of Dendrobium Area 1. Nebo and Kemira workings (Wongawilli seam) are close to Area 1, and there are two borehole connections through the Wongawilli seam pillars into Nebo and Kemira workings.

Table 1-7 Other operational or recent mines in the Southern Coalfield

Mine	Operator	Coal seam	Comment
Appin and West Cliff (Appin Mine)	IMC	Bulli seam	This mine is about 12 km north of Area 3C, and 13 km north of Area 5.
Tahmoor Mine	SIMEC	Bulli seam	Located approximately 10 km north-west of Area 5. Mining to cease in 2022.
Tahmoor South			Project approved April 2021. Longwall extraction 2022-2033. Located 7 km north-west of Area 5.
Wongawilli / Nebo	Wollongong Coal	Wongawilli seam	Bord and pillar mine, located 200m south of Area 1 and 1 km south of Area 2.
Wongawilli (Elouera)			Longwall mine, located 400 m south of Area 3B, and 4.5 km south-east of Area 5.
Russell Vale	Wollongong Coal	Wongawilli seam	Located about 5.5 km north of Area 3C, and 8 km north-east of Area 5.

[1] Bulli Coal and Bulli Coal seam are the accepted formal names for these stratigraphic units, however based on usage by IMC (e.g. 'Bulli Seam Operations', in stratigraphic logs etc) the informal term 'Bulli seam' is used throughout this document.

Mine	Operator	Coal seam	Comment
Metropolitan Mine	Peabody	Bulli seam	Located 22 km north east of Area 3C, and 25 km north-east of Area 5.
Historical operations			
• Cordeaux	• Corrimal	• Huntley	• Avon
• Kemira	• Mt Kembla	• Port Kembla	

1.7 Water management

NSW DPIE-Water and WaterNSW manage water resources, including groundwater, via Water Sharing Plans (WSP). The area around Dendrobium Mine is managed via the *Greater Metropolitan Region Groundwater Sources WSP*, which is divided into separate Groundwater Sources (Figure 1-3). Except for the entrance portal to the east of Dendrobium Area 1, all Dendrobium mine areas lie within the Sydney Basin Nepean Sandstone [Management Zone 2 (MZ2)] Groundwater Source. This Groundwater Source is classified by DPIE-Water as 'Highly Productive' under the Aquifer Interference Policy (AI Policy).

The total assigned entitlement[2] for all users within the Nepean Sandstone MZ 2 is 19,002 shares (which are essentially megalitres per year [ML/yr]), and equivalent to 52 megalitres per day [ML/d].

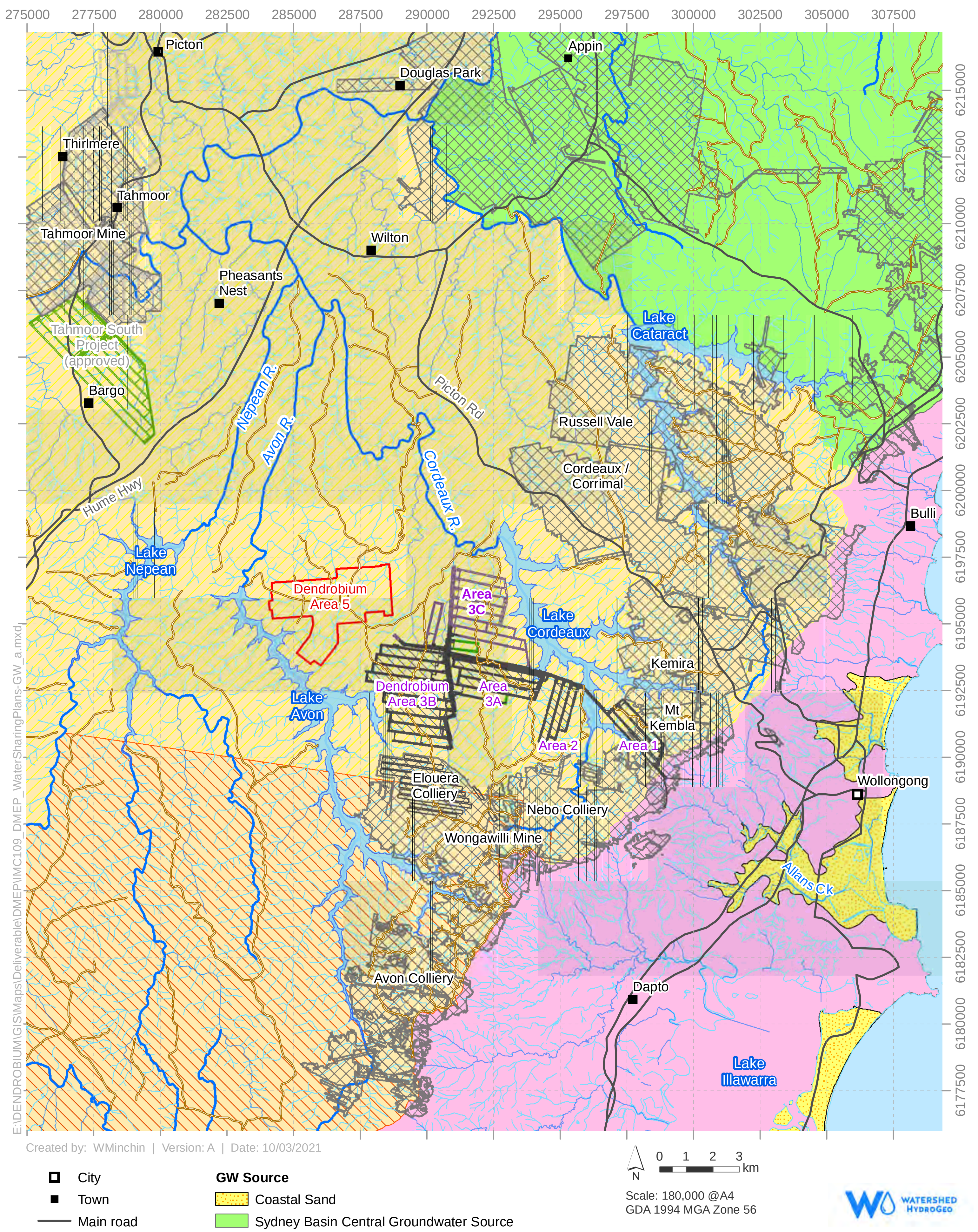
At the time of writing, IMC currently hold shares of groundwater entitlement sufficient to cover their current and predicted take (for Areas 1-3B and future areas, including the Project – Sections 6.5 and 6.9) from Nepean Sandstone MZ2 source and the incidental take from neighbouring Groundwater Sources:

- 9,755 shares for Sydney Basin Nepean Sandstone MZ2:
  - WAL 37464 = 300 shares
  - WAL 37465 = 3,962 shares
  - WAL 42386 = 3,653 shares; and
  - WAL 42385 = 1,840 shares.
- 75 shares for Sydney Basin South Groundwater Source (WAL 36473)

Area 5 is wholly within Nepean Sandstone MZ2 and given the distances involved, mining in this domain is unlikely to significantly increase the incidental take from other Groundwater Sources.

Surface water sources and management zones are presented on Figure 1-4. This shows that Dendrobium Mine is within the Upper Nepean Headwater Tributaries Source, and close to the Avon River, Cordeaux River Management Zones. These zones all converge on Pheasants Nest Weir, and these zones and that site are used to analyse reductions in surface water resource in this impact assessment (Section 6.8).

[2] https://waterregister.waternsw.com.au/water-register-frame [accessed 31/08/2021)



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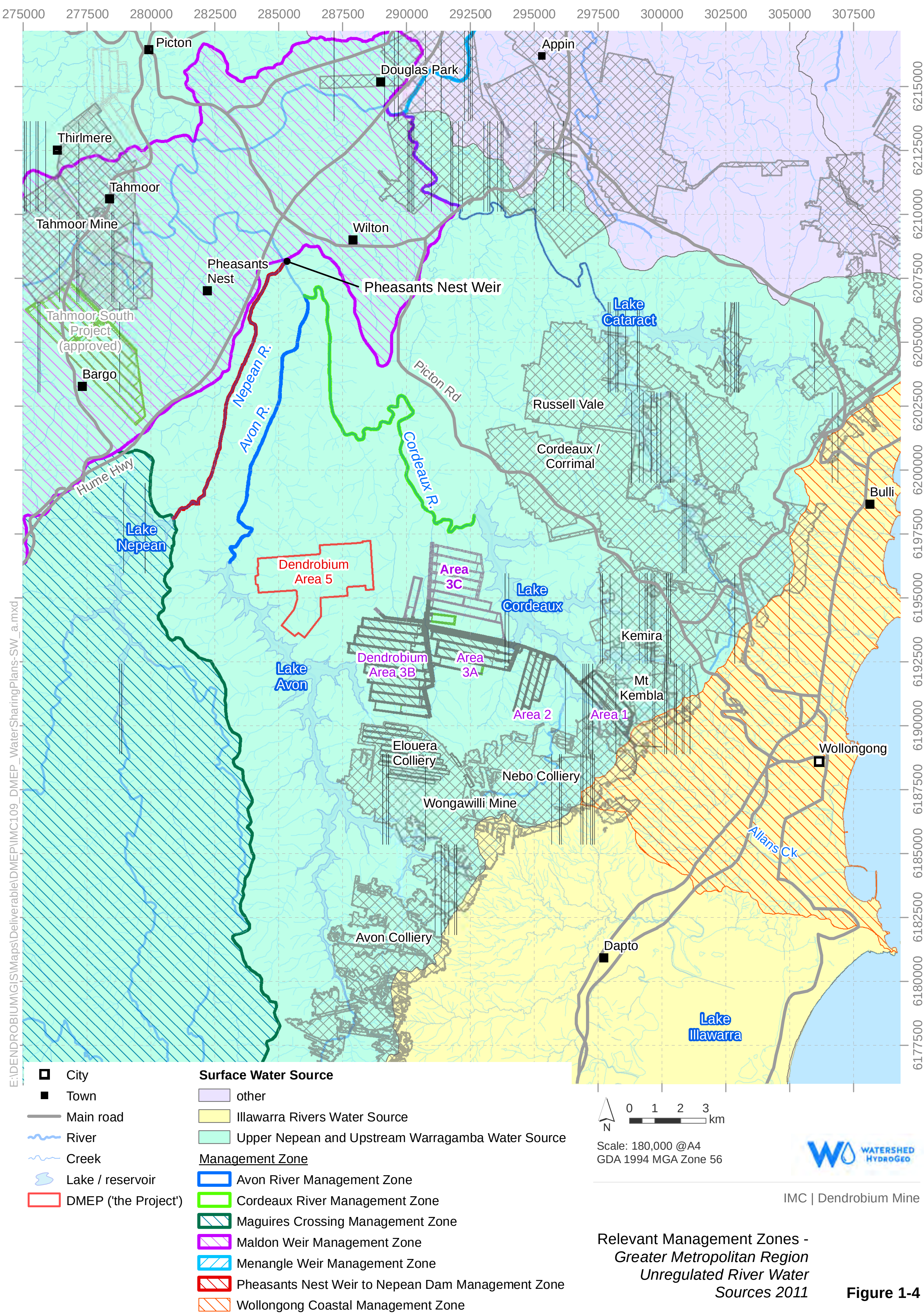
Relevant Management Zones -
WSP for Greater Metroplitan Region Groundwater Sources 2011

Figure 1-3



Relevant Management Zones -
Greater Metropolitan Region Unregulated River Water Sources 2011

Figure 1-4

2. Hydrogeological setting

2.1 Topography

Dendrobium Mine is located on the Woronora Plateau inland of the Illawarra Escarpment (Figure 2-1). The escarpment rises from the coastal plain to elevations in excess of 400 metres Australian Height Datum (mAHD) around Dendrobium. On the plateau, topography generally slopes to the north or northwest, toward the centre of the Sydney Basin. However, the plateau is dissected with the larger river valleys incised to between 50 m and 100 m into the terrain. In Area 5, ground elevation ranges between 330 mAHD (northeast corner of Longwall 510) to 440 mAHD (ridgelines above Longwalls 507 and 508 edge), averaging approximately 400 mAHD.

To the east of Area 5, the elevation of Donalds Castle Creek is 330 to 300 mAHD where it passes Area 5 from south to north. In the west, the elevation of Avon River is 265 to 250 mAHD from the Avon Dam wall to a point approximately 1 km downstream of Area 5. To the southwest and south, the thalweg of the Avon River valley was at 320 down to 270 mAHD, but has been flood behind the dam wall.

The elevation of the two Dendrobium portals, is approximately 127 mAHD (Kemira Valley portal) and 203 mAHD (Dendrobium Portal) (Figure 2-1). These are both lower than the lowest topographic elevations near to Area 5, as described above.

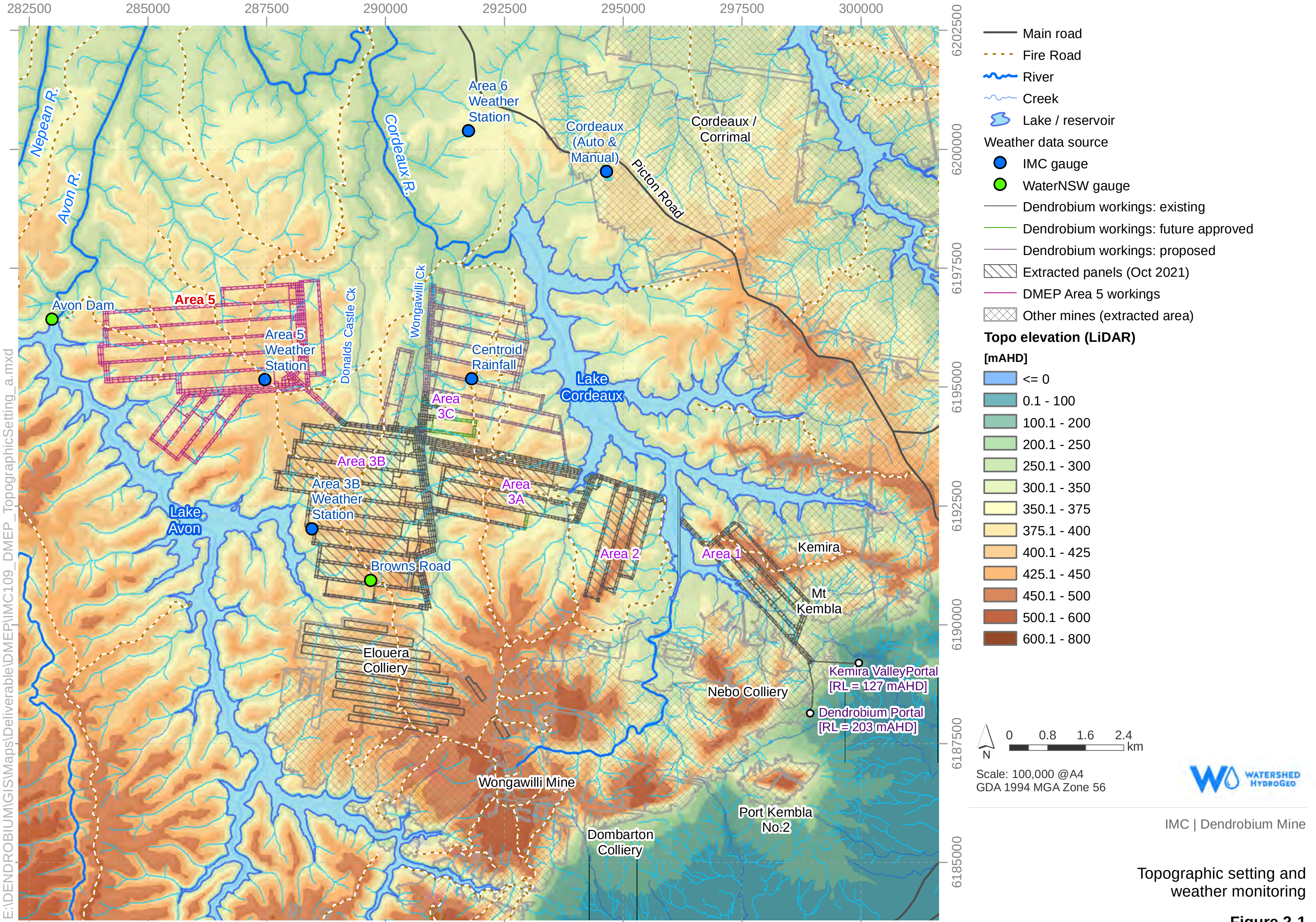
2.2 Climate

Weather (rainfall) data have been collected at the Dendrobium Mine since 2003. Dendrobium's rainfall monitoring sites are shown on Figure 2-1. This is supplemented at times by data from WaterNSW, and also from the Bureau of Meteorology (BOM)/SILO service, which provides access to long-term data and to other parameters, including temperature and potential evaporation.

Mean annual rainfall between 2002 and 2021 was 1050 mm (2.9 mm per day [mm/d] on average). Long-term averages (LTA) from SILO data for 1900-2021 are 1165 mm/yr for the area around Dendrobium Area 3A/3B and slightly lower (1074 mm/yr) around Area 5.

Rainfall decreases westward away from the Illawarra Escarpment. Picton, located 20 km to the northwest of Dendrobium, records an average annual rainfall of 801 mm (1880-2020). At Dendrobium, rainfall tends to be higher in the summer and early autumn months. It is common for a substantial proportion of the annual rainfall to be delivered in one or two large rainfall events (>150 mm), as has occurred in both 2020 and 2021, during which significant surface water runoff and groundwater recharge are generated.

Figure 2-2 shows rainfall trends at Dendrobium as derived from SILO rainfall data as shown by the Cumulative Rainfall Residual curve (CRR). This figure shows the occurrence of significant dry and wet periods from 1900 (where the CRR curve trends downwards and upwards, respectively), including the Millennium Drought and the severe 2017-2019 drought (also shown on Figure 2-3). Rainfall in 2020 and 2021 was well above average resulting in significant recovery of surface water flows and soil moisture storage.



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Topographic setting and weather monitoring

Figure 2-1

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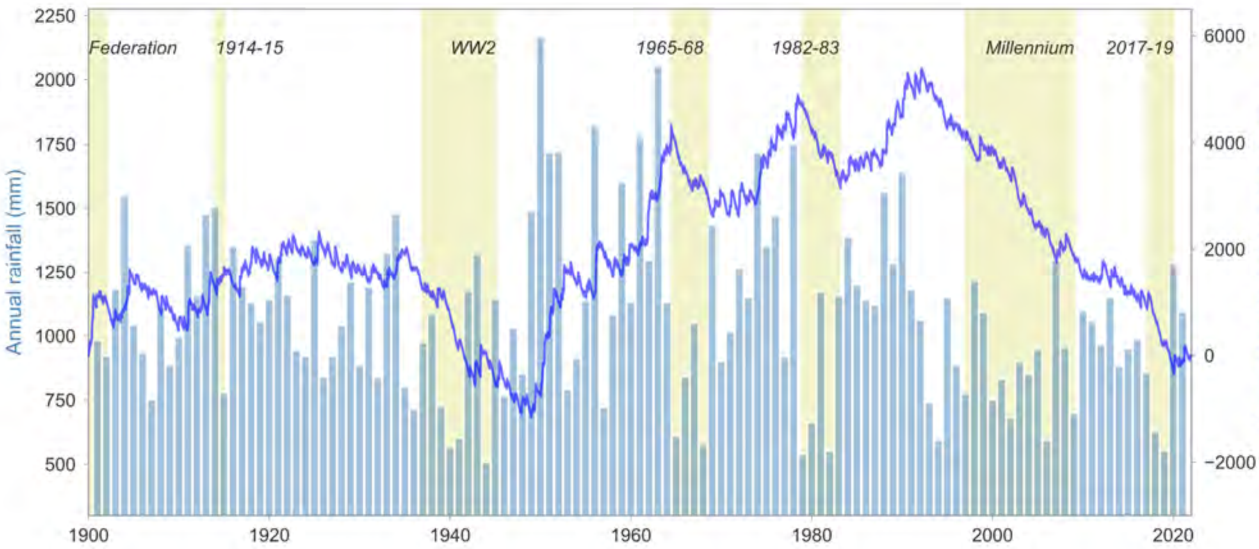


Figure 2-2 **Rainfall and evapotranspiration trends (SILO data at Dendrobium)**

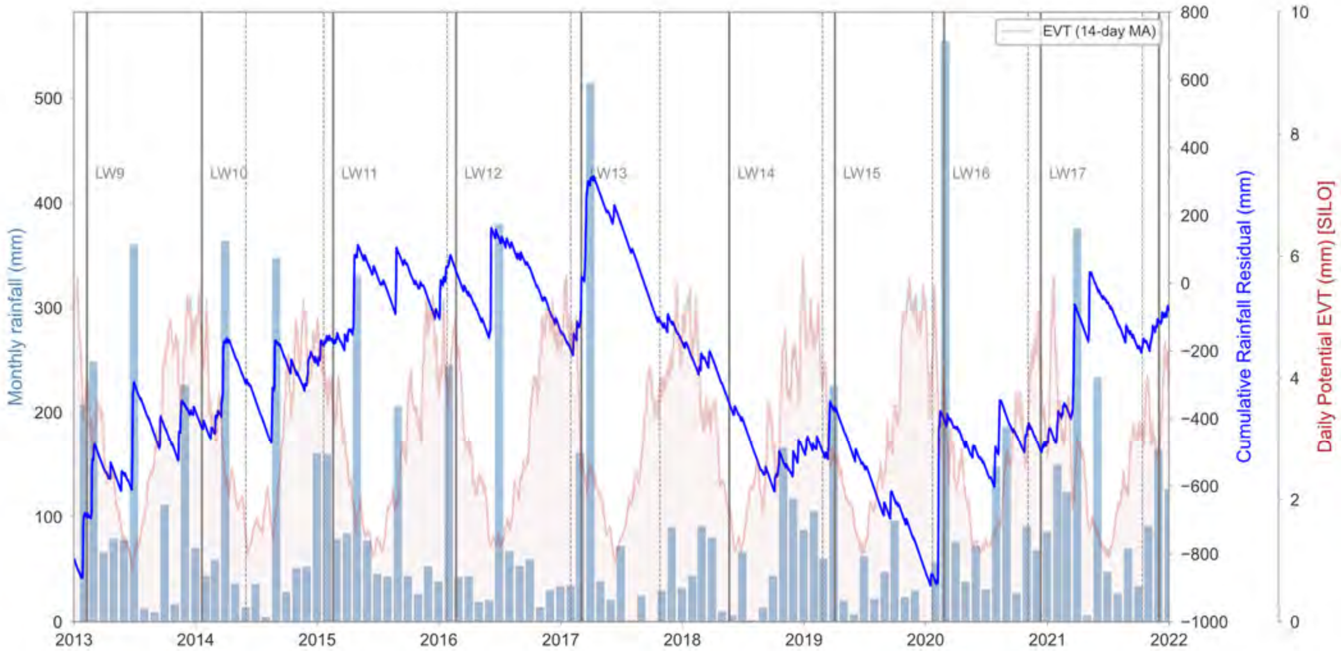


Figure 2-3 **Rainfall and evapotranspiration trends (SILO data at Dendrobium)**

Maximum daily temperature varies seasonally from approximately 20°C in the winter months (June – August) to 40°C or higher in the summer (December-February). Evapotranspiration also varies seasonally in line with temperature and solar radiation, peaking during the summer months. Potential evapotranspiration (PE) is approximately 1430 mm/yr at Dendrobium, and slightly higher at Wollongong on the coast (1520 mm/yr). Actual ET at Dendrobium is approximately 920 mm/yr. Based on average conditions, there is a slight excess in rainfall relative to PE in late summer, autumn and winter, whereas there is a rainfall deficit in spring and early summer.

2.3 Land use

Land above or surrounding Dendrobium longwall areas is mainly reserved as part of Sydney's drinking water supply catchments, WaterNSW's 'Special Areas', as shown on Figure 2-1. This includes the major reservoirs of the upper Nepean system (Section 2.4.5). These catchment areas are primarily native forest with some areas of swamp vegetation.

The Upper Nepean State Conservation Area is coincident with part of the Special Area, and at its closest is located over 1 km to the west and 600 m to the north of Area 5.

Cleared areas or urban areas are restricted to the coastal plain east of Dendrobium Mine (such as the suburbs around Wollongong) or inland (west) of Dendrobium, e.g. Yanderra and Bargo which are 8-10 km northwest of Area 5, and Wilton which is approximately 11 km north of Area 5.

Mining is present within (under) and on the fringes of the WaterNSW "Metropolitan Special Area" at a number of historical and current mines, as noted in Section 1.6 and on Figure 1-1.

2.4 Drainage

The Dendrobium mining area is located within the catchment of the Upper Nepean River. Drainage is to the north-northwest, towards the Nepean River, with most of the local surface runoff initially captured in Nepean, Cordeaux, Avon, and Cataract lakes, before eventually flowing into the Nepean River. Additional information on these lakes (reservoirs) is presented in Section 2.4.5.

Approximately 40% of proposed Area 5 workings lies within (beneath) the catchment of Lake Avon, a further 35% within the catchment of the regulated Avon River downstream of the lake, and the remaining 25% within the surface water catchment of Donalds Castle Creek, which is tributary to the Cordeaux River (downstream of Lake Cordeaux).

Figure 2-4 shows the watercourses around Dendrobium, including named watercourses (e.g. Donalds Castle Creek), and the tributaries identified e.g. (DC9, AR31, LA13; where "DC" refers to a tributary of Donalds Castle, "AR" is Avon River and "LA" is Lake Avon respectively).

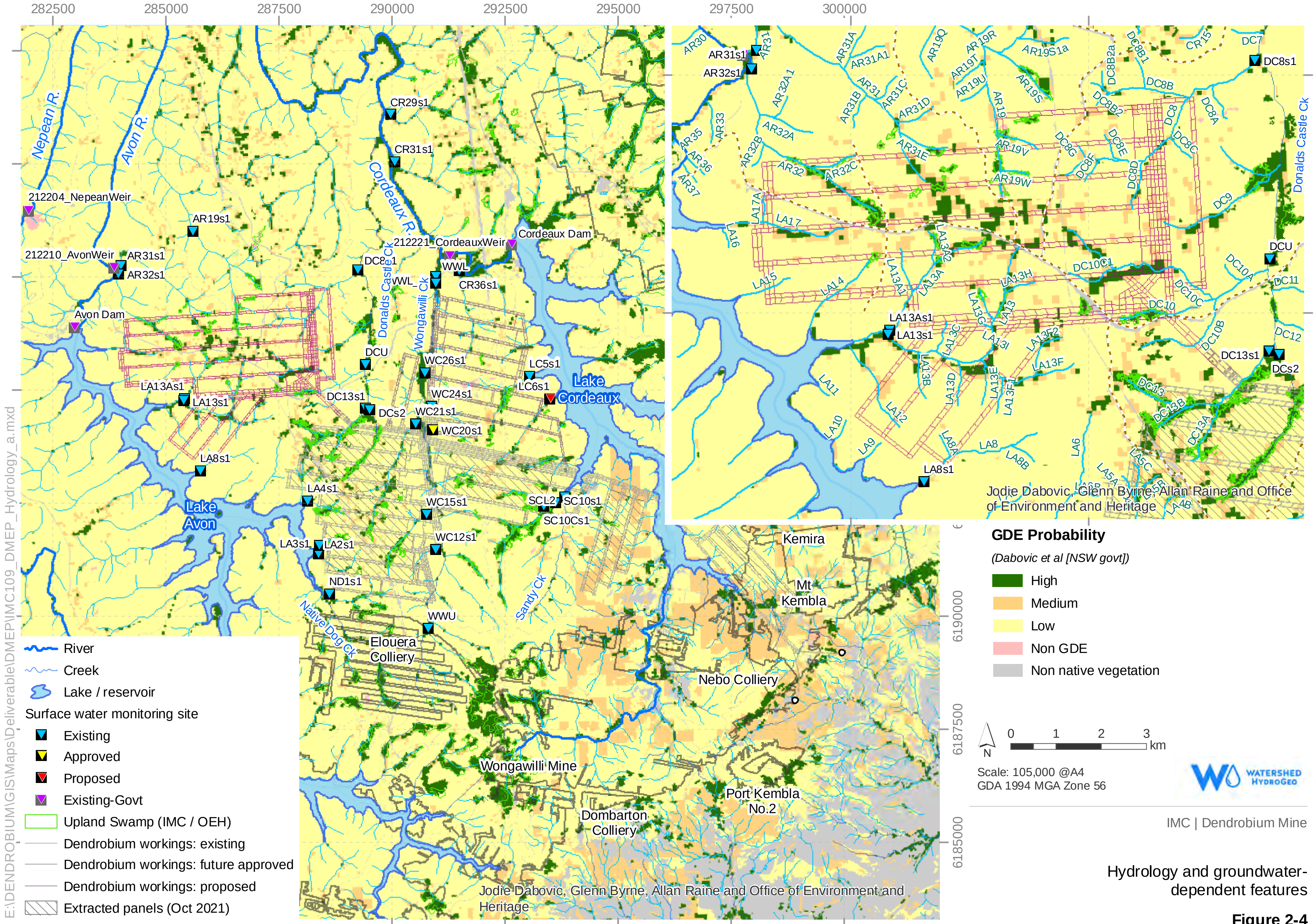
This allows identification of those sub-catchments most likely to be affected by the Project in Area 5. In the main, these are:

- Lake Avon tributaries: LA13 (and LA13A), LA8, LA12, LA14, and LA17.
- Avon River tributaries: AR32, AR19, and the top of AR31.
- Donalds Castle Creek tributaries: DC8, DC9 and DC10.

2.4.1 Monitoring

Surface water flow monitoring sites are marked on Figure 2-4, including operational or active sites and some as-yet un-rated sites and proposed sites around Areas 3B, 3C, and 5. Monitoring sites are to include gauging stations, rated for flow, where appropriate sites can be found (based on morphology and accessibility). Recommendations for further monitoring are in Section 7.2.1 and HEC (2022).

Monitoring includes a selection of sites downstream and within the mining area, as well as sites located away from the mining area to provide control sites and act as a comparison to impact sites. Pools within streams are monitored monthly before and following mining and weekly (when site access available) during active subsidence and in response to any observed impacts.



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Hydrology and groundwater-dependent features

Figure 2-4

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At the time of writing IMC operates 31 stream gauges, 6 rainfall gauges and >250 surface water monitoring/sampling sites at Dendrobium. Surface water monitoring sites fall into four categories:

1. Flow gauge sites at which stream flow is monitored at a calibrated gauge or weir.
2. Water chemistry sites at which samples are collected for laboratory analysis (e.g. DOC, Na, K, Ca, Mg, Filt. SO4, Cl, T. Alk., Total Fe, Mn, Al, Filt. Cu, Ni, Zn, Si), plus field parameters.
3. Water field parameter sites, at which water quality field parameters are measured (pH, Electrical Conductivity (EC), Dissolved Oxygen (DO), Oxygen Reduction Potential (ORP), in addition to water observations.
4. Water observation sites, at which pool water levels and flow status are noted and photographs taken upstream and downstream.

2.4.2 Stream hydrology

Stream level and flow has been monitored by IMC in Areas 3A and 3B since late 2007 (monitoring sites are marked on Figure 2-4). Gauging of streams within and downstream of the proposed mining areas has recently commenced and results are presented in HEC (2022). However, it is necessary to review some of the data as it is relevant to groundwater hydrology.

Hydrographs of flow in selected gauged watercourses from around Area 5 are presented in Figure 2-5. Flows in these watercourses are typically relatively flashy, although there is a baseflow component (Section 2.4.3) that can support flow during periods of low rainfall, as shown by many of these sites with very low (<0.1 or <0.01 ML/d) persisting through much of the severe 2017-2019 drought. Of the Area 5 sites displayed, sites such as AR31, LA8 and DCU were the most persistent through the drought, followed by AR32. The other sites showed more frequent cease-to-flow conditions.

Following the drought, flows responded to the wetter conditions occurring from mid-January 2020 and that persisted through to the time of writing. Peak flows have been in the order of 100 ML/d at some of these sites, but typically in the range 0.1-1 ML/d.

Analysis of groundwater-surface water interaction (baseflow discharge) is discussed in Section 2.4.3, and a brief description of water quality of watercourses is presented in Section 2.8.3 (and more in the Surface Water Assessment (HEC, 2022)).

Mining has occurred beneath some of these monitored catchments and the gauged records show discernible effects of mining (e.g. WC21, DC13, LA4) (see Section 2.4.4).

The End of Panel reports, conducted after each longwall panel, analyse the changes to median flow and the proportion of cease-to-flow days compared to contemporary changes to those same parameters at Reference Sites.

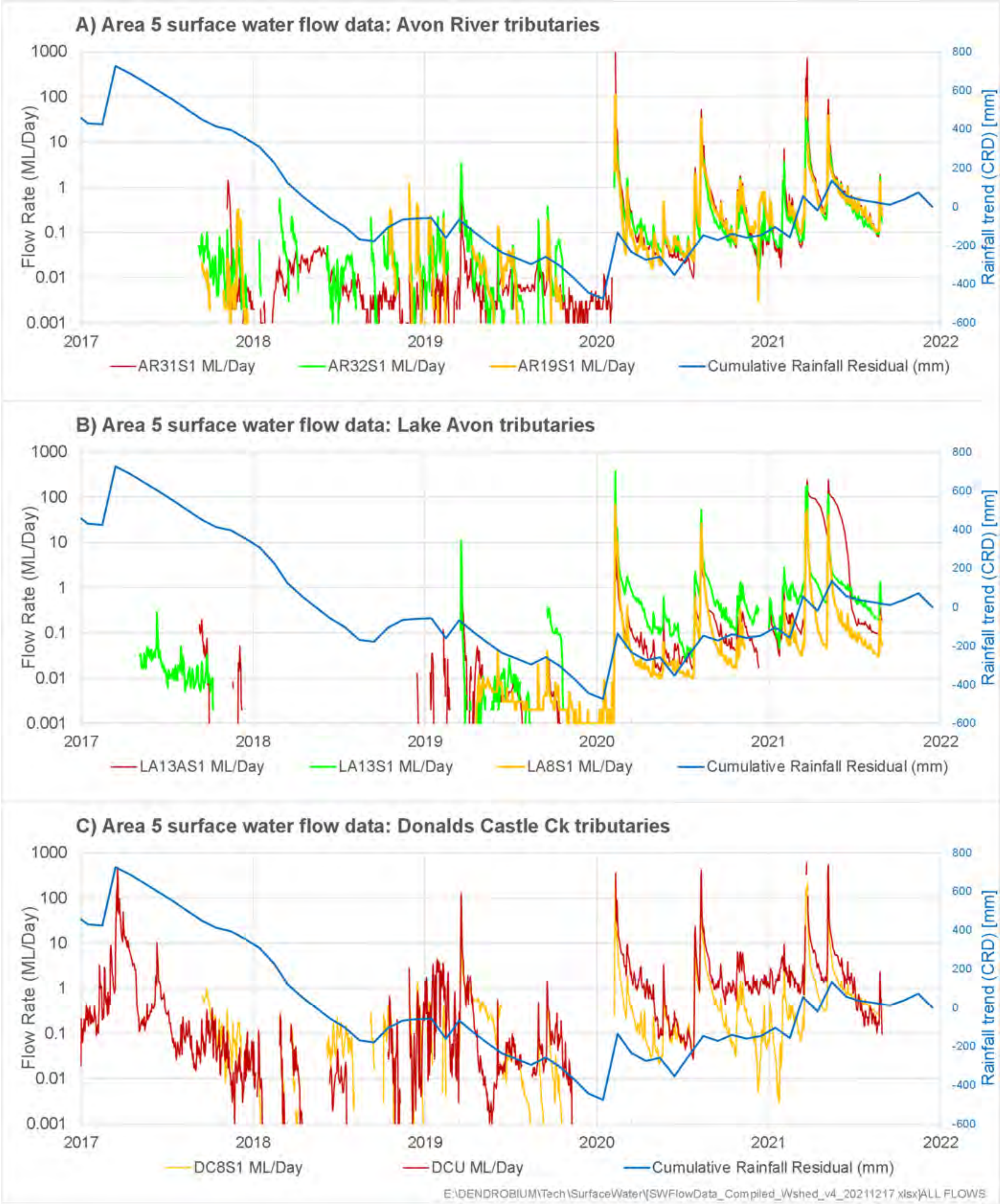


Figure 2-5 Surface water flow data for Area 5

2.4.3 Stream baseflow

Surface water (stream) flow and chloride or electrical conductivity data from some of the gauging stations around Dendrobium has been analysed to assess the baseflow (groundwater discharge) contribution. To do this, two methods have been applied:

- digital filters (also referred as to as analytical methods), such as the HYSEP method (Sloto and Crouse, 1996), which use local minima and 'turning point' concepts; and
- a chloride (or electrical conductivity [EC]) mass balance method, which uses baseflow estimates of river salinity (chloride or EC) data; an estimate of groundwater salinity', and a record of river flows, and combines these in a mass balance approach.

These relative advantages and weakness of these methods are document previously (HydroSimulations, 2019; Advisian, 2016), and key issue is that in our experience, and in the experience of others (Cartwright et al., 2014), chemically-constrained methods provide more conceptually-appropriate and reliable estimates of true baseflow contribution to watercourses.

As noted by Cartwright et al, there are uncertainties inherent in all methods, and we have used a range of end-member chloride or EC values to provide a range in the baseflow estimates, as summarised in Table 2-1. The latter three entries are for sub-catchments within Area 5.

AR19 and AR32 are the largest of the monitored sub-catchments draining Area 5. The % BFI estimated for these catchments, and for the smaller LA8 sub-catchment, are similar to those analysed for the slightly higher rainfall catchments in Areas 3A and 3B (Sandy, Wongawilli, and Donalds Castle Creeks), suggesting that the rainfall-runoff-baseflow relationships are similar in the Project area to those above historical Dendrobium Mine areas. The baseflow yield (mm/yr) are lower for these Area 5 sub-catchments, reflective of lower rainfall and higher evaporation (Section 2.2).

It is worth noting that the low BFI at LA8, compared to the higher BFI at AR19 and AR32, are consistent with the mapping of likely groundwater dependence on Figure 2-4, where there are greater areas of green (higher groundwater dependence) along AR32 and AR19, and almost none of LA8.

Table 2-1 Summary of calculated BFI and baseflow yield at Dendrobium

Watercourse	Site	Catchment area (sq.km)	Baseflow index (BFI)	Baseflow yield (mm/yr)	% Long-term average (LTA) rainl
Wongawilli Creek	WWL	20.08	10-16%	31 to 50	2.5 to 4.2%
Donalds Castle Creek	DCU	6.22	1-6%	1.5 to 10	0.1 to 1%
Sandy Creek	SCL2	7.03	8-20%	22 to 54	1.8 to 4.5%
AR19	AR19S1	3.53	7-11%	6 to 9	0.6 to 1%
AR32	AR32S1	2.96	10-16%	5 to 8	0.5 to 0.8%
LA8	LA8S1	0.93	2-5%	5 to 12	0.5 to 1.2%

source: E:\DENDROBIUM\Tech\Baseflow\Summary_2021.xlsx

Conceptually, it is plausible that swamps contribute some baseflow to downstream watercourses; however, the significance of that baseflow would be dependent on swamp-specific factors (swamp size or area, sediment type, position in the catchment), catchment-specific factors (topography, slope, geology, rainfall). Also, the thickness of swamp deposits also limits the volume of water that can be stored in them, despite their higher porosity, and also means that much of the stored water lies within or near the evaporation extinction depth (essentially, the root zone). In the past, Watershed HydroGeo has attempted to quantify the baseflow contribution from swamps, compared to that from the

Hawkesbury Sandstone, using the down-catchment surface water flow data, however the effects or role of swamps could not be identified with any confidence. More focussed and detailed water balance studies on Upland Swamps in this area are in progress by UNSW/WRL.

2.4.4 Effects of mining on stream flow

More detail on the effects of mining is provided in the Surface Water Assessment (HEC, 2022), as well as the Surface Water End of Panel reports (HGEO, 2019, 2020a, 2021a, 2022a), however the processes are relevant to the Groundwater Assessment and a brief discussion is provided here.

As noted above, some of the gauged watercourses have been mined under and exhibit effects due to that mining, e.g. DCS2, LA4, among others (see Figure 2-6A and B). Changes in median flow, due to the effect of Dendrobium Mine, are calculated via comparison with Reference sites (i.e. O'Hares Creek and upper Wongawilli Creek site WWU) after each longwall, are summarised in Table 2-2. Locations are shown on Figure 2-4, other than O'Hares Creek, which is located 25 km north of Dendrobium Mine.

Table 2-2 Summary of accumulated change in median flow due to mining

Subcatchment	Range in losses	Subcatchment	Range in losses	Subcatchment	Range in losses
SC10C	-0.150	SC10	-0.144	SCL2 / 2122205	-0.115
WC21	-0.100 to -0.166	DC13	-0.080 to -0.091	LA4	-0.016 to -0.040
WC15	-0.019 to -0.070	DCS2	-0.059 to -0.080	LA3	-0.006 to -0.060
WC12	+0.012 to +0.014	DCU	+0.096 to +0.140	LA2	-0.006 to -0.011
WWL	+0.083 to +0.018				

Units: ML/d — Range is min-max from End of Panel reports for Longwalls 14, 15, 16, 17, except for Sandy Creek sites which have only been assessed in Longwall 17 report.

-ve values show a reduction in flow/. +ve values show an apparent increase in flow compared to Reference Site flows.

Figure 2-6A shows the flow record at DCS2. Prior to Longwall 9, flow at DCS2 (red series) were of a similar magnitude, but slightly lower, to the reference site WWU (green series). Following the passing of Longwall 9 in mid-2013, the magnitude of flow at DCS2 declined further below the WWU series. From 2014, the frequency of cease-to-flow events increased, including an extended period during much of 2018. This is a result of reduced baseflow into the creek above the gauging station. Assessment in the End of Panel reports has shown that the reduction in flow is equivalent to 45-80% of median flow, where this can vary in each reporting period due to additional longwalls being extracted as well as the effect of wetter or drier conditions. In the last two years, flows have been more reliable with higher rainfall, however the greater difference between the magnitude of flows at DCS2 and WWU, compared to that of the pre-mining period, persists.

Figure 2-6B shows the flow record at LAS1. Prior to 2015, flow in tributary LA4 (red series) were of a similar magnitude, but slightly lower, to the reference site WWU (green series). Following the passing of Longwall 11 in early-2015, the magnitude of flow at LA4S1 declined further below the WWU series. From 2015, the frequency and duration of cease-to-flow events increased. There was a period of no monitoring in 2019-21 due to equipment failure and extended dry conditions. Altered flow conditions are evident, even in the wetter 2021 monitoring record, where the flows spike above WWU, but then recede rapidly to below the WWU series. Assessment in the End of Panel reports has shown that the reduction in flow is equivalent to 40-60% of median flow.

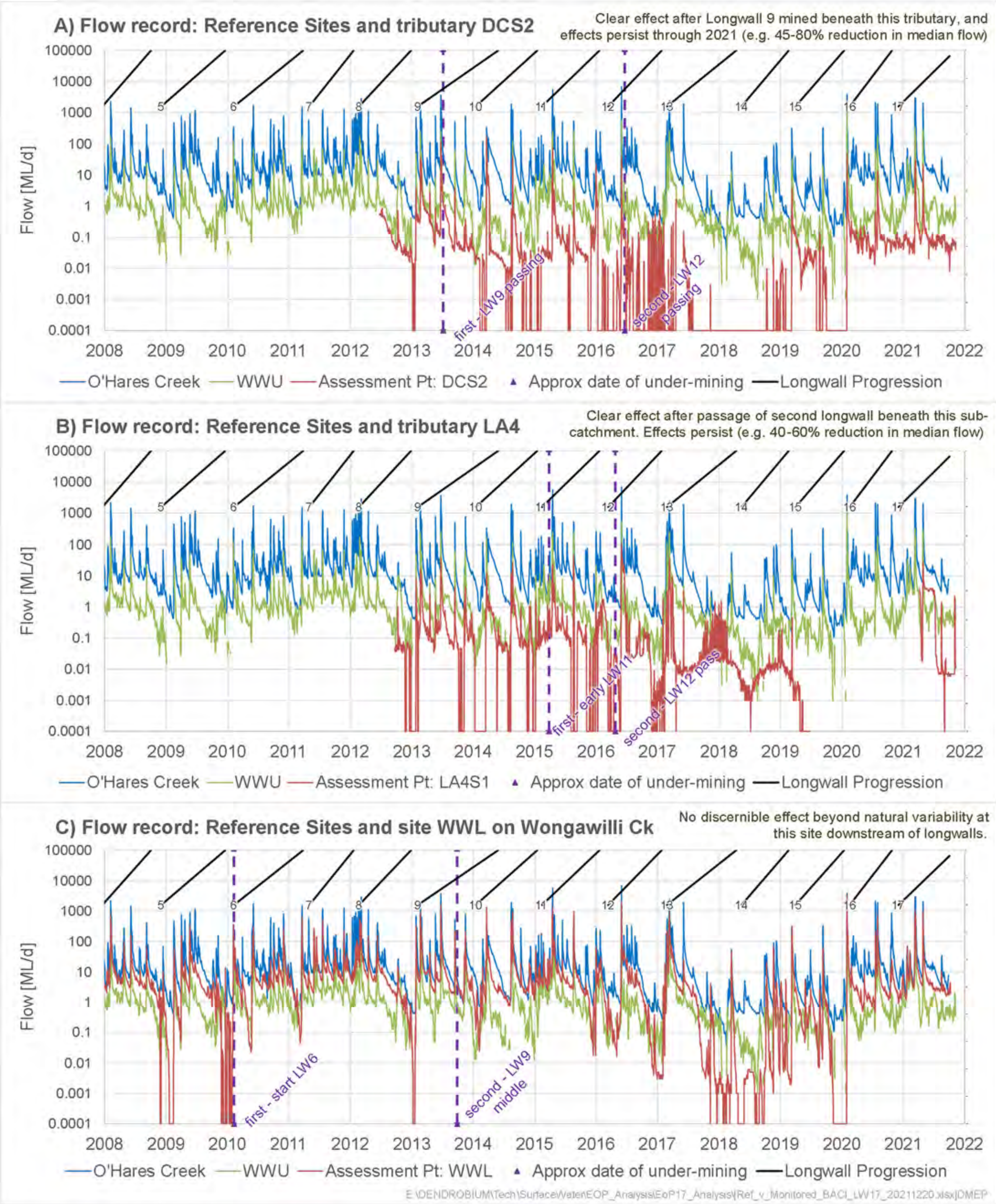


Figure 2-6 **Comparison of pre- and post-mining flows in Area 3B**

At both sites, the frequency of cease-to-flow has increased due to the mining (increased by 35% of the time at DCS2, 22% at LA4S1 based on the most recent End of Panel report (HGEO, 2022a)). Similar increases have been assessed at most sites around Area 3B.

Figure 2-6C shows the flow record for site WWL on Wongawilli Creek. This site is 3.5 km downstream of past mining in Areas 3A and 3B. Visually (from the hydrographs), and statically, there is no evidence for reduced flows at this site. This result has been assessed and reviewed multiple times in End of Panel reports (both through comparison with Reference Site flows and via comparison with rainfall-runoff modelling).

These effects described above for DCS2 and LA4 and tabulated in Table 2-2 are due primarily to fracturing of the creek bed. Similar cracking effects have been observed in creeks offset from longwalls, notably some cracking in WC15 [initially without observed flow diversion (HGEO, 2019) and subsequently with a clear effect on flow (HGEO, 2022a)] and in tributary LA4 at about 290 m from mining [with loss of flow (HGEO, 2019)].

Also, some watercourses which are not directly overlie longwalls but are near to longwall areas, show the effects of baseflow capture (Watershed HydroGeo, 2018; HGEO, 2019). Under average or wet conditions (such as those in 2020-2021), the effects are not apparent (HGEO, 2021b), but during drought conditions such as the severe rainfall deficit during 2017-18 (Section 2.2), the effect may be revealed. In essence, the magnitude of baseflow capture is small compared to average flow, but may result in a loss of flow that is significant at low flows, even enough to result in the cessation of overland flow while dry conditions persist.

As noted in the most recent End of Panel report (HGEO, 2022a), clear reductions in flow are evident when inspecting the hydrograph from site SC10C above Area 3A. However, analysis of the hydrograph suggests that the significant effects (reductions of approximately 0.08-0.015 ML/d) were evident during 2011-2016 (up to 5 years following mining), but these effects have declined and in the period 2017-2021, effects are not discernible from natural variability, suggesting recovering of the shallow groundwater system. This observation is consistent with local groundwater levels, and with the increased emergence of iron-staining and floc in this watercourse (Section 2.8.3).

As discussed in recent End of Panel reports (HGEO, 2022a) and in reviews of earlier reports (McMahon, 2015), while the loss of surface flow observed in the streams such as WC21, DC13S1, DCS2 is significant enough to be discernible on hydrographs for those streams, changes in surface water flow at downstream gauges are either very mild, as at DCU), or not discernible, as at the WWL site in the lower reaches of Wongawilli Creek (HGEO, 2022a), as briefly noted above in reference to Figure 2-6C. This suggests that flow may be lost from streams above or near to longwalls into shallow groundwater systems and then returned to the creek further downstream away from longwalls. A similar conceptual model is considered plausible for Wongawilli Creek (and all creeks around Dendrobium Area 3), i.e. losses were clearly identified at WC21 and WC15 but no flow losses were detected (beyond natural variability or error) at WWL. The findings for WC21 and WC15 is considered less reliable because the scale of losses in the Wongawilli Creek headwaters is small compared to the overall magnitude of flow at WWL. Accuracy of measurement and natural variability may mask the transmission of those losses downstream from the headwaters.

Tracer testing was carried out at WC21 in late 2021 to assess if and where flow re-emerges downstream following diversion into subsidence-induced fractures. The investigation is ongoing and will be reported on later in 2022.

Therefore the current understanding of returned flow remains in line with earlier assessments in respect of observed loss of surface flow and possibility of re-emergent flow, e.g.: "*Effects (baseflow losses) are not clearly observed in the downstream catchments to Donalds Castle Upper (DCU) and*

Wongawilli Creek Lower (WWL); this suggests that some or all flow lost in the headwater catchments is returned downgradient, but is not conclusive, as evapotranspiration (ET) might account for some fraction of that." (HydroSimulations, 2016).

This understanding is routinely re-assessed during the End-of-Panel process. The current understanding, supported by the latest End of Panel report (HGEO, 2022a), is in agreement with both the findings on longwall-induced alteration of habitat by the NSW Scientific Committee and with work on Waratah Rivulet, e.g. Mclean *et al*. (2010). The NSW Scientific Committee states: "*If the coal seam is deeper than approximately 150 m, the water loss may be temporary unless the area is affected by severe geological disturbances such as strong faulting. In the majority of cases, surface waters lost to the sub-surface re-emerge downstream*". (OEH, 2011). For context, the coal seam at Dendrobium Area 3B is typically >350 m deep, but is approximately 240 m deep under Wongawilli Creek. In Area 5, the Bulli seam is typically 320-370 m deep (Table 1-6).

2.4.5 Storage reservoirs

Avon Reservoir, Cordeaux Reservoir and Nepean Reservoir are water supply reservoirs or lakes formed by the damming of the upper Avon, Cordeaux and Nepean Rivers. These form part of the Upper Nepean Scheme (along with Cataract Reservoir) within the water supply network for Sydney and the Illawarra. WaterNSW manages the water supply areas and infrastructure, with additional oversight by the NSW Dams Safety. Key parameters are summarised in Table 2-3, including the elevation of the Full Supply Level (FSL).

Table 2-3 Water supply reservoirs near Dendrobium

Reservoir	Area (sq.km)	Catchment area (sq.km)	Operating Capacity (ML)	FSL (mAHD)	Deepest bed depth (mAHD)	Stratigraphy intersected (from Moffitt, 1999 and IMC geology model)
Avon	10.5	142	146,700	320.18	253.4	Hawkesbury Sandstone, and possibly the Bald Hill Claystone in the base of the reservoir.
Cordeaux	7.8	91	93,640	303.9	255.8	Hawkesbury Sandstone, Bald Hill Claystone, Bulgo Sandstone, Stanwell Park Claystone, Scarborough Sandstone
Nepean	3.3	320	67,730	317.25	247.2	Hawkesbury Sandstone, Bald Hill Claystone, Bulgo Sandstone.

FSL = Full Supply Level. Reservoir data from: http://www.waternsw.com.au/supply/visit/
Bathymetry data obtained from WaterNSW.

As shown on Figure 2-4, Area 5 is immediately north and east of the northern section of Avon Reservoir. The average lateral distance between the edge of Area 5 longwalls and Lake Avon FSL is about 400-600 m. The nearest of the proposed Area 5 longwalls to Lake Avon are 300 m away (Longwalls 501-503, 508 and 509) at their nearest point. The western edge of Area 5 is located 3.5 km east of Lake Nepean.

Cordeaux Reservoir is located 220 m west of Area 1 longwalls and 270 m east of Longwall 3 in Area 2. This reservoir is located over 4 km east of proposed Area 5 longwalls. The Sandy Creek arm of Lake Cordeaux is 380 m east of Longwall 6 in Area 3A. Lake Cordeaux's FSL is 303.9 mAHD.

Surrounding shallow groundwater levels are typically higher in elevation, resulting in groundwater discharging to the lake (Section 2.6.2, Figure 2-18), although this is not always the case, and dependent on which geological formations are present along the lake shore and beneath the lakes.

Drawdown in units at or below the base of the lakes can result in a reduction in hydraulic gradients and the associated groundwater inflows to the lake, and eventually to a reversal of the groundwater gradients leading to fluxes out of the lake and into groundwater.

Review of WaterNSW's annual inflow data for 1909-2015 for Avon indicates that annual inflow ranges 6,005-279,000 ML (16.5-765.4 ML/d), averaging 68,875 ML/yr or 188 ML/d. The average inflow was about 30% less than the long-term average in the last decade of data reviewed.

Inspection of the accounts for other years (e.g. 2013) suggests similar magnitude evaporative losses, i.e. approximately 8,000 ML for Avon Reservoir and 5,200 ML for Cordeaux Reservoir. These equate to approximately 800 mm/yr lost to evaporation from the Avon Reservoir and 630 mm/yr lost from Cordeaux Reservoir.

Discussion of the empirical risk of the Project to reservoirs is provided in Section 3.1, with numerical model-based estimates of induced leakage from these reservoirs in Section 6.7.

2.5 Geology

Dendrobium Mine is located within the (Southern) Sydney Basin, part of the Southern Coalfield, one of the five major coalfields that lie within the Sydney-Gunnedah-Bowen Basin. Figure 2-7 summarises the stratigraphy of the Southern Coalfield. Figure 2-7 includes abbreviations for the stratigraphic units. In this report, units are typically referred to by their full name in the text but are often abbreviated on figures.

The Basin is primarily a Permo-Triassic sedimentary rock sequence and is underlain by undifferentiated sediments of Carboniferous and Devonian age. The Illawarra Coal Measures are the primary economic sequence of interest in the Sydney Basin, and consist of interbedded sandstone, shale and coal seams, with a thickness of approximately 200-300 m. The two main coal seams mined in the Southern Coalfield are the uppermost Bulli seam and the Wongawilli seam (Holla and Barclay, 2000). The vertical separation between the Bulli and Wongawilli seams is about 30-50 m in the Dendrobium area.

The Illawarra Coal Measures are overlain by Triassic sandstones, siltstones and claystones of the Narrabeen Group (BHP Billiton, 2013), and the Hawkesbury Sandstone (HBSS). The Hawkesbury Sandstone is the dominant outcropping formation across the study site, as shown in Figure 2-8.

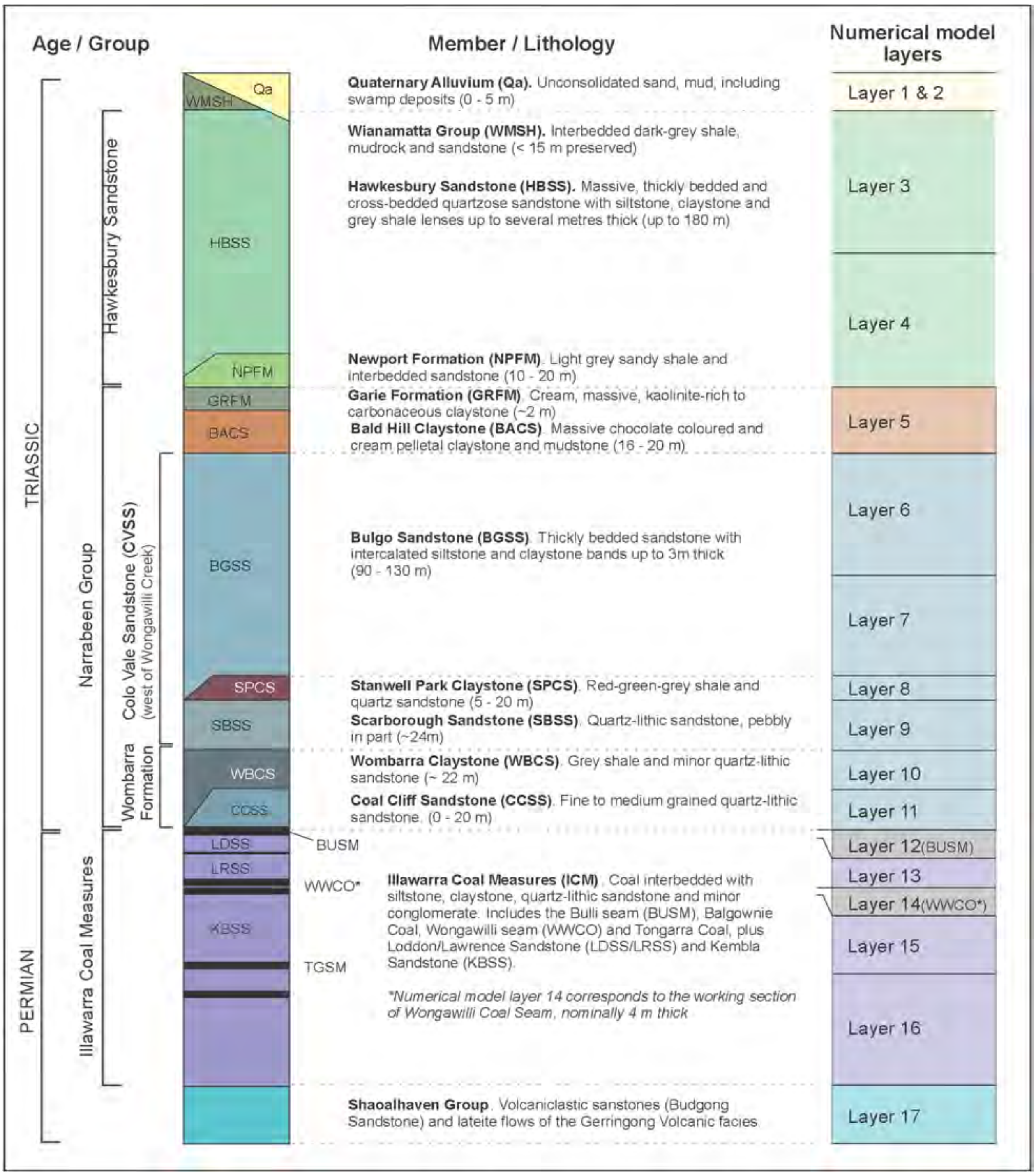
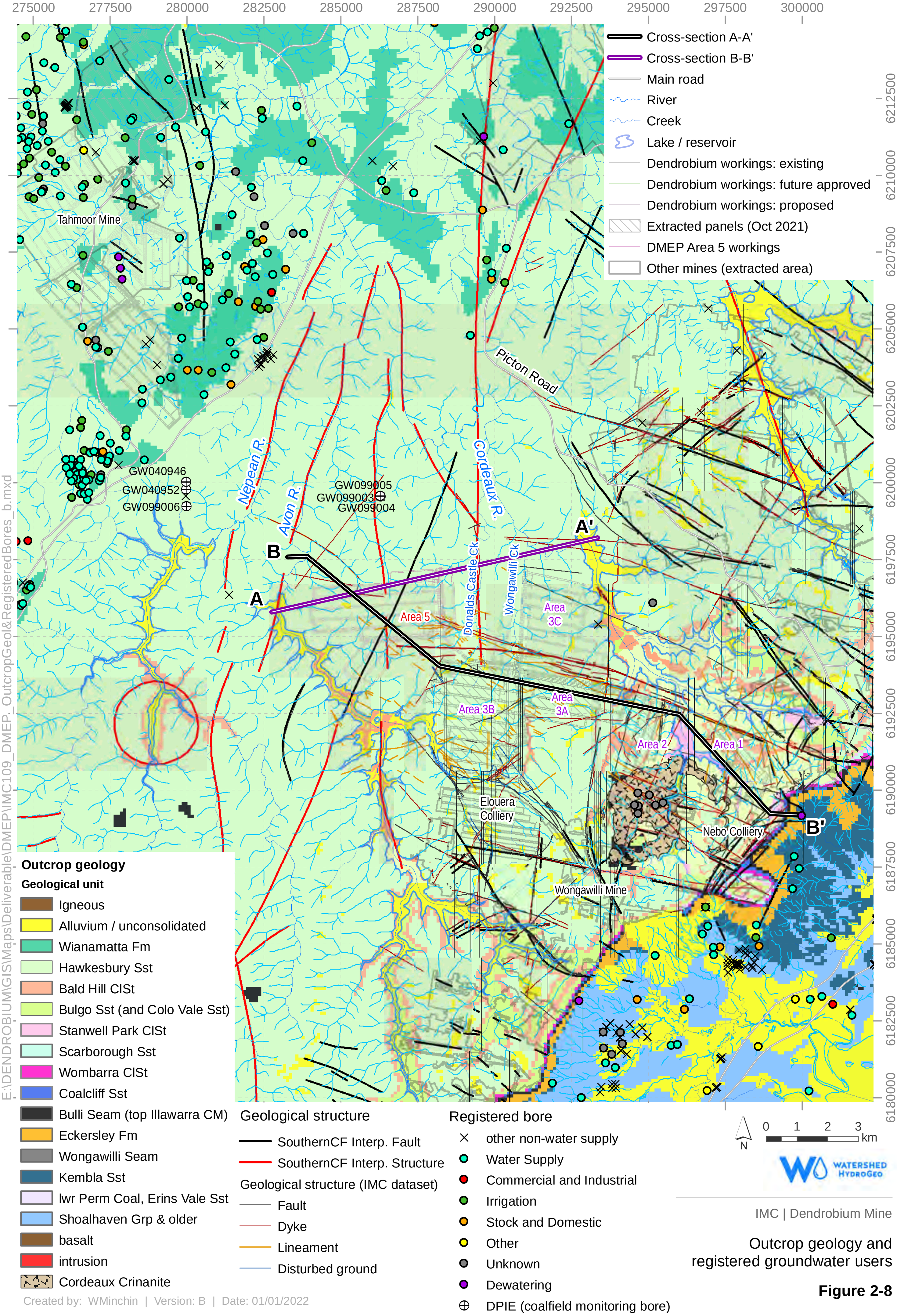


Figure 2-7 Stratigraphy of the Southern Coalfield and model layer framework



IMC | Dendrobium Mine

Outcrop geology and registered groundwater users

Figure 2-8

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This figure is based on the Southern Coalfield Geology map (Moffitt, 1999), updated to reflect local changes based on IMC's data.

To the north of Area 5 are isolated shale cappings of the Wianamatta Group (WMFM). There are also small pockets of Quaternary-aged swamp deposits ('Qs' on the Southern Coalfield Geology map – (Moffitt, 1999), located around the Southern Coalfield, including within Area 5. Mapping of swamp deposits is better viewed on Figure 2-4.

Two geological cross sections through Area 5 and other parts of Dendrobium Mine are shown in Figure 2-9 and Figure 2-10 (cross-section lines plotted on Figure 2-8).

The cross-section on Figure 2-9 illustrates the relative thickness of the Hawkesbury Sandstone and Bulgo Sandstone in relation to the other units, as well as the layered nature of the geological sequence with alternating sandstone and claystone lithologies. Note that the Stanwell Park Claystone is not fully extensive, or at least not sufficiently distinguishable from the underlying Scarborough Sandstone or overlying Bulgo Sandstone across the study area, resulting in 'windows' through this unit, and the more general classification of these three units into the Colo Vale Sandstone in the western part of the Dendrobium lease.

The cross section also shows the degree to which the Avon Reservoir and major watercourses such as Wongawilli Creek and Avon River are incised into the Hawkesbury Sandstone, even intersecting the Bald Hill Claystone in some locations. Other watercourses and features (e.g. Cordeaux Reservoir) nearer the escarpment are hosted in Narrabeen Group units.

Lastly, this cross-section shows the relative elevation of the Bulli and Wongawilli Coal seams between Area 5, through Areas 1-3 to the portals at the escarpment. The lowest parts of the historical Area 3B and proposed Area 3C workings (both Wongawilli seam) are at approximately -10 and -30 mAHD respectively. The lowest part of Area 5 (Bulli seam, offset from the cross-section) is at approximately 170 m elevation difference from Area 5, and 190-210 m difference from Areas 3B and 3C, back up to the mine entry near Area 1.

Figure 2-10 shows that Area 5 workings would be approximately 260 m below the base of Avon Reservoir (along this section line), and generally deeper below the ground surface in the centre of Area 5. There is approximately 150 m of Colo Vale Sandstone present, and the Hawkesbury Sandstone is up to approximately 150-160 m thick, but often thinner where it has been partially eroded.

2.5.1 Coal Seams

At Dendrobium Mine, IMC currently extracts coal from the Wongawilli seam. IMC propose to extract the Bulli seam in Area 5, and the proposed (revised) mine plan has been designed to focus on the highest quality coking quality within the Bulli seam. The Bulli and Wongawilli seams typically occur within a 30-50 m interval at Dendrobium (Figure 2-9 and Figure 2-10). The Bulli Coal seam thickness and depth of cover presented on Figure 2-11. A comparison of thickness and depth of cover for both seams is presented in **Appendix D**.

Figure 2-11 shows that the Bulli seam has a thickness ranging from 2.07 to 3.3 m in Area 5 (within the proposed mine footprint), averaging approximately 2.6 m. A maximum cutting height of 3.2 m is proposed, and it is likely that machinery constraints will mean that the minimum cutting height will be 2.4 m, even in areas where the seam thickness is <2.4 m.

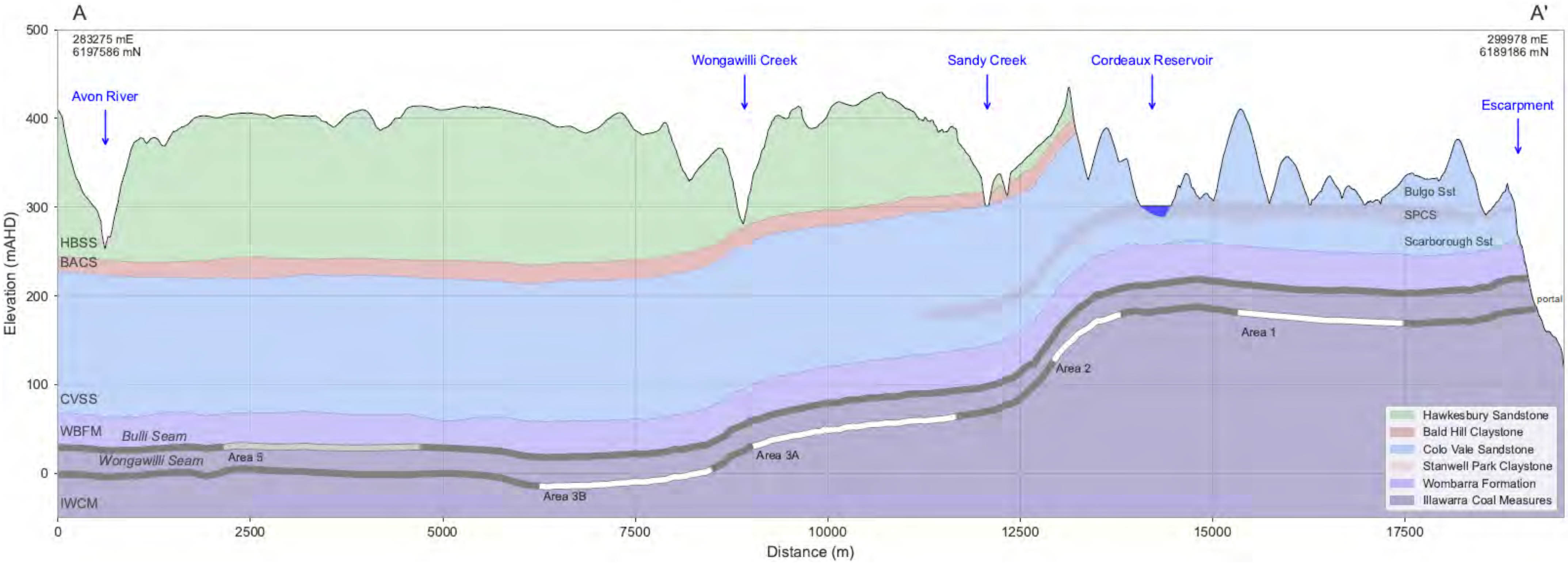


Figure 2-9 **Geological cross-section (west to east) through Area 5 and Areas 1-3B**

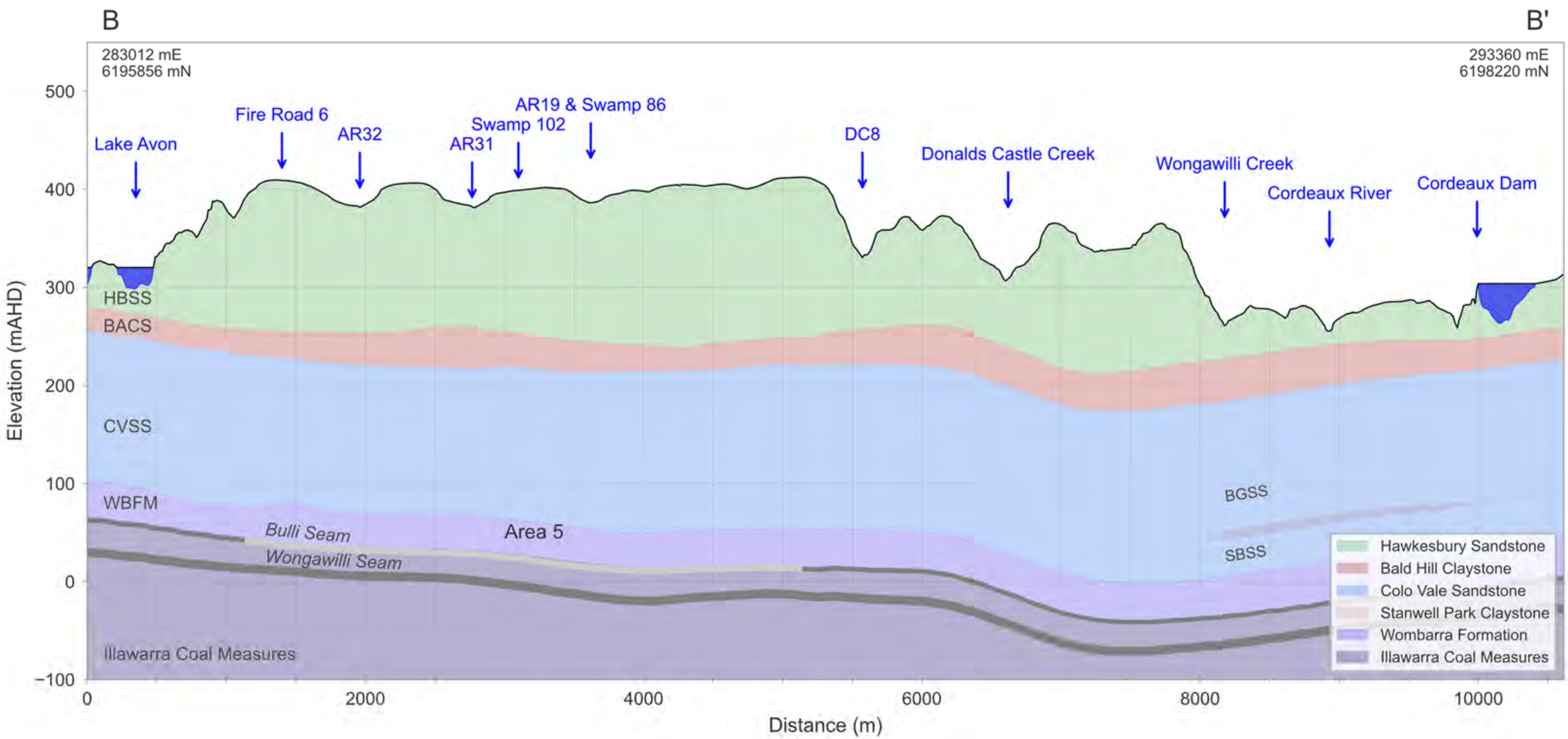
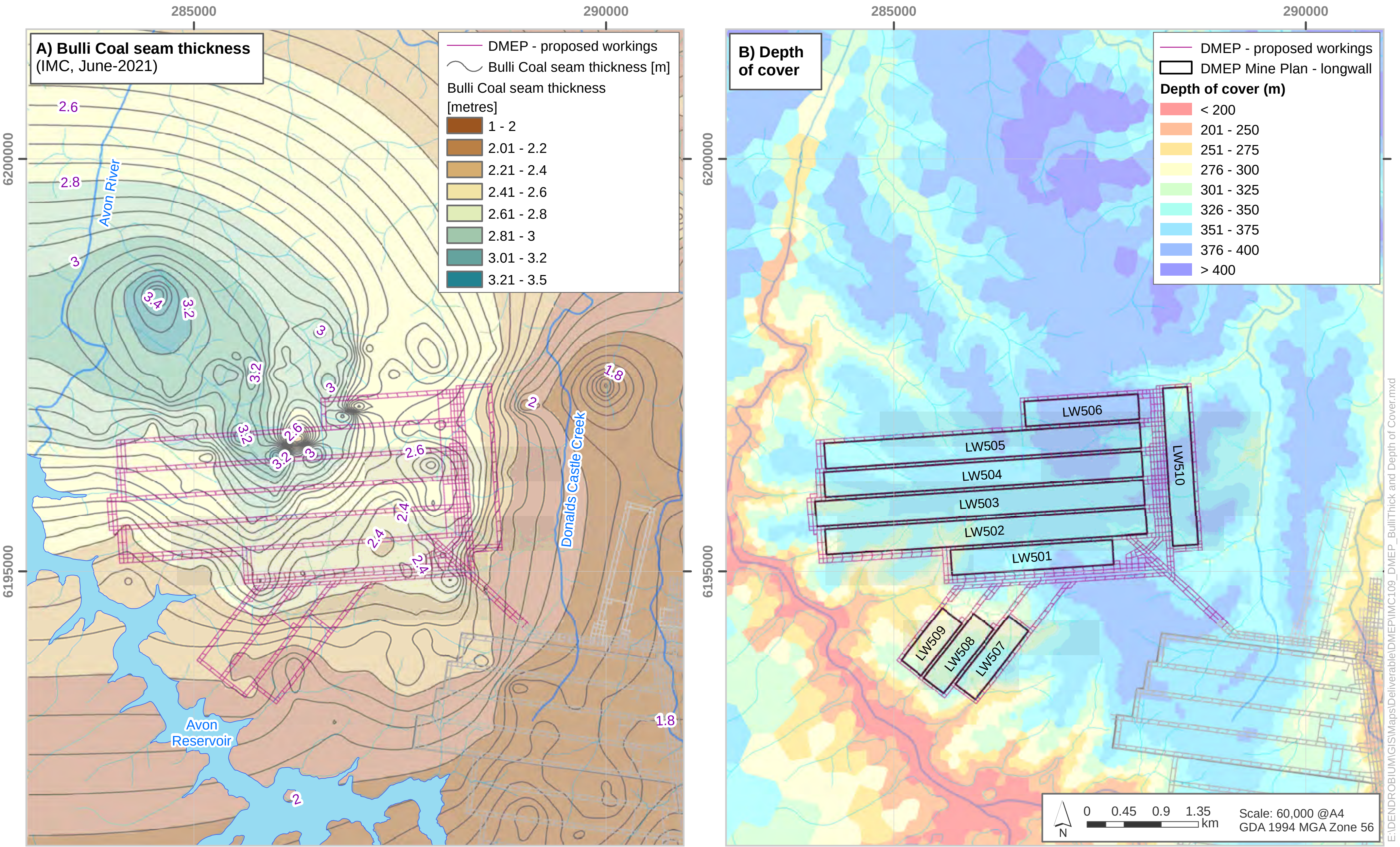


Figure 2-10 Geological cross-section (west to east) from Avon Reservoir to Cordeaux Dam



Rev: C | W Minchin | 07/12/2021

- Lake
- Watercourse
- Tribs
- Dendrobium Mine workings
- Mine workings (future/proposed)
- DMEP - proposed workings

WATERSHED HYDROGEO

DMEP Area 5 mine plan, Bulli Coal seam thickness and depth of cover

Figure 2-11

The Wongawilli seam has a total thickness of 7-10 m; however the working section is typically 3-4 m, with recent and future longwalls in Areas 3A, 3B and 3C having a maximum cutting height of 3.9 m. For modelling purposes, this is calculated from the floor of the deepest Wongawilli ply.

The dip of the Bulli seam is to the north toward the centre of the Sydney Basin with some warps and folds, which are evident in the cross-sections (Figure 2-9 and Figure 2-10). The dip is about 1:50 through Area 5 and somewhat less (1:40) through Area 3C. The figures above indicate the Bulli seam is located from 400 m to about 250 m below surface (see also Table 1-6), with the smallest depth of cover typically present beneath valleys in western part of Area 5, such as beneath LA8 (Longwall 507), LA13A (Longwalls 501 and 502), and LA13 (Longwalls 507-509).

Similar to the Bulli seam, there are some warps and folds in the Wongawilli seam and the regional dip to the north. The dip is similar to that of the Bulli Seam, being about 1:50 through Area 5, and slightly less (1:40) through Area 3C.

The cover depths described here are in excess of the 120 m minimum depth of cover described in DSC (2010) for longwall mining directly under stored waters, while proposed Area 5 longwalls are >300 m from reservoirs (Section 2.4.5).

2.5.2 Structure

Geological structures have been mapped in studies at a variety of scales, e.g. regional mapping (Moffitt, 1999), high level mapping using remote methods, selected borehole records and a walk-over (PSM, 2022), and local-scale mapping by IMC geologists that evolves with mine development.

Figure 2-8 presents regional structure, as mapped on the Southern Coalfield geology map (Moffitt, 1999), as well as the structure dataset provided by IMC geologists. A regional syncline runs through Area 3B and to the east of Area 5, plunging to the north. Several north-south trending lineaments are also present in this area, including the Narellan Lineament, Cordeaux River lineament and Avon River Lineaments – these latter two are near to or pass through Area 5. To the west of Dendrobium there are several 'domes', including the Mount Burke Dome located beneath Lake Nepean. These are usually associated with igneous intrusions (Section 2.5.3).

Lineaments faults and dykes have been mapped around the mine and documented in the Area 5 Structures Review (PSM, 2022). PSM presents structures mapped by a variety of methods along with commentary on the confidence or likelihood of these (e.g. most of the features interpreted from aeromagnetic surveys, as shown on PSM's Drawing 3, "are considered to have a low probability of existing in the field", based on lack of correlation with borehole data).

With respect to faulting, as investigated by seismic surveys, PSM concluded "No significant faulting identified within the Area 5 study area" other than "Four lower confidence normal style fault structures", two of potentially form a small graben (or a sill feature) at the western end of Longwalls 501 and 502.

With respect to lineaments, PSM concluded that "*PSM derived lineaments are based on topographic expressions. No evidence has been identified suggesting these are major geological structures persistent from seam to surface*". Furthermore, the potential for lineaments to be real geological features that re-activate and enhance subsidence or drawdown effects, as observed at mines in the Western Coalfield, has been shown to be minimal at Dendrobium. This is documented in a comparative analysis of structures and subsidence in the two coalfields (SRK, 2020), as well as analysis of effects on swamp water tables (Watershed HydroGeo, 2021a).

With respect to dykes, PSM stated "*There is no evidence supporting the inference of this dyke across Area 5 or extending to Avon Dam or Reservoir. The structure was not observed in cuttings where the* *dyke is projected during the site inspection undertaken as part of this assessment. Based on the lack of direct evidence, the dyke is unlikely to project into the Avon Dam or reservoir from seam to surface*".

PSM present an assessment of structures that could enhance or cause interaction between mining areas and the reservoirs and dams (see Drawing 11 of PSM). PSM concluded "Based on the information provided, there is no strong evidence suggesting there are geological structures persistent from seam to surface which would be affected by Area 5's mine subsidence".

Detailed investigation and mapping of geological structure would be carried out in Area 5 as development extends into these areas, and would be documented within the Extraction Plan / SMP process, as also noted in Section 9 of PSM (PSM, 2022).

An example of the application of this is the significant investigation and subsequent modification to the mine plan (shortened longwall) by IMC at Longwall 18, adjacent to the Elouera Fault and associated secondary structures. The presence of the Elouera Fault was known at the regional scale, but the local-scale nature and geometry of that was not able to be characterised until in-seam drilling and development (roadways) approached the feature.

PSM made a number of recommendations in their Section 10 regarding post-determination investigations in Area 5 (PSM, 2022), particularly relating to the area between Area 5 and Avon Reservoir and Avon River. We agree with these.

2.5.3 Igneous Intrusions

Drawing 9 of the geological structural review (PSM, 2022) presents IMC's mapping of known and interpreted igneous features around Area 5, specifically sills and associated cindering and heat-affected coal below and within the Bulli seam. Other notable intrusions are the Cordeaux Crinanite immediately south of Area 2 (Figure 2-8), as well as sills and associated cindering to the south of Area 3A, north and west of Area 3B (near to Area 5).

2.5.4 Swamp Deposits

The structure and hydrological function of Coastal Upland Swamps have been well studied (Young, 1982, 1986; Fryirs et al., 2014; Cowley et al., 2016). Upland Swamps form on accumulations of sandy and silty sediments on the broad and gently sloping headwater valleys. The geomorphic development of swamps is driven by positive feedback that operates when there is a significant excess of rainfall over evaporation (TSSC, 2014). Overland flow transports detritus from weathered sandstone exposed on the interfluves, which deposits and accumulates in the headwater valleys. High rates of precipitation, runoff and seepage from the sandstone substrate leads to waterlogging and an increased density of groundcover, thereby trapping more sediment and leading to the death of trees that are intolerant of high water tables.

The structure of swamps on the Woronora Plateau is described in literature (Young, 1982; Tomkins and Humphreys, 2006). Young identified four sediment types: Organic fines, organic sands, grey-brown sands and sandy yellow earths (clayey sand). These sediment types are recognised by other authors (Fryirs et al., 2014; Cowley et al., 2016). Measured cross-sections indicate a reasonably consistent structure: A basal layer of grey-brown, medium to coarse sand is overlain by increasingly organic rich sands and organic fines. There is commonly a lateral variation in facies caused by the fractionation of sediments during overland flow such that grey-brown sands accumulate at the swamp margins, whereas finer-grained sediments (silt, mud) and organic material accumulate towards the swamp axis (Young, 1982; Figure 39). Mottling of the sediments is common and indicative of waterlogging. Fibric mats of live and dead organic matter occur at the swamp surface to a depth of approximately 50 cm, providing some protection from erosion during runoff events.

Upland Swamps typically occur in areas where there is a reliable source of water, usually groundwater, in the presence of sediment as described above. Figure 2-4 shows mapping of potential groundwater dependence from the NSW government (Dabovic *et al.*, 2019), and the swamps are typically coincident with the green (high probability of groundwater dependence). We note that the remote-sensing based methodology of Dabovic *et al* detects potential groundwater dependence from all sources, and does not distinguish between groundwater within swamp sediments compared to that derived from the regionally extensive HBSS. Most, but not all Upland Swamps at Dendrobium, are perched above the pre-mining regional (HBSS) water table. Upland Swamps are thought to have a role in the catchment hydrology, primarily by contributing baseflow to streams after rainfall (Section 2.4.3). They are an important trap and storage of nutrients and sediment.

IMC's monitoring of Upland Swamps is described and mapped in Section 2.6.1. More on potential groundwater dependent ecosystems presented in Section 2.7.2.

2.5.5 Regional 3D Geological Model

The geological model provided by Illawarra Metallurgical Coal has been extended laterally beyond the Dendrobium area to form the basis for the groundwater model. This has been done using data from other sources, including the Illawarra Metallurgical Coal bore database which covers Appin, West Cliff, Cordeaux areas (to the north of Dendrobium), Wongawilli/Nebo areas (to the south) and Tahmoor Mine bore data and the regional groundwater model constructed for Tahmoor Mine, to the north-west of Dendrobium.

One result of using the detailed stratigraphic interpretation in the data sources stated above, in combination with detailed topographic information, is that the regional outcrop mapping has been updated in some areas from the published mapping (Moffitt, 1999). The outcropping geological units, based on the 3D mapping, is shown in Figure 2-8, which shows several differences from the Southern Coalfield mapping:

- A greater area where the Bald Hill Claystone and Bulgo Sandstone outcrop around Areas 1 and 2 and near Sandy Creek.
- the Wongawilli Creek valley is incised through the Hawkesbury Sandstone into the Bald Hill Claystone and Bulgo Sandstone between Areas 3A and 3B.

Similar incision through the Hawkesbury Sandstone into the Bald Hill Claystone and Bulgo Sandstone along the axis (thalweg) of the northern part of Lake Avon. While the Southern Coalfield mapping (Moffitt, 1999) suggested this for Lake Nepean, bathymetric data shows that the lake is more incised than the published outcropping mapping suggests. Sediment is likely to have accumulated and accreted behind the dam wall, so there may not be direct exposure of these rock units on the lakebed.

Some of the thicker stratigraphic units have multiple groundwater pressure sensors or piezometers placed in them within a single bore (Sections 2.6.1 and 2.6.2), and these piezometers frequently show some degree of head separation between upper, middle and lower portions of the Hawkesbury Sandstone, Bulgo Sandstone, and sometimes also within the Scarborough Sandstone. For this reason, it will be necessary to split or sub-divide these units for inclusion and representation in the groundwater model (Section 4.3.2).

The rules that have been used to sub-divide the Hawkesbury, Bulgo and Scarborough Sandstone units are as follows:

<u>Hawkesbury Sandstone</u>: this unit is sub-divided into three layers; upper, mid and lower. The lower Hawkesbury Sandstone is defined as the lower 40 m above the Bald Hill Claystone, then the mid Hawkesbury Sandstone was defined as the next 50 m, and the upper Hawksbury Sandstone the

remainder (variable thickness). Where erosion/topography has removed part of the Hawkesbury Sandstone, part or all of these sub-units may be removed (i.e. they are thinner or completely absent).

Bulgo Sandstone: upper and lower layers based on the lower being defined as 50 m above the Stanwell Park Claystone, and the upper Bulgo Sandstone is the remainder (to the base of the Bald Hill Claystone). Again, this is topographically controlled, so that these sub-units may be thinner/absent.

Scarborough Sandstone: earlier studies for Dendrobium sub-divided this unit, but given its depth and lack of interaction with environmental features, especially in Area 5, it is not sub-divided for this study.

These rules have been applied to the geological model, and the intersection of the different portions of these stratigraphic units with ground surface is the basis for the model isopachs in **Appendix G**.

2.6 Hydrogeology

The major hydrostratigraphic units within the study area are the Sydney Basin Permian and Triassic rock units, and within the Nepean Sandstone Groundwater Source these units are classified as 'Highly Productive' by DPIE-Water yet exhibit significant variation in their permeability and porosity.

The reason for the 'Highly Productive' classification is the presence of the Hawkesbury Sandstone. This unit is a thick sequence that is primarily sandstone, but with minor shales, mudstone and clay-rich lenses and horizons. The sandstone lenses have varying grain-size as is typical of a sedimentary sequence laid down under varying conditions. Coffey Geotechnics (2012a) showed detailed geophysical logs which showed variable gamma count, where that high gamma count is indicative of clay-rich horizons or laminae. This lithological variation and the thickness of the unit (up to 200 m thick) mean that although this unit is named as a single stratigraphic unit, it essentially forms a series of layered aquifers, each with a moderate resource potential, tending to higher resource potential where jointing and fracturing (secondary porosity) is more developed.

As a result of the lithological variation, as well as the variable presence of weathering and secondary porosity (i.e. naturally occurring joints and bedding planes) the hydraulic properties, namely hydraulic conductivity and porosity or storage, can show significant variability, as discussed in the following sections.

Bore yields of >5 L/s (which is the threshold for the 'Highly Productive' criteria) are possible, but yield in the area is variable e.g. testing in 2005 of two bores immediately north of Nepean Reservoir (Figure 2-8) by the NSW government produced substantially different yields:

- GW040952: screened 80-145 metres below ground (mBG) in Hawkesbury Sandstone, yield = 26 L/s.
- GW040946: screened 92-148 mBG in Hawkesbury Sandstone, yield = 2 L/s.

The deeper Narrabeen Group and Illawarra Coal Measures have poor groundwater yields and are generally unproductive.

2.6.1 Groundwater monitoring

Groundwater monitoring locations are described in the following section. Surface water monitoring sites are presented in Section 2.4.1

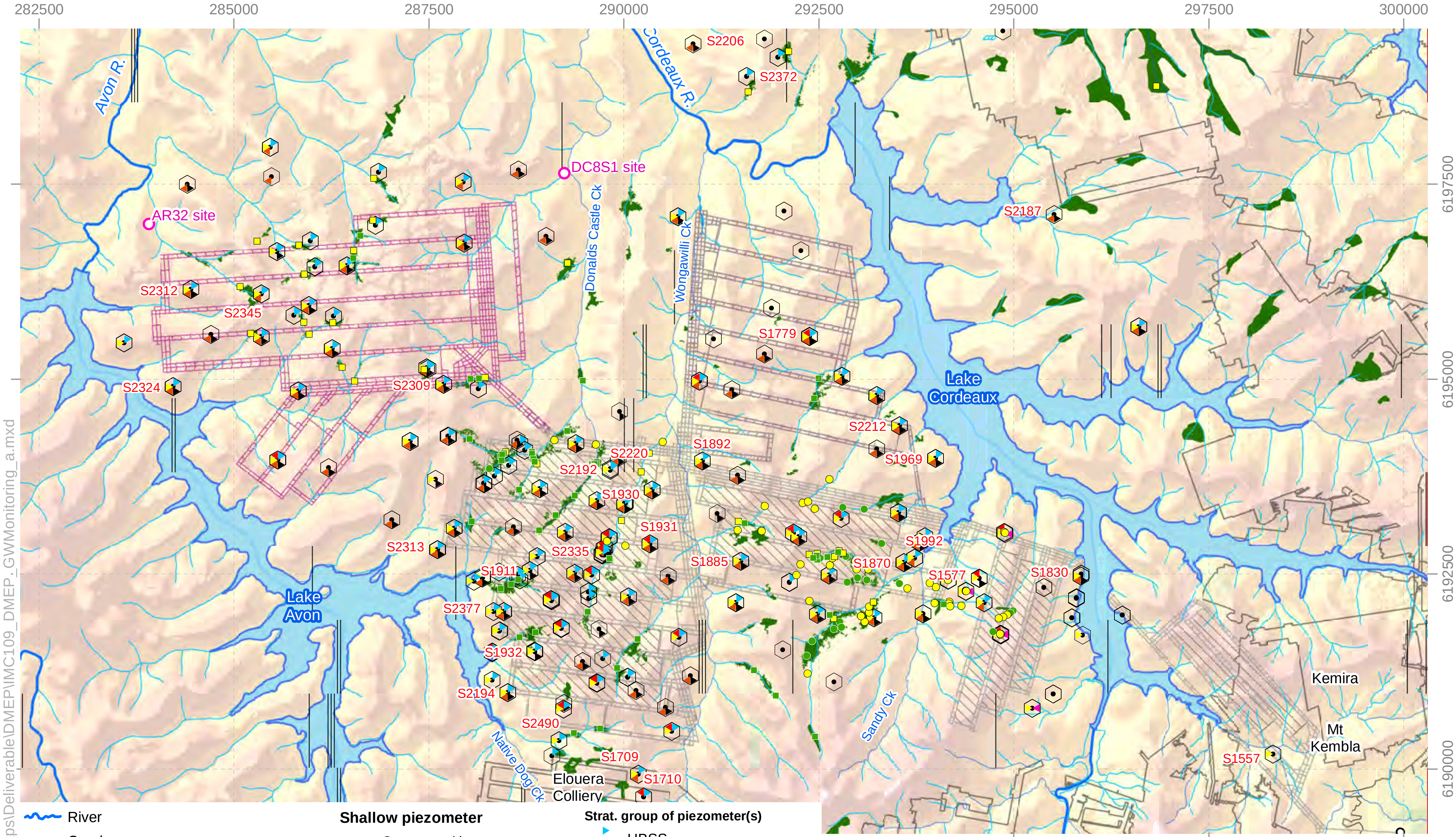
Figure 2-12 shows the location of monitoring sites around Dendrobium. The monitoring network is significant, one of the largest in NSW, and is regularly expanded in terms of size and scope. More detailed maps of the network are presented in **Appendix A**. There are already a number of monitoring sites around Area 5 (Figure A1). Groundwater level monitoring is typically conducted via:

- Multi-level vibrating wire piezometers (VWPs) installed within 'deep' bores. While there are questions about the absolute accuracy of VWPs, they do allow monitoring at multiple levels within a single bore, meaning they maximise the ability to monitor groundwater pressures in 3-dimensions and allow the vertical distribution of pressure, and therefore of drawdown, to be monitored. There are over 160 such bores, with over 860 such instruments, at Dendrobium, and this constitutes the bulk of the monitoring network and available dataset.
- A small set of standpipe piezometers installed into outcropping sandstone (typically 10-20 m deep). Additional standpipe piezometers will be installed at a selection of locations adjacent to VWP-equipped bores. A comparative study of groundwater levels or pressures recorded at standpipe piezometers and adjacent VWPs will be conducted once a suitable baseline of data has been established.
- A network of shallow piezometers installed into shallow substrate, primarily monitoring Upland Swamps (deposits are typically 1-3 m deep). There are approximately 100 such piezometers at Dendrobium Mine (Figure 2-12).
- Within the large network of "deep" VWP-fitted bores listed above, there are a number of special-purpose bores installed to investigate and monitor pre- and post-mining conditions within the footprint of longwalls or offset from longwalls (Figure 2-12). These include:
  - a set of "shallow sandstone" bores to monitor groundwater levels in the Hawkesbury Sandstone near to shallow swamp piezometers.
  - longwall "centre-line" or "over-goaf" bores - bores such as the 'Longwall 9' investigation (Parsons Brinckerhoff, 2015a) (bores S2192/S2220 – Figure A2) and then a number of bores more recently above Longwalls 6, 7, 12, 13, 14, 15, 16 and 17 (e.g. bores S2443, S2398, S1932-S2510, S2493 on Figure A2) (HGEO, 2020b, 2021c). More discussion of these in Sections 2.6.2 and 3.2.1.
  - "shoreline bores" - bores drilled between Area 3B and Lake Avon (e.g. S2313, S2314, S2377, S2436 and S2194 on Figure A2) as described in Sections 3.2.

Within Area 5 (details on Figure A4), within the above classifications, there are:

- Piezometers monitoring swamp deposits at Swamp 85 (2 piezometers) and Swamp 86 (2 piezometers) and piezometers monitoring regolith immediately adjacent to Swamps 85, 86, 97, 99, 100, 101, 103, 105, 107, 108 109, 110, 111, and 114 (a total of 15 such piezometers). Some of these commenced monitoring in 2015, with others commencing in 2017. If the Project was approved, this network would be expanded and allow >2 years of pre-mining baseline data.
- More than 30 'deep' bores equipped with VWPs, monitoring most "aquifer" formations (i.e. HBSS, BGSS and SBSS within the Narrabeen Formation, and the relevant coal seams). In the southeast of Area 5, monitoring commenced in 2009 (bores S1998, S2006, S2007). Monitoring at bores within and adjacent to the proposed mining footprint in Area 5 commenced in 2015, with further bores/piezometers installed since then.
- There are already two "shoreline bores" S2324 and S2325 that would facilitate monitoring of groundwater levels between proposed longwalls 502 and 503 and the Avon Reservoir. Further such bores could be drilled, packer tested and piezometers installed (focussing on the Hawkesbury and Bulgo Sandstone) prior to longwall extraction.

Groundwater quality (chemistry) samples are collected at 17 monitoring bores equipped with multiple sampling pumps, including six monitoring bores in Area 5 (Section 2.8.1).



River
Creek
Lake / reservoir
Upland Swamp (IMC / OEH)
Dendrobium workings: existing
Dendrobium workings: future approved
Extracted panels (Oct 2021)
DMEP Area 5 workings
GWL reporting site

Shallow piezometer

Swamp; w/ logger
Swamp; manual dip only
Not swamp; w/ logger
Not swamp; manual dip only

'Deep' bore

'Deep' bore

Strat. group of piezometer(s)

HBSS
BHCS
Narrabeen Fm
Bulli Coal / Eckersley Fm
Wongawilli Coal / lower units
other

'priority' bores referred to in reporting text/charts are labelled, e.g S2192

N
0 0.5 1 1.5 km
Scale: 67,500 @A4
GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Groundwater monitoring: regional context

Figure 2-12

E:\DENDROBIUM\GIS\Maps\Deliverable\DMEP\IMC109_DMEP_GWMonitoring_a.mxd

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A NSW government program to improve groundwater monitoring in coal basins has led to the installation of a number of bores in the Southern Coalfield. Six such bores are located in relatively close proximity to the Project. These are shown 2 km north and 4 km west of Area 5 on Figure 2-8. Data, commencing in late 2021, has recently been made available from these sites via the WaterNSW data portal.

2.6.2 Groundwater levels

As described in the preceding section, groundwater levels or pressures are monitored at numerous sites around Dendrobium Mine. The data from many of the bores is analysed regularly as part of the End of Panel reporting process. This study has reviewed data from Area 5, which is generally further from recent or active or recent mining, however the focus in the following sections is on illustrating the key processes which are relevant to the hydrogeological effects of mining at Dendrobium, and using the historical monitoring of these effects to describe the likely effects of the Project.

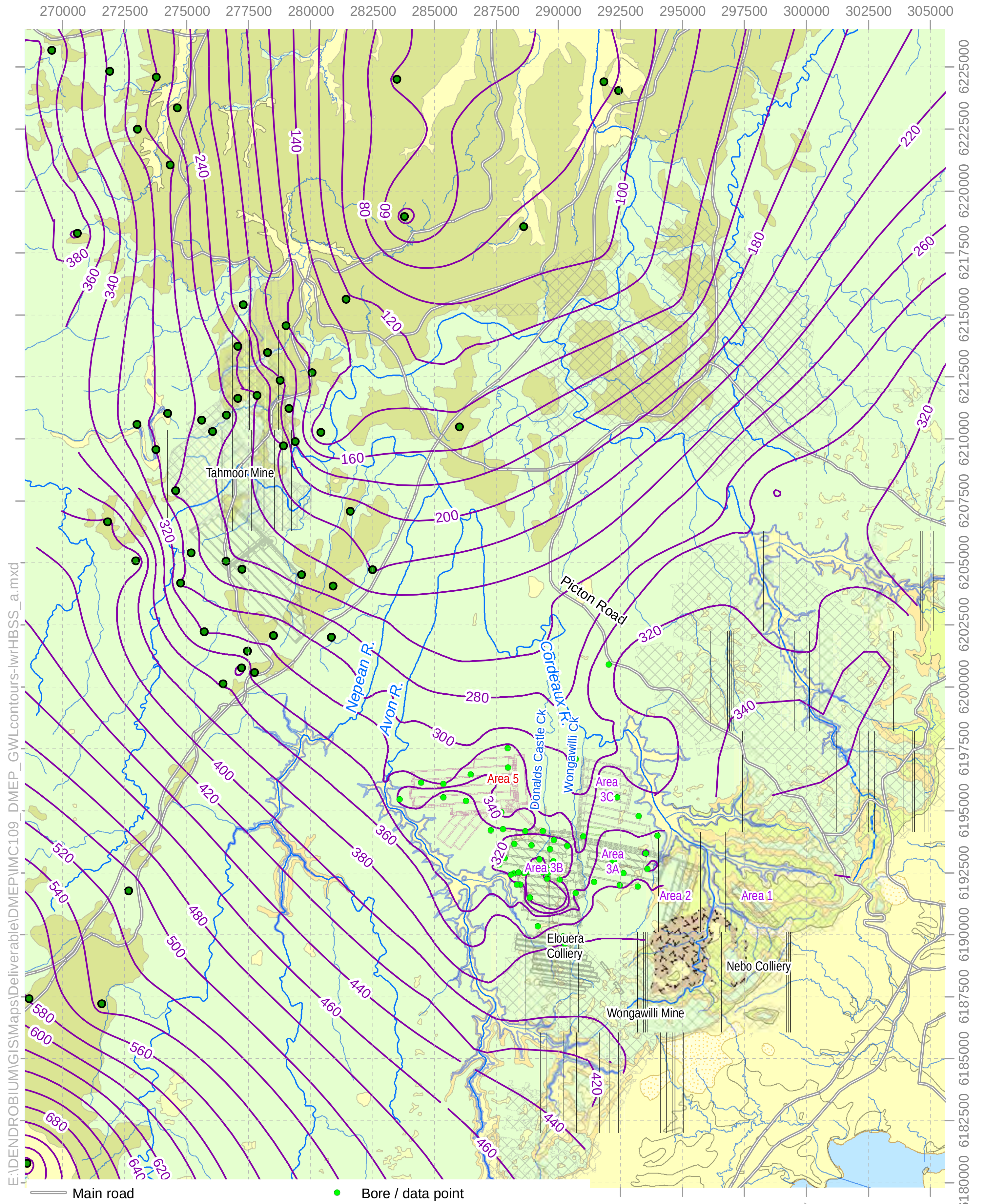
Regional groundwater flow (contours)

Groundwater levels for three key stratigraphic horizons have been contoured to produce maps to understand regional groundwater flow patterns, and to illustrate mining effects. These maps are for the lower Hawkesbury Sandstone, the Bulgo Sandstone and the Bulli seam. Data from other mines and from the government groundwater database has been included where available. Regional groundwater levels are taken from whatever date is available, but the data from the mine sites is for late 2021.

Figure 2-13 displays the contoured groundwater levels for the lower Hawkesbury Sandstone. The map indicates that the dominant regional groundwater flow direction is to the south or south-west to north (broadly following regional drainage, i.e. the Nepean River system). Contours are perturbed around Dendrobium (especially Areas 3B and 3A) and the Tahmoor and Appin mine areas.

Figure 2-14 presents contour water level data for the Bulgo Sandstone (generally lower, but some ‘upper’ Bulgo Sandstone data is used to improve spatial coverage). The pattern of groundwater gradients in the Bulgo Sandstone appears less influenced by surface drainage than the shallower Hawkesbury Sandstone water levels, although regional groundwater flow directions broadly remains northward, toward the centre of the Sydney Basin. Drawdown within the Bulgo Sandstone is clearly evident around Dendrobium Mine, and also at the Tahmoor and Appin mines (typically tens of metres to approximately 100 m drawdown).

Figure 2-15 presents contouring for the Bulli coal seam groundwater levels. This is shown here in instead of the Wongawilli seam because the data was more easily extended to the north (i.e. around Tahmoor and Appin) and so presents a more complete regional coverage, as well as being the coal seam to be targeted by the Project. Flow directions are northward toward the centre of the Sydney Basin, consistent with the overlying units. Localised drawdown cones are apparent in measured and inferred water levels at Dendrobium, Appin and Tahmoor mines. This drawdown can be several hundred metres, caused by the dewatering and associated depressurisation of the coal seams in order to allow access and safe working within Bulli seam workings.



Main road
River
Creek
Lake / reservoir
Dendrobium workings: existing
Dendrobium workings: future approved
Dendrobium workings: proposed
Extracted panels (Oct 2021)
DMEP Area 5 workings
Other mines (extracted area)

Bore / data point
GWL contours (c.a 2021): lwr HBSS

N
0 1.5 3 4.5 km

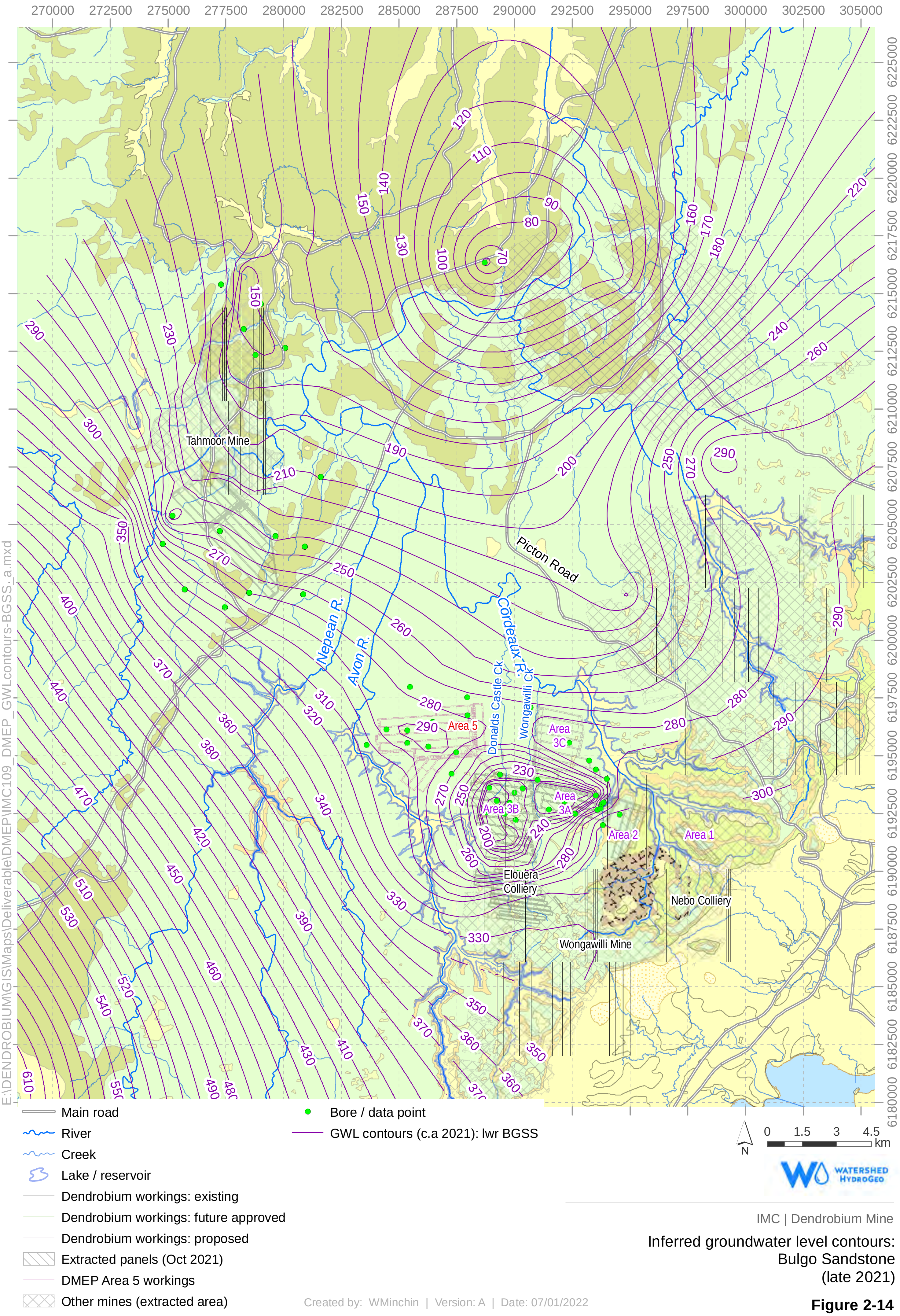
WATERSHED HYDROGEO

IMC | Dendrobium Mine

Inferred groundwater level contours: lower Hawkesbury Sandstone (late 2021)

Created by: WMinchin | Version: A | Date: 07/01/2022

Figure 2-13

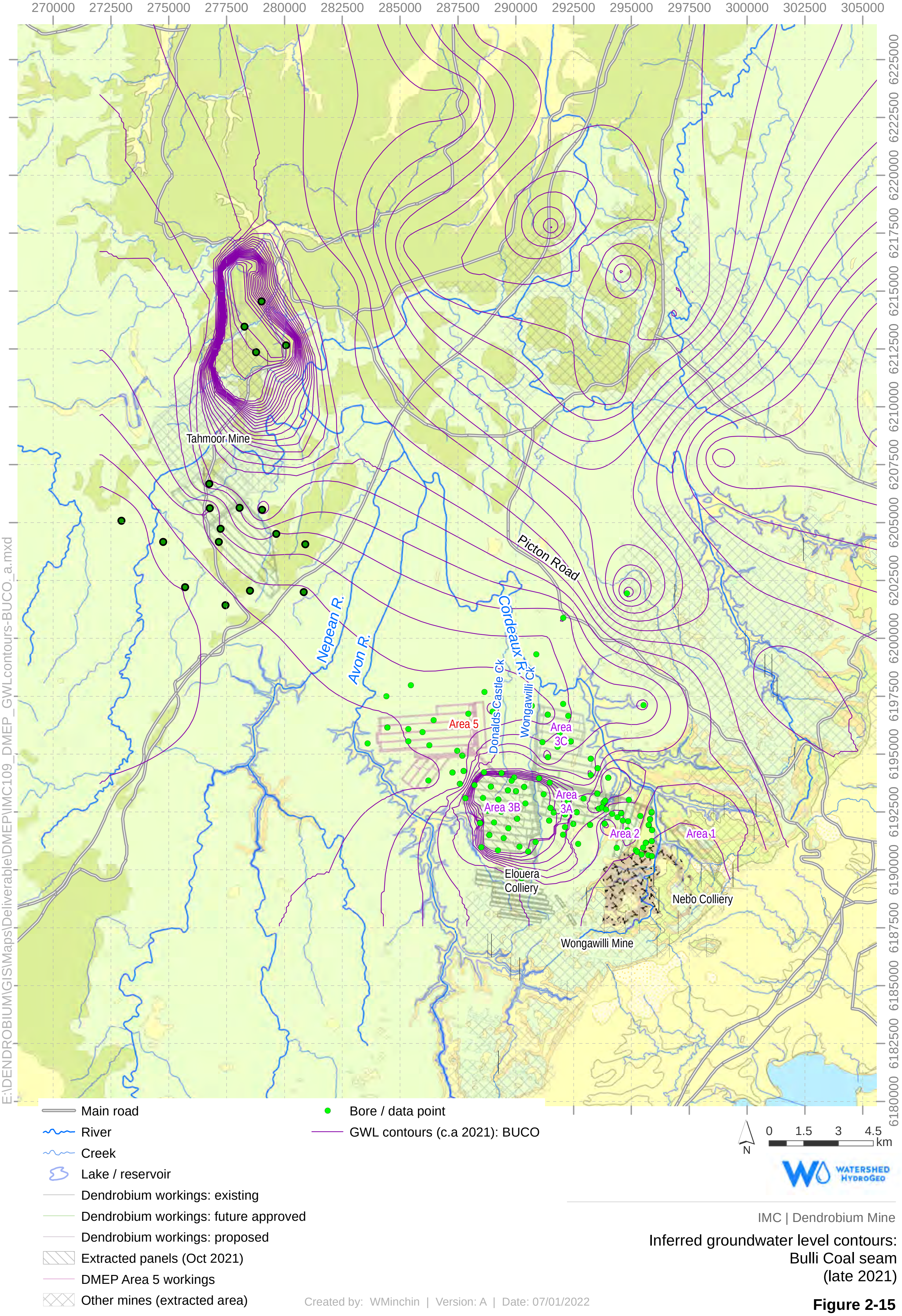


IMC | Dendrobium Mine

Inferred groundwater level contours:
Bulgo Sandstone
(late 2021)

Created by: WMinchin | Version: A | Date: 07/01/2022

Figure 2-14



IMC | Dendrobium Mine

Inferred groundwater level contours: Bulli Coal seam (late 2021)

Created by: WMinchin | Version: A | Date: 07/01/2022

Figure 2-15

Temporal trends (hydrographs)

Hydrographs of all VWP-equipped monitoring sites at Dendrobium are presented in **Appendix B**, which can be compared to the monitoring sites mapped in **Appendix A**. The hydrographs presented in this sub-section of the report focus on:

- Pre- and post-mining data from over-goaf bores, to illustrate the drawdown effect and the post-mining behaviour, especially in the Hawkesbury Sandstone (HBSS).
- Effects outside the longwall footprint, especially adjacent to significant watercourses (in this example, Wongawilli Creek).
- Effects outside the longwall footprint, especially adjacent to water supply reservoirs (in this example, Avon Reservoir – which is also adjacent to the Project).

These hydrographs show the effects due to mining at Dendrobium that have been observed, and illustrate the effects that expected due to the Project.

Groundwater response above the goaf

A set of monitoring bores are located in the centre-line of longwalls at Dendrobium. Detailed analysis of these bores, including groundwater levels, is presented in separate reports (HGEO, 2020b, 2021c), and focus here is on one of the longer post-mining groundwater level records (bores S2192-S2220).

Bore S2192 was installed above Longwall 9, with piezometers in the HBSS, BGSS and in the Stanwell Park Claystone SPCS). A hydrograph of all those piezometers is presented in **Appendix B** (with a set of hydrographs for all VWP-equipped monitoring sites at Dendrobium), and shows drawdown of >50 m in the SPCS as Longwall 9 approaches this site, drawdown of 30-50 m in the two BGSS piezometers, and drawdown of 10-30 m in the HBSS, prior to this bore being decommissioned, immediately before the longwall passes beneath the site.

After mining passed this site, a replacement bore S2220 was installed. Piezometers in the HBSS are installed at the same depth as those in S2192. A combined hydrograph is presented in Figure 2-16.

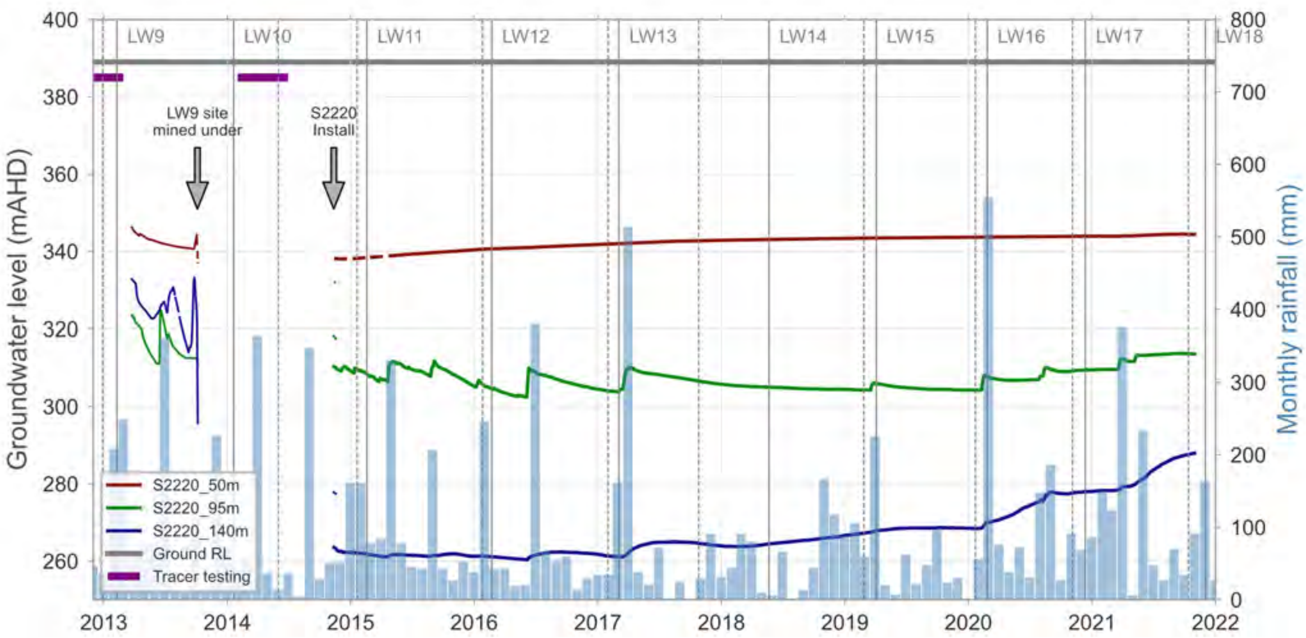


Figure 2-16 Groundwater level trends above a longwall (Longwall 9, bores S2192-S2220)

This combined hydrograph shows that drawdown due to Longwall 9 (probably with some contribution from Longwall 10) in the lower HBSS was approximately 70 m (piezometer at 140 m depth), and 20 m in the mid-HBSS (piezometer at 95 m).

Significantly, the post-mining hydrograph for S2220 also shows:

- Pressures in the S2220-140m piezo are relatively stable until 2017 (3 years after mining at this site) and then recovered 4-5 m during the 2017-2019 drought and then a further 15 m since Feb-2020. The pressure hydrograph is relatively flat during the worst months of the drought, but importantly, it seems to sustain its recovery and not recede during that time (even in late 2019).
- S2220-95m hydrograph is more responsive to wet/dry periods. It declined slightly during the 2017-19 drought, and has recovered 9 m since Feb-2020. Based on the shape of the hydrograph, it seems likely that groundwater levels would not be sustained when a drought occurs again. We hypothesise that this horizon is connected (laterally) to surface drainage, i.e. to WC21/Wongawilli Creek system or Donalds Castle Creek. This one may not sustain its recovery during dry periods unless the lower strata re-saturates further (if that happens).
- S2220-50m - recovery was greater during the 2017-2019 drought than in the recent wet period, but overall recovery of 2 m since early 2017, and the measured pressures are only 1 m lower than the earliest recorded pressures in the 50 m piezometer in bore S2192.

Another example that shows the drawdown effects the full stratigraphic sequence is at bore S1932 (**Appendix B**). This clearly shows the depressurisation in the coal seams (WWSM) and other deep units (CCSS) developing as mining approaches the site. Drawdown is present but milder in the Scarborough Sandstone (SBSS) and Bulgo Sandstone (BGSS), but when the neighbouring longwall (Longwall 15) is extracted, 30-80 m drawdown occurs within a matter of weeks in these units. Drawdown of approximately 25 m is present in the lower HBSS (piezometer at 96m) by the end of Longwall 15 (when this bore was decommissioned prior to undermining), approximately 9 m in the mid-HBSS (piezometer at 48 m) and no measurable drawdown in the shallowest piezometer.

Groundwater response between longwalls and watercourses

Bores S1930 and S1931 (locations on Figure 2-12 and Figure A2) provide good data on the response of pressure in the HBSS and some deeper piezometers in relation to Wongawilli Creek, which is offset several hundred metres from the nearest longwalls. Figure 2-17 shows the hydrograph for S1931.

This shows that groundwater levels in the Newport Formation ('NPFM') immediately below the base of the HBSS, and in the Bald Hill Claystone (BHCS) are very similar to the base of Wongawilli Creek near this site (i.e. approximately 285 mAHD). As mining occurs in Area 3A (during 2010-2013), drawdown propagates through all monitored horizons, causing 200 m depressurisation in the coal seams, 100 m in the SBSS, and 10-30 m drawdown in the BGSS piezometers. Drawdown in the shallower piezometers accelerates as longwalls in Area 3B are extracted, and is at its maximum after Longwalls 11-13 are extracted (the nearest three panels to this site). During 2017-2020, the base of the HBSS is effectively desaturated, and recovery commenced in 2019-20 in most of the shallow piezometers (down to the 157 m deep piezometer in the BGSS). This drawdown in shallow strata adjacent to the creek, resulting in reduced baseflow discharge, in combination with the severe drought, is the likely cause of more frequent cease-to-flow events in this reach of Wongawilli Creek (Section 2.4.4).

The hydrograph for S1930 (**Appendix B**) shows similar patterns of behaviour for the piezometers monitoring the upper BGSS and lower HBSS. Mining-related drawdown in the mid-HBSS was relatively mild (approximately 4 m drawdown by mid-2018) and not detected in the shallow HBSS at this site. The piezometers in the BGSS failed at this site, but the lower HBSS (piezometer at 87 m) shows 20 m drawdown due to mining, and a subsequent 10 m recovery, where recovery commenced in 2017 (i.e. approximately 3 years after mining). Groundwater levels in the mid-HBSS remain stable, neither recovering nor declining further after 2018.

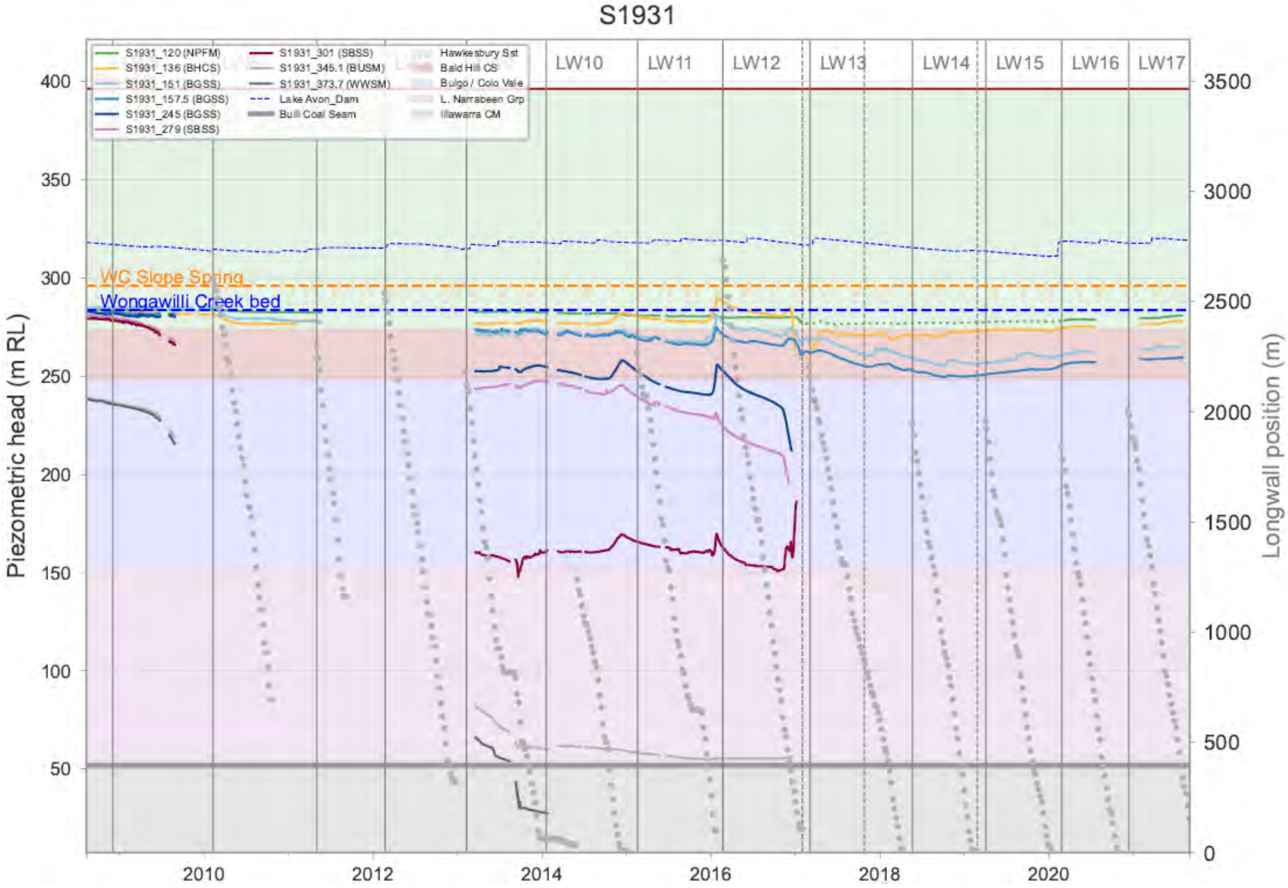


Figure 2-17 **Groundwater level trends adjacent to significant watercourse (bore S1931)**

The post-mining recovery in the lower HBSS, NPFM and BHCS piezometers described in the previous paragraphs is the likely cause of iron-staining events in Wongawilli Creek (see “WC slope spring” label and elevation marked on Figure 2-17, similar to that observed at tributary SC10C (Section 2.8.3).

Groundwater response between longwalls and reservoirs

Groundwater levels have been monitored at numerous pre- and post-mining sites between Area 3B longwalls and Avon Reservoir (Figure 2-12 and Figure A2). The hydrograph for S2313, adjacent to Longwall 12, is presented in Figure 2-18. Historical water levels for Avon Reservoir are marked on the chart. This shows that groundwater levels in the lower HBSS (piezometer at 131 m), and in the upper BGSS (piezometer at 182 m) were similar to lake water levels prior to Longwall 12 being extracted. Review of water levels from nearby bore S2009 indicate that groundwater levels in the lower HBSS were approximately 323-327 mAHD in 2009-2010, i.e. just above lake levels.

Extraction of Longwall 12 caused 14 m drawdown in the lower HBSS, and >30 m drawdown in the upper BGSS piezometer. There was little effect on groundwater levels in the upper or mid-HBSS (piezometer at 49 m). Groundwater levels have recovered slightly since early 2020 (approximately 5 m in the upper BGSS and 2 m in the lower HBSS), yet both remain below the lake level.

A similar picture is observed in hydrographs from sites S2314, S2436 (which is located at the lake shoreline) and S2194, also adjacent to Avon Reservoir.

Site S1992 in Area 3A monitors groundwater levels between Area 3A longwalls and Cordeaux Reservoir. The hydrograph (**Appendix B**) shows that lower BGSS water levels are initially higher than Cordeaux lake levels, and decline approximately 50 m as a result of extraction of Longwalls 6-8, and remain below lake levels. However groundwater levels in the upper BGSS (piezometer at 92.5 m) have remained above lake levels, despite declining 15 m as a result of mining.

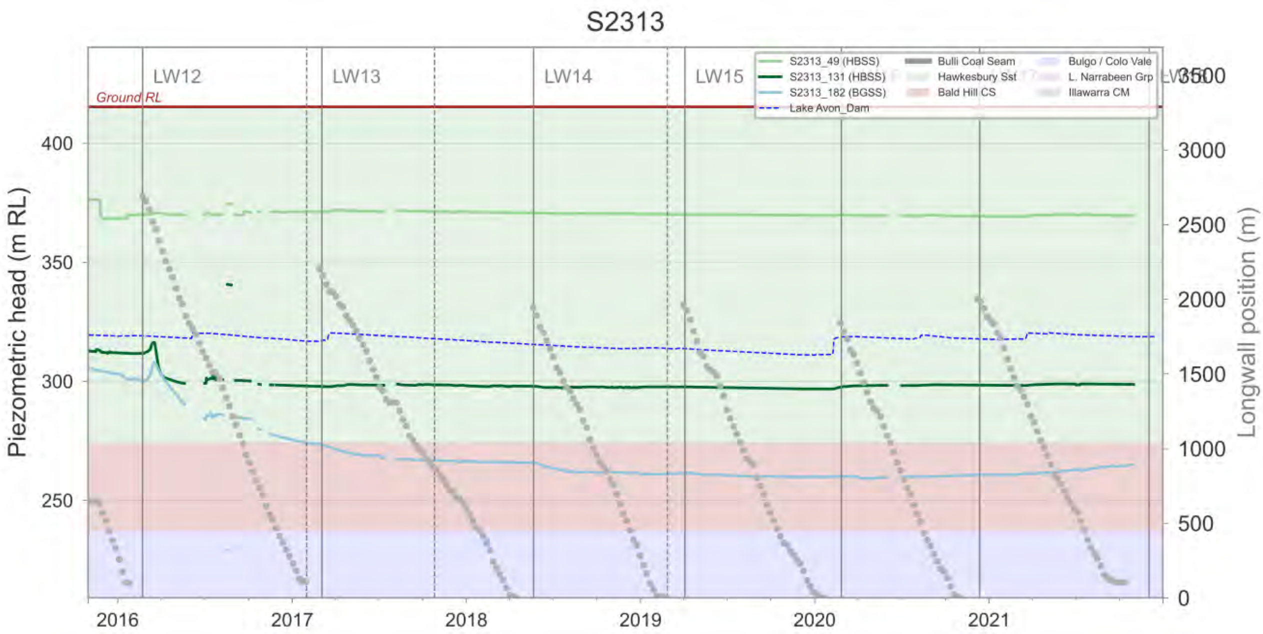


Figure 2-18 Groundwater at site between longwalls and Avon Reservoir (S2313)

The important observation here is that prior to mining, the reservoirs would 'gain' storage through groundwater discharge from the surrounding strata. Mining has caused localised drawdown, meaning that groundwater gradients in the strata near and below the base of the reservoirs will be away from the lake and there will be seepage losses from Avon Reservoir in some areas (Sections 2.4.5 and 2.6.4).

Ground pressure profiles

HGEO developed and continues to update two profiles showing groundwater pressures/levels in over-goaf piezometers through time in relation to stratigraphic position and height above longwalls (HGEO, 2020b, 2021c). The most recent profile for Area 3B is presented here (Figure 2-19). The cross-sections summarise data from numerous individual hydrographs (**Appendix A**). For each sensor, symbols are plotted that reflect the piezometric head (blue symbols) and the dominant groundwater level trends (green and red triangle symbols). Strata that are inferred to be fully saturated (pressure head >0) are shown with blue shading.

Empirical estimates for the height of fracturing and/or depressurisation are also presented on the figure, namely the models of Tammetta, Ditton and Merrick, Mills, and Galvin and Mackie (see discussion of those in HGEO, 2021), along with some observations of the mode of fracturing made by HGEO based on core logging from these bores.

HGEO reported the following significant observations:

- Piezometers installed post-mining commonly show positive pressure heads at discrete horizons indicating isolated saturated strata or perched water tables. Perched horizons may coalesce vertically (where there is overlap in terms of total head) and horizontally, but commonly also form vertically discontinuous multiple perched horizons.

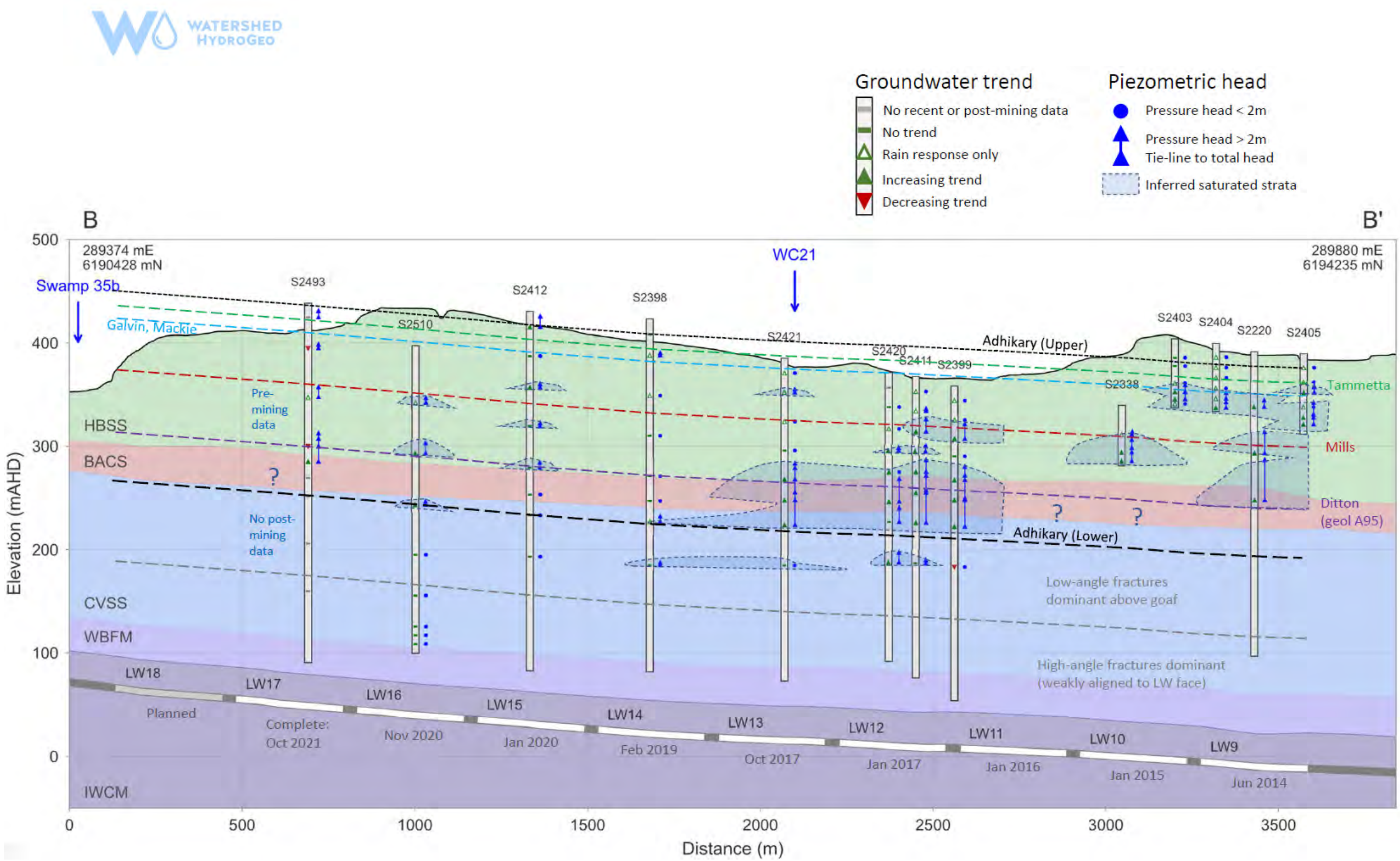


Figure 2-19 Groundwater pressure profile for Area 3B (over-goaf bores)

HGEO: Profile_HOF_Area_3B_3A_V5.pdf

- Perched saturated zones can occur at any stratigraphic level, but in both areas appear to be most common and extensive between the upper Colo Vale Sandstone [‘CVSS’] (equivalent to the upper BGSS) and lower HBSS.
- These saturated zones are much less extensive in more recently extracted longwalls (Longwalls 14 to 17), suggesting that perching is highly heterogeneous or, more likely, that they take approximately 3 years to develop (consistent with the descriptions accompanying hydrographs in Figure 2-16 and Figure 2-17, above).
- Increasing groundwater level trends are dominant in the perched horizons between upper CVSS and lower HBSS, although not seen in all sensors. Rainfall responses (with or without an underlying trend) are most common in the middle and upper HBSS. Decreasing groundwater level trends are less common but noted in hole S2399 (above Longwall 11-12 pillar), S2398 (Longwall 14) and the off-goaf hole S1871.

The observations imply that groundwater levels (and therefore storage) above the goaf recover to some extent in the years following longwall extraction. It is assumed that rainfall recharge, which may be enhanced due to surface fracturing, percolates through the fractured strata and is retarded at certain stratigraphic layers or restrictions in the fracture network. More discussion of this is provided in Sections 3.2.1 and 3.3.

2.6.3 Infiltration recharge

Groundwater is recharged from rainfall and water bodies, as well as potential downward leakage from overlying strata.

Rainfall recharge primarily occurs to the Triassic Hawkesbury Sandstone or to the outcropping Narrabeen Group around Areas 1 and 2 and the escarpment (Figure 2-8), and to the smaller isolated areas of swamp deposits.

Estimates of average or long-term rainfall recharge to surficial strata have been collated from a review of literature and from analysis of Dendrobium field data (Table 2-4). The weight of evidence from multiple studies is that recharge to the Hawkesbury Sandstone is within a range of 0-8.5% of LTA rainfall (Advisian, 2016).

A soil moisture balance model that accounts for varying rainfall and evaporation on a daily basis (from SILO), and accounts for soil moisture deficits developed for previous modelling studies for Dendrobium. This water balance model has been updated for this study, and is regularly compared to updates from BoM’s AWRA-L model.

The modelled recharge, as calculated by the water balance model on a daily basis and then aggregated into model stress periods, is presented in the modelling section (Section 4.4.4).

Table 2-4 Summary of regional groundwater recharge estimates

Reference	Analysis method	Recharge	
		% LTA rain	mm/yr
(URS, 2007)	water table fluctuation ("WTF")	3-10%*	n/a
(Office of Water, 2011)	Unknown/ not stated. Also note, these are estimates for the whole of the Nepean Sandstone Groundwater Source, not just the higher rainfall area around Dendrobium Mine. 2011 report superseded by NRC, 2021 report.	6%	58
(NRC, 2021)		5%	48
(Coffey, 2012a, 2012b)	Baseflow separation, WTF	2.7 or 6%	n/a
(Pells and Pells, 2013)	unknown	5%	50
(EMM, 2015)	Sydney Basin-wide estimate, based on review of Crosbie, modelling assessments. Table 5.1 indicates 1% to Permian, 5% to HBSS/Narrabeen Group, <5% Wianamatta Group.	5 % Triassic	n/a
		1 % Permian	n/a
(Crosbie, 2015)	Chloride mass balance in shallow groundwater.	3-8.5%	40-100
(HydroSimulations, 2016)	Chloride mass balance baseflow separation, WTF	6.5%	65
(BoM, 2018)	AWRA-L model (2005 to Oct-2021)	7.5%	90
this study	Soil moisture balance model (2005 to Oct-2021) for Triassic rock outcrop	6.6%	80

LTA: Long-term Average. BFI : Baseflow Index. * URS stated that local variation might be 2-16%, but "realistic range" is 3-10%. AWRA-L model results for (~5x5 km) model cell at Lat -34.39, Long 150.71

2.6.4 Surface water - groundwater interactions

Analysis and estimates of baseflow (groundwater discharge) to streams is presented in Section 2.4.3.

The hydraulics of groundwater-lake interactions are described in Section 2.6.2, noting that prior to mining, gaining behaviour was more likely, and following longwall extraction (if located within several hundred metres of the reservoir) losing behaviour is more likely. A water balance investigation of Avon Reservoir found that the potential changes to this behaviour as a result of mining (i.e. the change to the flux) could not be detected given the other uncertainties present in the data (evapotranspiration rate, other inputs to the system, including anthropogenic influences), and so this component of the reservoir water balance remains unverified, either through field data or water balance techniques.

2.6.5 Mine inflow

Groundwater inflow to mine workings cannot be directly measured but is determined through a detailed mine water balance. Records of mine inflow are an important data source, because the inflow to the mine workings is related to the effective extent and permeability of the connected fracture zone above the longwalls and the permeability and storage properties of the coal seam and the overlying strata.

Dendrobium

At Dendrobium Mine, the accounting of water via pumps in the mine workings is metered and controlled through the System Control and Data Acquisition (SCADA) system and used to calculate a daily Mine Water Balance[3]. The water balance accounts for all water that enters, circulates and leaves the mine, including via air moisture and coal moisture, and groundwater inflow is determined by water balance for each mine domain. Key metrics of the water balance are summarised and reported against Trigger Action Response Plan (TARP) to Dams Safety NSW.

Estimates of groundwater inflow to each mine area are plotted in Figure 2-20 alongside longwall timings, rainfall trends (residual mass) and modelled infiltration recharge (Section 2.6.3). This data serves as an important target of subsequent modelling, given that inflow is a function of the height and intensity and connectivity of fracturing above longwalls, the depth of cover in relation to that fracturing, and the natural or host properties of the stratigraphic units.

Table 2-5 summarises the inflow to each area for the 12 months to the end of June 2021, i.e. the last full "water year". This includes a record for Area 3C, where first workings commenced in May 2020. Total accumulated inflow over this period was approximately 2,690 ML, equivalent to a daily average of 7.4 ML/d.

Table 2-5 Dendrobium Mine inflow: 12-month summary for Jul 2020-Jun 2021

Statistic	Area 1*	Area 2	Area 3A	Area 3B	Area3C	Dendrobium Total
Minimum	--	0.09	0.09	0.23	0.00	1.16
Average	0.44	1.51	0.84	4.50	0.07	7.37
Maximum	--	4.74	6.99	8.42	0.29	12.91

Units in ML/d. *flowmeter in Area 1 failed in early 2017 → therefore the historical average is reported.

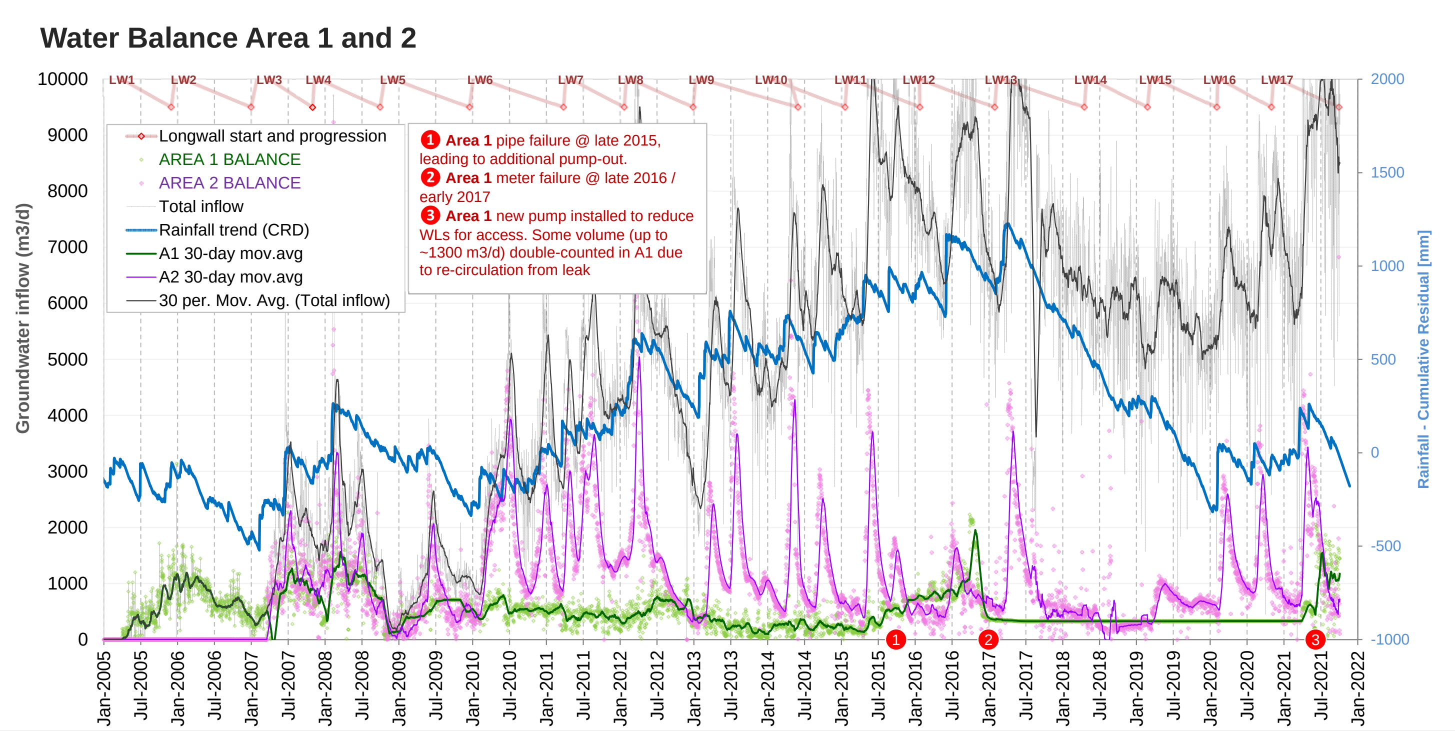
Figure 2-20 shows that since the commencement of Area 3B Longwall 9 total groundwater inflow to Dendrobium Mine has ranged between about 4,000-12,000 m^3/d (i.e. 4-12 ML/d) (averaging 6.7 ML/d). The highest water-year total was 3,040 ML in 2016-17 (8.3 ML/d). The water-year total for 2020-21 was 2665 ML (7.3 ML/d).

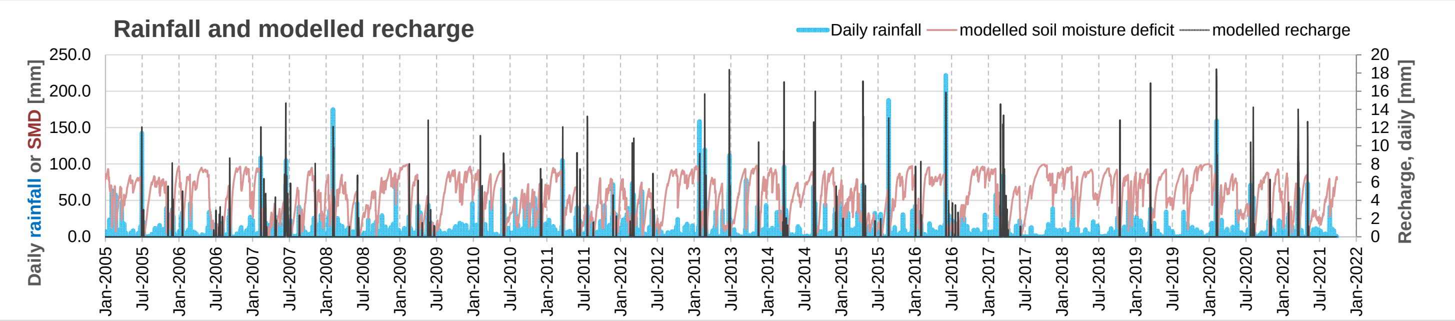
Inflows have generally been greatest in Area 3B, then Area 3A, then Areas 2 and 1 respectively, corresponding to total longwall area extracted. The other thing to note about the specific areas are the different character or shape of the hydrographs.

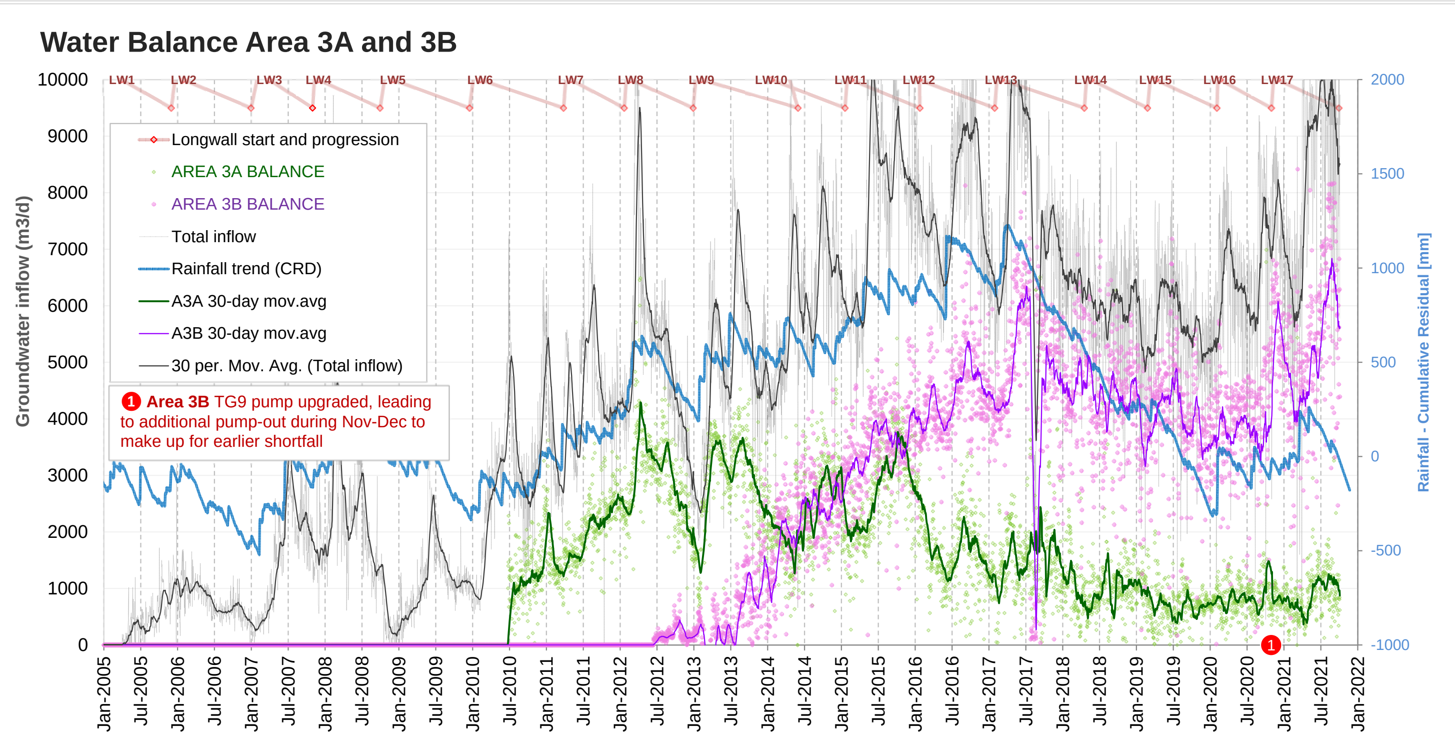
Area 1 has been consistently low, probably reflective of the presence of some overlying workings (Mt Kembla Mine), and lateral proximity to Kemira workings. Area 2 is most like a surface water hydrograph, responding quickly to short-term rainfall totals of >100 mm (approximately), but with a low 'dry period' inflow. Area 3A was also quite variable during the extraction of this area and for a few years after, but the inflow has declined and is a smoother hydrograph since about 2017.

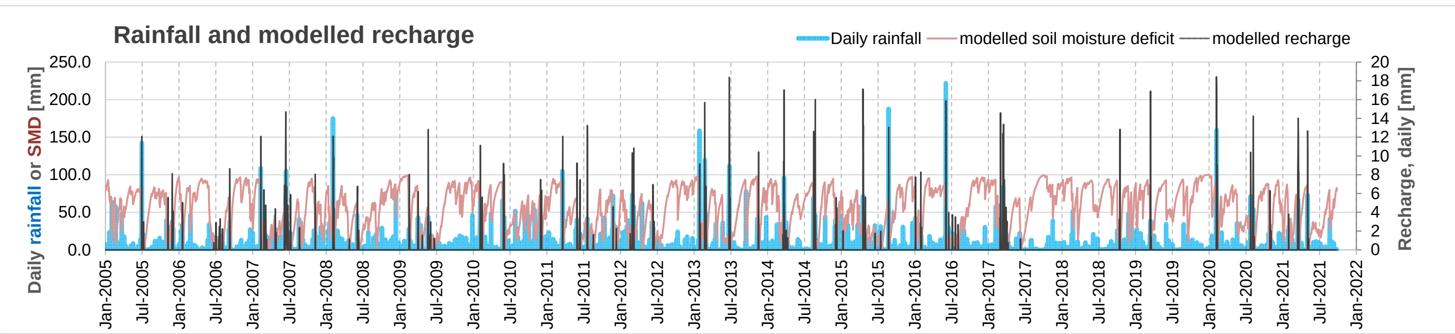
Inflow to Area 3B increased consistently with newly-extracted area until 2017 (Longwall 13), and plateaued between 2017 and early 2021 (while longwall area increased), and wetter again in 2021, as shown in the able above.

[3] IMC document DENP0049 outlines the procedure for the mine water balance.









Groundwater Inflow Trends by Mine Area **Figure 2-20**

Neighbouring mines

Table 2-6 presents a summary of the available historical inflow data for nearby Southern Coalfield mines. Some of this information has been sourced from Geoterra (2015), Coffey Geotechnics (2012a) and Annual Environmental Monitoring Reports (AEMR) for Tahmoor. The data from Tahmoor Mine is considered most reliable of these other mines.

Table 2-6 Summary of Inflows to neighbouring mines

Mine	Available record	INFLOW [ML/d]		
		Minimum	Mean	Maximum
Tahmoor	2009-2015	--	3.9	6.2
	2016-2021	--	3.7	6.7
Appin & Tower	2007-2009	0.06	1.85	2.8
	2016-19 (annual averages)	0.5	1.1	2.1*
Cordeaux	1992-2002	--	1.2	--
Bellambi / NRE No1 / Russell Vale	2005-2009	0.05	0.4	0.7
	2010-2015	0.15	0.8	1.45

* possibly an over-estimate due to 'make up' pumping in Jul-Sep 2016 to remove additional stored water.

The inflow at other mines has typically been lower than Dendrobium's inflow. This is conceptualised as being related to several factors:

- Dendrobium Mine extends for a distance of about 10 km in the east to west direction, cutting across groundwater flow paths;
- longwalls at Dendrobium are generally wider than elsewhere – Tahmoor's longwalls are relatively similar (many have 283-285 m void width); and
- panel widths (W) are also consistently larger compared to depth of cover (D), i.e. a lower ratio of D/W, at Dendrobium than at other mines, which is especially so in Dendrobium Area 2.

2.6.6 Hydrogeological properties and parameters

Hydrogeological properties most relevant to regional groundwater flow and response to mining are those related to permeability (expressed as horizontal and vertical hydraulic conductivity; Kh and Kv), porosity (η) and aquifer storage (Ss and Sy). These properties are quantified in this section with reference to field and laboratory measurements. Longwall subsidence results in significant changes in hydrogeological properties. Those changes are discussed in Section 3 (specifically Section 3.2).

The statistics presented in this section are for pre-mining strata properties. These form the basis for parameterisation of the numerical groundwater model, and that constrain changes during the history matching process.

Hydraulic conductivity

Hydraulic conductivity (K) is the capacity of a rock mass to transmit water under a given hydraulic gradient and is expressed here in units of m/day. Strata K is typically assessed using packer tests (or Lugeon tests). Packer tests involve the isolation of sections of the borehole using a pair of inflatable rubber packers that seal against the borehole wall. Pressure tests are then applied to each isolated section to determine hydraulic conductivity of the formation adjacent to the borehole and the hydraulic characteristics of fractures within the interval (Houlsby, 1976). Coal seams are more reliably tested using injection fall-off tests (IFOT), which are similar in principle to packer tests.

Hydraulic conductivity of the coal seams and overlying strata in the project area is very well characterised by more than 3,400 packer tests carried out by IMC at Dendrobium Mine, in addition to many more tests known to the authors from neighbouring mines and other projects across the Sydney Basin. Pre-mining packer test and IFOT data lists statistics for each major hydrostratigraphic unit are listed in Table 2-7.

Table 2-7 Hydraulic conductivity (K) for major stratigraphic units from packer testing

Unit	No. of Tests	Arithmetic mean K (m/day)	Standard Deviation (log10 K)	Harmonic mean K (m/day)	Significant trend with depth
Hawkesbury Sandstone	439	1.41E-02	0.84	1.27E-04	Yes; p = 3.8E-19
Bald Hill Claystone	122	3.04E-03	1.07	8.47E-06	Yes; p = 3.5E-10
Bulgo Sandstone	408	2.38E-03	1.01	1.22E-05	Yes; p= 4.2E-29
Stanwell Park Claystone	33	1.65E-02	1.39	9.67E-06	Yes; p = 7.1E-05
Scarborough Sandstone	87	1.36E-02	1.53	4.13E-06	Yes; p = 8.0E-06
Wombarra Claystone	79	4.08E-03	1.07	1.06E-05	Yes; p = 1.1E-03
Coal Cliff Sandstone	53	4.39E-03	1.07	9.10E-06	Not significant (p > 0.05)
Bulli Coal seam	107	8.75E-03	0.75	1.39E+00	Not significant (p > 0.05)
Coal Interburden (Eckersley Formation)	55	6.10E-04	0.86	1.22E-05	Yes; p = 1.8E-04
Wongawilli Coal seam	93	1.15E-02	0.99	5.37E-05	Not significant (p > 0.05)
units below WW seam	37	4.36E-04	0.71	1.85E-05	Yes; p= 7.6E-03
Cordeaux Crinanite	53	6.52E-03	0.94	4.90E-05	Not significant (p > 0.05)

Scatter plots of pre-mining hydraulic conductivity versus depth for each major stratigraphic unit are in **Appendix B**, with examples shown in Figure 2-21 for Hawkesbury Sandstone and Bald Hill Claystone.

It is apparent from the scatter plots and Table 2-7 that most of the upper stratigraphic units display a trend of decreasing hydraulic conductivity with depth. Linear regression of the log-transformed packer test data indicates that the trend is significant (at the 95% confidence level) for Hawkesbury Sandstone and the Narrabeen Group (except of the lower most unit, Coal Cliff Sandstone). The regression intercepts and slopes are broadly similar for the Hawkesbury Sandstone and Narrabeen Group. The implication is that the depth dependence of hydraulic conductivity is somewhat independent of lithology and stratigraphic unit. A decrease in hydraulic conductivity with depth is well recognised in the Hawkesbury Sandstone (Tammetta and Hewitt, 2004a) and is related to a decrease in weathering, fracture frequency and aperture width with increasing depth. The packer test results have been used to assign values for hydraulic conductivity in the numerical model in dipping strata according to their depth of burial and to layer subdivisions within stratigraphic units (Section 4.5 and 6.1).

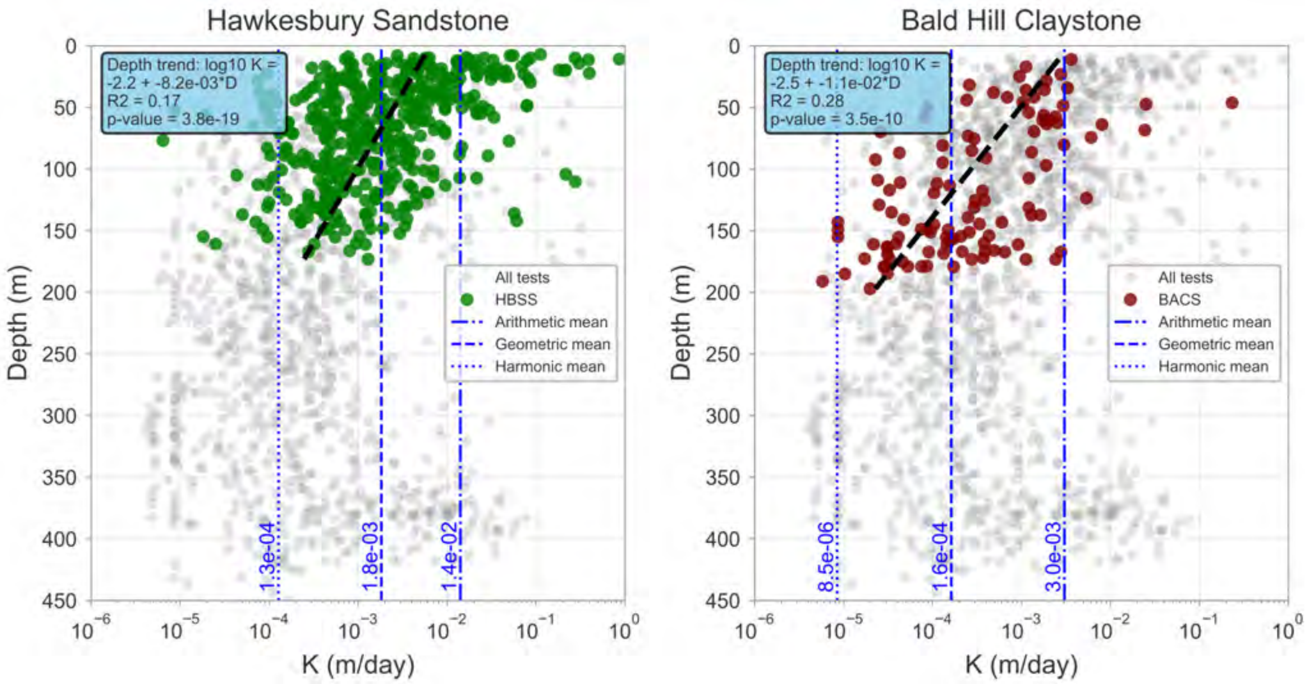


Figure 2-21 Scatter plot of hydraulic conductivity vs depth (HBSS and BACS)

The Permian coal interburden units display a weak relationship and/or shallow regression slopes, whereas the coal seams show no significant depth relationship.

Hydraulic conductivity vertical anisotropy

Packer testing estimates the average hydraulic conductivity of the packer-isolated borehole interval but does not provide information on anisotropy. That is, the hydraulic conductivity when measured vertically versus horizontally – or in any other direction. In layered sedimentary rocks, it is common for the horizontal hydraulic conductivity (Kh) to be higher than the vertical hydraulic conductivity (Kv) by one or more orders of magnitude (where “horizontal” and “vertical” are relative to the orientation of the bedding). This is because groundwater can flow preferentially through horizontal layers of relatively high K (e.g. coarse sandstone layers), but vertical flow is impeded by laterally extensive layers of low K (e.g. claystone or siltstone beds). Anisotropy can manifest at scales ranging from centimetres to hundreds of metres (the scale of formations themselves). If the rock mass is fractured, then the preferred flow direction will be largely controlled by the characteristics of the fracture network. Fracture-flow and anisotropy may dominate where the rock mass is affected by mine subsidence (e.g. above the goaf), faulting or jointing.

Aquifer anisotropy can be important in controlling the propagation of groundwater drawdown impacts from mining. In this assessment, vertical anisotropy has been estimated for each major stratigraphic unit using three approaches:

1. Rock core permeability tests, in which Kv and Kh is measured on the same rock core sample in a laboratory. The resulting Kh/Kv ratio relates to the cm scale of the sample.
2. Packer testing results, in which the relevant scale is tens of metres. In addition, the packer test measurements include permeability due to fracture flow, where fractures are present.
3. Borehole Magnetic Resonance survey data (BMR), in which the relevant scale is in the order of metres to tens of metres. BMR is a down-hole geophysical technique that can estimate Kh in a continuous depth profile with a vertical resolution of centimetres.

In the latter two methods, Kv is not measured directly, but is estimated based on the assumption that Kv = Kh at the scale of the measurement. According to Domenico and Schwartz (Domenico and Schwartz, 1998), for a sedimentary sequence comprising multiple layers, the equivalent Kh and Kv of the sequence is given by the arithmetic mean and harmonic mean of the layer Kh values, respectively. Estimates of vertical anisotropy as expressed by the ratio of Kv/Kh are shown in Table 2-8, below

Table 2-8 Estimates of vertical anisotropy in hydraulic conductivity (Kv/Kh)

Unit	Core (range, n)	BMR[1] (average Kv/Kh)	Packer tests (average Kv/Kh)
Hawkesbury Sandstone	3E-5 – 846 (36)	0.02	0.07
Bald Hill Claystone	0.12 – 12 (3)	0.15	0.05
Bulgo Sandstone	0.19 – 0.82 (5)	0.003	0.07
Stanwell Park Claystone	nd	0.09	0.07
Scarborough Sandstone	nd	0.10	0.04
Wombarra Claystone	nd	0.78	0.08
Coal Cliff Sandstone	nd	nd	0.09
Bulli Coal seam	nd	0.58	0.22
Coal Interburden	nd	0.27	0.10
Wongawilli Coal seam	nd	0.01	0.05
units below WW seam	nd	0.40	0.21
Cordeaux Crinanite	nd	nd	0.32
Arithmetic mean (sedimentary)	nd	0.22	0.09

Note: 1. BMR = harmonic mean / arithmetic mean using 1 m vertical moving average for each geological unit.
nd = Not determined / no data for specified unit.

Estimated Kv/Kh varies depending on the scale and type of measurements used in the calculations. Ratios determined using packer data indicate an average Kv/Kh in the order of 0.1, which is a ratio commonly adopted in groundwater modelling (range 0.04 to 0.22). Ratios calculated from the BMR data are slightly higher (~0.2), but are within the same order of magnitude (range 0.003 to 0.78). Estimates from core lab measurements vary widely reflecting the high variability at the centimetre scale.

The sedimentary unit-scale estimates derived from packer and BMR data are considered most appropriate for informing sub-regional scale groundwater modelling which is vertically discretised at that scale (Section 4.5). Vertical anisotropy in fractured domains (e.g. above goaf) is estimated based on the assumed dominant orientations of fractures (Sections 3.2 and 3.3).

2.6.7 Aquifer storage (Sy and Ss)

Specific yield (Sy) or drainable porosity has not been measured directly at Dendrobium. Testing of total and effective porosity percentage has been completed for Dendrobium core from the upper stratigraphic units, such as the Hawkesbury Sandstone, Newport Formation, Bald Hill Claystone and Colo Vale Sandstone (the equivalent of the Bulgo Sandstone). Effective porosity is considered a better approximation of Sy, although some practitioners consider that laboratory-determined effective porosity may be an overestimate of the porosity that is ‘drainable’ in the field. Table 2-9 provides total and effective porosity results from laboratory testing of core samples, based on a dataset from Dendrobium and from Appin Mine. This includes average porosity and effective porosity for some geological units, where effective porosity is a reasonable approximation for specific yield.

Table 2-9 Summary of porosity (%) determined from Dendrobium and Appin core samples

Geological Unit	Total Porosity (%)				Effective Porosity (%)	
	Min	Mean	Max	Count	Min	Count
Hawkesbury Sandstone	3.8	15.4 (14.9)	23.6	68 (4)	11.2	2
Newport Formation	2	2.4	2.6	3		
Bald Hill Claystone	4.1	6.1	9.9	6		
Colo Vale Sandstone	3.7	9.4	18.1	10		
upper Bulgo Sandstone		(8.2)		(5)	3.3	5
lower Bulgo Sandstone		(5.6)		(4)	0.7	4
Stanwell Park Claystone		(8.2)		(3)	0.2	2
Scarborough Sandstone		(8.5)		(4)	1.5	2
Wombarra Claystone		(3.7)		(1)	0.2	1
Coal Cliff Sandstone		(7)		(2)		

Total porosity data in parentheses () is from Appin Mine. All Effective Porosity measurements are from Appin Mine.
Source: E:\DENDROBIUM\Tech\AquiferProperties\Packer\Dendrobium_AquiferPropertiesDatabase_20161219.xlsx

IMC has also used Borehole Magnetic Resonance (BMR) imaging in selected drillholes to provide continuous logging of density, gamma count, porosity and hydraulic conductivity. Some analysis of downhole BMR traces was carried out and is summarized as follows. The BMR porosity estimates are made on a 0.1 m interval, with estimates of total porosity and three constituents: clay-bound water, capillary water, and ‘free water’. Of these constituents, free water + capillary water = effective porosity, where we consider that ‘free water’ is equivalent to drainable porosity or Sy.

The BMR ‘free water’ results indicate that Sy is in the range 1% to 6.3%. For the HBSS, the BMR free water volume (approx. 6%) and estimated effective porosity from BMR (6 + 4 = 10%) compare well against the effective porosity from the laboratory (11%, Table 2-9). The BMR free water values for Narrabeen Group (i.e. BGSS, SPCS, SBSS) are typically higher than the effective porosity values in Table 2-9.

A review of all the available porosity data shows that this parameter decreases approximately with depth, similar to hydraulic conductivity.

As expected, the values of total porosity, and even the effective porosity from Appin Mine, are higher than those suggested for specific yield in studies conducted in the Sydney metropolitan area and elsewhere, which indicate a specific yield of between 0.01 and 0.02 is reasonable for typical HBSS (Tammetta and Hewitt, 2004b). Specific yields for Sydney Basin sedimentary strata in the context of drainage due to longwall subsidence generally vary between 0.005 and 0.015.

The information from the core tests and BMR and from previous modelling will be used as the basis for the initial parameterisation of the groundwater model (Section 4.5.1).

Field data or direct measurements of specific storage (Ss) are generally not available. The specific storage of HBSS has been estimated to be approximately 1E-6 m^{-1} in the shallower zones where fracture flow is the dominant flow process (Kelly et al., 2005) along with similar estimate of 1.5E-6 m^{-1}, for intervals between ground surface and 300 m depth based on pumping tests in HBSS from Tammetta and Hawkes (2009).

Estimates of Ss can also be derived from Young’s Modulus and porosity, based on calculations in (Mackie, 2009) and methods utilising porosity determined from core testing are recommended (Evans et al., 2015) Calculations for strata at Dendrobium suggest that for coal, Ss generally lies in the range

5E-6 m^{-1} to 5E-5 m^{-1}, and interburden from 1.7E-6 (unfractured, fresh rock) to 8E-6 (fractured rock). These estimates are similar to model parameters from other mines in the Southern Coalfield which suggest that Ss is in the order of 1E-7 to 3E-5 m^{-1} for the coal seams, and about 1E-6 m^{-1} for overburden or interburden. As in previous modelling, a trend of generally decreasing Ss with depth is represented in modelling, based on overburden pressure at depth steadily decreasing the 'elastic storage' of the rock formation.

2.6.8 Investigation into the role of lineaments

IMC has carried out investigations into the role of lineaments in subsidence and groundwater impacts.

SRK (2020) assessed the presence of surface structures, including lineaments, and the role these might play in enhancing subsidence and environmental impacts around mining areas. SRK noted that the conditions at Dendrobium (Southern Coalfield) are different to those in the Western Coalfield (e.g. at Springvale Mine) where lineaments around mining areas enhanced subsidence effects to significant distances, leading the transmission of effects out to hundreds of metres or a kilometre or so from Springvale workings. SRK's conclusions, based on review of structural and historical subsidence data at Dendrobium, were that "*There is evidence of very minor displacement on discontinuous surface structures immediately above the mined areas*", and more significantly, "*no conclusive evidence … in the data to indicate movement on structures outside the mine areas*". Related to this last point, SRK noted that "*longwall mining activities to date at Dendrobium appear to have had little effect in the reactivation of surface lineaments. Very minor displacement on faults is evident… over Area 3B.*".

Other relevant investigations relating to lineaments includes:

- **Impacts to swamps**. Analysis of hydrological impacts to upland swamps by (Watershed HydroGeo, 2021a) found that all identified impacts occur within 60 m of the longwall footprint. There is no evidence for anomalous impacts to swamps (at greater distances) associated with mapped lineaments.
- **Spatial analysis**. Analysis of the spatial relationship between mapped lineaments and anomalous groundwater depressurisation found no significant correlation (HGEO, 2020c). Similarly, no correlation was found between the chemistry of mine inflow and proximity to mapped lineaments (HGEO, 2020d).

2.6.9 Fault zone hydrogeology

No large faults are mapped or expected within the Project area (Section 2.5.2), although that understanding may change in future, as noted below.

Investigations were carried out by IMC into the Elouera Fault, located to the south of Longwall 18 in Area 3B (HGEO, 2020e) as part of the SMP for that panel. The investigation provided detailed information regarding the structure, permeability, and stress conditions along a major oblique fault, and demonstrated a robust framework for future studies if required.

The investigation found that the fault zone comprised multiple anastomosing fault "cores" (slip surfaces) within a broad damaged zone between 8 and 31 m thick. Packer data and cross-hole tracer tests showed that permeable zones are discontinuous on a scale of tens of metres and the fault does not form a continuous conduit to groundwater flow. Observations of groundwater levels in the vicinity of the fault, relative to the nearby Avon Reservoir are consistent with a non-transmissive fault.

Should the Project be approved, as workings stretch into Area 5, more investigation of geological conditions, including the characterisation of structures, would occur. Where these investigations encounter structural features of concern, more detailed and focussed investigation would be carried out, including modelling as per IESC guidance and other practice (IESC, 2021; McCallum et al., 2018). This would be carried out at SMP/Extraction Plan phase, as done for Longwall 18 and the Elouera Fault.

2.7 Groundwater receptors

2.7.1 Groundwater users

The distribution of groundwater bores, as registered in the NSW government database, is shown on Figure 2-12. Bores around Dendrobium are all exploration and monitoring bores associated with mining. The non-mining bores are located on the coastal plain (east of the escarpment) and 10 km west and further south of Dendrobium, around Bargo/Pheasants Nest and the Southern Highlands respectively. This highlights the un-populated nature and lack of groundwater abstraction and use immediately around the Dendrobium mining areas, consistent with the dominant land use (Section 2.3).

The details of the nearest groundwater works, including whether they are considered 'water supply works', as per the AIP, are summarised in Table 2-10. All other Groundwater Works on Figure 2-12 are further from Area 5, and many of them are along the coastal plain, and stratigraphically separated from the coal measures. Bores to the north and west of Dendrobium (and the Project), i.e. around Bargo, Wilton and Pheasants Nest, are typically completed in the Hawkesbury Sandstone.

Table 2-10 Bores (GW works) nearest Dendrobium Mine

GW work ID	Distance from approved Dendrobium Mine	Distance from Area 5	Description
GW040945	7.3 km west of Area 3B	2.7 km west	WaterNSW test bore drilled to investigate groundwater supply between the Avon and Nepean Reservoirs.
GW099003-5 (three bores)	6 km north of Area 3B	2.6 km north	Monitoring bores drilled north of Area 5. No monitoring data available.
GW112386	1.9 km north of Area 3A, 1.9 km northeast of Longwall 21 (area 3C).	4.5 km east	Monitoring bore installed by WaterNSW on western edge of Lake Cordeaux.
GW105262	11.6 km northwest of Area 3B	6.9 km northwest	Water supply bore, completed in the Hawksbury Sandstone, near Bargo
GW102528	10.4 km north of Longwall 21 (Area 3C) and of Area 3B.	7.7 km north	Domestic/stock bore completed in the Hawkesbury Sandstone, just south of Wilton.
GW068119 and others	4.5 km south of Areas 1-2	12.5 km southeast	Multiple private bores: GW068119 and nearby private bores are located on the coastal plain, and in the lower Permian units (e.g. Shoalhaven Group).

Given the distances involved, effects (drawdown due to the Project) at these bores are considered unlikely. However simulated drawdown at these sites is included in the model predictions in Section 6.6.5.

2.7.2 Groundwater Dependent Ecosystems (GDE) and environmental features

High Priority GDEs

The relevant WSPs (Section 1.7) list a number of High Priority GDEs in this region, of which the three closest are:

- Thirlmere Lakes: located 17 km (or more) north-west of the Project;
- O'Hares Creek: located 19 km (or more) north-east of the Project; and
- Macquarie Rivulet: located 20 km (or more) south of the Project.

Given the distances involved, there is no groundwater-related risk from the Project.

Upland Swamps

Figure 2-12 and Figure A4 show the regional distribution of Upland Swamps around the Southern Coalfield, based on regional mapping by NSW OEH (now BCD) and by IMC's botanists and field team in the area around Dendrobium.

Regular reporting of the effects on hydrology (groundwater levels and soil moisture) is provided in the End of Panel reports. A review of these impacts was conducted in 2019, and then updated recently (Watershed HydroGeo, 2021a). That study concluded that identified impacts at piezometers monitoring swamp deposits around Areas 2, 3A and A3B have occurred within a distance of 60 m of extracted longwalls. Monitoring has been recommended to confirm this distance is applicable to swamps in the vicinity of Area 5 (and, previously, at sites elsewhere at Dendrobium Mine).

The Surface Water Assessment (HEC, 2022) further describes hydrological effects on the Uplands Swamps above and adjacent to the Project. Upland Swamps are prone to groundwater and soil moisture changes as a result of subsidence and associated fracturing, increasing susceptibility to erosion and fire, and are therefore a primary focus of the Biodiversity Assessment (Niche, 2022).

Other potential groundwater-dependant features

Mapping of potential GDEs from the BoM's GDE Atlas has been reviewed, but based on advice from NSW government following recent SMP assessments, more recent mapping of likely groundwater dependence for possible terrestrial GDEs ("HEVAE" mapping) is provided Figure 2-4 (Dabovic et al., 2019).

Within and adjacent to Area 5, areas of green and orange (higher and moderate potential groundwater dependence) occur along LA13, DC10, AR32, AR31 and AR19, and to a lesser extent on DC9. Areas of green are also mapped away from the watercourse, in the plateau or ridgeline at the centre of Area 5.

Cross-referencing against swamp and vegetation mapping (e.g. Figures 8, 9 and 10a) of the BDAR (Niche, 2022) confirms that the mapped Upland Swamps correlate well with the HEVAE mapping. The other threatened ecological community, the Shale Sandstone Transition Forest (Figure 8 of Niche) is located along the ridgeline between the Donalds Castle Creek and Lake Avon catchments, and is not well correlated with the HEVAE mapping.

The threatened flora recorded (Figure 10 of Niche) near to Area 5 longwalls are *Leucopogon exolasius* (above Longwalls 507-509) and the same species near Avon Dam wall. These records do not correlate with creeks or HEVAE mapping.

Based on advice in Niche (2022), the vegetation communities noted above, aside from Upland Swamps (see sub-section above) and some areas in creek lines (where moderate and higher probability of groundwater dependence has been mapped), are generally not considered sensitive to changes in groundwater level.

Niche conclude that changes to groundwater levels associated with the Project are likely to have only localised effects on riparian vegetation and the composition of these communities (tending to species that have a lesser reliance on groundwater). Niche advise that previous observed impacts of longwall mining to riparian vegetation (at Waratah Rivulet and Cataract River) were restricted to dieback as a result of methane gas release, from which the vegetation regenerated, and other localised changes (these are discussed in Niche, 2022).

2.8 Water quality

IMC collects samples of water from groundwater monitoring bores, underground mine seepage and inflow sites and at surface water monitoring sites. Each water sample is analysed for field parameters (pH, EC, Eh and temperature), major ions and minor ions / metals. Stable isotopes of carbon and hydrogen, and radiogenic isotopic tracers of groundwater age (tritium and carbon-14) are analysed at representative sites.

2.8.1 Groundwater quality

Groundwater samples are collected at 17 monitoring bores equipped with multiple sampling pumps, including six monitoring bores in Area 5. Most sampling pumps are located within sand pack intervals within the HBSS and BGSS. The SBSS is monitored at two locations: S1886 (Area 2) and S1870 (Area 3C). In Area 3B, six monitoring bores with sampling pumps are located between the mined and planned longwalls of Area 3B and the eastern shore of Lake Avon.

In general, groundwater salinity tends to increase with 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). End-of-Panel reviews have shown no clear spatial pattern in the distribution of groundwater quality in HBSS and BGSS bores (in terms of salinity). Similarly, most sites show no systematic trends in groundwater salinity. The most recent review (HGEO, 2022b) showed possible freshening trends within the HBSS at two bores located adjacent to Lake Avon (S2314, S2436).

2.8.2 Mine water quality

Samples are routinely collected from Dendrobium underground workings, inter-seam boreholes and flooded adjacent mine workings. Monthly water samples are taken from the main discharge points of the mine and from completed longwall panels. More than 3,400 water samples have been collected and analysed at Dendrobium Mine since 2004, providing an extensive database for ongoing characterisation of waters from various sources (Figure 2-22).

Samples of mine inflow (via the goaf) have compositions that are characteristic of groundwater from coal seams and coal measures: Elevated salinities (~800 to 3,000 µS/cm) relative to shallow groundwater and surface water and strong enrichment of Na relative to Cl. Mine inflow water is dominated by Na and HCO_3 with near neutral to alkaline pH. Minor ions are Si, Ba, Sr, Mg and Li, which are derived from silicate weathering and carbonate dissolution. Major and minor ionic ratios (particularly Na/Cl, Li/Cl and Sr/Cl), EC and tritium are useful in discriminating water sources (groundwater, surface water, mine water) and different source areas within the mine.

Tritium and carbon-14 provide a means to estimate and monitor the component of modern water entering each mine area. At Area 3B, tritium concentrations are typically <0.2 TU, with 2-3 pMC (percent modern carbon), consistent with very low contributions of surface water. Slightly higher surface water contributions are indicated at Area 2 (~0.3-0.5 TU; 4 to 5 pMC), consistent with the lower depth of cover and consequent stronger correlation of inflows with rainfall events at Area 2 (Section 2.6.5). For comparison, surface water samples have ~1.6 TU (median) and ~95 pMC.

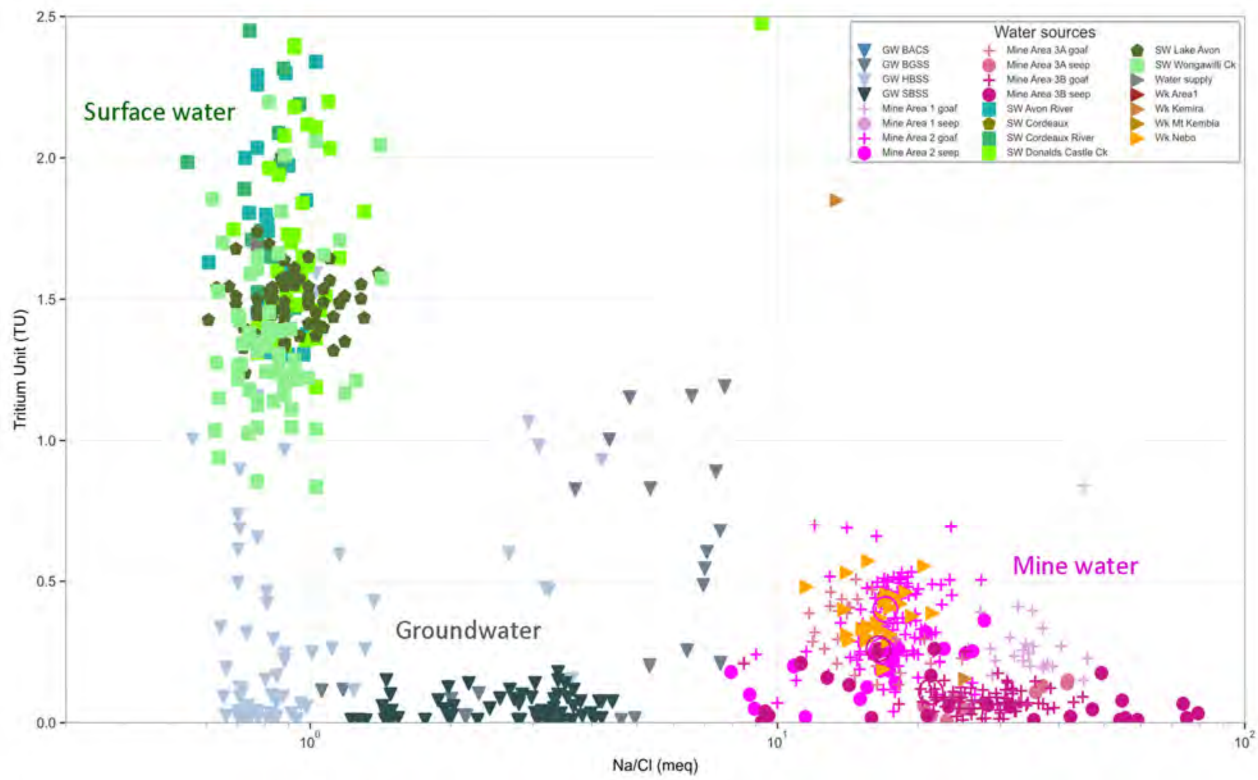


Figure 2-22 Bivariate plot of tritium (TU) versus Na/Cl ratio for all water samples

There is some spatial variation in salinity between and within mine areas (e.g. seepage in Area 3B freshens to the south); however there is no spatial correlation with mapped lineaments at the surface or underground (HGEO, 2020f).

IMC recently commissioned a study to sample and characterise water egress from nearby abandoned mine portals along the Illawarra Escarpment to inform the understanding of the water quality of long-term post-closure discharges.

2.8.3 Surface water quality

Surface water samples are collected from major rivers, tributaries, pools, springs and at the margins of Lakes Avon and Cordeaux. Monitoring includes a selection of sites downstream and within the mining area, as well as sites located upstream and away from the mining area (control sites). Pools within streams are monitored monthly before and following mining and weekly (when site access available) during active subsidence and in response to any observed impacts.

Streams draining the Dendrobium area contain relatively fresh water (<150 µS/cm) dominated by sodium and chloride ions, reflecting mostly direct rainfall runoff. Water pH is typically mildly acidic (pH 5.4 to 6.6), likely due to drainage from swamps and organic-rich soils. Dissolved trace metals are present in very low concentrations, mostly below the ANZECC guidelines for protection of 95% of freshwater species (where trigger levels are set). Exceptions to this are dissolved aluminium and zinc in some locations. Elevated concentrations of zinc in WWU4 may be related to previous mining at

Elouera (1994–2007) which passed beneath the upper catchment (**Appendix E**). The slightly elevated aluminium concentrations are to be expected since aluminium (and most metals) are more soluble in waters of low pH, with aluminium being derived from the weathering of aluminosilicate minerals. Median dissolved oxygen (DO) levels are variable and typically between 85 and 96% saturation, but as low as 44% in some frequently isolated pools.

Longwall subsidence can result in fracturing of streambeds and this fracturing can lead to changes in stream water quality (McNally and Evans, 2007). Reviews of surface water quality at Dendrobium show that watercourses that have been directly mined under typically show one or more of the following water quality effects compared with baseline conditions:

- A transient increase in EC, evident at one or more monitoring sites, but not always detectable at downstream locations.
- An increase in water pH from baseline mildly acidic conditions to near neutral conditions; or, more rarely, a decrease in water pH (e.g. Native Dog Creek associated with Elouera Mine).
- Transient increases in dissolved Fe and Mn (+/- Zn and Al) at sampling locations immediately down-stream of the affected area.
- Iron-staining is typically localised to reaches overlying or immediately adjacent to / downstream of a longwall footprint. In the case of SC10C and Wongawilli Creek, iron staining has emerged in baseflow several years after adjacent mining due to recovery of groundwater levels within fracture networks above extracted longwalls (HGEO, 2021d). Other sites in the Southern Coalfield, such as LA5 (Dendrobium Area 3B), Native Dog Creek (Elouera Mine), Eastern Tributary (Metropolitan Mine) and Lizard Creek (Cordeaux Mine) have also exhibited iron-staining effects.

The effects of longwall subsidence observed at Dendrobium are similar to those reported elsewhere, such as along Myrtle and Redbank Creeks near Tahmoor Mine (Wright et al., 2015; Morrison et al., 2019). The quality of surface waters in areas above extracted longwall panels was degraded along Redbank Creek (Morrison et al., 2019), with higher salinity and metal concentrations compared to an unaffected reference site. In many cases, metals concentrations decline further downstream of the sections overlying mining, e.g. iron (Fe), nickel (Ni), cobalt (Co), but others remain at elevated levels, e.g. manganese (Mn), barium (Ba), strontium (Sr), noting that the sampling was conducted in dry conditions with minimal runoff present. The decline in some metals is attributed to oxidation and precipitation.

These effects on water quality are further discussed in Section 6.10 in the context of potential impacts associated with Area 5.

3. Mining effects: review and conceptualisation

The initial part of this section provides a review of literature and conceptual models of fracturing and deformation due to longwall mining, and the empirical models used to estimate the extent (height) of this fracturing (Section 3.1).

Then we present a summary of recent focussed investigations into subsidence and fracturing at Dendrobium (Section 3.2), followed by a site-specific conceptual model (Section 3.3), which is supported by insights from the nearby Tahmoor Mine. This latter sub-section addresses a recommendation of IEPMC (2019a).

Following presentation of the site-specific conceptual model two sets of estimates of the height of fracturing are presented (Section 3.3.1), one because it remains a useful screening tool to understand ‘risk’, and the second is based on the site-specific model, and addresses the SEARs requirements regarding subsidence and the height of fracturing assessment(s).

After the description of the deformation and height of fracturing model, Section 3.4 outlines the conceptual model of the groundwater-related or hydrological effects of longwall mines, focussing on effects during or in the short-/medium-term after longwall mining. This has been refined based on data analysis for Southern Coalfield mines and Dendrobium Mine in particular.

Longer term effects, especially those that may occur after mine closure, are addressed in Section 3.5.

Effects as mining progresses and in the short-term afterward (i.e. “operational” effects) are likely or possible to occur via a number of “risk pathways”. The two primary causes of environmental risk, with respect to groundwater and groundwater-surface water interaction are:

- Longwall subsidence and the associated deformation and fracturing of strata.
- Groundwater drawdown, as a result of on-going mine dewatering – which is enhanced by the subsidence/deformation process.

The primary risk pathways for effects due to the proposed longwalls are summarised (Section 3.6).

3.1 Literature review of longwall subsidence effects

Longwall coal mining results in ground subsidence and associated deformation and fracturing of overlying and adjacent strata (Peng and Chiang, 1984; Whittaker and Reddish, 1989). While authors differ in their terminology, there is general agreement on the overall patterns of deformation. Forster and Enever (1992) carried out studies at pillar and longwall mines in NSW and developed a conceptual model to describe a sequence of deformational zones above longwall and pillar extraction areas (Figure 3-1). A similar conceptual model was provided by the Department of Planning (2008) and other authors have developed similar or alternative conceptual schemes.

In these conceptual models, fracturing is most intense and vertically connected immediately above the collapsed longwall (goaf) (the ‘caved zone’), and within the ‘fracture zone’ the intensity of fracturing grades upwards through to less fractured strata (Booth, 2002). Near the ground surface, subsidence and tension across the subsidence trough combine to cause ‘surface cracking’ which may extend a few tens of meters in depth. Depending on the height of the fractured zone above the goaf, the surface fracture zone may be separated from the deeper fracture zone by a "constrained zone” in which strata fracturing is minimal and permeability remains relatively low (Booth, 2002). At Dendrobium, the longwall geometry is such that a constrained zone is likely not present (Section 3.3).

In addition to fracturing of strata extending upward from extracted longwall panels, deformation and fracturing is also observed:

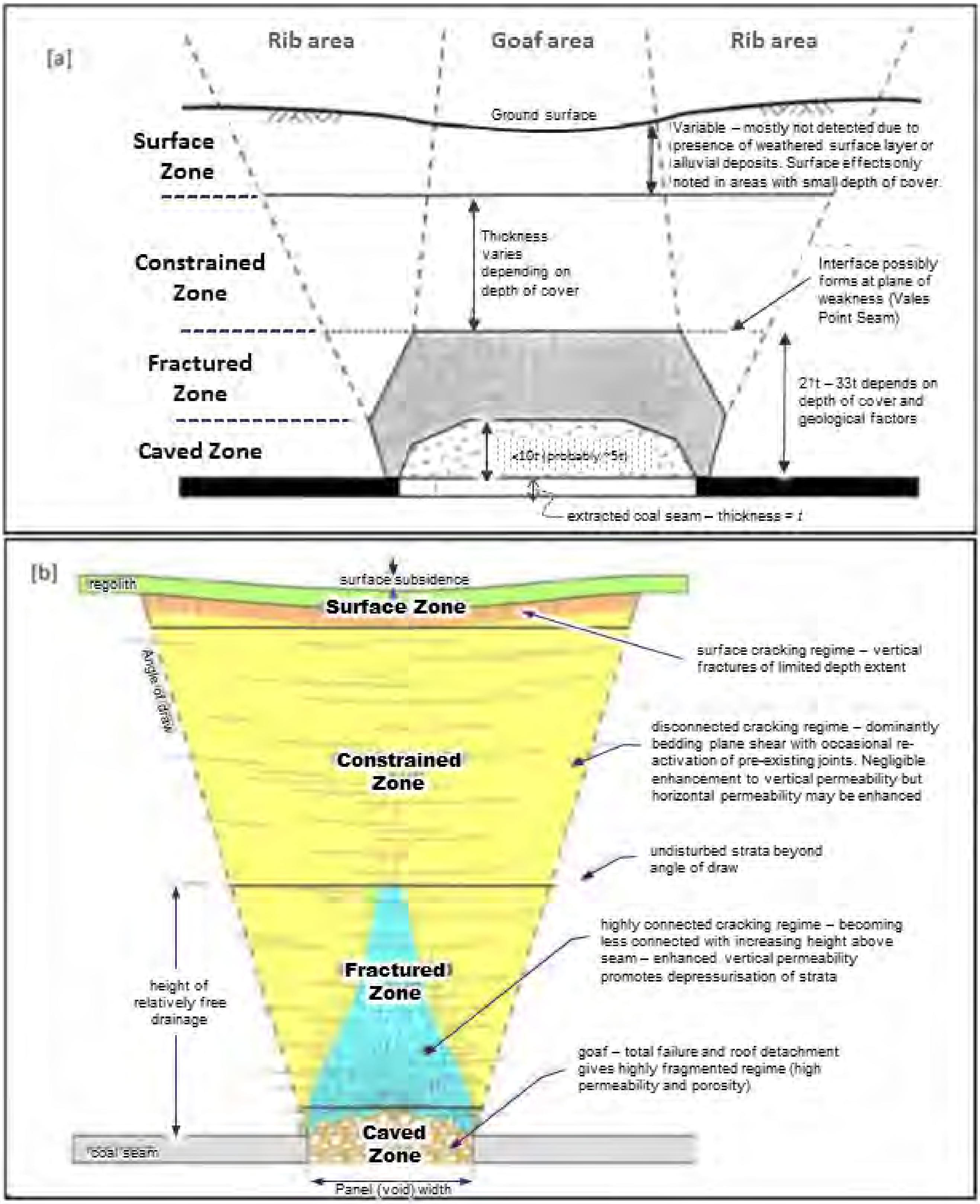
- **Beyond the longwall footprint**. Deformation and fracturing of geological strata may also occur outside the footprint of longwalls via mechanisms such as valley closure and for formation of basal shears (SCT, 2016; Walsh et al., 2014), and reactivation of existing geological structures or lineaments, as observed at Springvale Mine (Galvin et al., 2016).
- **Beneath the mined panel**. Deformation due to unloading and heaving can occur in the floor strata (Meaney, 1997; Karacan et al., 2011).

Fracturing of the overlying and adjacent strata can cause significant changes in aquifer characteristics such as hydraulic conductivity and secondary porosity (storage), and potentially can provide pathways for vertical groundwater movement between shallow groundwater and surface water systems and underground mines (Advisian, 2016; McNally and Evans, 2007). Therefore, the height to which vertically connected, and potentially free-draining fracture networks extend above the mined seam is important in assessing potential impact of longwall mining on groundwater and surface water systems.

Several authors 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 and Merrick, (2014) and (Adhikary et al., 2020) (Table 3-1). 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 models. It is important to note that the terms used by authors may not be equivalent; Tammetta refers to the “height of desaturation” (more precisely, complete depressurisation); Ditton and Merrick refer to a “zone of continuous cracking” (A-Zone), and Mills refers to a zone of large downward movement (Zone #2).

Table 3-1 Conceptual zones of deformation associated with longwall mining

<table>
<tr><th colspan="3">Conceptual Zone</th><th>Mills (2011)</th><th>Tammetta (2012)</th><th>Ditton (2014)</th><th>Geometry (from literature)</th></tr>
<tr><td>⑦</td><td colspan="2">Surface / tensile cracking zone (SCZ)</td><td></td><td></td><td>D-zone</td><td>Depth of increased surface fracturing (due to lower depth of cover/confinement) <=20 m, with enhanced horizontal hydraulic conductivity.</td></tr>
<tr><td rowspan="2">③</td><td colspan="2">Zones of mostly horizontal shear offset from the longwall panel footprint</td><td></td><td rowspan="3">Disturbed Zone</td><td></td><td>Offset from goaf, extending approx. 600 m from longwall edge (but subject to ongoing assessment).</td></tr>
<tr><td colspan="2">Constrained Zone</td><td>Zone of no disturbance (#5)</td><td>C-zone</td><td>>1.6 x panel width (W) (Mills, 2011).</td></tr>
<tr><td>③</td><td rowspan="2">Fractured Zone</td><td>upper zone of Disconnected Fracturing (DFZ)</td><td>Zone of stress relaxation (#4);
Zone of bedding plane dilation, some fracturing (#3)</td><td>B-zone</td><td><=1.6 x panel width (W) (Mills, 2011);
B/B95 – Ditton and Merrick (2014); or
H (Tammetta, 2013)*.
Adhikary & Poulsen (2020)</td></tr>
<tr><td>②</td><td>lower zone of Connected Fracturing (CFZ)</td><td>Zone of large downward movement (#2)</td><td rowspan="3">Collapsed Zone</td><td>A-zone</td><td><=1 x panel width (W) (Mills, 2012);
H (Tammetta, 2013)*; or
A/A95 – Ditton and Merrick (2014).
Adhikary & Poulsen (2020)</td></tr>
<tr><td rowspan="2">①</td><td colspan="2">Caved Zone</td><td rowspan="2">Zone of chaotic disturbance (#1)</td><td rowspan="2"></td><td>5-10 x t (Forster & Enever, 1992; Guo et al., 2007);
5-20 m (Mills, 2011).</td></tr>
<tr><td colspan="2">Mined seam (extracted panel)</td><td>Mined seam thickness (t).</td></tr>
<tr><td>⑧</td><td colspan="5">Buckling/heaving of ‘floor’ strata, caused by unloading after panel extraction (Meaney, 1997; Karacan et al., 2011)</td><td>Assumed to be in the order of 10-30 m.</td></tr>
<tr><td colspan="7">Numbers in circles, e.g. ①-⑧, correspond to zones on Figure 3-5.
* Tammetta’s conceptual model is for groundwater response, not geomechanical changes, so can be applicable to both ② and ③.</td></tr>
</table>



(source Forster & Enever, 1992 and Department of Planning, 2008)

Figure 3-1 General Conceptual Models of Subsidence and Deformation above longwalls

Adhikary *et al.* (2020) reviewed strata-caving mechanics and the observations of Tammetta (2013) and developed empirical equations defining upper and lower bound estimates for the height of connected fracturing. The equations are functions of the effective panel width (W') and height of mining (t) only. When applied to Dendrobium Area 3B, the lower and upper bounds are 199- 387 m, which are close to the estimates based on Ditton & Merrick (2014) [216-258 m; Geol-A95] and Tammetta (2013) [351-377 m), respectively. The authors emphasise that seam-to-surface fracturing does not imply seam-to-surface connection. In addition, rock mass dilation may result in sudden and complete piezometric pressure drops throughout overlying strata that are independent of (and beyond) the connected fracture network (as noted by Booth, 2002). Initial piezometric pressure loss may recover to various degrees depending on the fracture network, recharge rate, and aquitard integrity including the presence of self-healing clay-rich aquitards. Those conclusions are consistent with observations at Dendrobium.

It is acknowledged by most authors that the conceptual zones are not clearly bounded, but are gradational and indistinct. However, as discussed in later subsections, the assignment of certain parameter thresholds and depth approximations are necessary when simulating subsidence effects on groundwater systems using numerical models.

Post-mining compression and reconsolidation of strata following longwall extraction can result in closure of fracture networks and reduction in storage within the caved zone and fracture zone. (Figure 3-1). This concept is described by multiple authors (Zhang et al., 2016; Seedsman, 2018). Using gas drainage data, Zhang *et al.* estimated 40-80% permeability reduction (average 65%) in the caved zone from the initial high permeability that occurred after longwall extraction. This reduction due to reconsolidation occurred over a period of months, and is focussed on the centre of extracted panels, with less compression at the edges and corners due to the pillars. Similarly, Booth (2002) describes recovery of shallow groundwater levels as a result of compression and fracture closure after passage of the longwall, followed by further recovery as residual fracture storage is re-filled via recharge and lateral flow.

3.1.1 Reviews of height of fracturing (HoF)

In 2018, the Independent Expert Panel for Mining in the Catchment (IEPMC) was established to provide expert advice to the Department of Planning, Industry and Environment (DPIE – now DPE) on the impact of mining activities in the Greater Sydney Water Catchment Special Areas, with a focus on risks to quantity of water. Final reports (IEPMC, 2019a, 2019b) identify height of fracturing and associated groundwater depressurisation above longwall mines as a critical issue that has emerged since the 2008 Southern Coalfield Inquiry (SCI) and since approval of mining at Dendrobium.

In relation to hydrogeological impacts and height of fracturing, the IEPMC considered that:

Models of sub-surface behaviour zones can be useful for conceptualising the impacts of mining on the surrounding rock mass and groundwater system, but it is important to appreciate their limitations. While it is convenient to divide subsurface behaviour into a series of zones with distinct physical and/or hydrogeological characteristics, in reality 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.

Further, the Panel considered that:

[*Rather than carrying out a full analysis of the Tammetta and Ditton databases to validate those empirical models], it would be quicker and more productive for Dendrobium Mine and Metropolitan*

Mine to develop their own site-specific databases. This conclusion aligns with Condition 19 of the Dendrobium Area 3B SMP approval and investigations by IMC into the height of fracturing above extracted longwalls.

A further review into the Height of Fracturing at Dendrobium Mine was carried out by Bruce Hebblewhite for DPE (Hebblewhite, 2020, 2019). In those reports, Professor Hebblewhite:

1. Also cautioned the use of model concepts (for height of fracturing), without significant qualification, and/or detailed analysis of the underpinning data. The breakdown of the overburden into distinct zones should only be regarded as an artefact or concept, to aid in understanding, rather than an exact definition of what is occurring in the ground.
2. Proposed that the term "height of depressurisation" be adopted in relation to groundwater impacts, rather than height of fracturing, or height of connective cracking. This proposed terminology is directly linked to the application of the term for groundwater purposes, as well as being directly linked to the means of measurement or estimation.

3.2 Investigations at Dendrobium Mine

IMC carried out extensive investigations into the nature and extent of deformation in strata overlying and adjacent to extracted longwalls allowing development of a site-specific conceptual model for Dendrobium. The aims of the investigation were to quantify:

1. The extent and nature of fracturing and depressurisation above extracted longwalls.
2. Strata movement and permeability between mined longwalls and storage reservoirs.

The results of those investigations, summarised below, have informed the latest iterations of groundwater modelling at Dendrobium.

3.2.1 Investigations over extracted longwalls

IMC drilled investigation holes above extracted Longwalls 9 and 12-17 in Area 3B and Longwalls 6 and 7 in Area 3A, allowing assessment of effects above longwalls of different width (305 m and 249 m respectively, including first workings). Holes were drilled to depths of between 280 and 300 m. Observations from the post mining holes were compared with tests in pre-mining holes at the same drill sites (HGEO, 2021e, 2020g, 2020h; Parsons Brinckerhoff, 2015a). An example of the pre- and post-mining "goaf hole" bore logs from above Longwall 14 is presented on Figure 3-2.

The main conclusions from the over-goaf investigations are as follows:

- All holes drilled above extracted longwalls show a significant increase in permeability throughout all strata to the surface. Packer tests indicate an increase in permeability of 2 to 3 orders of magnitude (OM) relative to pre-mining conditions. Above the pillar zone between Longwalls 11 and 12 packer tests indicate distinctly lower post-longwall permeability than the centreline holes throughout all strata.
- In both mine Areas 3A and 3B, mining-induced fracturing, including high-angle (> 20°) fracturing is highly variable but appears to extend to the surface. The frequency of fracturing generally decreases with height above the goaf, with a high proportion of high-angled fractures within ~120 m of the Wongawilli Coal seam (Figure 3-3). The intensity of high angle fracturing due to panel extraction generally reduces with height above the extracted panel (the exception to is noted below), while low angle fracturing occurs more consistently to the surface.

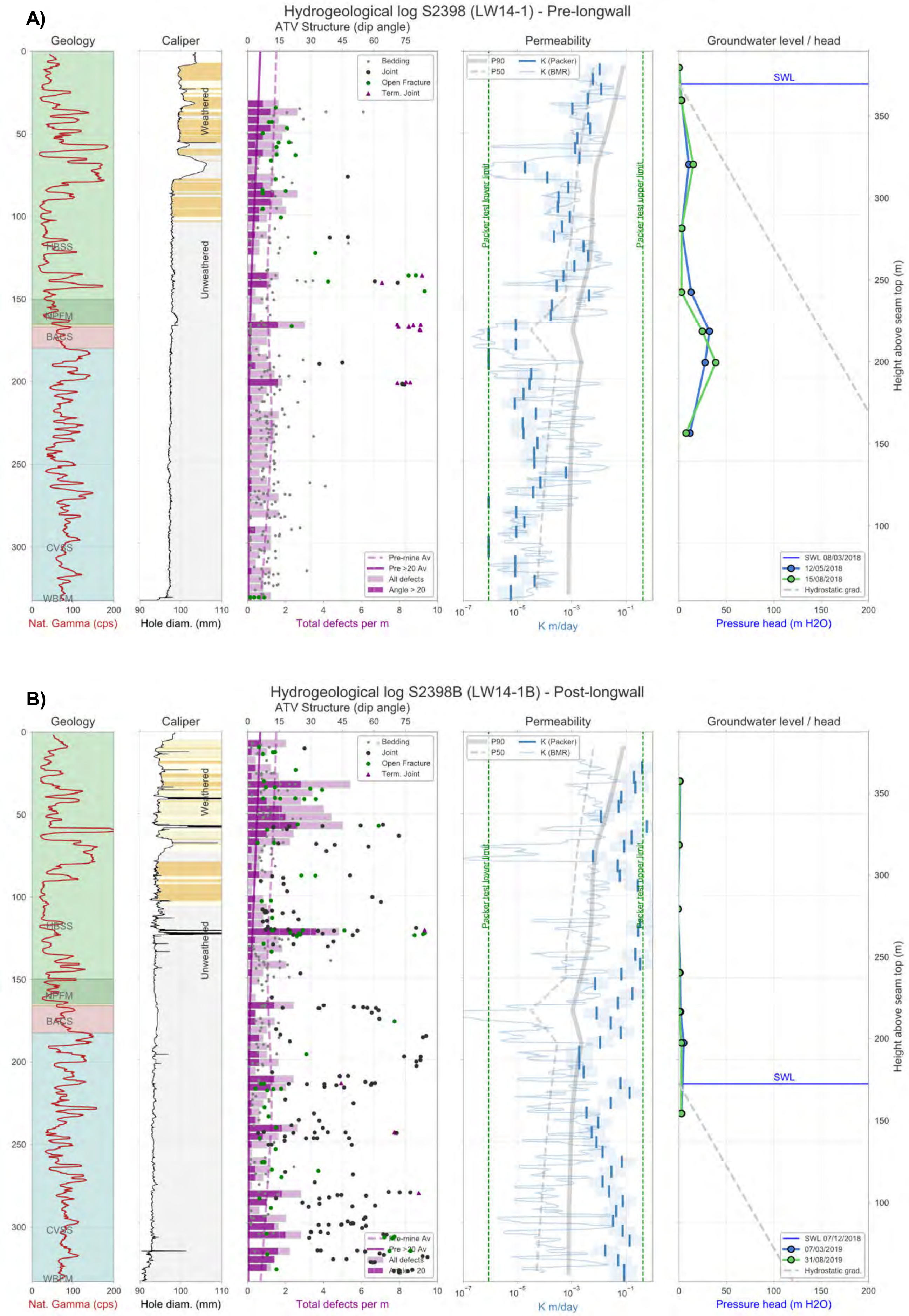
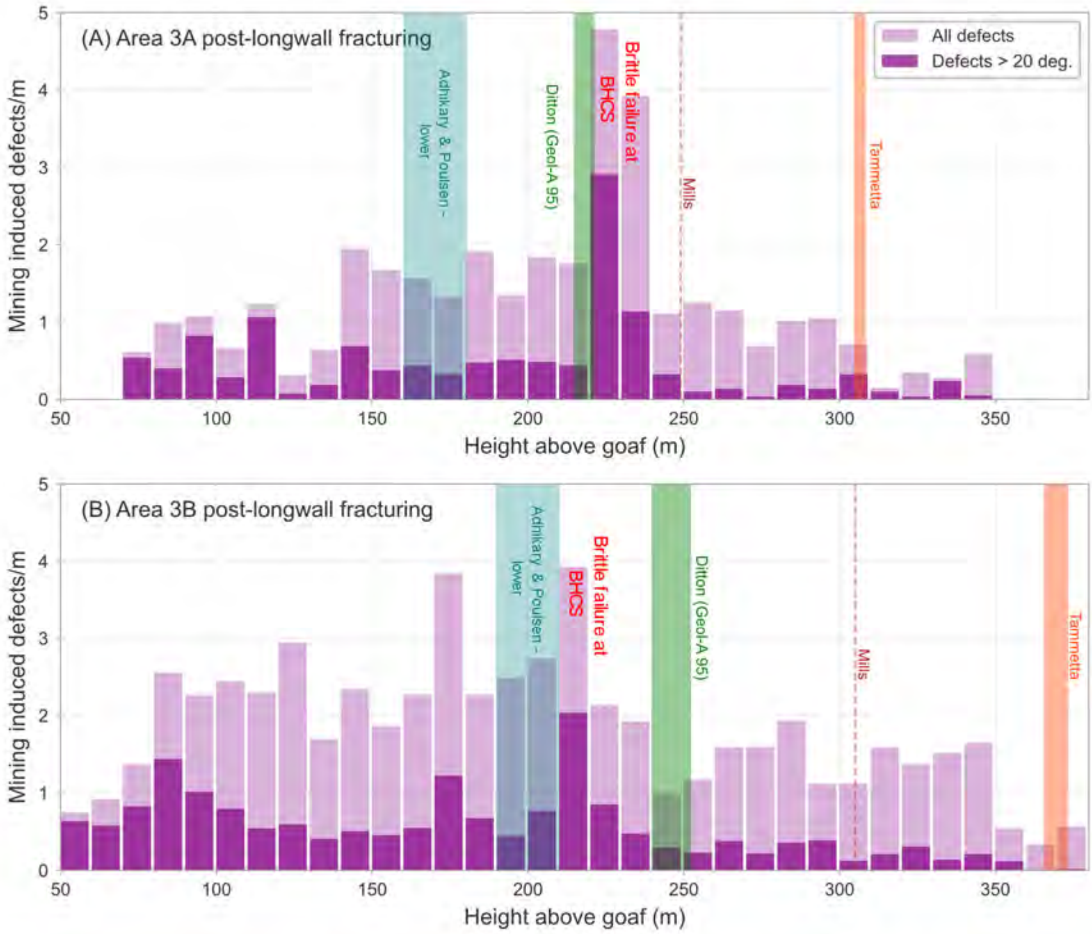


Figure 2-23 Pre- and post-mining conditions above Longwall 14 (boreholes S2398 and S2398B)



modified from HGEO (HGEO, 2021e)

Figure 3-3 Change in fracture mode with height above extracted panel

- On average, the frequency of fracturing above the 249 m wide longwalls is less than that above the 305 m wide longwalls, although the profiles are variable (Figure 3-3).
- Anomalous fracturing is noted at the Bald Hill Claystone in several holes (Figure 3-3).
- Changes in vertical permeability cannot be measured directly from packer testing. However the high proportion of high-angle fractures in strata within 120 m of the goaf and general decrease with height implies that the ratio of vertical to horizontal permeability decreases with height above the goaf (whereas horizontal permeability is elevated throughout all strata).
- Assessment of near-surface cracking was beyond the scope of the investigation since vertical drill holes are unlikely to intersect subvertical features. No significant increase in fracture-frequency was noted in the near-surface (~30 m) compared with underlying strata.
- 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. 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.
- Vibrating wire piezometers (VWP) indicate that strata are depressurised well-ahead of mining with deeper formations affected before and to a greater extent than shallow units. Following longwall extraction all strata record significant depressurisation, with near-zero pressure

heads recorded in most piezometers (Figure 3-2). Complete depressurisation is recorded throughout the Hawkesbury Sandstone (HBSS) in most holes drilled above goaf.

- Piezometers installed after longwall extraction show evidence for groundwater recovery and perching. The perched horizons are most extensive in strata between the upper CVSS and lower HBSS (> ~220-250 m above the coal seam) and above longwalls extracted three or more years ago (Section 2.6.2 and Figure 2-19). The observations imply that rainfall recharge (and stream flow loss), which may be enhanced due to surface fracturing, percolates through the fractured strata and is retarded at certain stratigraphic layers or restrictions in the fracture network. The overall hydraulic gradient remains downward; however, the increasing head trends in some piezometers implies that the rate of recharge exceeds the rate of downward drainage at those perched horizons. Therefore, not all rainfall that infiltrates at the surface above the goaf reports directly to the goaf as mine inflow.

The study concluded that fracturing (and groundwater depressurisation) following mining extends to the surface in Areas 3A and 3B and so is likely also in Areas 1 and 2. This aspect of the observations is therefore consistent with the empirical model of *depressurisation* put forward by Tammetta (2013). The study further concluded that mine water inflow and shallow groundwater drawdown are largely influenced by the intersection of the fracture zone(s) with saturated HBSS which is has both higher permeability and drainable storage (Sy) than underlying units. However, observations of perching and recovery above extracted longwalls is counter to the model of Tammetta (2013), which states "*This zone is severely disturbed and is completely drained of groundwater during caving. It is subsequently unable to maintain a positive pressure head. It will behave as a drain while the mine void is kept dewatered*.". The observations imply that while defects and fracture networks occur through the sequence, they do not necessarily result in surface-to-seam connection over all goaf areas (Section 2.6.2 and Figure 2-19). The very low levels of tritium and carbon-14 observed in mine inflow in Area 3B supports this concept.

This conclusion is supported by recent modelling and analysis by Adhikary et al. (2020) in their review of strata-caving mechanics. The authors noted that rock mass dilation may result in sudden and complete piezometric pressure drops throughout overlying strata that are independent of (and beyond) the connected fracture network. This is also consistent with effects observed adjacent to Tahmoor's Western Domain.

With regard to surface-cracking, the best evidence is available from Waratah Rivulet (near Metropolitan Mine) and from recent investigations at Tahmoor. Drilling along Redbank Creek above Tahmoor Mine indicate that the depth of increased K is approximately 20 m over 285 m wide panels with cutting height 2-2.5 m (SCT, 2018, 2020). This is in agreement with earlier literature estimates of 10-20 m depth (and the data from Waratah Rivulet), but could also be viewed as being approximately 8-10 x cutting height (*t*).

Evolution of inflow (Area 3A)

Within Dendrobium Mine there are no domains or areas where inflow has ceased, although 'baseline' inflow to Area 2 is approximately 0.5 ML/d and inflow is clearly declining in Area 3A (down from approximately 2 ML/d to less than 1 ML/d in recent years). This is illustrated in Figure 3-4, along with some comments about the potential causes of this.

The main point to note from this analysis is that the significant peaks in inflow do not continue after 2015, and the milder peaks after that time do not correlate consistently to heavy rainfall events. This is good evidence for a lack of seam-to-surface connectivity, either from the time of mining or a change in this behaviour over time.

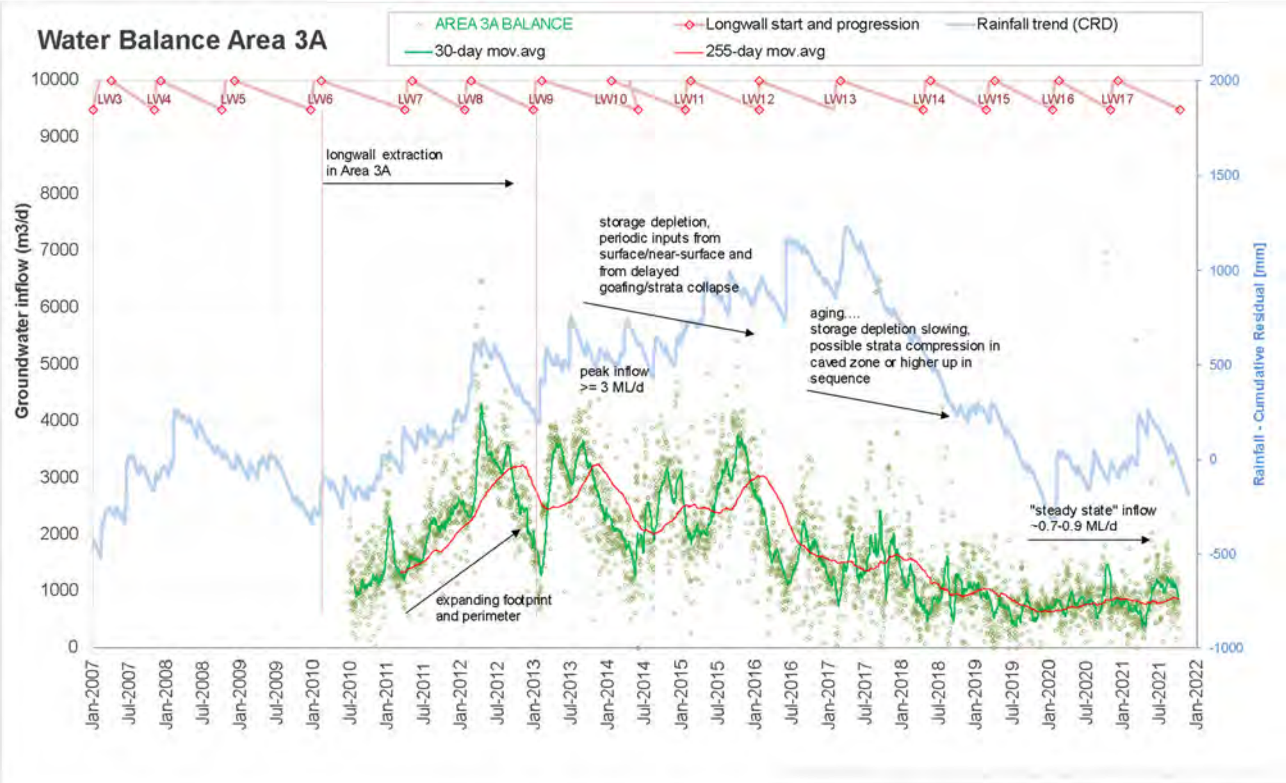


Figure 3-4 Evolution of inflow flux at Dendrobium Area 3A

3.2.2 Investigations adjacent to storage reservoirs

Changes in strata permeability and potential seepage losses from Avon Reservoir have been investigated by IMC through the drilling and installation of boreholes at 8 locations within the barrier zone adjacent to Area 3B. At each location strata permeability is measured using double packer tests both prior to and following extraction of the adjacent longwall. In addition, Time Domain Reflectometry (TDR) cables are installed at 5 of the 8 locations which monitor strata movement including the precise depths and timing of shear movements. The most recent assessment of results was carried out following the extraction of Longwall 17 (HGEO, 2021f).

A summary of observations since 2015 have shown:

- A significant increase in strata permeability is observed at 3 of the 8 sites (AD2, AD4, and AD7), where a significant change is more than 0.5 orders of magnitude ("OM"). Differences in sampling frequency mean that the apparent increase at site AD8 is unreliable. At those 3 sites the average increase in permeability is in the order of 0.74-1.0 OM. The other sites show little or no change in strata permeability as a result of mining, including mild decreases in permeability at 3 sites. The ratio of measured pre- to post-mining K is 0.5-10 (average of 4).
- There is no consistent relationship between post-mining strata permeability and distance from the goaf footprint. Rather, the sites that record a significant increase in permeability tend to be those within tributary valleys, suggesting topography and effects such as valley-closure are important.
- Time-Domain Reflectometry (TDR) monitoring has identified strata movement or shear at single or multiple levels at four out of the five monitored locations, and at distances up to several hundred metres from the active longwall. At three sites (AD1, AD2 and AD3),

significant TDR anomalies occur at depths corresponding with the top of the Newport Formation suggesting the presence of a basal shear plane related to valley-closure within the Newport Formation.

With respect to the shear planes, the evidence from packer testing near Area 3B (SCT, 2017a; HGEO, 2021f, 2020i) and near Area 3A/Sandy Creek (SCT, 2019) does not support these being the primary potential groundwater pathways in off-goaf areas.

3.3 Site-specific model of fracturing at Dendrobium

This section addresses a recommendation of IEPMC. The 'model' developed here is based on concepts described above, refined considering using site-specific data and observations, and relies on existing empirical models for the height of various conceptual zones. The primary aims of this model are:

- to understand the risk to water resources and environmental features related to proposed longwall mining;
  - This includes short-term effects, including depressurisation and drawdown; and
  - medium to longer-term effects, including groundwater recovery and water quality effects.
- to develop quantifiable inputs to numerical groundwater model(s) that will allow for quantified forecasts of likely or potential effects.

The following text in this section describe the conceptual model of the changes that occur to the hydraulic conductivity and storage properties of the strata around Dendrobium Mine. In the following text, numbers in circles, e.g. ①-⑳, correspond to the zones on Figure 3-5, some of which are also listed in Table 3-1 (general model) and Table 3-2 (site-specific model).

As was foreshadowed in Section 3.1, it is well recognised that styles of deformation and fracturing above (and adjacent to) extracted longwalls, vary gradually with height rather than forming discrete zones with well-defined boundaries. Investigations at Dendrobium described in the previous section support this view, whereby broad zones of similar deformation styles and groundwater responses can be identified, but for which the boundaries are indistinct or variable across the mining domain. Nevertheless, it is important to note that numerical models are discretised in three dimensions (as layers and cells) such that it is often necessary to approximate complex or continuous parameter variations as a number of zones or steps.

The zones of enhanced K, i.e. the deformation zones ①②③⑦, above the mine void/goaf on Figure 3-5 is a schematic representation of monitoring data of post mining strata conditions at Dendrobium Mine and the conceptualised 'likely' case for the current remaining mine domains at Dendrobium Mine.

After panels of coal are extracted the strata immediately overlying the extracted seam collapses into the void (forming a 'goaf'). The strata above the goaf deform and fracture in response, and subsidence occurs at the ground surface, manifesting as a trough along the axis of the extracted panel. At Dendrobium, some mode of fracturing due to mining subsidence occurs from the seam to the surface (Figure 3-3).

Table 3-2 Dendrobium Mine conceptual model of subsidence fracturing

Conceptual Zone		Description	Evidence / reference	Assumed geometry (height/depth))
Off-goaf (outside panel footprint)				
④	Off-goaf: Zones of strata relaxation, exacerbated by high relief topography	Zones of horizontal shear offset from the longwall panel footprint	Effects on Kh not consistent, average of x4 increase (up to x10) in Kh based on packer testing (Section 3.2.2).	Offset from goaf, extending approx. 600 m from longwall edge, near to major valleys.
Above goaf				
⑦	Surface cracking zone (**SCZ**)	Zone of increased fracturing, with increased vertical permeability more likely around panel edges.	Dendrobium over-goaf holes do not clearly identify this zone, so depth estimated conservatively Section 3.2.1). Bores at Tahmoor suggest depth is ~20 m over 285 m panels with cutting height 2-2.5 m.	Estimated at 10-12 x *t* (i.e. approximately 24-45 m at Dendrobium). This depth is considered to be conservative.
③	Dilated or disconnected zone (**DFZ**)	Zone of bedding plane dilation, some fracturing.	Zone of low angle fractures from over-goaf holes (Section 3.2.1). Initial decline in groundwater pressures, following by groundwater recovery observed following mining (Figure 2-19).	This zone extensive between Connected Fracture zone and Surface Cracking zone. Geometry guided by: ▸ B/B95 – Ditton and Merrick (2014); ▸ H (Tammetta, 2013). ▸ ~ Adhikary & Poulsen (2020) Upper
②	Connected fracture zone (**CFZ**)	Zone of intense fracturing, with greater frequency of high angle defects.	High angle fractures from over-goaf holes (Section 3.2.1) Assumed to remain depressurised (i.e. below horizons of groundwater recovery following mining)	▸ A95 – Ditton and Merrick (2014). ▸ ~Adhikary & Poulsen (2020) Lower.
①	Caved Zone ("goaf") Mined seam (extracted panel)	Zone of chaotic disturbance, with possible re-compression.	No direct evidence of caved height. Caved height from literature.	▸ 5 x *t* (i.e. approx. 16-20 m) (Guo et al., 2007) Mined seam thickness (*t*) listed in Sections 1.5.1 and 1.5.2.
⑧	Buckling/heaving of 'floor' strata		Buckling/heaving of 'floor' strata described by mining engineers. No direct evidence for permeability or depth.	▸ 5 x t (i.e. approx. 16-20 m) (Karacan et al., 2011).

Numbers in circles, e.g. ①-⑧, correspond to zones on Figure 3-5.

MSEC (2018) calculated subsidence of 0.8 m (above pillars) and 2.4 m (along the longwall centreline) for Longwall 13, with an average subsidence of 1.5 m for a mined height of 3.9 m (about 40%). This leaves a residual void space of 2.4 m (calculated as 3.9 m – 1.5 m) due to open fractures within the overburden.

The strata in the lower parts of the fractured zone ①② shows significantly more low angle and high angle defects than host rock (Figure 3-3), and are known to have a substantially higher hydraulic conductivity ⑱ than the undisturbed host rocks ⑤:

- horizontal hydraulic conductivity (Kh) is known, from recent packer testing, to be increased by 2-3 orders of magnitude (Section 3.2.1); and

- vertical hydraulic conductivity (Kv) cannot be measured *in situ*, but based on the defect logging and presence of intense high angle fracturing, is assumed to be significantly higher than host strata.

This fracturing encourages groundwater to move out of storage (elastic storage (S or Ss) and drainable porosity, Sy) and drain downwards towards the goaf ⑬⑭⑮.

This declining continuity between separate fractures with increasing height above the seam means that fracturing becomes gradually less well-connected in a vertical sense, i.e. tending toward being vertically 'disconnected' ③. Kh increases due to the parting of bedding planes by 2-3 orders of magnitude in the upper part of the sequence above a panel, to approximately 0.1-10 m/d. Kv is not enhanced to the same extent due to reduced frequency of these high angle fractures to act as vertical pathways ⑫. This is supported by observations at Dendrobium (see Section 3.2).

Specifically, observations of groundwater levels and isotopes in Areas 3A and 3B imply that the horizons of the upper CVSS/BGSS and lower HBSS do not drain vertically to the goaf, or that the rate of vertical drainage though those strata is less than the rate of recharge into the top of the sequence. Alternatively, the degree of connectivity from these horizons to the goaf reduces over time (<3 years approximately), potentially via re-consolidation or re-compression of fractured strata. ㉒

Regardless of the mechanism, groundwater impact models must account for restricted vertical drainage above a specified height threshold and recovery of groundwater levels in overlying strata.

At mines where the depth of cover greatly exceeds the longwall width, strata overlying the fractured zones may sag but not significantly fracture, resulting in a degree of hydraulic isolation of those fracture zones from the surface and near surface (⑦ - see below). This is referred to as the 'constrained zone' by Booth (1986) and others and the zone of vertical stress relaxation by Mills (2011). However, longwall geometries and depths of cover at Dendrobium are such that a constrained zone does not occur above the goaf, i.e. defects and higher Kh is observed through the entire sequence above these longwalls (Section 3.2.1).

The Bald Hill Claystone is shown to be more prone to high angle fracturing than adjacent horizons. The concept is that this unit is weaker or more brittle, and less able to resist subsidence and sagging than the neighbouring strata. ㉑

Note that for the purposes of numerical modelling, including subsequent calibration to match observations of depressurisation and recovery (where these occur), and acknowledging that zone boundaries are gradational, it is considered that transitions in deformation styles are best represented by the following published equations:

- The top of the vertically connected fracture zone (CFZ) is approximated by the Ditton and Merrick (2014) Geology Zone (95th percentile) A-zone height, which is similar, but slightly higher than Adhikary's (2020) Lower limit. (note that for Bulli seam workings, such as proposed for Area 5 or at Tahmoor Mine, the Ditton A height is quite similar to Tammetta H, and both are greater than Adhikary's Lower limit) (see Figure 3-6 and Figure 3-7).
- The top of the dilated or disconnected fracturing zone (DFZ) could be approximated by the maximum of the height of depressurisation "H" of Tammetta (2013) in Area 3B, which is broadly equivalent to Adhikary's (2020) Upper limit, and the Ditton and Merrick (2014) Geology Zone (95th percentile) B-zone height. However more conservative assumptions have been made (Section 3.3.1).

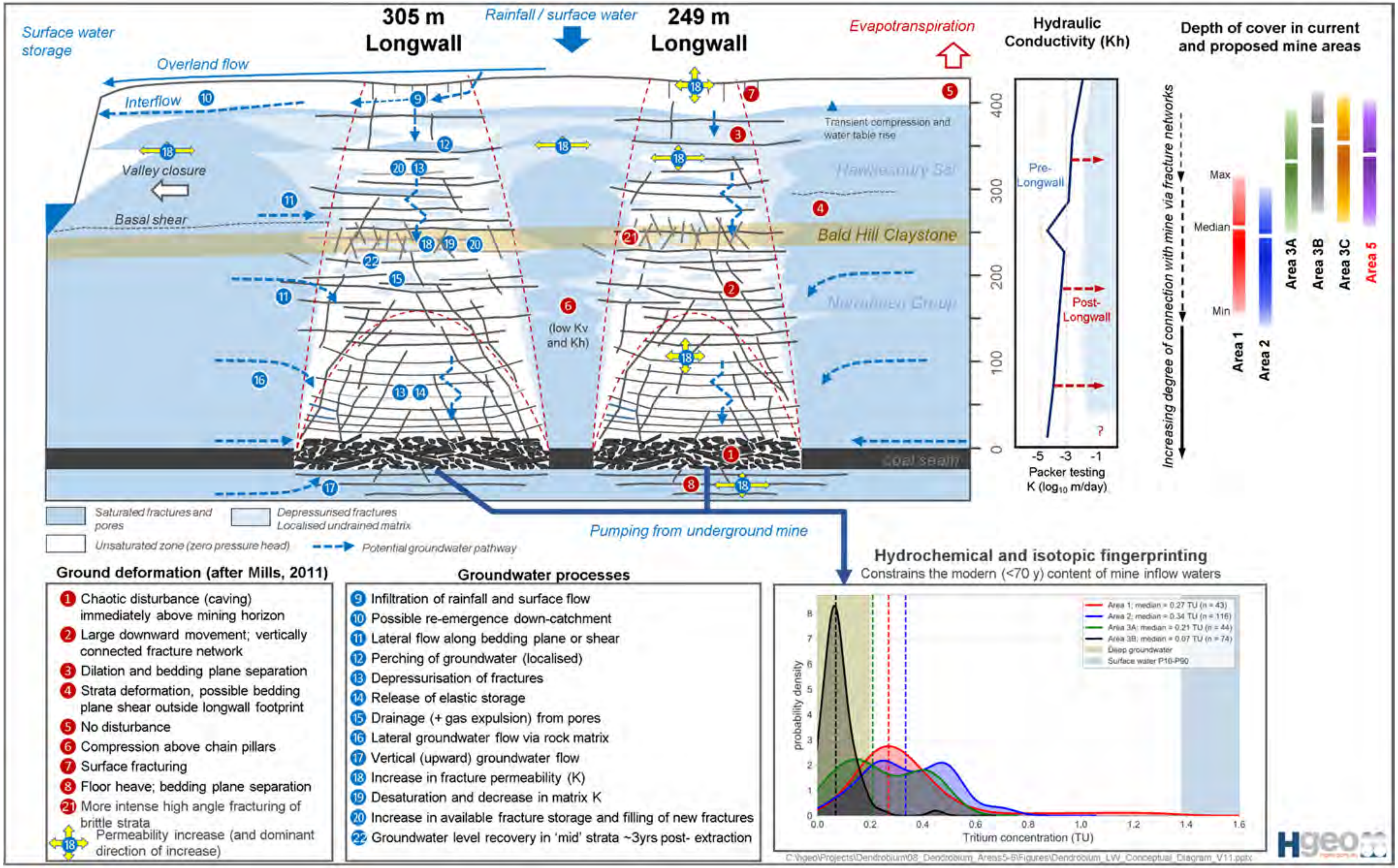


Figure 3-5 Conceptual model of groundwater and associated effects

In the surface cracking zone ⑦, fracturing of the surficial and near-surface strata can occur due to the effects of compression and tension on unconfined strata within and around the edges of the subsidence trough.

It is important to emphasise that we consider that the surface cracking zone ⑦ and its possible interaction with the disconnected fracture zone or dilated zone③, is chiefly responsible for the effects on watercourses observed at Dendrobium (and at Tahmoor Mine). The creation of additional storage (secondary porosity) and fracturing of the HBSS leads to hydrological and water quality effects. These are further described in Sections 3.4 and 3.5.

Within approximately 600 m of the longwall goaf minor enhancements to Kh may occur ④, sometimes at specific horizons or planes. This enhancement is considered more likely in the upper parts of the strata offset from longwalls where there is incised topography. In the lower sections above pillars the compression of overlying strata ⑥ is likely to restrict the potential for secondary porosity and permeability to develop (as described for Longwall 12 investigations in HGEO, 2020c), and may even reduce Kh in these areas. Further, there is evidence that the centre of the caved zone will compress, and reduce K in this area, while higher K will remain around the edges of the extracted panel.

At distances exceeding approximately 500-600 m from the mine, strata are assumed to be relatively unaffected ⑤ (noting that in different geological settings, such as the Western Coalfield, the effects of geological structure (i.e. geological lineaments) has been shown to result in changes to permeability and effects on environmental receptors to much greater distances (Section 2.6.8). This has not been the case at Dendrobium.

3.3.1 Height of fracturing assessment

Risk assessment using Tammetta H

H is "the height of complete groundwater drainage" (Tammetta, 2013), and is sometimes considered a proxy for the height of connected fracturing. H is a function of panel (void) width, cutting heights and depth of cover. Coal seam thickness and depth of cover are presented in Figures D1 and D2 (**Appendix D**).

This method serves as an indicator for the risk of water ingress to the mine workings from overlying strata and potentially from the surface. The use of this method provides some consistency with analysis previously presented to agencies. An alternative method of estimating the height of connected fracturing, which is more consistent with evidence from field data, is presented in the following sub-section.

A spatially-distributed calculation of this has been made using the relevant parameters at Dendrobium and at other nearby longwall mines (Elouera and Cordeaux). Figure D3 (**Appendix D**) presents this in terms of the depth to the top of this zone, and the stratigraphic unit in which the connected fracturing zone is estimated to extend to.

The colour scale has been set to identify areas where the Tammetta H rises to intersect the surface or is likely to intersect the cracking that extends downward from the surface. Areas shown in purple or red on Figure D3 (left-hand pane) and purple on the right pane have the greatest potential for seam-to-surface connection, according to the Tammetta model.

Figure D3 suggests that, with the exception of parts of Area 3A and Area 1, the historical and approved areas of Dendrobium Mine have a similar potential for fracturing to the surface or to near-surface strata. The Tammetta model suggests that the potential for connection to the surface, and the potential for significant depressurisation, above the proposed longwalls in Area 5 is much lower. Within Area 5, most areas have a vertical separation between the conceptual zones of >50 m (yellow and green shading), with small areas of <50 m spacing (orange shading) in the valleys of AR31, LA13A and LA8.

The right-hand pane of Figure D3 indicates that a zone defined by the Tammetta H would intersect the Bald Hill Claystone (BHCS) or the upper Bulgo Sandstone (BGSS) across approximately half of Area 5. This is primarily the case for the southern longwalls (507-509, near Avon Reservoir), and Longwall 510 which is the panel nearest Donalds Castle Creek. In the remaining area, Tammetta H is estimated to intersect the lower HBSS, with a smaller area intersecting the mid-HBSS above the centre of Longwalls 503-505, near tributary AR31.

Height of connected fracturing assessment for the Project

This section illustrates how the conceptual model of fracturing developed for Dendrobium applies to the Project, with specific reference to considering "connective fracturing above the longwall panels" (Subsidence SEARs, Table 1-1). This section is considered to be the key part of the "height of fracturing assessment" for the Project (Table 1-1).

In order to carry out this assessment of the height of connected fracturing, the following steps were followed. Some additional detail and analysis follows this initial summary.

- A site specific model needed to be developed, as per IEPMC recommendations.
- Monitoring data and observations gathered from Areas 2, 3A and 3B have been analysed, including multiple lines of evidence such as geotechnical and permeability data, groundwater drawdown and recovery, mine inflow hydrographs and water quality. Similar groundwater level and inflow data from other sites, notably Tahmoor Mine, has also been considered as a secondary source.
  - Based on Areas 3A and 3B observations, some degree of fracturing extends to the surface, and results in initial depressurisation following longwall extraction.
  - However, observations from Areas 3A and 3B of groundwater pressure recovery in the upper strata leads to considering that a zone of vertically disconnected fracturing is present.
- Given the differences in cutting height between Areas 2, 3A and 3B and Area 5 (specifically the lower cutting height in the Bulli seam), it is difficult to directly translate findings from the historical areas to Area 5. As a result, the existing empirical models were reviewed in order to determine which is most consistent with the evidence outlined above.
- Ditton A and Tammetta H heights (Section 3.1.1), which are considered conceptually representative of the connected fracture zone, are similar for Area 5 (refer to Figure 3-7 and associated discussion below) and neither extend near to the surface.
- Accordingly, the heights of modes of fracturing for Area 5 has been estimated (and later simulated in numerical modelling) based on the following:
  - CFZ represented by Ditton A (generally similar to Tammetta H for Area 5), which experiences depressurisation while-ever mine dewatering is occurring.
  - DZF generally extends from the top of the CFZ to the SCZ. This zone experiences initial depressurisation followed by recovery after approximately 3 years or less (i.e. including during the period when mine dewatering is occurring).
  - This approach has been endorsed by the Peer Reviewer for the Height of Fracturing assessment (Hebblewhite, 2022).

Based on these steps, a spatially distributed estimate of the connected fracture zone (CFZ) has been made using the relevant parameters at Dendrobium and at nearby longwall mines. Figure D4

(**Appendix D**) presents this in terms of the vertical separation between the top of the zone and the base of the surface cracking zone (SCZ), and the stratigraphic unit in which the connected fracturing zone is estimated to extend to.

Figure D4 shows that the CFZ and SCZ are potentially connected (red shading) in Areas 1 and 2, and a small area of the western part of Longwall 17 in Area 3B, and with more variation in the mapping of the vertical separation between Areas 1, 2, 3A and 3B. The vertical separation distance is likely to be greater than 100 m in Area 5, with the CFZ extending to within the BHCS or the lower HBSS. The potential for seam-to-surface connection in Area 5 is therefore significantly lower than in previously mined areas at Dendrobium.

Two profiles, one for the approved domains and one for the Project (Area 5), are shown in Figure 3-6 and Figure 3-7 (**Appendix D**). These profiles show the various empirical model estimates in relation to the total depth of cover (black line), depth of surface cracking (blue) and the Bald Hill Claystone (BACS – shaded pale green) for context.

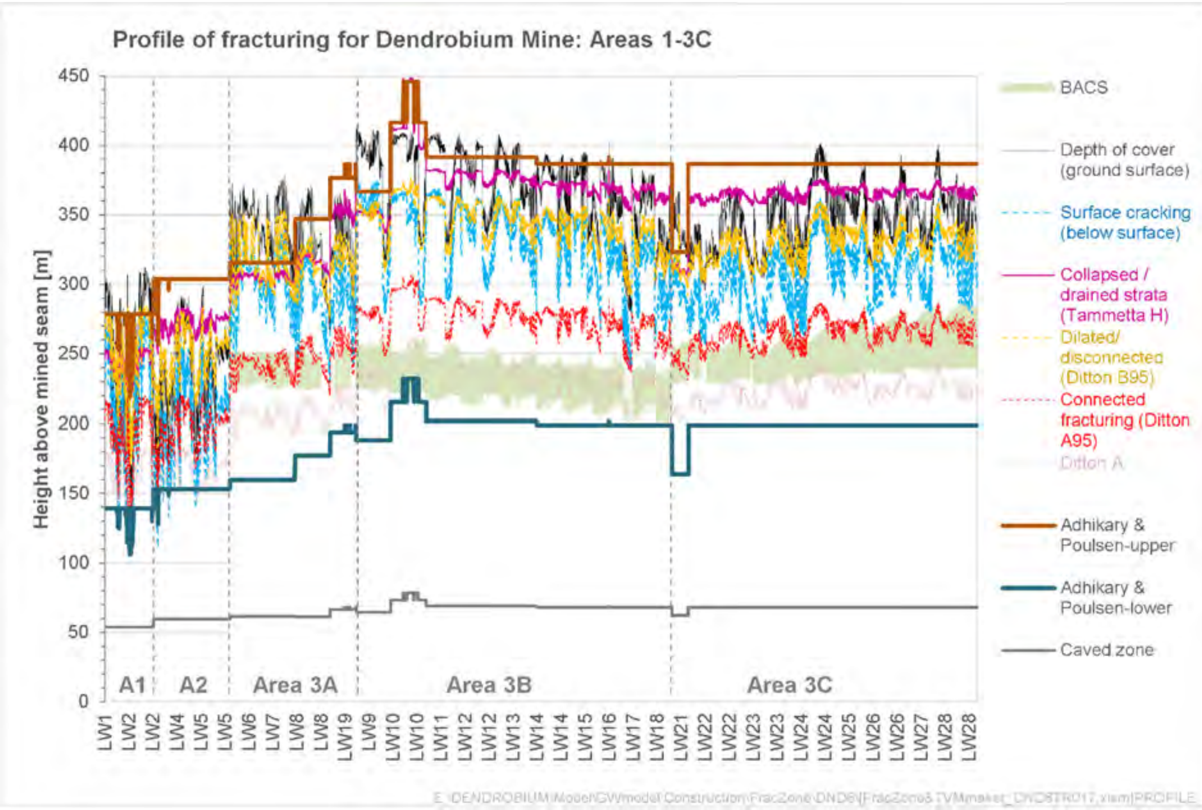


Figure 3-6 Profile illustrating estimated height and mode of fracturing in Areas 1 - 3C

Some observations from this are:

- The Adhikary-lower estimate, which appears to be consistent with groundwater level observations in Area 3B (Figure 2-19), does not intersect with the surface or SCZ above Area 2 (Figure 3-6), which suggest that it is too low for this area. This last finding is consistent with the analysis with post-mining fractures on Figure 3-3, suggesting that it is appropriate for estimating connected fracturing at higher cutting heights (Area 3B), but not so for lower cutting heights (e.g. Area 2, and perhaps Area 5).
- Adhikary-upper and Tammetta H are similar in Areas 1-3C (Figure 3-6), but there is more variance between them in Area 5 (Figure 3-7).

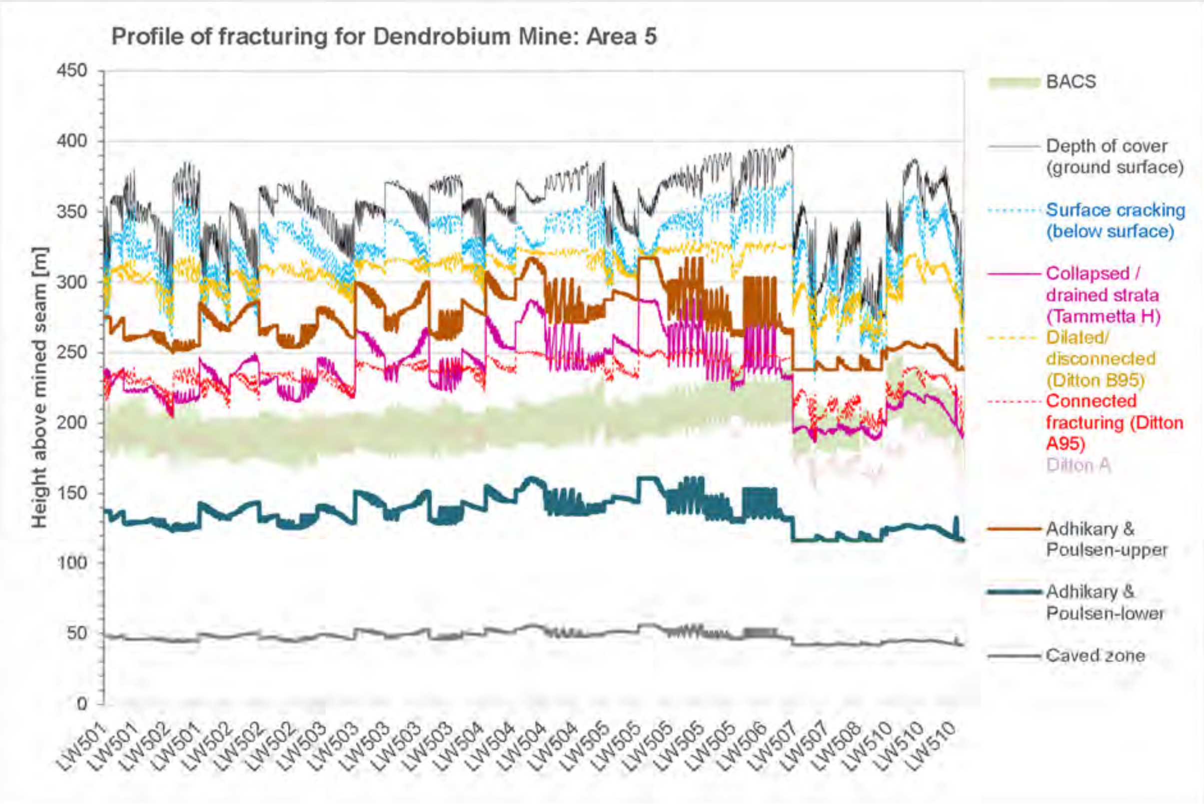


Figure 3-7 Profile illustrating estimated height and mode of fracturing in Area 5

With respect to the model developed for Dendrobium, and the subsequent impact assessment:

- The zone of connected fracturing (CFZ) is shown in red, and:
  - This intersects the surface cracking zone above Area 2 (and also Area 1, although workings above Area 1 complicate that potential connection).
  - In Area 5, this line is very similar to the Tammetta H (Figure 3-7). Neither of them intersect the surface cracking zone. In general they rise above the BACS, except for Longwalls 507-510, and into the lower HBSS.
- For conservatism, and without other evidence, the DFZ is assumed to extend above the connected fracture zone to the surface cracking zone across much of Dendrobium, including in Area 5. In general, this is supported by considering the maximum of the Ditton B95, Tammetta H, Adhikary-upper (orange, purple and green lines respectively).

3.3.2 Translation to numerical modelling

The regional numerical model developed for this study, and for the most recent SMP assessments, incorporate changes to parameters (K, S) consistent with the recent finding of the over-goaf investigations and the site-specific model of fracturing and deformation described above, while being calibrated to the observations of depressurisation. This includes both short-term drawdown in different parts of the sequence (consistent with premise of Tammetta (2013)), and consistent with the longer term responses, including subsequent recovery in the conceptualised dilated zone.

Details on the parameterisation in the groundwater model are presented in Section 4.6.

3.4 Hydrogeological conceptual model: effects during mining

This section focusses on the groundwater or hydrological response to the fracturing and deformation behaviour described in the preceding sections. Some effects will persist, possibly for decades or even permanently.

The strata movements and deformation that accompany subsidence would alter the hydraulic and storage characteristics of the host strata (Tammetta, 2016). As there would be an overall increase in rock hydraulic conductivity ⑱, groundwater levels can fall either due to actual drainage of water into the goaf ⑬⑭⑮⑯ or by an increase in storage capacity due to an increase in porosity ⑳.

Fractures that are directly connected to the goaf and mine workings would form a pathway for seepage of pore water downwards towards the goaf and so rapidly depressurise. However, this does not mean that these areas contain no groundwater, but that there can be free drainage through the fractures ⑬. Desaturation can occur over time in this zone. As the matrix drains due to the presence of fractures, the declining moisture content in the matrix may result in lower (primary) hydraulic conductivity ⑲. Where the downward drainage of water in the fracture system encounters restrictions (partially closed fractures or fracture terminations), the fractures may fill or perch and would then drain at a rate dependant on the rock matrix or fracture hydraulic conductivity.

Within the mine workings themselves (at seam level), heave and buckling of the floor are relatively common observations during the removal of the coal seam or other strata. Upward flow through the floor is observed around the mine, and this is likely exacerbated by the deformation within the floor of the workings ⑧⑱.

This conceptual framework is in broad agreement with observed chemistry trends. Estimates of the modern water content for each mine area (see graph in Figure 3-5) indicate that, to a first order approximation, the degree to which modern water contributes to the mine water balance (i.e. a measure of the degree of or potential for connection to the surface) decreases with increasing depth of cover, assuming constant mining parameters. The depth of cover at Area 2 (median = 240 m) is such that it would suggest connected fracture networks ② intersecting with surface fracturing which would lead to greater connection (i.e. direct transfer of larger volumes of water/solute) and hence a greater proportion of modern water detected in the mine. By contrast, the depth of cover at Area 3B and Area 5 is significantly greater (median = 365 m and 345 m respectively – also illustrated by the colour bars on the right of Figure 3-5), such that the rapid connection with surface water systems has not been observed or inferred from water fingerprinting and it follows that a slower, less transmissive connection exists between the goaf and surface water systems. The mapping and profiles described in Section (see Figures D4-D5 in **Appendix D**) illustrate this variation in height of connected fracturing in relation to depth of cover and surface cracking depth.

The greatest drawdown effects occur in the strata within or immediately above the mined coal seam. Within and adjacent to the connected fracture zone ② which, at Area 3B includes the Scarborough and Bulgo Sandstones. The Bald Hill Claystone is also potentially within this ‘connected’ zone due in part to the brittle failure of the geological unit. The drawdown is often >50 m, or the strata become completely depressurised (pressure head is zero).

Above the connected fractured zone (i.e. where fracturing is poorly connected or disconnected ③), the magnitude of drawdown becomes less towards the surface, but sudden reductions in pressure are still likely to occur due to enhanced Kh and secondary porosity following longwall extraction. For example, drawdown in the mid-Hawkesbury Sandstone is typically about 10-20 m, and in the shallower horizons of the Hawkesbury Sandstone it has been observed to be approximately 5-10 m (e.g. at S2192-S2220 directly overlying Longwall 9 and in the 23-26 m pre- and post-mining piezometers in S2335/S2335A). The key difference compared to the underlying CFZ is that groundwater levels are observed to recover in the DFZ (and this difference is important in leading to subsequent effects – Section 3.4.3). At Dendrobium, recovery is typically observed as commencing a few years after mining.

Outside the longwall footprint, there is potential for the modification or enhancement of Kh ④⑱ beyond the mine footprint (Section 3.2.2), and this may cause or exacerbate leakage from reservoirs to the adjacent strata and toward the mine footprint. Thus far, basal shear planes ⑪ are "not considered to be a significant conduit for flow from the reservoir into the mine" (SCT, 2017b).

Groundwater drawdown in all units decreases with distance from the extracted panels. For example, and most importantly given the value of this aquifer compared to the other units in this area, within the lower Hawkesbury Sandstone drawdown is approximately 5-10 m at a distance of 1 km from the longwall (based on observations in HydroSimulations (2014b) or review of bore S2009). Deeper in the sequence, e.g. the Bulli seam, 5-10 m drawdown occurs at about 2-3 km from extracted longwalls. Note that the responses described here are considered general or average responses only; responses in individual piezometers can vary depending on the conditions from one location to another.

3.4.1 Effects on watercourses

Broadly, longwall mining causes the following effects to watercourses:

- diversion of surface water flow;
- reduction in stream baseflow due to groundwater depressurisation or drawdown.

These are described in further detail below (with the effects on water quality in streams described in Section 3.4.3).

Fracturing in the base or bed of watercourses has occurred at Dendrobium, most notably within streams directly mined under by Area 3B, e.g. WC21, Donalds Castle Creek to DCS2, as well as at other mines in the Southern Coalfield, e.g. along the Bargo River and Redbank Creek above Tahmoor and at Waratah Rivulet above Metropolitan Colliery. Down-slope movements and valley closure will enhance these strains and result in an increase in fracture frequency and/or width at these locations. Experience at Dendrobium and Appin mines suggests that 95% of observed fracturing occurs within the longwall footprint, about 99% within the footprint plus a further 50 m buffer (i.e. above or within the chain pillars), and a remaining 1% occur beyond that distance, such as impacts observed at LA4 (HGEO, 2017). MSEC indicate that the furthest observed effect, cracking with associated water loss, was at 290 m from Dendrobium longwalls. Cracking, without associated water loss, has been observed at 400 m elsewhere in the Southern Coalfield.

Where such surface fracturing occurs, it is likely to result in persistent or permanent changes to hydrology ⑨ (Figure 3-5), such as the effects analysed in headwater streams around Area 3B which include 20-60% reduction in median flow and 15-40% increase in the average number of cease-to-flow days (HGEO, 2022a).

Surface water that is redirected into and through near-surface fractures ⑨ may either migrate downwards towards the goaf ⑬, be lost to some other process such as evapotranspiration, be returned to surface drainage somewhere down-gradient ⑩, or some combination of these. In the case of returned flow, net loss from the catchment is minimal. The End of Panel report for Longwall 17 (HGEO, 2022a) notes that groundwater recovery around Area 3A longwalls, almost a decade after mining, appears to have led to an improvement in flow quantity in tributary SC10C since approximately 2017, where this tributary previously cleared showed mining effects on flows through the gauging station.

Leakage of water and transmission through the surface fracturing zone and re-emergence downstream can result in effects on water quality (HGEO, 2021d, 2021a; McNally and Evans, 2007). The corollary to the instance of groundwater recovery leading to an improvement in baseflow and flow quantify at SC10C, noted above, is that iron-staining and water quality effects become more prevalent after groundwater levels recover. Examples of the effects on water quality at Dendrobium are:

- iron staining in SC10C tributary which was directly mined under by Longwall 8 (Area 3A), caused by gradual groundwater recovery and high rainfall in 2020-21;
- iron staining along Wongawilli Creek, originating from a spring adjacent to Longwall 6, caused by a similar groundwater recovery mechanism.

Surface cracking effects in the bed of watercourses or streams that are mined under or adjacent to longwalls will likely persist in the long-term. Rehabilitation is a possibility, and trials are being planned at Dendrobium (WC21) and have been carried out at Tahmoor (at pools on Redbank and Myrtle Creeks) and other areas. The effectiveness of this is unclear, although preliminary information from Tahmoor is that one of these sites has seen improvement in pool hydrology. If such measures are ineffective, persistent flow losses, such as those estimated in recent End of Panel assessments (HGEO, 2020a), in creeks overlying extracted panels are likely to continue (see also Section 2.4.4). Losses that occur to drawdown are more likely to be transient; these might be short-lived if caused by increased strata porosity, but if caused by drawdown within and around zones of connected fracturing these effects may persist long after dewatering ceases.

3.4.2 Risks to water supply reservoirs

Figure 3-8 shows a comparison of distance from each longwall to the nearest reservoir (Avon reservoir in the case of Area 5 longwalls). This is compared to the depth of the seam below the reservoir FSL (at the nearest point) as well as compared to the width/depth of cover (W/D) relationship.

Comparing these two parameters on the charts above, Area 5 longwalls are:

- Longwalls 510 and 506 have a negligible risk of causing interaction between the reservoir and groundwater due to their significant distance from the reservoir.
- Longwalls 504 and 505 have a very low risk of causing some interaction, based on their distance (>400 m) and the greater depth or lower W/D.
- Longwalls 501, 503 and 508 have a low risk of causing interaction, based on their greater depth than the other longwalls. They are analogous to the distance and depth and W/D of historical Area 3B longwalls 15, 16 and 17, but have the advantage of a lower cutting height than the Area 3B panels.
- Empirically, of the Area 5 panels, Longwalls 507, 509 and 502 have the greatest risk of inducing leakage from the reservoir. Longwall 507 has the lowest depth of cover within its footprint (caused by the LA8 valley), but has a shorter frontage to the reservoir than the other two panels, and this frontage is restricted to the commencing end of the panel. It can be seen from Figure 3-8 that Longwalls 502 and 508 have similar distance and depth parameters to the current Area 3B longwall (Longwall 18) or to Longwall 17. Longwall 502 has the largest frontage to the reservoir and 509 the smaller depth of cover (under LA13), and both have frontage on the long edge of the panel, where experience suggests subsidence-related greater effects can occur. As in the previous point, these panels have a lower cutting height than Area 3B longwalls.

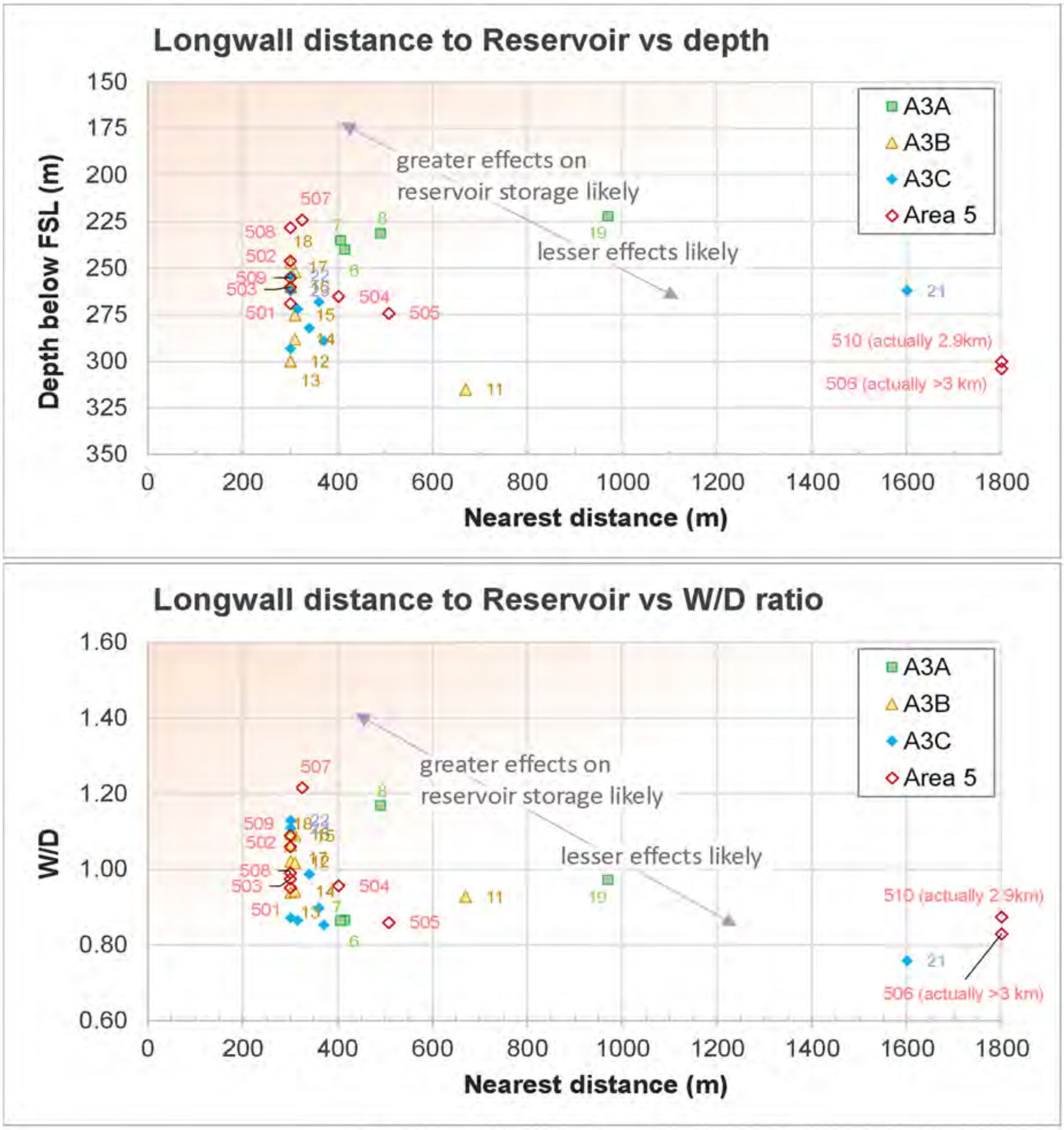


Figure 3-8 Distance and risk of induced leakage from Avon Reservoir

Estimation of the leakage from the reservoir is presented in Section 6.7. The risks identified above are used to guide recommendations from monitoring.

3.4.3 Water quality effects

As also noted in Sections 2.8.3 and 3.4.1, both groundwater and surface water quality are likely to be affected by longwall mining in Area 5. The processes by which this could occur are conceived to be:

1) groundwater recovery and resaturation of shallow fracture networks; and
2) eventual upward flux of deep groundwater following flooding of workings and re-pressurisation of the goaf.

The effects of these would include:

- transient increase in EC (salinity);
- changes to water pH from baseline mildly acidic conditions to near neutral conditions; or, more rarely, a decrease in water pH;
- increases in dissolved iron (Fe) and manganese (Mn), primarily, with potential changes to zinc (Zn), aluminium (Al), nickel (Ni), cobalt (Co), barium (Ba), strontium (Sr). Elevated concentrations are typically restricted to immediately downstream of the longwall footprint; and
- iron-staining is typically localised to reaches overlying or immediately adjacent to / downstream of a longwall footprint. In the case of SC10C and Wongawilli Creek, iron-staining has emerged in baseflow several years after adjacent mining.

Many of these effects are caused by recovery of groundwater levels within fracture networks above extracted longwalls (typically from within the surface cracking and dilated zones).

3.5 Hydrogeological conceptual model: effects following mine-closure

Following mine closure and the cessation of mine dewatering, groundwater levels will recover and flood the workings. The deepest parts of the mine will flood first, which would include Area 5. Figure 3-9 illustrates the elevation profile of Dendrobium Mine, and the elevation of the overflow or spill point near Area 1.

Eventually groundwater levels above and surrounding the mine will reach a new equilibrium. The equilibrium groundwater levels may be at different levels to pre-mining conditions (either lower or higher), given the changes to permeability and porosity and consequent changes to recharge/discharge pathways or characteristics, as well as due to post-closure management.

Recovery and flooding of the workings has the potential to result in discharge of groundwater in two broad areas:

1. within the Special Area above Dendrobium Mine (including the Project), if and once groundwater levels rise to levels above topographic elevations.
2. at the Illawarra Escarpment:
    - via Dendrobium Mine portals (Figure 3-9);
    - through natural discharge locations in the coal seams and adjacent strata along the escarpment, eventually to watercourses along the coastal plain; and
    - through neighbouring and adjacent mine workings (i.e. Nebo/Wongawilli Mine, Kemira and Mt Kembla), eventually to watercourses along the coastal plain.

Estimates of impacts related to post-mining groundwater discharge are presented in Section 6.10.

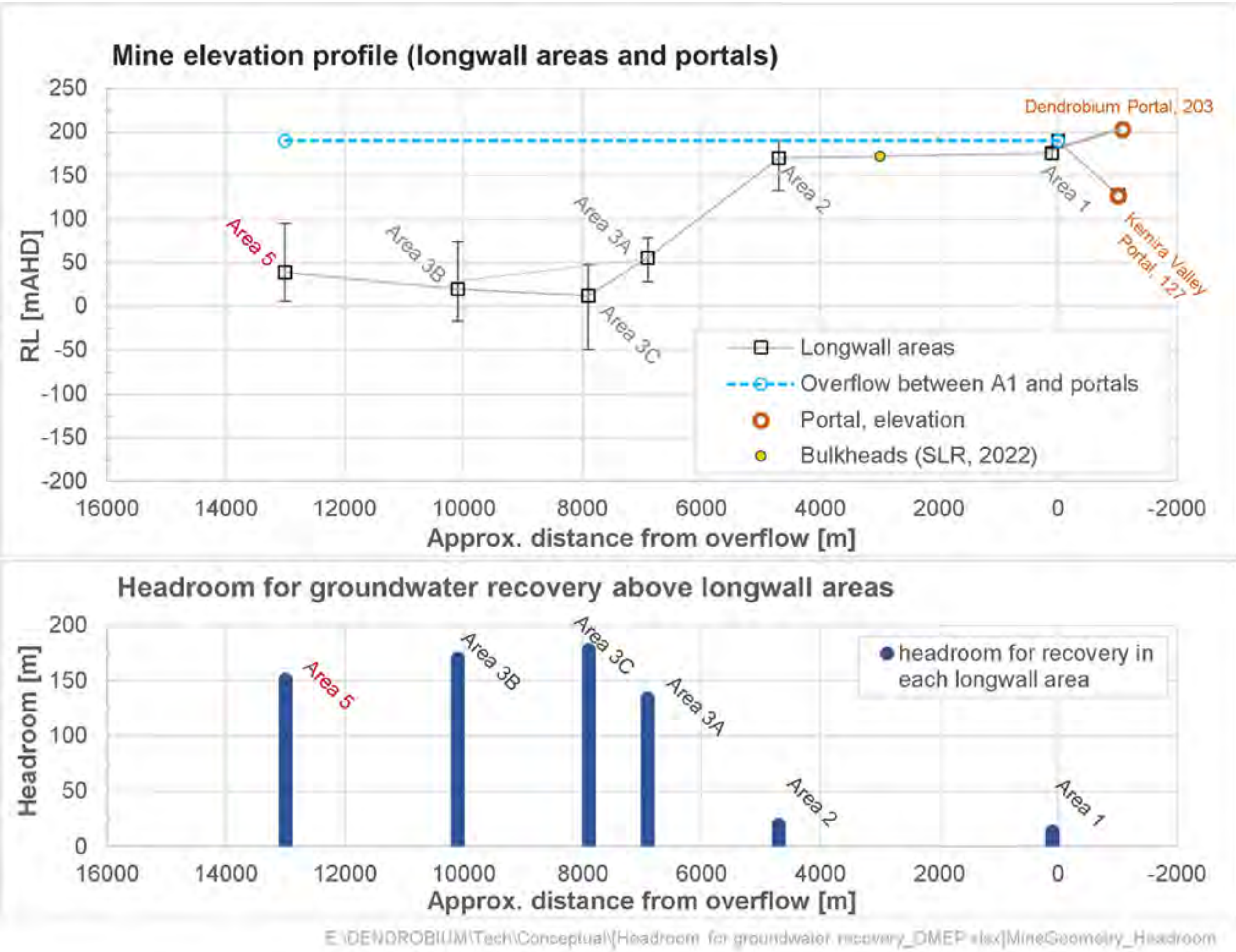


Figure 3-9 **Elevation profile of Dendrobium mining domains**

3.6 Summary of conceptual model – causal or risk pathways

A conceptual model of the relevant "causal pathways" or risk pathways has been developed (Figure 3-10). This is similar to those developed for the Bioregional Assessment program (Peeters et al., 2021). This framework is based on the linkages or processes that result from:

- a driver, which in this case is the Project;
- activities and processes associated with that driver;
- end points (including receptors); and
- a description of the stress and consequence on the landscape / receptors.

In general, the risks may occur because of, or be amplified due to geological structures, including faults and lineaments. Dendrobium Mine planning avoids significant faults (such as the Elouera Fault – Section 2.6.9). Effects due to interaction with lineaments has not been identified to date at Dendrobium Mine, unlike in some other geological basins (SRK, 2020).

Additional comments around the method for observation and quantification of these effects or stresses has been included on Figure 3-10, as a precursor to the following sections on groundwater modelling.

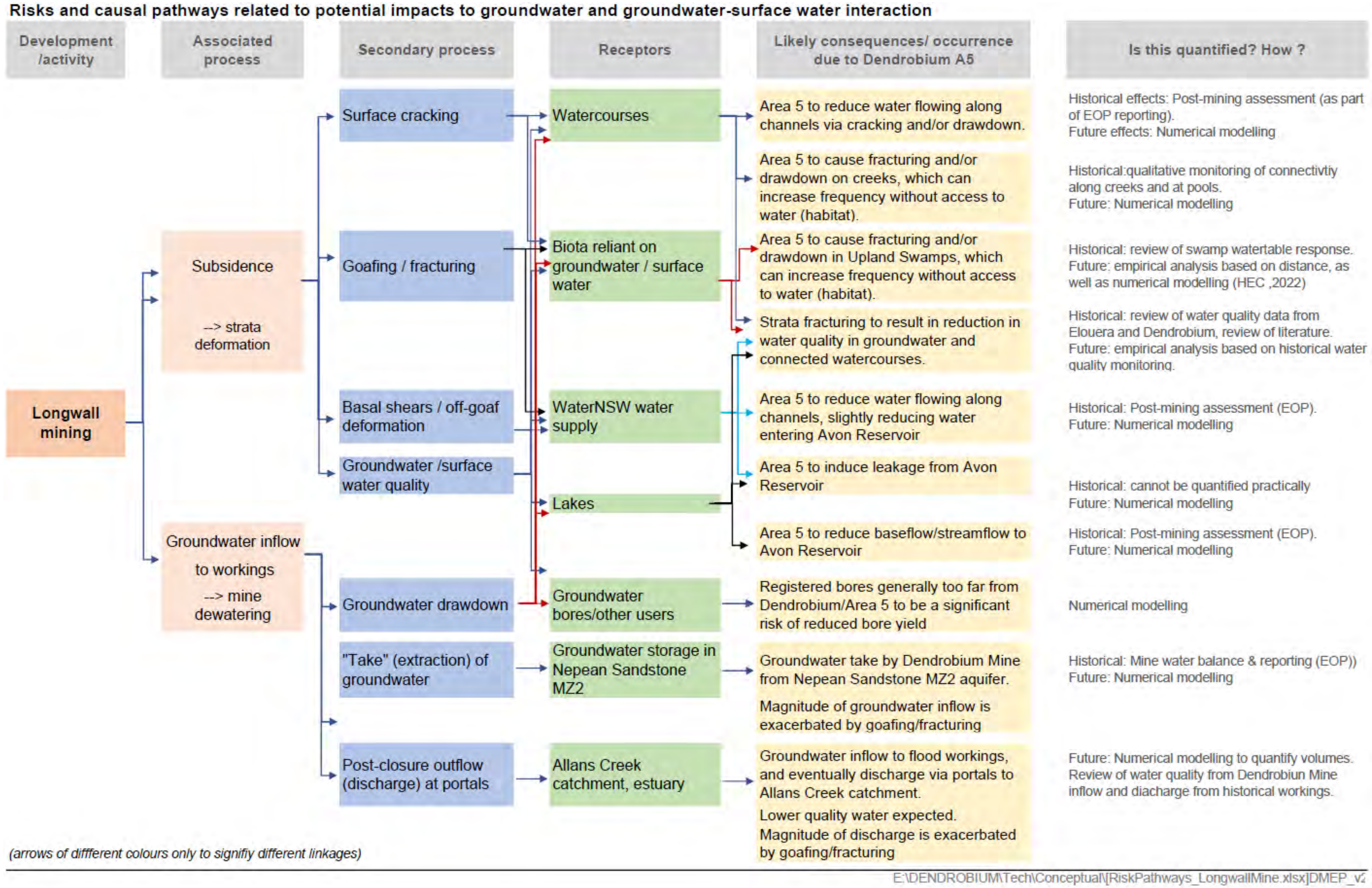


Figure 3-10 Risk pathways associated with Dendrobium Mine and proposed Area 5

4. Numerical model

The conceptualisation of the groundwater regime is the key to the modelling and impact assessment, and to the development and calibration of the numerical model against field data. The conceptual model is an idealised and simplified representation of the natural system, and is a description of how the groundwater system operates given the available data and analysis carried out to date. The conceptual groundwater model of the Project and surrounding area was developed based on various data sources, including:

- topographical data (e.g. LIDAR) and geological maps and the 3D geological model developed by the mine geologists;
- meteorological data hydrological data and analysis by IMC and others; and
- results from previous hydrogeological investigations and modelling, and relevant data from the publicly available datasets or literature.

The earlier sections of the report detail the conceptual understanding of the hydrogeological system at the Project. The purpose of the numerical modelling sections (Sections 4-6) is to describe the model setup, calibration or history-matching, and predictive scenarios undertaken with the numerical model and considering uncertainty.

4.1 Modelling objectives

The objectives of the assessment and modelling are defined in in Section 1.3. In summary, the numerical model must quantify the likely mine inflow, drawdown and associated change in fluxes (flow in watercourses, leakage from reservoirs) and post-mining behaviour (groundwater recovery and fluxes). Of these, operational and long-term effects on surface water (watercourses) is likely the prediction of primary interest.

To provide more confidence in the model's ability to inform the impact assessment and decision-making process, 'calibration' of historical mine inflow, groundwater levels and drawdown and changes in surface water flows is carried out via history-matching. Model development and history matching are described in Section 4.2 to 4.8 and Section 5. The subsequent application of the model to make forecasts of behaviour and effects associated with the Project is described in Section 6.

The workflow in Figure 4-1 summarises the modelling workflow.

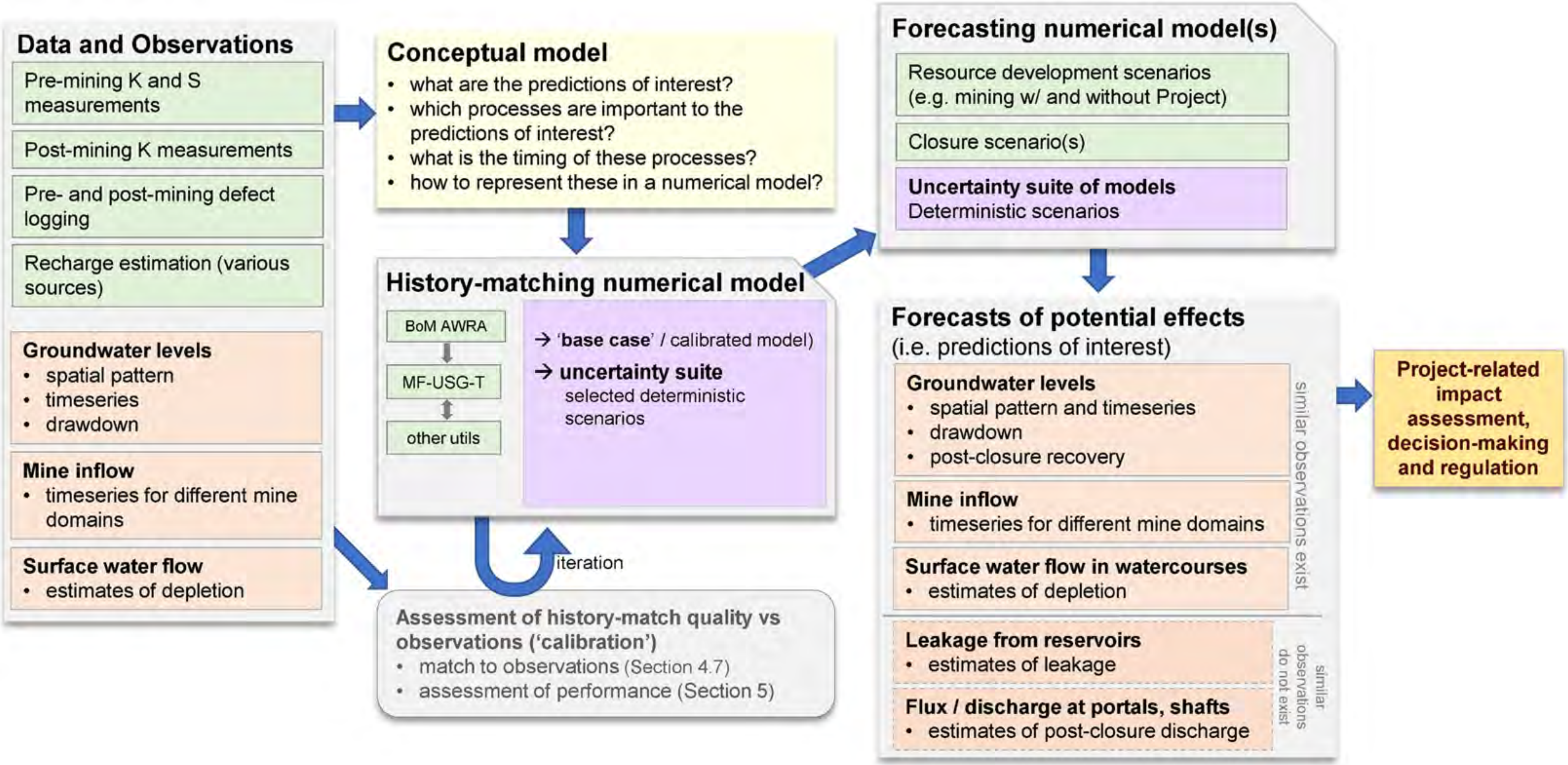


Figure 4-1 Workflow to integrate data and to achieve modelling objectives

4.2 Model code and design

The conceptualisation of the Project site, and the requirements of some agencies, means that a 3-dimensional (3D) numerical groundwater model is required to address the objectives in Section 1.3.

The Dendrobium groundwater model reported here utilises MODFLOW-USG-Transport v1.8.0 ("MODFLOW-USG" herein; (Panday, 2021; Panday et al., 2013). This is a MODFLOW variant that uses the Control Volume Finite Difference method, which allows for an unstructured model grid (as opposed to structured grids). MODFLOW-USG has been used in modelling efforts for Dendrobium Mine from 2015 to present, including SMP applications and the 2019 EIS, ensuring a level of consistency in progressive modelling approaches.

Other than the incorporation of unstructured grids, MODFLOW-USG has two features that are important. The 'upstream-weighting' capability allows for simulation of unsaturated flow, and the Time-Varying Material properties (TVM) package allows for hydraulic conductivity and storage properties to be varied through time (Panday, 2021), which is the most important conceptual behaviour and effect associated with longwall mining.

4.2.1 Model confidence classification

The Australian Groundwater Modelling Guidelines (Barnett et al., 2012a) recommend adoption of "confidence level" classification terminology with further guidance on the application of the classification provided by Middlemis and Peeters (2018). The confidence level classification comprises Class 1, Class 2 and Class 3, in order of increasing confidence level. The level of confidence typically depends on the available knowledge and data, consistency between the calibration conditions and predictive analysis scenario, and the level or severity of stresses being simulated (relative to baseline conditions). The AGMG includes a table of quantifiable indicators with which to assess a models confidence level based on those attributes. Middlemis and Peeters (2018) recommends that the confidence level should be determined by indicating which attributes in the table are satisfied for a given model and considering the score counts in each class.

Using this approach, the current Dendrobium groundwater model is considered to satisfy many attributes of 'Class 2' (medium confidence), as well as some 'Class 3' (high confidence) attributes. The annotated classification table, updated following model calibration, is included in **Appendix K**.

4.2.2 Qualitative uncertainty analysis

The IESC recommends that a qualitative analysis of uncertainty should be carried out at an early stage of the groundwater impact assessment workflow. The qualitative assessment provides an overview of sources of uncertainty within a risk management framework and provides guidance in relation to further quantitative uncertainty analysis, if required. A qualitative assessment:

- Identifies key decisions and specific forecasts.
- Identifies assumptions and parameters important to each forecast.
- Identifies uncertainty or gaps in knowledge, data and assumptions.
- Assesses the degree to which existing and new data may reduce uncertainty

In respect of the current assessment the key model forecast are as follows:

- Groundwater inflow to the underground mine.
- Groundwater depressurisation / drawdown at key receptors:
  - Groundwater user bores.

- Streams.
- Changes in surface water flow due to depressurisation and surface fracturing.
- Seepage losses from water storage reservoirs.
- Direct and indirect groundwater and surface water take for the purpose of water licensing.

A qualitative uncertainty analysis relating the forecasts of interest to this assessment is presented in Table 4-1. The table also includes reference to data used to constrain the relevant model parameters, as well as whether a factor or parameter is to be tested or varied in subsequent modelling.

Table 4-1 Qualitative assessment of model forecast uncertainty

Key knowledge / assumptions	Knowledge and uncertainty	Uncertainty in key forecasts	Scope for uncertainty reduction	How dealt with
Height of (connected) fracturing above goaf	Site specific observations and estimates from empirical models.	**Moderate**. Model predictions of inflow and drawdown are sensitive to this.	**Yes**. Reduced through analysis of field data (e.g. Section 3.2), and model history matching against groundwater level monitoring and mine inflow measurements.	Field data to constrain heights for historical areas. Alternative empirical models indicate similar heights for Area 5.
Hydraulic conductivity (Kv) of over-goaf fracturing	Parameters (Kh, Kv, Sy and drain conductance) are order of magnitude estimates.	**High**. Especially close to the mine and in relation to long-term recovery.	**Yes**. As above.	Model calibration to inflow and drawdown. Deterministic scenario considering caved zone Kv.
Surface cracking	Not well-constrained; order of magnitude estimates; high spatial variability	**High**. Estimates of surface water loss strongly dependent on fracture parametrisation.	**Limited**. Some scope for uncertainty reduction through observed surface water reductions.	Model calibration to surface water losses. Deterministic scenario considering Kh and Kv.
Past and future mine plans	Past mining well defined; future mining rates likely accurate ±20%	**Low**	N/A	-
Neighbouring mines	Well-known. Some uncertainty regarding historical workings and connections between workings	**Low**: provided that connections with Dendrobium are closed post-mining	N/A	-
Horizontal hydraulic conductivity (Kh)	Well-understood from an extensive database of packer testing and core measurements	**Low**. Affects estimated rate of drawdown and recovery. In most contexts, this would be moderate/high, but given the presence of fracturing, this is lower relatively.	**Yes**. Scope for further uncertainty reduction through history matching and use of pilot points to identify heterogeneity.	Model calibration to flux and groundwater levels. Deterministic scenarios considering alternative Kh and Kv.

Key knowledge / assumptions	Knowledge and uncertainty	Uncertainty in key forecasts	Scope for uncertainty reduction	How dealt with
Vertical hydraulic conductivity (Kh)	Not well-constrained known; order of magnitude estimates	**Low**. Affects estimated vertical leakage and depth-pressure relationships.		Model calibration to groundwater levels. Deterministic scenarios considering alternative Kh and Kv.
Specific yield (Sy)	Moderate; data from BMR at Dendrobium and from test pumping elsewhere	**Low**. Affects estimates of drawdown and recovery, as well as initial dewatering rates.	**Yes**. Scope for further uncertainty reduction through history matching	Model calibration to groundwater levels and inflow.
Specific Storage (Ss)	Not well-constrained; order of magnitude estimates	**Low**. Affects estimates of drawdown and recovery.		Model calibration to groundwater levels.
Recharge	Well-constrained by regional water balance studies; baseflow separation, rainfall-runoff models, hydrochemistry and published studies	**Low**. Forecasts sensitive to long term averages rather than short term variability.	**Limited**. Scope for further uncertainty reduction; high correlation with Kh and Kv.	Model calibration to groundwater levels.

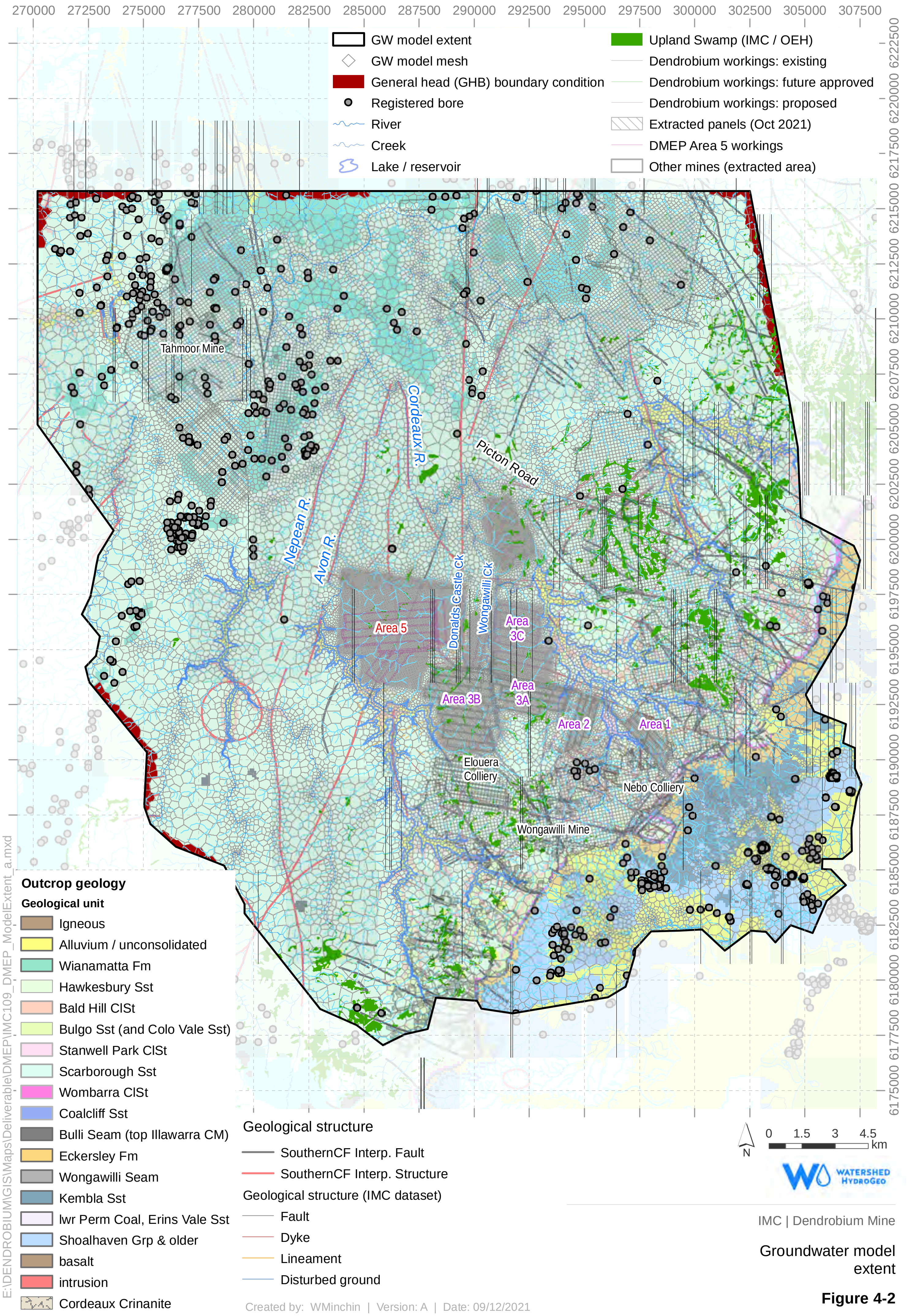
4.3 Model structure

4.3.1 Spatial discretisation: model mesh

The model mesh utilises the ‘unstructured’ capability of MODFLOW-USG and primarily uses the Voronoi style model mesh, meaning that model cells can be almost any shape and with variable dimensions. Also, layers do not have to be fully extensive across the model domain.

The model mesh was created using AlgoMesh Software v2.0 (HydroAlgorithmics, 2020). Greater cell refinement was applied to areas of interest, such as mine footprints and watercourses. Cells within the mining footprint were given a regular grid structure (i.e. square cells) oriented as consistently as possible with longwall panels. Figure 4-2 (regional) and Figure 4-3 (Project detail) show the model mesh geometry as well as indicating some of boundary conditions applied to the model.

Cells used to represent the mining areas at Dendrobium (Areas 1-3B) are given a uniform width and length of 60 m, while those for future and proposed domains (Areas 3C and Area 5) are assigned uniform width and length of 50 m (Figure 4-3). Revisions to the mine plan has mean not all longwalls are aligned exactly to the mesh, but this is not significant in terms of simulating groundwater and subsidence effects.



WATERSHED HYDROGEO

IMC | Dendrobium Mine

Groundwater model extent

Figure 4-2

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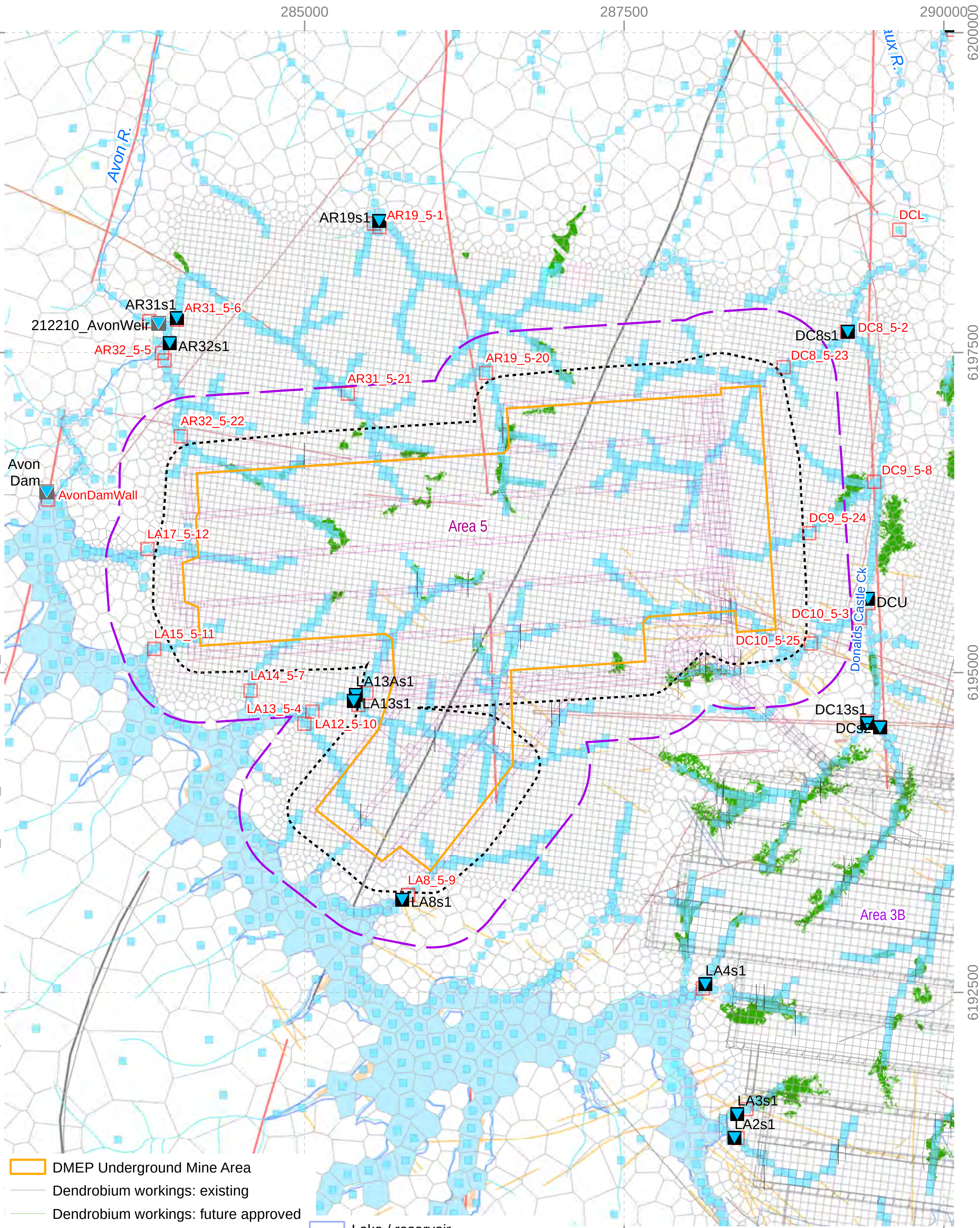


DMEP Underground Mine Area
Dendrobium workings: existing
Dendrobium workings: future approved
Dendrobium workings: proposed
DMEP Area 5 workings
Other mines (extracted area)
Study Area (600m offset)
Study Area (35deg Angle of Draw)
Stream (SFR) boundary condition
Lake (RIV) boundary condition
General head (GHB) boundary conditio
GW model mesh

Lake / reservoir
Upland Swamp (IMC / OEH)
River
Creek

Surface water monitoring site
Existing
Approved
Proposed
Existing-Govt
Model SW flow output location

Created by: WMinchin | Version: A | Date: 09/12/2

Scale: 40,000 @A4
GDA 1994 MGA Zone 56

N

0 0.3 0.6 0.9 km

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Detail of groundwater model mesh in Area 5

Figure 4-3

4.3.2 Hydrostratigraphy and model layering

The model consists of 17 layers (consistent with other recent modelling at Dendrobium). Each layer has a maximum of 47,359 cells. The 'pinch-out' functionality was used for this model and removed any cells where the thickness was calculated as less than 0.1 m (i.e. where geological units are eroded away). This results in a total of 741,889 active cells.

Table 4-2 summarises the stratigraphy framework for the 17 layers adopted in this model (see also Figure 2-7). This is the same as in HydroSimulations (2019c). The geometry of the model layering is based on the geological model supplied by IMC, which is defined by hundreds of exploration drill logs. Layers have a variable thickness across the model domain, but the average thickness across the model domain and the typical thickness within Area 5 (on the ridgeline in the centre of Longwall 503, as a representative location) are described in Table 4-2.

Table 4-2 Model layer assignment

Layer	Stratigraphy	Secondary Lithology	Thickness [m], mean	Thickness, Area 5
1	Regolith	Swamp deposits	Regolith: 5, swamp: 2	Regolith: 5
2	Hawkesbury Sandstone (upper)		24	47
3	Hawkesbury Sandstone (middle)		40	60
4	Hawkesbury Sandstone (lower)	Crinanite (Area 2)	33	40
5	Bald Hill Claystone	plus Garie and Newport Fms / Crinanite (Area 2)	27	31
6	Bulgo Sandstone (upper)	Colo Vale Sandstone (Area 3B) / Crinanite (A2)	53	37
7	Bulgo Sandstone (lower)	Colo Vale Sandstone (A3B) / Crinanite (A2)	40	37
8	Stanwell Park Claystone	Colo Vale Sandstone (A3B) / Crinanite (A2)	17	26
9	Scarborough Sandstone	Colo Vale Sandstone (A3B) / Crinanite (A2)	35	39
10	Wombarra Claystone	Crinanite (A2)	25	32
11	Coalcliff Sandstone	Wombarra Formation (A3B)	11	8
12	Bulli seam		2.3	2.5
13	Lawrence & Loddon Sandstones		28	40
14	Wongawilli seam	(working section)	4.2	4.1
15	Kembla Sandstone		19	20
16	lower Permian Coal Measures		24	25
17	Shoalhaven Group and older		100	25

Thickness from E:\DENDROBIUM\GIS\Data\Model\AlgoMesh\Output\DND5v1\DND5v1.shp

4.3.3 Temporal discretisation: model stress periods

The model stress period schedule is included as **Appendix F** to this report, along with annotations of longwall extraction and rainfall events mentioned below. The stress period schedule is similar to that for previous modelling for Dendrobium, but modified to account for the Project.

The modelled time period, covering 1939 to 2200, is discretised into a total 218 stress periods:

- Historical period: 128 stress periods covering the period 1939 to October 2021, of which the first stress period is a steady state period used to initialise groundwater levels in response to simulated hydraulic conductivities, recharge and other boundary conditions.
- Predictive period: 90 stress periods covering the period November 2021 to 2200. The proposed end of longwall mining at Dendrobium is in 2038 (following Area 5 and then the second half of Area 3C), and the end of the modelling period is chosen to simulate post-closure recovery and any persistent groundwater effects.

Stress periods are set at a fine resolution for the duration of historical, approved and proposed mining at Dendrobium so that each longwall was typically represented by 3 or 4 stress periods (fewer for shorter longwalls). This allows simulation of the progressive changes to the groundwater system in response to longwall extraction.

In addition, in an attempt to simulate the dynamics of very high rainfall periods, such as those leading to the distinct short-term groundwater inflow events observed in Area 2 (Section 2.6.5), many of the key events have been identified. A series of shorter stress periods of a few days or a week have been defined to capture the intense rainfall event and the following period where the bulk of the inflow occurs. Fifteen such high rainfall/inflow sequences or events are included in the model time period (**Appendix E**).

4.4 Boundary conditions

A summary of the boundary conditions is presented below, with emphasis on any changes to that presented in previous modelling.

4.4.1 Regional groundwater flow

General Head Boundaries (GHB) are set around parts of the model domain where regional groundwater flow is conceptualised as being into or out of the model (rather than predominantly 'parallel' to the edge of the model). Inflow is conceptualised as occurring along the southwestern boundary to represent northward groundwater from the Southern Highlands entering the active model domain, while outflow occurs along the northern boundary to represent the continued northward flow toward the centre of the Sydney Basin (Section 2.6.2).

In these areas GHBs are set to allow groundwater flux in the more transmissive parts of the hydro-stratigraphic sequence, typically layers 2, 3, 4, 6, 7, 9, 10, 12 and 14 (Section 4.3.2). The elevation or stage of these is based on nearby groundwater levels from observation bores (where available), otherwise extrapolated levels from contouring or previous modelling. The locations and applied head are shown on the maps in **Appendix G**.

A check on modelled fluxes to/from the model via GHBs indicates that these boundary conditions do not have undue influence on groundwater behaviour near Dendrobium Mine (Section 5.2).

4.4.2 Reservoirs

MODFLOW 'River' boundary conditions have been employed to represent the reservoirs or lakes, as in previous modelling. The historical record of water levels in the Avon and Cordeaux Reservoirs has been employed. The predictive modelling uses the reservoir FSL as the stage. These are 320.18 mAHD for Lake Avon, and 303.76 mAHD for Lake Cordeaux.

These boundary conditions are set in model layer 1, with bed conductance estimated based on model cell area and a hydraulic conductivity of 1E-3 m/d (similar to the geometric mean of Hawkesbury Sandstone Kh). Resultant modelled conductances are 1 to 36 m^2/d, governed by the dimensions of the relevant cells. The locations of the River cells are shown in Layer 1 in Figure G1 (**Appendix G**).

4.4.3 Watercourses (creeks and rivers)

Watercourses are represented using the MODFLOW 'Streamflow-Routing' (SFR) package. This incorporates user-specified estimates of runoff (actually 'quickflow', which includes runoff and the 'lateral' or interflow component of stream flow) to each segment of the watercourse network. The groundwater model then simulates gains (baseflow) and losses (stream leakage) between a stream 'reach' and the connected groundwater model cell. The SFR package considers a group of reaches between upstream tributaries (or the start of a watercourse) and downstream tributaries as a 'segment', and allows the user to specify an inflow as an input to each segment and each model stress period. For this model, inflows are used to input runoff to the modelled watercourse (SFR) network – see discussion of quickflow estimates below. The SFR package then accounts for the accumulated flow to each reach (i.e. [runoff] + [gains to that reach] – [losses to that reach]) along the network (Figure G1 in **Appendix G**, with detail around Area 5 shown in Figure 4-3).

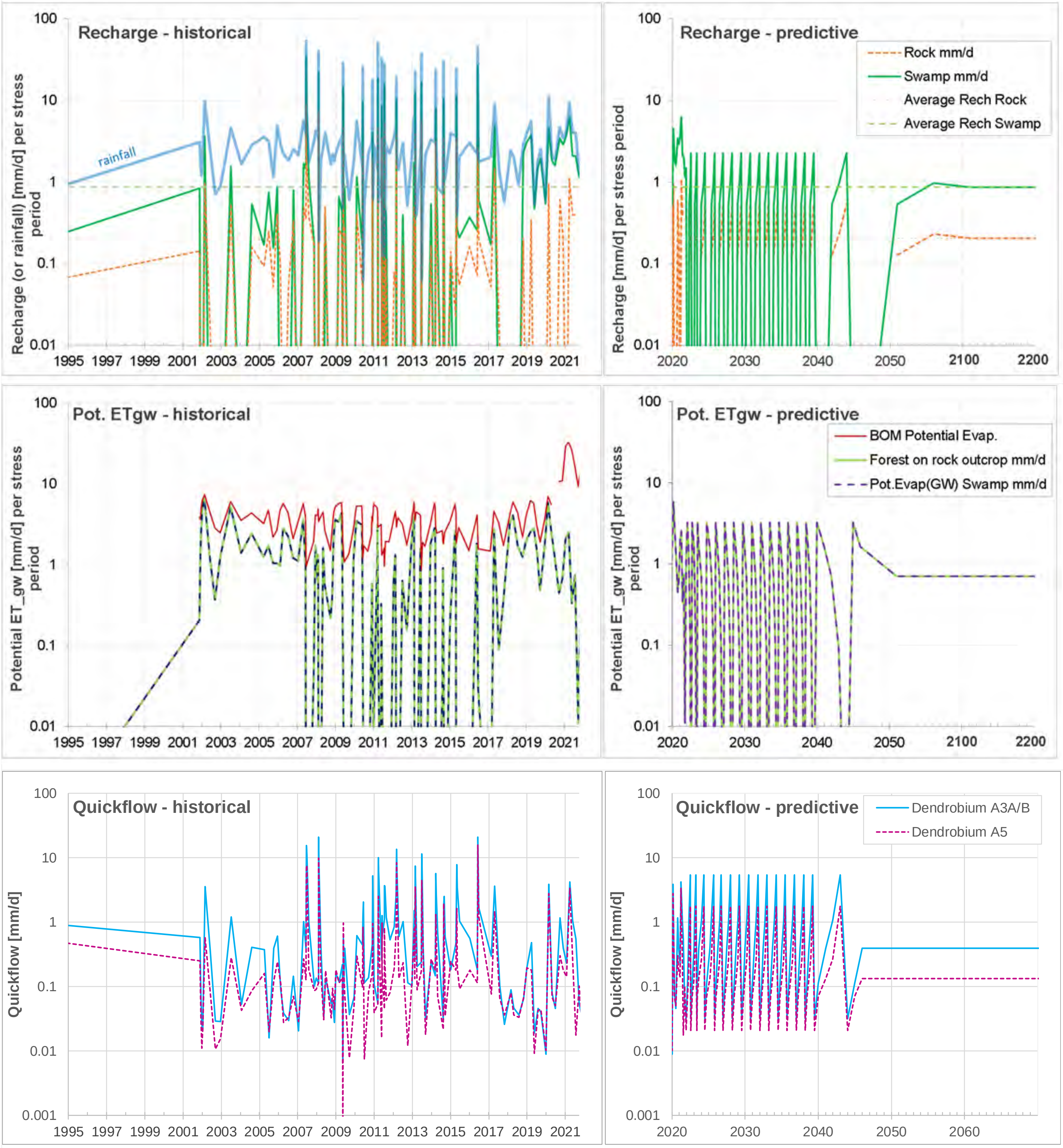
The model simulates variable stream stages based on the accumulated flow to each SFR reach, based on a user-specified channel width and Manning's roughness. The channel widths are set based on the hierarchy of streams in the LPI watercourse mapping, with the widths ranging from 1.5 to 25 m based on IMC Environmental Field Team (IMCEFT) mapping of stream features and review of aerial photography. Watercourses (Streams) are all set within model layer 1. Stream bed permeability was initially set to 0.01 m/d for rock outcrop, but subsequently modified to an assumed hydraulic conductivity of 0.05 m/d (rock outcrop) and 0.2 m/d (swamp areas). The hydraulic conductivity values are chosen to be slightly higher than the relevant K applied to the groundwater flow equation. These values were not modified transiently in response to mining and associated subsidence effects, but the higher K (0.05 m/d) was required to improve calibration to stream flow losses (Sections 4.7.4 and 5.3.4).

The channels are assumed to be rectangular, which is a simplification of the real (approximately V-shaped) cross-section of these watercourses. Mannings roughness is specified as a uniform value of 0.4, which is a deliberate over-estimate of the more realistic value of 0.04 (USGS, 1998) that corresponds to streams that are 'clean, winding, some pools and shoals' (roughness = 0.04) to streams with "Sluggish reaches, weedy, deep pools" (roughness = 0.07). The modelled value is selected to compensate for the rectangular cross-section assumed in the SFR package is applied to improve the simulated magnitude and variation in stage (water depth).

The quickflow estimates are derived from BoM's AWRA-L hydrological model, and averaged across each groundwater model stress period. The estimates of runoff, obtained from the AWRA website, incorporate what we consider to be runoff plus interflow, which together form the 'quickflow' component of a stream flow hydrograph. As for recharge simulation, the model domain has been divided into three broad 'weather' or 'climate' zones, where there is a difference in rainfall, potential evaporation leading to infiltration recharge and to runoff and interflow. Long-term estimates of quickflow from the AWRA-L modelling are shown in Table 4-3.

Table 4-3 AWRA quickflow estimates

Zone	Location (AWRA model cell)	Description	LTA (2005-2021) quickflow [AWRA]	Runoff multiplier (multiple of 'Centre' zone)
Southwest	(-34.45,150.75)	Including Dendrobium A1, A2, and the escarpment and coals plain	502 mm/yr	146%
Centre	(-34.4,150.71)	Including Dendrobium A3A, A3B, A3C, and the eastern edge of Area 5	344 mm/yr	100%
Northwest	(-34.3,150.65)	Most of Area 5, and Avon Dam	199 mm/yr	58%



Recharge and ET estimated by WatershedHG	…\Model\Recharge\WaterBalance_RRR\Rainfall_Recharge_Runoff_DendrobiumV13_DND6_Oct2021.xlsx
Quickflow estimates from BOM (AWRA-L 'Runoff')	…\Model\Gwmodel\Boundaries\Stream\WshedFinev2_Areas_Rocalc.xlsx

Figure 4-4 Model inputs of recharge, ET and quickflow (average by stress period)

The daily runoff rate for those three climate zones have been aggregated by stress period and then applied those to each segment of the stream network using contributing catchment to each SFR segment (calculated using GIS tools from a hydrologically-enforced DEM).

For the predictive period, a cycle of quickflow volumes is applied to 5 stress periods and then repeated. This cycle is the 10th percentile, 30th percentile, 50th percentile, 70th percentile, 90th percentile, where those percentiles are calculated from the stress period averages applied in the historical period. This cycle is simulated for stress periods 129-211 (late 2021 to 2045 – see **Appendix E**, with the aim allowing the model to provide information on the future effects on or during low, moderate and high flows. The median (50th percentile) estimate of runoff is applied to the longer stress periods 212-218 at the end of the simulation (2046 to 2200).

4.4.4 Rainfall recharge

Rainfall recharge is simulated using the MODFLOW Recharge (RCH) package consistent with previous modelling (HydroSimulations, 2016, 2019; Watershed HydroGeo, 2020a).

The model domain is divided into three zones representing broad 'average rainfall' zones, aligned with BoM long-term average rainfall contours, with higher rainfall and recharge at the top of the escarpment, declining to the west (away from the coast), consistent with estimates by AWRA and Crosbie (2015). These are then sub-divided into two zones based on outcrop geology: unconsolidated (swamps) and rock units. The long-term average recharge rate for the area immediately around or above Dendrobium mining areas (Zones 3 and 6, Figure 4-5) has been estimated as described in Section 2.6.3. is the subject of the calculations described below, and then the recharge to the inland and escarpment areas (which are generally drier and wetter, respectively) has been weighted by comparison with the results and mapping of Crosbie (2015).

Temporal variation in rainfall recharge to the area above Dendrobium mining areas has been calculated based on a water balance calculated on a daily timestep and accounting for runoff, soil moisture deficit and recharge based on inputs of rainfall and potential evaporation (Section 2.6.3). Rainfall and potential evaporation data are available from several sources:

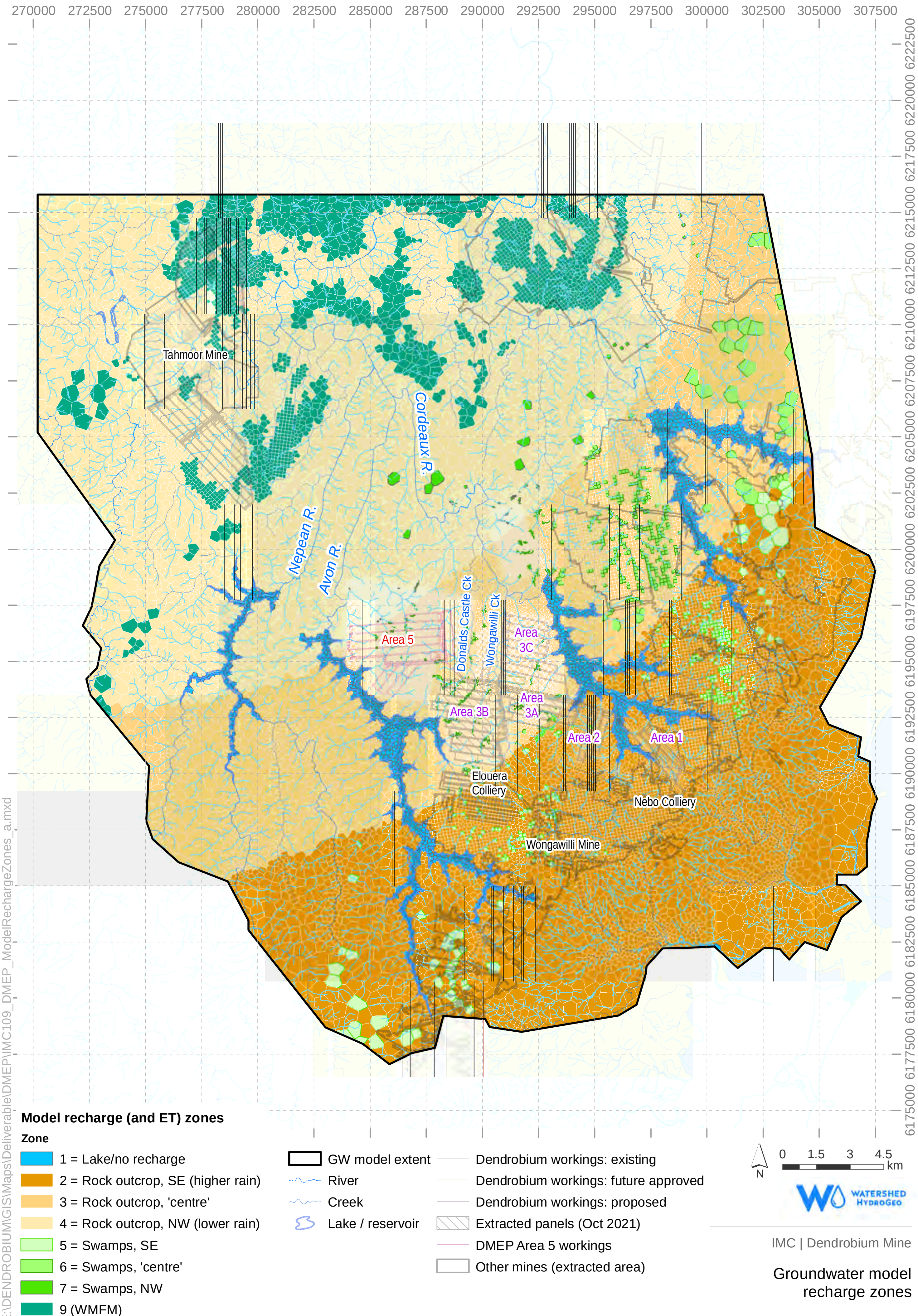
- Dendrobium site data for the Centroid, Area 3B, Area 1-2 and Area 5 stations; and
- SILO Data Drill records for a location situated approximately in the middle of all Dendrobium areas (Lat. -34.4, Long. 150.7).

This water balance has been calibrated against literature values, especially Crosbie (2015) and AWRA model estimates by BoM (Table 2-4). The modelled estimates of recharge were then aggregated across model stress periods (Section 4.3.3 and **Appendix E**).

The average recharge as calculated by the water balance model for the areas of rock outcrop is equivalent to about 6.6% of long-term average rainfall, which matches well with independent regional estimates made by BoM's AWRA-L model to October 2021 (7.5%).

Estimates of rainfall recharge to unconsolidated deposits within swamp areas are not available but are conceptualised as being more than that of the rock outcrop. As a result, average modelled recharge of about 330 mm/year is assumed, equivalent to 25-30% of long-term average rainfall. On-going research by universities may improve on these estimates in future.

Of note from Figure 4-4 (upper plot) is the extended period of low (or no) recharge from mid-2017 through 2019, followed by higher recharge in response to wet conditions through much of 2020 and into early 2021.



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IMC | Dendrobium Mine

Groundwater model recharge zones

Figure 4-4

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The groundwater model simulates variable recharge rates until model stress period 128 (equivalent of October 2021), and then a repeated sequence of recharge at 10th/30th/50th/70th/90th percentiles as calculated from the period 1985-2021) has been utilised to simulate recharge for stress periods 129-212 (year 2050). This is used to provide some understand of effects under variable weather conditions. Average recharge rates are used for the remaining period 2051-2200.

4.4.5 Evapotranspiration

The water balance model outlined in the previous section provides estimates of evapotranspiration in the soil zone. Where there is an excess of potential evaporation (PE) on a day during the sequence, this excess PE is then averaged across model stress periods (Figure 4-4) and applied to the MODFLOW model via the Evapotranspiration (EVT) package. The potential rate of evapotranspiration from groundwater was modelled at approximately 700 mm/yr for the outcropping rock at Dendrobium, and approximately 300-400 mm/yr for swamps. No evapotranspiration is simulated from lake or reservoir areas.

Rooting depths (‘extinction depths’) were set at 4.5 m for areas on outcropping rock, which are primarily sclerophyll forest. This is based on literature (Zolfhaghar, 2013), but then modified based on previous modelling at Dendrobium. The vertical extent of roots within swamp deposits is likely to be in the range of 0.4-0.8 m, based on information in SMI Environment Centres (2019), and 0.8 m has been adopted in the model.

The potential rate of evapotranspiration from shallow water tables, and the rooting (‘extinction’) depths, were not changed in the post-mining environment.

4.4.6 Mine dewatering

MODFLOW ‘Drain’ boundary conditions are used to represent mining, specifically simulating the dewatering of the workings. The drains are not shown on Figures in Appendix G, but were applied to all historical, approved and proposed mine workings. Drains were activated to fit the scheduling of all mining areas, but focussing on Dendrobium, as outlined in Table 1-5, Table 1-6 and **Appendix F**.

Drains are set at 0.1 m above the base of the mined seam to simulate dewatering of the workings. Conductances were varied during calibration to assess the effect on inflow rates and groundwater drawdown. Conductances are summarised in Table 4-4, although may vary slightly based on cell size.

Table 4-4 Model Drain parameters

Mine	Coal Seam	Model Layer	Conductance (m^2/day)
Dendrobium longwalls – Areas 1 to 3C	Wongawilli seam	14	2.5
Dendrobium longwalls – Area 5	Bulli seam	12	2.5
Dendrobium mains and roadways	BUSM and WWSM	12 and 14	0.05
Other mines			
Longwalls (e.g. Kemira, Elouera)	Wongawilli seam	14	3.75
Longwalls (e.g. Appin, Tahmoor)	Bulli seam	12	2.25
Bord and pillar / partial extraction	Wongawilli seam	14	0.75
Bord and pillar / partial extraction	Bulli seam	12	0.75
Outlets / discharges (all mines)	BUSM and WWSM	12 and 14	1.0E+6

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4.5 Parameterisation – hydraulic properties

This section outlines the modelled pre-mining or 'host' hydraulic properties. The application of subsidence-affected or post-mining parameters is described in Section 4.6.

Aquifer hydraulic properties – hydraulic conductivity (Kh and Kv), specific yield (Sy) and specific storage (Ss) – were assigned to the 'base case' or calibrated groundwater model using a combination of parameter zones, and depth-varying parameters, consistent with previous modelling for Dendrobium (HydroSimulations, 2019; Watershed HydroGeo, 2020a). Alternative parameters sets are used to assess some of the uncertainty related to host parameters – these are described in **Appendix L**.

4.5.1 Hydraulic conductivity (K)

The database and analysis of hydraulic conductivity, most of it from packer testing or injection falloff tests (IFOT), discussed in Section 2.6.6 is a sound basis for modelling. That includes identification of significant trends in K with depth for many of the relevant stratigraphic units, with non-significant (weak) depth trends for others.

The modelling here adopts a generalised depth trend for all units, and with perturbation from that generalised depth trend for different units, e.g. sandstones and coal units more permeable and claystones less permeable (**Appendix H**). A summary of the modelled values (median, arithmetic mean and range) by layer is shown Figure 4-6, along with the arithmetic mean from the field testing.

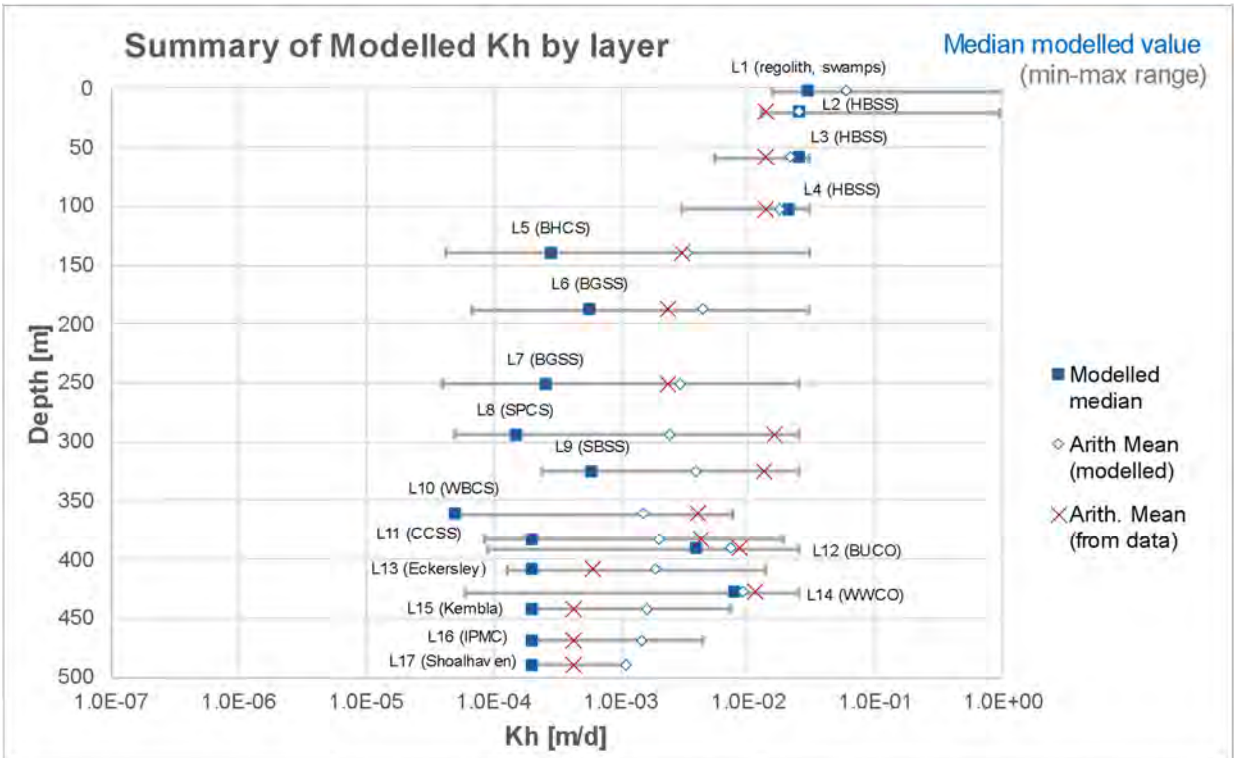

Figure 4-6 Summary of modelled Kh by layer

A similar summary of model Kv is presented on Figure 4-7 compared to the harmonic mean of packer testing results (Section 2.6.6). The ratio of modelled Kh to Kv is summarised in Table 4-5, compared to statistics from packer testing.

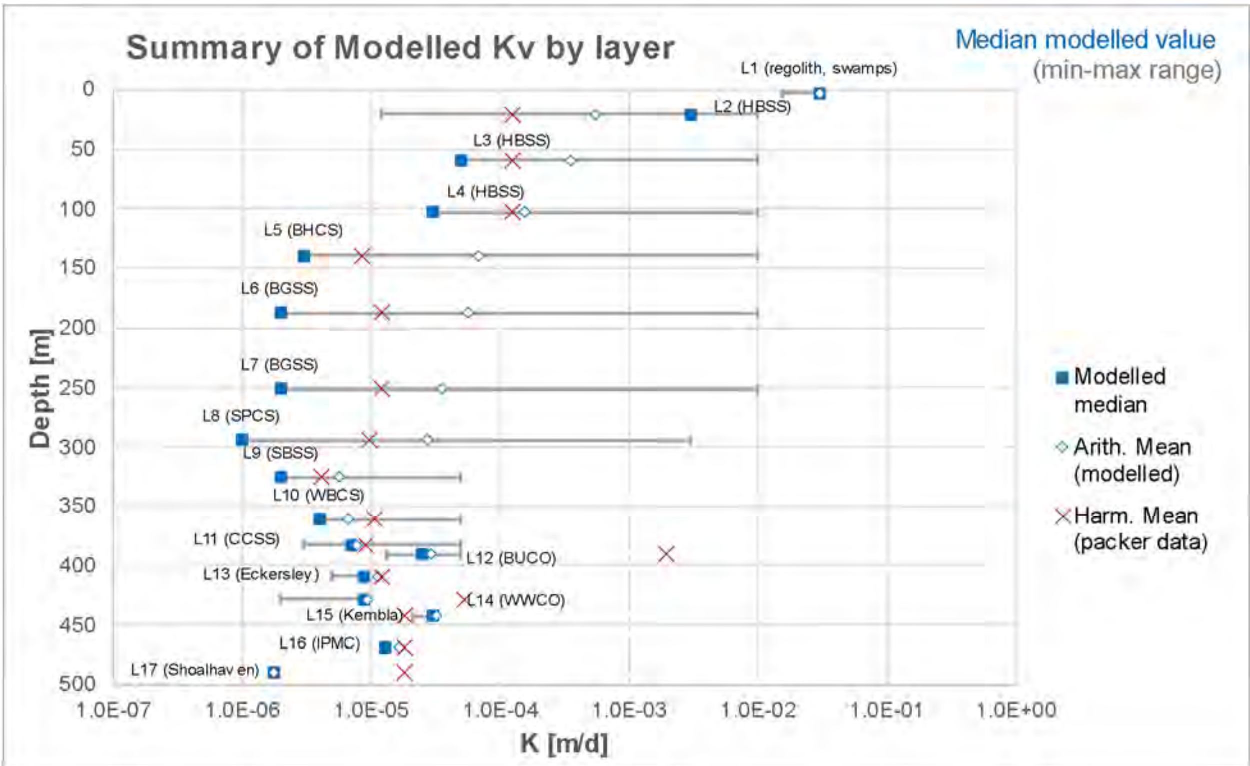

Figure 4-7 Summary of modelled Kv by layer

Table 4-5 Ratio of horizontal to vertical hydraulic conductivity (Kv/Kh)

Layer	Strat unit	Harmonic/arithmetic mean from packer data	Modelled Kv/Kh	
			Mean	Median
1	Regolith	--	1.00	0.9
2	HBSS	0.07	0.20	0.12
3	HBSS	0.07	0.10	0.00
4	HBSS	0.07	0.06	0.003
5	BACS	0.05	0.14	0.02
6	BGSS	0.07	0.04	0.01
7	BGSS	0.07	0.04	0.01
8	SPCS	0.07	0.03	0.01
9	SBSS	0.04	0.02	0.004
10	WBCS	0.08	0.07	0.08
11	CCSS	0.09	0.04	0.03
12	BUSM	0.22	0.08	0.01
13	Coal Interburden	0.10	0.05	0.05
14	WWSM	0.05	0.02	0.001
15	Kembla Sst (below WWSM)	0.21	0.14	0.15
16	lwr coal measures (below WWSM)	0.21	0.07	0.06
17	Shoalhaven Grp (below WWSM)	0.21	0.01	0.01

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4.5.2 Aquifer storage

Model parameters of natural or 'host' confined and unconfined storage (Ss and Sy, respectively) are based on review of literature, core tests, NMR and previous modelling outlined in Section 2.6.7. This includes:

- broad trend of decreasing storage with depth;
- higher Sy and Ss in units that are dominantly sandstones and the coal seams compared to units that are dominantly claystone/mudstone.

Sy and Ss are applied in zones, with layers comprising 1-4 zones depending on whether they represent multiple lithologies (e.g. layer 1 includes regolith, swamps, alluvium, while other layers are intruded by crinanite).

Modelled storage parameters are summarised below, with more detail of zones in **Appendix H**.

Table 4-6 Ratio of horizontal to vertical hydraulic conductivity (Kv/Kh)

Layer	Strat unit	Modelled storage	
		Ss	Sy
1	Regolith	unconfined	0.10
	Swamps	unconfined	0.30
	Alluvium	unconfined	0.10
	Wianamatta Formation	unconfined	0.10
2	HBSS	5.00E-03	0.05
3	HBSS	1.00E-06	0.025
4	HBSS	1.00E-06	0.012
5	BACS	1.00E-06	0.006
6	BGSS	9.00E-07	0.008
7	BGSS	8.00E-07	0.007
8	SPCS	7.00E-07	0.005
9	SBSS	6.00E-06	0.010
10	WBCS	5.00E-07	0.004
11	CCSS	4.00E-07	0.004
12	BUSM	2.00E-07	0.004
13	Coal Interburden	2.00E-07	0.004
14	WWSM	2.00E-07	0.004
15	Kembla Sst (below_WWSM)	3.00E-07	0.005
16	lwr coal measures (below_WWSM)	3.00E-07	0.004
17	Shoalhaven Grp (below_WWSM)	3.00E-07	0.005

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4.6 Representation of mining effects

Table 4-7 provides a summary of the methods used to represent strata deformation in the numerical model. This is provided as an initial overview, with further discussion in subsequent text.

Table 4-7 Summary of model implementation of strata deformation effects

Impact feature	Model implementation	Reference
Connected fracture network above the goaf	TVM (Time-varying properties) whereby K and Sy increase in specified zones after longwall extraction.	Sections 4.6.1 and 4.6.2
Near-surface fracturing and stream-flow diversion	TVM: Increase in Kh and Kv in the surface cracking zone.	Section 4.6.3
Depressurisation and recovery within the HBSS	"Stacked Drains" activated during longwall extraction and deactivated after 3 years. Required to improve stream flow loss simulation.	Section 4.6.5.
Off-goaf (valley closure) effects	TVM: Increase in Kh, applied in multiple deterministic scenarios (Section 6.1), given that effects are variable.	Section 4.6.4

Refer back to conceptual model in Section 3.3 .

Background to this section is provided in Section 3, specifically in Section 3.3. Simulation of mining-induced changes to the hydraulic properties of rock strata within and above longwall panels has typically been limited to simulating the 'connected fracture zone'. Previous modelling at Dendrobium has employed, at different times, three different methods of simulating the fracturing and deformation processes, which were summarised in HydroSimulations (2019) and IEPMC (2019b):

- Transient or time-varying material ('TMP' or 'TVM') properties. In this method, strata properties in the fracture zones are modified (Section 3.3, and Drain boundary conditions are activated only within the coal seam to simulate dewatering of that horizon.
- 'Stacked Drains'. This method relies on a set of Drain boundary conditions being imposed in each layer within the connected fracture zone to represent the free-draining fracture network. This essentially simulates the depressurisation effect within the fracture zone. Connected Linear Networks (CLN). This method, employed for a previous SMP assessment for Dendrobium Mine (HydroSimulations, 2016) simulated the fracture network within the goaf as conduits rather than porous media assumptions implemented via the TVM approach. All fractures within a vertical column of cells were aggregated as a single conduit (CLN).

Each of these have their strengths and limitations, and all have been applied at Dendrobium in the past. These fall under broad descriptions of simulating the deformed and fractured strata via equivalent porous medium (TVM), representation of discrete (or aggregated) fractures as a dual permeability (CLN), and simplified representation of the hydrogeological effect without necessarily representing the change to strata properties (Stacked Drains). A review of the former two methods outlines some of the limitations, mainly in the context of simulating coal seam gas and fault representation (Turnadge et al., 2018).

Given that IMC has initiated a (separate) study investigating post-closure hydrology and there is data from Dendrobium's centreline bore investigations (Section 3.2), the use of time-varying material properties (TVM) functionality in MODFLOW-USG has been adopted for this modelling. We consider that this equivalent porous media approach to simulating fracturing and deformation is appropriate because it is an appropriate scale for comparison to observations such as the centreline bore packer testing data. The model is also not being used to explicitly simulate solute transport, which might benefit from simulate of discrete fractures or dual porosity methods. The main limitation regarding the equivalent porous medium approach for this application is the difficulty in assuming the location and geometry of individual fractures that may affect surface water features and simulating the local effect of these (e.g. causing flow to be diverted beneath the stream bed for a distance). The same issue of predicting the location and geometry of these would also affect other modelling approaches.

The TVM method (or its equivalent in MODFLOW-SURFACT) was previously used at Dendrobium in earlier model variants and is also used at other sites in the Southern Coalfield (e.g. Tahmoor Mine, Metropolitan Mine).

Surface flow reductions predicted by the groundwater model presented in some previous studies at Dendrobium (e.g. LW17 SMP Groundwater Assessment) have been overly conservative compared to flow losses that have been estimated in recent End of Panel reports (HGEO, 2020a, 2021a, 2022a) via the revised TARP calculation methods (described in the latest Area 3A, 3B and 3C WIMMCP documents).

However, calibration of this revised model, thus far using TVM alone, has not yet simulated surface water reductions that sufficiently match the historical losses estimated in recent those End of Panel assessments. 'Stacked Drains' (Section 4.6.5) have been implemented in conjunction with TVM. In part, this also deals with the conceptual uncertainty that is associated with whether connective fracturing is present to greater heights above the seam only for a period of time (months to years) after longwall extraction before reducing in hydraulic conductivity/connectivity.

4.6.1 Modified hydraulic properties

The conceptual "zones" of deformation and fracturing are represented in the model via enhanced hydraulic properties. Some commentary on specific zones is provided below, along with a schematic (Figure 4-8) showing the application of the zones across and above modelled longwall panels.

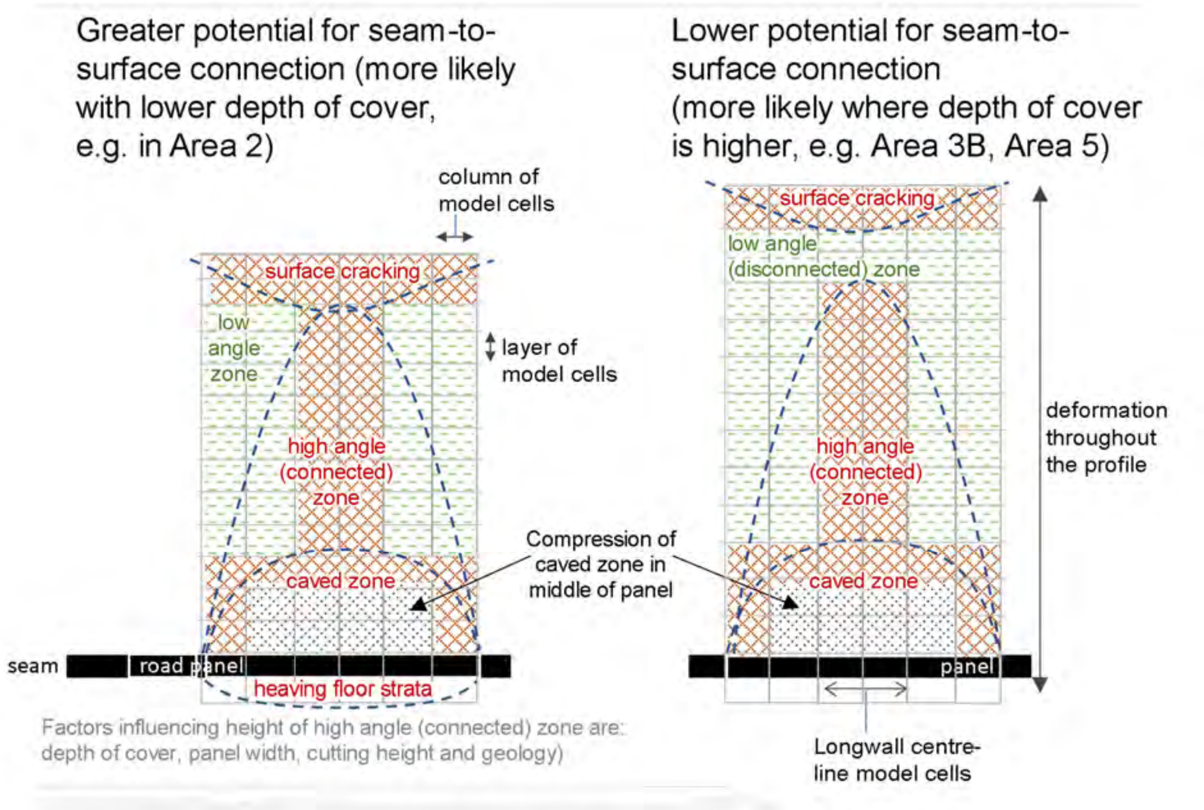


Figure 4-8 Model representation of conceptual property zones above the goaf

Hydraulic conductivity

Hydraulic conductivities (Kh and Kv) are modified within these conceptual zones. Table 4-8 summarises these changes or enhancements, both within the longwall footprint and outside the goaf.

Table 4-8 Summary of enhanced hydraulic conductivities used in the TVM package

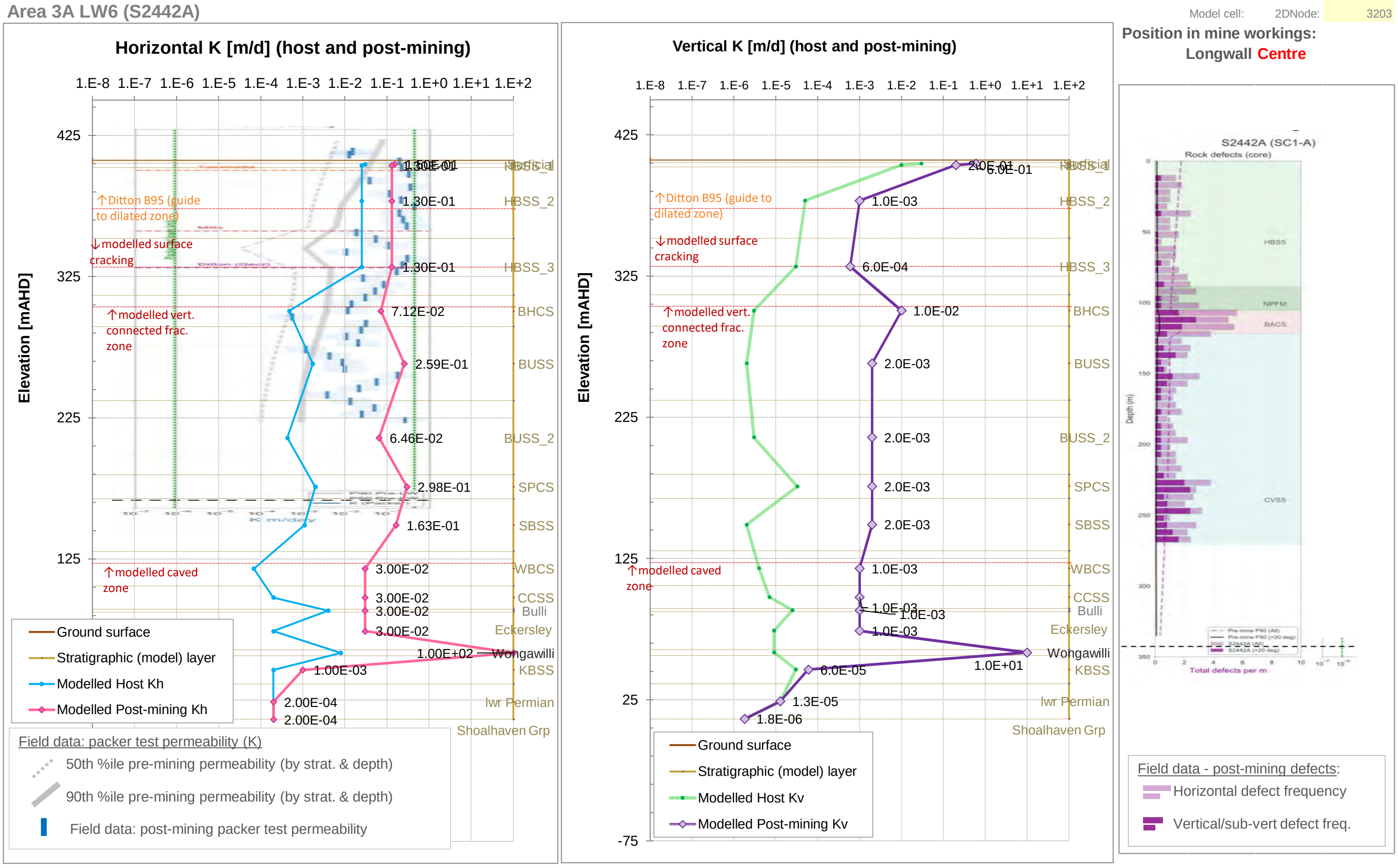
Feature	Numerical model representation		Comment
	Kh (post-mining)	Kv (post-mining)	
within footprint			
Surface cracking zone (SCZ)	Max of: Host x 5 and 1.3E-1 m/d	X 20	
Low angle (disconnected) fracture zone (DFZ)	x 20	x 2	Within low angle zone, BACS host Kv multiplied by x 5 to simulate brittle fracture.
Seam-to-surface (where high angle/connected zone intersects surface cracking	Max of: Host x 5 and 0.13 m/d	Max of: x 20 host and 1.0 m/d	Applied to where high angle/connected zone intersects surface cracking zone
High angle (connected fracture) zone (CFZ)	Max of: x 150 and 0.01	Max of: x 50 and 0.002	Applied to centre-line model cells, based on comparison of overgoaf investigations.
Caved zone: edge of panel	0.3	0.01	
Caved zone: centre of panel	0.03	0.001	
Longwall panel (seam)	100	10	
Roadway	50,000	0.1	High to ensure drainage in un-sealed closure scenarios
Bord & pillar / partial extraction	500	0.01	
Underlying floor	x 5	x 2	
Outside footprint			
Off-goaf <100m	x 4	no change	Tested in uncertainty scenarios (Section 6.2). Absolute values of 6E-2 to 2.5E-1 m/d also appropriate.
Off-goaf <300m	x 3	no change	
Off-goaf <600m	x 2	no change	

TVM parameters from: ...\FracZone&TVMmaker_DND6TR017.xlsm

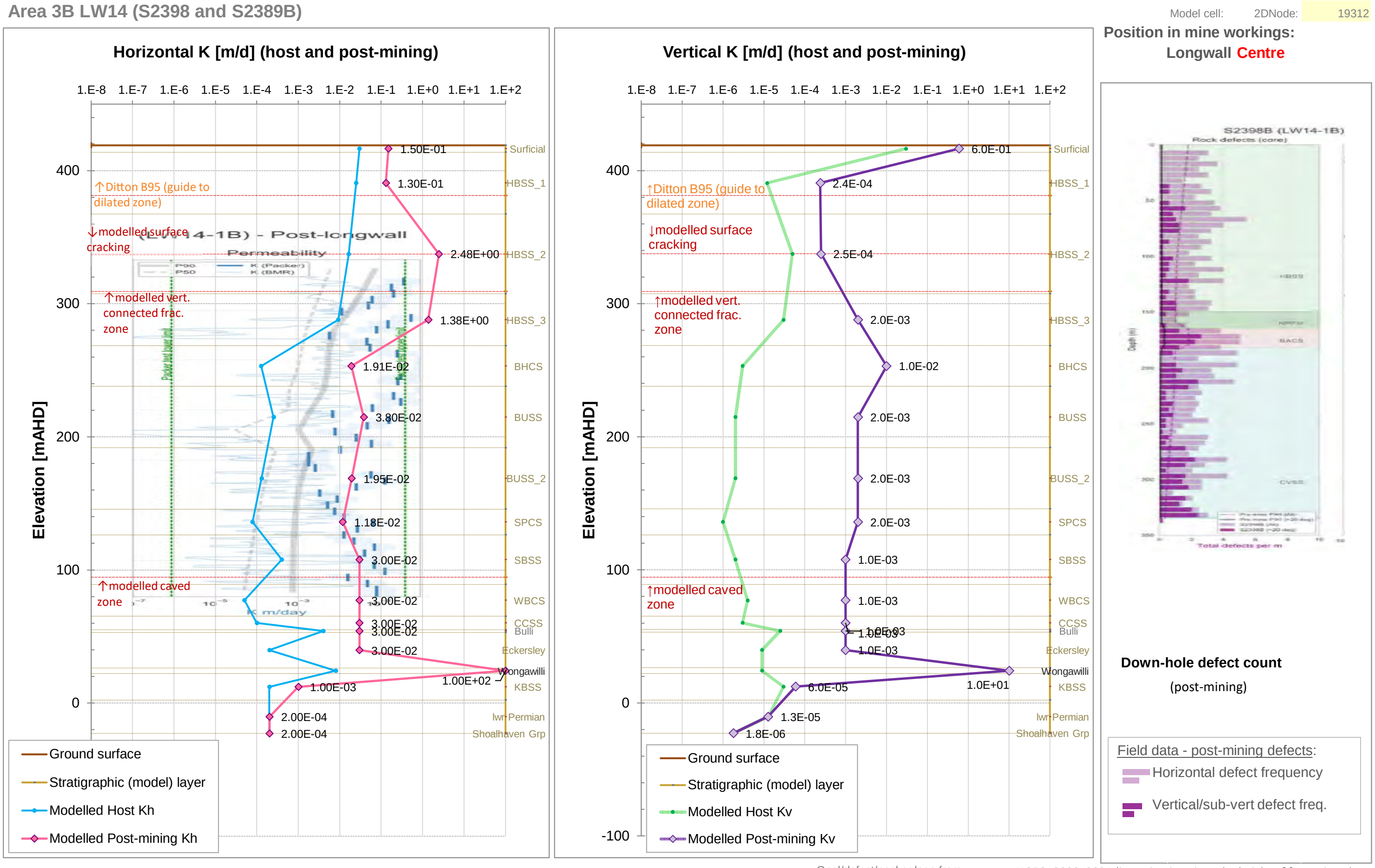
Figure 4-9 presents the modelled profiles of hydraulic conductivity in the centre-line of the longwalls against data from the recent Height of Fracturing investigations, as described briefly in Section 3.2.1. A similar figure (Figure 4-10) shows the modelled profile for two longwalls without field data, one in Area 2 where the depth of cover is low, and another in the centre of proposed Longwall 505 in Area 5.

The details of the various conceptual zones or components are described in the following sections.

A) Area 3A LW6 (S2442A)



B) Area 3B LW14 (S2398 and S2389B)



Geol/defect/packer logs from: HGEO, 2020, 2021 (investigations into the height of fracturing above extracted longwalls in Area 3, Dendrobium)

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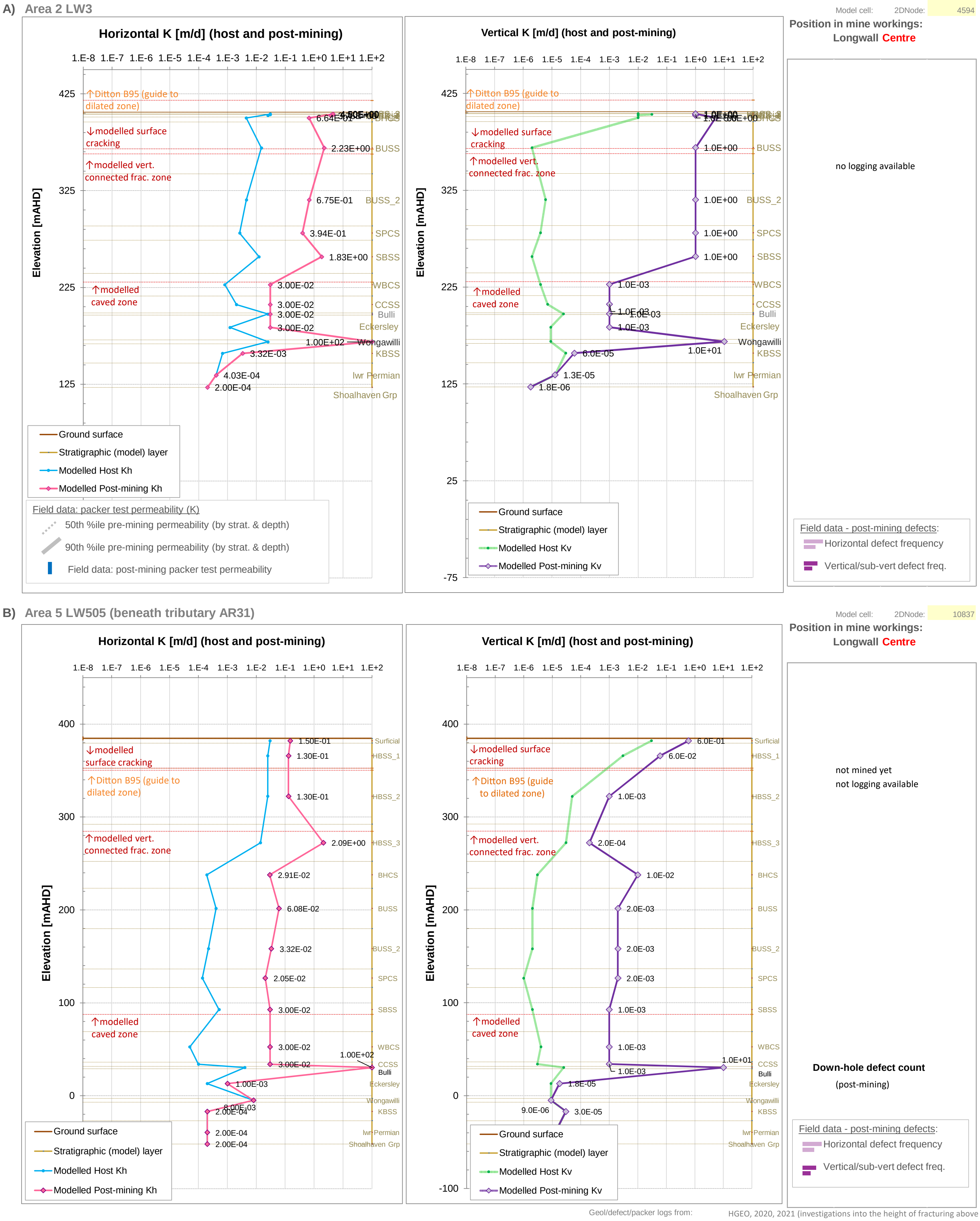
Profiles illustrating modelled K compared against field data **Figure 4-9**



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Modelled deformation and fracturing profiles - sites without field data

Figure 4-10

4.6.2 High angle ('connected') and low angle fracture zones

Horizontal hydraulic conductivity (Kh) is increased throughout the sequence, from seam to surface, within the longwall footprint. This concept is clearly supported by the count of low-angle defects which have clearly and consistently increased from pre- to post-mining throughout the profile.

The results of model calibration to mine inflow, suggested that along with modification of the hydraulic conductivity, differentiation of model cells that are along the centre-line of panels and those that are off-centre should be adopted, where in the connected fracture zone a higher K is applied to the centre of the zone (Figure 4-8). A similar feature applies in the caved zone, but where the higher K is present along the panel edge.

Where the connected fracture intersects the modelled surface cracking zone, a higher Kv is applied (Table 4-8). This was in an effort to improve calibration to inflow in Area 2.

4.6.3 Surface cracking zone

Surface cracking effects, extending down from the surface, were not the focus of HGEO (2020b), although some of the data is relevant. Further data that informs the modelling of this process is available from other studies, e.g. defect logging and packer testing in the Longwall 9 boreholes (Parsons Brinckerhoff, 2015; PSM, 2017), as well as from SCT (2016) and SCT (2019). These studies include data that show fracturing through the vertical profile, with no separation between fracturing from the panel and from the surface (i.e. no 'Constrained zone'). Overlapping of upward extending 'connected fracturing' and downward extending surface cracking means that estimation of the depth of the surface influenced (unconfined) cracking zone is difficult (a complication also noted by Advisian, 2016).

We have assumed that the depth of the surface cracking zone is approximately 10 x cutting height (t). This depth estimate (10 x t) is based on experience at Dendrobium, Tahmoor and Metropolitan Mine.

The representation of this surficial and near-surface process has been the primary focus of recent calibration effort. The profiles on Figure 4-9 and Figure 4-10 show the currently modelled Kh and Kv in the near-surface zone.

4.6.4 Off Goaf (Valley Closure and Strata Deformation)

This process has been simulated by increasing horizontal hydraulic conductivity of the strata between the longwalls and the nearest 'deep' valley (Section 3.2.2). This has been done by selected model cells within a certain distance or buffer (<100 m from the longwall, 100-300 m and 300-600 m from the nearest panel edge) and assigning a K multiplier to each buffer area, with the multiplier declining with distance from the longwall.

Kh multipliers selected were x4, x3 and x2 (for areas <100 m, <300 and <600 m from panels, respectively for scenario analysis (Section 6.2), based on previous modelling at Dendrobium. HGEO (2018b and 2019b) revised the estimates of how Kh enhancement should be simulated in order to carry out a conservative assessment of the potential connection between Lake Avon and the goaf. As a result of these, absolute values of 6E-2 (representative) to 2.5 E-1 m/d (conservative/maximum) for model cells lying within 300 m of a panel edge is also viewed as alternatives to using multipliers (Section 6.1).

Focussing on the prediction of reservoir loss or leakage, Kh enhancement is simulated in the strata from the base of the nearest valley, i.e. in the lower Hawkesbury Sandstone and Bald Hill Claystone around the Avon Reservoir shoreline south and west of Area 5 and west of Area 3B.

4.6.5 Stacked Drain parameters

As noted in Section 4.6, 'Stacked Drains' were eventually re-adopted for the purpose of this Groundwater Assessment. The simulation of inflow and groundwater drawdown using TVM alone was appropriate, especially in the Illawarra Coal Measures and Narrabeen Group strata, but the simulated reduction in surface water was not matching that assessed from field data. Further investigation into modified hydraulic conductivities and porosities (specific yield) should be carried out to improve modelling in the future.

In the current model, 'Stacked Drains' were set in 2 layers – the layer at the top of the estimated high angle (connected) fracture zone and in the layer above this. These Drains were set to have a stage 0.1 m above the bottom of the layer.

In earlier modelling for Area 3 SMP applications the 'Stacked Drains' had been set with a conductance that declines with height above the mined seam, with conductances varying, as a result of calibration, from 13 m^2/d above the seam down to 2 m^2/d. HydroSimulations (2019) described a more advanced method of estimating the conductance of the stacked drains using the Thiem equation in a similar fashion to how it can be applied for the 'CLN' package of MODFLOW-USG (Panday et al., 2013).

Further details of the calculations are available in HydroSimulations (2019), but the conductances used in this modelling are derived from that, having been also used in the SMP Groundwater Assessments for Longwall 18 and Longwalls 22 and 23 (Watershed HydroGeo, 2020a, 2021b). The conductances applied are listed below, and have been the subject of calibration for drawdown and surface water losses:

- Layer 2: 0.01 m^2/d
- Layer 3: 0.23 m^2/d
- Layer 4: 0.31 m^2/d
- Layer 5: 0.04 m^2/d
- Layer 6: 0.20 m^2/d
- Layer 7: 0.12 m^2/d
- Layer 8: 0.12 m^2/d

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In terms of the representation of drawdown above and around longwall areas, which was a previous concern of the IEPMC, the results in Sections 5.3.1 (groundwater pressures and drawdown), 5.3.2 (mine inflow) and 5.3.4 (surface water losses) indicate the Stacked Drains and TVM properties are appropriate.

4.6.6 Aquifer storage

The extraction of the longwall results in an increase in porosity (storage) in the subsurface. i.e. the removal of approximately 3.9 m of coal initially leaves a void, which then collapses in the workings. Subsidence at the surface reduces the volume available (left-hand columns in Table 4-9). The subsequent deformation in the strata between the seam and the surface results in re-distribution of that porosity through the sequence.

In the current model, the drainable porosity (Sy) increase has been concentrated in the mined seam, and the caved zone, as outlined in the right-hand columns of Table 4-9. This is based on Advisian (2016) summary of this process as: "In areas nearer the zone of extraction, such as the caved zone, both vertical and horizontal cracking is thought to be substantial and therefore significant increases in vertical and horizontal permeability are expected, as well as increases in porosity." PB (2015) stated that the greatest strain occurred below their lowest extensometer (i.e. below the Bulgo Sandstone).

Table 4-9 Modelled Enhancement of Porosity / Specific Yield

Void space calculation		
Parameter	**Value**	
Mining height	3.9	m (Table 1-5)
Depth of Cover [m]	340	average in panel
Subsidence	0.8	m, above pillar#
	2.5	m, centre-line#
	1.65	m, averaged
Void space created	=3.9-1.65	
	=2.25	m (#1)
Average increase in porosity	= (3.9-1.65) / 340 = 0.66%	

Modelled porosity enhancement					
Layer	**Thick-ness* (m)**	**Host**		**Post-mining**	
		Sy	**Void (m)**	**Sy**	**Void (m)**
					2.25 m (#1)
Wombarra Fm (L11)	30	0.004	0.06 m	0.033	0.495 m
Bulli seam (L12)	2.5	0.016	0.04 m	0.06	0.15 m
LRSS (L13)	20	0.005	0.14 m	0.05	1.5 m
Wongawilli seam (L14)^	4	0.015	0.06 m	0.10	0.4 m
Total			0.3 m		2.45 m
Porosity or void space difference			= 2.45 – 0.3 = 2.1 m		

from MSEC, 2020 (Longwall 22-23 Subsidence assessment); * example thickness within panel; ^ working section only

Table 4-9 shows good agreement between the calculated void space created and the modelled distribution of void space. It is possible that the development of additional porosity occurs in a non-systematic fashion (PB, 2015). Currently we consider that most of the Sy enhancement will occur in the zones nearest the mined seam (as per Advisian, above), however, future investigation should consider whether that additional storage is more prevalent higher in the profile. As long as the model approximates the total porosity enhancement, then the role of this in delaying groundwater level recovery would be taken into account. Specific storage (Ss) has not been modified from host values.

As discussed with the model reviewer, changes to Sy via the TVM package (in this case, TVM v2 package (Merrick, 2016)) can be numerically problematic, despite this package being coded to conserve water volume. We have confirmed that the overall mass balance error or discrepancy is very low and acceptable (Section 4.8) and that the timeseries of mass balance errors does show peaks in mass balance error, but also remains acceptable.

4.6.7 Other Workings

Roadways (gate roads and mains) and bord and pillar areas are simulated with the parameters set out in Table 4-8. The roadways and mains are attributed with very high Kh in order to simulate free drainage, if required, in mine closure scenarios. The drift between Areas 3B/3C and Area 5 has the same value applied to Kv, in order to simulate this drainage across multiple layers.

4.7 Observation data

History-matching or calibration has considered four types of observation:

- groundwater levels;
- mine inflow (dewatering);
- surface water flow; and
- surface water losses.

4.7.1 Groundwater levels

A large dataset of groundwater levels has been collated across a total of approximately 800 target instruments (bores, piezometers) at which over 1.3 million daily groundwater level observations have been used to derive “calibration targets”. The locations of boreholes and piezometers used for groundwater level calibration are mapped on Figure 2-12 and maps in **Appendix A**.

Of those sites/piezometers, over 780 are piezometers in ‘deep’ bores. From the sub-daily or daily data recorded at those sites, the data have been converted into over 26,000 targets using a progressive approach executed via a script. This approach initially attempts to use the value on the last day of the model stress period, and if there is no (appropriate data), then the median value for the last week of the stress period is used, or then it calculates the median value over the last month for each model stress period. This approach maximises the use of groundwater data in cases where data gaps coincide with the end date of the stress period.

Data quality assessment of these sites has been conducted via three main steps:

- Piezometer elevations and their recorded stratigraphy have been checked against the geological/groundwater model layering. Where there is agreement, a weighting of 1 has been assigned (69% of instruments). Where there is disagreement by 1 layer, a weighting of 0.5 has been assigned (26% of instruments), 0.25 for 2 layers (4%), and a weighting of 0 assigned where there is disagreement by more than that (<1%). This process has also led to some correction of assigned stratigraphic units This step has been added to address previous comments by DPIE-Water.
- Clearly erroneous data has been removed (e.g. groundwater levels >600mAHD)
- Some suspect data has been assigned a weighting <1, based on a review of hydrographs, but identifying suspect data is not always possible, especially in this environment.

The overall weighting for a transient observation (‘target’) is then calculated as the product of the piezometer weighting and the data weighting. Comparison of modelled groundwater levels and the targets is presented in Section 5.3.1.

Late in this study, data was made available for a number of DPIE-Water coal basin[4] monitoring sites located within 4 km of Area 5 (bores GW09906/GW0409046/GW0409052 near Nepean Dam and bores GW099003-5 at Fire Trail 6B). These have been used as a form of verification (Section 5.3.1). The sites are shown on Figure 2-8. The data commenced in September or October-2021, so there is only a very short overlap with the model’s historical period (Section 4.3.3). No data-cleaning was carried out, other than correcting the data for GW099003 for which the datum was erroneously set at 0 mAHD.

4.7.2 Mine inflow

Mine inflow is calculated using the IMC site water balance (Section 2.6.5). The groundwater inflow to a longwall mine represents an accumulated response to both host properties (K, Sy) and to fracture zone properties (height, changes to K), and as such is a key target for calibration.

The daily inflow to each mine area has been aggregated for each model stress period. This process tends to remove extreme daily values in the inflow record, although some erroneous data is likely to

[4] https://www.industry.nsw.gov.au/__data/assets/pdf_file/0003/167070/expanding-the-water-monitoring-network.pdf

remain, but further 'cleaning' of the data is not possible. As such, the aggregated values are assumed to be reliable.

4.7.3 Surface water flow

Surface water flow is measured at numerous gauging stations around Dendrobium Mine (Section 2.4.1). This data is not used for a quantitative comparison in model calibration. It is a lower priority of the groundwater modelling, especially given that the model uses externally sourced estimates of runoff (Section 4.4.3); surface water *losses* are the priority (Section 4.7.4). The observed flow data is used in a qualitative fashion in order to assess the model's ability to simulate the approximately magnitude and timing of surface water flows.

4.7.4 Surface water losses

There are 13 gauging stations operation by IMC that have been mined under (or near). Analysis of flow data at these sites (Section 2.4.4) has shown a range of changes to flow magnitude due to mining. As requested by WaterNSW, these losses are calculated as a rolling or cumulative change in median observed flow for the period commencing at the date when each sub-catchment is mined under. These losses are used as the targets for model calibration, in order to provide estimates of flow losses that can then be most reliably compared to field data in future.

Comparison of modelled results with this data is an important recent additional to the history-matching process, given the focus on better understanding surface water losses due to mining. Comparison of the model against these results is presented in Section 5.3.4.

4.8 Model execution

We had endeavoured to speed up the model runs, but the requirement to simulate cumulative mining effects due to a long history and significant spatial extent of mining in this area, and the processes and effects required to be simulated, has meant that run times remain lengthy:

- The historical model of 128 stress periods runs in 7-9 hours.
- The 'Full Development' predictive model (90 stress periods) takes approximately 20 hours to run.

At the end of that calibration period (late 2021, model stress period 128), the modelled cumulative mass balance error was less than 0.01%, which is well within the 1-2% error recommended by the Australian Groundwater Modelling Guidelines (Barnett et al., 2012a).

Figure 4-11 presents a timeseries of the mass balance error for each timestep in the model simulation (both historical and predictive). In the historical period, there are infrequent spikes in error, usually in the early timesteps in a stress period, but typically the error is very low and acceptable. For the forecast period, errors are also very low and acceptable. Following mine closure (i.e. after stress period 74), mass balance errors rise for a period, likely associated with flux along the open roadways (Kh = 50,000 m/d) simulated for assessment of post-closure behaviour. As more of these workings are flooded, the mass balance error declines and is acceptable.

This performance is achieved using the MODFLOW-USG 'SMS' solver (Panday et al., 2013; Panday, 2021) with a head close criterion of 0.02 m (outer iterations) and 0.001 m (inner iterations). Other solver settings are available on request. Adaptive time-stepping is used to improve numerical stability. Heads and budget outputs are saved on multiple timesteps (usually 4) during each stress period, producing approximately 15 gigabytes (Gb) of output for each historical model run, and 10 Gb for each of the predictive scenarios.

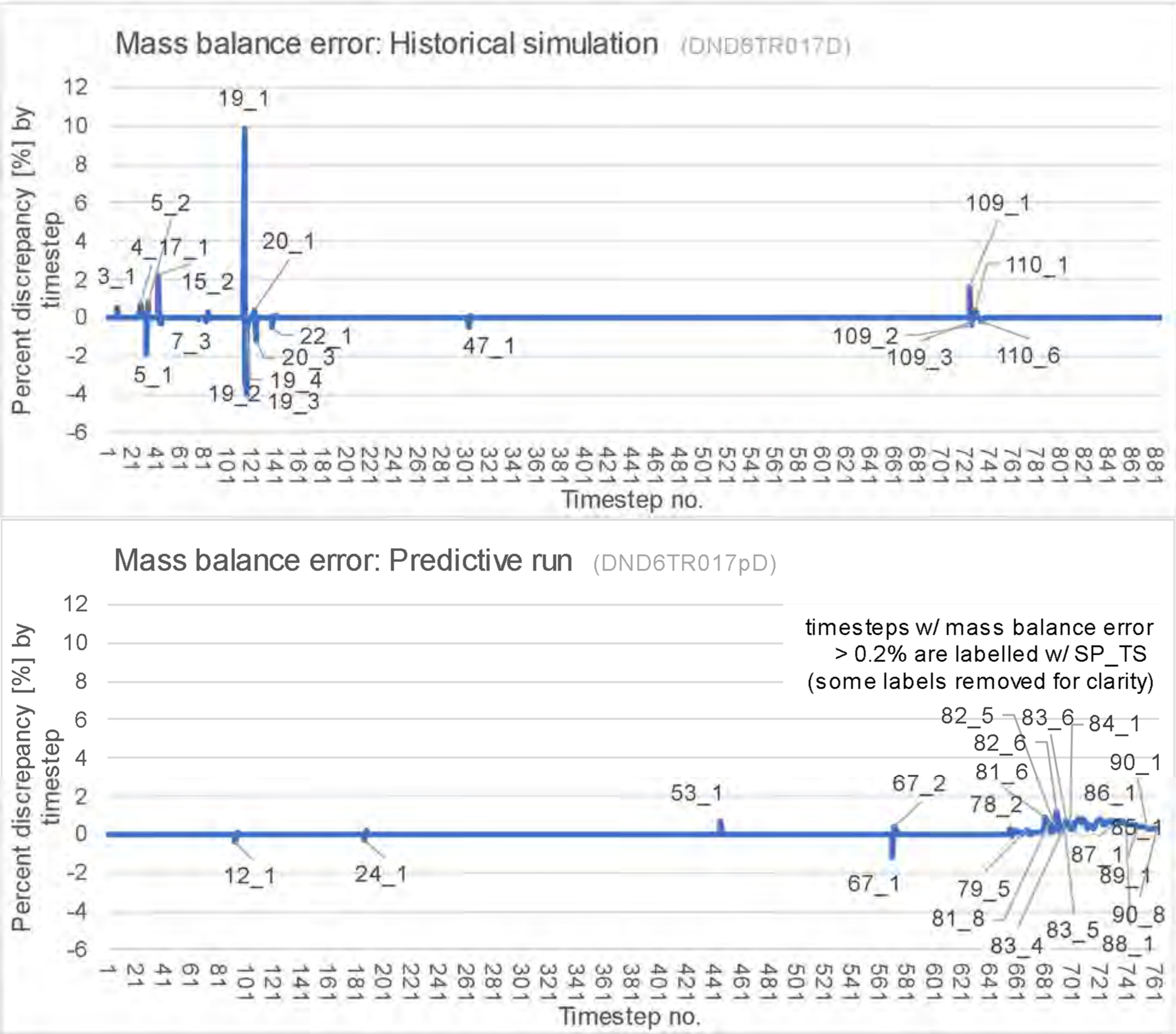

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Figure 4-11 Time series of model mass balance (closure) error

5. Model performance and history matching

This section presents model results for the historical period (Section 4.3.3) compared to observed data or targets (Section 4.7). Subsections describe the general approach for calibration (Section 5.1), and broad review of the simulated regional water balance (Section 5.2). The capability of the model in replicating observed data is presented for the different types of observations (Section 5.3).

Model history-matching is considered in the Model Confidence Classification (Section 4.2.1 and **Appendix K**). Model history-matching is also commonly referred to as model “calibration” and the terms may be used interchangeably.

5.1 Approach

Model history-matching is the process of replicating observed mine inflow and groundwater levels by varying key model parameters such as hydraulic conductivity and storage within the range of reasonable values defined by the extensive database from Dendrobium and neighbouring mines (Appin, Tahmoor). Given the issue raised previously regarding uncertainty in future surface water losses (Section 1.2.2, Table 1-3), specific focus has been made on assessing historical losses (Section 2.4.4 and 4.7.4) and calibrating the model to these (Section 5.3.4).

The modelling relies on many available values of hydraulic conductivities and storage parameters from Dendrobium supported by data from neighbouring mines (Section 2.6.6), and modification of boundary condition properties (Section 4.4), including review and implementation of independent estimates of recharge (Sections 2.6.3 and 4.4.4) and runoff (Section 4.4.3). Trial and error calibration methods were used to modify the host hydraulic conductivity (horizontal and vertical), and specific yield of modelled layers or zones (Section 6.2), as well as the parameters that govern the subsidence and fracturing processes with the aim of matching observed data, including surface water losses. It should be emphasised, that the focus has been on simulating the subsidence deformation, and associated effects on groundwater inflow, groundwater drawdown and surface water losses. This deformation is the most important feature for simulating a longwall operation and its effects on hydrology.

5.2 Water balance

At the end of that calibration period (late 2021, model stress period 128), the modelled mass balance error was less than 0.01%, which is well within the 1-2% error recommended by the Australian Groundwater Modelling Guidelines (Barnett et al., 2012a).

A tabulated regional water balance is summarised in Table 5-1. This presents the average water balance for the historical period, 1991-2021. This includes Dendrobium (up to and including Longwall 17), historical mining around Dendrobium (e.g. Nebo, Elouera, Wongawilli, Kemira etc.), and the parts of Appin, Tahmoor and Cordeaux Mines within the active model domain (Figure 4-2).

In general, the largest inputs of recharge and stream leakage are expected. These are balanced by evapotranspiration. Net groundwater storage change is close to zero for this period, representing a slight reduction in modelled groundwater levels across the model for the period.

Table 5-1 Modelled water balance: model-wide water balance – 1991-2021

Modelled component	Catchment process	Historical simulation	
		In	Out
Storage	groundwater storage	157.3	152.2
Constant Head	flow to ocean, estuaries	0.0	0.0
Drains	Mine inflow/ dewatering	0.0	28.8
River Leakage	Groundwater exchange w/ Reservoirs	28.2	5.9
Evapotranspiration	Evapo-transpiration from GW	0.0	337.6
Head Dep Bounds	Regional groundwater flow	17.3	1.8
Recharge	Infiltration recharge	180.9	0.0
Stream Leakage	GW-SW interaction w/ watercourses	189.7	20.8
Total (ML/d)		573.4	573.4

Units are ML/d.

E:\DENDROBIUM\Model\Gwmodel\Runs\DND6\DND6TR017\Proc\ZoneBudget\WaterBalance\MassBalance_LST_dTR017D_calib&predict.xlsx. Stress periods 3 to 128, model run DND6TR017D

A review of the inputs and outputs via Head Dependent Boundaries (GHBs) for historical scenarios (all mining or full development and a 'No Dendrobium' scenario indicates that the difference in Head Dependent Bounds is minimal, i.e. <0.1% difference. This confirms that the general head boundaries are set at a sufficient distance from Dendrobium Mine to avoid undue influence on groundwater level or drawdown and other fluxes.

Previous comments by the IEPMC/IAPUM have been that a water balance for a more focussed area is preferred. To address this, such a water balance for the proposed Area 5 mine footprint and surrounds is presented in the forecasting section (Section 6.4.2).

5.3 History-matching or calibration

5.3.1 Groundwater levels

This section describes the calibration to groundwater levels from the Dendrobium monitoring network, as well as an informal verification against a short record of data from nearby DPIE-Water monitoring sites.

Contour maps of modelled groundwater levels are then presented at the end of this section.

Dendrobium monitoring sites

A summary of model performance with respect to the overall simulation of groundwater levels is provided below, with modelled heads plotted against the observed head targets (described in Section 4.7.1) on Figure 5-1.

This shows results that tend to cluster around the 1:1 line, but with some spread (variance) from that line. The key reasons for the variation between observed and modelled heads on the X:Y plot are:

- difficulty in matching the timing of drawdown. The model may match the pre-mining head, and also the final post-mining head reasonably well, but during the period of drawdown, the model can be out by 100 m or more because it either draws down too quickly or too slowly compared to observed (examples of this are on the later hydrographs, e.g. Figure 5-2 and Figure 5-5);
- allied to the above, longwall progression and commencement of significant impacts at a monitoring point occurs over small time increments compared to model stress periods;

- potentially incorrect layer assignment. Some VWPs located in the mid-Bulgo Sandstone may be assigned to the lower Bulgo Sandstone but could be validly assigned to the upper Bulgo Sandstone. Such piezometers have been weighted down in the calculation of statistics (Section 4.7.1), but that does not affect the display;
- incorrect or suspect data which has not been identified or cannot be confirmed as incorrect, and so is used 'as-is'; and
- incorrect or imperfect parameterisation of the model re: K and S parameters, either on a local or larger-scale.

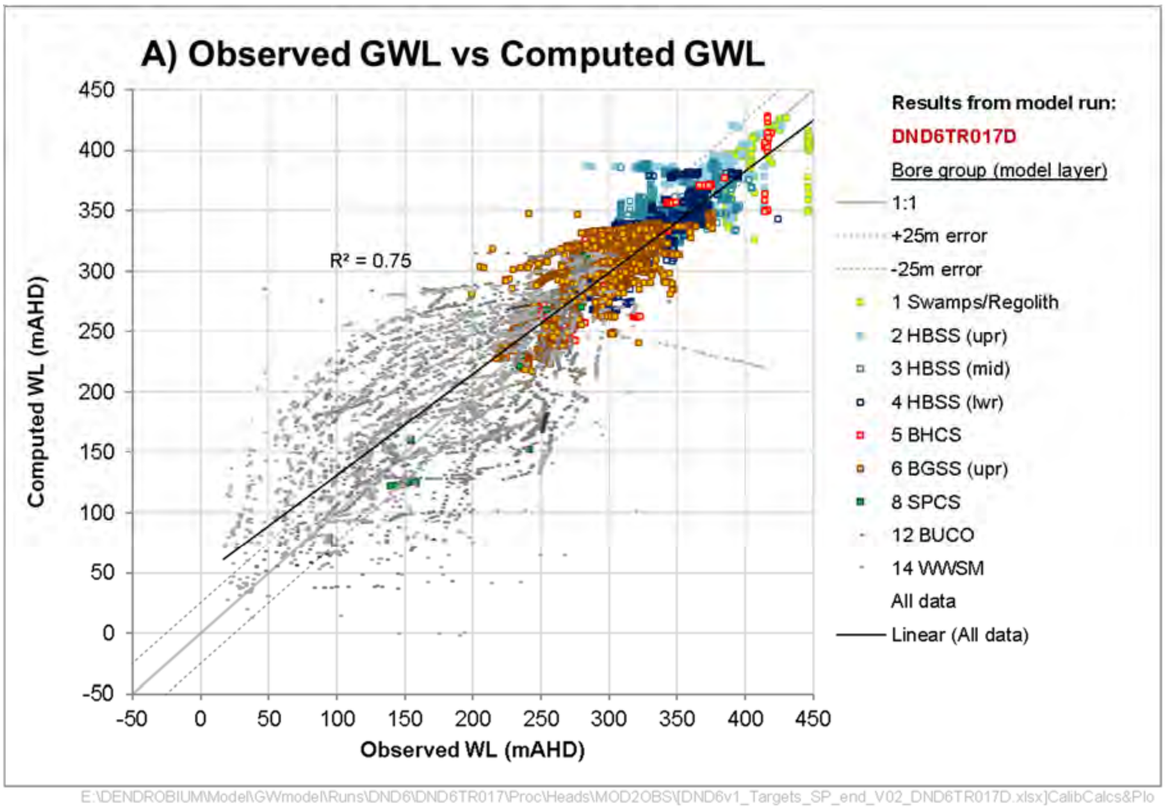


Figure 5-1 Summary of groundwater level calibration

The size of the dataset (Section 4.7.1) has meant that data 'cleaning' or the application of 'weights' cannot be carried out rigorously. Steps have been made to correct or remove clearly erroneous data (e.g. provided instructions to the data managers to fix some calculated heads obtained from some of the VWPs, such as occasional miscalculation between groundwater level (mAHD) and pressure head (m). However, it is often difficult to identify clearly incorrect data (Section 4.7.1).

The SRMS error for the correlation between observed data and the transient model groundwater levels is 8.8%. This value is within the often-quoted example of 10 % (MDBC (Murray Darling Basin Commission), 2000; (Barnett et al., 2012a), and considered acceptable for a model of this scale and complexity, in a fractured rock environment, and considering the accuracy of the VWPs and the size of the dataset. The mean residual groundwater level is -2.8 m.

More importantly, a number of representative groundwater level hydrographs are presented in the following pages. These are chosen to show model performance in the various mine domains, and to show the representation of groundwater processes in response to longwall mining and in areas adjacent to various receptors, such near to Cordeaux Reservoir (Figure 5-2), Wongawilli Creek (Figure 5-3, Figure 5-5) and Avon Reservoir (Figure 5-3), as well as bores investigating groundwater response directly above longwalls (Figure 5-4, Figure 5-5).

The format of these hydrographs has been updated following previous comments by DPIE-Water hydrogeologists and others to improve clarity and interpretation:

- Piezometer positions (elevations) are shown on the left-hand axis.
- The key has been re-oriented to emphasise that the model layers and piezometers are set out in order of depth.
- In the legend, the observed data (piezometers) are aligned to their corresponding model layer, noting that multiple piezometers might be present within a single model layer, and that model layers are, with the exception of the coal seams, larger or thicker than the strata that is truly monitored by the piezometer.

Key points to note from the hydrographs shown below are:

- Modelled drawdown in the coal seams and in the deeper strata is a good match to observed drawdown, but noting that variance of 10s of metres can occur.
- Modelled drawdown in response to longwall extraction in the upper Bulgo Sandstone, Bald Hill Claystone and Hawkesbury Sandstone is well represented, which is consistent with observations of drawdown or depressurisation through much of the stratigraphic column above or adjacent to longwalls, e.g. S1930, S2220, S1932.
- The model also now better replicates some of the groundwater level stabilisation and/or recovery that is observed in many of the bores near to or above longwalls, e.g. S1930, S2220, S2377.

A set of full set of modelled versus observed hydrographs is presented in **Appendix I**.

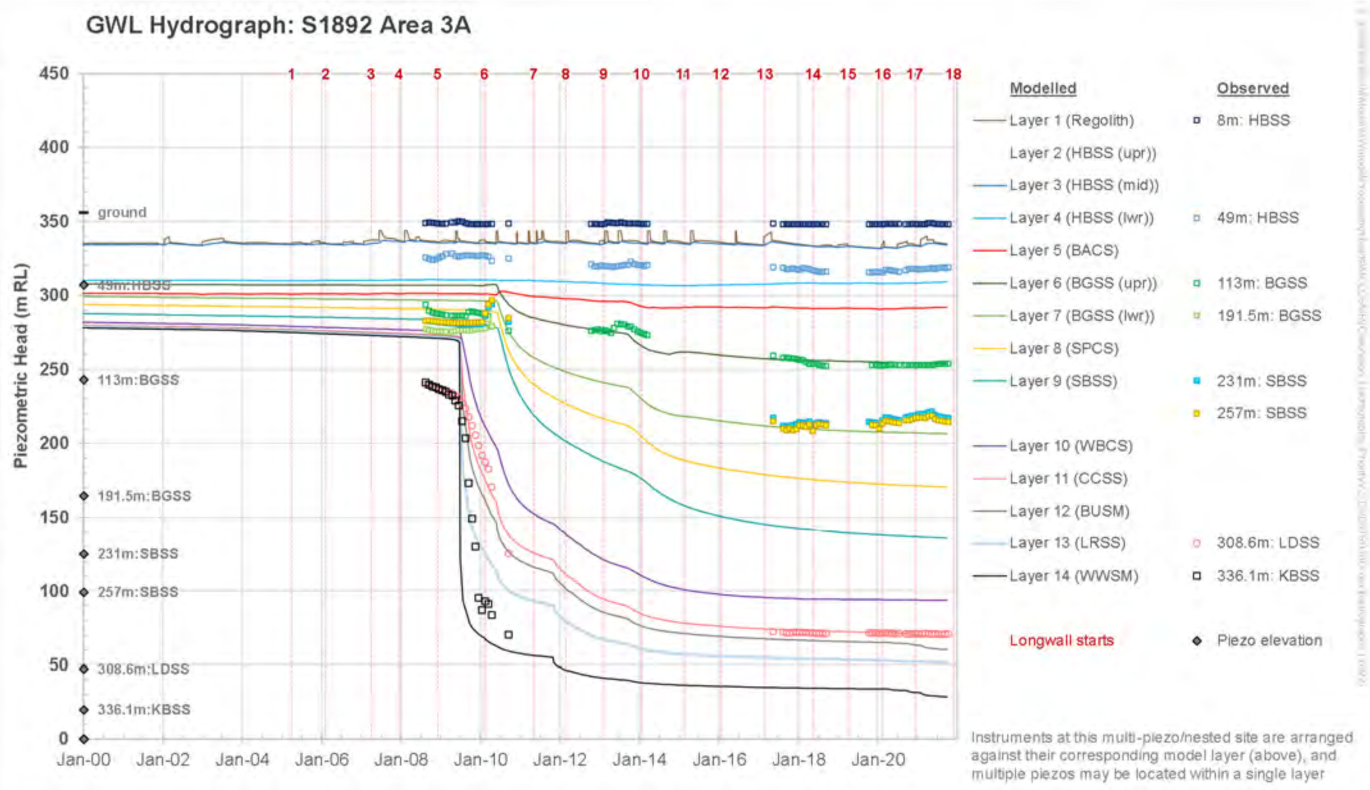


Figure 5-2 Modelled vs observed groundwater level hydrograph – Bore S1892

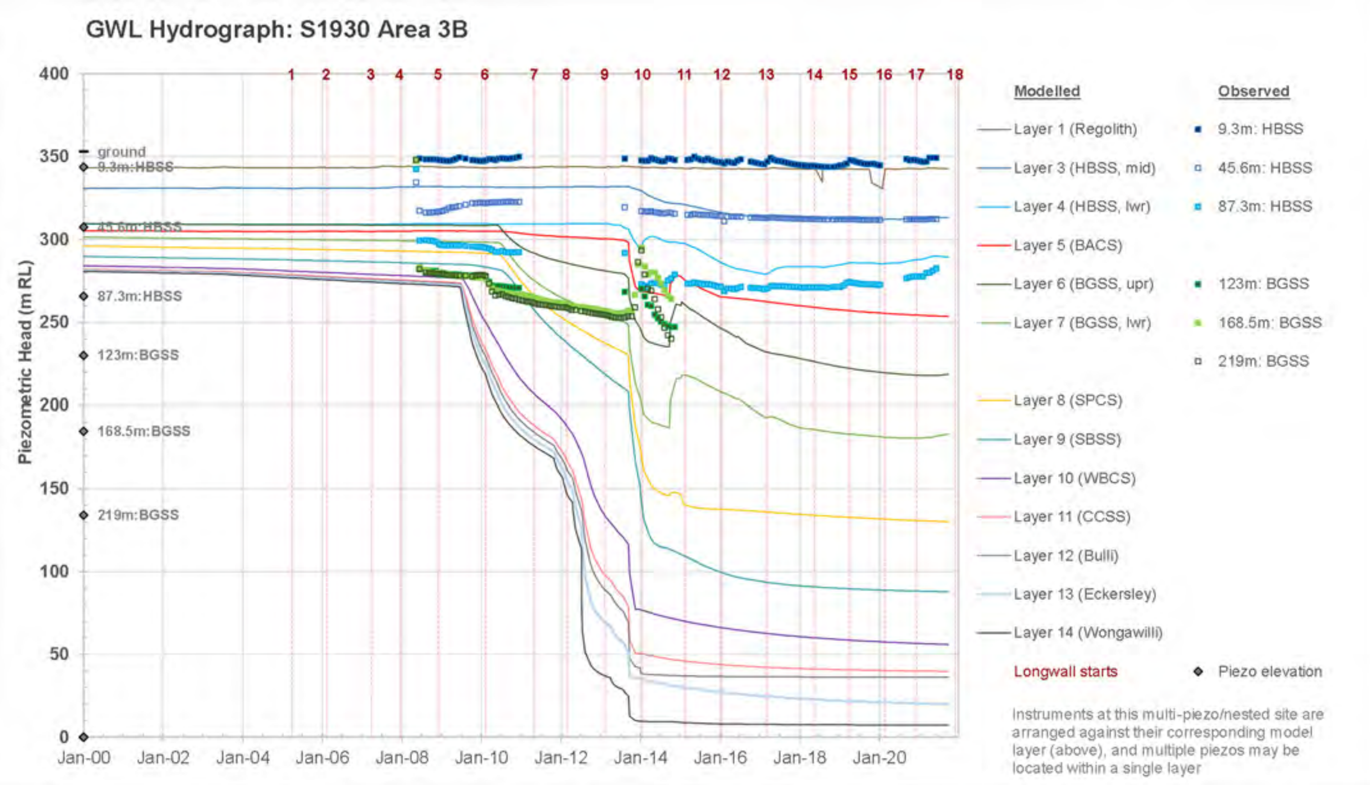


Figure 5-3 Modelled vs observed groundwater level hydrograph – Bores S1930

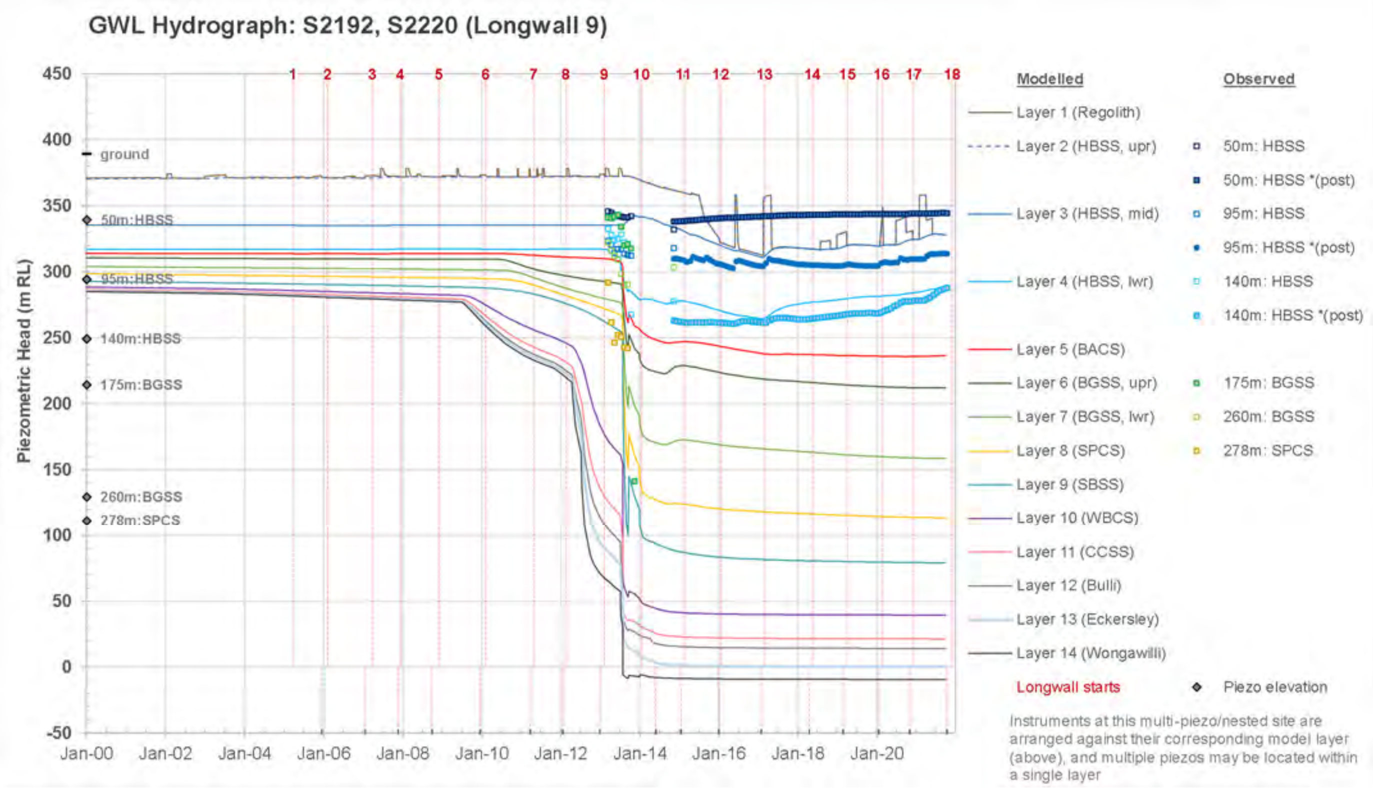


Figure 5-4 Modelled vs observed groundwater level hydrograph – Bore S2192-S2220

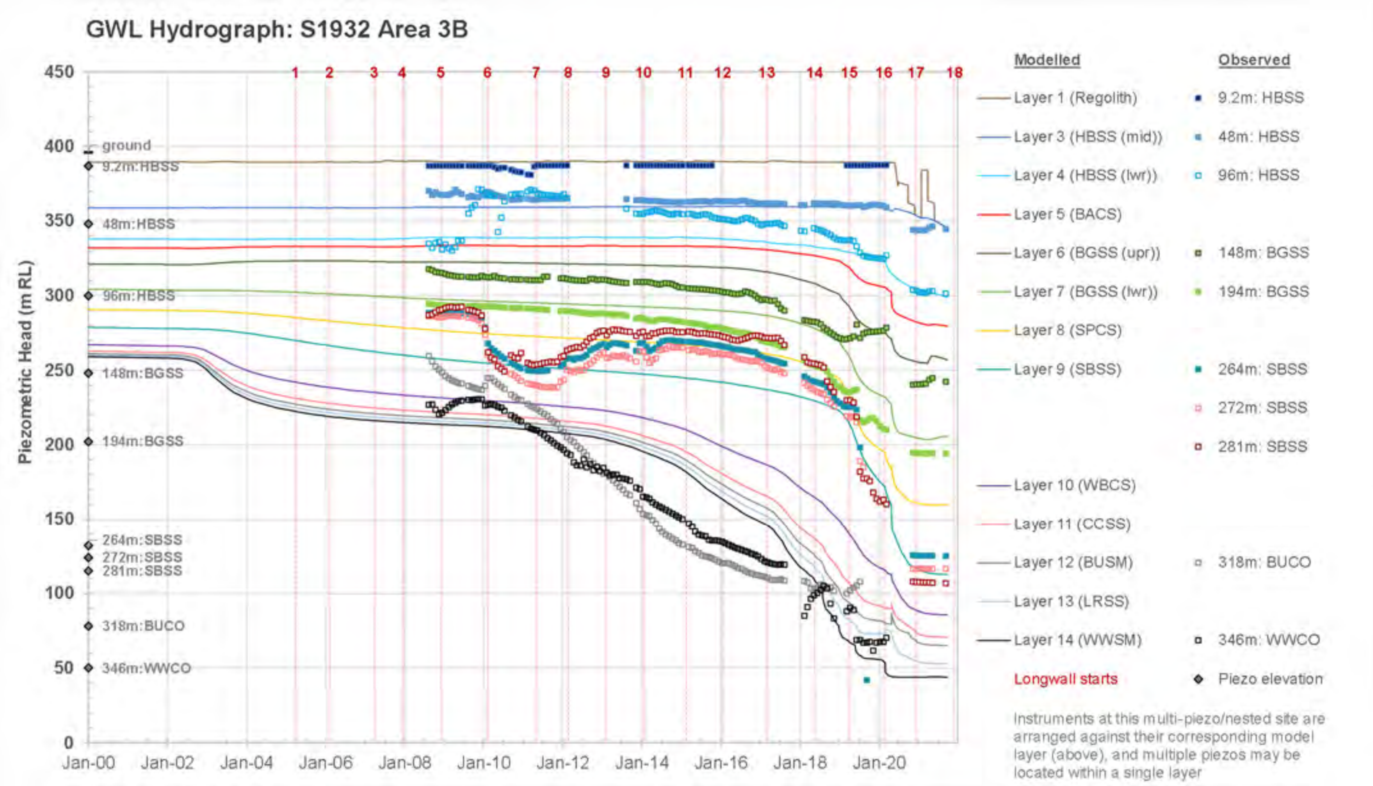


Figure 5-5 Modelled vs observed groundwater level hydrograph – Bores S1932-2521

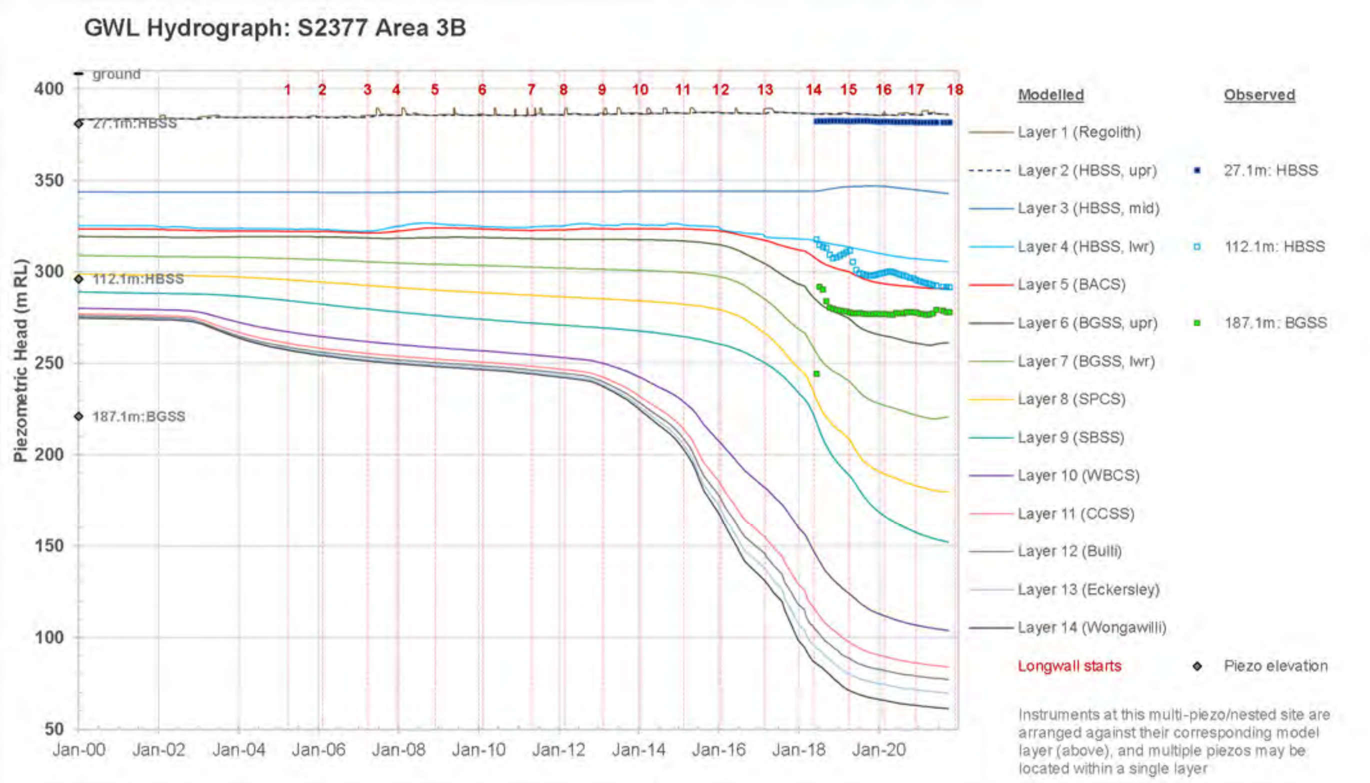


Figure 5-6 Modelled vs observed groundwater level hydrograph – Bore S2377

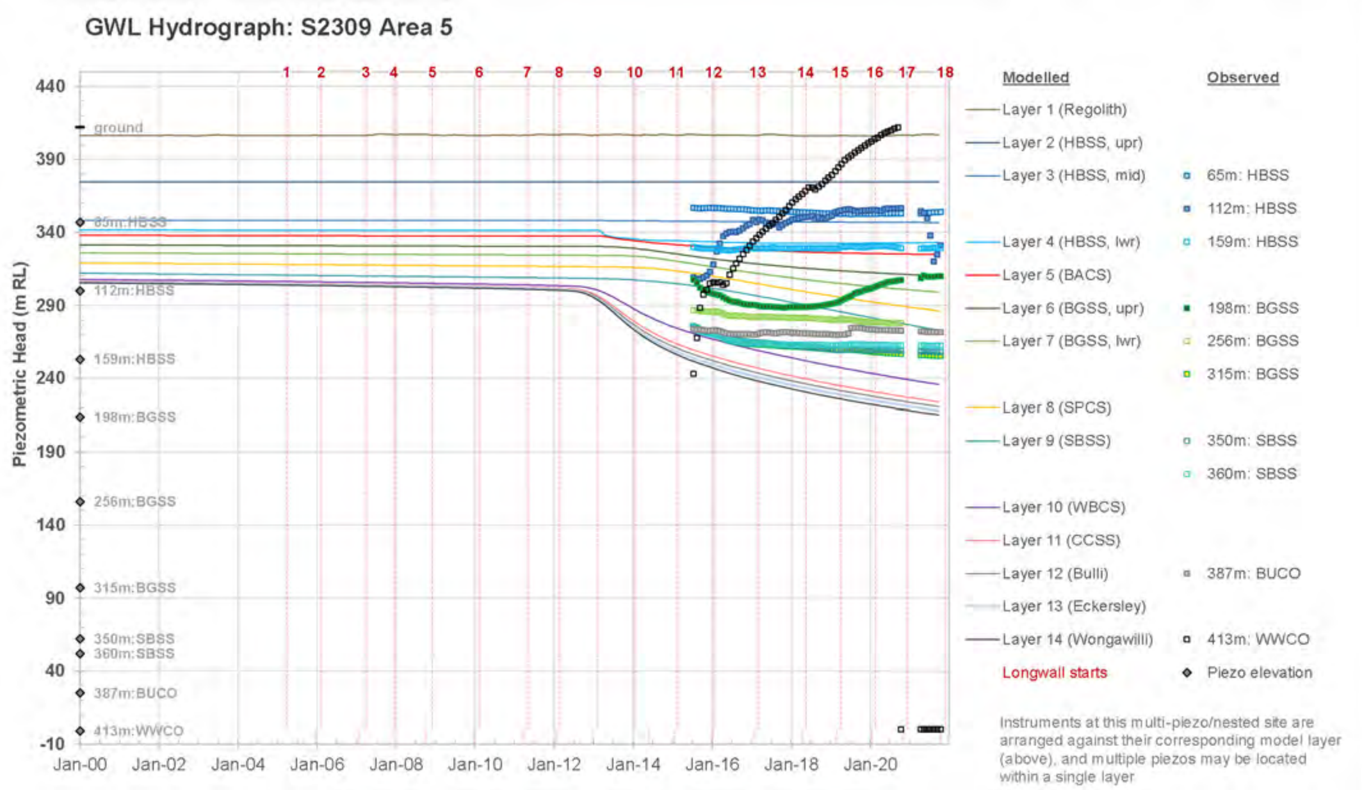


Figure 5-7 Modelled vs observed groundwater level hydrograph – Bores S2309

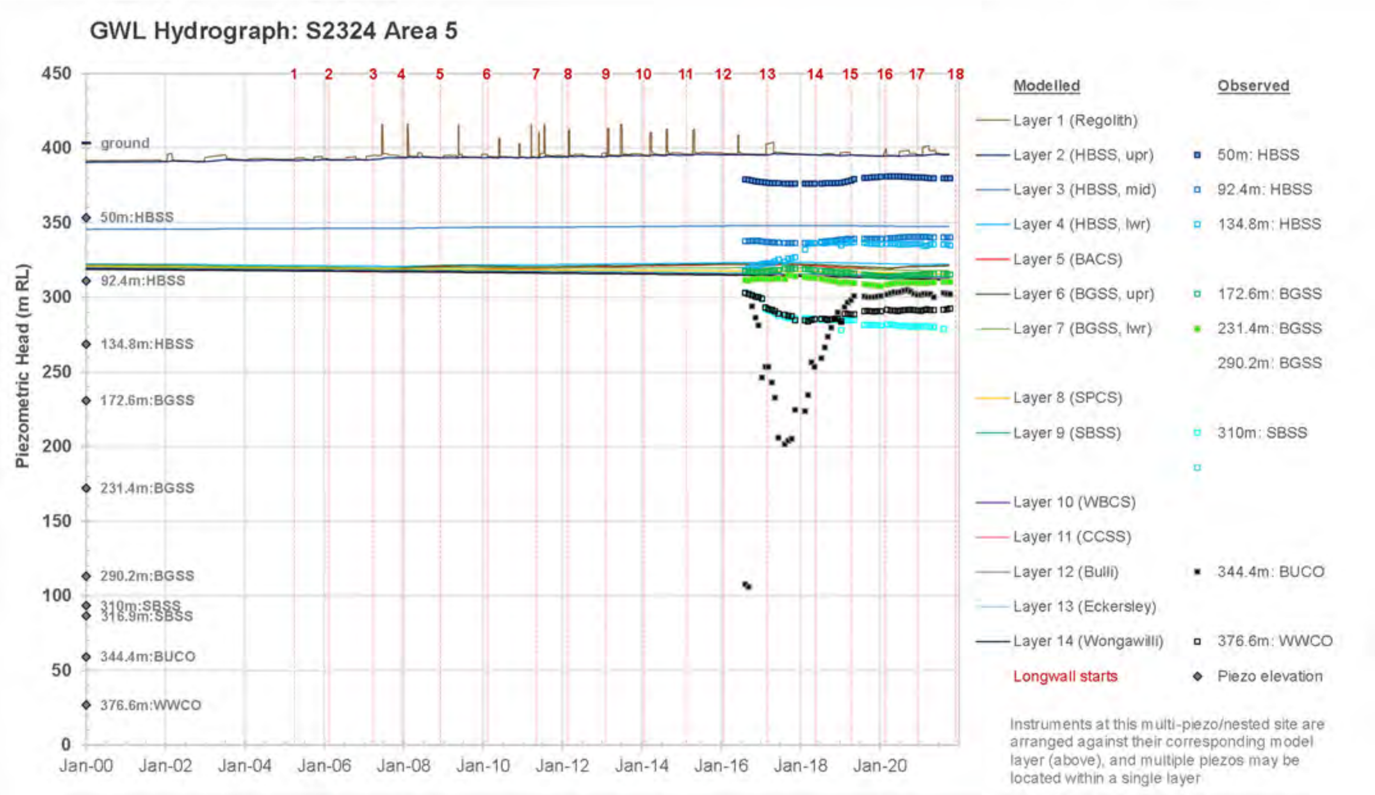


Figure 5-8 Modelled vs observed groundwater level hydrograph – Bore S2324

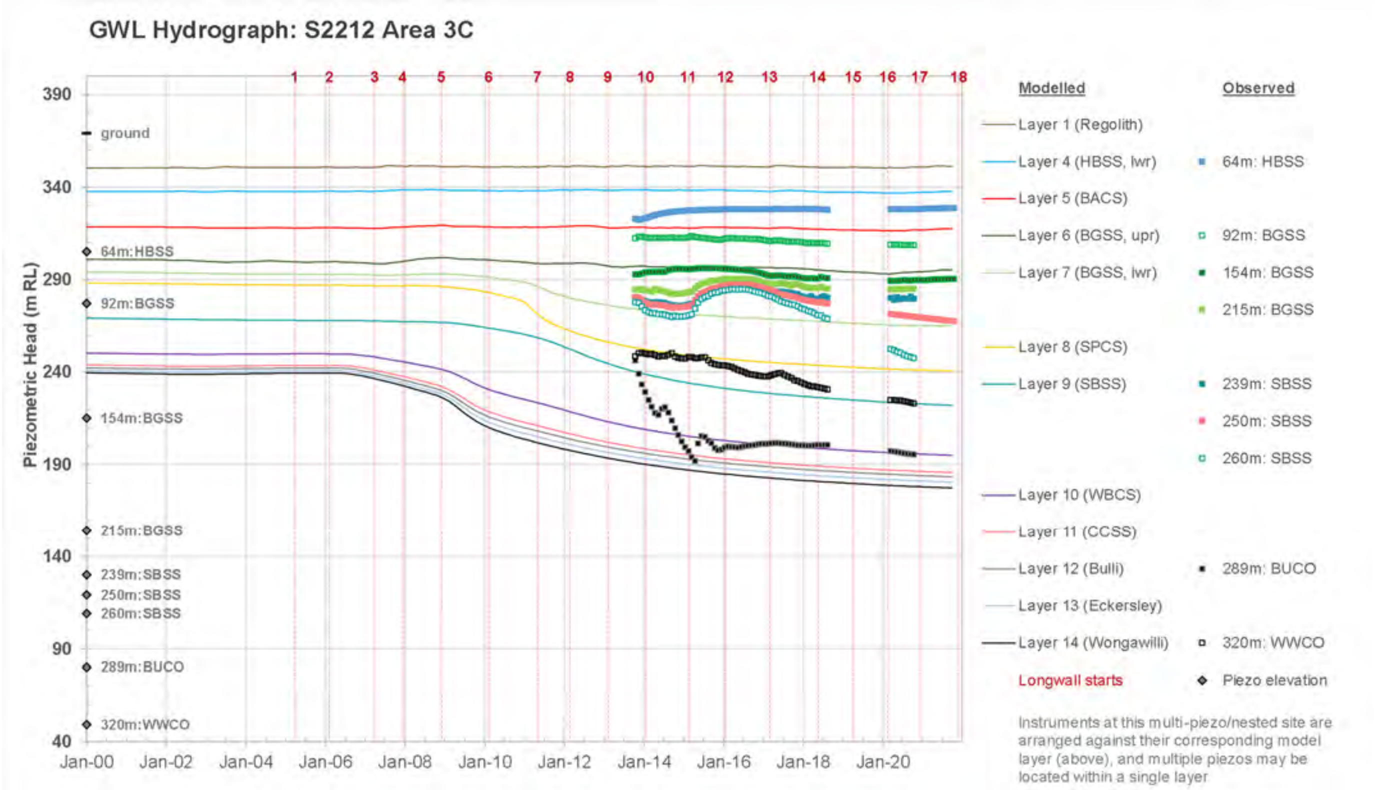


Figure 5-9 Modelled vs observed groundwater level hydrograph – Bore 2212

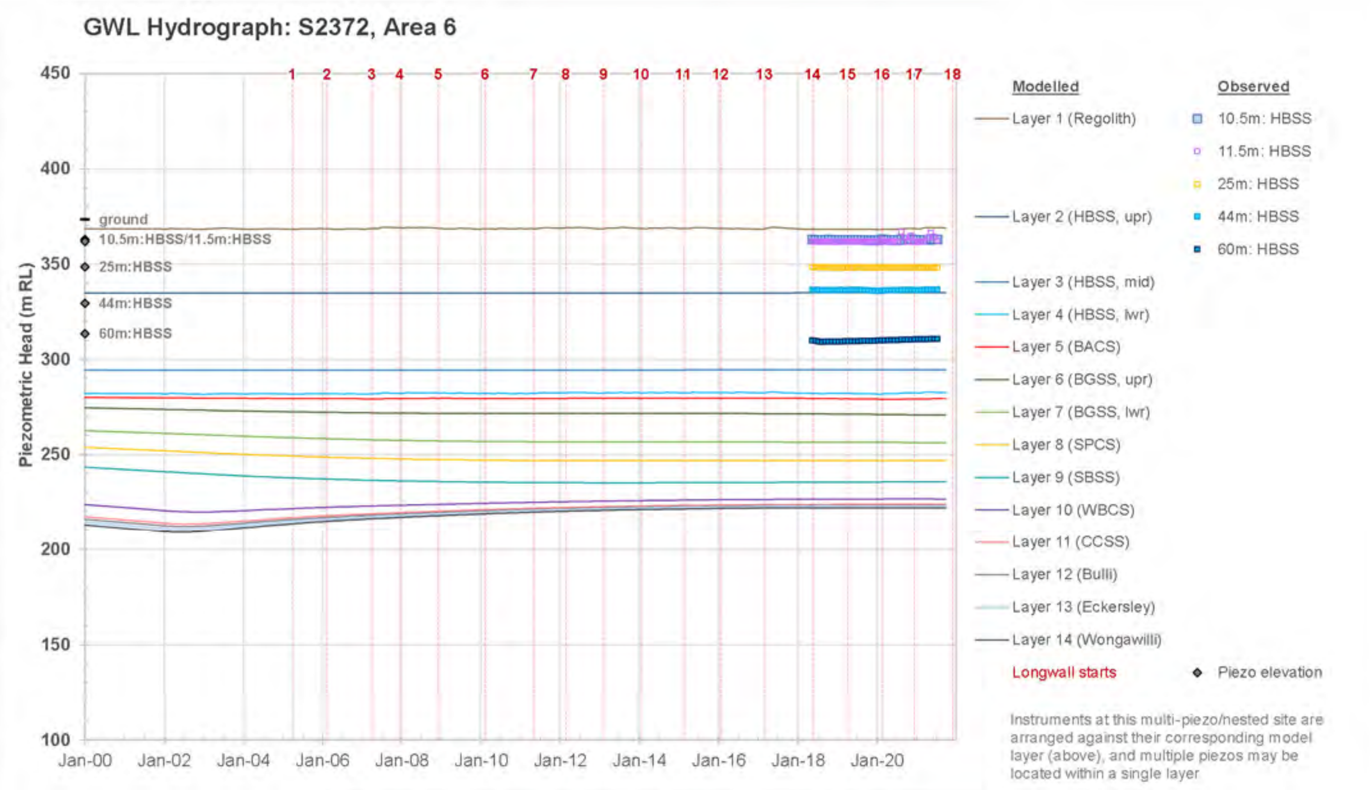


Figure 5-10 Modelled vs observed groundwater level hydrograph – Bore S2372

DPIE-Water monitoring sites

As noted in Section 4.7.1, toward the end of this study, new data was made available from a DPIE-Water coal basin monitoring network, specifically for some sites near to Area 5. Two hydrographs showing these nested (or nearly nested) piezometers are described briefly below.

Groundwater levels for three piezometers (GW099006/GW0409046/GW0409052) near Nepean Dam are shown on Figure 5-11. Modelled groundwater levels are a good match in layer 4 (bore GW099006) and layer 6 (GW049046), but do not match either the early or late time data in the Bald Hill Claystone (layer 5 – bore GW046045).

Groundwater levels for three piezometers (GW099003-5) at Fire Trail 6B to the north of Area 5 are shown on Figure 5-12. At this site, the model is a good match for more recent data from bore GW099003 (layer 9), and a moderate match to recent data from GW099005. The model is a poor match to data from GW099004.

Step changes in the observed data on these figures are likely to be contemporaneous with installation of equipment or sampling, however there is no explanation for the magnitude of some of these step changes (some approximately 100 m). Additionally, some of the data appears suspect, but that is not confirmed, and the data is currently displayed ‘as is’.

Figure 5-11 Modelled vs observed groundwater level at DPIE-W bores – Nepean Dam Rd

Figure 5-12 Modelled vs observed groundwater level at DPIE-W bores – Fire Trail 6B

Groundwater level contour maps

Figures J1/J3/J5/J7/J9 (**Appendix J**) present modelled water levels for five layers in the geological sequence, each at four different times in the model simulation. Of these times, two are within the simulated historical period: 1991 (essentially modelled as “pre-Dendrobium”) and 2021 (present day). The mapping for 2021 for the Hawkesbury Sandstone, Bulgo Sandstone and Bulli seam can be compared to the contouring derived from observed data (Section 2.6.2; Figure 2-13-Figure 2-15). **Appendix J** also presents maps from future periods (Figures J2/J4/J6/J8/J10), as part of the forecasting sections of this study. The figure numbering may appear out of order, however, is set out to allow the reader to review each layer for the two historical periods and then the two future periods on the immediately following figure.

The water level contours for the water table (Figure J1) are tightly bunched, being strongly influenced by local topography, bending around valleys (watercourses, reservoirs). Groundwater levels range from over 500 mAHD on the escarpment and in the highlands to the south-west of the model domain, declining to the north (following the drainage lines) as well as down the escarpment and across the coastal plain (bottom-right of Figure J1) to sea level (0 mAHD) in the south-eastern corner of the model.

The other layers show progressively smoother contouring down through the geological sequence, with reducing influence of topography. In general, the smoother contours in the pre-mining water levels on Figure J3/J5/J7/J9 make it clear that the dominant flow direction is to the north, except around the escarpment, where groundwater discharges toward the southeast.

The lower Hawkesbury Sandstone (layer 4) outcrops or is close to surface in many areas, e.g. along Wongawilli Creek, Cordeaux and Avon Rivers, so it shows the most influence of topography, followed by the Bulgo Sandstone (especially near Dendrobium Areas 1 and 2.

Historical workings in the south (Nebo/Wongawilli) and north-east of Dendrobium (Cordeaux/Corrimal Collieries) are visible due to their effects on the Wongawilli seam and Bulli seam contour mapping.

Modelled groundwater levels for 2021 are broadly similar to the earlier levels, but show the development of mining at Dendrobium and Elouera Colliery (to the south of Dendrobium), where longwall mining has disturbed the groundwater system. This includes perturbations or bulls-eyes in the contouring that are visible in all layers (e.g. in the water table above Areas 1 and 2 and Longwalls 9-11 in Area 3B, and over Elouera, as well as in the Hawkesbury Sandstone and Bulgo Sandstone in many areas. We note that that the hydrographs presented earlier can be better for the purpose of visualising mining effects given the scale of the contours.

5.3.2 Mine inflow

Mine inflow or dewatering rates represent one of the key history-matching targets, given that inflow is a function of the hydraulic properties and height of the zone of connected fracturing above the longwalls, as well as of the adjacent (unfractured) strata.

Figure 5-13 and Figure 5-14 display the model calibration of groundwater inflow to the Dendrobium Mine workings, as calculated by IMC’s site water balance (Section 2.6.5). The groundwater model results have been calculated considering time-weighted averages (Mackie, 2013) with reference to model output periods (Section 4.3.3).

Modelled total mine inflow (Figure 5-13) is a reasonable match to observed inflow. While it is generally higher than the observed data, especially during Areas 1 and 2 (as noted below), The annual totals and general behaviour are simulated to an appropriate degree.

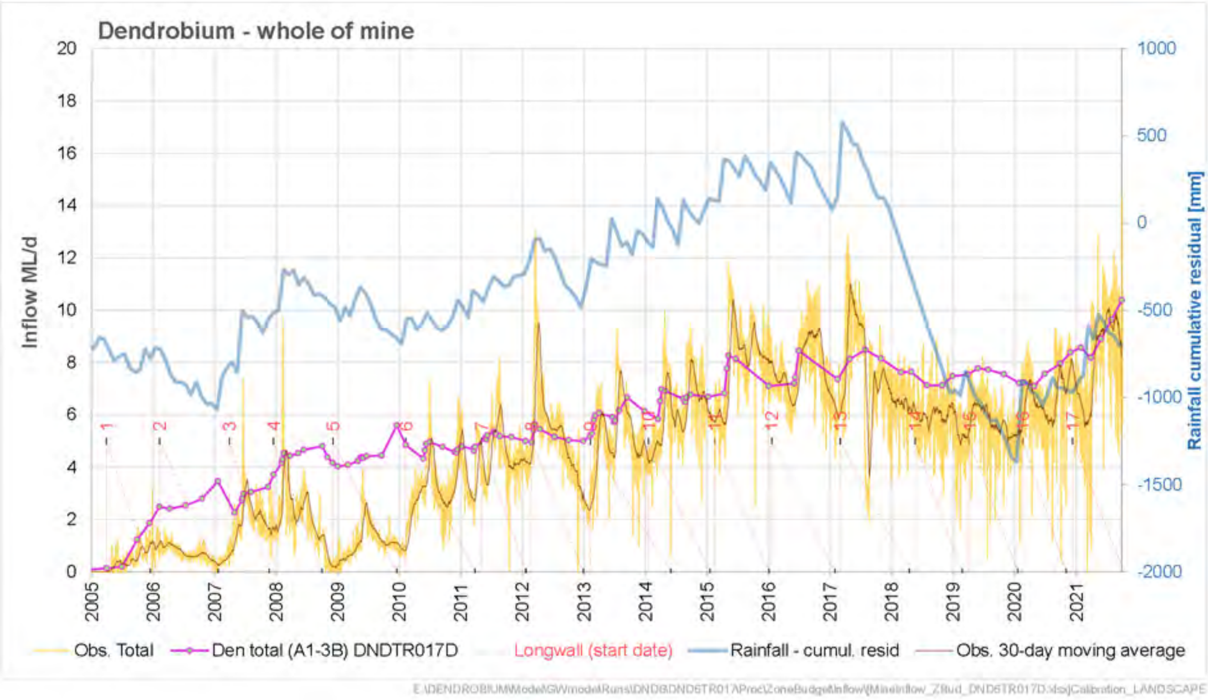


Figure 5-13 Comparison of modelled and observed mine inflow (whole mine)

Noting that Areas 3A and 3B are most similar, in terms of depth of cover and stratigraphic sequence to the Project (Area 5), the following points are made for each area (Figure 5-14):

- Area 1: modelled inflows are over-estimated during through the mining period (2005-2007), and then decline to more realistic rates, although still high compared to the rates for much of the period. This is considered appropriate for considering long-term (post-mining) behaviour.
- Area 2: modelled inflows are well matched during Longwall 3 (2007) and then over-estimated during through the mining period (2008-2010). Following that, the average inflow is well matched, however the model is not simulated the variability, including the peaks following high rainfall events, and then decline to more realistic rates, although still high compared to the rates for much of the period. This is considered appropriate for considering long-term (post-mining) behaviour.
- Area 3A: modelled inflows are well matched during Longwalls 6 and 7 (2010-2012) and then slightly underestimates for the years 2013-2015 following cessation of mining in this area. Following that, the average inflow is well matched.
- Area 3B: modelled inflows are well matched during Longwalls 9 and 17 (2013-2021). This modelling represents the best match to Area 3B inflow compared to previous modelling for Dendrobium, including the rise in inflow to 2017, subsequent plateau (even slight decline) to late 2020, and recent rise (2021).

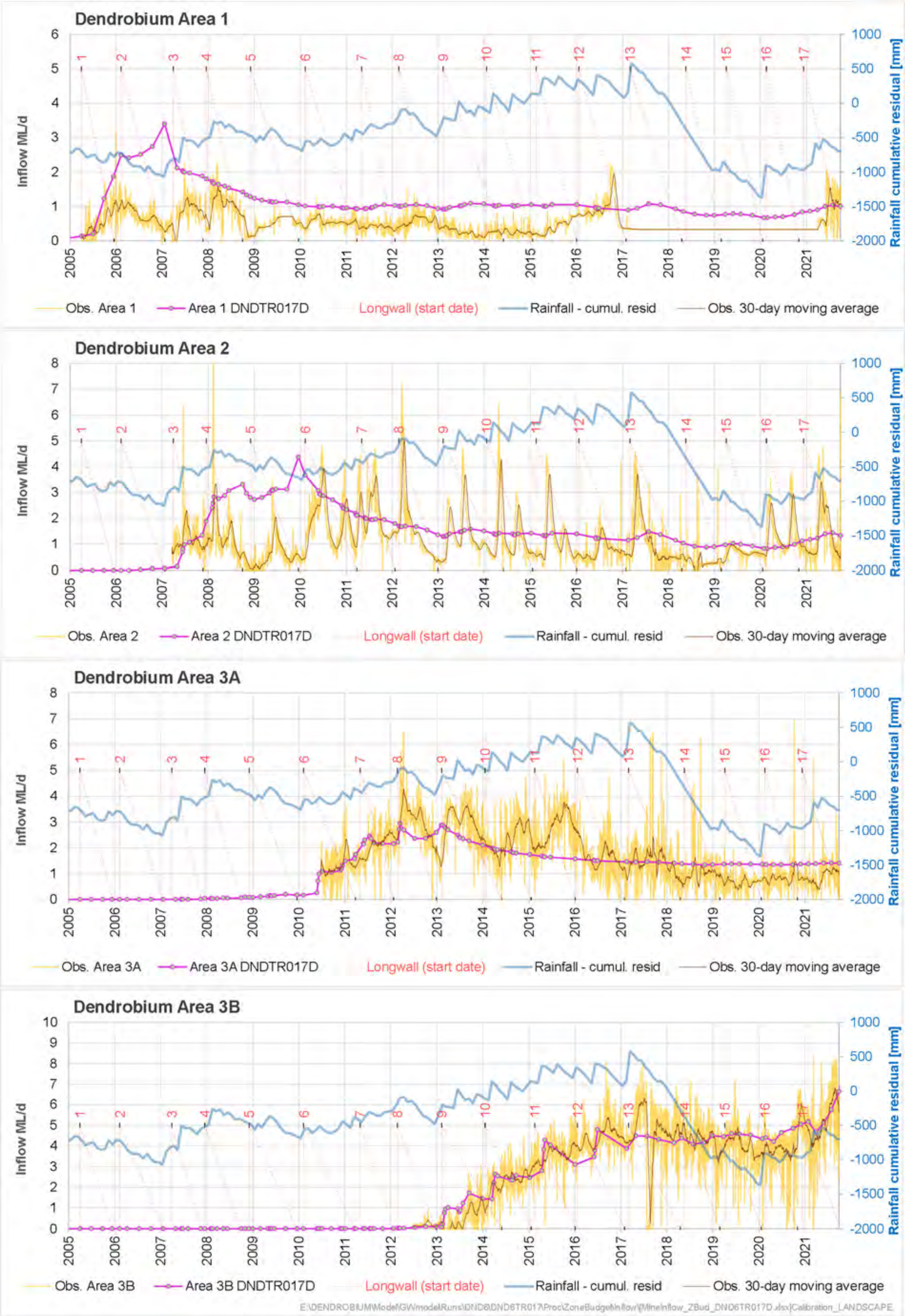


Figure 5-14 Comparison of modelled and observed mine inflow (by mine area)

5.3.3 Surface water flow

Previous modelling at Dendrobium has typically relied on the MODFLOW River package to simulate exchange between groundwater and surface water (baseflow and leakage), with no capability to represent transmission of flow (and flow losses) along a watercourse. The SFR package allows this (Section 4.4.3).

The simulation of the absolute magnitude of flow is not the primary objective of this component of the model, however the ability of the model to simulate flow to a reasonable degree should give confidence that the subsequent simulation of changes in surface water flow are realistic. To assess this, Figure 5-15 displays four hydrographs comparing modelled and observed flow at sites DC13S1, WC21, WWL and AR19. The hydrographs also display the modelled 'natural' or 'no mining' scenario (Section 6.1), used in the calibration of mining-related flow losses (Section 5.3.4).

These sites are selected because DC13 and WC21 are sub-catchments were the effects of historical mining in Area 3B are clear. WWL is the main site downstream of Areas 3A and 3B. AR19 is one the larger sub-catchments in Area 5, and not yet mined under.

As noted above, here is no attempt to made to exactly match the magnitude of flow, where the observed flow displayed is daily average flow, compared to the flow simulated by model time-step (ranging from 0.1 to 120 days). The hydrographs show that the AWRA-L runoff, combined with the groundwater-surface water interaction simulated by the model simulates the hydrographs to a reasonable degree.

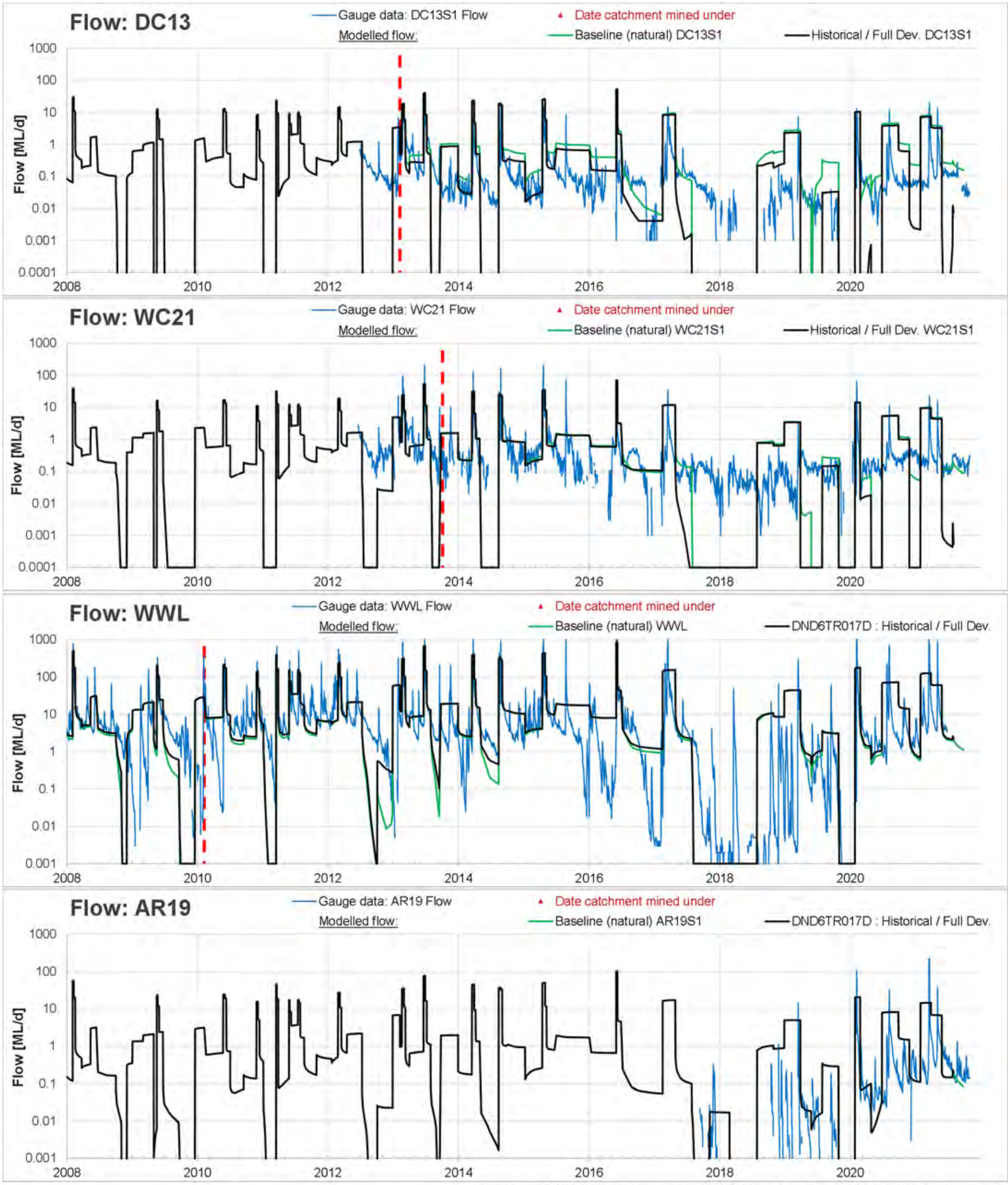


Figure 5-15 Comparison of modelled and observed stream flow (selected sites)

5.3.4 Surface water losses

The charts in the previous section show that the model is capable of simulating appropriate magnitude of surface water flow along the watercourses above the mine. However the forecast of primary interest in this area is the potential reduction in surface water flow in WaterNSW's Special Area.

As noted in Section 2.4.4, regular compliance reporting (End of Panel reports) document the estimated change in flow, specifically the mining-related change to cease- to-flow frequency and the change in median flow at the surface water gauging sites in Areas 3A and 3B (and in Area 3C and potentially Area 5, in future). The methods for this analysis are documented, and are independent of groundwater modelling conducted at Dendrobium (Watershed HydroGeo, 2019).

By comparing the modelled historical scenario and a 'natural' (no-mining) scenario during the calibration process, the ability of the model to estimate flow losses can be assessed. A summary of the modelled changes to surface water flow compared to the results in the latest End of Panel report (HGEO, 2022a) is presented on Figure 5-16. This shows that, with the exception of the Donalds Castle Creek sites (DC13S1, DCS2 and the downstream site DCU), the model is good at replicating the observed losses, and tends to slightly over-estimate the losses.

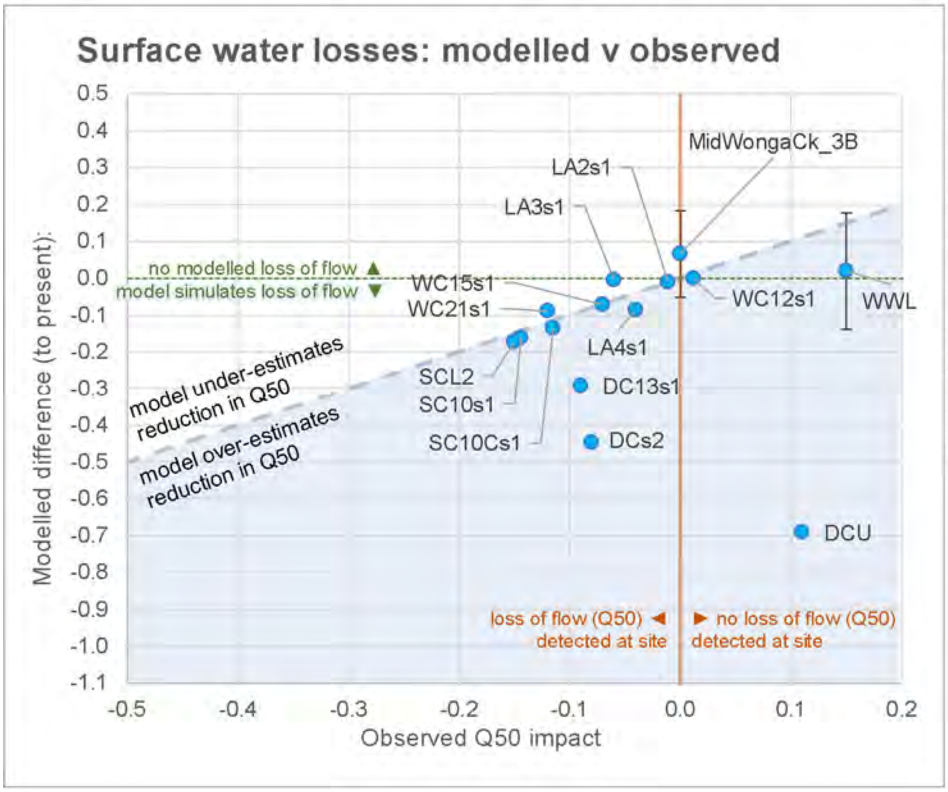


Figure 5-16 Summary of modelled surface water effects

On the whole, considering all the sites where the field-based estimates of loss are made, the comparison below shows that the model provides realistic, yet slightly conservative estimates.

Sites	Total observed loss (ML/d)	Total modelled loss (ML/d)	% difference
All sites (Area 3A and 3B)	-0.88	-1.46	66%
All sites except Donalds Castle sites	-0.71	-0.72	1%

There is only one site where the model significantly under-estimates historical losses (LA3S1), for which the field-based estimates of loss are less reliable due to a much shorter baseline periods than for the other sites, and also possibly in the middle reach of the Wongawilli where a reliably quantified loss cannot be made (no suitable site for a gauging station). At WC21, the simulated losses are a reasonable approximation, albeit are 25% lower (0.03 ML/d) than observed. At all other sites, the model is a good match or over-estimates the losses determined from field data.

5.3.5 Summary of model performance

The comparison of model results with multiple types of observations (groundwater levels including longwall mining stresses, mine inflow flux and stream flow losses) in the preceding section provides confidence that the model is suitable for use in predictive analysis.

As noted in **Appendix K**, the model is capable of simulating the key fluxes (mine inflow, stream flow effects) and the effects on groundwater pressures adjacent to longwalls that are required to assess the impacts of the Project. The main process that is 'uncalibrated' is induced flux from the reservoir, for which observations are not possible.

6. Forecasting of effects

This section presents results from the calibration or 'base case' model, which is the calibrated model presented in Sections 4 and 5. The results presented here include estimates of mine inflow to Area 5, and resultant drawdown, reduction in stream flow and induced reservoir losses.

6.1 Forecasting scenarios

To assess the effects of the proposed Area 5 several predictive scenarios are used to represent different stages of mine development at Dendrobium, and these are summarised in Table 6-1. Comparison of the outputs of these runs allows quantification of the effect or impact of the development(s), and assessment of project-specific and cumulative impacts.

Table 6-1 Summary of development scenarios

Scenario	Run	Name	Dendrobium			Other Mines	Comment
			A1-3B	A3C	Area 5		
D	6TR017D	Full development	Yes	Yes	Yes	All	Refer to Section 1.6 for a list of other mines.
C	6TR017C	Baseline – Approved	Yes	Yes	N	All	Comparison against D gives effects of the Project (Area 5).
B	6TR017B	Baseline – Other Mines	No	N	N	All	Comparison against D gives effects of Dendrobium (all areas).
A	6TR017A	Baseline – Natural ('Null')	No	N	N	None	'Null run' as per Barnett et al, 2012. Comparison against D gives cumulative impacts.

Each predictive run simulates the period to the year 2200, which is detailed in **Appendix E**, with a sequence of climatic inputs (recharge, evapotranspiration) based on historical average conditions.

6.1.1 Mine schedules

The mine plan for Area 5 and the schedule are presented in Table 1-6 (along with future workings in Area 3C) and **Appendix E**. The schedule for the other longwalls is presented in Table 1-5.

6.1.2 Mine closure

In both scenarios C and D, Dendrobium Mine is simulated as being closed in 2039. Although not realistic in the case without Area 5, the use of a common date facilitates comparison of the two scenarios.

Closure is simulated via the cessation of mine dewatering (i.e. MODFLOW Drains inactivated – with the exception of the Drain representing the portals located at the escarpment), and simulating the installation of bulkheads across the mains (roadways) between Area 1 and Area 2 (closer to Area 1), as outlined in SLR (2022).

Given the size of the bulkheads in relation to model cells, the modelling assumes that the overall effect is to modify the permeability of the cell from that of an open roadway (modelled Kh = 5E+4 m/d) to that of the surrounding and intact coal seam (Kh = 2E-2 m/d).

6.2 Uncertainty analysis

Given the constraints of model run-times (especially including both historical and predictive model periods), in combination with the long history of mining and record of flux and level data, a deterministic scenario analysis has been selected as the most practical approach for uncertainty analysis. This approach is described in relevant IESC guidelines as *"scenario analysis with subjective probability assessment"*, and focusses on the predictions of interest while being guided by the uncertainties identified (Section 4.2.2) and our experience with parameter sensitivity in this model.

The suite of deterministic uncertainty scenarios selected are summarised in Table 6-2.

Table 6-2 Summary of uncertainty scenarios

Run	Name	Description
DND6TR018	Hydraulic conductivity realisation #2	Kh and Kv parameterised randomly in each cell, as per statistical population of permeability data in **Appendix C**. Model parameterisation summarised in **Appendix L**.
DND6TR019	Hydraulic conductivity realisation #3	Kh and Kv parameterised randomly in each cell, as per statistical population of permeability data in **Appendix C**. Model parameterisation summarised in **Appendix L**. This modified slightly to broadly increase Kh.
DND6TR021	Off-goaf #1	See Section 3.2.2. Kh increased by distance, with increments of 100m (Kh x 4), 200 (Kh x 3) and 600 m (Kh x 2) from adjacent longwall. This applied to cells in the upper 3 layers of the model in relevant valleys, e.g. typically lower and mid-HBSS and BACS adjacent to Avon Reservoir.
DND6TR022	Off-goaf #2	Kh increased by distance, with increments of 100m (Kh x 4), 200 (Kh x 3) and 600 m (Kh x 2) with a minimum Kh of a constant value of 3E-2 m/d for all cells within 600 m of the nearest longwall. This applied to cells/layers as per previous.
DND6TR023	Off-goaf #3	Kh increased to a constant value of 2.5E-1 m/d for all cells within 600 m of the nearest longwall. This applied to cells/layers as per previous. Based on the investigations at Area 3B to date, this is considered to be a 'worst case' scenario for off-goaf deformation.
DND6TR024	Surface cracking #1	Increased K in surface cracking zone: Kh to 0.5 m/d (x 5 base case), Kv to 0.42 (x 3 base case).
DND6TR025	Caved zone #1	Increased Kh and Kv within modelled caved zone: Kh and Kv both increased by order of 0.5 magnitude from base case.

6.3 Climate change

Climate change is predicted to affect rainfall and other climatic variables, of which rainfall has the most significant effect on recharge to groundwater. Two sources of projected changes in rainfall have been reviewed:

- NARCliM (NSW / ACT Regional Climate Modelling) for the 'Illawarra, Metropolitan Sydney and South East and Tablelands' area.
- Climate Change in Australia Technical Report ['CciA'] produced by the CSIRO and BoM covering Australia's NRM regions, including the 'Eastern Australia' region.

Table 6-3 presents the median projection for change in rainfall from these sources for 2030 and longer-term projections for 2070 and 2090.

Rainfall projections are somewhat similar, at least on an annual basis, for 2030, but quite variable for the 2070-2090 forecast (Table 6-3). NARCliM projections generally suggest a wetter climate for 2070, while 'CciA' projections suggest a drier climate, but the range in the annual NARClim projections in included to highlight the range (with the models predicting both drier and wetter).

Table 6-3 Climate Change Projections – Percentage Change in Rainfall

Period	2030				2070			2090	
	NARCliM			'CciA' RCP 4.5	NARCliM			'CciA' RCP 4.5	'CciA' RCP 8.5
	Illawarra	Metropolitan Sydney	South East and Table-lands		Illawarra	Metropolitan Sydney	South East Tablelands		
Summer	+1.5	-0.2	+0.8	-2.0	+10.9	+12.3	+8.8	-2.0	4.0
Autumn	+5.6	+9.7	+6.5	-4.0	+15.1	+13.6	+11.0	-7.0	-8.0
Winter	-4.9	+0.0	-2.6	-3.0	-6.6	-0.1	-4.1	-10.0	-16.0
Spring	-1.5	-2.6	-7.5	-2.0	-1.3	+3.1	-11.2	-10.0	-16.0
Annual	**-0.4**	**-1.7**	**-1.8**	**-1**	**+6.5**	**+8.9**	**+1.4**	**-7.0**	**-10.0**
Annual range	-12 to +12	-13 to +18			-9 to +30	-9 to +24			

https://climatechange.environment.nsw.gov.au/Climate-projections-for-NSW/Interactive-map

Based on experience in rainfall-runoff-recharge modelling (including for consideration of climate change projections for water resource assessments in other settings) and literature, a general rule is that broad changes in rainfall (e.g. rainfall increased by 3%) are typically magnified 2-4 times when converted to rainfall recharge (e.g. recharge then increased by 6-12%) ('rainfall elasticity in recharge'), as has been described as occurring for historical climate variability (Barron et al., 2012). Using this concept, the tabulated changes in rainfall are predicted to result in changes in rainfall recharge similar to:

- NARCliM 'recharge scenario': -1.2%, -5.1% and -5.4% in 2030, increasing to +19.5%, +26.7% and +4.2% in 2070 (for the Illawarra, Metropolitan Sydney and South East and Tablelands areas).
- CciA 'recharge scenario': -3% in 2030, falling to -25.5% in 2090. Note that the CciA 'recharge scenario' uses the mean from the RCP4.5 and RCP8.5 projected change in rainfall for 2090 (Table 6-3).

The effect of the predicted climate change has not been specifically assessed for the Project groundwater inflow as the average change in inflow over the remaining life of the Dendrobium Mine is likely to be minor, given that there is only a small change in average rainfall by 2030 based on the NARCliM and CciA projections (Table 6-3). In the short-term, climate variability, rather than climate change, will govern whether rainfall is similar to the long-term average or not. During the post-mining period (i.e. relying on the 2070 and 2090 predictions) from NARCliM and CciA differ in their prediction with respect to the likely changes in rainfall. If rainfall were to increase, this would result in quicker recovery, while conversely if rainfall were to decrease this would result in slower recovery.

6.4 Simulated water balance

Modelled water balances are useful for understanding how a change in one or more water balance components (a stress or stresses) can affect others. In previous reporting, we have provided regional water balances for the whole of the model domain. This is done again here (Section 6.4.1), as well as for two 'Study Areas' focussing on the proposed Area 5 mining domain (Section 6.4.2). These latter two water balances focussed on the area of specific interest are provided in response to comments made by IAPUM.

6.4.1 Regional (whole-of-model) water balance

Table 6-4 presents the model water balance for mine development scenarios A, C and D, along with the calculated difference in the water balance (right-hand columns) to show the incremental change due to the Project, as well as the cumulative mining effect.

The cumulative mining effects are primarily the dewatering and subsidence and drawdown effects associated with future longwall mining at Dendrobium, Tahmoor, the modelled areas of Appin Mine, and continued dewatering in existing workings at those sites. This dewatering results in changes to all parts of the regional water balance, significantly causing increased leakage from watercourses to groundwater, reduced baseflow to watercourses, reduced evapotranspiration, and changes to groundwater storage.

Table 6-4 Modelled water balance: whole model domain – 2025-2040

Modelled component	Catchment process	Null/Natural		Dendrobium, no Project		Full development		Change in water balance: Project effect			Change in water balance: Cumulative mining effect		
		Scenario A		Scenario C		Scenario D		=Scenario D - Scenario C			=Scenario D - Scenario A		
		In	Out	In	Out	In	Out	delta IN	delta OUT	Net	delta IN	delta OUT	Net
Storage	Groundwater storage	177.41 (decline in GWL)	196.45 (rise in GWL)	182.42	212.00	184.39	212.10	1.97	0.10	1.88	6.98	15.65	-8.67
Constant Head	Sea/ocean	0.00	0.04	0.00	0.04	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Drains	Mine inflow/ dewatering	0.00	0.00	0.00	16.72	0.00	20.88	0.00	4.16	-4.16	0.00	20.88	-20.88
River Leakage	Groundwater exchange w/ Reservoirs	0.74	3.48	0.86	4.01	0.88	3.97	0.03	-0.04	0.07	0.14	0.50	-0.36
Evapotrans -piration	Evapo-transpiration from GW	0.00	245.53	0.00	236.33	0.00	235.25	0.00	-1.08	1.08	0.00	-10.28	10.28
Head Dep Bounds	Regional groundwater flow	0.05	1.25	16.21	1.87	16.21	1.87	0.00	0.00	0.00	16.16	0.62	15.53
Recharge	Infiltration recharge	189.79	0.00	189.79	0.00	189.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stream Leakage	GW-SW interaction w/ watercourses	114.32	35.58	119.58	37.90	120.47	37.66	0.90	-0.24	1.13	6.15	2.08	4.07
Total		**482.3**	**482.3**	**508.8**	**508.8**	**511.8**	**511.8**	**2.90**	**2.91**	**-0.01**	**29.43**	**29.45**	**-0.02**

Units are ML/d. E:\DENDROBIUM\Model\Gwmodel\Runs\DND6\DND6TR016\Proc\ZoneBudget\WaterBalance\ZonBud_AreaWaterBalance_DND6TR016D-C-B-A.xlsx

6.4.2 Area 5 'study area'

Within the Subsidence Assessment (MSEC, 2022), two alternative Study Areas are defined. For consistency with that assessment, we have adopted the same areas for the mass balance presented here. The first study area was defined by MSEC using the 'Angle of Draw' (the justification for these Study Areas is provided by MSEC).

Table 6-5 Modelled water balance: Area 5 'angle of draw' study area – 2025-2040

Modelled component	Catchment process	Null/Natural		Dendrobium, no Project		Full development		Change in water balance: Project effect			Change in water balance: Cumulative mining effect		
		Scenario A		Scenario C		Scenario D		=Scenario D - Scenario C			=Scenario D - Scenario A		
		In	Out	In	Out	In	Out	delta IN	delta OUT	Net	delta IN	delta OUT	Net
Storage	Groundwater storage	2.12 (decline in GWL)	2.42 (rise in GWL)	2.14	2.42	9.63	2.59	7.49	0.17	7.32	7.51	0.16	7.34
Constant Head	Sea/ocean	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drains	Mine inflow/ dewatering	0.0	0.0	0.00	0.00	0.00	4.18	0.00	4.18	-4.18	0.00	4.18	-4.18
River Leakage	Groundwater exchange w/ Reservoirs	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Evapotrans-piration	Evapo-transpiration from GW	0.0	2.66	0.00	2.65	0.00	1.38	0.00	-1.28	1.28	0.00	-1.29	1.29
Head Dep Bounds	Regional groundwater flow	0.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Recharge	Infiltration recharge	2.64	0.0	2.64	0.00	2.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stream Leakage	GW-SW interaction w/ watercourses	0.95 (leakage)	0.30 (baseflow)	0.95	0.30	1.81	0.12	0.86	-0.18	1.04	0.86	-0.19	1.05
Interzone Flow	GW flow to adjacent zone	0.56	0.89	0.58	0.94	7.57	13.39	6.99	12.45	-5.46	7.01	12.50	-5.50
Total		**6.28**	**6.28**	**6.31**	**6.31**	**21.65**	**21.65**	**15.34**	**15.34**	**0.00**	**15.37**	**15.37**	**0.00**

Units are ML/d. E:\DENDROBIUM\Model\Gwmodel\Runs\DND6\DND6TR016\Proc\ZoneBudget\WaterBalance\ZonBud_AreaWaterBalance_DND6TR016D-C-B-A.xlsx

Table 6-6 Modelled water balance: Area 5 '600m buffer' study area – 2025-2040

Modelled component	Catchment process	Null/Natural		Dendrobium, no Project		Full development		Change in water balance: Project effect			Change in water balance: Cumulative mining effect		
		Scenario A		Scenario C		Scenario D		=Scenario D - Scenario C			=Scenario D - Scenario A		
		In	Out	In	Out	In	Out	delta IN	delta OUT	Net	delta IN	delta OUT	Net
Storage	Groundwater storage	3.02 (decline in GWL)	3.44 (rise in GWL)	3.04	3.44	10.78	3.57	7.73	0.13	7.60	7.75	0.13	7.63
Constant Head	Sea/ocean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Drains	Mine inflow/ dewatering	0.00	0.00	0.00	0.00	0.00	4.18	0.00	4.18	-4.18	0.00	4.18	-4.18
River Leakage	Groundwater exchange w/ Reservoirs	0.00	0.05	0.00	0.05	0.01	0.03	0.00	-0.02	0.03	0.01	-0.02	0.03
Evapotrans-piration	Evapo-transpiration from GW	0.00	3.82	0.00	3.80	0.00	2.49	0.00	-1.31	1.31	0.00	-1.33	1.33
Head Dep Bounds	Regional groundwater flow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Recharge	Infiltration recharge	3.71	0.00	3.71	0.00	3.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Stream Leakage	GW-SW interaction w/ watercourses	1.38	0.46	1.38	0.46	2.25	0.25	0.87	-0.21	1.08	0.87	-0.21	1.09
Interzone Flow	GW flow to adjacent zone	1.11	1.45	1.17	1.57	8.30	14.54	7.13	12.97	-5.84	7.19	13.08	-5.89
Total		**9.23**	**9.23**	**9.32**	**9.32**	**25.05**	**25.05**	**15.74**	**15.74**	**0.00**	**15.82**	**15.83**	**0.00**

Units are ML/d. E:\DENDROBIUM\Model\Gwmodel\Runs\DND6\DND6TR016\Proc\ZoneBudget\WaterBalance\ZonBud_AreaWaterBalance_DND6TR016D-C-B-A.xlsx

6.5 Predicted mine inflow

Figure 6-1 presents the predicted calibrated model or 'base case' rate of inflow (i.e. ML/d) of groundwater entering different areas of Dendrobium Mine inflow from 2005 until the proposed end of the mine (Area 3C, proposed to be completed in ~2038).

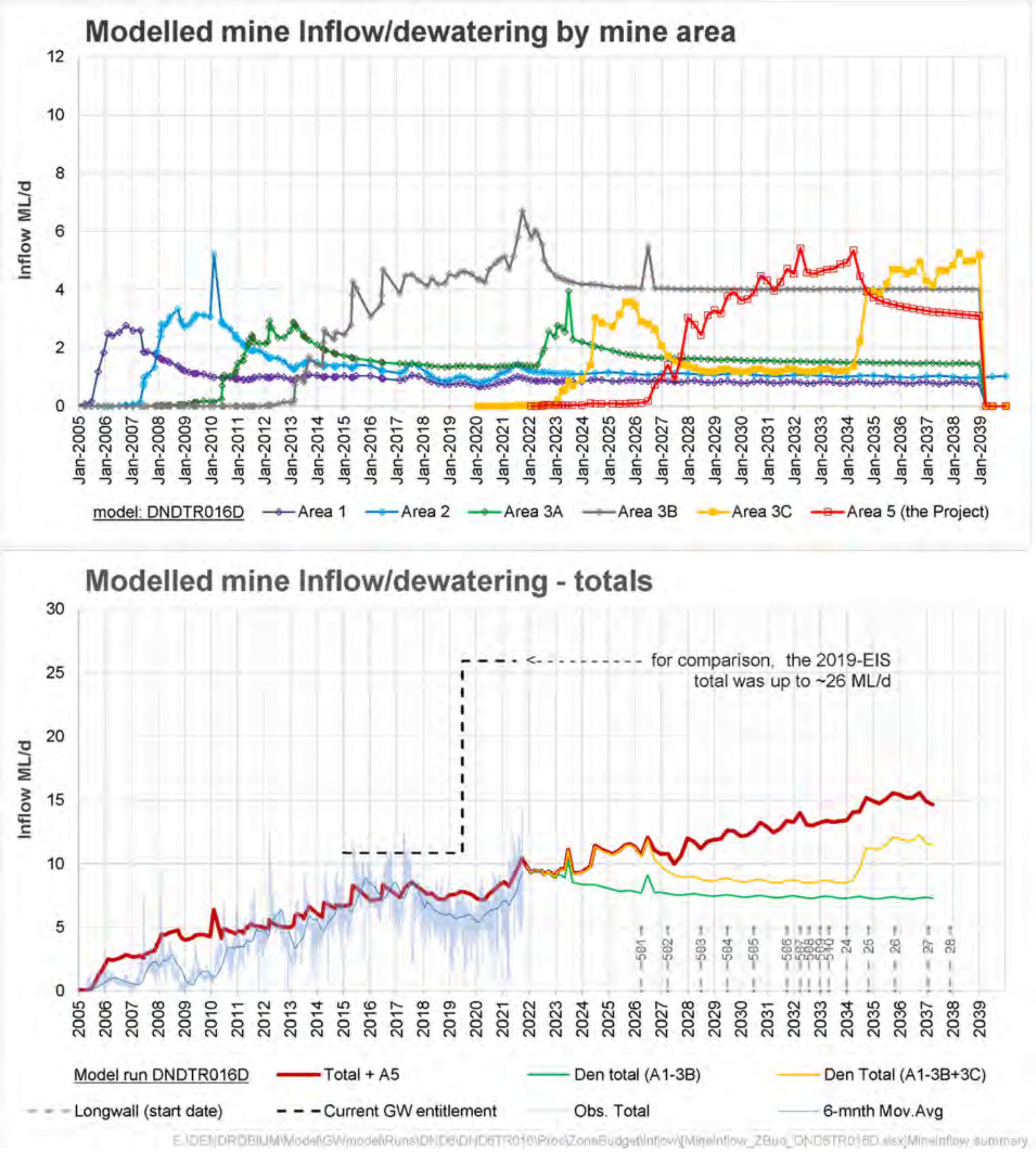


Figure 6-1 Simulated groundwater inflow - detail

The modelling indicates that inflows would rise from the current rate until the end of Area 3B, with a maximum inflow of 6-7 ML/d. Following that, a small peak of 3-4 ML/d would occur in Area 3A (up from 1.5 ML/d) due to the extraction of a single panel, Longwall 19). The first longwalls in Area 3C would cause inflow of 3-4 ML/d to that area by 2026. The second set of longwalls in Area 3C, commencing in

2034, are predicted to result in up to 4-5 ML/d of inflow to that area through to the proposed end of mining in 2038.

A chart of the annualised average inflow to Area 5 and for the whole of the mine is presented in the Figure 6-2. This simpler chart summarises the inflow predicted by the base case model as well as the uncertainty scenarios (error bars defined by the minimum-maximum range from those scenarios).

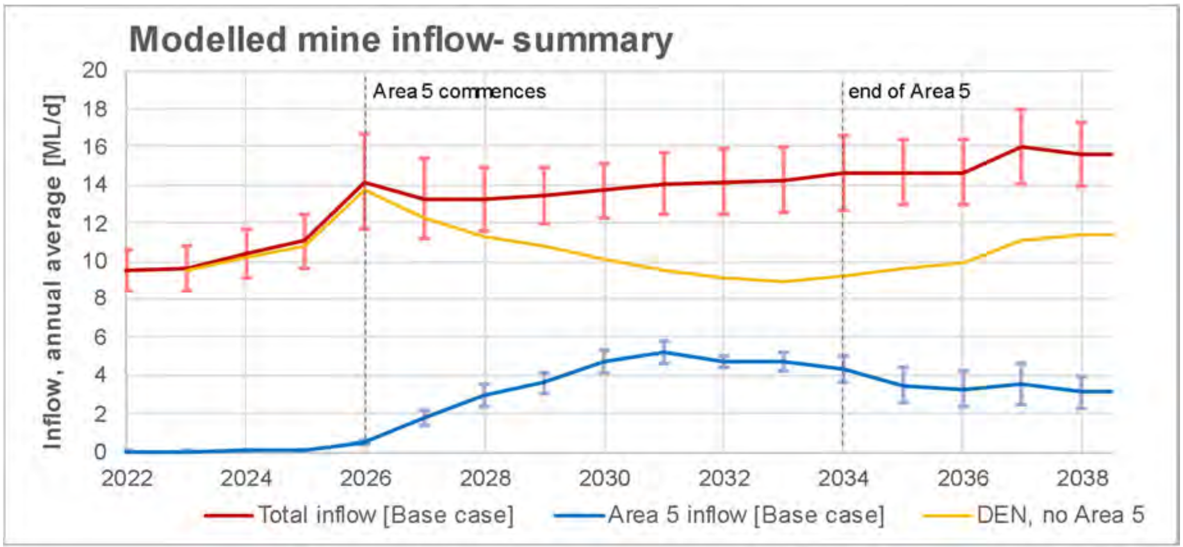


Figure 6-2 Summary of predicted groundwater inflow

Inflow to Area 5 is predicted to rise to a maximum of about 5.5 ML/d in 2032-34, averaging approximately 3.8 ML/d during the proposed extraction period (2026-2034) for that domain.

The forecast for Area 5 is similar to the recent inflow recorded at Tahmoor Mine (averaging 3.6 ML/d for the period 2016-2021), which also extracts from the Bulli seam with recent longwall panels being 283 m width (7% narrower than those proposed for Area 5).

These inflow predictions are considered further in discussion on water 'take' in Section 6.9. Long-term discharge from the Dendrobium Mine is presented in Section 6.10.

6.5.1 Other mines

Predictions of the inflow to the adjacent Kemira (Wongawilli seam) and Nebo workings have been provided to hydrologists for consideration in the mine water balance (HEC, 2022). Based on the current model assumptions associated with those workings, the inflow to these workings is estimated to be approximately 0.05 ML/d (range 0.04-0.07) for Kemira and 1 ML/d (range 0.6-3.2) for Nebo. The estimate for Nebo seems reasonable. Further work to improve the simulation of inflow to Kemira will be undertaken in the near future.

6.6 Groundwater level forecasts

A variety of methods of presenting modelled groundwater levels are provided in the following sections, including groundwater level hydrographs, contour maps of groundwater levels at particular time intervals, as well as contours of the maximum predicted drawdown (at various times) in a selection of model layers.

6.6.1 Groundwater level hydrographs

Hydrographs of modelled groundwater levels in the geological sequence are provided for four representative locations for Area 5. The hydrographs below show groundwater levels over time at two monitoring bore locations (S2309 and S2324 (Figure 6-3) and at two nominal locations near to the proposed mining area (Figure 6-4) – these latter two sites are simply nominal locations used to inspect model groundwater level results. All locations are marked on Figure 2-12, and the two sites that are not actual bore locations are labelled on that map as “GWL reporting site”. These nominal locations are selected as they are topographically downgradient or down-catchment from Area 5 and near to significant features or receptors:

- the first is 600 m north of the western end of Longwall 505, essentially mid-way between Area 5 and Avon River, and
- the second is 800 m northeast from Longwall 510 and adjacent to Donalds Castle Creek.

These figures show the degree of drawdown due to mining and illustrate that the recovery of water levels is predicted to be partial (in many cases), recovery being relatively quick in the upper layers but slower in the lower units (e.g. typically in all the layers below the Bald Hill Claystone [BACS]). The hydrographs and key points associated with each are presented below.

At monitoring bore S2309, which is adjacent to Longwall 501 but within (or above) the roadways that would be developed early in the life of Area 5 (Figure 6-3):

- The model suggests that drawdown from Area 3B longwalls has already commenced at this site.
- Groundwater pressures in the Bulli and Wongawilli seams are predicted to drawdown around 300 m as a result of the dewatering and subsequent extraction of Area 5 longwalls. Progressive increase in drawdown is predicted to occur for about 15 years before recovery begins in about 2040. Pressures in the coal measures are predicted to recover to above pre-mining levels in about 2100 due to increased hydraulic conductivity above the nearby longwalls. This establishes pathways to shallower (more productive) strata and allows for increased downward percolation after longwall extraction, resulting in a higher water pressure.
- Above the seams, all layers up to the BACS are predicted to experience significant drawdown (typically >100 m) due to extraction of Area 5 longwalls. Recovery to pre-mining levels is predicted by 2100, with the modelling again suggesting recovery could possibly occur to higher levels than pre-mining.
- Drawdown within the Hawkesbury Sandstone (HBSS) is predicted to be up to 50 m. The model simulates recovery of HBSS water levels to greater than pre-mining levels. This behaviour (recovery to pre-mining levels or more) is similar to that seen near Area 3A tributary SC10C, and in the vicinity of S2309 and nearby longwalls could result in both a recovery of baseflow to nearby tributaries (e.g. DC10 and DC10C) following mining, as well as an increase in iron-staining and associated water quality effects to those tributaries.
- The water table is not predicted to be significantly disturbed at this site outside of the longwall footprint, with a maximum drawdown of approximately 0.2 m.

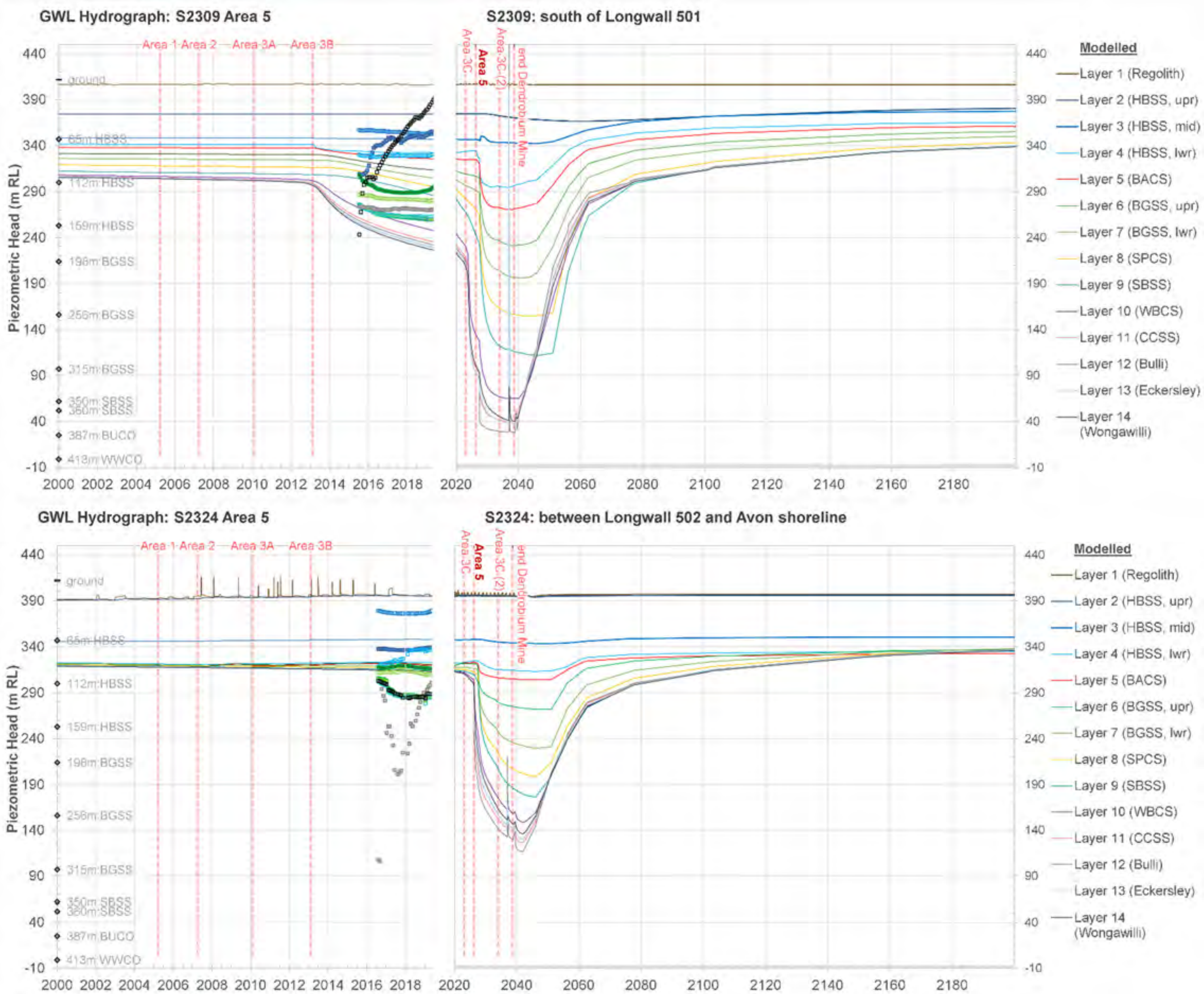


Figure 6-3 Predicted groundwater levels – hydrograph for sites S2309 and S2324

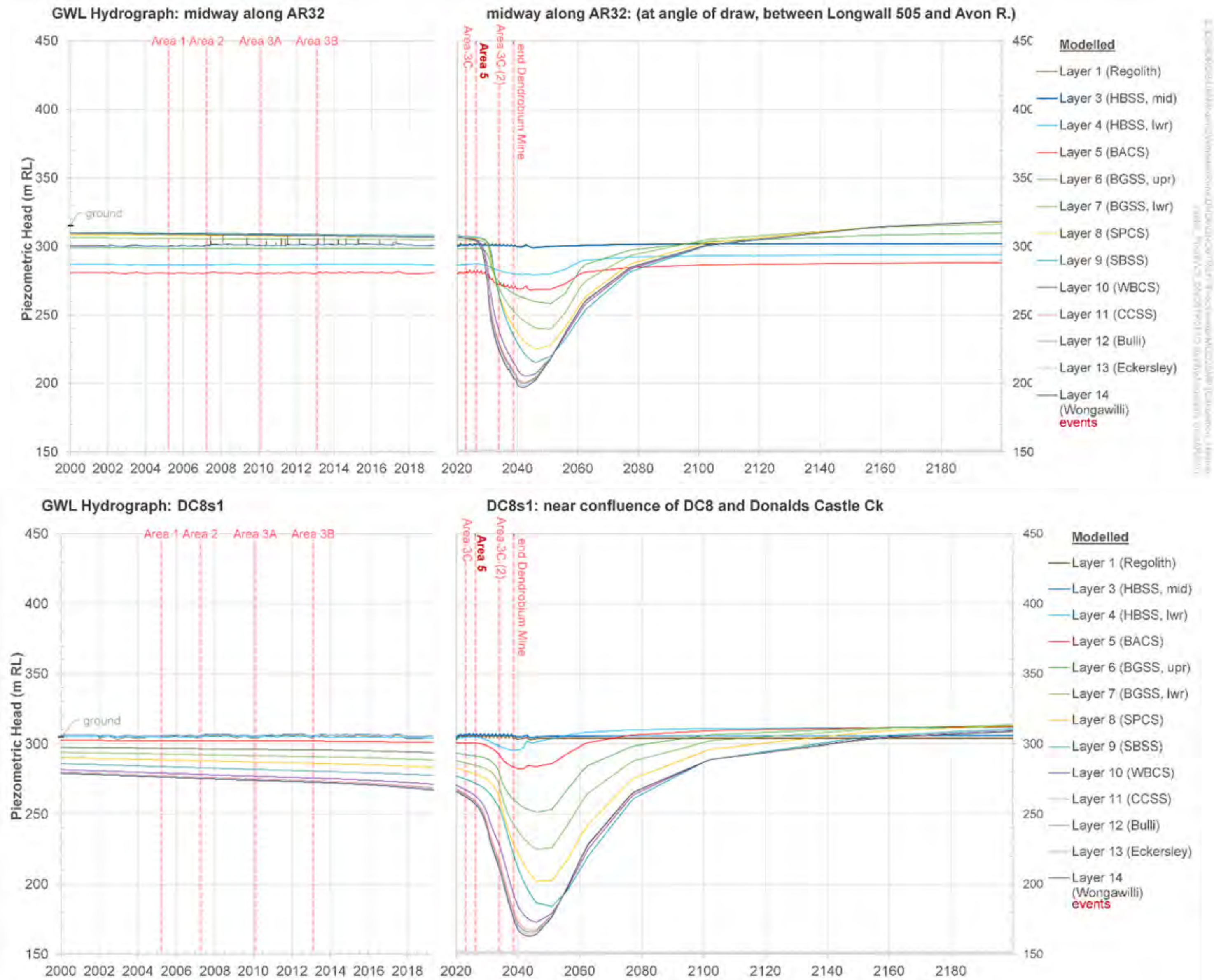


Figure 6-4 Predicted groundwater levels – hydrograph for sites near AR32 and DC8s1

At monitoring bore S2324, which is adjacent to Avon Reservoir and approximately 250 m south of Longwall 502 (Figure 6-3):

- Groundwater pressures in the Bulli and Wongawilli seams are predicted to drawdown approximately 200 m as a result of mining proposed for Area 5. Maximum drawdown is predicted to occur until about 2043. Pressures in the coal measures are predicted to recover to above pre-mining levels in 2125 due to increased hydraulic conductivity above the nearby longwalls. This establishes pathways to shallower (more productive) strata and allows for increased downward percolation after longwall extraction, resulting in a higher water pressure.
- Above the seams, all layers up to the BACS are predicted to experience significant drawdown (greater than 80 m) due to extraction of Area 5 longwalls. Recovery to pre-mining levels is predicted to be occur by 2125, with the modelling again suggesting recovery could possibly occur to higher levels than occurred pre-mining.
- Drawdown within the HBSS is predicted to be up to 10 m, recovering substantially by 2060 (approximately 30 years after mining). The model simulates recovery of HBSS groundwater levels to greater than pre-mining levels. The drawdown of approximately 8 m in the lower HBSS is most relevant to the potential interaction of groundwater with the Avon Reservoir near this location (Section 6.7.1).
- The water table is not predicted to be disturbed significantly at this site, with maximum modelled drawdown of 0.3 m, given the location outside of the mining footprint.

At the AR32 reporting location which is approx. 450 m northwest of Longwall 505 and near to tributary AR32 and Avon River (Figure 6-4), as well as being at the limit of the predicted angle of draw:

- The influence of AR32 is evident with heads of approximately 300 mAHD in the mid-HBSS, while heads in the lower HBSS and BACS are influenced by discharge to the more incised Avon River several hundred metres away. Pressures in the deeper strata are modelled as higher than in the BACS and HBSS, suggesting a natural upward gradient.
- Pressures in the Bulli and Wongawilli seams are predicted to drawdown approximately 100 m as a result of the extraction of Area 5 longwalls. Recovery is predicted to commenced in about 2045, with essentially complete recovery by 2125. Pressures in the seams are predicted to recover to above pre-mining levels due to increased hydraulic conductivity above the longwalls and the associated enhanced connection between strata.
- Above the seams, all layers up to the BACS are predicted to experience significant drawdown in the range of 50-100 m. Recovery to pre-mining levels is predicted to occur by 2120.
- Drawdown in the lower Hawkesbury Sandstone due to Area 5 extraction is predicted to be in the range 8-10 m. Recovery is predicted to be about complete by 2060, with long-term groundwater levels predicted to recover to pre-mining or approximately 5 m above that.
- The model predicts drawdown of 1-2 m in the upper and middle Hawkesbury at this location, and water table drawdown in order of 0.5-0.8 m at this location (also shown in Figure 6-7A).

At the DC8s1 reporting location which is approx. 700 m northeast of Longwall 510 and coincident with the DC8s1 surface water monitoring site on tributary DC8 (Figure 6-4):

- The influence of DC8 and Donalds Castle Creek in controlling heads at about 305 mAHD in the HBSS is clear. Pressures in the deeper strata (below the BACS) are simulated as responding slightly to previous mining in Area 3B.
- Pressures in the Bulli and Wongawilli seams are predicted to drawdown around 100 m as a result of the extraction of Area 5 longwalls, and potentially exacerbated slightly by the more distant Area 3C longwalls. Recovery is predicted to commence in about 2045, with essentially

complete recovery by 2100. Pressures in the seams are predicted to recover to above pre-mining levels due to increased hydraulic conductivity above the nearby longwall areas.

- Above the seams, all layers up to the BACS are predicted to experience significant drawdown in the range of 50-100 m. Recovery to pre-mining levels is predicted to occur by ~2100.
- Drawdown in the lower HBSS due to Area 5 extraction is predicted to be about 5-8 m. Recovery is predicted to be about complete by 2050, with long-term groundwater levels predicted to recover to pre-mining or approximately 2-4 m above that.
- The model predicts drawdown of 1-2 m in the upper- and mid- HBSS at this location, and drawdown in the range of 0.1-0.3 m in the water table at this location (also shown on Figure 6-7A).

6.6.2 Groundwater level contour maps

Figures J1 to J10 (**Appendix J**) present modelled water levels at four different times in the model simulation for five layers in the geological sequence, which are:

- water table (calculated as the water level in the uppermost saturated model layer, i.e. uppermost saturated stratigraphic unit);
- lower Hawkesbury Sandstone [HBSS] (model layer 4);
- upper Bulgo Sandstone [BGSS] (model layer 6);
- Bulli seam (model layer 12); and
- Wongawilli seam (model layer 14).

These time intervals selected for display are:

- Figures J1/J3/J5/J7/J9 show 1991 (essentially modelled as “pre-Dendrobium”) and 2021 (present day), as discussed previously (Section 5.3.1);
- Figures J2/J4/J6/J8/J10 show 2039 (end of proposed mining at Dendrobium) and 2200.

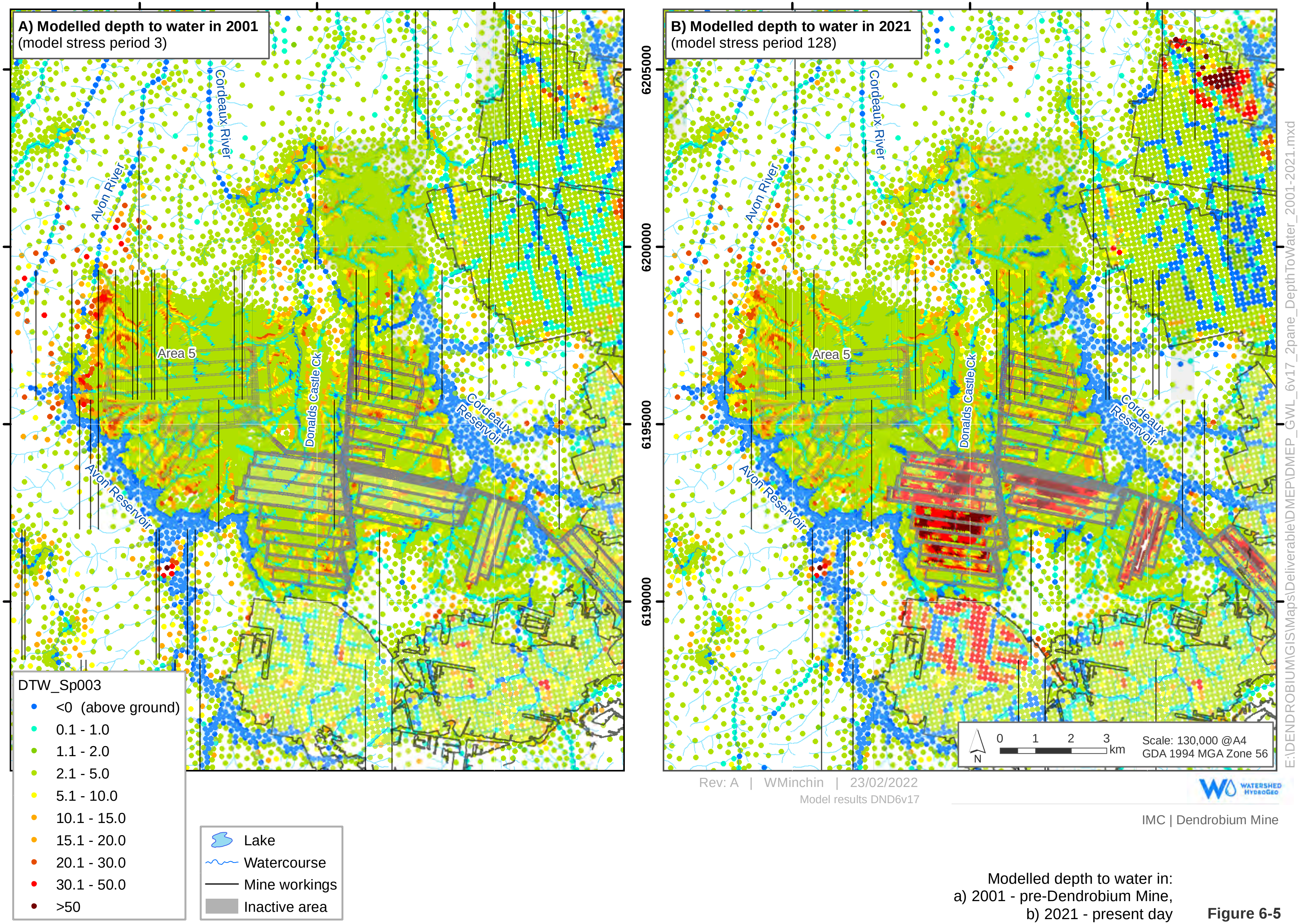
Comparison of the modelled heads in 2039 and those from the earlier time periods allows assessment of the effects of the approved and proposed areas of Dendrobium Mine, including Areas 3C, 5 and 6, on groundwater levels in those units. This includes significant drawdown in the Bulli and Wongawilli seams (approximately 300 m in the eastern part of Area 5, and approximately 250 m in the southwest around Longwalls 507-509, and 340 m within Area 3C. Drawdown in the upper BGSS is up to 120 m in the northern parts of Area 5 and in the lower HBSS is typically in the range 20-50 m over Area 5.

Figures J6A/J8A/J10A also indicate the likelihood that the cone of depression associated with the extracted longwall areas acts as a sink for groundwater. Flow directions would be modified as a result of the drawdown, resulting in groundwater flow toward the mine area for several decades from the time of mining until groundwater levels had recovered.

The second pane in Figures J4B/J6B/J8B/10B shows the predicted long-term groundwater levels. As with many of the hydrographs, this suggests that groundwater levels would recover to pre-mining levels, even in areas above the Area 5 footprint. However, the water table is not predicted to recover above the longwalls given the presence of surface cracking with enhances lateral drainage to valleys and so depresses water tables, especially on interfluves adjacent to drainage lines. This is shown more clearly in the following section.

6.6.3 Depth to water table maps

Figure 6-5 and Figure 6-6 show the modelled depth to the water table at four different times; pre-mining, present day (2021), end of proposed mining at Dendrobium (2039) and in 2200.



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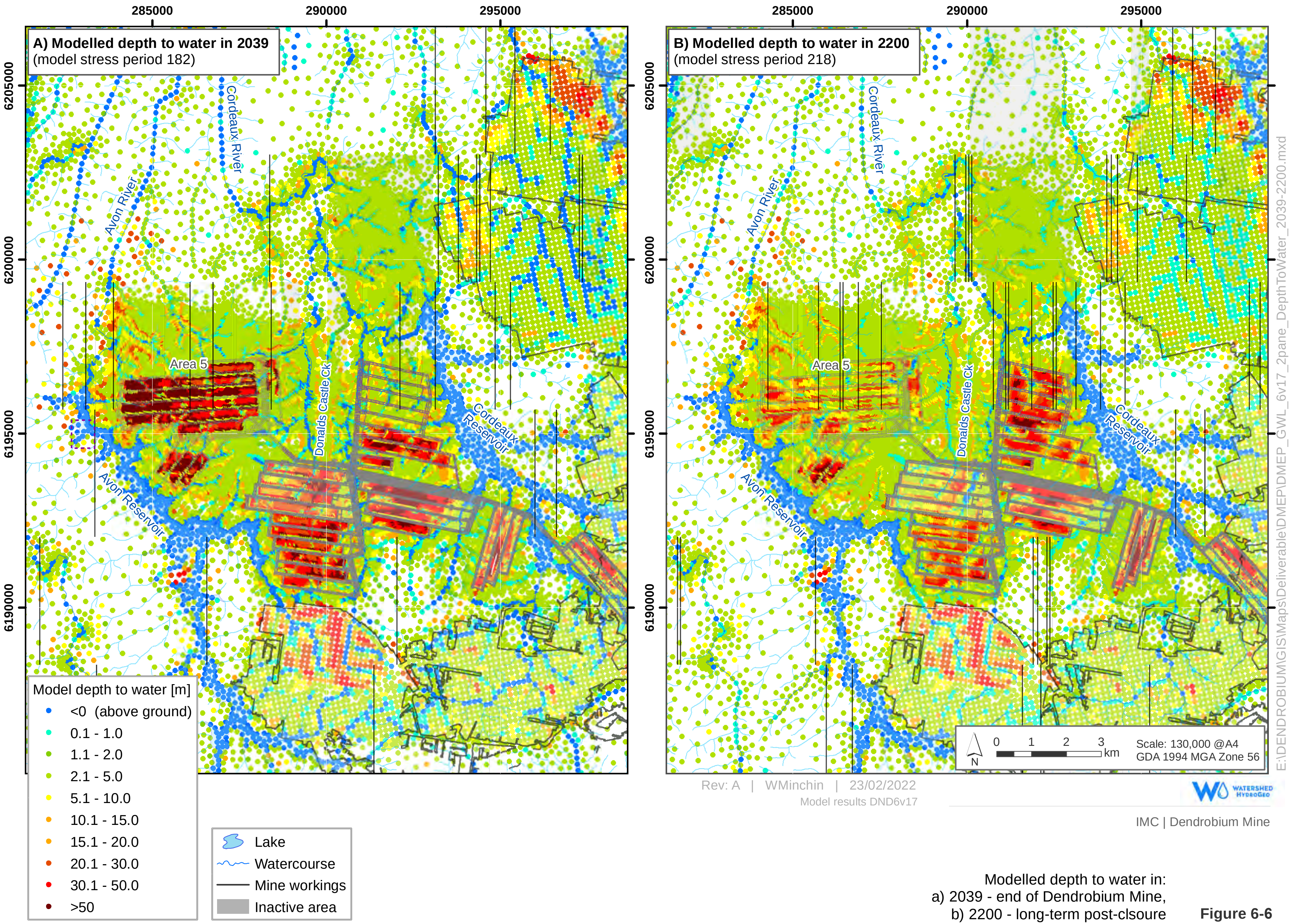
Model results DND6v17

IMC | Dendrobium Mine

Modelled depth to water in:
a) 2001 - pre-Dendrobium Mine,
b) 2021 - present day

Figure 6-5



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Rev: A | WMinchin | 23/02/2022

Model results DND6v17

IMC | Dendrobium Mine

Modelled depth to water in:
a) 2039 - end of Dendrobium Mine,
b) 2200 - long-term post-clsoure

Figure 6-6

These maps show the development of drawdown in the water table as mining progresses in the catchment, including at Cordeaux Mine (northwest of the pane), Elouera (to the south of Dendrobium Area 3B) and at Dendrobium.

The map for 2021 shows the model predicts significant drawdown above Areas 1, 2, 3A and 3B (to Longwall 17) at Dendrobium.

By 2039, the extent of drawdown in the water table has extended to Area 5 and A3C (especially the southern (earlier) half of Area 3C, and also includes Longwalls 18 and 19 in Areas 3B and 3A respectively.

In 2200, partial recovery is predicted in most areas within the longwall footprint. Interfluves parallel to drainage lines are generally predicted to be the areas with incomplete recovery, while some valleys show more complete recovery, as does the main ridgeline in the centre of Area 5. This is consistent with increased hydraulic conductivity in the near-surface above longwall panels (Section 3.2.1).

6.6.4 Maximum groundwater drawdown contour maps

The groundwater level contour maps presented above are useful for illustrating the simulated pattern of groundwater levels, and the inferred direction of flow, as a result of mining and other processes. The maximum drawdown predicted in every model cell in two ‘stratigraphic’ layers, as well as the drawdown in the simulated water table:

- water table (calculated from multiple model layers);
- lower Hawkesbury Sandstone (Layer 4); and
- upper Bulgo Sandstone (Layer 6).

These were selected because they are the layers or units that are typically in contact with or near to the surface and the associated ‘receptors’ (i.e. major watercourses, reservoirs or lakes, bores). Drawdown in the water table, expressed as depth to the water table at specific times, is also described in Section 6.6.3.

Comparison of results from mine development Scenarios D and B (see Section 6.1) allows calculation of the head difference, representing the drawdown due to Dendrobium Mine as a whole, inclusive of Area 5. The drawdown for each model cell was calculated for all timesteps, and then the maximum drawdown from that composite of times for each model cell was then interpolated and contoured, as shown on Figure 6-7 and Figure 6-8. This has been done to show the influence of Dendrobium Mine on the groundwater system. Primarily, these figures show the base case model drawdown. Furthermore, the results of the deterministic uncertainty scenarios have been summarised and included on these figures as the extent of the ‘best case’ (minimum – orange line) of all such uncertainty scenarios and ‘worst case’ (maximum – purple line) of all uncertainty scenarios 2 m drawdown contour.

Figure 6-7A presents the base case drawdown contours (dashed 1 m contour, red 2 m contour, and grey-black contours at 5 m intervals), and Figure 6-7B the min-max or best-worst cases from the deterministic scenarios run for this study (this is discussed more below). Figure 6-7A shows that within the longwall areas themselves, the model predicts drawdown of up to 40 m in multiple areas within Area 5. This is similar to the maximum predicted in Areas 3A and 3B, but slightly less than that simulated over Area 2 (65 m) and Area 3C (60 m).

Water table drawdown of >2 m is typically restricted to within about 200 m of the longwall footprint for most of the Dendrobium mine areas, with greater extent from the longwall footprint occurring where there is a lower depth of cover and where older stratigraphic units are exposed at the surface. Area 2 is the best example where the 2 m drawdown contour extends up to 500 m west of Longwall 5, or in the area southeast of Area 3C. The model predicts that the 2 m drawdown contour around Area 5 is relatively close to Area 5 longwalls. For Figure 6-7A, the 0.05 m drawdown contour (dashed blue line) has also been shown as an indicator for the area of influence over which drawdown in the water table might cause some change in fluxes such as baseflow/leakage, as well as changes in evapotranspiration. It is likely that this magnitude of drawdown would only result in very minor changes in such fluxes, and likely only for a short period of time. With respect to the Project, this area intersects Avon Reservoir and Avon River immediately below the dam wall, the Avon River tributaries AR19, AR31 and AR32, as well as Donalds Castle Creek and related tributaries.

The results from the uncertainty scenarios are summarised on Figure 6-7B. The extent of the 2 m drawdown contour does not vary significantly between all the uncertainty scenarios. The position of the maximum or worst-case contour tends to encroach on Avon Reservoir near to Area 5 for a greater length of the shoreline than do the base case or best-case contours. The pattern is similar for Cordeaux Reservoir near Area 3C and Area 2.

Figure 6-8 presents that same information but condensed to show the maximum predicted drawdown for the lower Hawkesbury Sandstone (HBSS) on Figure 6-8A and for the upper Bulgo Sandstone (BGSS) on Figure 6-8B.

Figure 6-8A shows the simulated maximum drawdown in the lower HBSS for the base case model, and from the deterministic uncertainty scenarios. The main contouring presents the base case model results. This shows that within the longwall areas themselves, the model predicts drawdown of up to 100 m within the main part of Area 5, and slightly less above Longwalls 507-510. This is similar to the maximum drawdown simulated over Areas 1, 2 and 3B, and likely above parts of Area 3C.

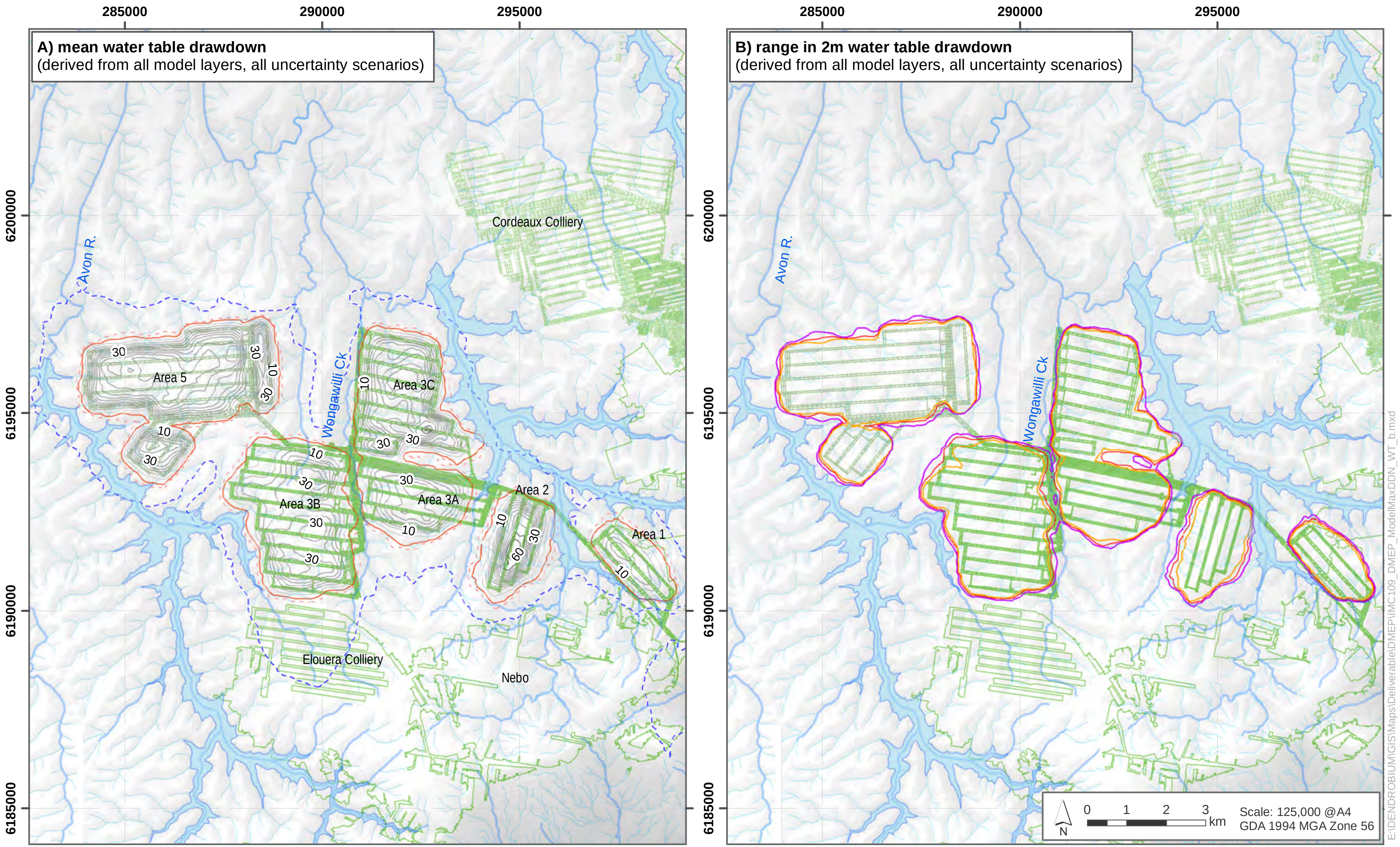
The base case estimate 2 m drawdown contour (red contour) extends up to 2.4 km to the north of Area 5 (halfway to Cordeaux River), but is less extensive in other directions due to it intersecting other features, namely Avon River and Avon Reservoir to the west and south of Area 5, Wongawilli Creek to the east, as well as by the cone of depression associated with Areas 3C (east) and Area 3B (southeast). In the other parts of Dendrobium Mine, this contour is similarly restricted by hydrological features., such as Cordeaux Reservoir, or by geological boundaries (usually where the HBSS is absent).

The extent of the minimum and maximum 2 m drawdown contour (derived from the uncertainty scenarios) may be limited in areas where strong hydrological features of geological features exist, but the difference can be significant, e.g. to the north of Area 5, the position or distance between these two contours ca be up to 800-900 m.

Figure 6-7B shows the same information for the upper BGSS. A maximum drawdown of approximately 140 m is predicted within the centre of Area 5. By comparison, the maximum simulated was also 140 m in Area 2, and approximately 100 m in Areas 3A, 3B and 3C.

As expected, the extent of the base case 2 m drawdown contour is larger than it was for either of the shallower layers discussed above. The 2 m contour is predicted to extend 4.5 km to the north of Areas 5 and 3C, and over 5 km to the west and southwest of Area 5. The increased extent of the 2 m contour in the BGSS compared to the HBSS is due to the extent of the BGSS and it being deep enough not to be exposed and eroded away in the base of the Nepean/Avon/Cordeaux valleys.

The results of the uncertainty scenarios suggest that the extent of the 2 m contour (relatively small change) could change significantly in some areas (e.g. to the north of Area 5 or southwest of Area 3B), typically where there are no strong hydraulic influences such as geological features or around reservoirs and major watercourses.



Rev: B | W Minchin | 25/03/2021

- Major town
- Town
- Lake
- Watercourse
- Tribs
- Mine workings

Base case model (Scen B - C)
Max. drawdown [m]

- 0.05
- 1
- 2
- 2.1 - 5.0
- 5.1 - 10.0
- 10.1 - 50.0
- 50.1 - 75.0
- 75.1 - 99.9
- >= 100

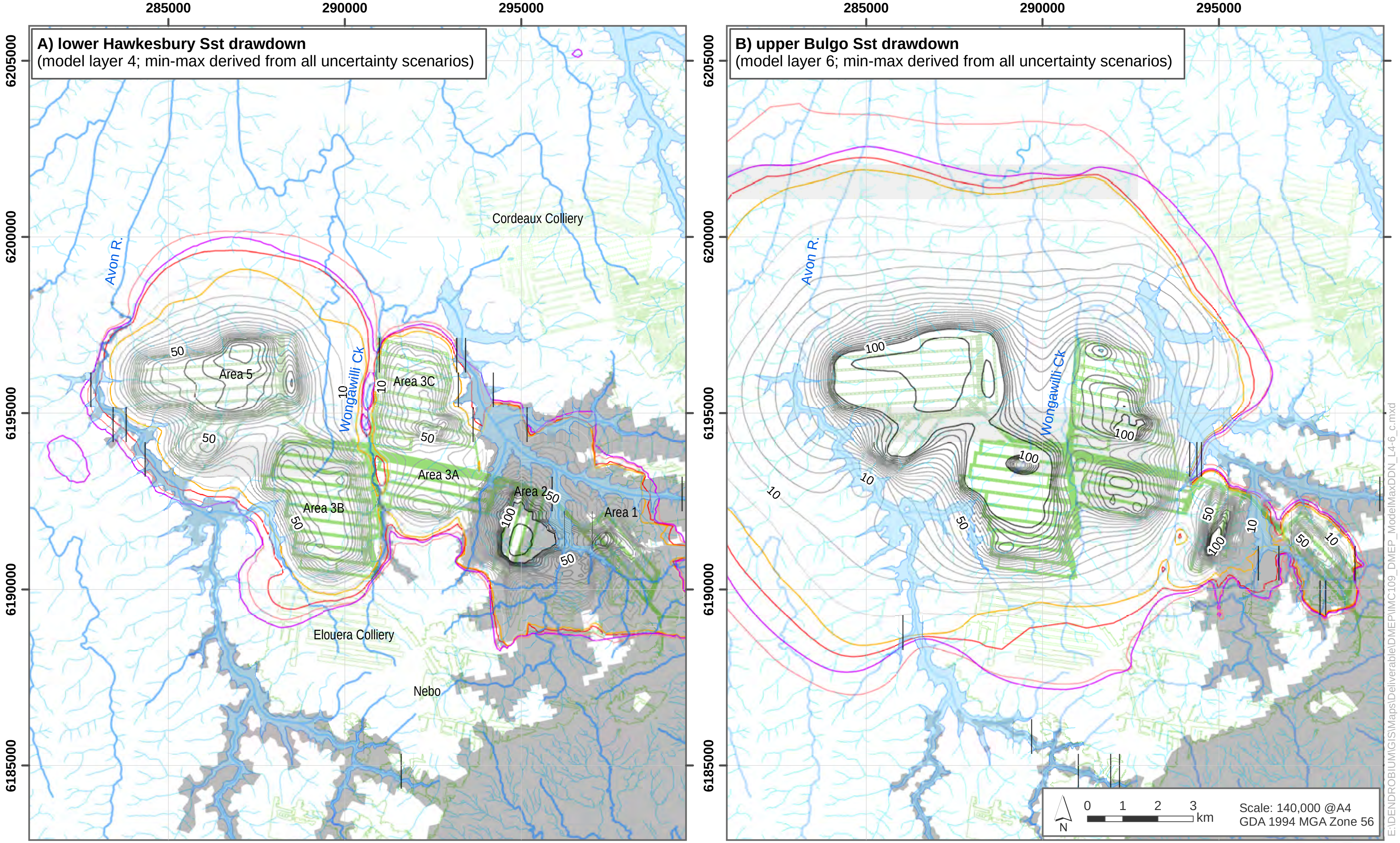
Range in drawdown from uncertainty scenario analysis

- 2m drawdown (MAX / Worst)
- 2m drawdown (MIN / Best)
- Inactive area

IMC | Dendrobium Mine

Modelled groundwater drawdown:
Maximum water table drawdown
due to Dendrobium Mine

Figure 6-7



Rev: C | W Minchin | 25/03/2022

- Major town
- Town
- Lake
- Watercourse
- Tribs
- Mine workings

Base case model (Scen B - C)
Max. drawdown [m]
- 1.0
- 2.0
- 2.1 - 5.0
- 5.1 - 10.0
- 10.1 - 50.0
- 50.1 - 75.0
- 75.1 - 99.9
- > 100.0

Range in drawdown from uncertainty scenario analysis
- 2m drawdown (MAX / Worst)
- 2m drawdown (MIN / Best)
- Inactive area

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater drawdown
Maximum drawdown due to Dendrobium
in lower HBSS and upper BGSS

Figure 6-8

6.6.5 Drawdown at groundwater bores

NSW Government maintains a database of registered 'Groundwater Works' that have been registered with them over time. The 'works' can generally be assumed to be bores, but also includes wells and excavations (Section 2.7.1).

764 'works' are located within the bounds of the groundwater model. The database includes an attribute for the purpose of the groundwater works, and of these, we consider that the following are 'water supply' works,

- 'Commercial and industrial'.
- 'Irrigation'.
- 'Stock and Domestic'.
- 'Water Supply'.
- 'Other'.
- 'Unknown'.

Works that are classed as 'Dewatering', 'Monitoring' and 'Exploration' are not considered 'water supply' works.

This classification means that 360 have been classed as 'water supply', and these are the features requiring assessment under the AIP. Locations are shown on Figure 6-9. Each of these has been assigned a model layer, water-bearing zones, bore construction details or bore depth – whichever are recorded in the bore database.

The AIP deems the threshold for 'minimal harm' at a water supply work to be 2 m drawdown due to the proposed activity or activities.

Comparison of development Scenarios C and D (see Table 6-1) suggests that none (0) of the 360 water supply works would be affected by more than the 2 m drawdown threshold by the Project, i.e. the mining of Area 5. This is not surprising, given the location of Area 5 domain within the Special Area, and hence the distance to water supply works.

The number of 'water supply' bores predicted to be affected by the 'whole of Dendrobium' and cumulative mining scenarios has been assessed by comparing development scenarios D-B and D-A respectively (Table 6-7), as well as the results from uncertainty scenarios.

Appendix M summarises the model results for all 'water supply' works and registered monitoring bores in the model domain and for the various mine development scenarios.

Table 6-7 >2 m Drawdown at 'water supply' works – Dendrobium and Cumulative

Case	No. of GW works affected > 2 m			
	Cumulative mining (excluding Dendrobium)	Cumulative mining (including Dendrobium)	Dendrobium Mine only (Areas 1-5)	Project (Area 5)
'Base case' model	204	204	0	0
Number of bores from deterministic scenarios and base case	144-220	144-220	0	0

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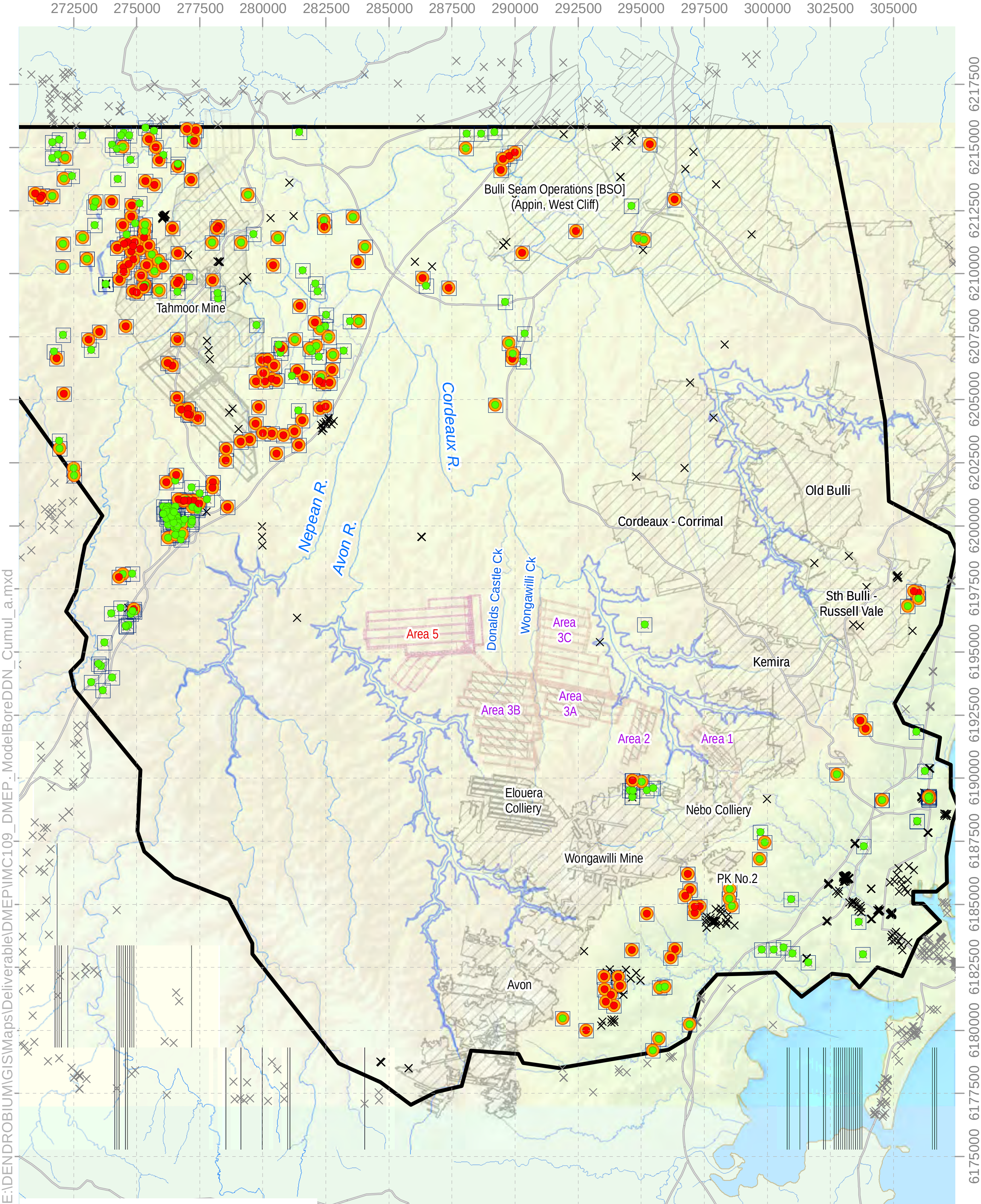
As shown in Table 6-7 there are no (zero) registered bores that are predicted to experience greater than 2 m drawdown due to the Dendrobium Mine. Only 5 ‘water supply’ works are predicted to have more than 0.5 m due to operations at Dendrobium (**Appendix M**).

Figure 6-9 summarises the range in maximum drawdown estimated from the base case model and the deterministic scenarios. Based on this, 204 (range 144-220) water supply works are predicted to experience greater than 2 m drawdown cumulatively (Table 6-7), however, more than 2 m drawdown is predicted to occur regardless of the Project or Dendrobium Mine as a whole, due to other unrelated historical/approved/proposed operations.

Figure 6-9 shows that most of the cumulatively-affected bores are located along the coastal plain (affected by the numerous historical mining operations along the edge of the escarpment) or around Tahmoor and Appin Mines. There are also cluster of bores to the south of Dendrobium Area 2 that are associated with Wongawilli Mine. These are classified as ‘unknown’ purpose, so have been considered conservatively as “water supply” works for this assessment, but are very likely to be for monitoring or exploration.



River
Creek
Lake / reservoir
Dendrobium workings: existing
Dendrobium workings: future ap
DMEP Area 5 workings
Other mines (extracted area)
Groundwater Model extent

Registered Groundwater Work
"Water supply" work/ bore
No

DDN due to Cumulative Mining (scenario,min)
<2m
>2 m drawdown

DDN due to Cumulative Mining (scenario, max)
<2m
>2 m drawdown

Scale: 200,000 @A4
GDA 1994 MGA Zone 56

N

0 1.5 3 4.5 km

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled maximum groundwater drawdown at Water Supply works (bores): cumulative mining effect

Figure 6-9

Created by: WMinchin | Version: A | Date: 04/03/2022

6.7 Estimated leakage from storage reservoirs

Three of WaterNSW's reservoirs are close to Dendrobium Mine, with Avon Reservoir situated about 300-900 m from the southern and western edge of Area 5 longwalls. Nepean Reservoir lies 3.2 km west of the nearest Area 5 longwall, and Cordeaux Reservoir is >4 km east. Effects on Avon Reservoir are the focus of the following analysis, given the proximity to the Project.

Modelling indicates that a loss from the reservoirs that would occur as a result of Dendrobium as a whole (including Areas 5 and 3C) and as a result of the Project. Results are shown on Figure 6-10, calculated from (Scenario D – Scenario B) and (Scenario D – Scenario C) respectively.

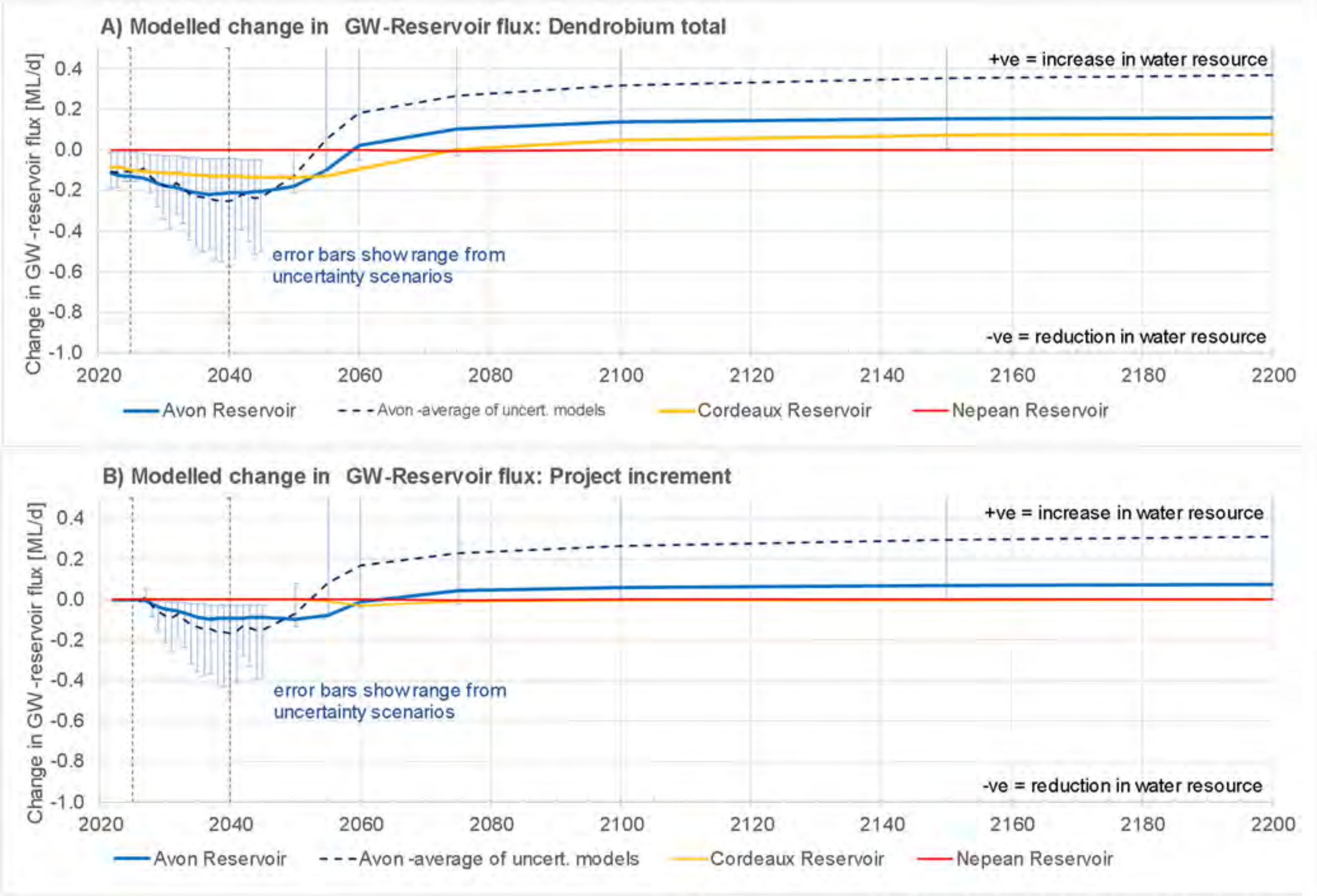


Figure 6-10 Predicted change in flux to reservoirs

The change in flux is calculated as the net change in baseflow + net change in leakage directly from the reservoir. The solid-coloured series on the charts show the 'base case' model estimate for each reservoir. The average and range in results calculated from the uncertainty scenarios (Section 6.2) for Avon Reservoir are presented as the dark blue dash line and as error bars. Losses from watercourses flowing into the reservoirs are presented separately in Sections 6.8.1 and 6.9.

6.7.1 Avon Reservoir

Figure 6-10A shows the hydrograph showing a loss of 0.12 ML/d in 2021 (due to Area 3B), then rising as Area 5 is developed and plateauing until about 2050, before declining over a further decade. The likely maximum loss is approximately 0.22 ML/d (range 0.05-0.58) for the whole of the Dendrobium Mine. The modelling suggests that an increase in groundwater flux to the reservoir is possible in the long-term, which is a result of increased hydraulic conductivity associated with subsidence. However prior to that time, the modelling suggests negative fluxes (losses) could persist until 2060.

The Project increment (Figure 6-10B) is estimated to be approximately 0.1 ML/d (range 0.03-0.46), where maximum loss at any time from the three off-goaf K scenarios (Section 6.2) are 0.26, 0.26 and 0.46 respectively. Consideration of these higher values of Kh in the model leads not only to the higher initial losses, as noted above, but also to a quicker recovery of a positive flux from groundwater to the reservoir in the years after mining.

The maxima reported here, both for the Dendrobium Mine as a whole and for the Project, are less than Dams Safety NSW threshold of 1 ML/d.

6.7.2 Nepean Reservoir

The losses for Nepean Reservoir are plotted on Figure 6-10, but are difficult to determine from that given their scale. Modelling indicates losses of less than 0.01 ML/d for Dendrobium as a whole and for the Project. This low level of flux is expected given the distance from Dendrobium longwalls (of which the Area 5 longwalls are the closest to the Nepean Reservoir) and the position of the Avon Reservoir and Avon River between the mine and Nepean Reservoir.

6.7.3 Cordeaux Reservoir

Figure 6-10 presents the losses from Cordeaux Reservoir (orange series on the charts). Total leakage from Cordeaux Reservoir due to all Dendrobium areas is estimated at up to 0.14 ML/d (base case model), peaking in the years after Area 3C is proposed to be completed, of which the second half is proposed for the period 2034-2038 (schedule in Section 1.5.2).

The range in peak loss from Cordeaux Reservoir as a result of Dendrobium Mine from the uncertainty scenarios is 0.08-0.24 ML/d, with the upper end of those estimates being from scenarios designed to assess the uncertainty in off-goaf K enhancement. As suggested by the Project increment (see below), these rates of loss are generally unrelated to the Project.

A small loss is predicted from Cordeaux Reservoir due to Area 5 extraction (0.01-0.03 ML/d).

6.8 Effects on stream flow

As described in the conceptual model (Section 3.4.1), longwall mining can cause a reduction in stream flow via two mechanisms:

- groundwater depressurisation or drawdown in the groundwater system that is connected to the watercourse (i.e. outcropping beneath the watercourse); and
- cracking, fracturing and deformation (e.g. ‘surface cracking’, upward extension of the ‘connected fracture zone’ to the surface, or development of basal shears) can enhance the hydraulic conductivity of stream beds and valley bottoms and result in loss of flow (if there is head gradient away from the stream).

It is also possible that changes to hydraulic properties associated with longwall mining can cause small increases to flow in watercourses, and this effect may be more noticeable following groundwater level recovery (even partial recovery) some years or even decades after mining. We note the modelling cannot predict whether or where/local-scale fracturing is going to occur, usually immediately above longwalls. The model is based on and well calibrated to losses on a sub-catchment scale (Section 5.3.4).

The numerical model has been used to estimate loss from watercourses for the modelled scenarios. These effects are described in the following sub-sections, outlining effects on smaller sub-catchments local to the Project, as well as broader catchments, including those catchments that contribute flow to the water supply reservoirs near Dendrobium Mine.

It is important to note that the model uses a cycle of wet and dry periods, simulated as percentiles from the modelled historical runoff, recharge and excess potential evaporation (Sections 4.4.3, 4.4.4 and 4.4.5 respectively). The actual timing of future wet or dry years is highly unlikely to match the modelled timing, but the reason for using a variable sequence, rather than a constant 'average' weather condition is to provide information of hydrological effects in a realistic sequence, and to be able to review likely variability in effects in wet or dry periods.

6.8.1 Local sub-catchment stream flow effects

The MODFLOW GAGE package has been used with the SFR package to extract timeseries flows at 63 sites around the model domain (those around Area 5 are shown on Figure 4-3), many of which are existing surface water gauging sites, as well as others that are of interest but not gauged. Of these, 22 are reported below (Table 6-8), but a statistical summary of losses at all sites has been provided to HEC for consideration in the Surface Water Assessment. Estimates of flow and loss can be provided for other sites on request.

The losses are calculated for two time periods; the first which is for the period commencing in 2026 (start of longwall mining in Area 5) up to a point 3 years after longwall mining in Area 5 is complete. This period is selected based on the concept that mine subsidence and groundwater drawdown may not have reach their full effect immediately at the end of the final longwall. The second period, "post-A5" in Table 6-8, covers all simulated effects from 2038-onward.

The results indicate that streams with a significant length directly above longwalls are affected most (via surface cracking), while outside the longwall footprint, the watercourses in more deeply-incised valleys are affected due to depressurisation of the layers that represent a connected groundwater system. Given the uncertainty associated with hydraulic properties in the surface cracking zone, results of the deterministic scenario that considered high K within that zone (Section 6.2) have been presented in Table 6-8 for comparison. It is noted that simulating increased K can result in greater or smaller losses than for the base case model.

Table 6-8 Predicted maximum reduction in flow in key sub-catchments and watercourses

All modelled losses in ML/d		AR19s1	AR19_5-20	AR31s1	AR32s1	AR32_5-5	DC8s1	DC8_5-2	DC9_5-24	DC10_5-3	DC13s1	DCU	DCL	LA8s1	LA8_5-9	LA12_5-10	LA13as1	LA13s1	LA13_5-4	LA14_5-7	LA15_5-11	LA17_5-12	WWL
Cumulative mining effect – base case																							
2026-2037 (Project [A5])	mean loss	-0.178	-0.177	-0.017	-0.107	-0.562	-0.086	-0.086	-0.013	-0.075	-0.287	-0.966	-1.034	-0.014	-0.014	-0.015	-0.129	-0.157	-0.264	-0.040	-0.018	-0.030	-0.611
	max loss	-0.265	-0.262	-0.030	-0.155	-0.972	-0.160	-0.160	-0.020	-0.129	-0.373	-1.258	-1.381	-0.039	-0.039	-0.035	-0.181	-0.297	-0.470	-0.053	-0.024	-0.044	-0.847
2038-2200 (post-A5)	mean loss	-0.147	-0.164	-0.003	-0.070	-0.135	-0.018	-0.018	0.000	-0.006	-0.185	-0.708	-0.661	-0.004	-0.004	-0.001	-0.053	-0.063	-0.096	-0.002	-0.004	-0.001	-0.134
	max loss	-0.268	-0.264	-0.006	-0.120	-0.356	-0.051	-0.051	-0.001	-0.024	-0.297	-1.562	-1.625	-0.013	-0.013	-0.001	-0.102	-0.141	-0.248	-0.009	-0.007	-0.004	-0.267
Dendrobium (total) Impact – base case																							
2026-2037 (Project [A5])	mean loss	-0.178	-0.177	-0.019	-0.107	-0.786	-0.086	-0.086	-0.013	-0.074	-0.287	-0.966	-1.033	-0.014	-0.014	-0.015	-0.129	-0.157	-0.264	-0.040	-0.018	-0.030	-0.812
	max loss	-0.265	-0.262	-0.030	-0.155	-1.155	-0.159	-0.159	-0.020	-0.128	-0.373	-1.258	-1.380	-0.039	-0.039	-0.035	-0.181	-0.297	-0.470	-0.053	-0.024	-0.044	-1.017
2038-2200 (post-A5)	mean loss	-0.147	-0.164	-0.003	-0.070	-0.259	-0.018	-0.018	0.000	-0.006	-0.185	-0.708	-0.660	-0.003	-0.003	-0.001	-0.053	-0.062	-0.096	-0.002	-0.004	-0.001	-0.237
	max loss	-0.268	-0.264	-0.006	-0.120	-0.625	-0.051	-0.051	-0.001	-0.024	-0.297	-1.562	-1.624	-0.013	-0.013	-0.001	-0.102	-0.141	-0.248	-0.009	-0.007	-0.004	-0.467
Project Impact (Area 5) – base case																							
2026-2037 (Project [A5])	mean loss	-0.178	-0.177	-0.019	-0.107	-0.407	-0.085	-0.085	-0.013	-0.074	0.000	-0.074	-0.145	-0.018	-0.018	-0.015	-0.129	-0.169	-0.286	-0.040	-0.018	-0.030	-0.006
	max loss	-0.265	-0.262	-0.030	-0.155	-0.692	-0.158	-0.158	-0.020	-0.127	-0.001	-0.129	-0.316	-0.037	-0.037	-0.035	-0.181	-0.295	-0.467	-0.053	-0.024	-0.044	-0.012
2038-2200 (post-A5)	mean loss	-0.147	-0.164	-0.003	-0.070	-0.142	-0.018	-0.018	0.000	-0.006	-0.002	-0.009	-0.029	-0.003	-0.003	0.000	-0.053	-0.062	-0.095	-0.002	-0.004	-0.001	-0.038
	max loss	-0.266	-0.262	-0.006	-0.120	-0.301	-0.049	-0.049	-0.001	-0.023	-0.004	-0.026	-0.083	-0.012	-0.012	-0.001	-0.100	-0.141	-0.247	-0.008	-0.007	-0.004	-0.121
Dendrobium (total) Impact – increased K in surface cracking zone																							
2026-2037 (Project [A5])	mean loss	-0.160	-0.179	-0.018	-0.112	-0.719	-0.077	-0.077	-0.014	-0.069	-0.309	-1.014	-1.081	-0.014	-0.014	-0.015	-0.130	-0.159	-0.266	-0.040	-0.018	-0.031	-0.730
	max loss	-0.267	-0.264	-0.031	-0.158	-1.079	-0.160	-0.160	-0.021	-0.130	-0.399	-1.313	-1.439	-0.040	-0.040	-0.035	-0.181	-0.301	-0.474	-0.053	-0.024	-0.045	-0.914
2038-2200 (post-A5)	mean loss	-0.154	-0.171	-0.003	-0.080	-0.254	-0.019	-0.019	0.000	-0.007	-0.215	-0.744	-0.672	-0.004	-0.004	-0.001	-0.047	-0.062	-0.111	-0.003	-0.004	-0.002	-0.180
	max loss	-0.270	-0.266	-0.006	-0.128	-0.573	-0.051	-0.051	-0.001	-0.025	-0.336	-1.714	-1.775	-0.013	-0.013	-0.001	-0.102	-0.144	-0.252	-0.009	-0.007	-0.004	-0.407

These results are from the base case model scenarios [TR017] except for the last block of results [TR024]. For conservatism, the statistics here filter out potential increases in flow that might occur due to groundwater recovery in the presence of increased hydraulic conductivity.

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6.8.2 Surface water losses from sub-regional catchments

Losses from catchments on a larger scale to those presented in Section have been estimated. These are presented as annualised changes in flux on Figure 6-11.

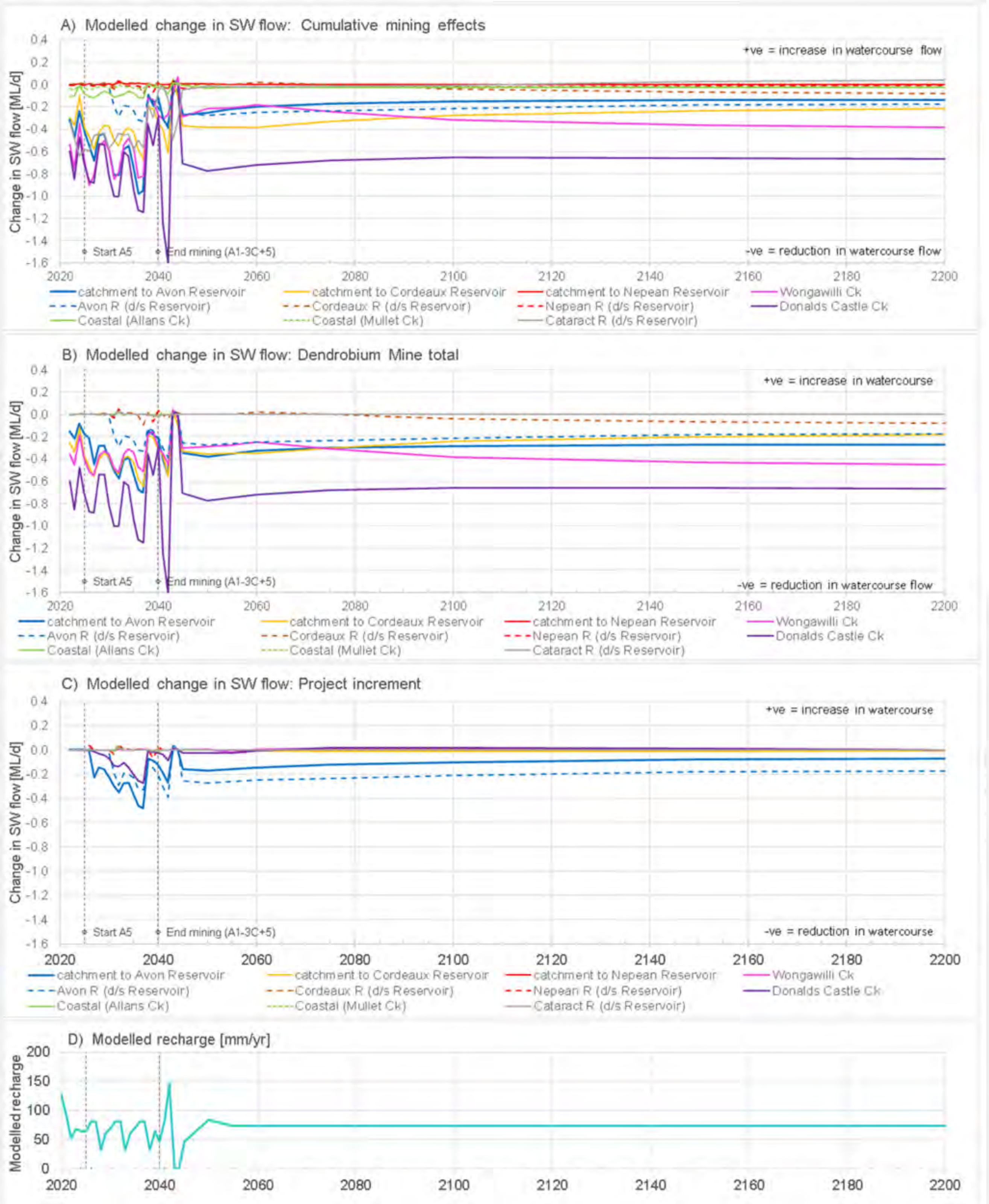

Figure 6-11 Modelled surface water impacts: sub-regional catchments

The figures above show the variability of losses related to mining are related to both the extent and time elapsed after mining (and whether groundwater levels have recovered), the presence of surface cracking associated with that mining, and the weather (which is indicated by the modelled recharge series on Figure 6-11D). That is, losses tend to be greater at high flows compared to losses during dry periods.

With respect to the Project (Figure 6-11C), the losses are predicted to be greatest in the catchment to Avon Reservoir, the Donalds Castle Creek catchment and the catchment to the Avon River downstream of the reservoir. The losses in the Donalds Castle Creek catchment are predicted to reduce significantly over time (approximately a decade after the cessation of Area 5), while the post-mining effects on the Avon Reservoir and Avon River catchment are predicted to persist, albeit having reduced to approximately half or a quarter of the peak rate (during operations).

The losses predicted as a result of the full development of Dendrobium Mine are shown on Figure 6-11B. This chart shows that losses are modelled to be greatest within the Donalds Castle Creek (noting the over-estimation of historical losses – Section 5.3.4), Wongawilli Creek and to the watercourses contributing to both Cordeaux Reservoir and Avon Reservoirs.

6.8.3 Cumulative losses from water supply catchments

IEPMC (2019) recommended that it would be appropriate to use the groundwater model to estimate cumulative losses from the groundwater catchment to the water supply reservoirs. The groundwater model (Figure 4-2) covers the full catchment to Lake Cordeaux, but does not quite cover the full catchment of Lake Avon, and only smaller fractions of the catchment to Lake Nepean (Table 6-9). The model includes most, if not all, the significant mining operations with the catchment of Lake Cordeaux and Lake Avon.

Nevertheless, the model has been used to provide estimates of the cumulative loss of flow in the modelled parts of these catchments due to mining operations. This has been obtained via Scenario A results minus Scenario D results.

Results are summarised in Table 6-9 (timeseries presented in Section 6.9). The losses reported in Table 6-9 are the annualised losses in ML/d, and are the total of losses from watercourses and the reservoirs. The periods in Table 6-9 were selected based on lower reliability in simulating mining operations before 2000, and up to 'present day' (i.e. 2021), the potential life of mine (to approximately 2040) and a 30-year period post-mining (i.e. to 2070).

Table 6-9 Modelled cumulative losses from reservoir catchments

Reservoir	Catchment Area (km^2)	% of catchment in model	Period 2000-2021		Period 2022-2040		Period 2041-2070	
			Mean	Peak	Mean	Peak	Mean	Peak
L. Cordeaux	91	100 %	-0.5	-0.7	-0.6	-0.9	-0.5	-0.8
L. Avon	142	97 %	-0.4	-0.7	-0.8	-1.3	-0.5	-0.7
L. Nepean	320	33 %	0	<0.1	<0.1	<0.1	<0.1	<0.1

Losses in ML/d, based on simulated mining at all mines in Section 1.6.

-ve values mean a reduction in surface water resource.

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6.9 Water 'take' or capture

The AIP requires estimation of 'take' or groundwater and surface water captured or lost from the environment or hydrological systems. This is done on the basis of Groundwater Sources defined within the Water Sharing Plan (WSP) for the *Greater Metropolitan Region Groundwater Sources 2011* (Section 1.7). Dendrobium lies almost wholly within the Sydney Basin – Nepean Sandstone Groundwater Source, (and within Management Zone 2 of that), thus most of the water removed from the natural system by mining operations is from that Groundwater Source.

Total estimated water losses from water supply catchments (i.e. watercourses plus reservoirs) are presented on the following figures for three resource development scenarios:

- cumulative mining effects on Figure 6-12;
- total Dendrobium Mine (A1-3C + Area 5) on Figure 6-13; and
- Project increment (i.e. Area 5) on Figure 6-14.

These figures show annual totals (ML/yr) for each year to 2050, and then at increasing intervals into the long-term based on model stress periods. The losses presented are those that occur within watercourses or reservoirs within each specified catchment, i.e. not accumulated from upstream.

The exception to this is the accumulated total to Pheasants Nest Weir, which is provided as the estimated total take within the Upper Nepean and Upstream Warragamba Water Source, as well as being the estimated total effect on the water resources managed by WaterNSW (more on the partitioning between WaterNSW's catchments is presented in Section 6.8.2). The accumulated totals to Pheasants Nest Weir are also tabulated in Table 6-10.

An indication of the simulated wet/dry conditions has been included in Table 6-10 to illustrate the sensitivity of modelled losses to weather conditions. As noted previously, the modelled weather conditions (represented via runoff, recharge and potential evaporation processes) are highly unlikely to occur in the same sequence in reality, but are used to show what the peak take (e.g. occurring in a wet year near the end of mining) is likely to be compared to average or lower predicted takes (occurring during periods of severe drought).

The modelling suggests that the maximum wet year loss from the catchment to Pheasants Nest Weir due to Dendrobium Mine as a whole would be in the order of 1454 ML/yr (4 ML/d). The Project increment is predicted to be 428 ML/yr (equivalent of 1.2 ML/d), noting there are uncertainties of maximum take associated with future prevailing weather conditions (which are significant in terms of predicted surface water losses) as well as modelled hydrogeological parameters.

Table 6-10 Annualised effects on surface water resources in the Upper Nepean catchment

Year	Cumulative mining			Dendrobium Mine total			Project Increment			Indicator of climate conditions
	Flux to /from water-courses	Flux to /from Reservoir	Total [ML]	Flux to /from water-courses	Flux to /from Reservoir	Total [ML]	Flux to /from water-courses	Flux to /from Reservoir	Total [ML]	Dry Av. Wet
2022	-641	-140	-782	-497	-73	-571	0	0	0	
2023	-890	-144	-1034	-678	-77	-755	0	0	0	
2024	-417	-148	-566	-311	-80	-392	0	0	0	
2025	-790	-151	-941	-598	-83	-681	0	0	0	
2026	-1008	-154	-1162	-752	-86	-837	28	0	27	
2027	-1085	-157	-1241	-888	-89	-976	-86	-4	-90	
2028	-715	-162	-877	-573	-94	-667	-63	-8	-72	
2029	-671	-168	-839	-540	-100	-640	-75	-13	-88	
2030	-864	-172	-1036	-707	-105	-812	-113	-17	-130	
2031	-1258	-175	-1433	-1014	-107	-1122	-270	-19	-288	
2032	-1222	-177	-1400	-1022	-110	-1132	-234	-21	-254	
2033	-851	-182	-1033	-707	-114	-822	-205	-26	-231	
2034	-818	-186	-1004	-687	-119	-805	-219	-29	-248	
2035	-1053	-190	-1242	-897	-122	-1020	-288	-31	-319	
2036	-1406	-193	-1599	-1165	-125	-1290	-372	-34	-406	
2037	-1501	-196	-1697	-1289	-128	-1417	-392	-35	**-428**	
2038	-319	-194	-512	-348	-126	-475	-70	-35	-105	
2039	-500	-192	-691	-498	-125	-623	-137	-34	-172	
2040	-426	-192	-618	-450	-126	-576	-116	-34	-150	
2041	-958	-192	-1150	-986	-126	-1111	-197	-34	-231	
2042	-1240	-191	-1432	-1329	-125	**-1454**	-277	-34	-311	
2043	-618	-191	-809	-641	-125	-766	-205	-33	-238	
2044	-645	-191	-836	-642	-126	-767	-204	-32	-236	
2045	-703	-192	-894	-707	-126	-833	-162	-32	-195	
2050	-708	-180	-887	-759	-115	-874	-173	-37	-210	
2055	-677	-148	-825	-724	-84	-809	-172	-34	-206	
2060	-628	-89	-717	-676	-27	-703	-153	-14	-167	
2075	-614	-22	-635	-665	38	-627	-120	11	-109	
2100	-623	11	-612	-677	67	-610	-101	19	-82	
2150	-628	28	-600	-684	82	-602	-87	23	-65	
2200	-635	34	-601	-691	88	-604	-91	26	-65	

This is for the catchment to Pheasants Nest Weir, including Avon, Cordeaux and Nepean Reservoirs and catchments. The "climate" sequence indicates modelled dry/wet conditions (based on modelled recharge). -ve value means a reduction in water resource.

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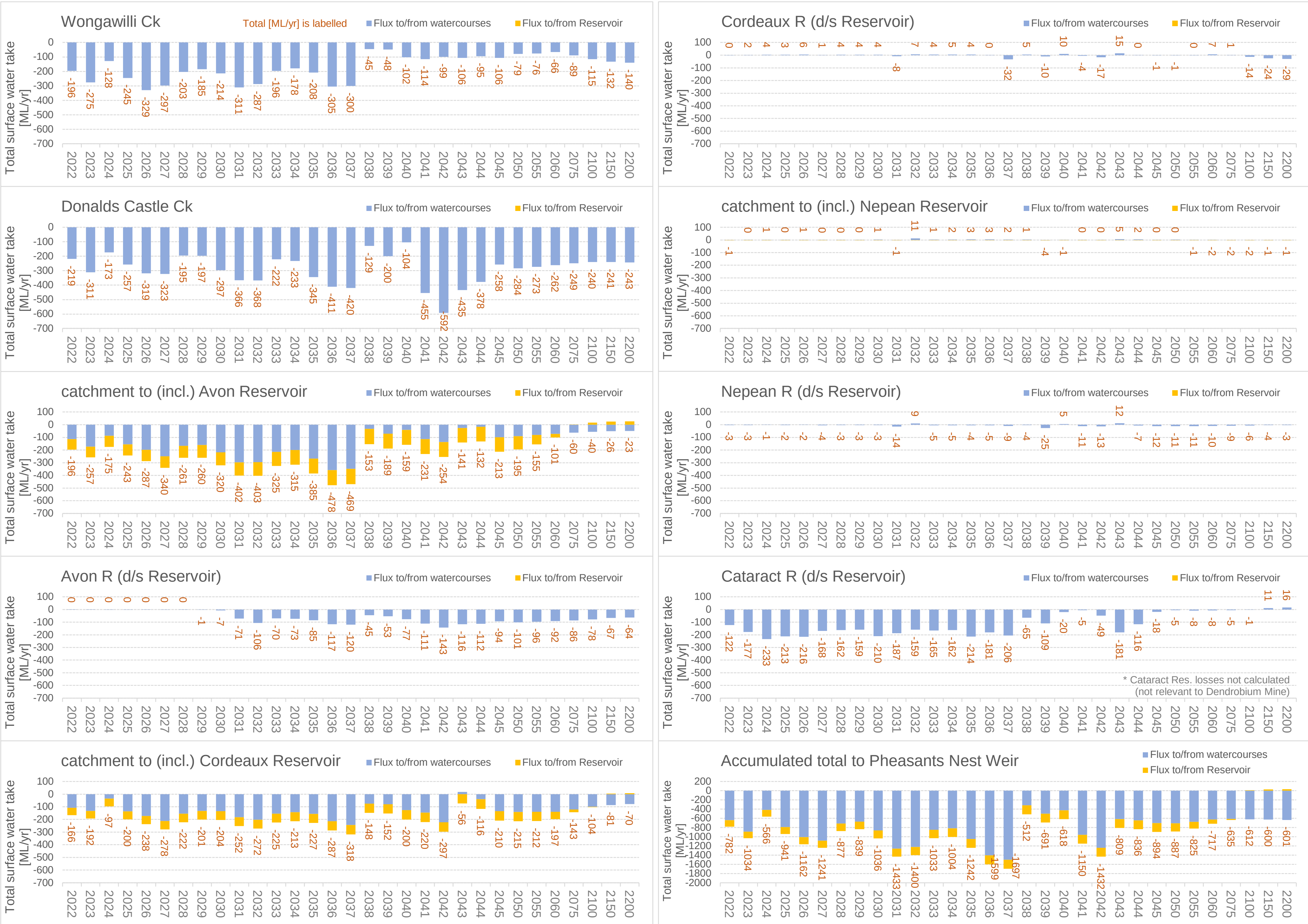

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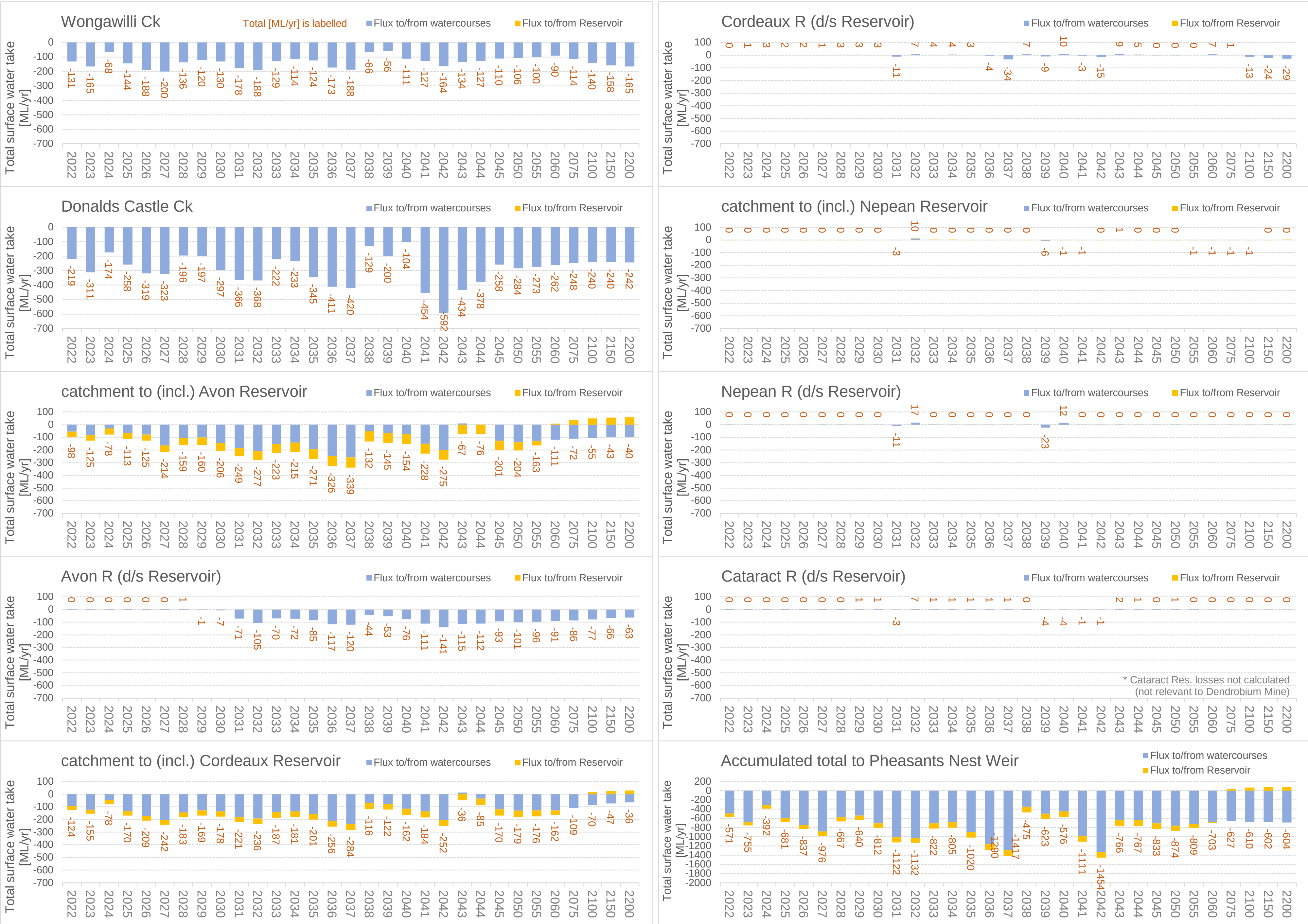
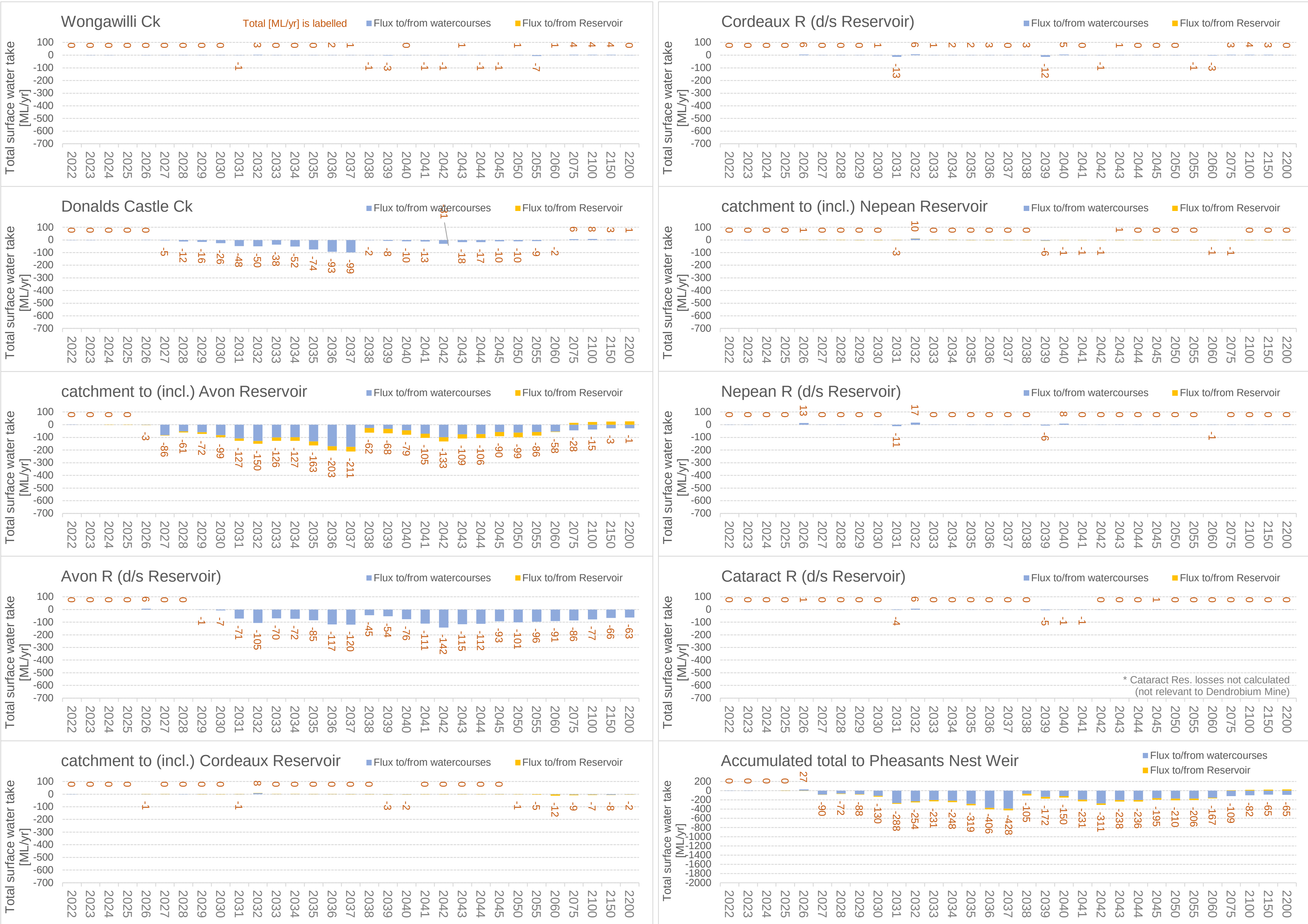
Modelled reduction in surface water resources: cumulative mining effects **Figure 6-12**



Modelled reduction in surface water resources: total Dendrobium effect **Figure 6-13**



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Modelled reduction in surface water resources: Project increment **Figure 6-14**

6.9.1 Summary of take and licensing

Table 6-11 presents recommendations for water licensing, based on the estimates of 'take' derived from maximum mine inflow (Section 6.5) and reduction in stream flow (Section 6.8.1) and reservoir losses (Section 6.7), as well as partitioning of groundwater 'take' or inflow from nearby Groundwater Sources (e.g. Sydney Basin South) and relevant surface water zones (see Figure 1-3 and Figure 1-4).

Table 6-11 Recommendations for licensing (shares or ML/yr)

Water Source / Management Zone	Estimated peak Take		Entitlement held (Section 1.7)	Comment
	Dendrobium Mine (A1-5)	Project (A5) Increment		
Groundwater: *Water Sharing Plan for the Greater Metropolitan Region* ***Groundwater*** *Sources 2011*				
Sydney Basin – Nepean Sandstone MZ2	5830	1970	9755	Maximum groundwater take via mine inflow (Section 6.5).
Sydney Basin – Nepean Sandstone MZ1	34	5	--	Maximum groundwater flow from this zone to Nepean MZ2 as a result of Dendrobium or the Project as predicted by modelling.
Sydney Basin South	53	5	75	
Surface Water: *Water Sharing Plan for the Greater Metropolitan Region Unregulated* ***River Water*** *Sources 2011*				
Upper Nepean and Upstream Warragamba Water Source	1454	428	n/a	Maximum 'incidental surface water take' from Sections 6.8.2 and 6.9. Peak surface water losses may not be contemporary with peak groundwater takes listed above.
Illawarra Rivers Water Source	17	<1	--	

sources:
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E:\DENDROBIUM\Model\GWmodel\Processing\Zonebudget\GWTake_ZBud_DND6TR17D-C-B.xlsx

Note that the maximum predicted inflow to the mine is approximately 5600-5900 ML/yr (Section 6.5) is not the same as the sum of the licensing recommendations in Table 6-11. This is because the peak takes from different Water Sources are not simultaneous.

Dendrobium Mine currently holds entitlement for 9755 units for Nepean MZ2 (Section 1.7), which is approximately 3925 ML or 41% greater than the predicted peak groundwater take in Nepean Sandstone MZ2.

6.10 Long-term groundwater discharge and water quality

Once mining is completed and dewatering of the workings ceases, groundwater will fill the mine workings and the goaf, and cause groundwater pressures in overlying and surrounding strata to recover (Section 6.6.2). Recovery of groundwater levels within and surrounding the mine will result in changes in groundwater flow direction and the following potential effects over various timescales:

1. Groundwater recovery in shallow geological strata and discharge to overlying and surrounding watercourses in Special Areas via mine-induced fractures (years to decades after mining).
2. Flooding of the mine and deeper fracture zones leading to reversal in groundwater gradients and potential migration and discharge of deep groundwater to overlying and surrounding watercourses within Special Areas (many decades after mining).
3. Egress of water from mine portals at the Illawarra Escarpment (decades after mining).

WaterNSW (2018) previously stated that there was particular concern "*that any additional increases in iron, manganese and possibly aluminium and other species dissolved from undermined catchments* *will impact on raw water quality delivered to Sydney Water and other customers*". In that context, the three pathways or mechanisms and risks, with estimates of potential impacts, are presented below.

6.10.1 Groundwater recovery and discharge from shallow strata

Field observations at Dendrobium Mine and the adjacent Elouera Mine show that, over the short- to medium-term following longwall extraction (years to decades), groundwater recovery in shallow geological strata can result in discharge of groundwater of poorer water quality via mining-induced fractures within watercourses overlying and surrounding a longwall mine. (Sections 2.8.3 and 3.4.3). These effects are distinct from the longer-term effects of groundwater upwelling and discharge from deeper strata because, in the initial years to decades following mine closure, groundwater gradients in deeper strata remain downward or toward the mine workings (Section 6.6.1).

The shallow groundwater discharge effects are well documented in End of Panel reports and are summarised below. The observations provide a sound basis for estimating the magnitude of similar effects at Area 5. Water quality time-series plots for metal concentrations at representative upstream (or impacted locations) and downstream monitoring sites are shown in **Appendix E**.

The primary land use is a water supply catchment or Special Area (Section 2.3). Therefore, the water quality of this "beneficial use" is characterised by the natural (pre-mining) water quality, the standards set in raw water supply agreements (WaterNSW, 2021) and the relevant ANZECC guidelines.

End of Panel reporting for Dendrobium Mine has identified the following groundwater quality effects in watercourses that overlie or are within ~400 m of Dendrobium and Elouera:

- Anomalous water quality in first- and second-order tributaries WC21, SC10C, LA4, DCC whose headwaters directly overlie extracted longwalls. Those effects include transient or persistent increases in EC (up to 200 µS/cm higher than the baseline of ~100 µS/cm), increases (or decreases) in pH and increases in dissolved metal concentrations such as Fe, Mn, Al and Zn (Table 6-12). These effects are significantly diluted downstream, for example at WC_FR6 and DCL3, as discussed below and shown in **Appendix E**.
- Iron-staining in creeks is commonly associated with watercourses that have been directly mined beneath or are within the area of influence (≤400 m). In recent years, new or recurrent iron-staining has been noted on Wongawilli Creek, WC21, LA5 and SC10C. In most cases the iron-staining can be traced back to individual springs from fractures within or adjacent to the watercourse. Groundwater monitoring indicates that reactivation of iron-rich springs correlates with recovery in shallow groundwater levels, including above mined longwalls, following high rainfall as occurred in 2020-2022. Sampling of discharged groundwater at springs shows elevated Fe and Mn, but not significantly elevated in Al and Zn (Table 6-12).
- At the upstream monitoring site on Wongawilli Creek, WWU4, there is an increase in concentrations of dissolved Zn, Mn and Al from late 2007. This site is up-gradient of Dendrobium mining influence, and the effects are likely related to mining at the Elouera Mine (now part of Wongawilli Mine) located south of Dendrobium. As such, the effects form part of the baseline conditions for Dendrobium but nevertheless illustrate localised surface water quality effects from longwall mining. Notably, zinc concentrations at WWU4 increase immediately after the end of mining at Elouera Mine and decline gradually over ~12 years. In 2020 and 2021 Zn concentrations increase again (to a lesser extent) due to the high rainfall in those years and reflects a rise in groundwater levels and a resurgence in seepage through mine-related surface (or near-surface) fractures. There is a slight increase in Zn at the downstream monitoring location (WC_FR6) corresponding to the Elouera Mine effect. No corresponding changes in Mn and Al are apparent downstream at WC_FR6.

Table 6-12 Summary of water quality in the HBSS and at selected stream sites

Location	Period (pre-/post-mine)	Statistic (median, 95th %ile)	EC (µS/cm)	pH**	Dissolved Fe (mg/L)	Dissolved Mn (mg/L)	Dissolved Al (mg/L)	Dissolved Zn (mg/L)
WWU4 (upstream of Dendrobium, downstream of Elouera)	Pre 3B	P50 (n=102)	89	5.5	0.08	0.09	0.06	0.028
		P95**	122	4.7	0.25	0.22	0.12	0.060
	Post	P50 (n=86)	89	5.5	0.06	0.05	0.04	0.024
		P95	121	4.5	0.16	0.09	0.08	0.037
Groundwater (HBSS)	All	P50 (n=221)	144	5.8	0.80	0.65	0.01	0.012
		P95	375	4.6	23.1	1.3	0.95	0.09
WC Spring	Post 3B	1 sample	na	na	22.4	1.8	0.01	0.02
WC12 Spring	Post 3B	1 sample	na	na	19.4	1.5	0.07	0.007
SC10C Pool1	Pre 3A (baseline)	P50 (n=30)	98	5.5	0.25	0.05	0.12	0.003
		P95	128	4.7	1.3	0.21	0.19	0.02
	Post	P50 (n=266)	205	5.1	0.78	2.01	0.15	0.23
		P95	370	3.5	22.9	4.2	2.21	2.16
DC13 Pool2B	Pre 3B (baseline)	P50(n=13)	107	5.4	0.08	0.02	0.08	0.003
		P95	124	5.0	0.25	0.07	0.138	0.039
	Post	P50(n=93)	99	5.1	0.16	0.06	0.14	0.01
		P95	304	3.9	2.0	2.1	4.6	0.98
WC_FR6 (downstream of mining)	Pre 3A (baseline)	P50 (n=206)	102	6.2	0.28	0.04	0.04	0.005
		P95**	126	5.4	0.83	0.07	0.09	0.011
	Post 3B	P50 (n=298)	94	6.2	0.20	0.04	0.03	0.007
		P95**	139	5.5	0.76	0.12	0.08	0.022
DCL3 (downstream of mining)	Pre 3B (baseline)	P50 (n=234)	142	5.9	0.24	0.04	0.04	0.003
		P95	173	5.2	0.97	0.18	0.11	0.009
	Post 3B	P50 (n=172)	135	6.0	0.26	0.03	0.04	0.005
		P95	182	5.4	0.9	0.18	0.10	0.03
WaterNSW‡ Nepean WFP					5.0	1.5	1.4	na
ANZECC*						1.9	0.055	0.008

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems. ** P5 reported for pH.
‡ (WaterNSW, 2021) raw water supply standards for the Nepean Water Filtration Plant (WFP) in Table 4.2.

- At downstream locations on Donalds Castle Creek and Wongawilli Creek (DCL3 and WC_FR6), water quality effects corresponding to those observed at impacted first-and second-order tributaries are negligible to minor (**Appendix E** and Table 6-12). Median concentrations of Fe, Mn, Al and Zn have not changed significantly compared with the pre-mining baseline. Concentrations remain below the ANZECC guideline for protection of 95% of freshwater aquatic species, and below the baseline P95 concentrations. There is a slight increase in Zn at WC_FR6 from 2007 associated with the end of operations at Elouera Mine, and transient increases in Zn concentration (above the ANZECC guideline) are more frequent at both downstream locations after mining commenced at Dendrobium; however, the median values remain below the guideline. Surface water remains well within WaterNSW raw water supply requirements for dissolved metals.

- Relatively few analyses are available of arsenic (As) in water samples. Of 427 analyses collected since 2002, all but 9 are below 0.001 mg/L, the laboratory limit of reporting (LOR) and ANZECC guideline for protection of 95% or aquatic species. The few detections are from monitoring sites well up-stream and beyond the influence of mining at the time of sampling.

In summary, transient increases in EC, decreases (or increases) in pH and increases in some metal concentrations are apparent in some first- and second-order watercourses that pass directly above or within 400 m of extracted longwalls. The effects are related to groundwater seepage through near-surface subsidence fractures and also diversion and re-emergence of surface water flow through fractures in watercourses. Discharges are typically high in iron, resulting in localised iron-staining of affected watercourses. The effects diminish downstream due to precipitation of iron oxyhydroxides (causing orange discolouration) and dilution with increasing flow downstream. Dilution is such that, at downstream monitoring sites such as DCL3 and WC_FR6, the effects and changes in solute load are negligible or minor. Similar effects are anticipated for tributaries that pass over or within 400 m of Area 5 longwalls. Water quality effects in tributaries that directly enter Lake Avon, such as LA12-LA15 and LA17, may result in a transient increase in metal loads to the lake. Those minor catchments represent approximately 6% of the total catchment contributing to Lake Avon, and are unlikely to significantly influence the overall water quality in Lake Avon.

6.10.2 Mine flooding and groundwater discharge from deeper strata

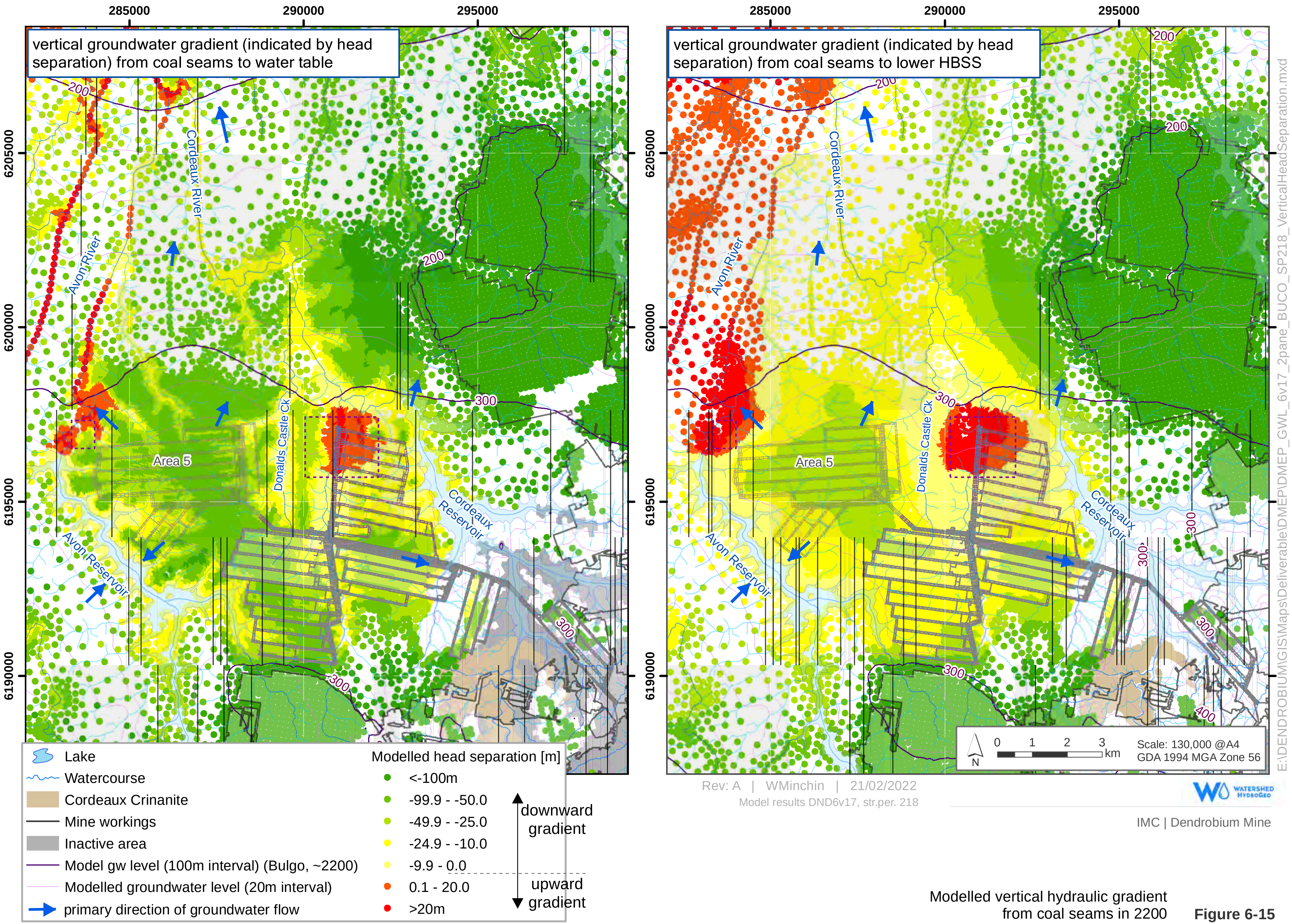
Agencies have previously raised an issue of the potential effects of the Dendrobium Extension Project on water quality. The particular issue is described as follows: "*groundwater pressures may recover towards pre-mining conditions in the decades following closure of the mine. This has the potential to increase discharges of poor-quality water from some sites into the Special Areas for an unknown period of time.*" (IEPMC, 2019). This corresponds to point #2 in Section 6.10.

The potential water quality impacts to water reservoir storages due to groundwater recovery and discharge within the Special Area following mine closure was assessed previously (Watershed HydroGeo, 2020b). The analysis has been updated based on the current EIS groundwater model and summarised below. The analysis estimates the upward groundwater flux following mine closure, and calculates the likely groundwater quality of discharge using a mass balance approach, based on the known concentration of dissolved metals within mine inflow and deeper strata.

Figure 6-15 presents estimated vertical groundwater gradients between the Bulli Coal Seam overlying strata after closure (year 2200), with symbology used to indicate areas where a persistent or near persistent upward gradient occurs (yellow-red-orange). The figure shows the calculated gradient from the seam to the water table, and also from the seam to the lower HBSS (which is used because the Avon Reservoir, and much of the Cordeaux Reservoir, and most major watercourses, are hosted within this unit). The maps show that the areas most likely affected up upward groundwater fluxes are:

- the north-western part of Area 3C; and
- the north-western corner of Area 5 (under tributary AR32, adjacent to Longwall 505).

Neither of those areas are immediately adjacent to Avon or Cordeaux water supply reservoirs. It is important to note that groundwater discharge could be facilitated by fracturing of strata above the longwall footprint and along watercourses within or very close to the longwall footprint. Groundwater flux beyond the pillars will be limited by the permeability of the (unfractured) host formation.



Modelled vertical hydraulic gradient from coal seams in 2200

Figure 6-15

One of these areas (shown as dashed boxes in Figure 6-15), was selected to assess water quality effects associated with upward groundwater flux associated with the Project. The area selected is the zone covering part of tributary AR32 described above. The strongest upward gradient in this area occurs just outside the longwall footprint, so vertically connected fracturing is not present in much of this zone, and therefore does not significantly enhance the rate of upward flux.

This area represents approximately 0.5% of the Avon River catchment to this point just downstream of Avon Dam wall. The zone was subdivided into vertical zones:

1. Upper/mid-Hawkesbury Sandstone (model layers 1-3).
2. Lower Hawkesbury Sandstone (model layer 4).
3. 'Deep' groundwater; Bald Hill Claystone and below (model layers 5-14).

Modelled lateral and vertical fluxes to and from the lower Hawkesbury Sandstone were examined. The lower Hawkesbury Sandstone is the focus of this analysis because it is the unit that is in connection (through a thin regolith layer) to the Avon Reservoir and incised valleys around Dendrobium Mine.

Review of modelled fluxes indicates that the post-mining upward flux from deep strata to the lower Hawkesbury Sandstone in this area is approximately 2 m3/d in the zone being assessed. This is 1-1.5% of the lateral flux from other parts of the HBSS, and 1% of the average baseflow to watercourses (primarily a section of Avon River and its tributary AR32) within this zone. These ratios could rise in dry periods to approximately 5-8% in dry years.

The upward gradient indicates that solutes could migrate upward in groundwater after groundwater pressure recovery in a fraction of the selected zone. The magnitude of this effect on groundwater quality should be small given that the upward flux component would only be 1-1.5% of the average lateral flux in the lower Hawkesbury Sandstone in this local area around AR32 and its confluence with Avon River.

Considering solute transport via a mass balance approach, further analysis of these fluxes is carried out using the water quality database held by IMC and summarised for key metals (as identified by WaterNSW; Section 6.10). The modelled fluxes and concentrations are summarised in Table 6-13, noting that the fluxes are scaled up for the whole catchment to this point on Avon River. The greatest increase being for arsenic (0.13%), and the next highest is zinc (0.01%). The concentration of zinc in groundwater in the fractured zone is less than the relevant (aesthetic) guideline, while the arsenic concentration is slightly higher than the ANZECC guideline level (0.001 mg/L).

Table 6-13 Summary of solute (metal) loads in groundwater flowing to Avon River

Solute	Existing (pre-mining) condition			Additional loading, long-term post-mining		
	Baseflow flux	259	[m^3/d]	Upward flux to HBSS	2	[m^3/d]
	HBSS concentration	Baseflow load (=conc. x baseflow flux)	Up-scaled load for Avon R. catchment	Deep groundwater concentration	Upward flux load (=conc. x flux)	% change in baseflow loading for Avon catchment
	[mg/L]	[g/d]	[g/d]	[mg/L]	[g/d]	
Aluminium	0.132	34	6835.2	0.024	0.05	0.001%
Arsenic	0.001	0.3	53.1	0.035	0.07	0.13%
Manganese	0.479	124	24784.8	0.025	0.05	<0.001%
Zinc	0.022	6	1138.7	0.037	0.07	0.01%
Iron	4.847	1255	250938.7	0.115	0.23	0.001%

Metal concentration in deep groundwater based on maximum of IMC and Sydney Water averages presented in Table 6-12.
E:\DENDROBIUM\Model\GWmodel\Processing\Zonebudget\DND6TR17pD_GWUpflow_v2.xlsx

Therefore, potential impacts on the water quality of the water supply (i.e. Avon River downstream of Avon Reservoir) as a result of the Project due to changes in groundwater flux are considered to be negligible. It is theoretically possible, in the absence of dilution from another source of water, that upward flux of deep groundwater may cause arsenic concentrations to rise above ANZECC freshwater guideline triggers in very localised areas near AR32. However, this is considered unlikely given that upward flux groundwater would be diluted by recharge and lateral flow through the HBSS.

6.10.3 Summary of potential risks to Special Area water quality

Based on the modelled water balance and the water chemistry of 'deep' groundwater (Section 6.10.2), as well as monitoring data that illustrates historical effects of 'shallow groundwater' flow through and leaching from surface or near-surface fracture networks (Section 6.10.1), the 'shallow' process is considered more likely to cause greater loading of metals to water storages than would upward flux groundwater from the goaf. The historical data shows that this is likely to occur within a period of years after longwall extraction, rather than multiple decades. Of the metals assessed, Zinc (Zn) is most likely to be present above ANZECC guidelines as a result of mining effects, however there is no standard for this in WaterNSW's raw water supply agreements. Notwithstanding, these impacts are expected to be negligible on the scale of the catchment to a water supply reservoir or the catchment to Avon River.

This process, and the associated water quality effects, are similar to those that are already observed around Dendrobium Mine (and other mines) in the Southern Coalfield. In relation to this, IEPMC (2019) note "*Although surface fracturing elevates metal loads in watercourses, there is no evidence that mining in the Special Areas is currently compromising the ability of WaterNSW to meet raw water supply agreement standards*".

6.10.4 Groundwater discharge from mine portals

The most direct pathways for mine water egress is via the Dendrobium portals (specifically the Kemira Valley portal, due to its elevation), via abandoned mine headings and portals along the Illawarra Escarpment, and natural discharge points. Note that unlike the processes described in the preceding sections, this process occurs outside WaterNSW's Special Area.

Modelling as part of this EIS indicates that egress from the mine portals would be low initially at the time of mine closure, from <0.1 ML/d (Figure 6-16) rising to 0.5 ML/d within a few years.

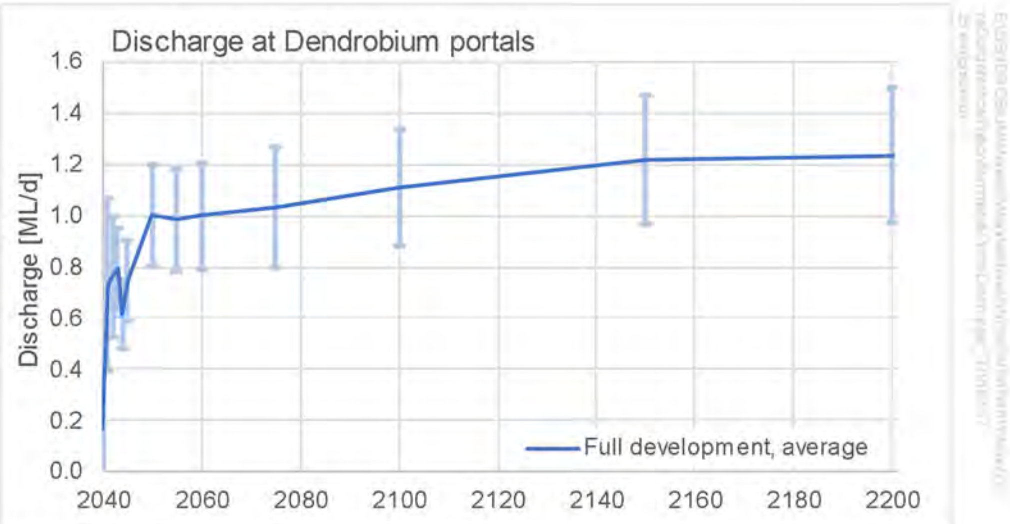


Figure 6-16 Modelled discharge at Dendrobium portals

Groundwater flux from Areas 2, 3 and 5 would be limited by both the bulkheads proposed (SLR, 2022), and by the elevation gradients from those areas toward the portal (Section 3.5; Figure 3-9).

The bulkheads will limit or modulate the egress of water from Areas 2, 3 and 5 toward the Dendrobium portals through the roadways themselves, but will not cause it to cease completely, as water will pass through the coal seam around the bulkheads and into the mains or Area 1 workings. Inflow to Area 1 will drain to the portals. The modelling indicates that once workings in Areas 2, 3 and 5 flood and water levels recover to above the elevation of the bulkheads, then the volume of discharge would increase over time, reaching approximately 1.2 ML/day (range from uncertainty scenarios is 0.95 to 1.5 ML/d), as shown on Figure 6-16.

This long-term flux has been reviewed for both Scenario D (Full Development, which includes Area 5) and Scenario C (Dendrobium without the Project). The model results indicate that the difference in this discharge rate between the scenarios is <1%. That is, the simulated mining in Area 5 makes almost no difference to this flux compared to the flux from Areas 1-3C.

Some water may move to either the Wongawilli/Nebo or Kemira workings, depending on the water management in those mine areas and the relative head or floor elevations in the workings. Additional water from Dendrobium to those neighbouring mine workings is likely then to discharge to the escarpment, assuming those workings also drain (e.g. Kemira to the Kemira Valley).

Groundwater discharge from the portals is likely to be of similar quality to mine goaf inflow waters. IMC recently commissioned a study to sample and characterise water egress from nearby abandoned mine portals along the Illawarra Escarpment to inform the understanding of the water quality of long-term post-closure discharges. That study is still in progress (HGEO, 2022c, in prep.); however initial results, based on the first two sampling events, are summarised in Table 6-14.

The results indicate that mine portal drainage tends to be brackish, neutral to slightly alkaline and dominated by bicarbonate and mixed cations (Na, Mg, Ca), similar to goaf outflow water at Dendrobium. Metal concentrations are typically low, consistent with the neutral to slightly alkaline pH, but may exceed guidelines for freshwater aquatic ecosystems for some metals at the discharge points.

Table 6-14 Summary of water quality at selected mine portals

Portal	Samples	Major ion water type	EC (µS/cm)	pH	Fe (mg/L)	Al (mg/L)	Zn (mg/L)
Bulli Drift	1	HCO_3-Cl-Na-Mg-Ca	1720	8.1	<0.05	<0.01	0.006
Corrimal drainage	2	HCO_3-Cl-Na-Mg-Ca	650	7.6	2.03	0.05	0.041
Den-LDP26	2	HCO_3-Na-Mg-Ca	1750	8.1	5.00	0.02	0.036
Forrest 11 West	1	HCO_3-Mg-Ca	753	8.2	<0.05	<0.01	<0.005
Kemira Tunnel	2	HCO_3-Na	4560	8.1	<0.05	0.02	0.041
O'Briens Drift	1	HCO_3-Mg-Ca	669	8.0	<0.05	<0.01	<0.005
Tom Thumb	1	HCO_3-Cl-Mg-Ca	439	8.0	<0.05	<0.01	<0.005
ANZECC* Guideline					-	0.055	0.008

* ANZECC 2000 - Water Quality Guidelines: 95% protection levels (trigger values) for the protection of freshwater aquatic ecosystems, South-East Australia, low lying river ecosystems.

Further analysis of post-closure water quality impacts is provided by SLR (SLR, 2022), however, in summary the concept is to prevent uncontrolled seepage from adits and portals close to the escarpment by controlling groundwater movement from Areas 2, 3 (and 5) toward Area 1 via modulation bulkheads. At the same time, Area 1 will be allowed to drain continually to the Kemira portal. This would prevent groundwater recovery in Area 1 workings and so prevent groundwater movement from Area 1 into overlying Mt Kembla Mine workings in the Bulli seam, which could in turn discharge to other locations not associated with Dendrobium Mine along the escarpment. Allowing Area 1 to drain means that seepage is directed towards the Kemira Valley Coal Loading Facility where it would be captured and directed to Port Kembla via gravity pipeline (similar to the existing discharge regime to Allans Creek).

7. Conclusions

A significant amount of field investigation and analysis has been completed in recent years, investigating a number of important processes and effects of longwall mining at Dendrobium Mine (including the Project):

- Investigation into the mode and height of fracturing above longwalls, including development of a site-specific model for connected and disconnected fracturing (as per previous recommendations of the IEPMC).
- Investigation of changes to permeability between longwalls and reservoirs.
- Improved analysis of surface water losses in watercourses above and adjacent to longwalls.
- Further work to characterise the water quality of long-term mine water discharge from Dendrobium Mine and neighbouring mines.

Additionally, IMC commissioned SLR to provide a concept plan for mine closure at Dendrobium, considering both ‘approved’ mining and the Project (if approved).

The numerical groundwater model has evolved from previous assessments (e.g. Coffey, (2012a and 2012b); HydroSimulations (2014, 2016a, 2016b, 2018, 2019a, 2019b, 2019c); and WatershedHG (2020 and 2021). It uses the MODFLOW-USG-Transport software code (and has done so since 2016) with variable cell sizes and orientation to simulate drawdown in more detail around mine workings and watercourses, and in less detail via more widely spaced model cells in areas away from Dendrobium. However additional functionality regarding the representation of watercourses and calibration to recent surface water losses estimated from field data, along with inclusion of the site-specific fracture model has improved the reliability of the estimates of surface water loss above and adjacent to longwall areas.

This model has been assessed for calibration using a very large dataset of over 26,000 targets derived from many observations of groundwater levels from approximately 800 bore and piezometer locations. The model has also been calibrated for mine inflow in each mine area as well as the total inflow and corresponding groundwater levels, as well as constraining the model to field testing of permeability while incorporating the accepted and conceptually appropriate relationship between hydraulic conductivity with depth.

Rainfall recharge input to the groundwater model has also been calculated based on various estimates from analysis of field data and literature, and is routinely compared to BoM’s AWRA-L long-term average estimates of recharge and runoff – the two models compare favourably with one another, adding confidence to this key input. The AWRA-L runoff component is used in the groundwater model to specify the quickflow component of surface water flow.

The calibrated model provides suitable and improved capability for assessing groundwater drawdown and inflow at Dendrobium. The model has subsequently been used to simulate the effects of the proposed development of Dendrobium Area 5 as well as other approved future longwalls in Areas 3A-3C. Longwall extraction within Area 5 is proposed to occur between 2026 and 2034.

Additional focus on the post-closure behaviour of the mine is included in this report, both in terms of the concepts and the numerical simulation of groundwater level recovery and long-term outflow at the portals following installation of the bulkheads proposed in closure planning (SLR, 2022).

The following results and information were obtained from the groundwater modelling.

The model matches historical inflow to the Dendrobium Mine with reasonable accuracy for total mine inflow and the pattern of inflow over time to individual areas.

Dendrobium Mine inflows or groundwater capture ('take') from the surrounding geological sequence is predicted to be in the order of 16 ML/d. Of that peak, approximately 6 ML/d (averaged over months – daily inflows can peak at higher rates for shorter periods) could be derived from Area 5 workings.

Based on the above, groundwater take is predicted to peak at about 5,600-5,900 ML/yr. This predicted inflow is an increase on historical inflows at Dendrobium Mine, however the predicted inflow to Area 5 appears consistent with previous areas considering differing longwall geometry, and also consistent with the nearby Tahmoor Mine that also extracts from the Bulli seam.

In the case of the Avon Reservoir, the simulated leakage from the reservoir due to the development of the whole of Dendrobium, including Area 5 is predicted to be up to approximately 0.4 ML/d based on the base case model. The range in maximum losses predicted by the base case and deterministic scenarios is 0.05-0.58 ML/d (mean of 0.26 ML/d, base case estimate). The peak rate of loss for seven of the eight uncertainty scenarios is less than 0.4 ML/d for the whole of Dendrobium. The incremental rate of loss due to Area 5 is predicted to be approximately 0.03-0.4 ML/d (mean 0.18 ML/d).

Leakage loss from Cordeaux Reservoir as a result of the whole of Dendrobium Mine is predicted to be approximately 0.14 ML/d (base case model), up to 0.24 ML/d for the most conservative deterministic scenario. The incremental effect of Area 5 is predicted to be <=0.03 ML/d, which is unsurprising given the distance from the Project to this reservoir.

Leakage from Nepean Reservoir is predicted to be approximately 0.01 ML/d, which is low due to the distance from mining.

Incidental stream flow losses (due to baseflow capture and stream bed cracking) has been estimated using the groundwater model and tabulated as required in Table 6-8 (for specific watercourses around Area 5) and in Table 6-9 and Table 6-10 for broader-scale catchments. The predicted 'take' from watercourses is up to 1450 ML/yr from the whole of Dendrobium Mine, including Area 5. The incremental take due to mining in Area 5 is predicted to be up to about 428 ML/yr (Table 6-11).

Modelling suggests that groundwater drawdown is unlikely to exceed AI Policy minimal impact criterion at any of the 360 water supply works located within the bounds of the numerical model, due to the Project (i.e. no bores were predicted to be affected by the base case run). Similarly, no bores were predicted to be affected by Dendrobium Mine as a whole. These findings are expected given the position of Dendrobium Mine and the Project within the Special Area and distance to registered 'water supply' bores. Many 'water supply' works within the model domain are predicted to be affected by cumulative mining effects, however almost all of these are predicted to experience greater than 2 m drawdown due to historic and/or cumulative mining that is not associated with Dendrobium Mine (**Appendix M**).

After mining, groundwater levels are likely to equilibrate over decades or longer. In Area 5, modelling suggests that groundwater levels in the deeper units, in particular, but also within the Hawkesbury Sandstone, may recover to greater pressures than in shallower strata, leading to the possibility of an upward gradient. Analysis of whether this might result in poorer quality water from the coal measures upwelling from the goaf and fractured zones to the Hawkesbury Sandstone aquifer, with the potential to reduce the quality of water in that strata, suggests that the potential for this pathway is minimal, especially in the presence of dilution of any water from the deeper units that migrates from surrounding groundwater in the shallower units, as well as from surface water runoff. The most noticeable effect on surface water and shallow groundwater quality will be movement of groundwater through freshly fractured strata and discharge to nearby streams, which can lead to discharge of iron floc and associated water quality effects. The locations for this tend to be discrete, influenced my local-scale fracturing, and therefore difficult to predict. However, this process is observed to occur within a period of years after longwall mining and subsidence. The effects on water quality on the scale of water supply catchments is minimal, and does not currently compromise the ability of WaterNSW to meet raw water supply standards.

Based on advice in Niche (2022) and mapping of likely groundwater dependence, most of the vegetation communities above the Project (outside of those mapped as Upland Swamps) are considered to have a low reliance on groundwater, and so would have limited sensitivity to changes in groundwater level. Upland Swamps are reliant on the subsurface presence of water, and those features above or within approximately 60 m of longwalls are likely to experience changes to water availability. Some ecological communities along creek lines (where moderate and higher probability of groundwater dependence has been mapped), may experience localised effects and could result in changes in community composition towards species less reliant on groundwater interaction, however it is not anticipated to lead to an overall change in the mapped community types.

The nearest High Priority Groundwater Dependent Ecosystems (GDE), as defined in the relevant WSP are along O'Hares Creek, the Thirlmere Lakes and the Macquarie Rivulet Estuary. O'Hares Creek catchment is approximately 18 km northeast of Dendrobium Area 5 (14 km north of Area 3C), and Macquarie Rivulet is about 16 km south of Dendrobium. Thirlmere Lakes are approximately 16 km from Area 5. No drawdown effects would occur at these locations as a result of mining at Dendrobium Mine, including Area 5.

7.1 Aquifer Interference Policy Assessment

Assessment of the Aquifer Interference (AI) Policy is summarised in Table 7-1.

Table 7-1 Summary of AI Policy Assessment – Fractured and Porous Rock

Sydney Basin Porous Rock (Nepean Sandstone and Sydney Basin – South Groundwater Sources)	
Category	**Highly Productive (Nepean Sandstone) and Less Productive (Sydney Basin – South)**
Water Table Less than or equal to a 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40 m from any: - high priority groundwater dependent ecosystem; or - high priority culturally significant site; listed in the schedule of the relevant water sharing plan. OR a maximum of a 2 m water table decline cumulatively at any water supply work.	The relevant Water Sharing Plan is the 'Greater Metropolitan Groundwater Sources' (dated 1 October 2011). There are no High Priority Groundwater Dependent Ecosystems (GDEs) listed in this WSP within 14 km of Dendrobium, including Area 5. Hence there are no known groundwater-related risks to such sites due to activity at Dendrobium. There are no Culturally Significant Sites in the Study Area listed in the WSP. Hence there are no known risks of this development to such sites. There is a negligible risk of drawdown in excess of the water supply work drawdown criterion at any 'water supply works' within the Permo-Triassic or shallow strata due to mining at Dendrobium. **Level 1 minimal impact consideration classification.** (see discussion in Section 6.6.5 regarding the cumulative drawdown effects associated with other mining operations).
Water pressure A cumulative pressure head decline of not more than a 2m decline, at any water supply work.	The base case model suggests that no water supply works would be affected by drawdown from Project or by Dendrobium as a whole. Therefore, there is a negligible risk of drawdown in excess of the water supply work drawdown criterion at any 'water supply works' due to mining at Dendrobium. Many bores in the region are predicted to experience greater than 2 m drawdown due to historic and/or cumulative mining that is not associated with Dendrobium (Section 6.6.5). **Level 1 minimal impact consideration classification.**
Water quality Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40m from the activity.	Mining-induced changes to shallow strata is likely to result in changes to salinity and metals concentrations in shallow groundwater and connected surface water. This will be mainly detected as iron-staining along creeks. It is possible that fracturing of the strata in the Dendrobium Mine area may result in mixing of potentially chemically different groundwater between overlying (shallow) and underlying (deep) units. However, it is considered unlikely that this will result in changes to the beneficial use of groundwater in the Permo-Triassic rock units. In both instances, the risk of water quality impacts decreases with distance from the mine footprint. Impacts are limited primarily to elevated concentrations of Al and Zn, but within raw water standards. **Level 1 minimal impact consideration classification.**

7.2 Recommendations

7.2.1 Monitoring and data gathering

A review of groundwater monitoring infrastructure, covering available data, scheduled installations and other planned monitoring bores/piezometers should be conducted to ensure adequate spatial coverage of monitoring of Area 5 that meets IEPMC's (2019a) recommended 2- or 4-year baseline requirement (depending on the type and importance of the monitoring site). That is for Area 5 additional monitoring should generally be considered for installation by early 2024, if not before.

Surface water monitoring around Area 5 is dealt with by HEC (2022), and we consider that the current network has good spatial coverage. However, we make some recommendations based on experience in Area 3B and from the modelling in this study as follows:

- A flow monitoring site on the lower part of Donalds Castle Creek located downstream of Area 5 (i.e. 'DCL'), below the confluence of DC8.
- Sites AR32A1, AR31S1, AR19S1 and DC8S1 would provide useful data on the downgradient effects of mining, however monitoring of the tributaries closer to the proposed longwalls should also occur, if suitable sites are available. Such sites should be 300-500 m (approximately) downgradient of panels, similar to existing gauging sites WC21S1 and DC13S1 in Area 3B, to monitor for the maximum effects of longwalls (gauging sites above longwalls are unreliable and unrepresentative of catchment effects once mining occurs).
- Flow gauging should also be carried out, where suitable sites existing, on tributaries DC10, LA17, DC9, LA14 (in order of the catchment area proposed to be mined under).

Additional short-term focus on arsenic in water quality monitoring is recommended for watercourses and shallow groundwater already affected by longwall subsidence. IMC already have an extensive monitoring program, but a short-term focus on this metal, and others that WaterNSW may identify in addition to those metals discussed in Section 6.10.1, would allow IMC and agencies to understand the potential for this to be a concern in the Special Area. It may prove not to be, given the low rate of detections thus far.

WatershedHG recommends that multiple groundwater monitoring sites between the mine areas and the Avon Reservoir are installed, focusing on the Hawkesbury Sandstone, Bald Hill Claystone and upper Bulgo Sandstone. As has been done around Area 3B, this should include some pre-mining testing of permeability, followed by packer testing in the post-mining environment. Given the empirical assessment of risks presented in Section 3.1, this should focus on the end of southern and western edge of Longwall 502 (S2324, S2325 already active in this area, and should be sufficient), south of Longwall 507, south of Longwall 508-509, and northwest of Longwall 509.

Similarly, at least one bore with piezometers in the HBSS and BGSS is recommended for the area between Area 5 (Longwall 510) and Donalds Castle Creek, perhaps augmenting the coal seam monitoring already occurring at bore S2291 (Figure A4). A similar site should be installed between Area 5 (Longwall 505) and Avon River.

At least one round of surface water flow observations should be conducted to determine flow conditions (using the qualitative "no flow"/"trickle"/"flowing" methodology used by IMC) along watercourses flowing above and near to longwalls in Area 5 particularly during the current (2021-22) wet conditions period to establish the flow conditions. If and when the weather leads to extended dry conditions, a further survey should be carried out as a priority to assess whether these tributaries flow under such dry conditions or have some persistent baseflow. Watercourses around Area 3C should also be included. This would provide a valuable 'drought baseline' dataset.

It is recommended that Dendrobium's extensive programme of water level monitoring, in both 'deep' and 'shallow' (swamp) groundwater systems, be continued in areas of recent, approved and proposed mining.

Formal comparison and analysis of data from existing open standpipe piezometers (or similar) with co-located vibrating wire piezometers (VWP) should be carried out. Consideration of co-located monitoring for shallow formations at selected sites should also be considered.

The recent practice of pre- and post-mining permeability testing above longwalls should be continued for 2-3 of the earlier longwalls in Area 5, should the Project be approved. Following that, the need for further such investigations near Longwalls 507-509 could be reviewed.

Monitoring regarding post-closure behaviour should include:

- Groundwater level and pressure monitoring adjacent (west of) the proposed bulkheads between Areas 1 and 2.
- Groundwater level and pressure monitoring at selected sites around domains where mining occurred (possibly including Area 5, should it be approved). This should be targeted at monitoring the rate of recovery in different stratigraphic units, and the eventual pressure or water level.
- Groundwater quality monitoring at selected sites around domains where mining occurred (possibly including Area 5, should it be approved).
- Surface water quality monitoring within the Special Area (including in creeks flowing from Area 5, should it be approved) and in the receiving waters for the mine portal discharge.

More on this is presented in SLR, 2022, and is expected to be refined and confirmed in future mine closure management plans.

7.2.2 Indicative performance measures

Performance Measures regarding environmental effects and for the purpose of regularly assessing compliance will be required to be developed and agreed pending Project approval. With regard to groundwater and related hydrological effects, the measures should include features or processes similar to those used in Area 3B (the current mining domain), such as:

- Groundwater level depressurisation and recovery at representative monitoring sites around Area 5, such as between Area 5 longwalls and the following receptors (Avon Reservoir, and Avon River and Donalds Castle Creek).
- Groundwater inflow to Area 5 would be monitored as it is in other Dendrobium mining domains. This should be compared to predictions, and the total inflow to all Dendrobium areas compared to groundwater entitlement.
- Qualitative assessment of flow conditions along Avon River (west of Longwalls 504 and 505) and along Donalds Castle Creek (to the east of Longwall 510).
- Quantitative assessment of flows at any downstream flow gauging site on Donalds Castle Creek (see recommendation regarding installation of this site, Section 7.2.1) and comparison against predicted flow reductions. Although it would be desirable, similar assessment of flows on Avon River may not be possible or practical, due to the size and regulated nature of this river.
- Performance measures related to losses directly from Avon Reservoir are impractical due to the inability to monitor this flux in the field or by water balance assessment of the reservoir inputs and outputs. However, on-going modelling assessment following geotechnical investigations along the shoreline could be done to assess potential for leakage to exceed the Dams Safety NSW threshold.

In terms of contingency plans should such measures be breached, further setbacks of longwalls from features or receptors could be considered.

7.2.3 Modelling

This study is focussed on effects and impacts associated with Area 5, based on calibration to mining and hydrological data from 2005-2021.

The groundwater modelling should be reviewed periodically to assess the on-going ability of the model to simulate or replicate groundwater levels and inflows as the mine progresses. The model should be verified again in approximately 2025, after more groundwater data has been gathered in Area 5. It is most likely to be verified prior to that date in any case, as it is used for more regular SMP Groundwater Assessments.

The current understanding of geological structure is documented in PSM (2022). As the level of knowledge is improved or developed, i.e. if further structural features are identified within Area 5 (or elsewhere) that have the potential to act as significant conduits or barriers to groundwater flow, then these should be included in a revised version of the groundwater model.

As per recommendations by the IEPMC (2019a), the groundwater model would be updated with new data and assumptions as necessary.

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HGEO, 2021d. Iron-staining in Wongawilli Creek, August 2021 (No. D21162), Report by HGEO Pty Ltd for South32 Illawarra Metallurgical Coal.

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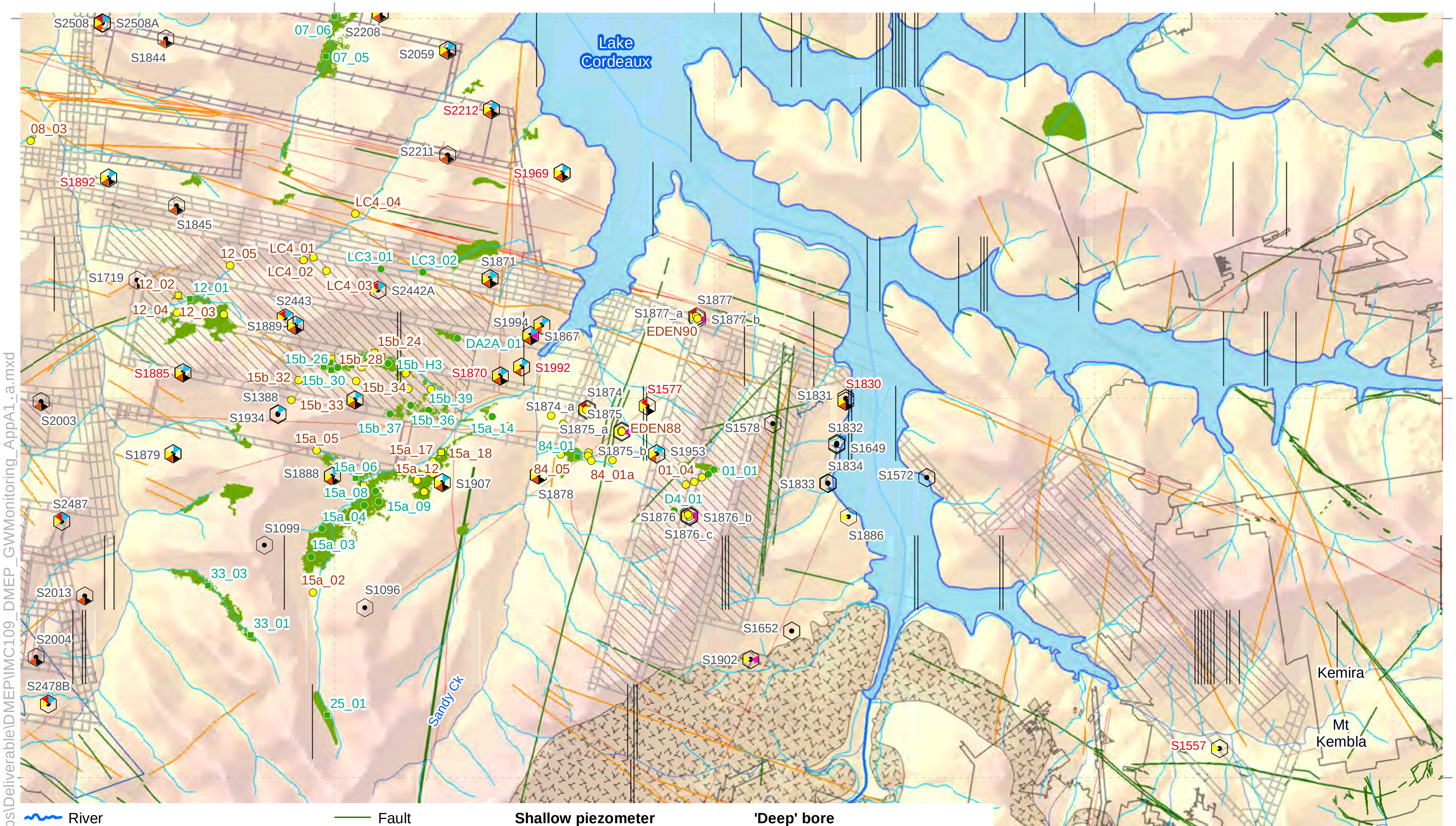
Appendix A: Groundwater monitoring network at Dendrobium [2021]



River
Creek
Lake / reservoir
Upland Swamp (IMC / OEH)
Dendrobium workings: existing
Dendrobium workings: future approved
Extracted panels (Oct 2021)
DMEP Area 5 workings

Fault
Dyke
Lineament
Disturbed ground
Cordeaux Crinanite

Shallow piezometer
Swamp; w/ logger
Swamp; manual dip only
Not swamp; w/ logger
Not swamp; manual dip only

'Deep' bore
'Deep' bore

Strat. group of piezometer(s)
HBSS
BHCS
Narrabeen Fm
Bulli Coal / Eckersley Fm
Wongawilli Coal / lower units
other

0 0.25 0.5 0.75 km

Scale: 35,000 @A4
GDA 1994 MGA Zone 56

N

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Groundwater monitoring:
Areas 1, 2 and 3A

Figure A1

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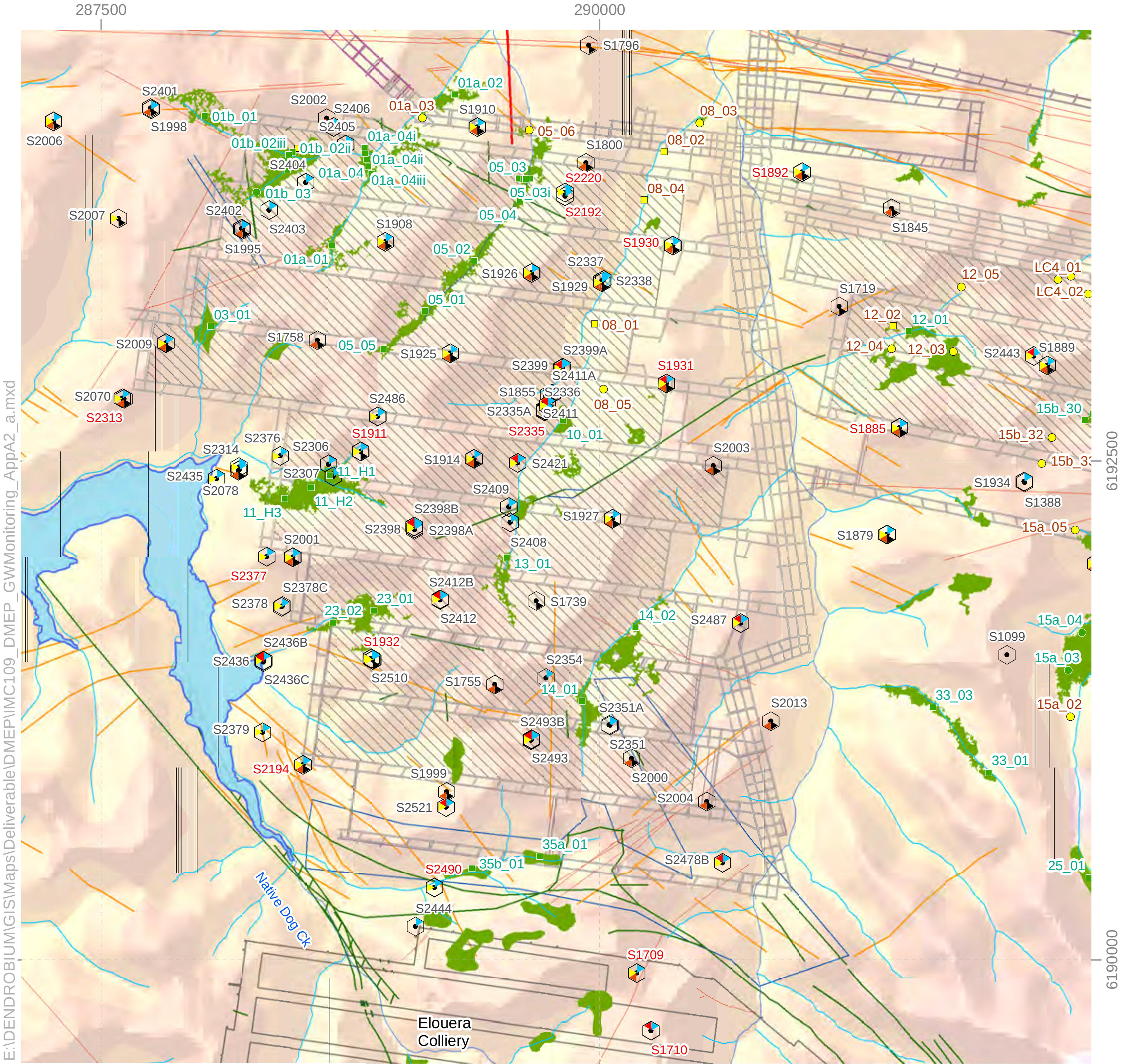

River
Creek
Lake / reservoir
Upland Swamp (IMC / OEH)
Dendrobium workings: existing
Dendrobium workings: future approved
Extracted panels (Oct 2021)
DMEP Area 5 workings
Fault
Dyke
Lineament
Disturbed ground
SouthernCF Interp. Fault
SouthernCF Interp. Structure
Cordeaux Crinanite

Shallow piezometer

Swamp; w/ logger
Swamp; manual dip only
Not swamp; w/ logger
Not swamp; manual dip only

'Deep' bore

'Deep' bore

Strat. group of piezometer(s)

HBSS
BHCS
Narrabeen Fm
Bulli Coal / Eckersley Fm
Wongawilli Coal / lower units
other

N

0 0.2 0.4 0.6 km

Scale: 27,500 @A4
GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Groundwater monitoring:
Area 3B

Figure A2

E:\DENDROBIUM\GIS\Maps\Deliverable\DMEP\IMC109_DMEP_GWMonitoring_AppA2_a.mxd

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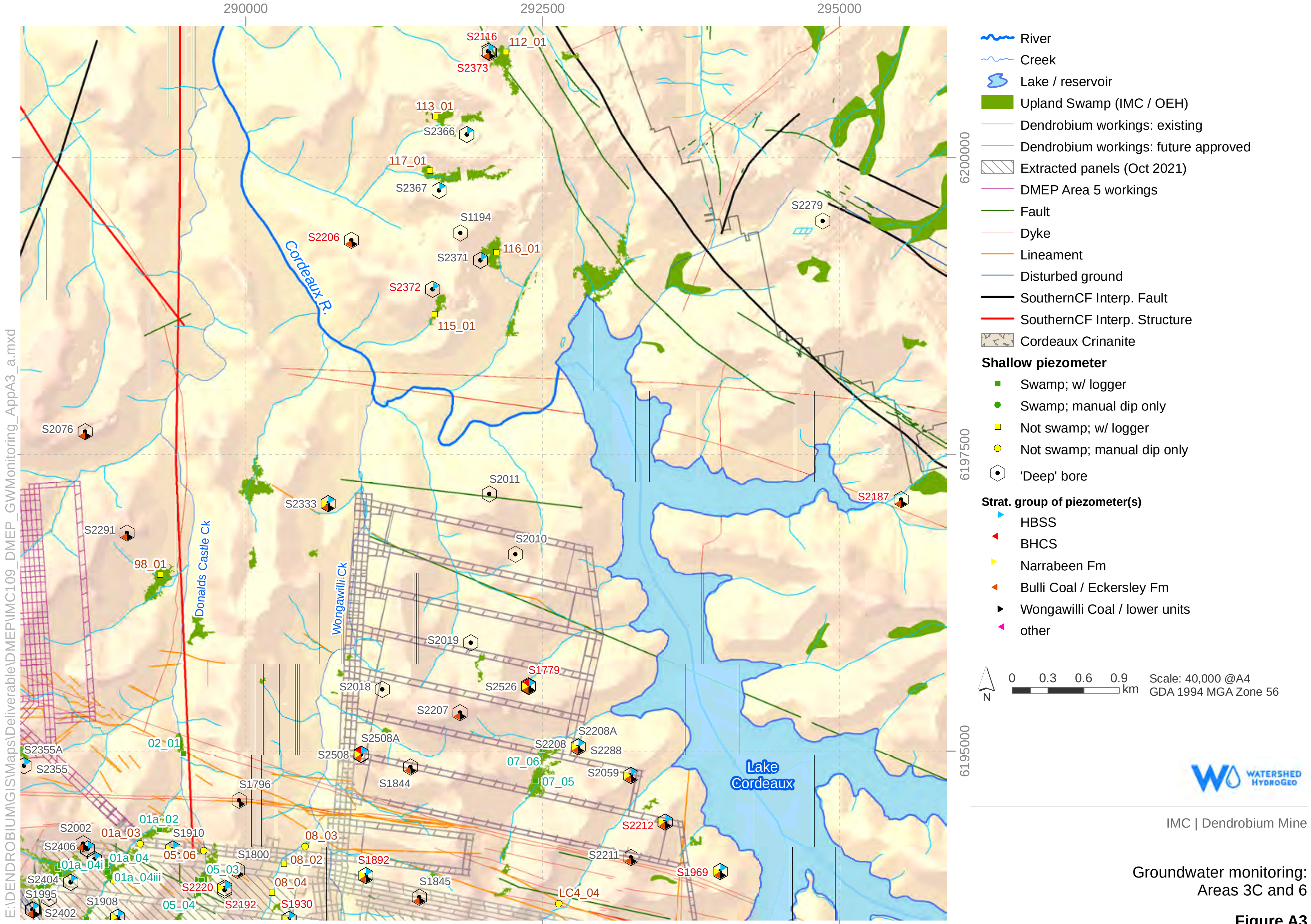
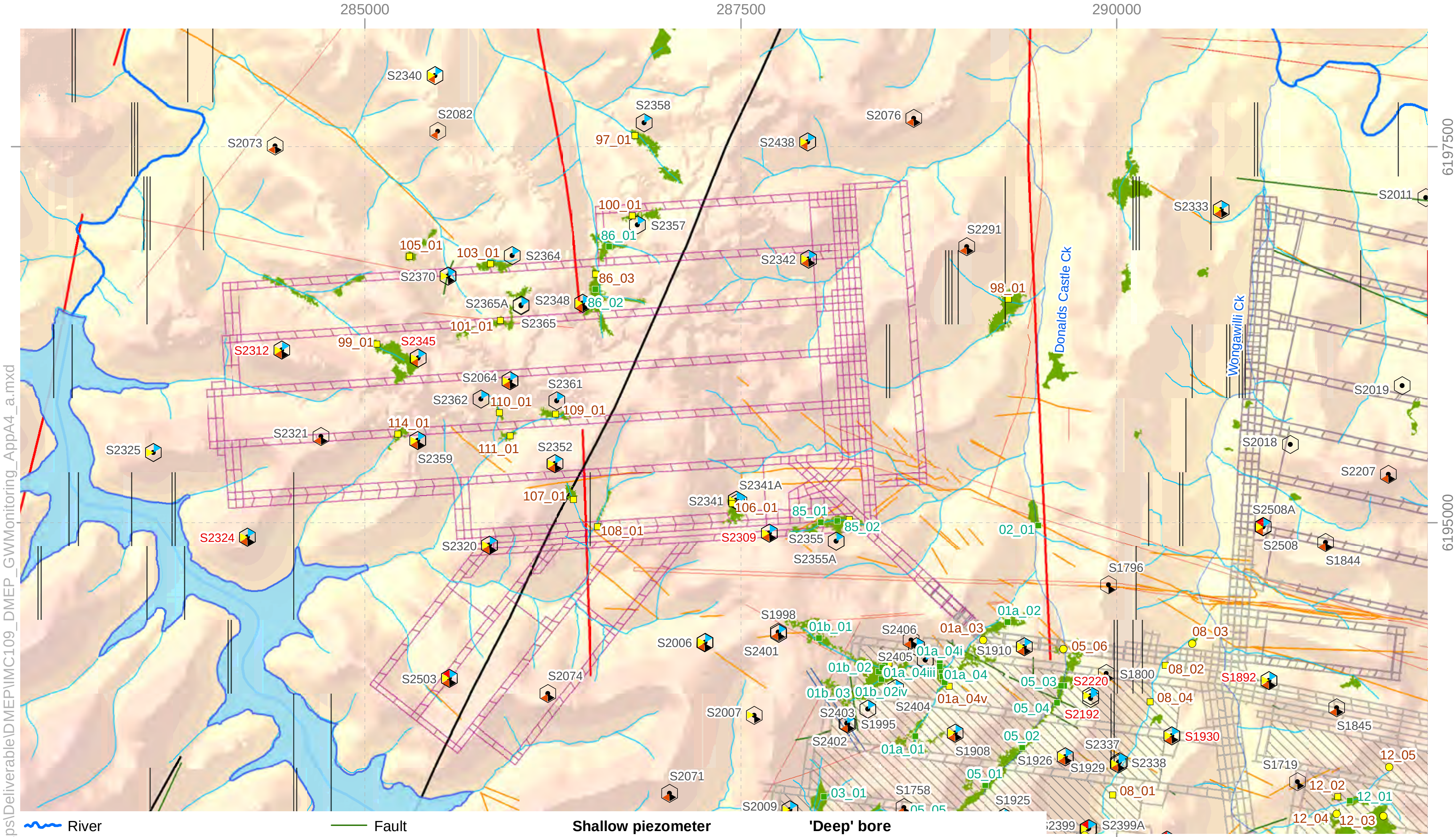


WATERSHED HYDROGEO

IMC | Dendrobium Mine

Groundwater monitoring:
Areas 3C and 6

Figure A3



River
Creek
Lake / reservoir
Upland Swamp (IMC / OEH)
Dendrobium workings: existing
Dendrobium workings: future approved
Extracted panels (Oct 2021)
DMEP Area 5 workings

Fault
Dyke
Lineament
Disturbed ground
SouthernCF Interp. Fault
SouthernCF Interp. Structure
Cordeaux Crinanite

Shallow piezometer
- Swamp; w/ logger
- Swamp; manual dip only
- Not swamp; w/ logger
- Not swamp; manual dip only

'Deep' bore
- 'Deep' bore

Strat. group of piezometer(s)
- HBSS
- BHCS
- Narrabeen Fm
- Bulli Coal / Eckersley Fm
- Wongawilli Coal / lower units
- other

N

0 0.25 0.5 0.75 km

Scale: 35,000 @A4
GDA 1994 MGA Zone 56

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Groundwater monitoring:
Area 5

Figure A4

E:\DENDROBIUM\GIS\Maps\Deliverable\DMEP\IMC109_DMEP_GWMonitoring_AppA4_a.mxd

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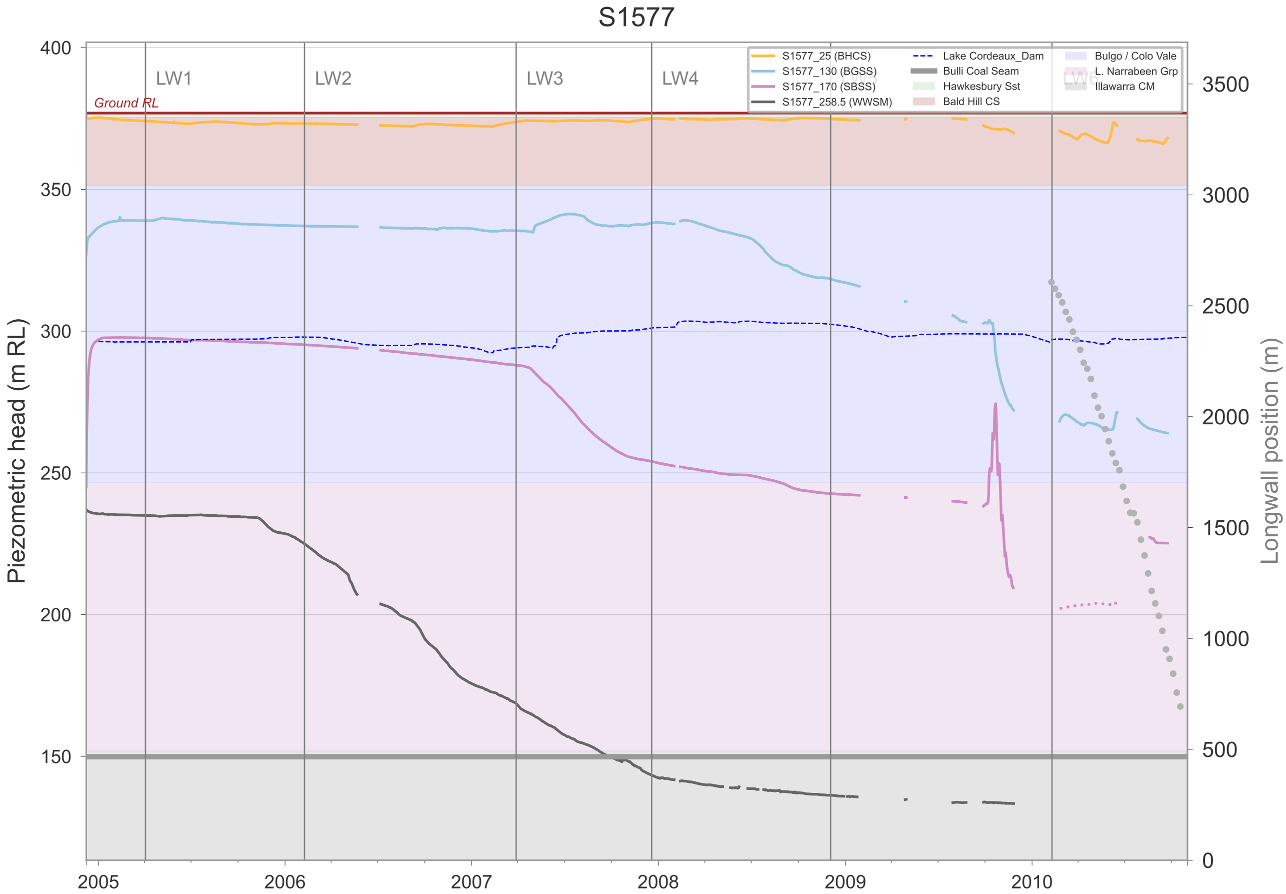
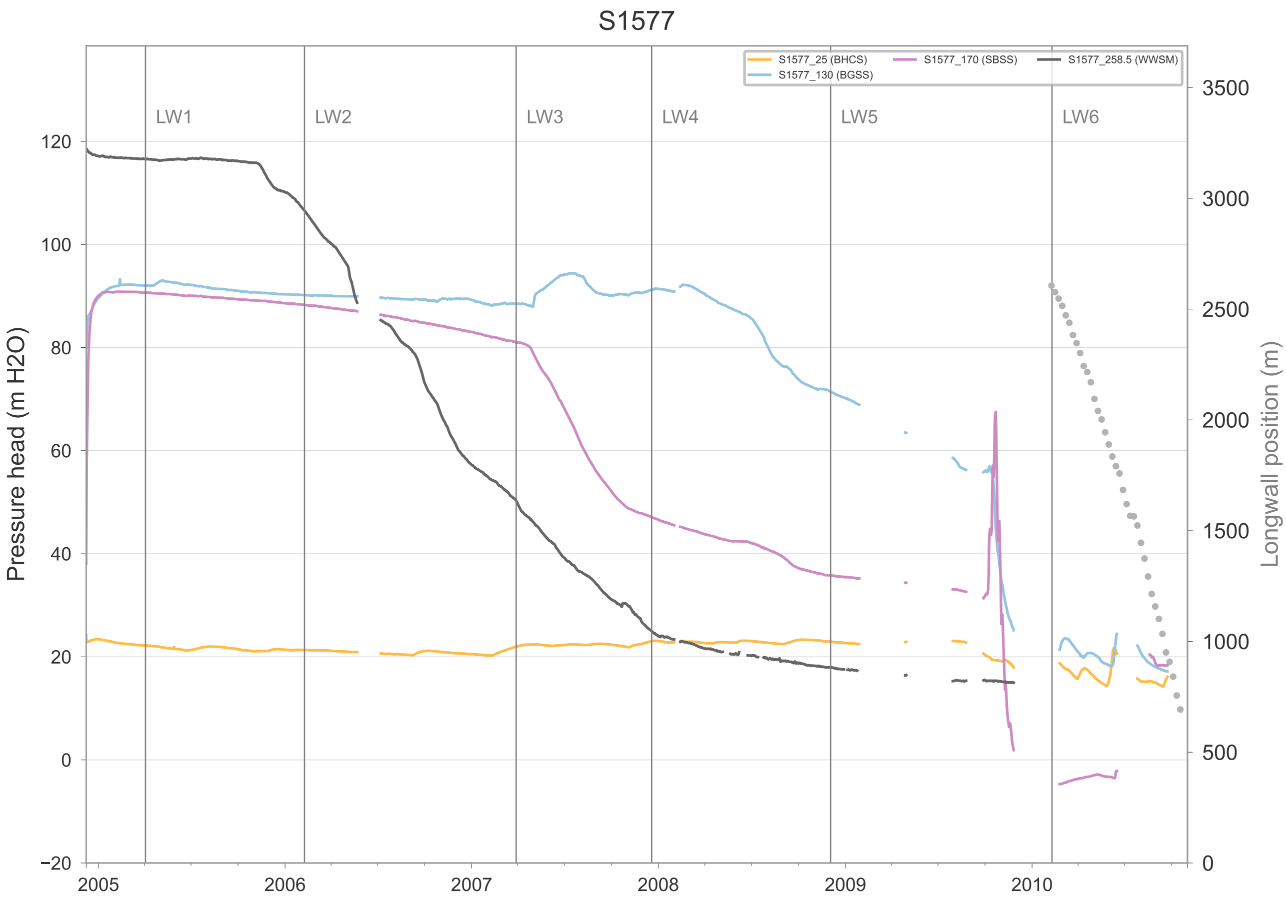
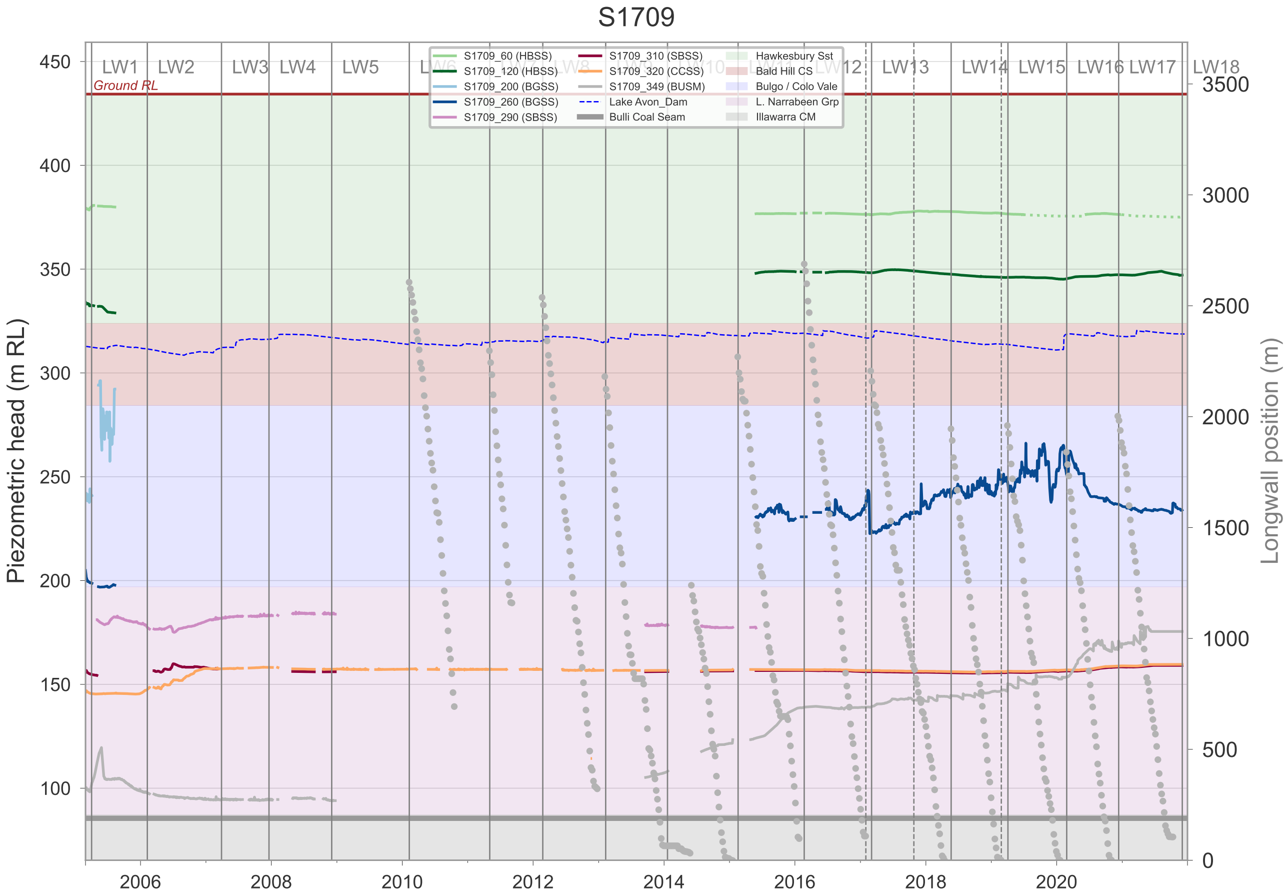
Appendix B: Groundwater level hydrographs

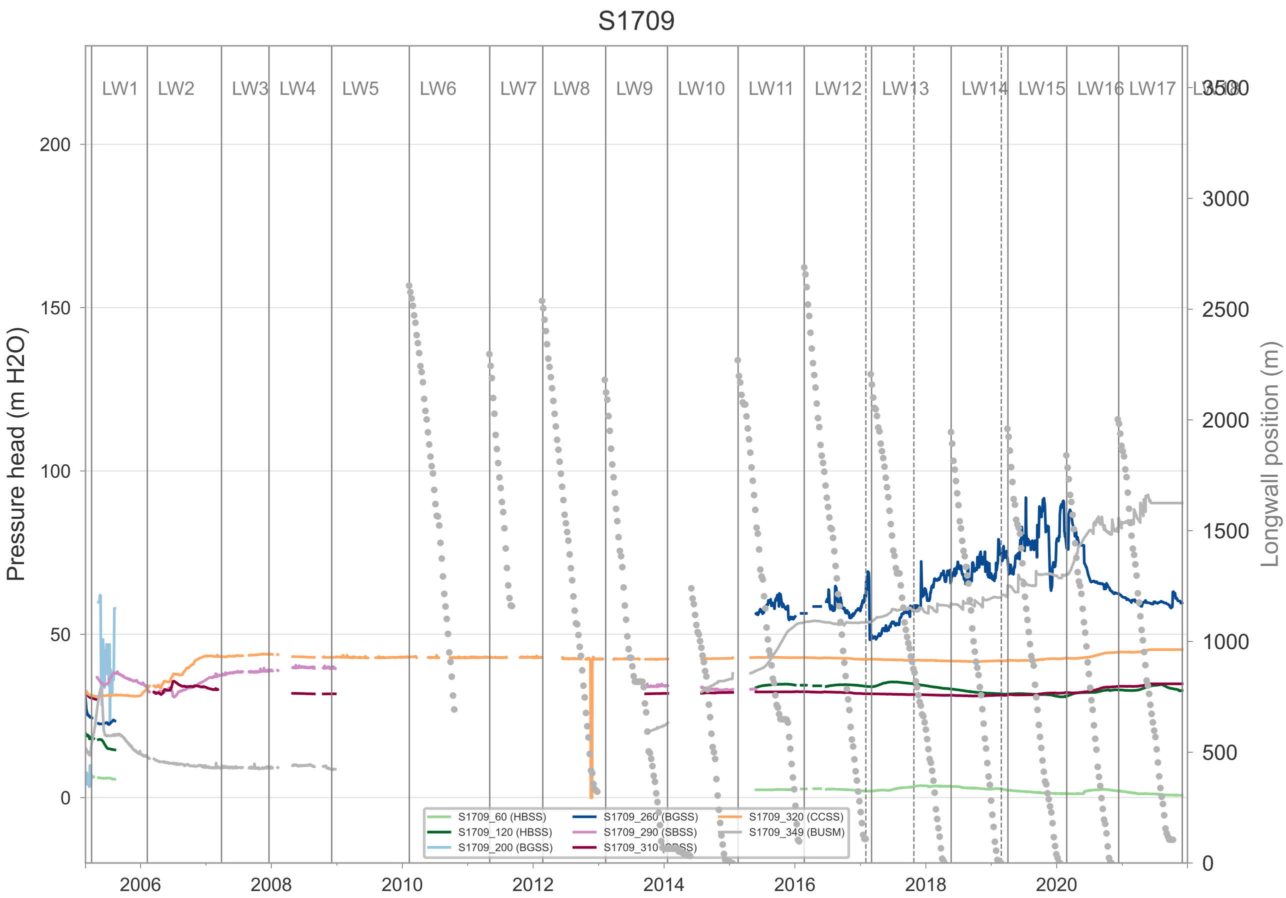
Groundwater hydrographs



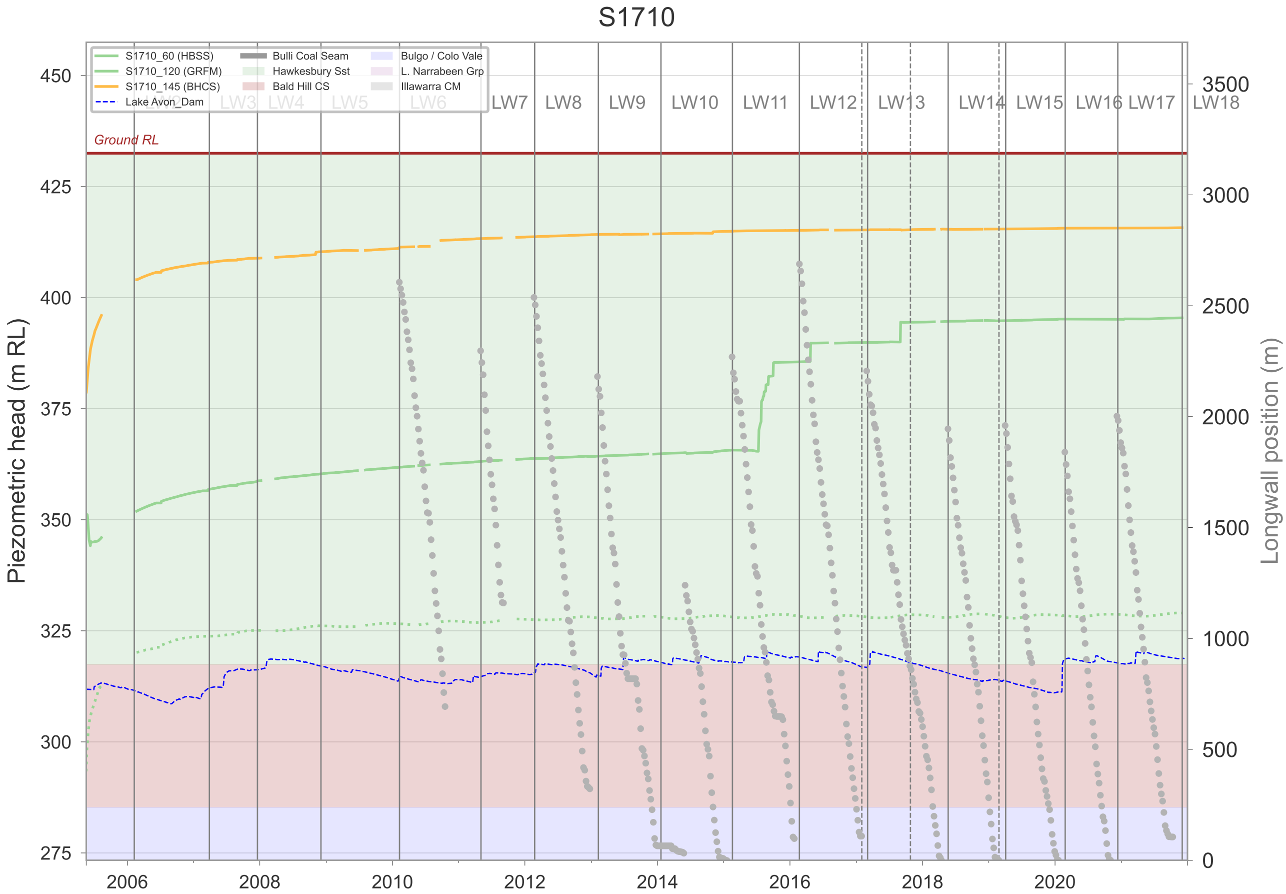


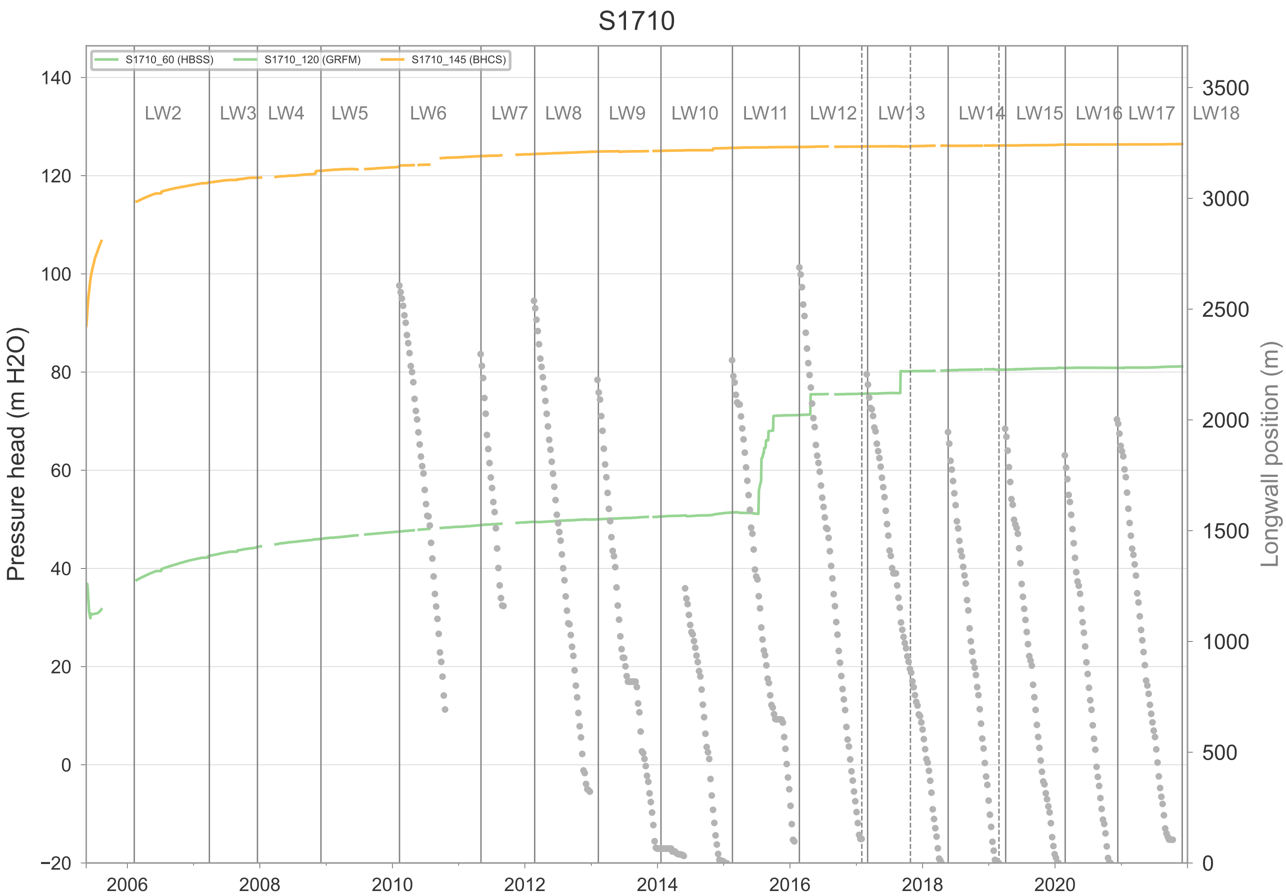
Groundwater hydrographs



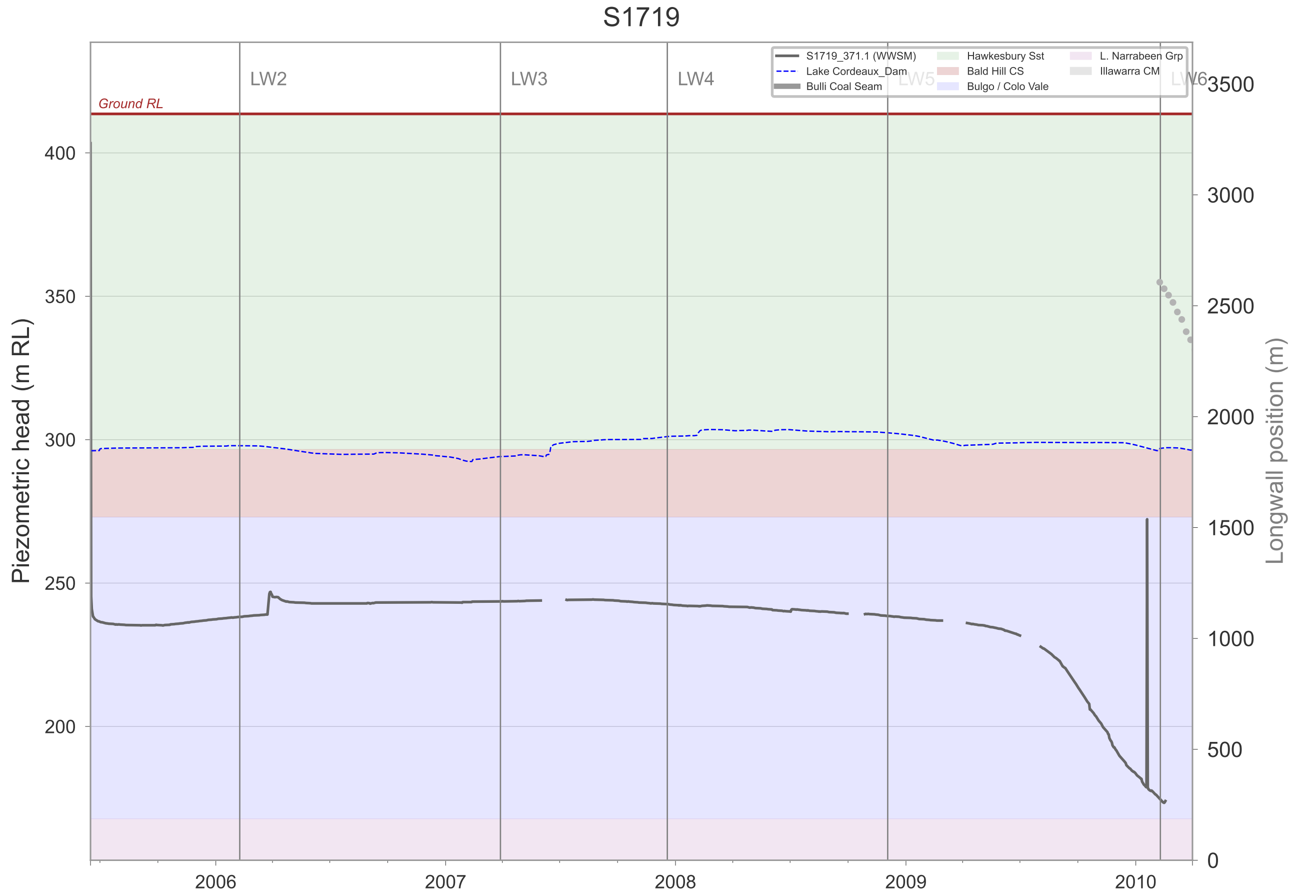


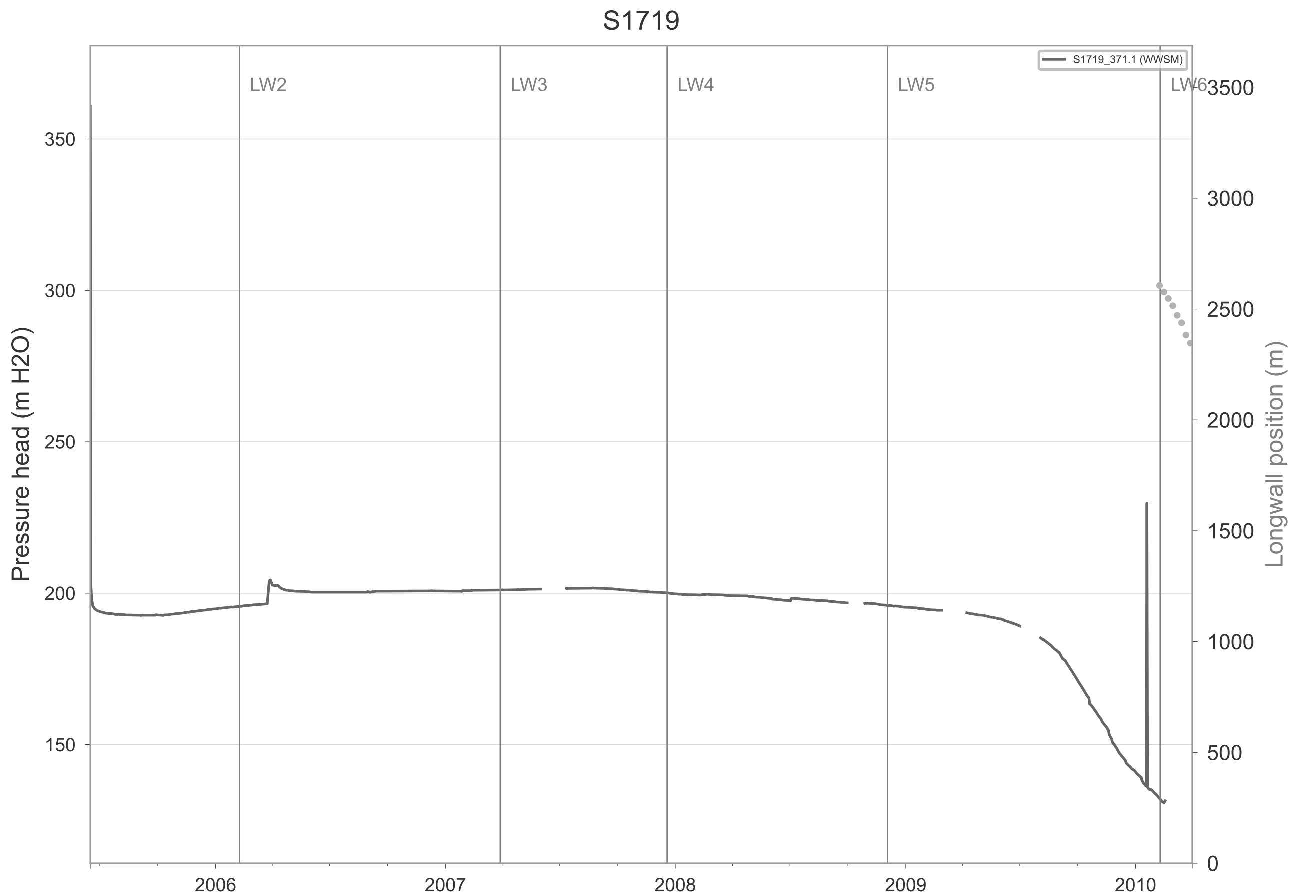
Groundwater hydrographs



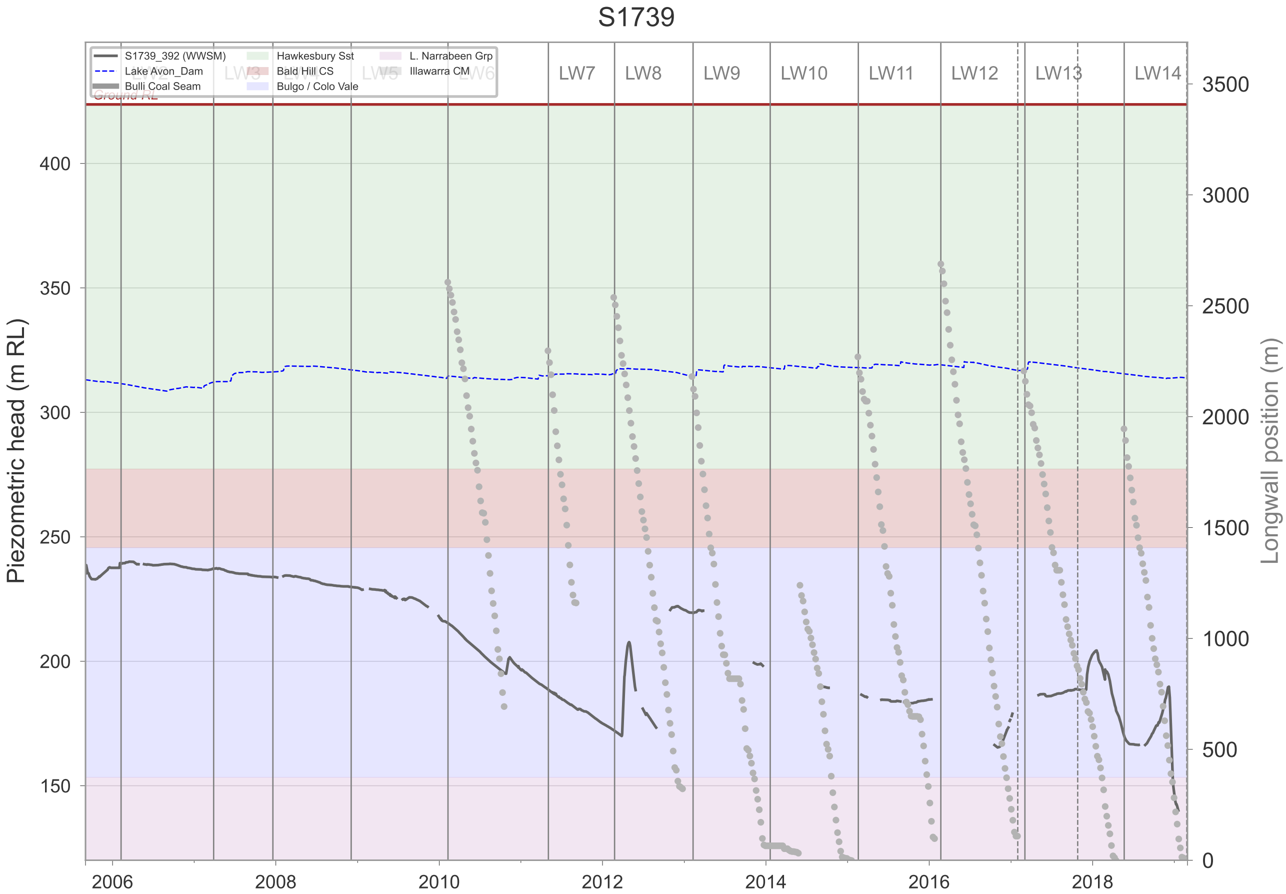


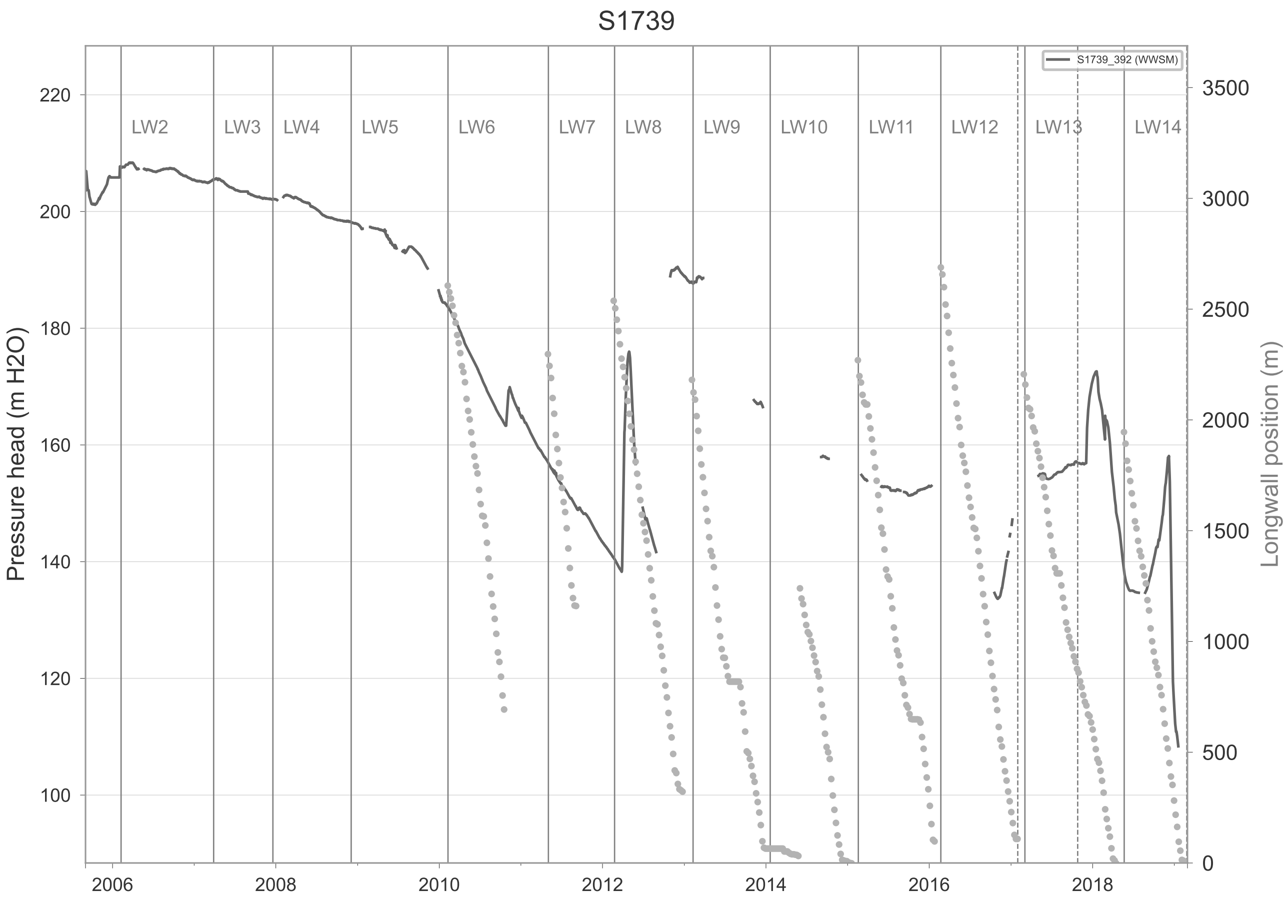
Groundwater hydrographs



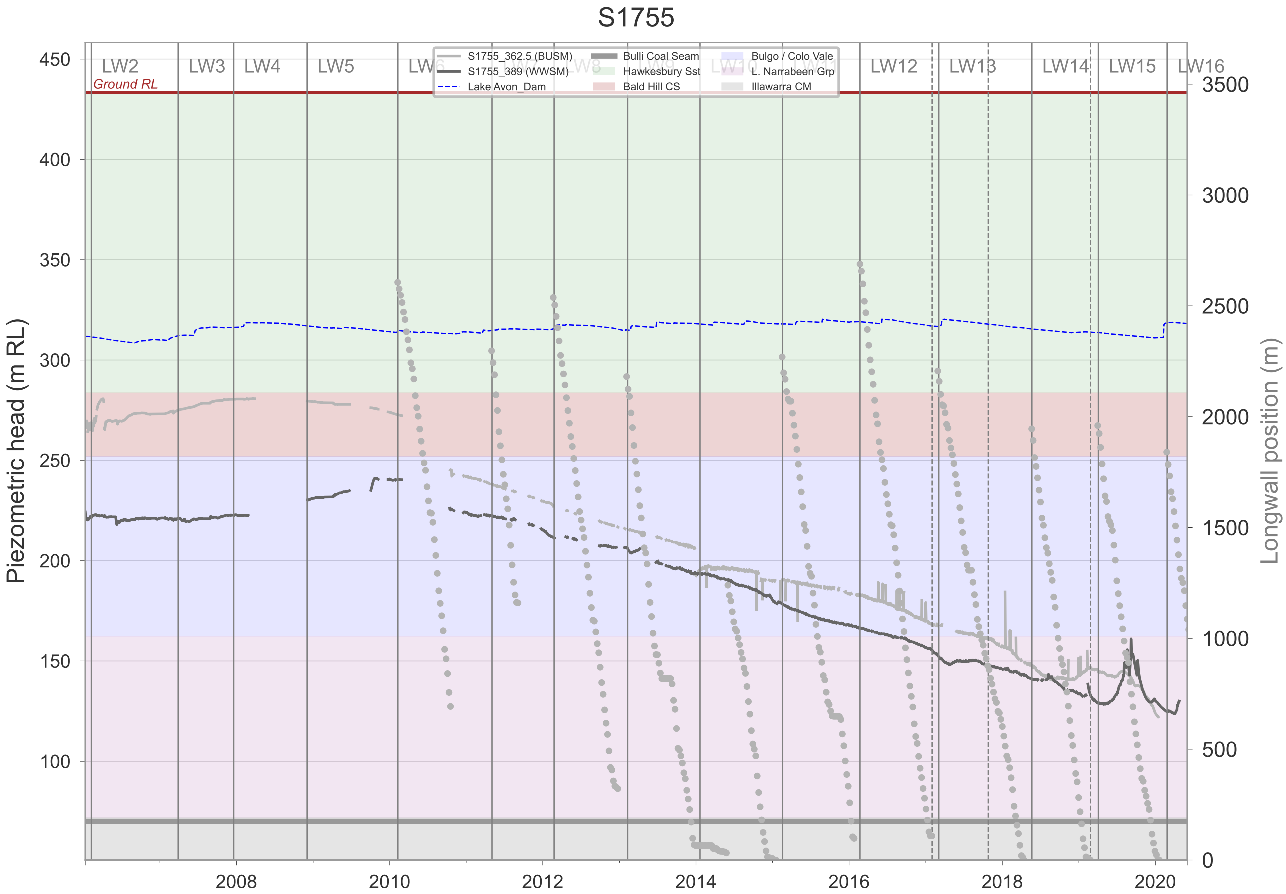


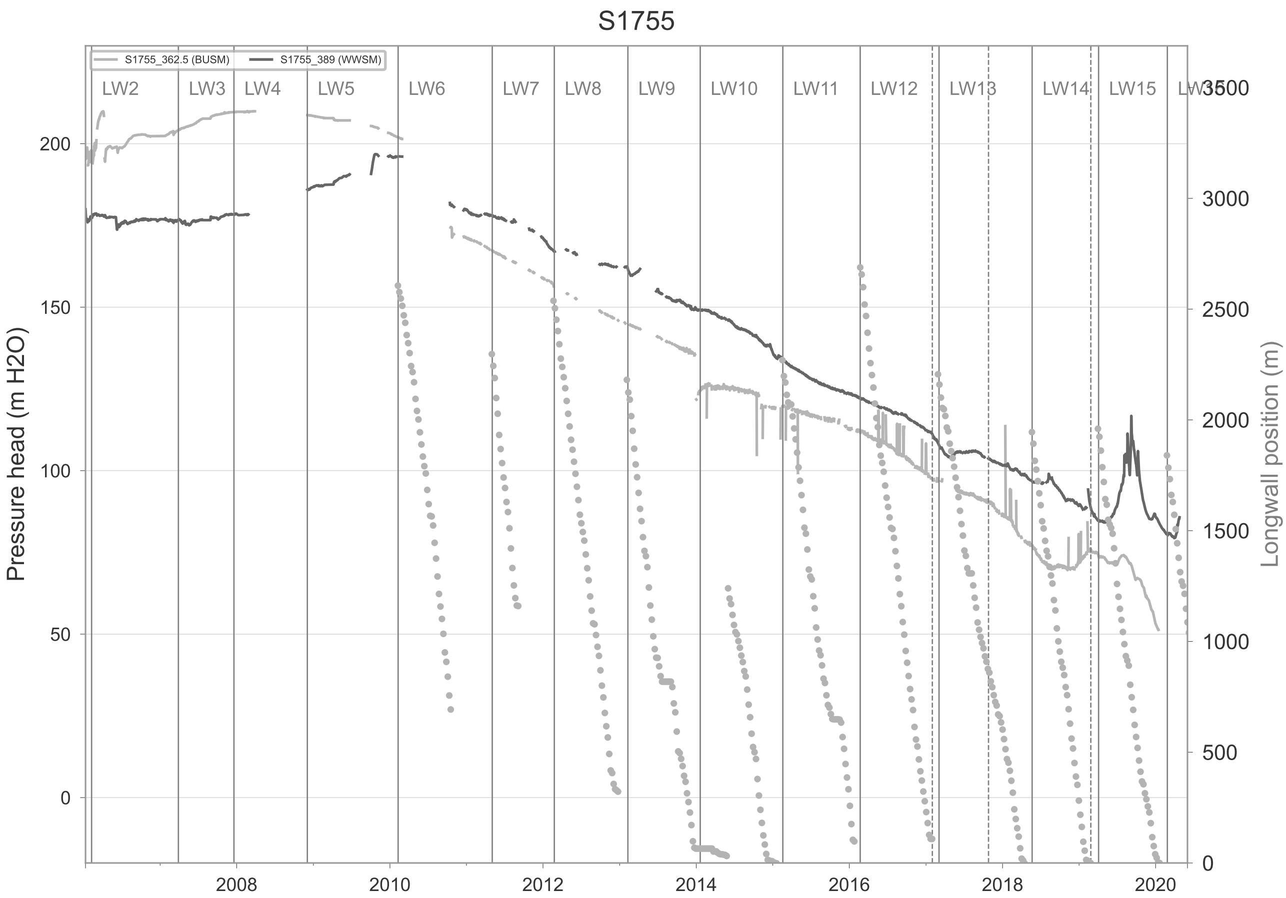
Groundwater hydrographs



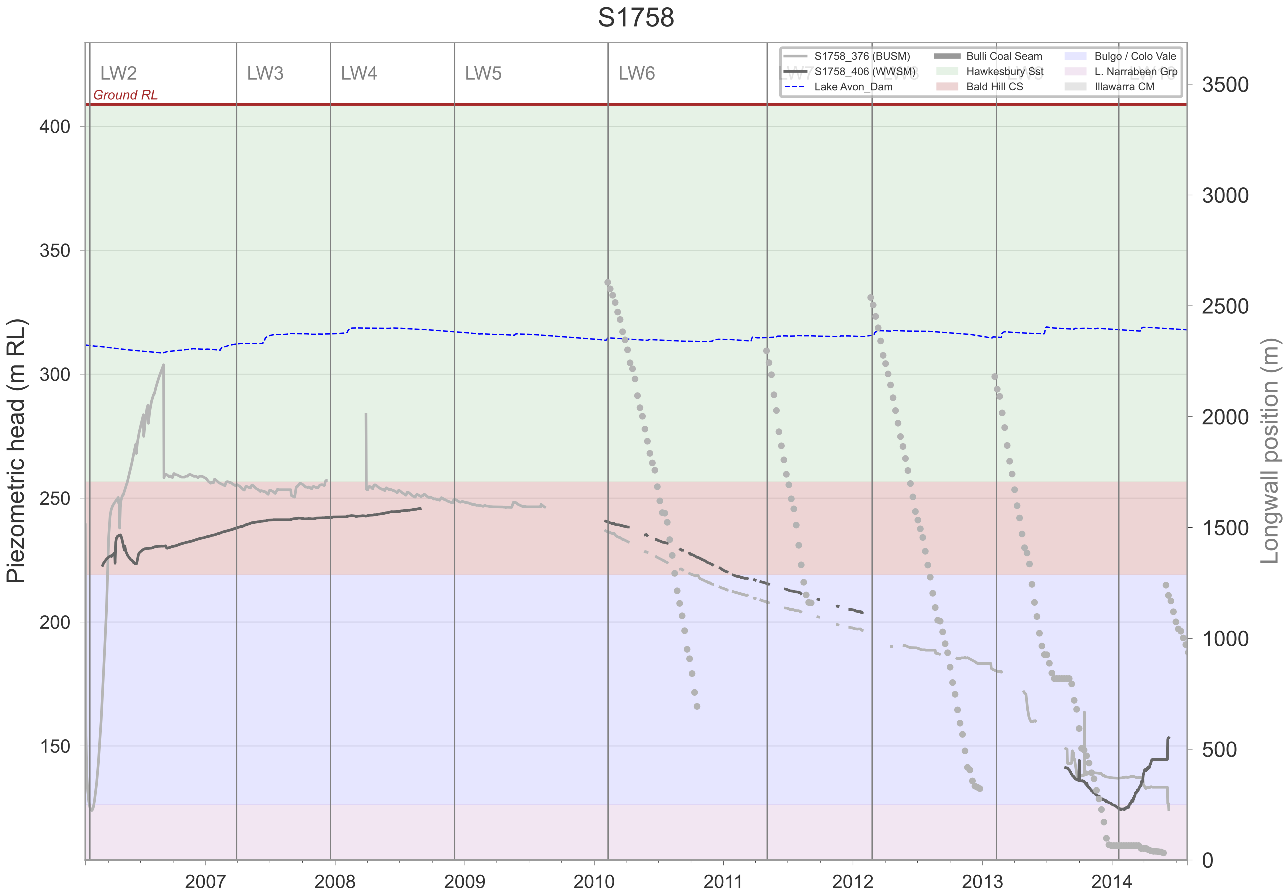


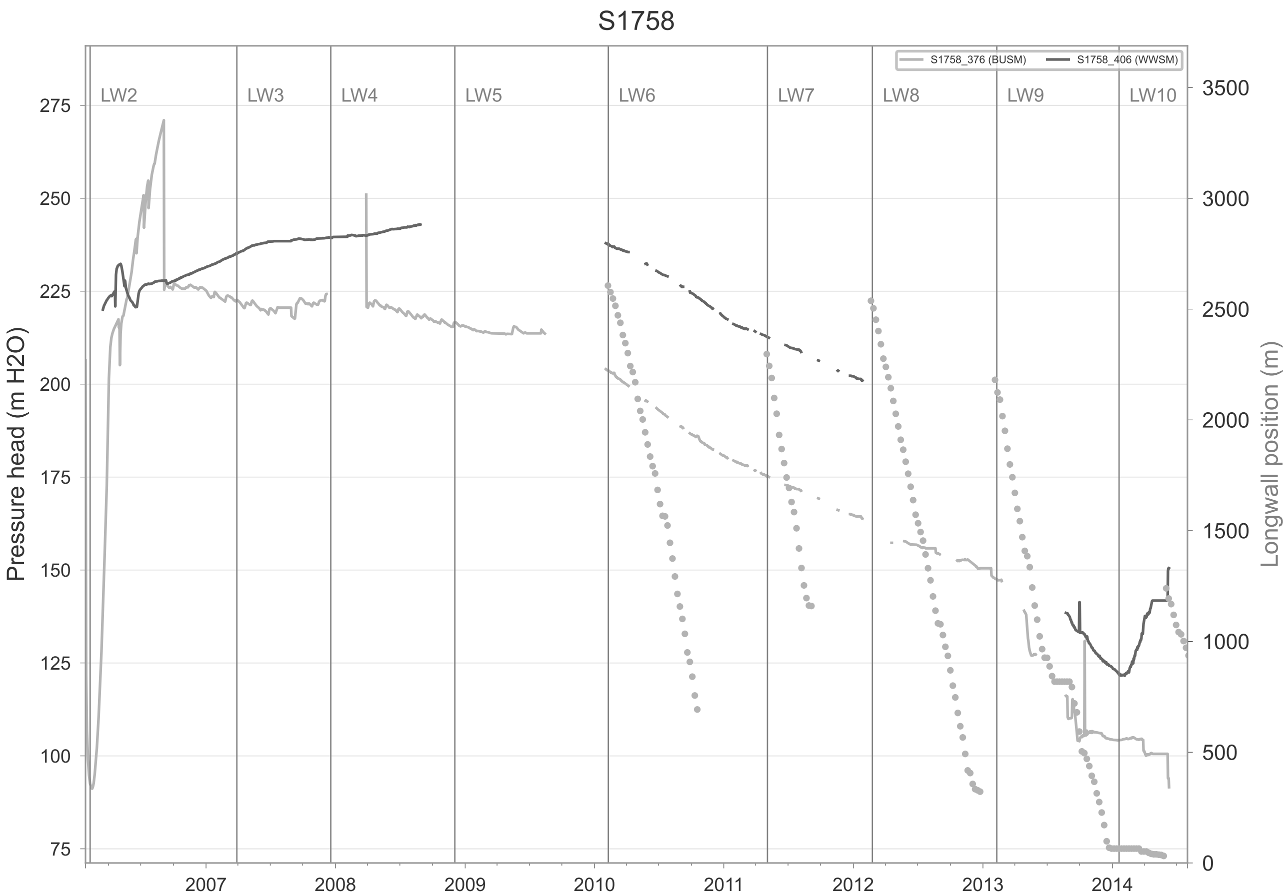
Groundwater hydrographs



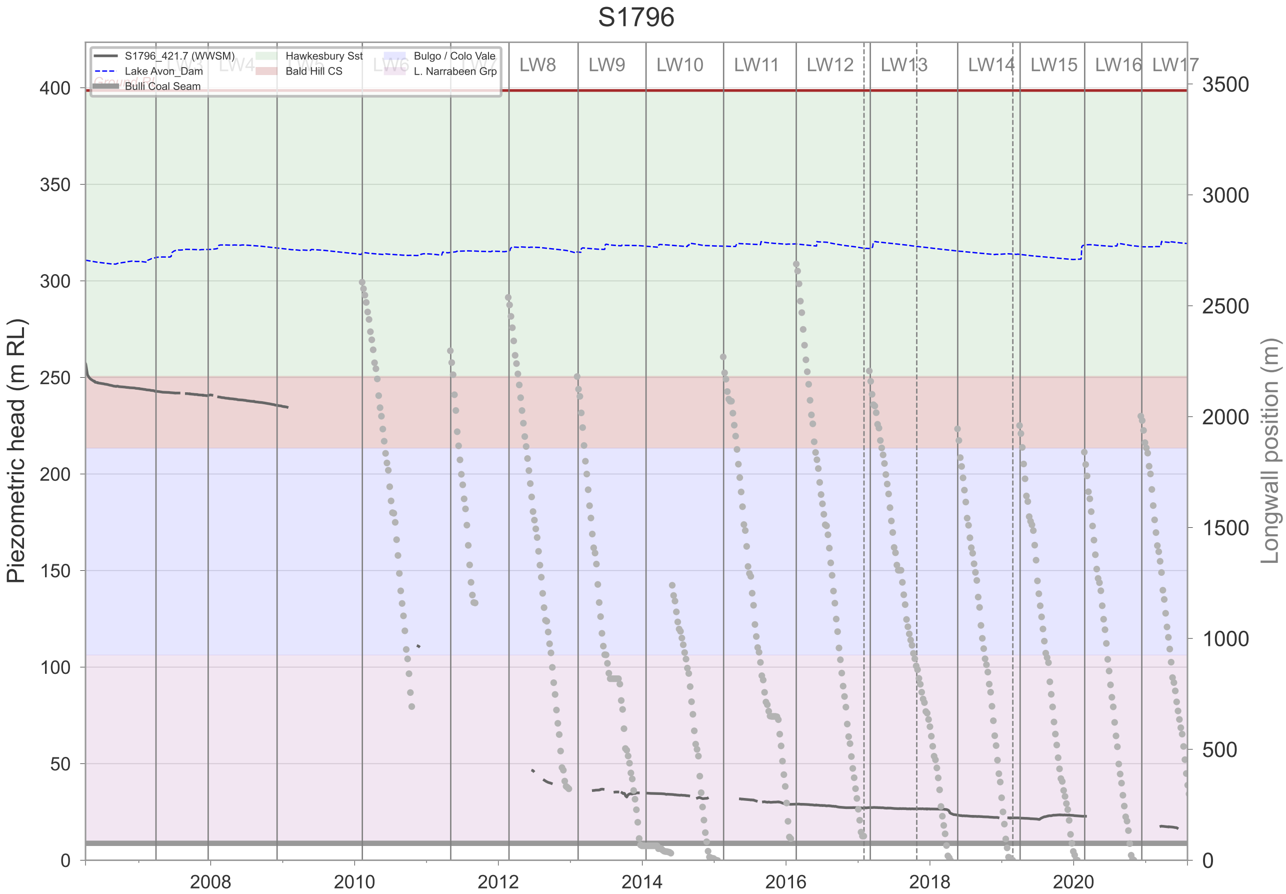


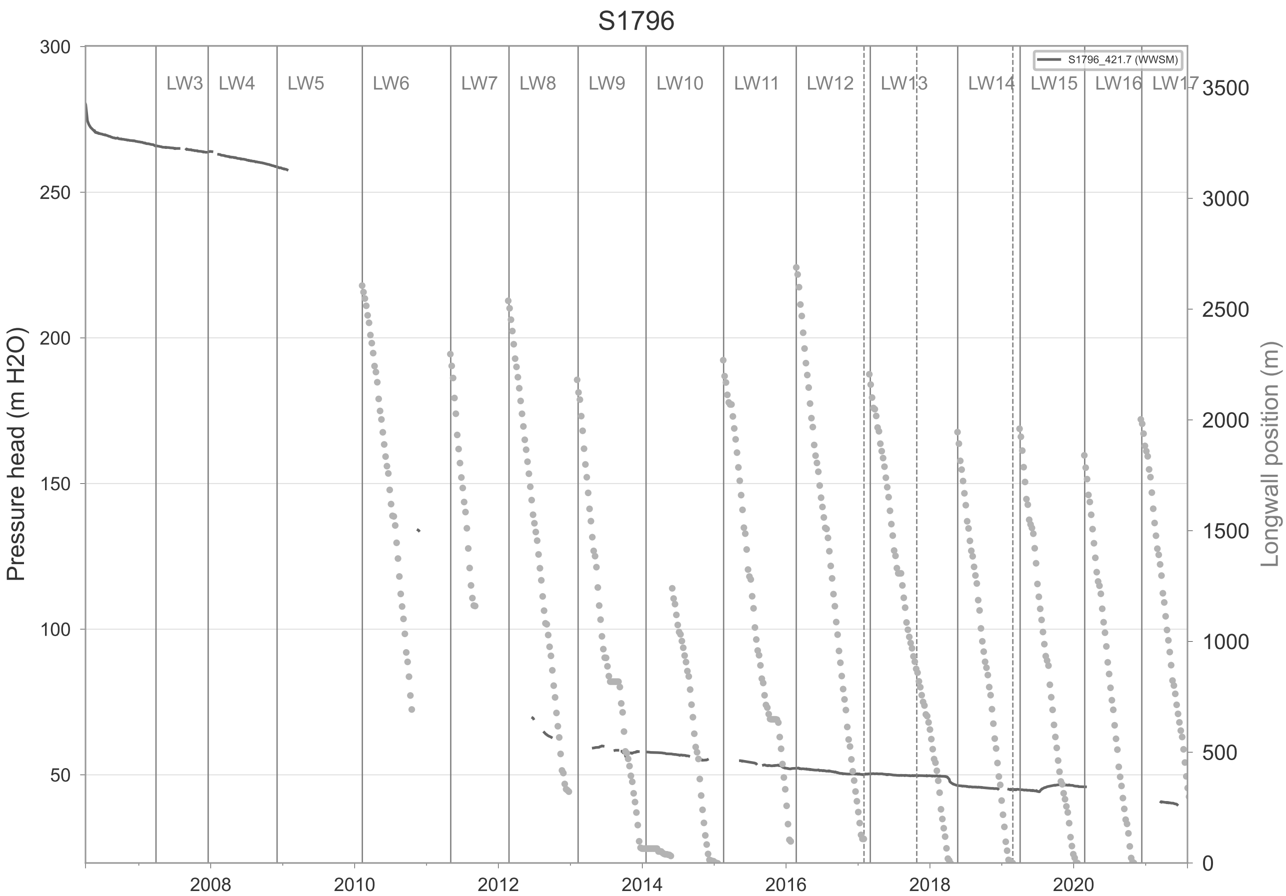
Groundwater hydrographs



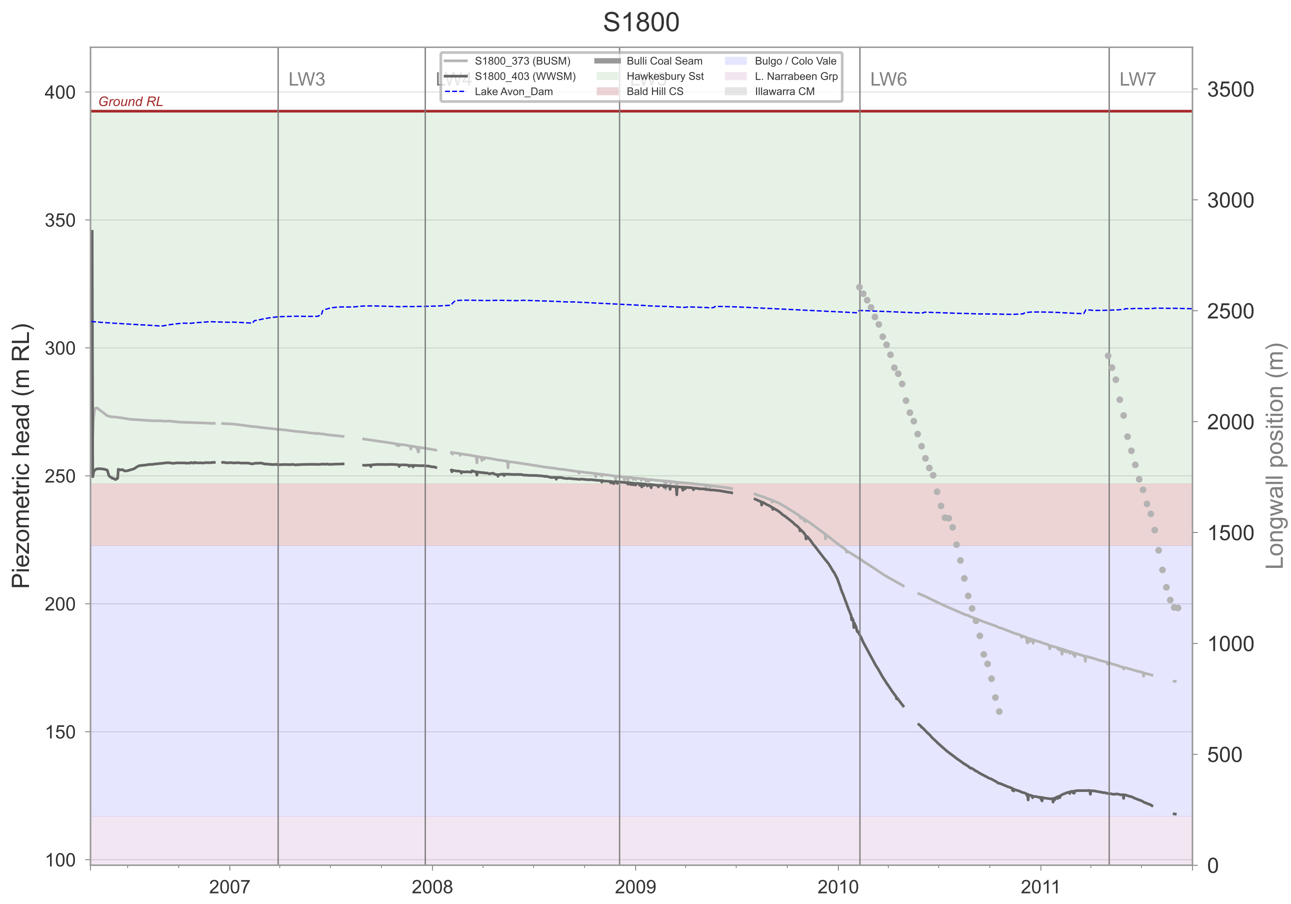


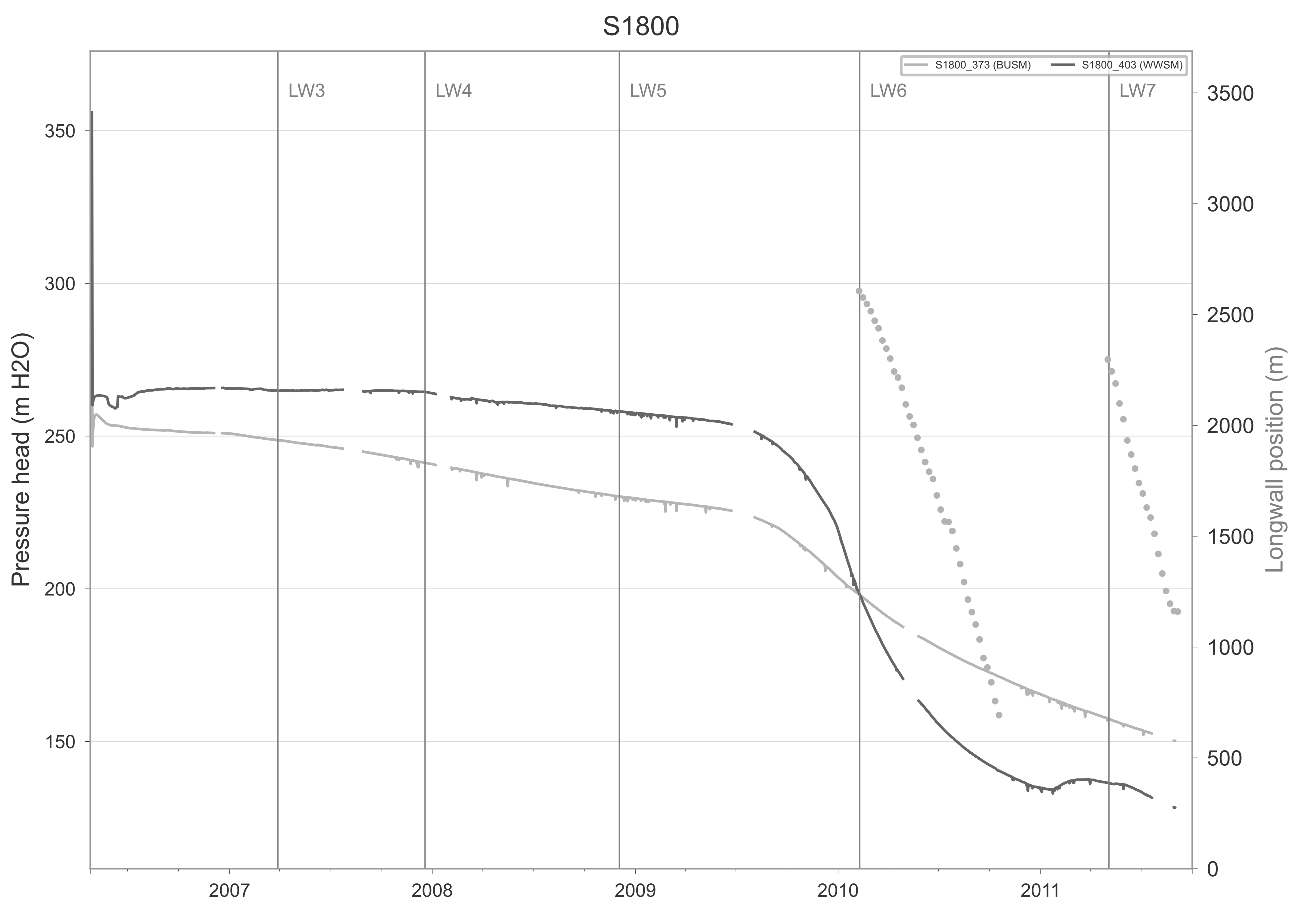
Groundwater hydrographs



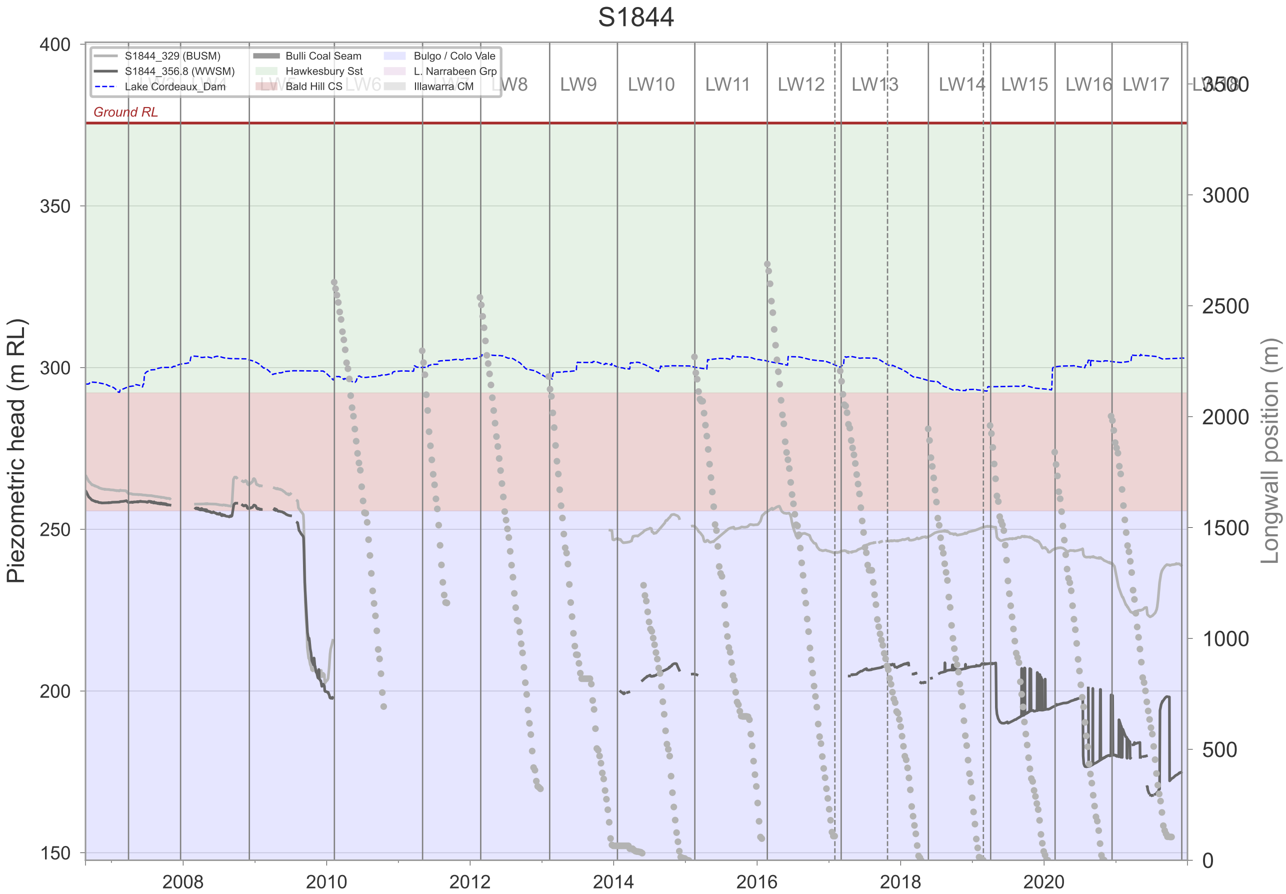


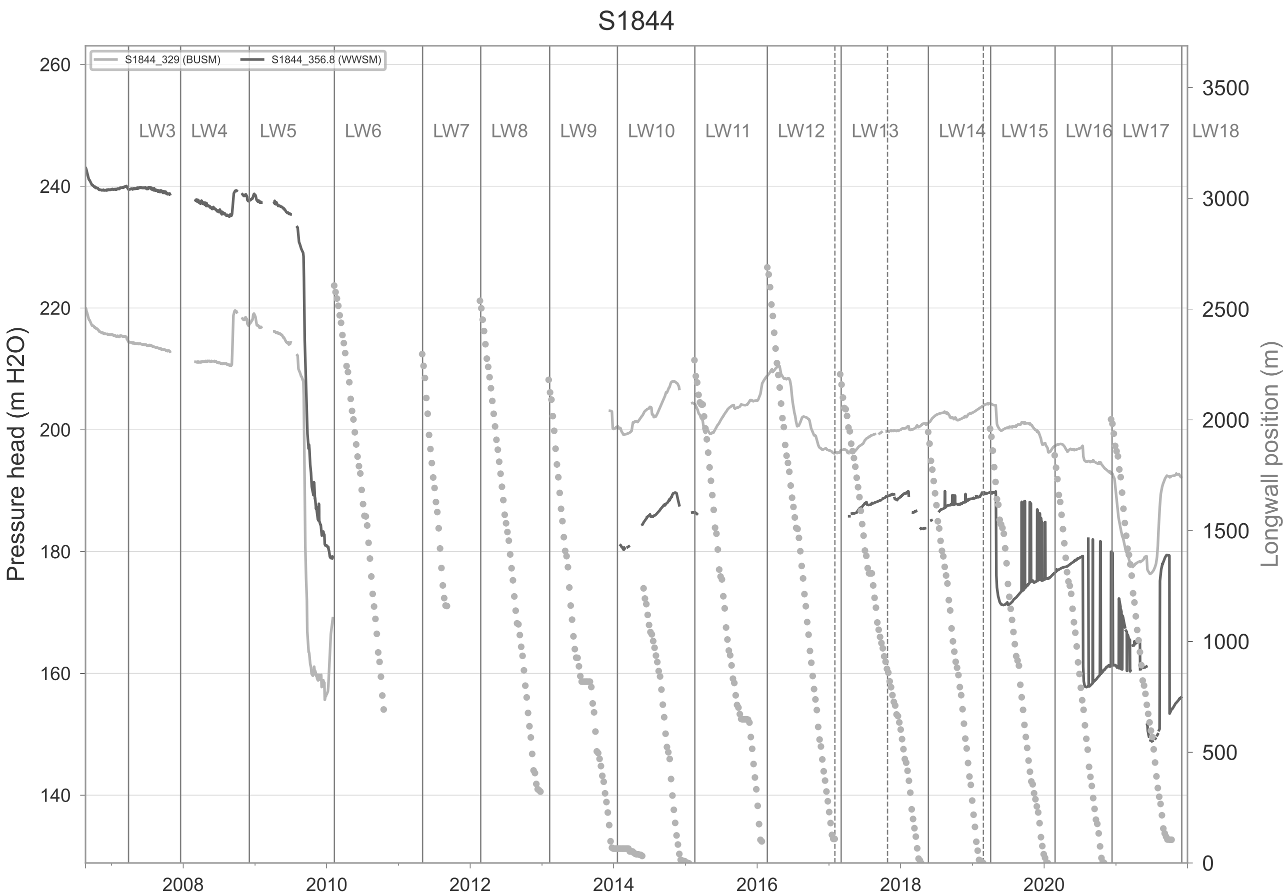
Groundwater hydrographs



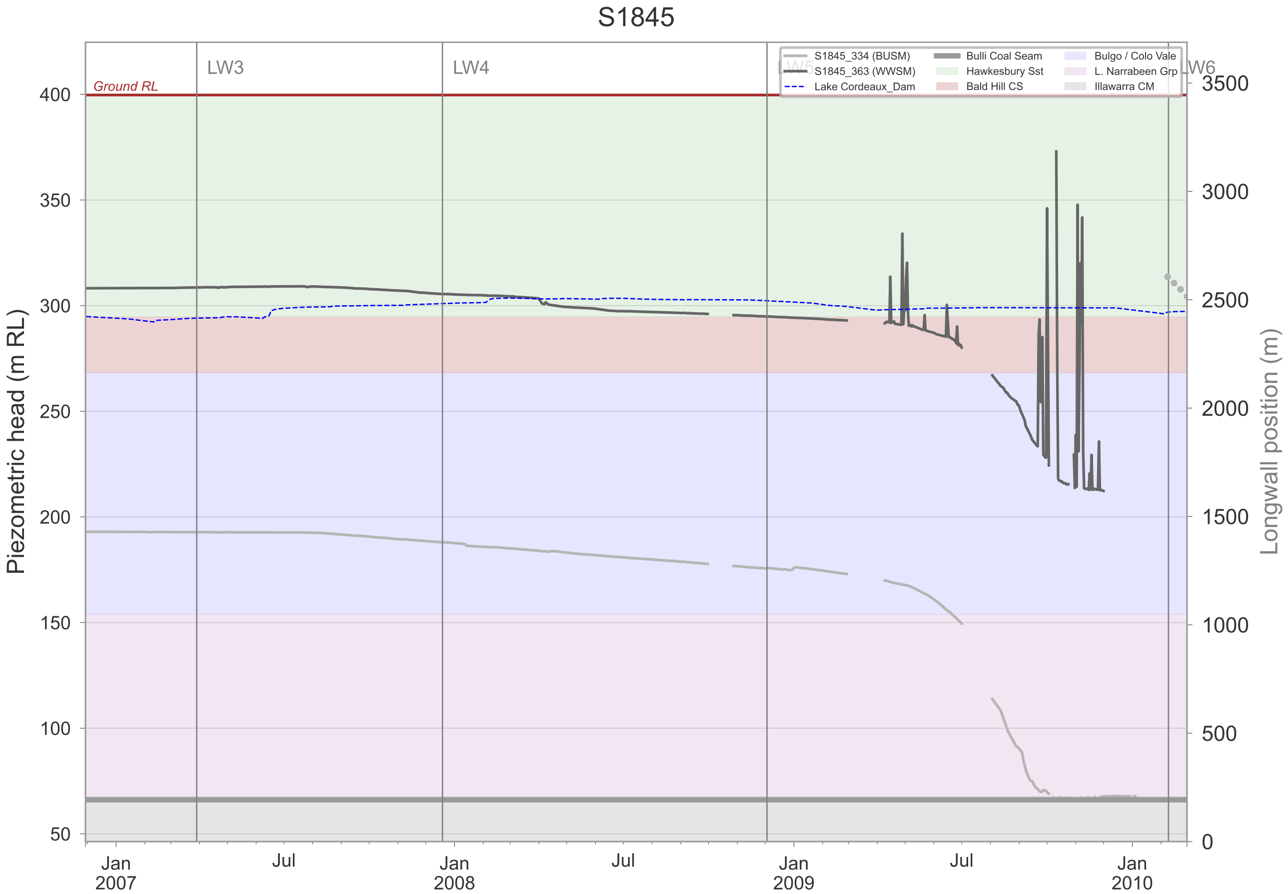


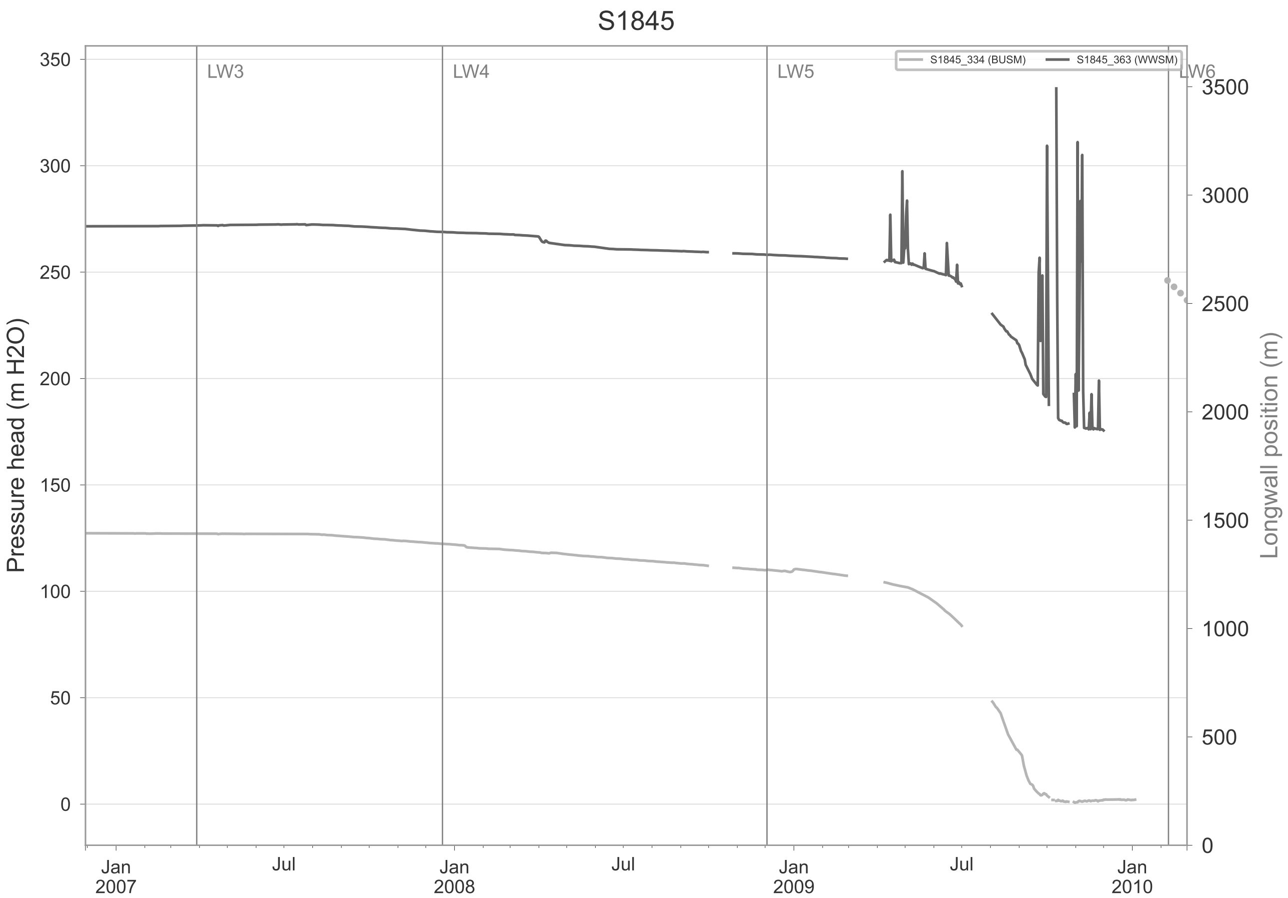
Groundwater hydrographs



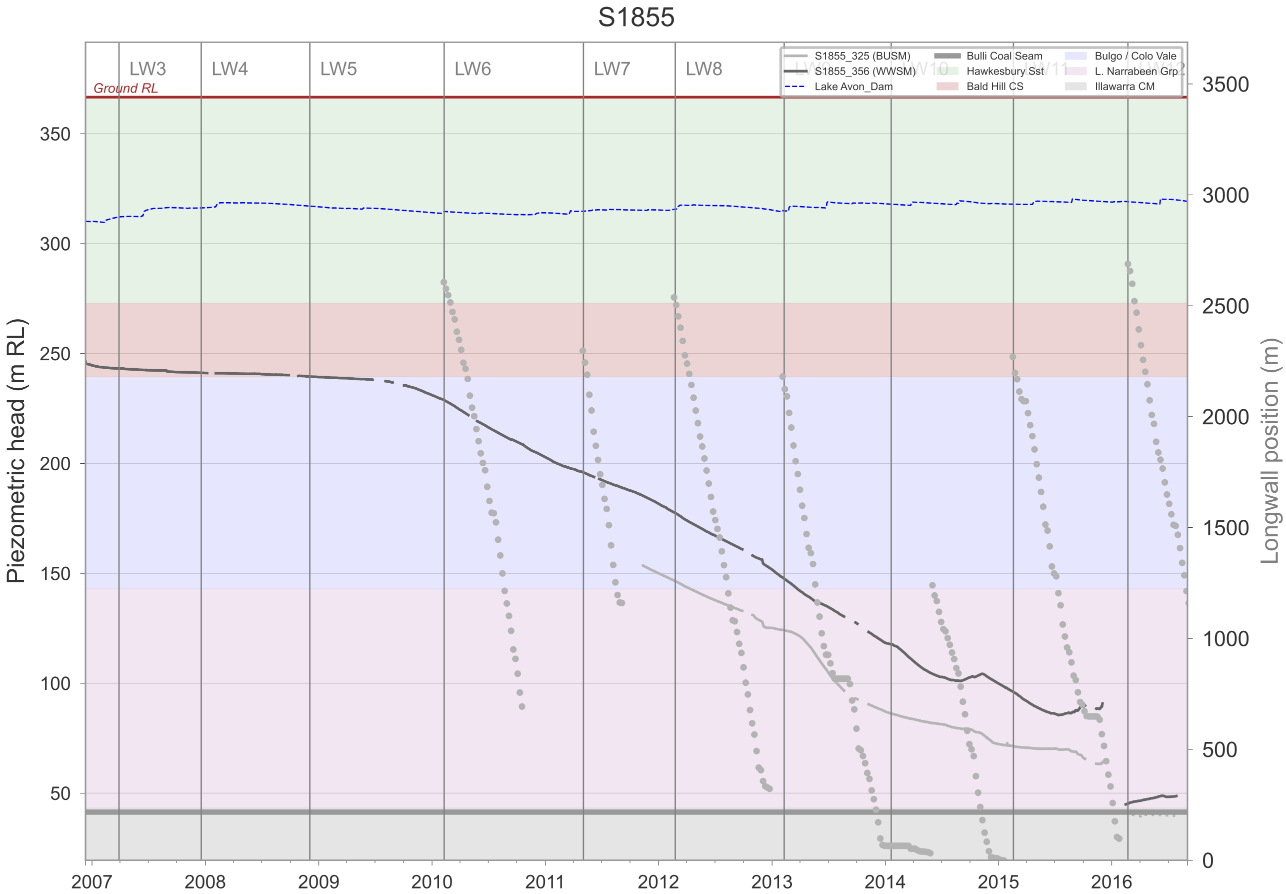


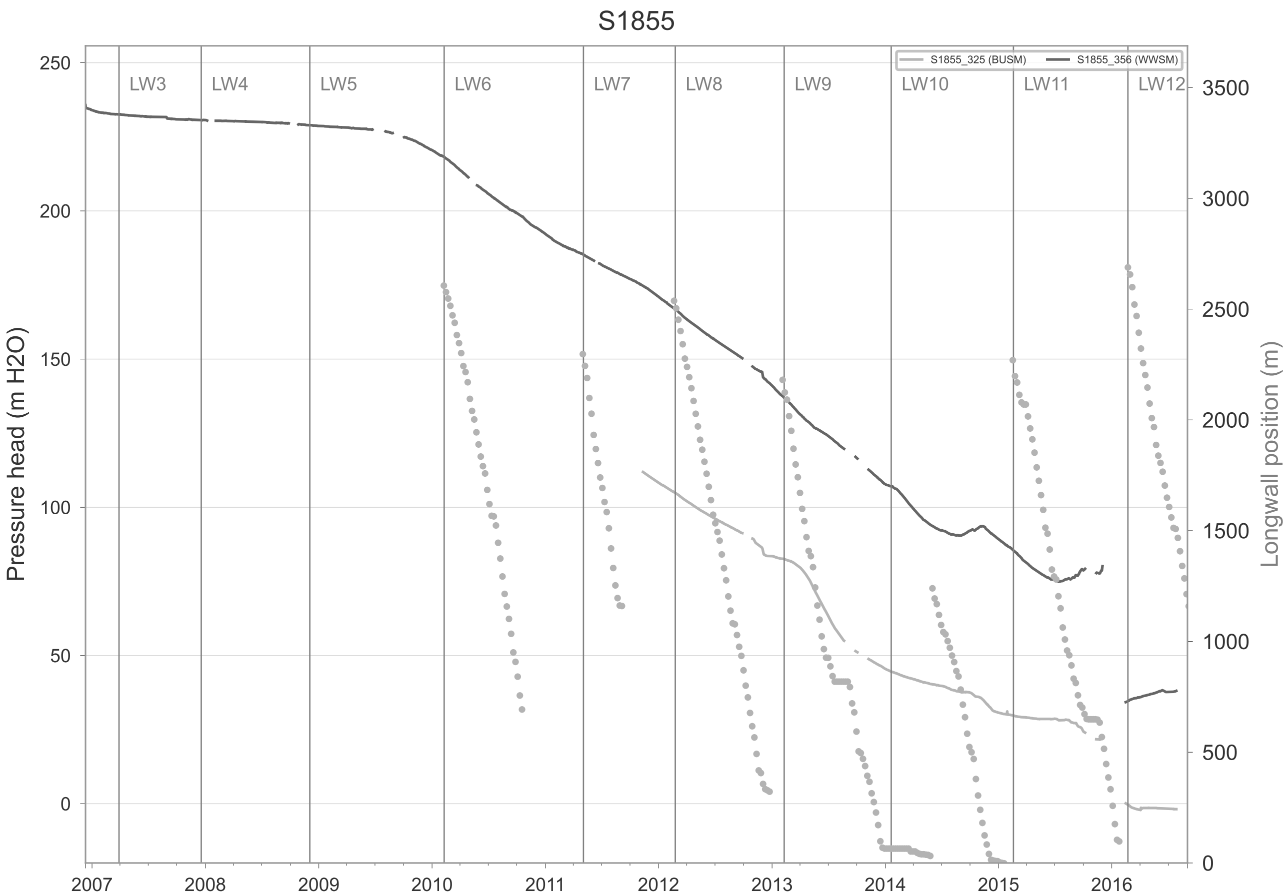
Groundwater hydrographs





Groundwater hydrographs





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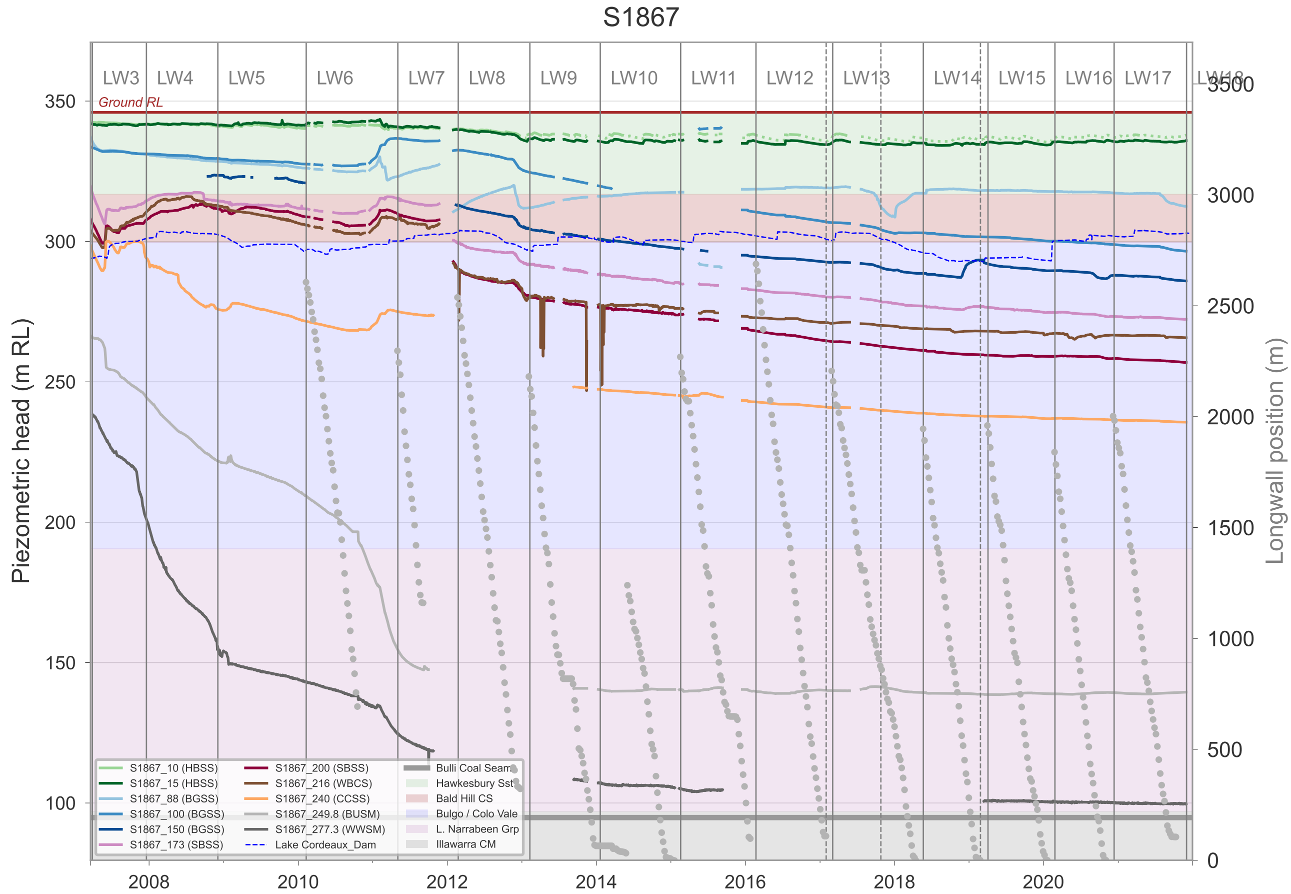

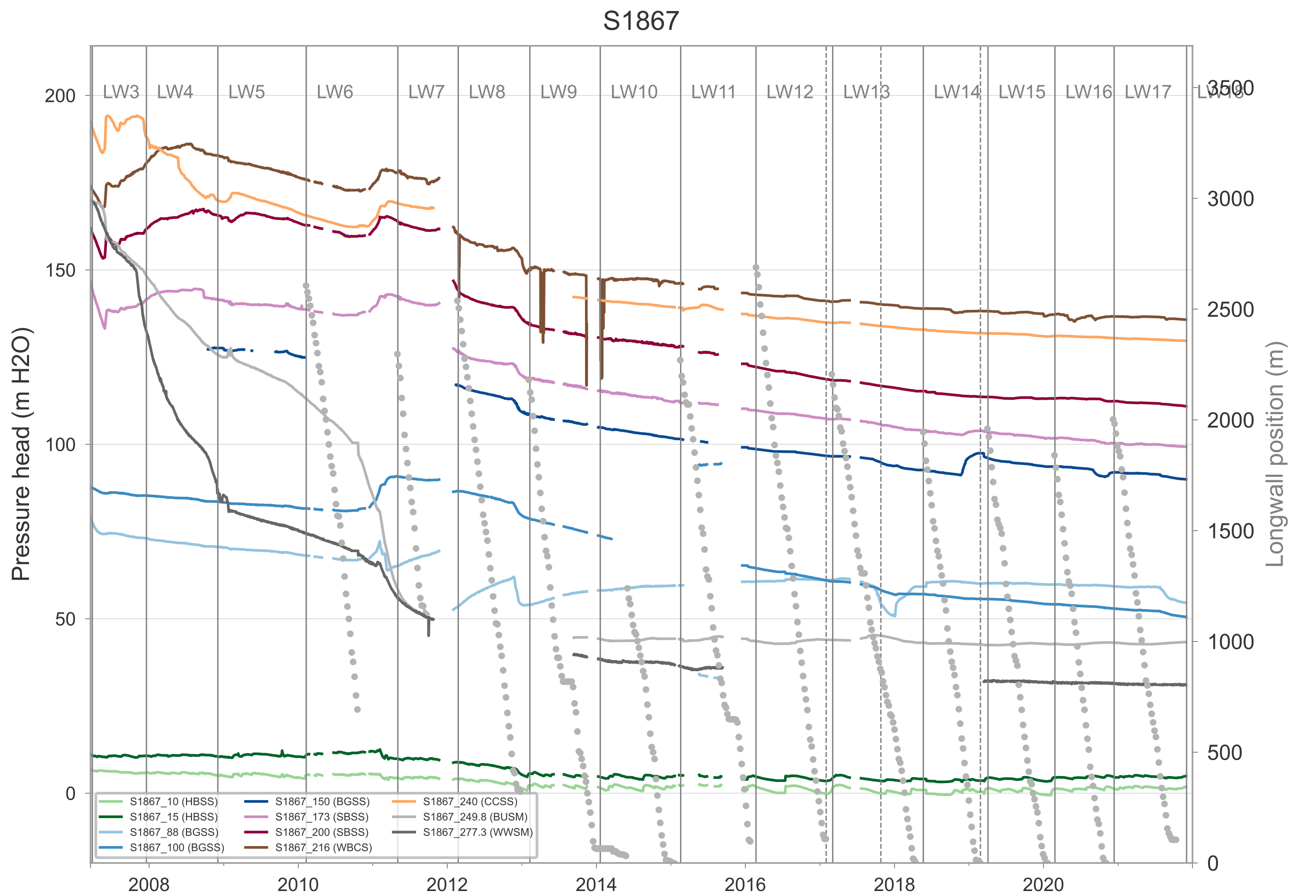

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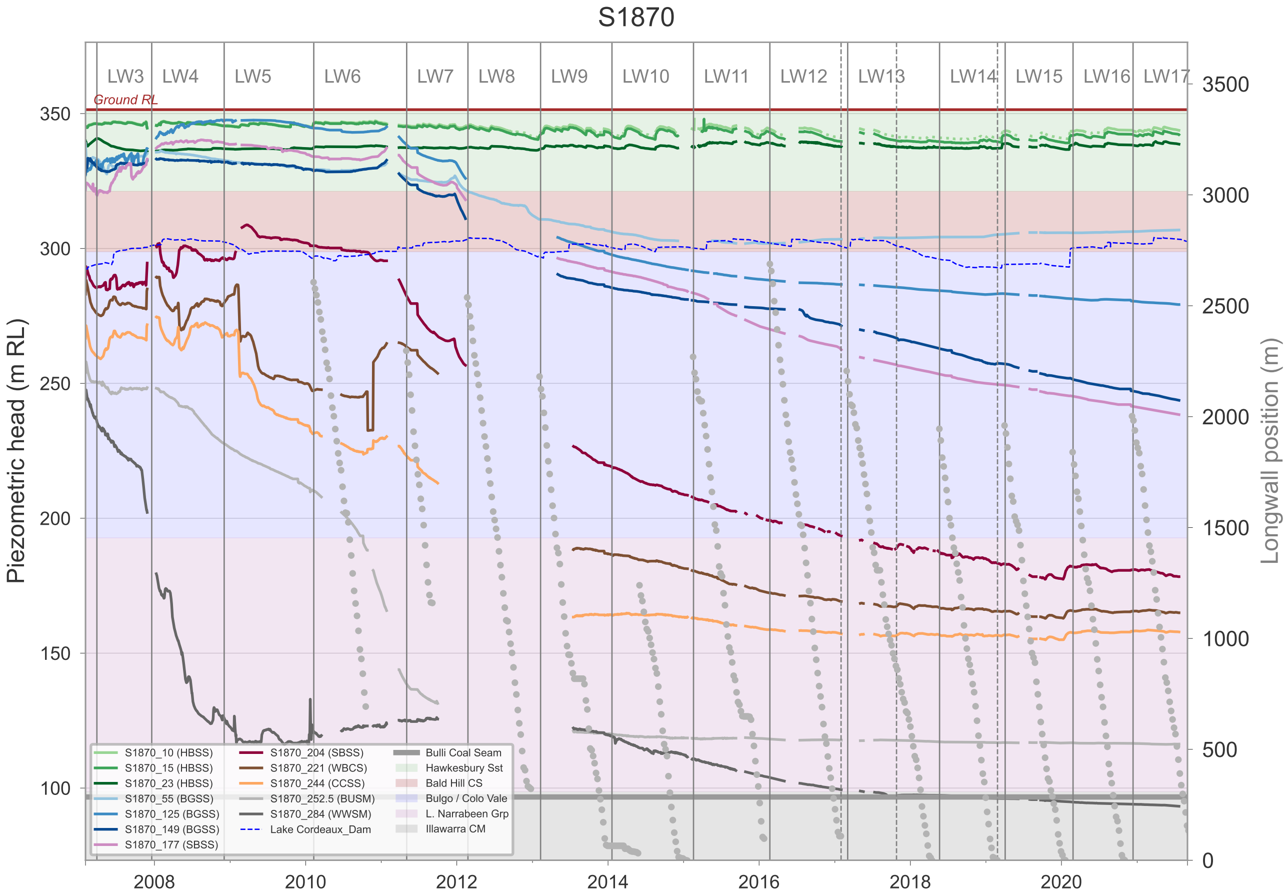

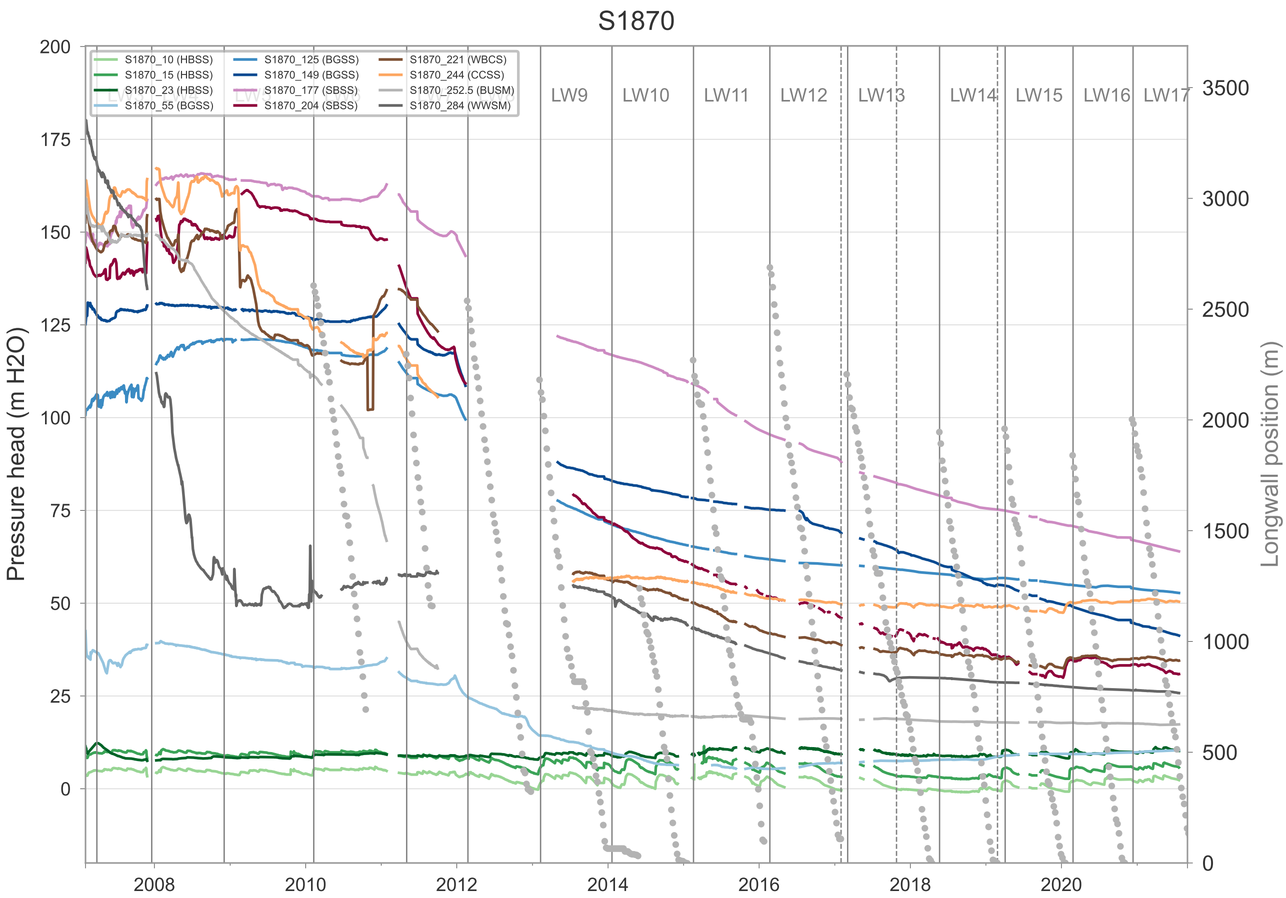

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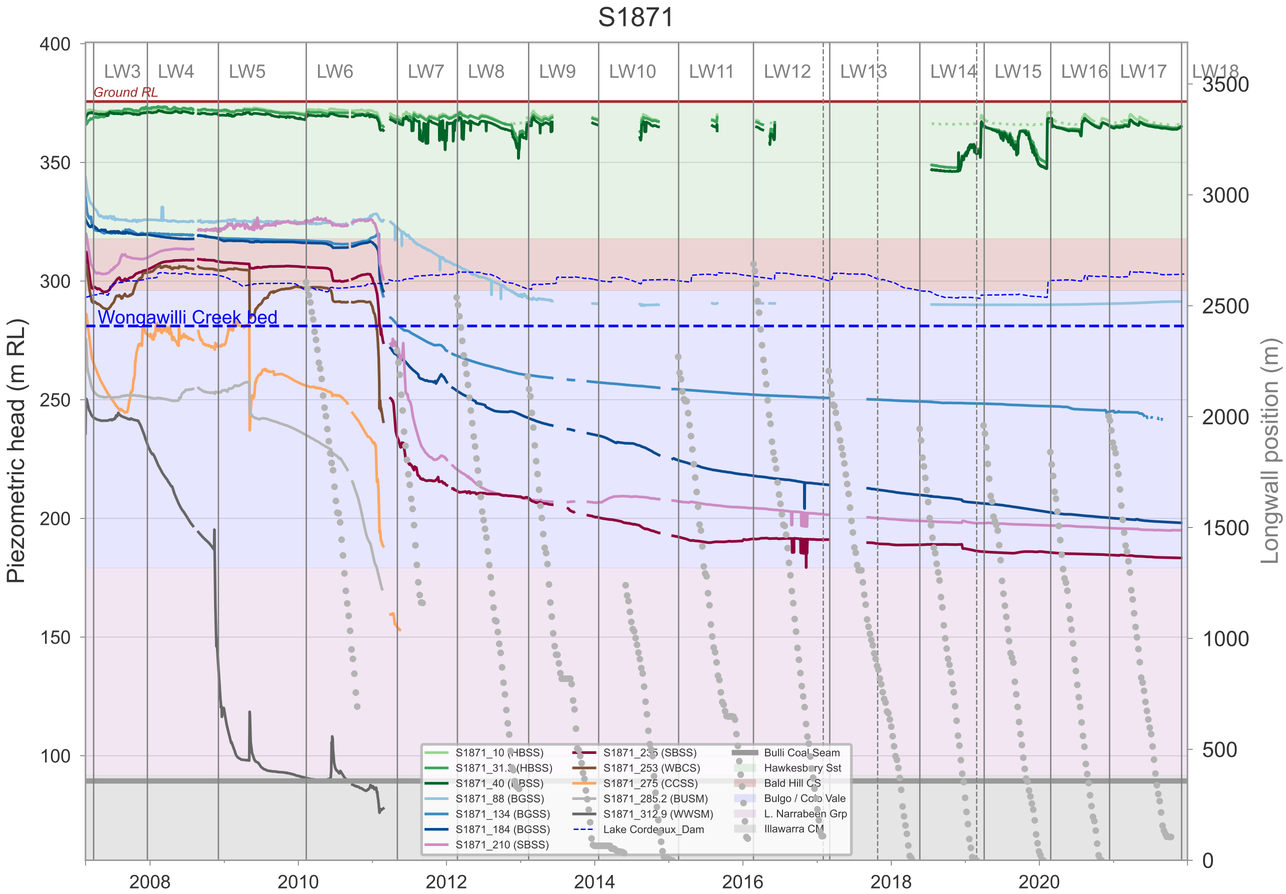

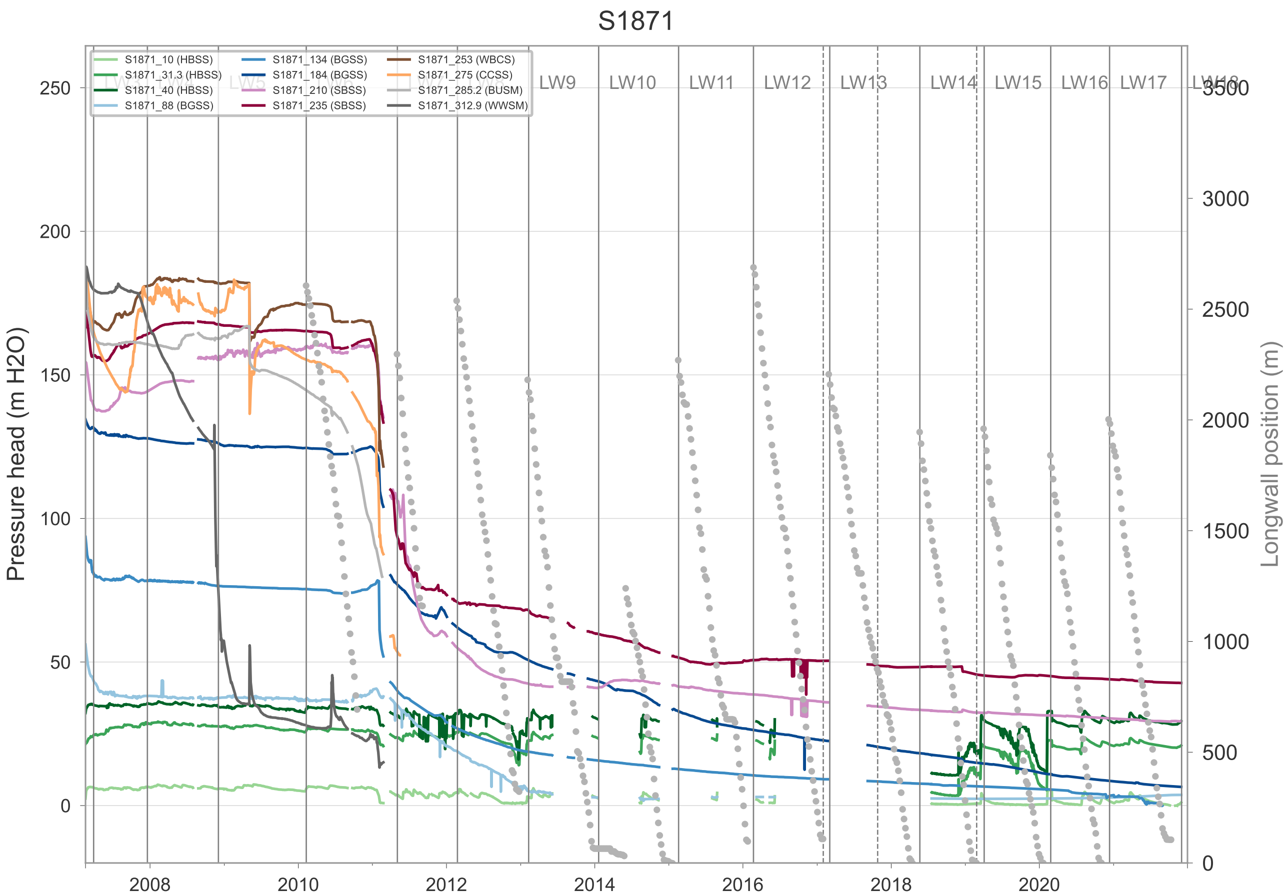

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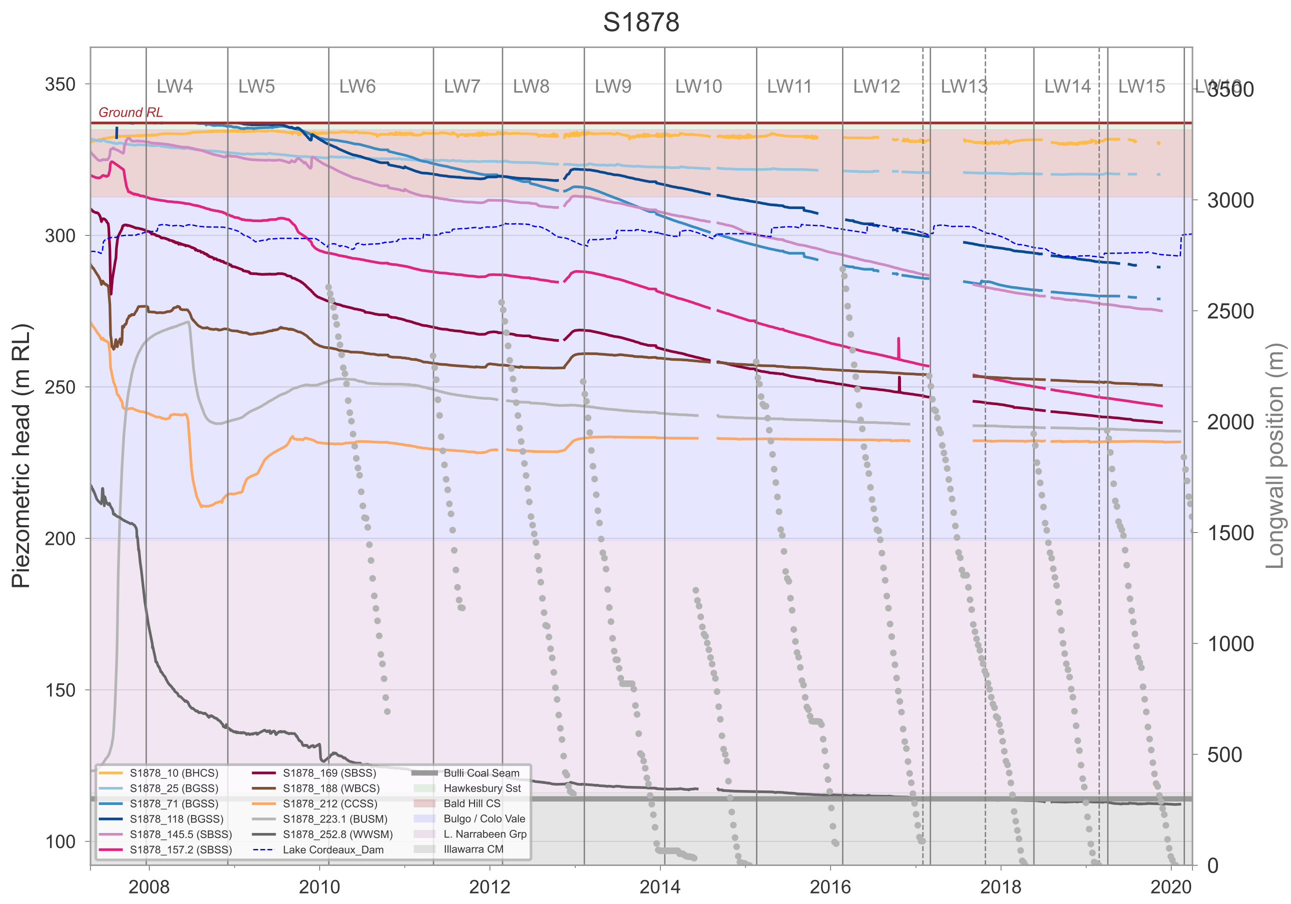

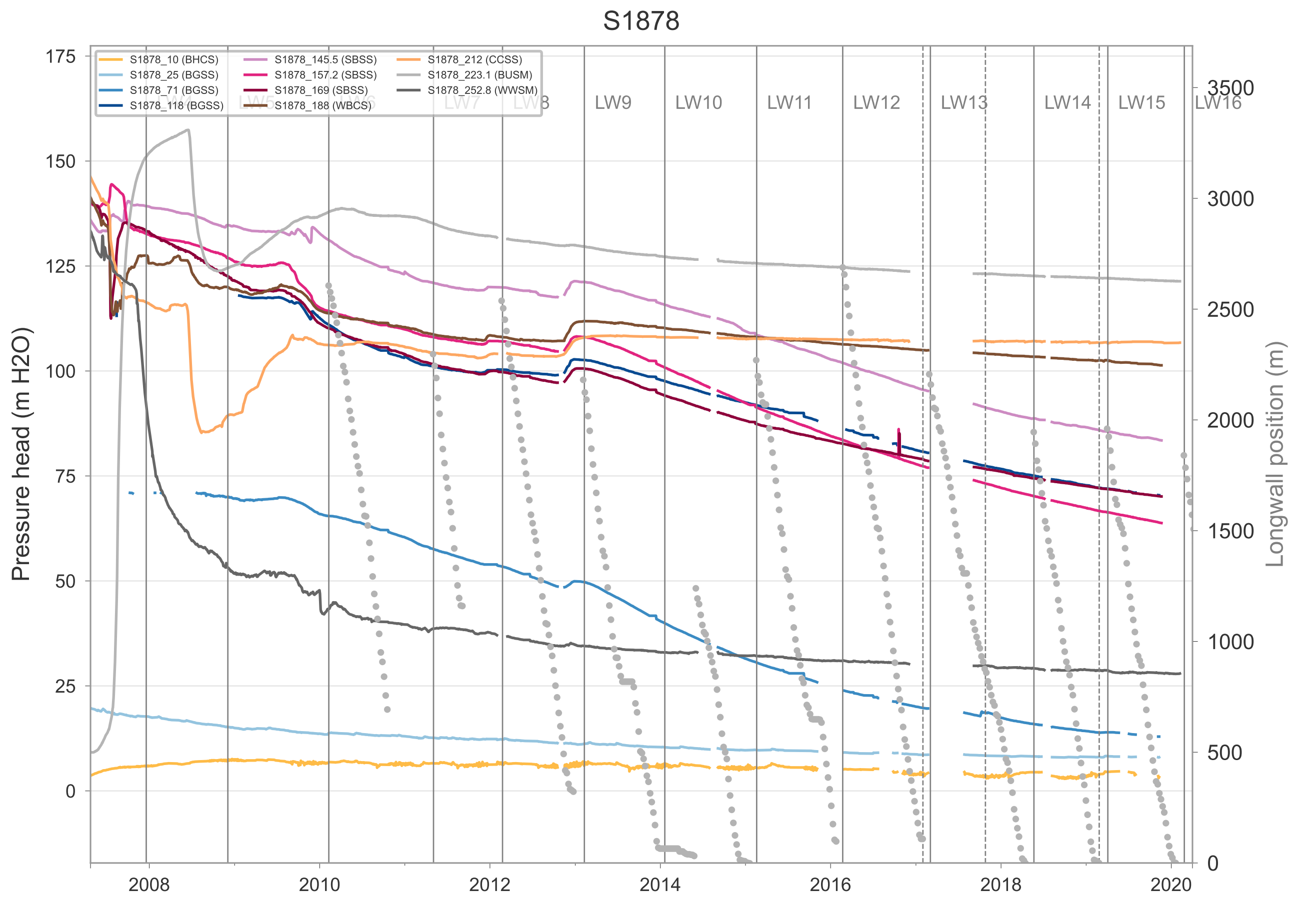

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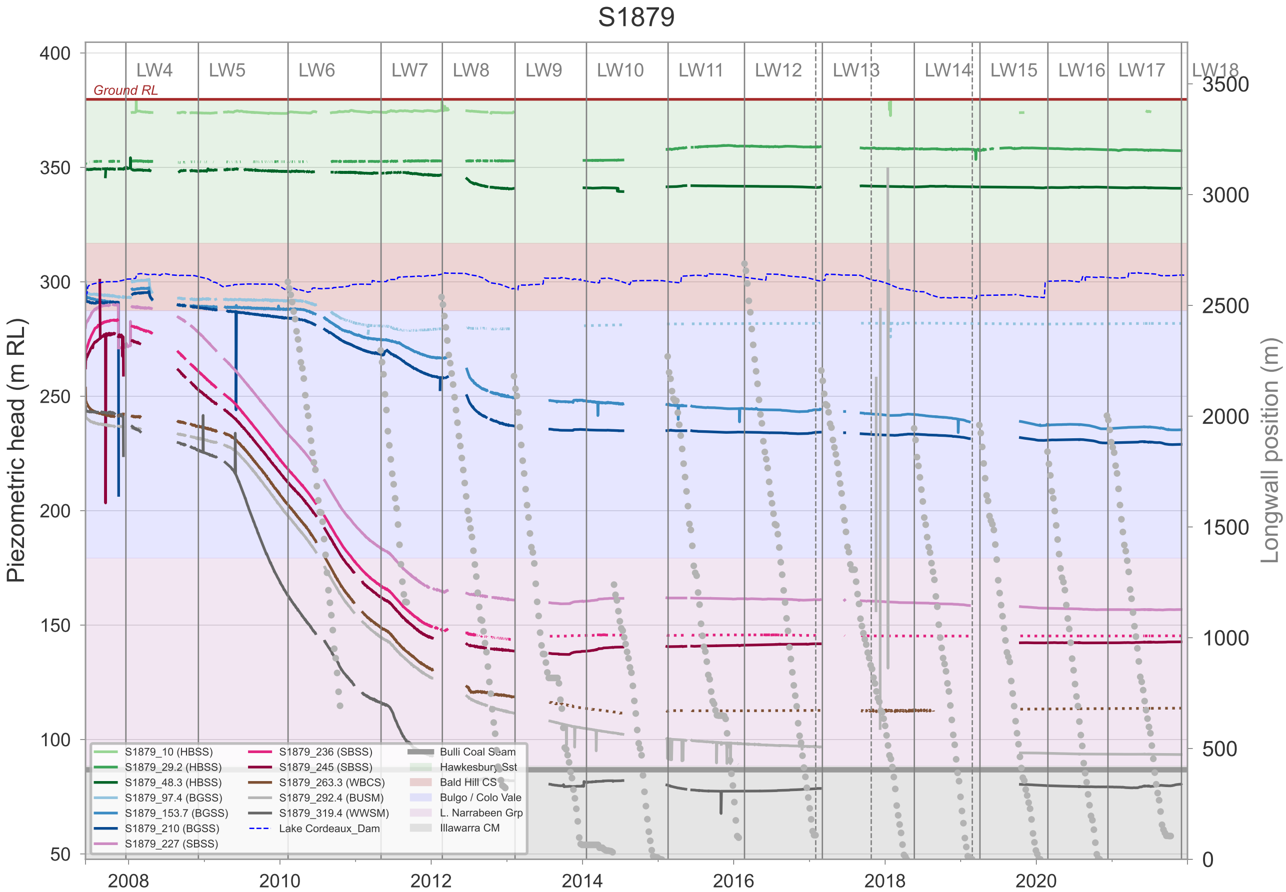

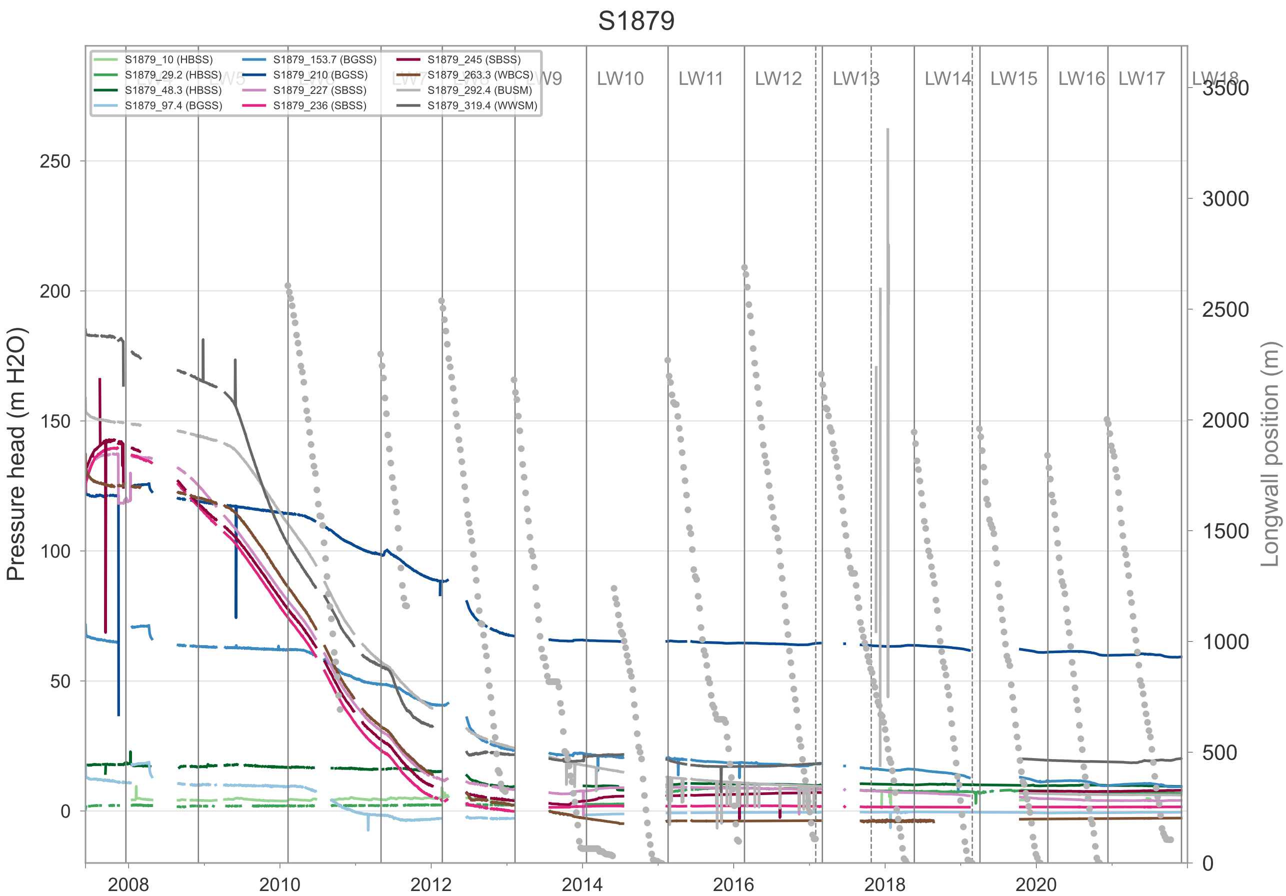

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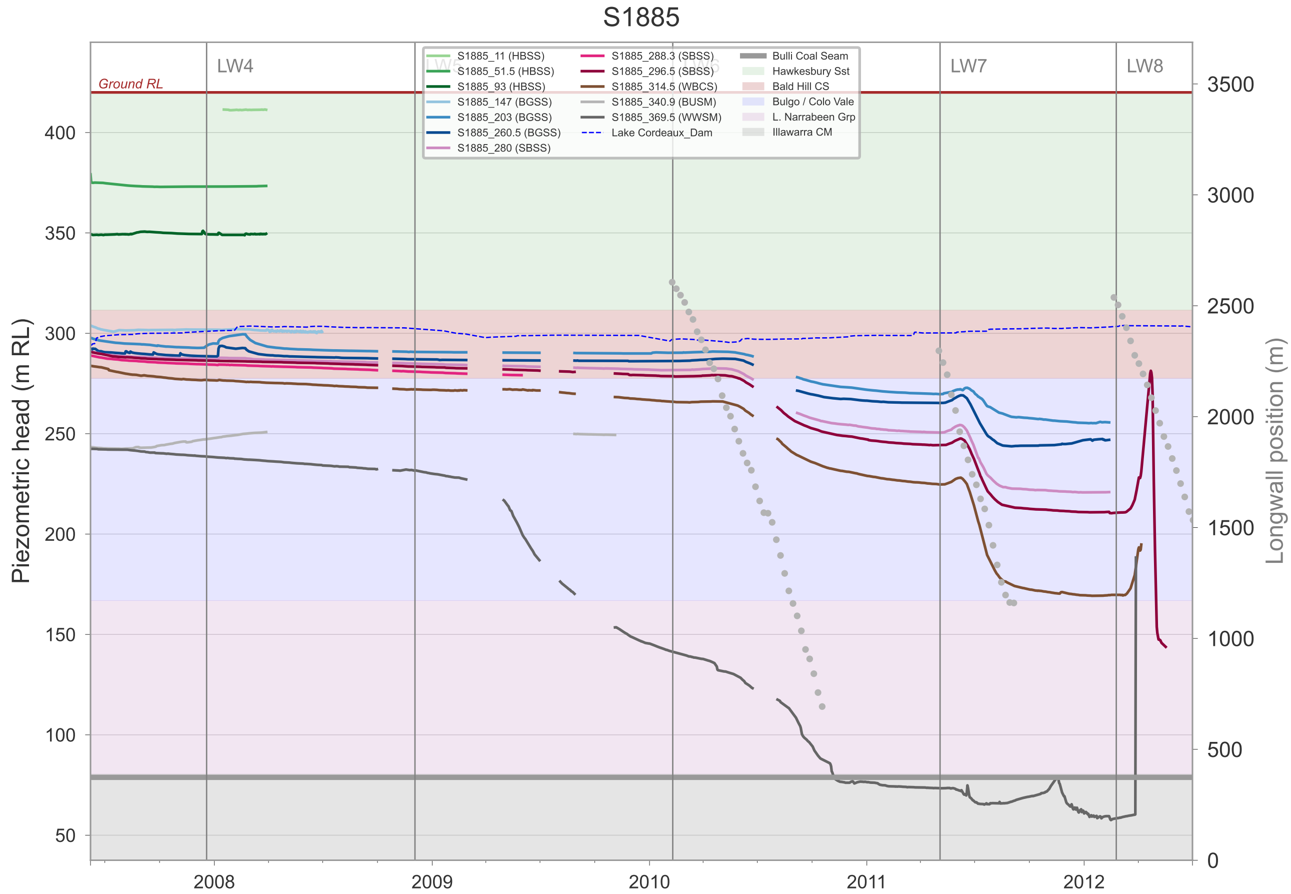

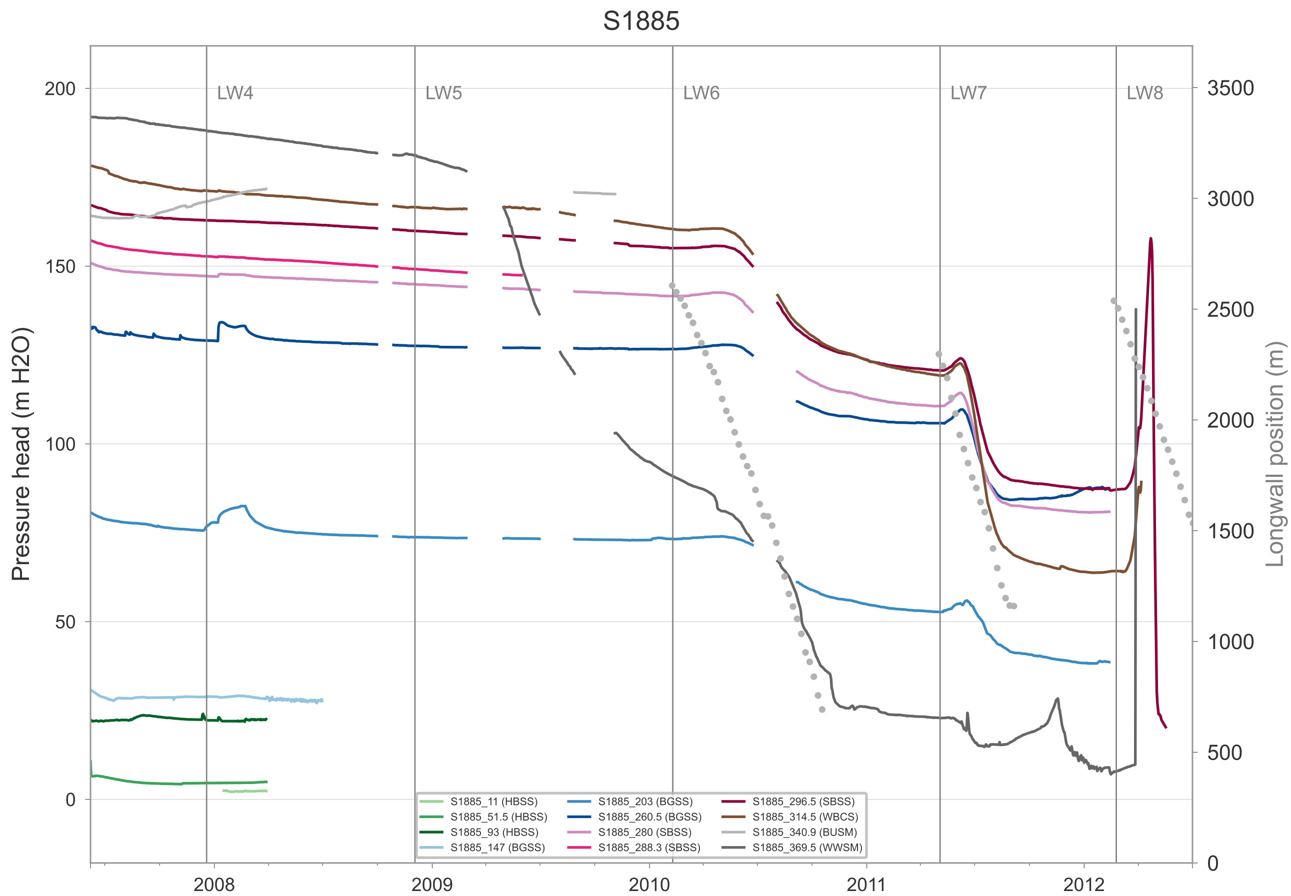

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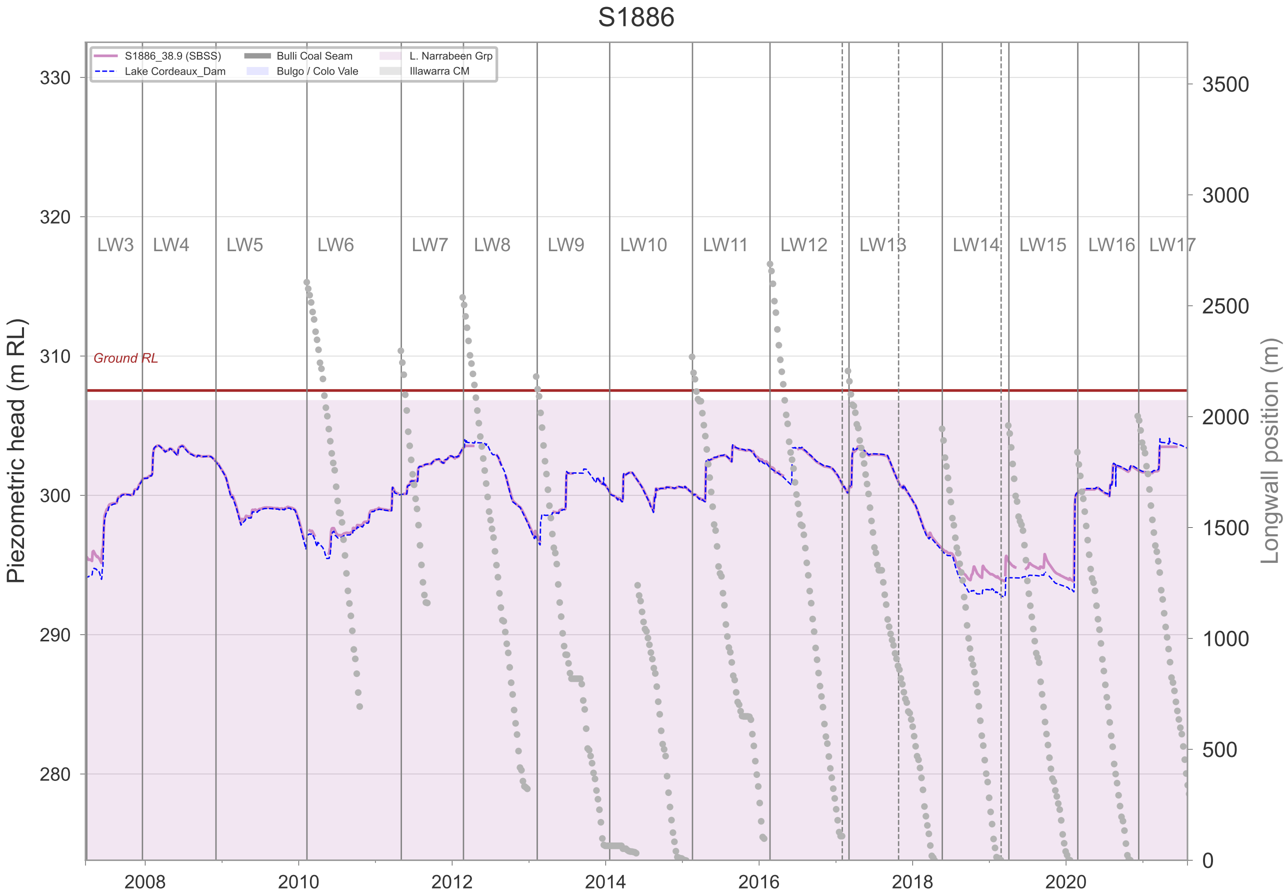

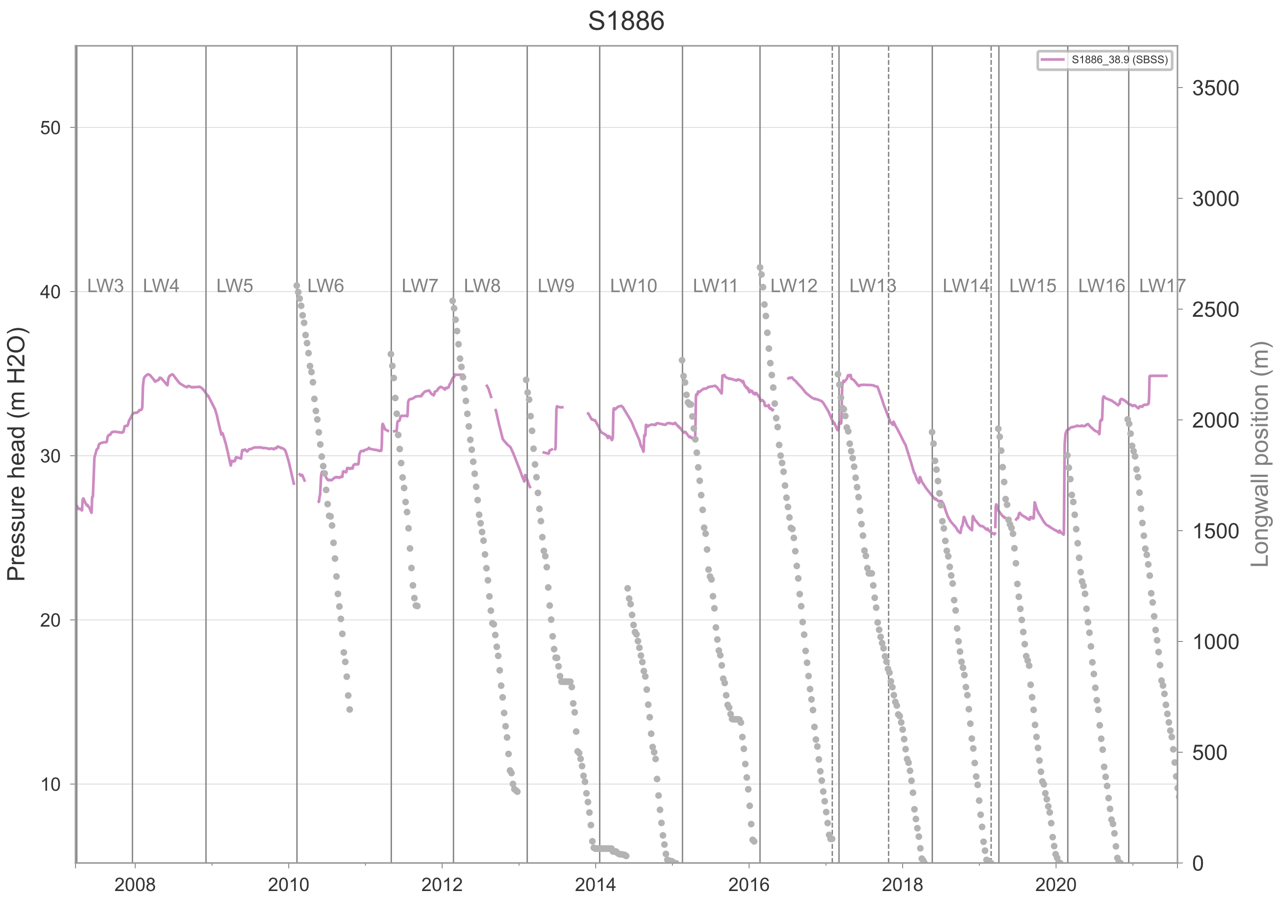

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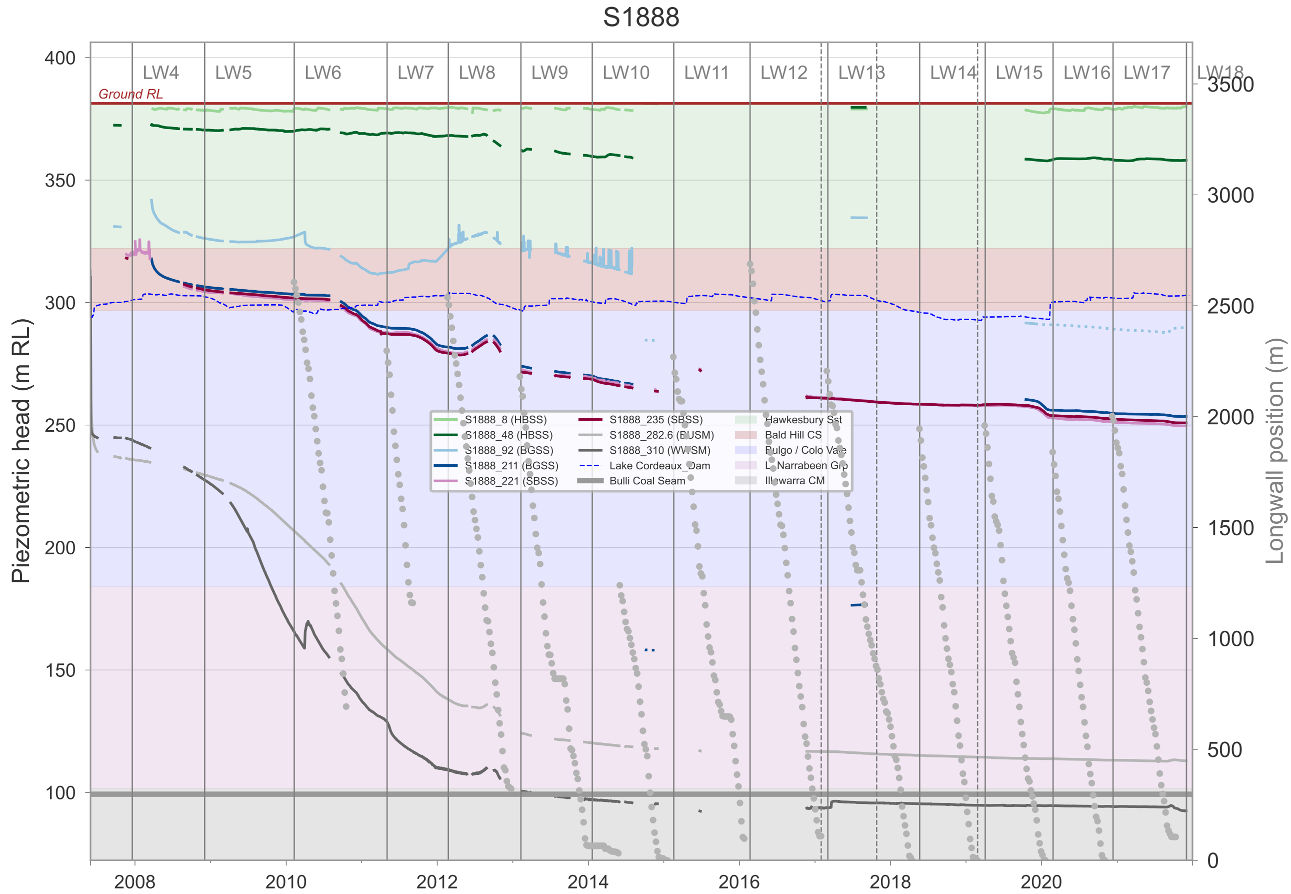

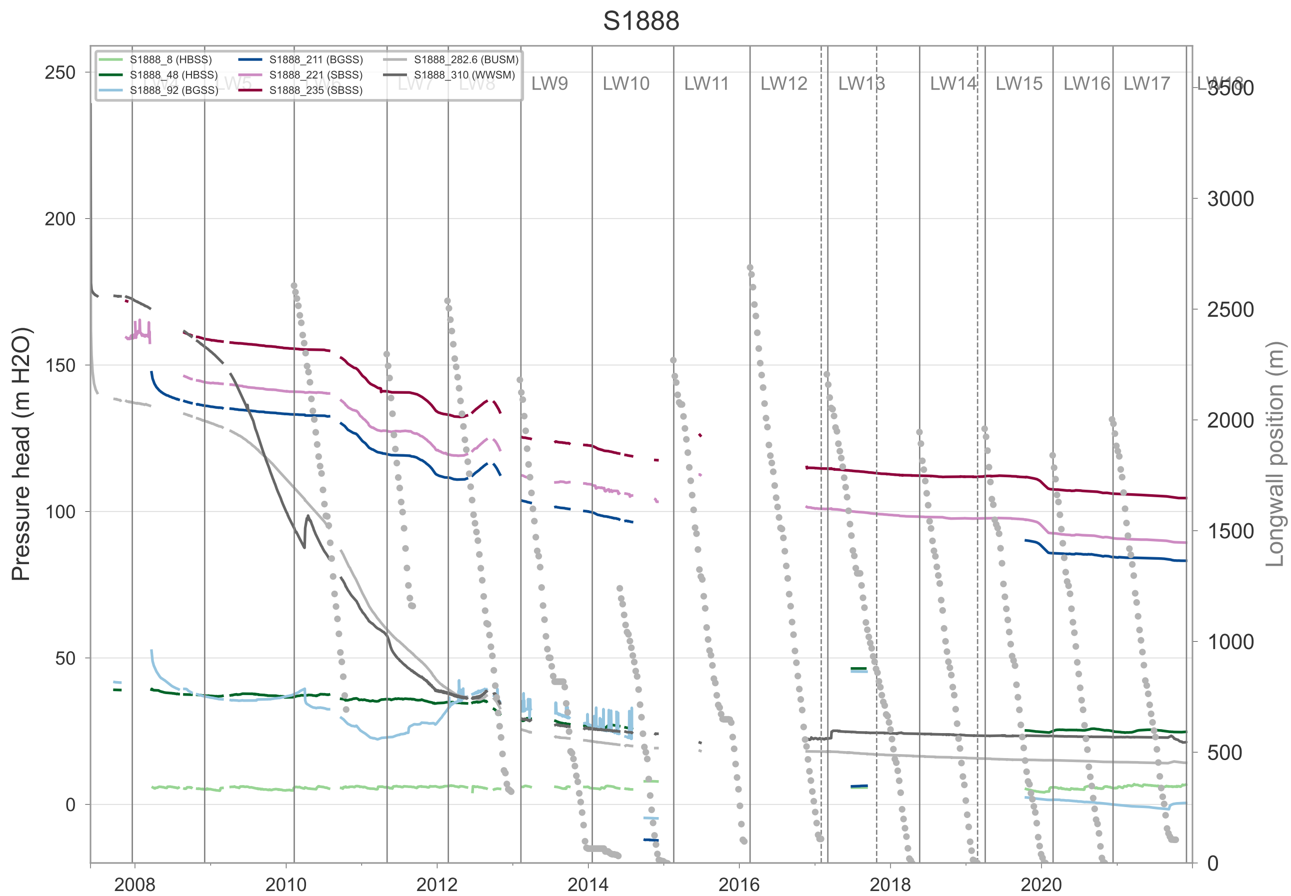

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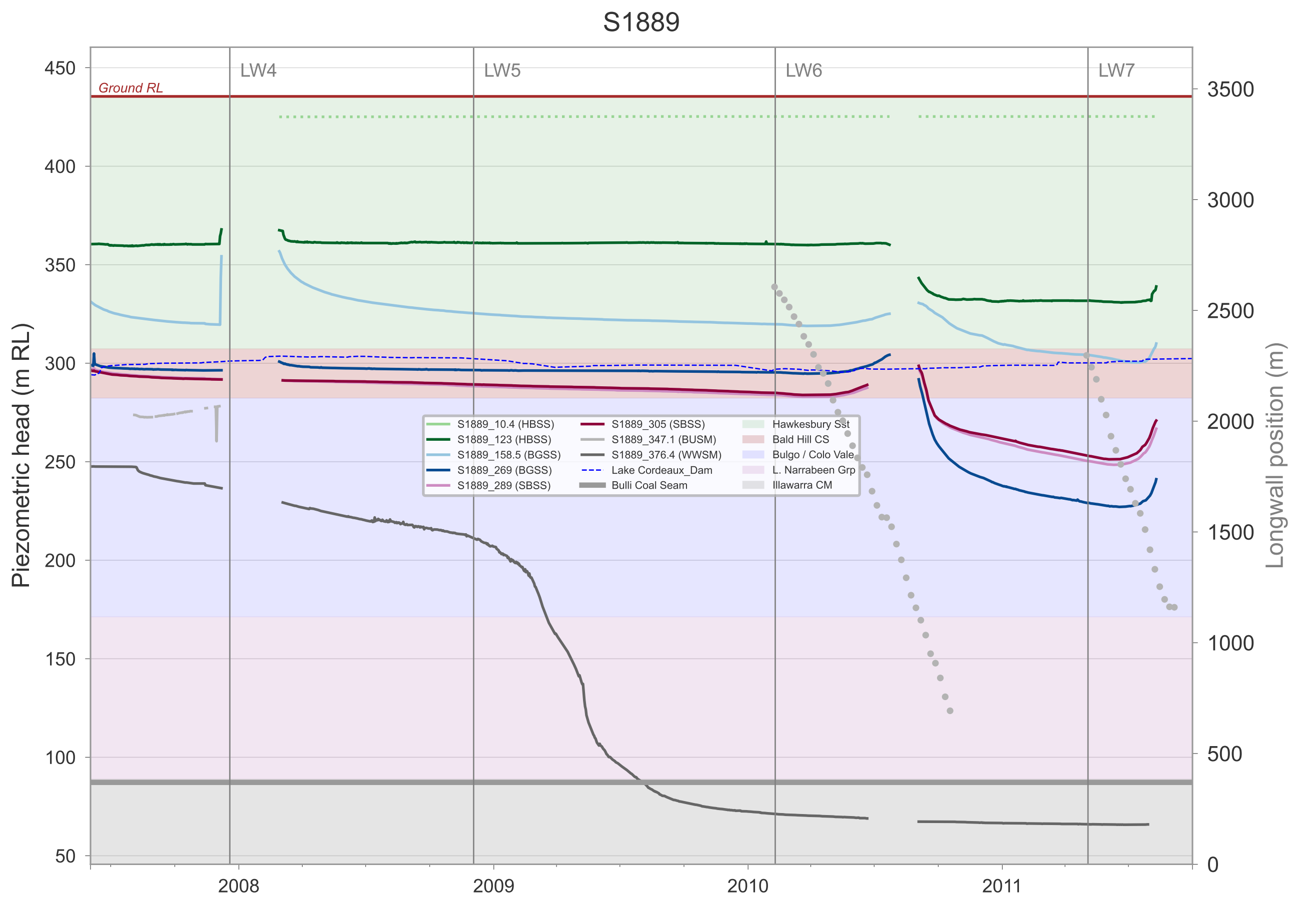

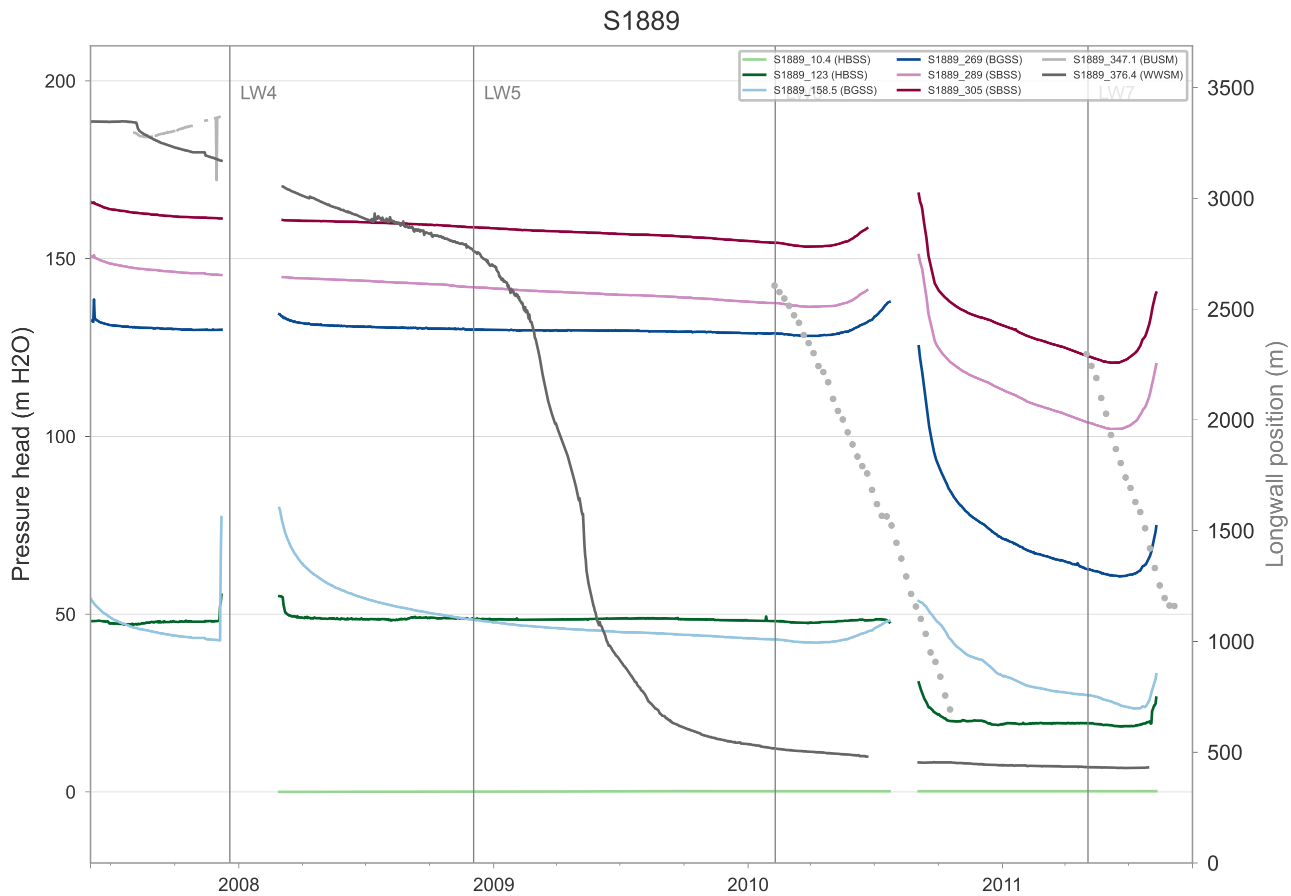

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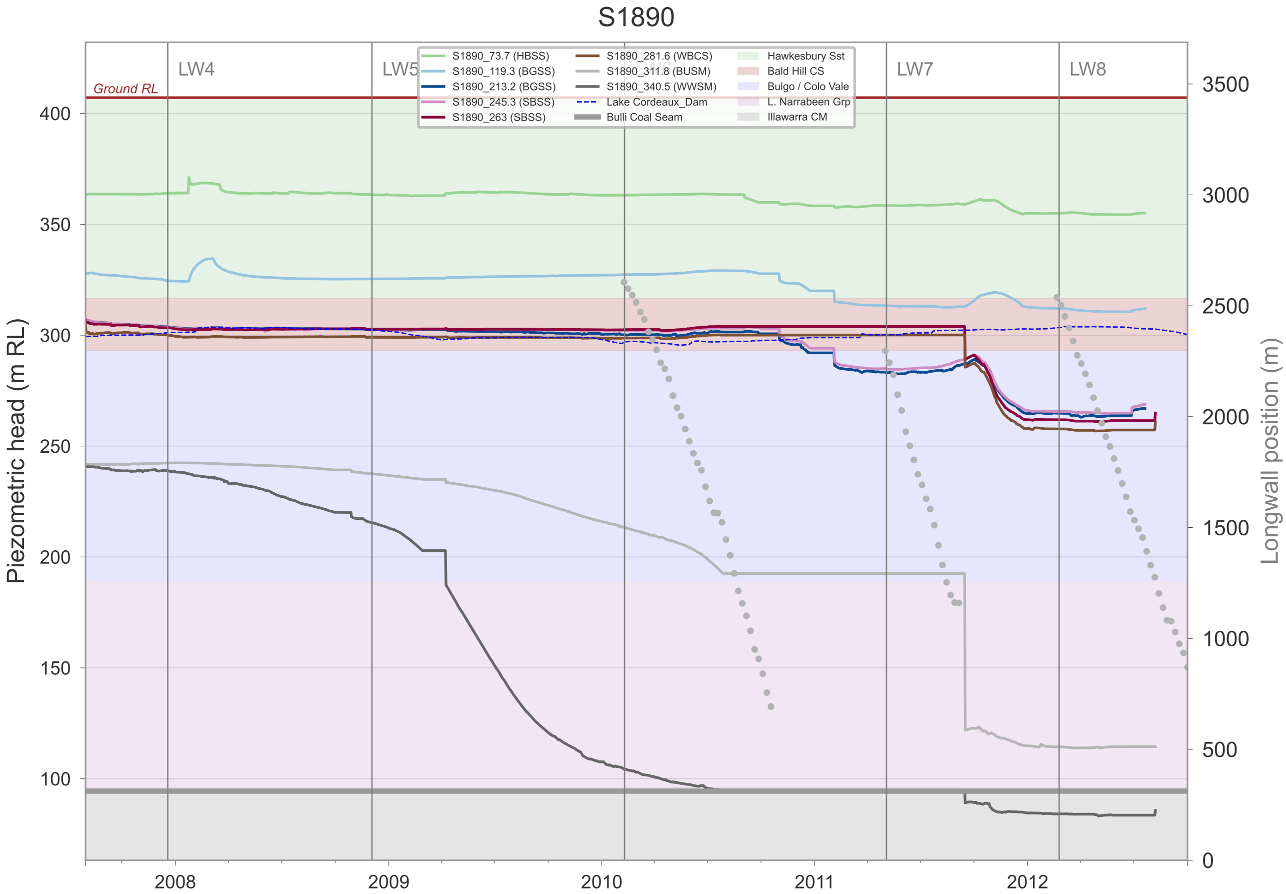

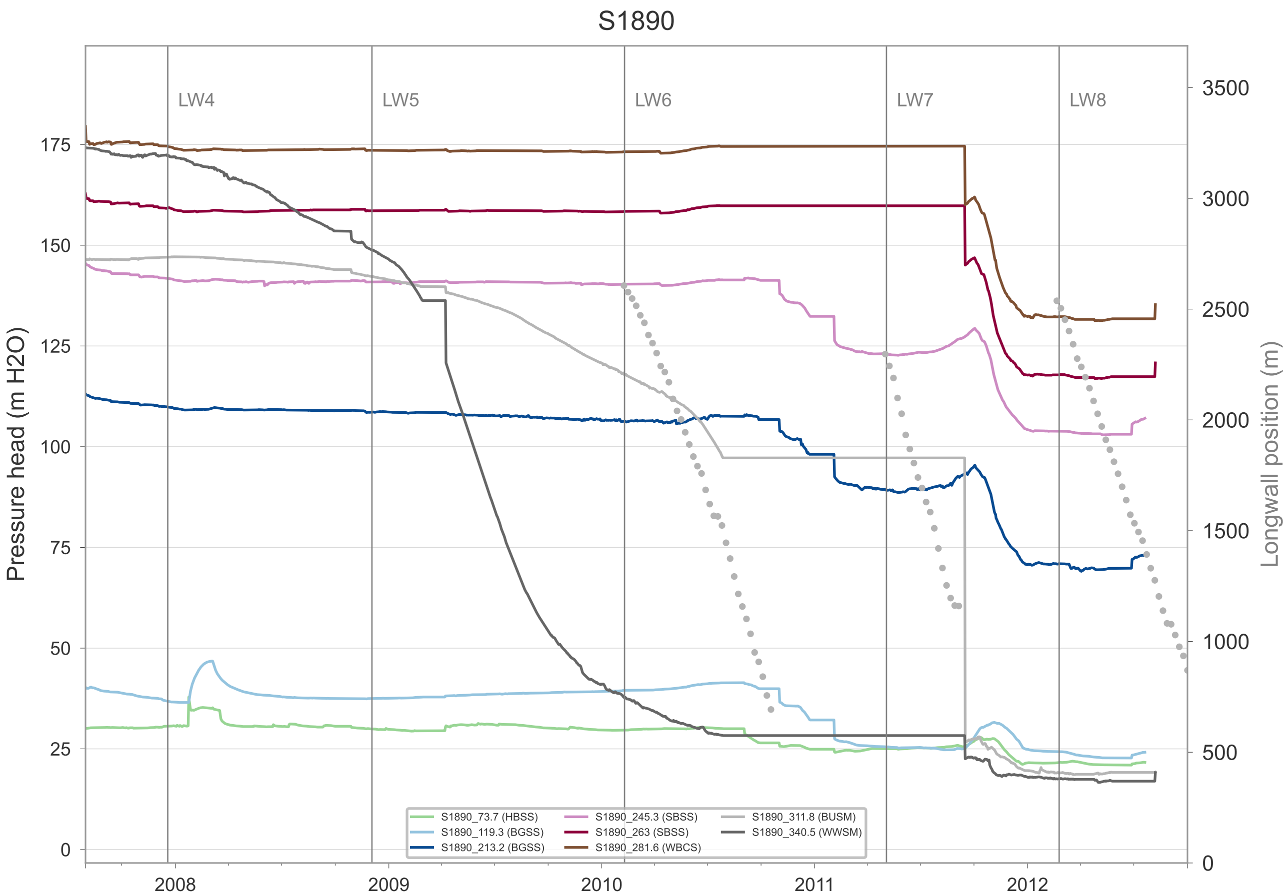

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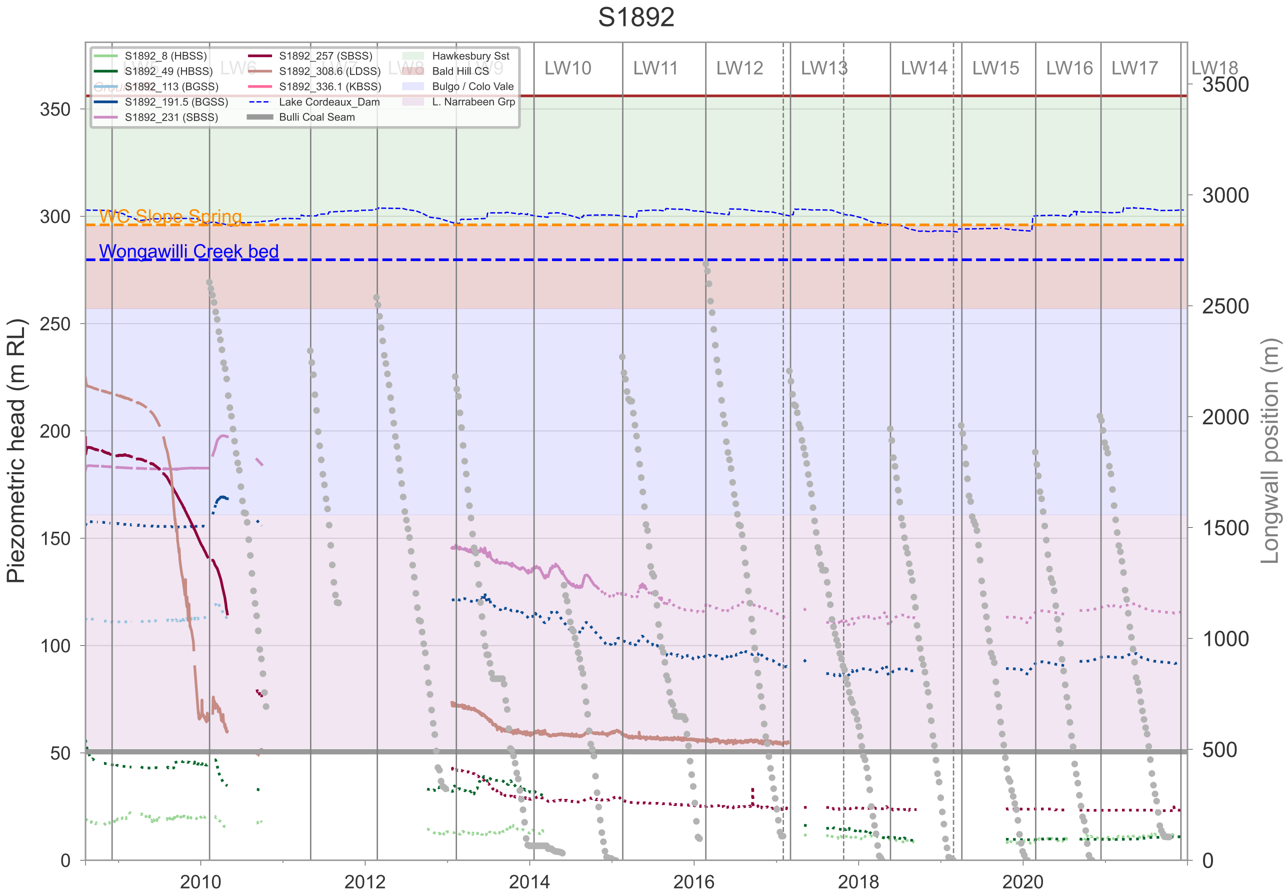

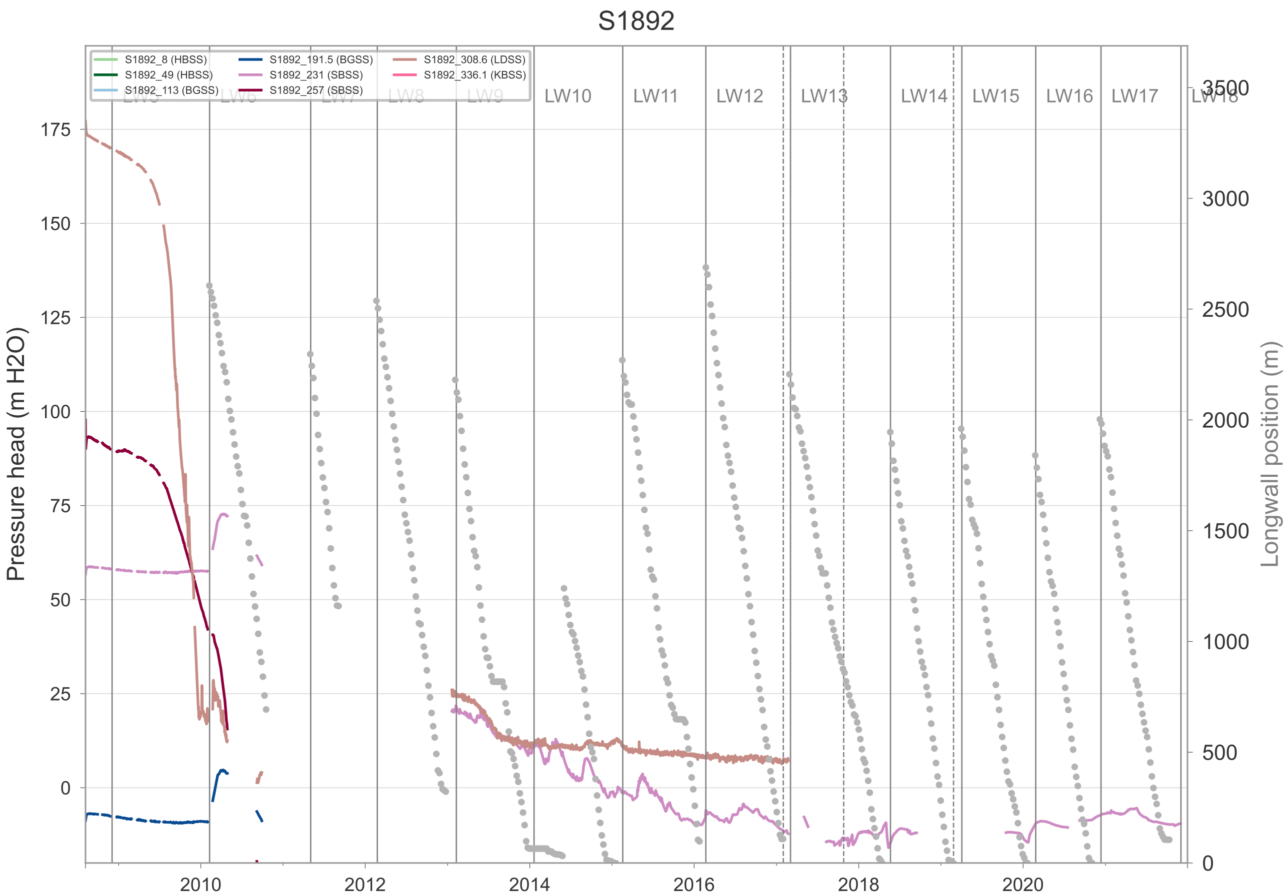

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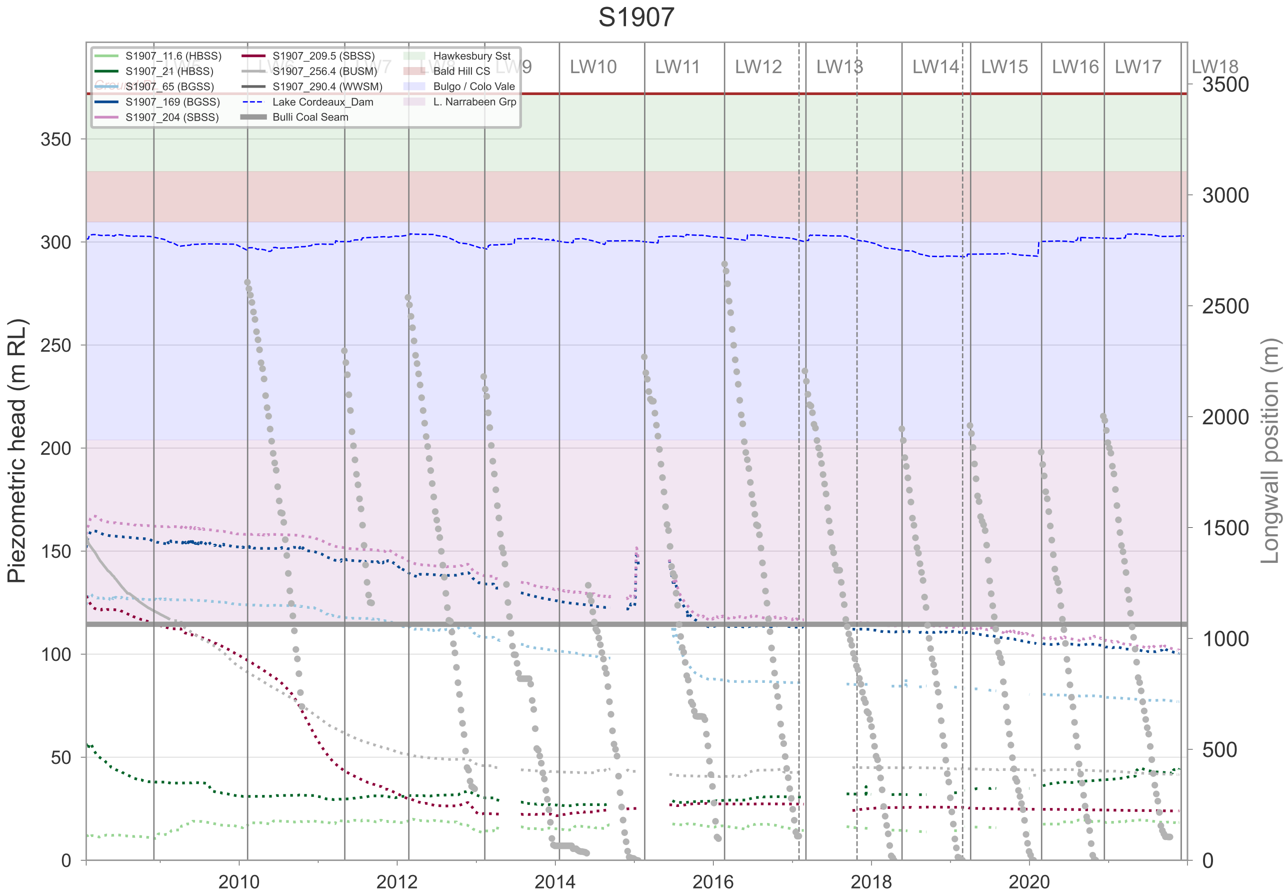

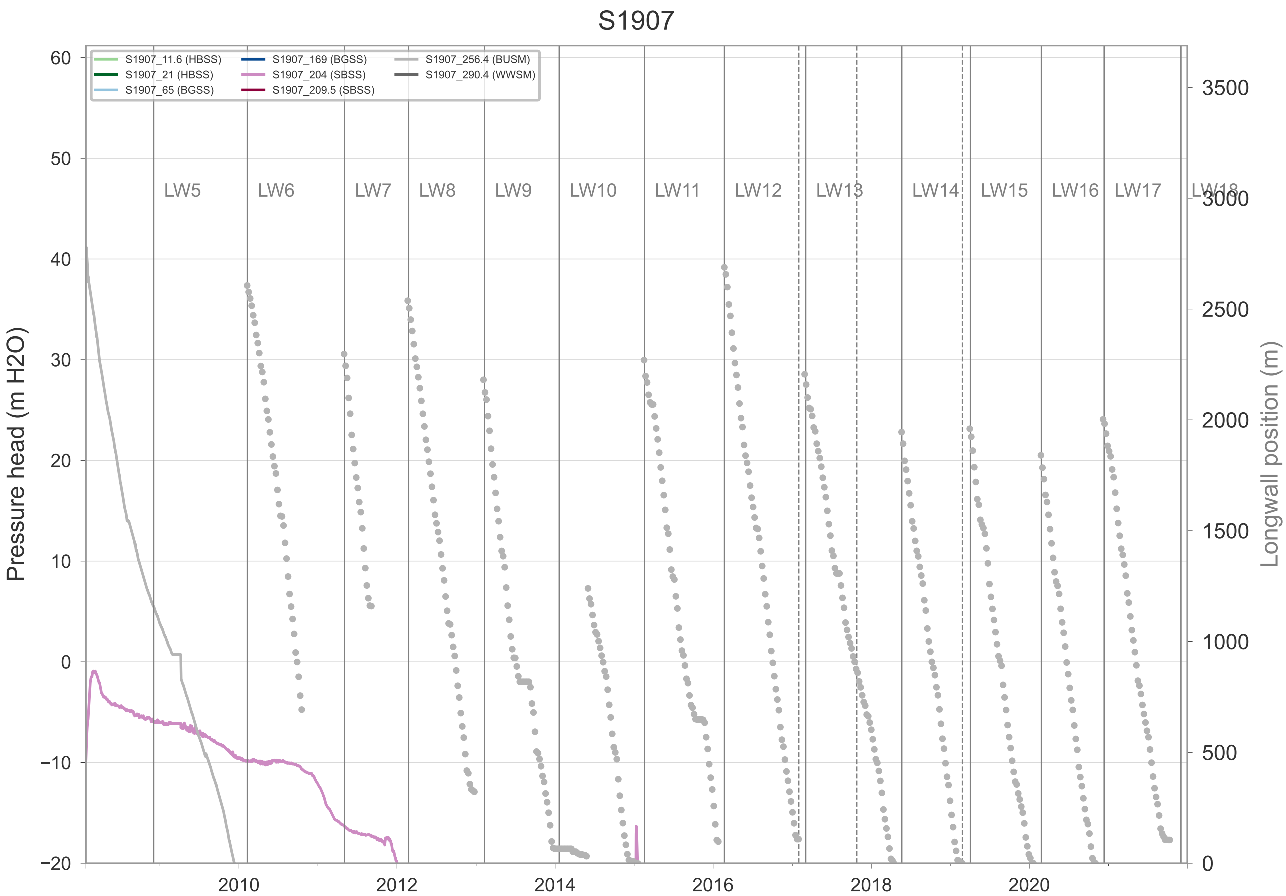

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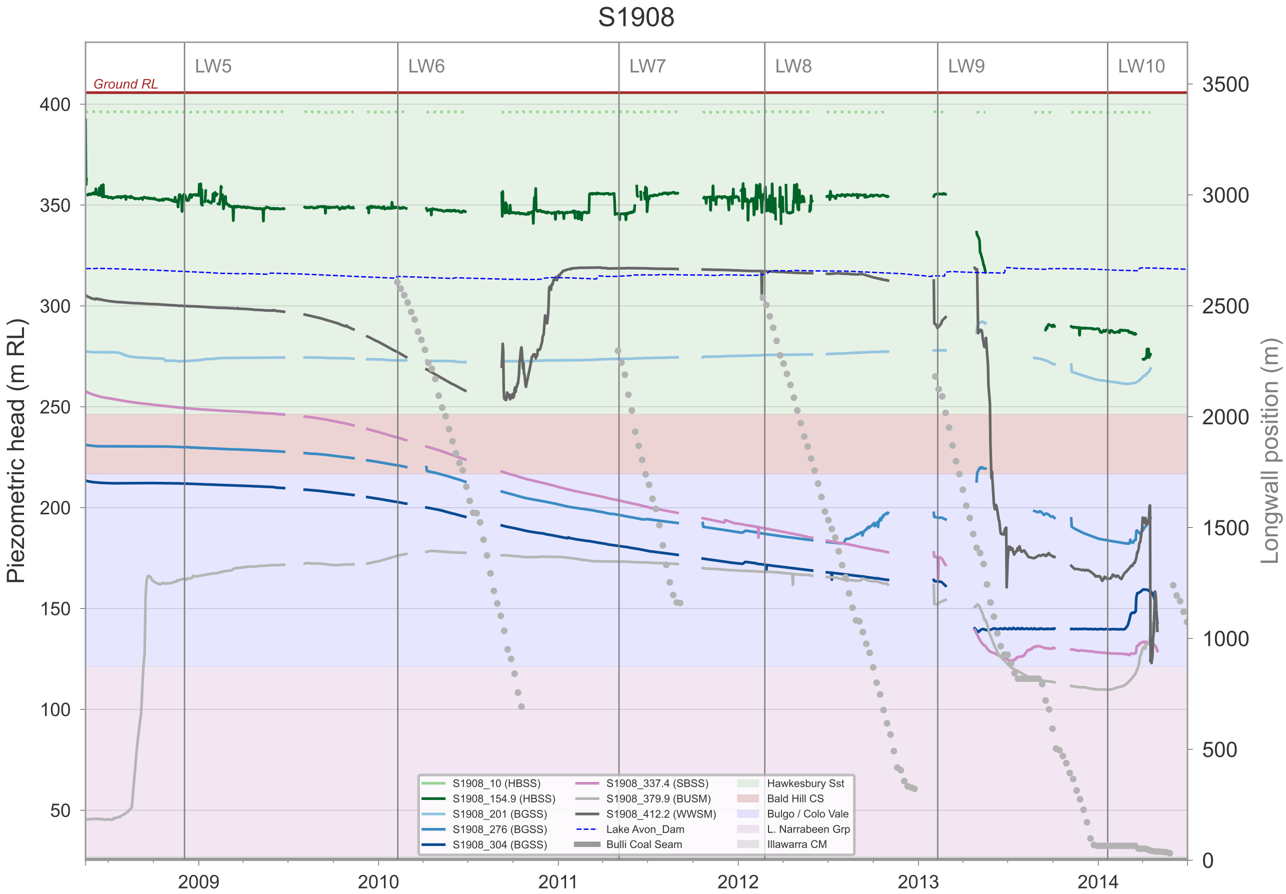

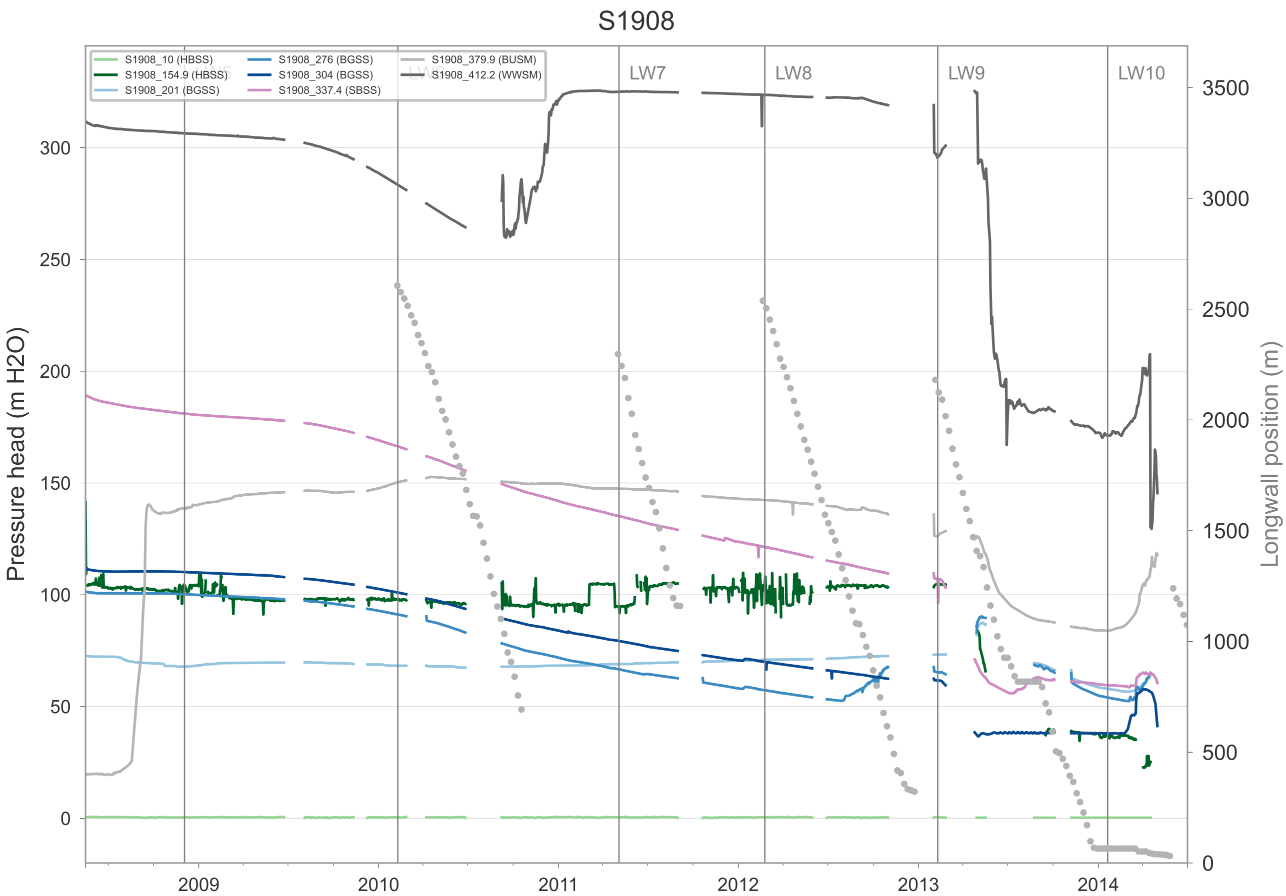

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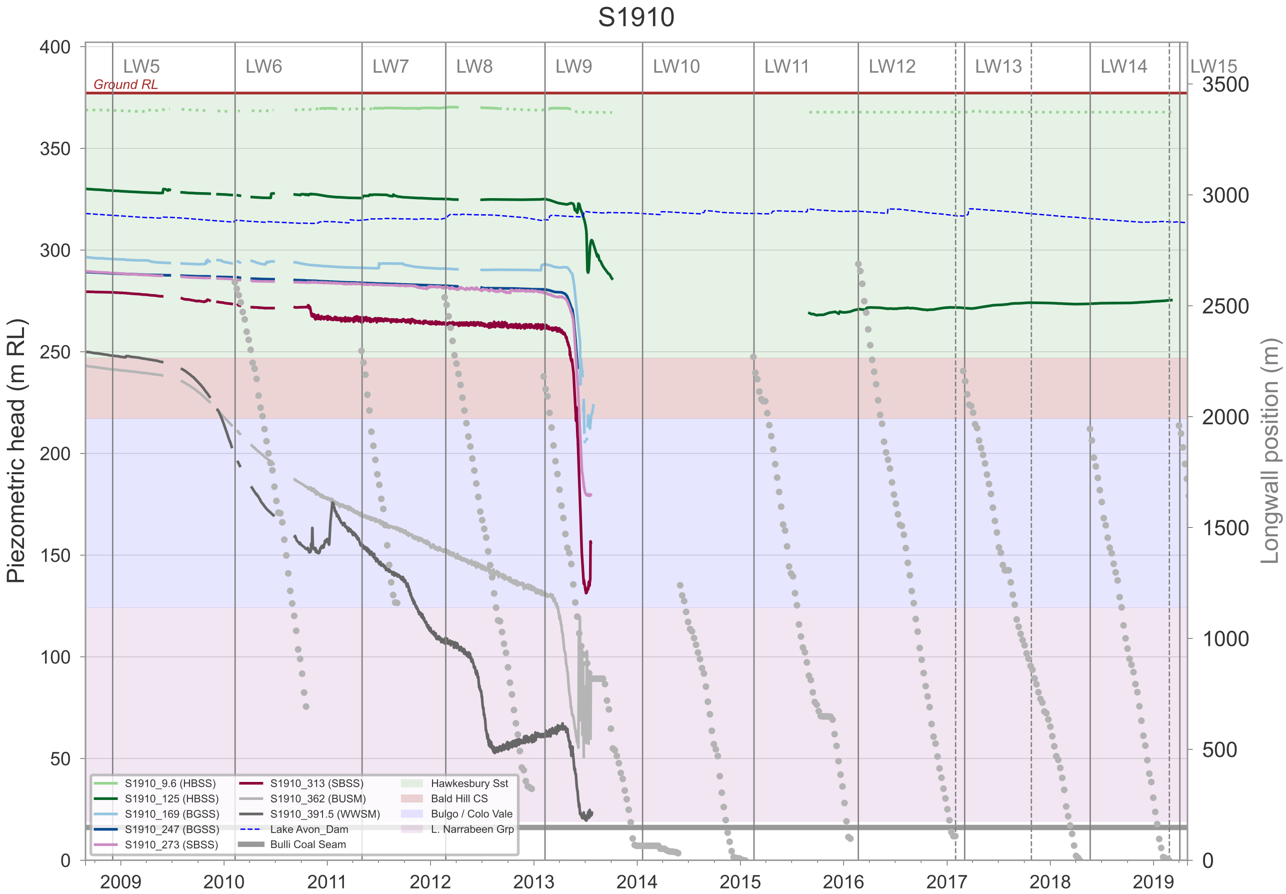

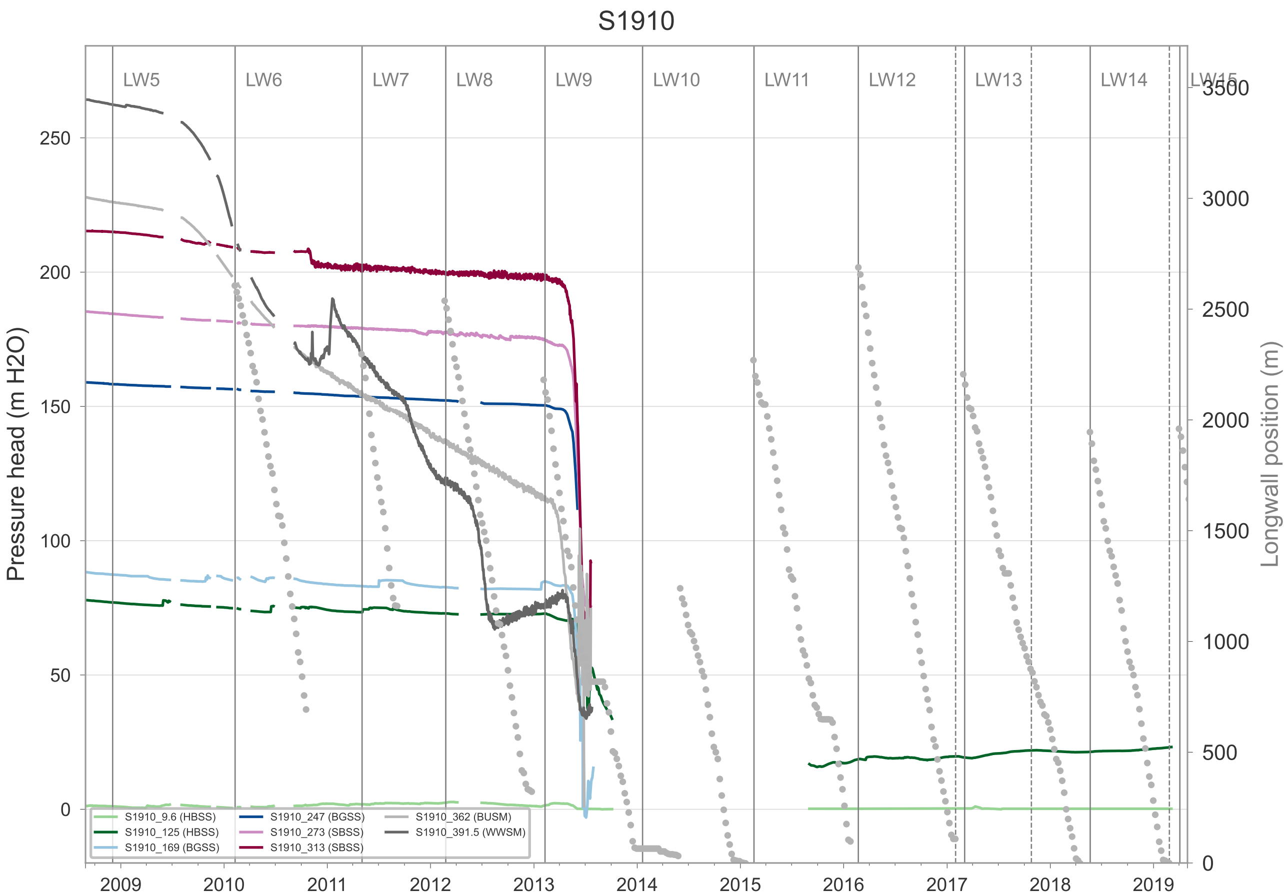

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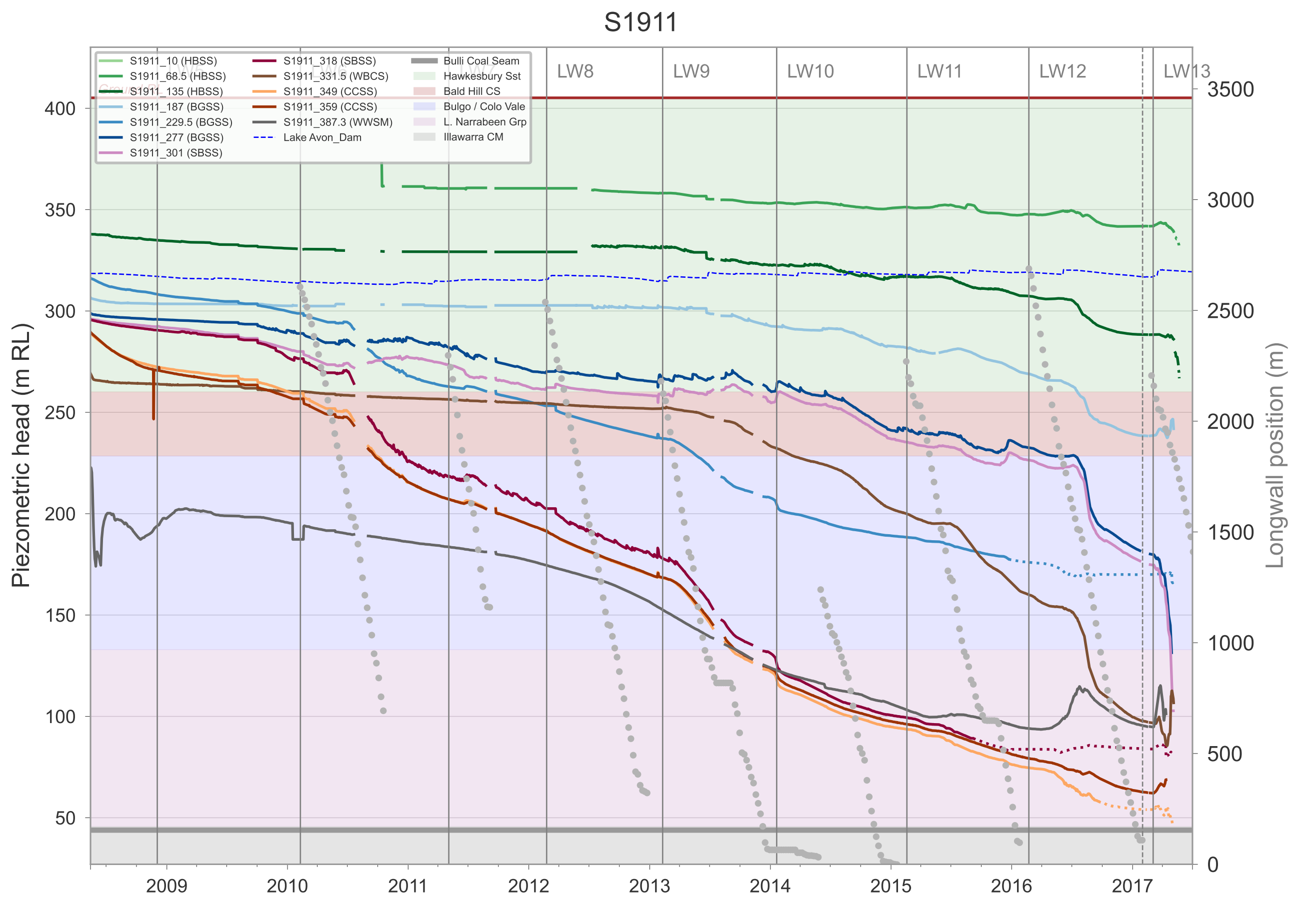

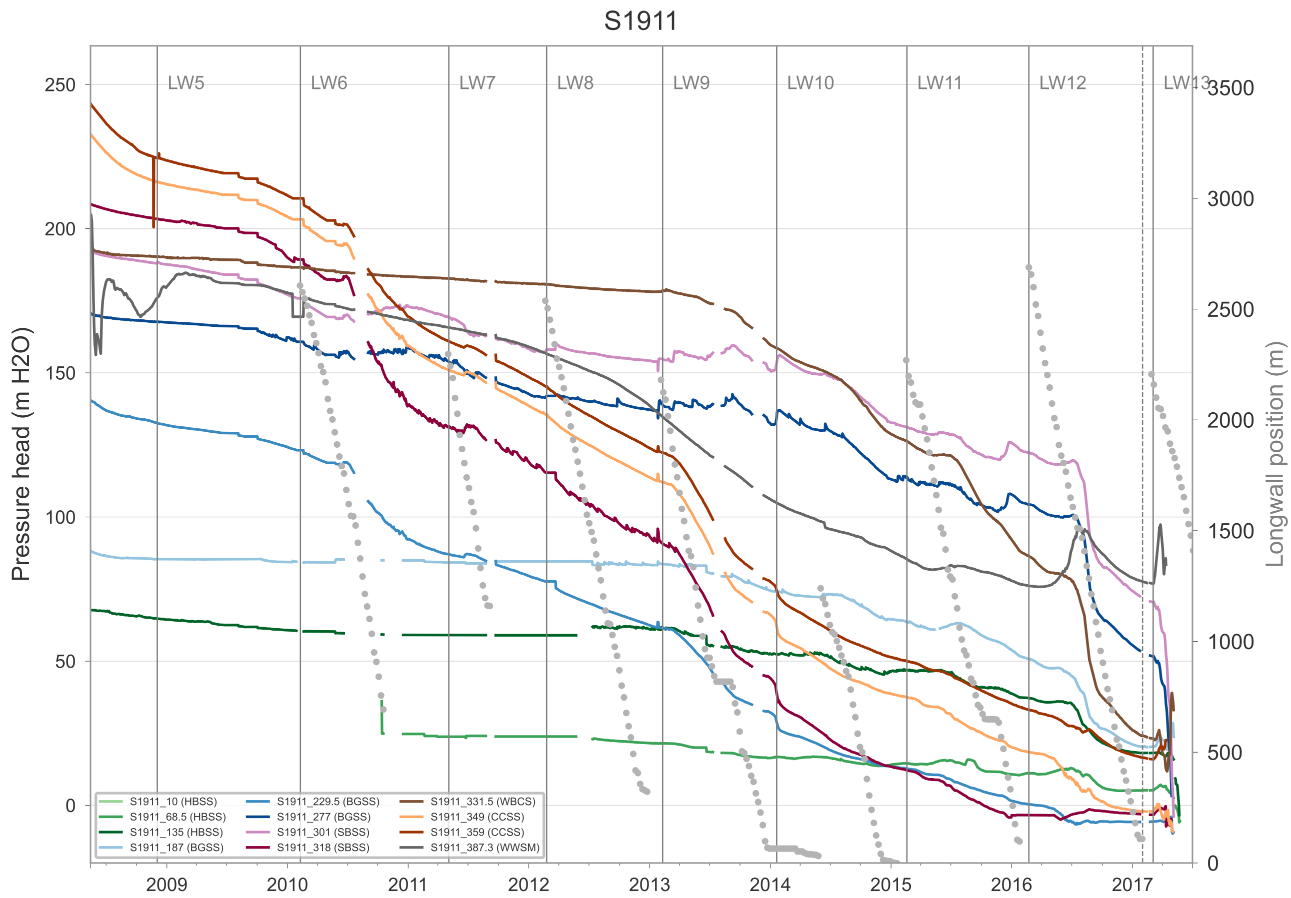

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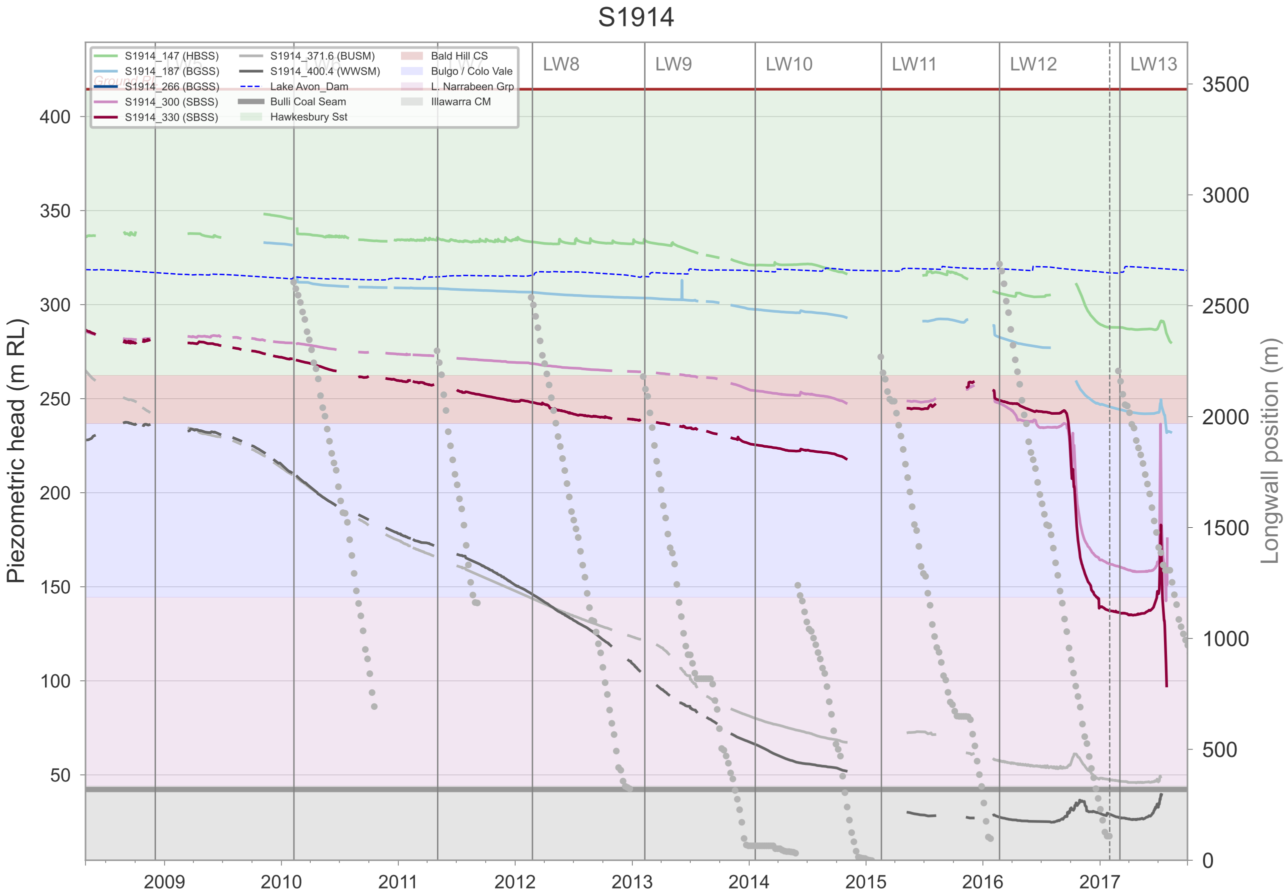

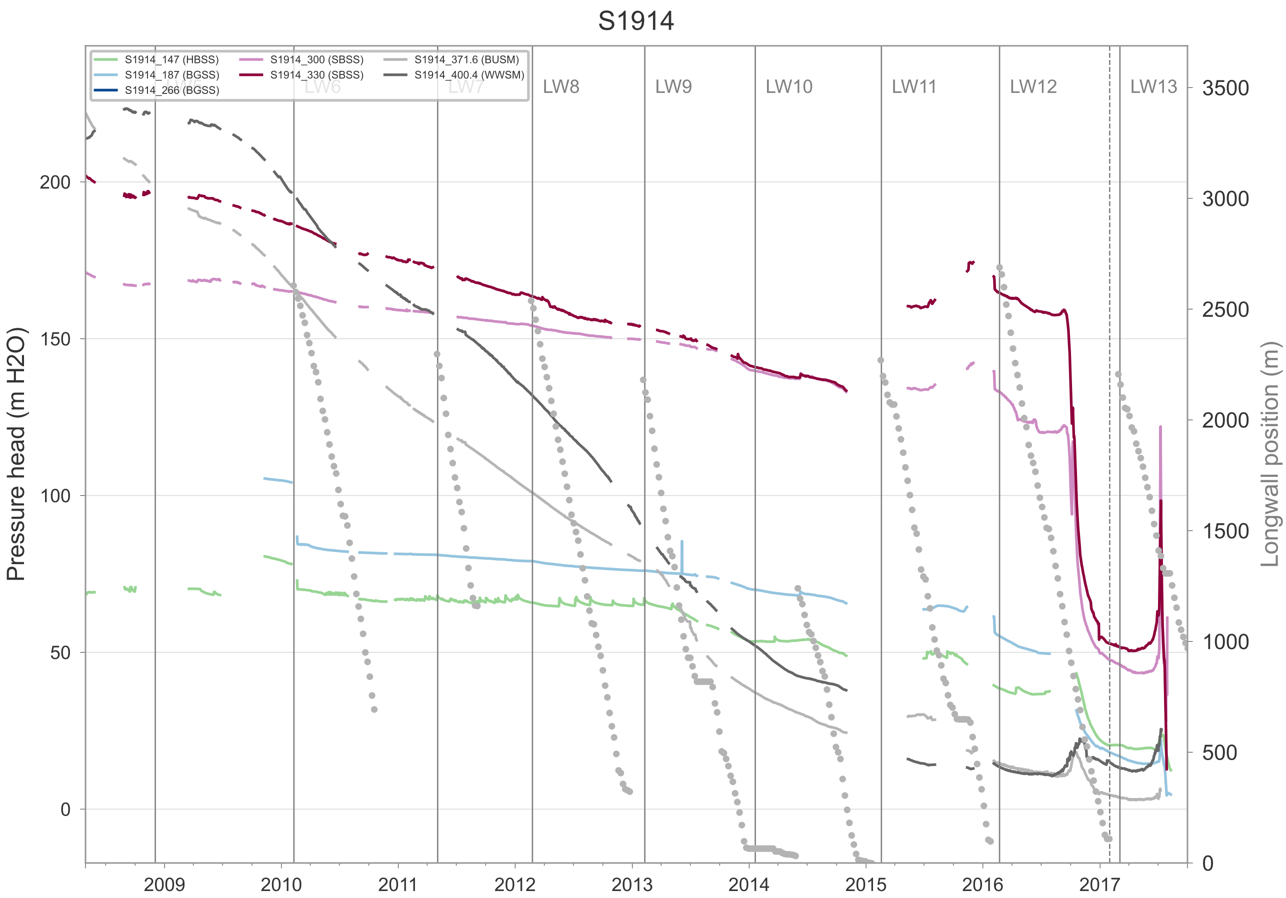

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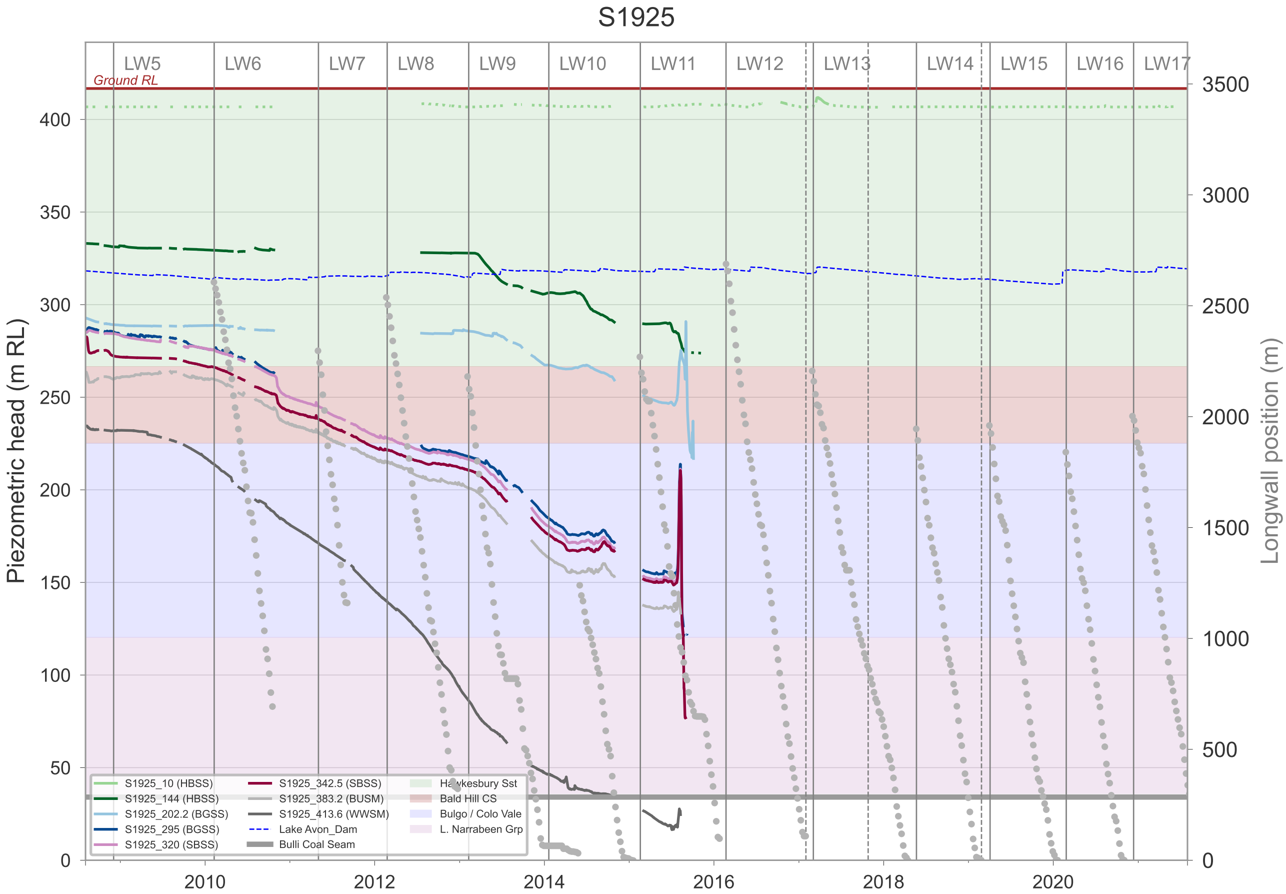

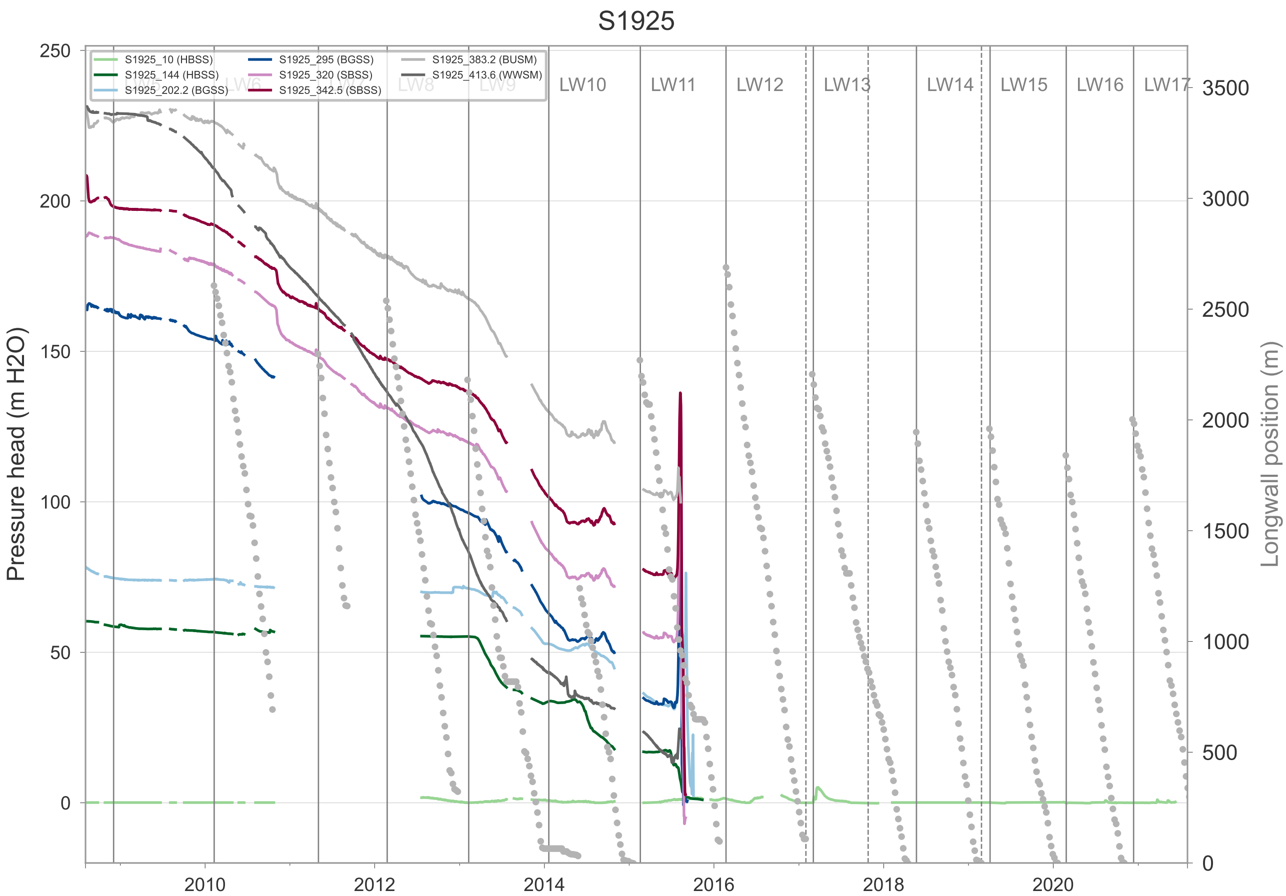

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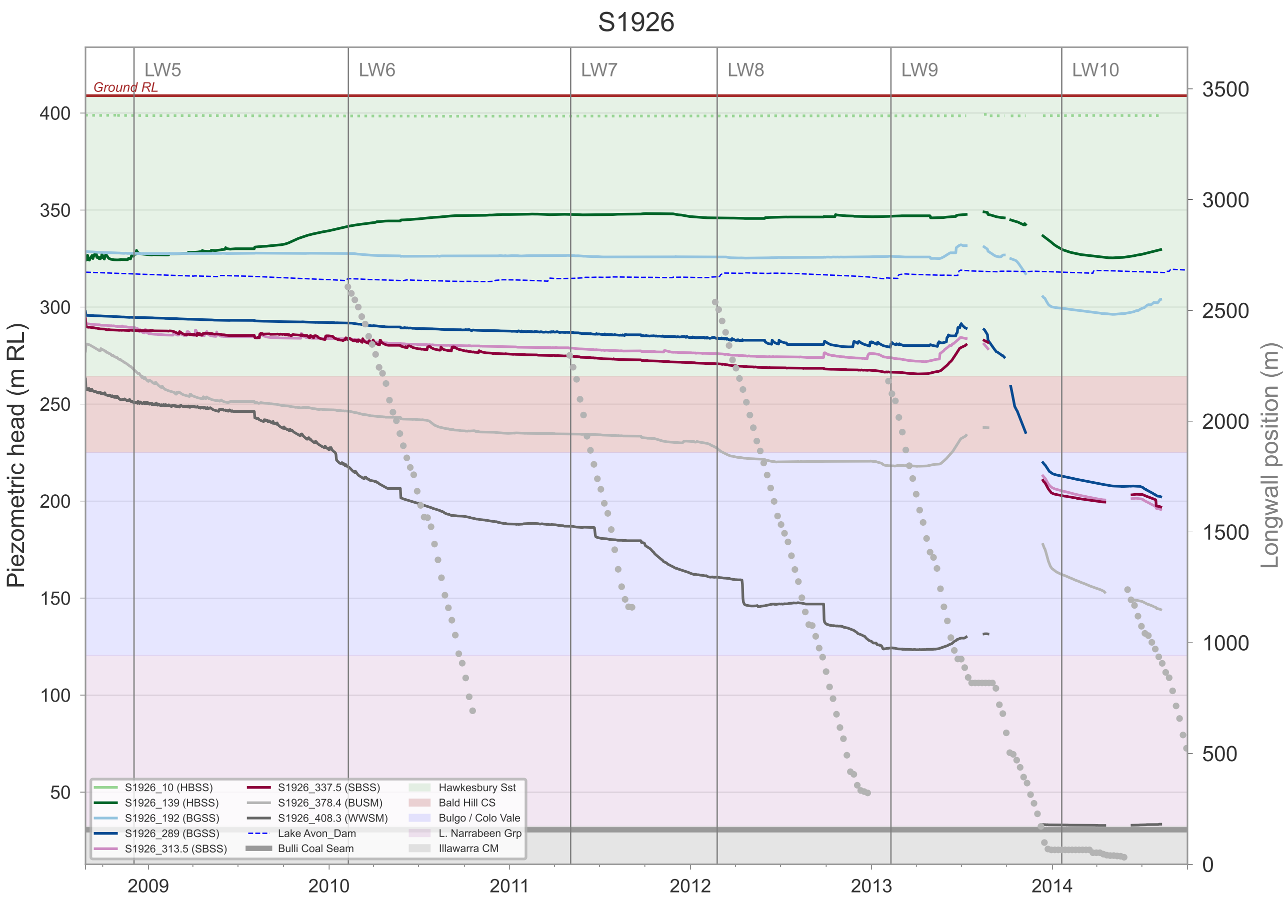

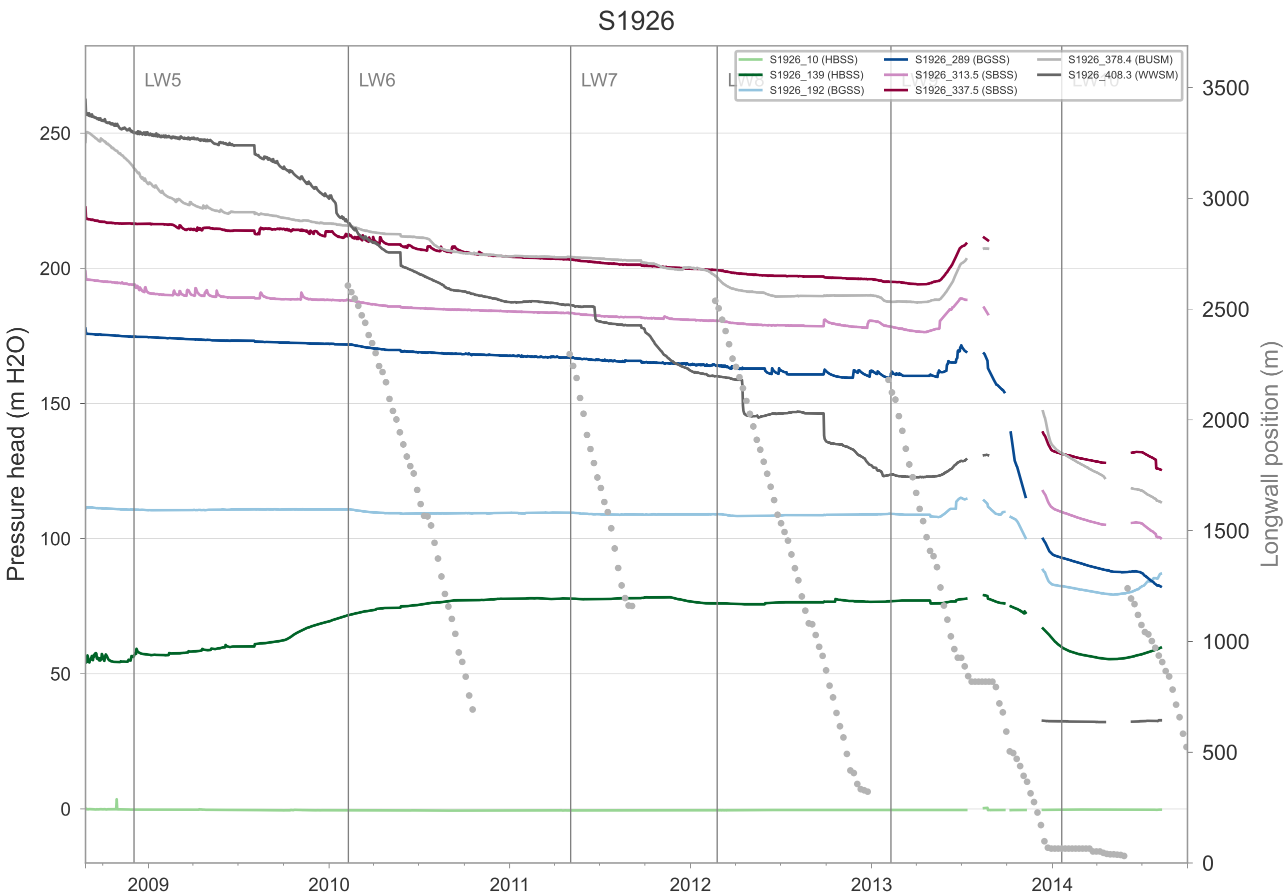

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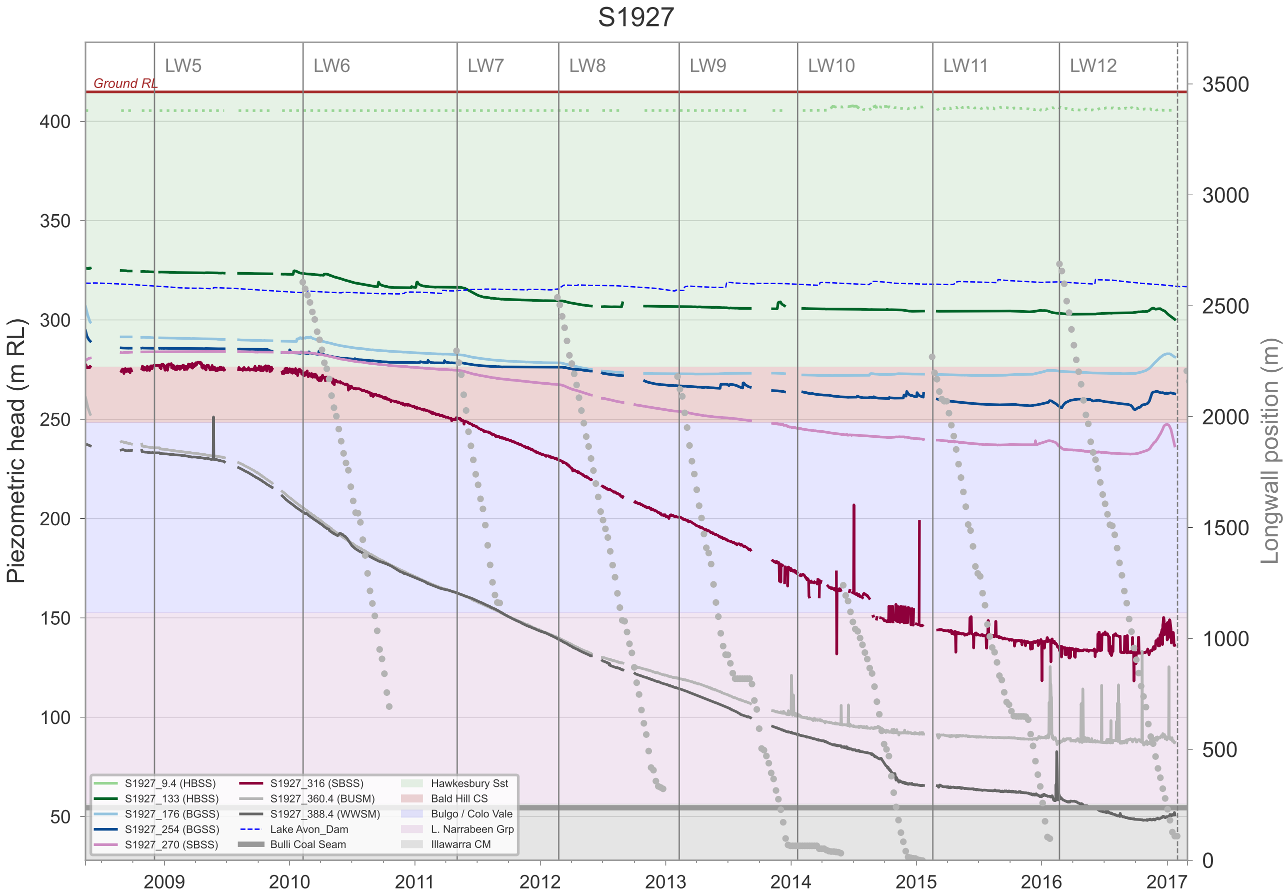

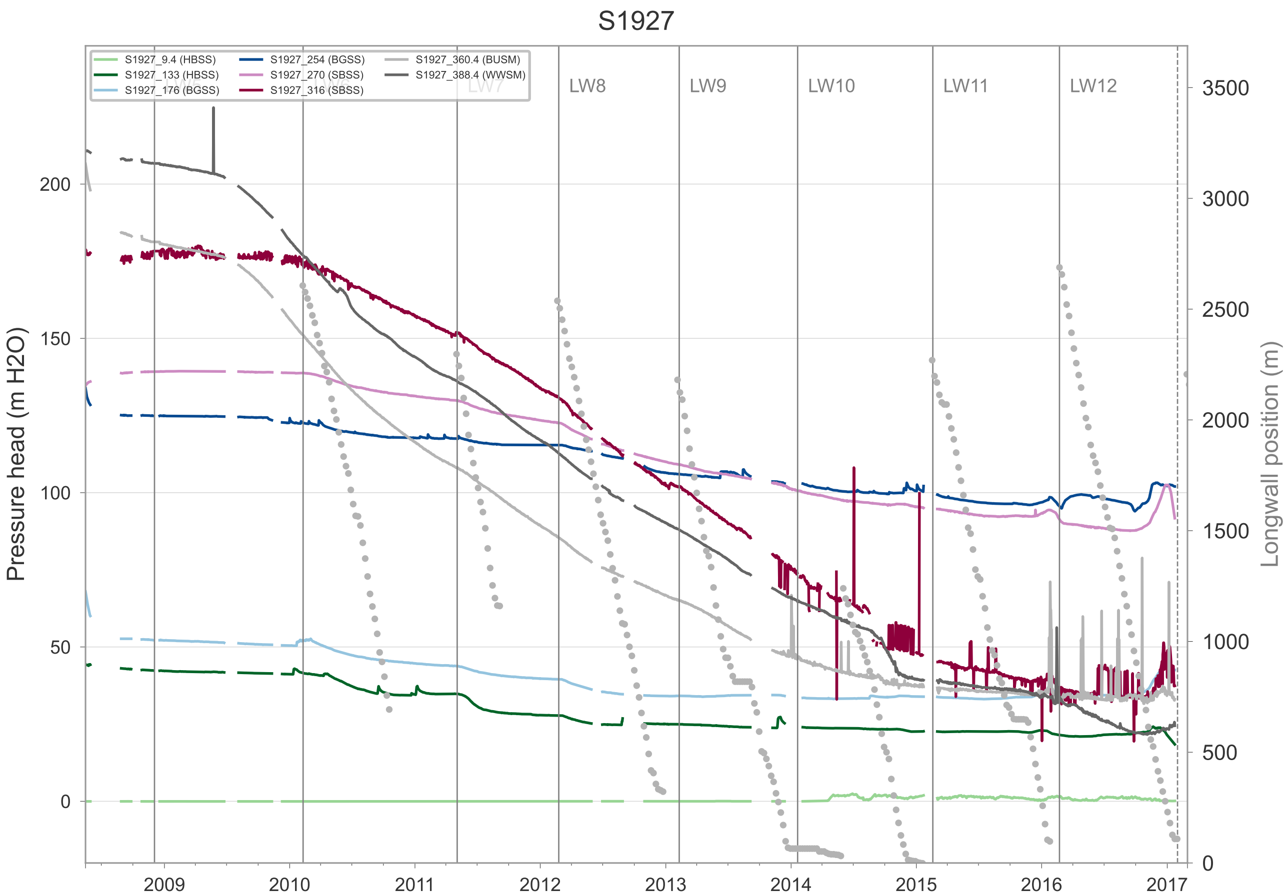

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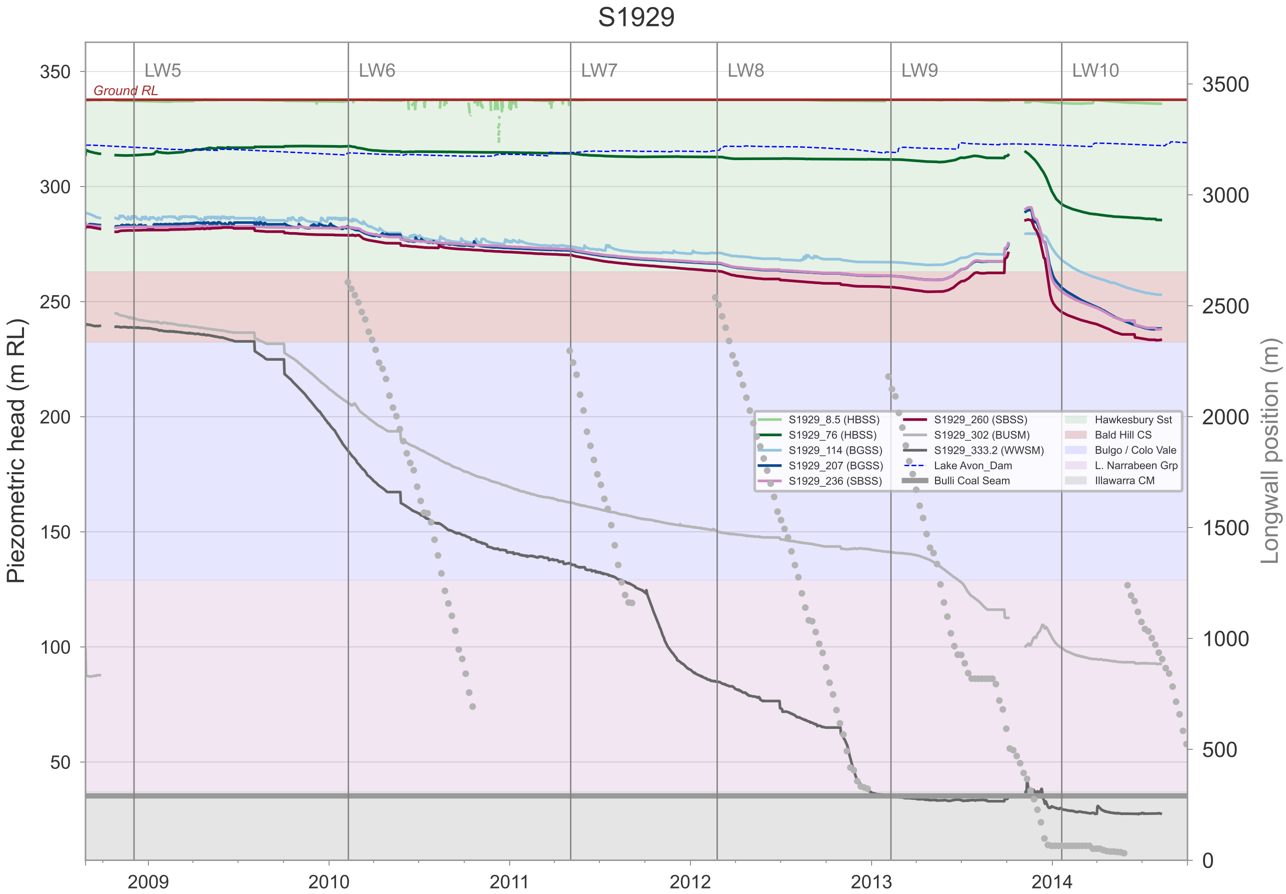

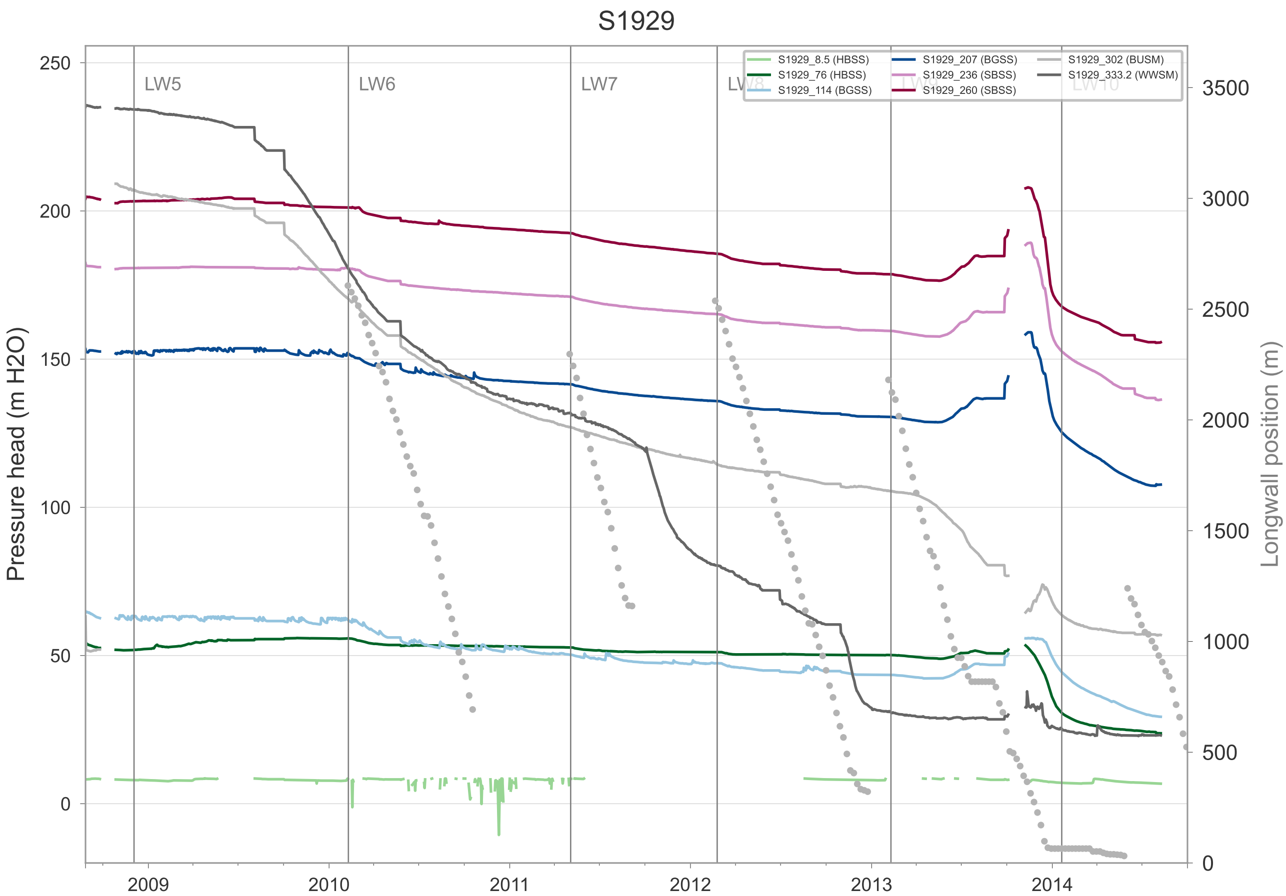

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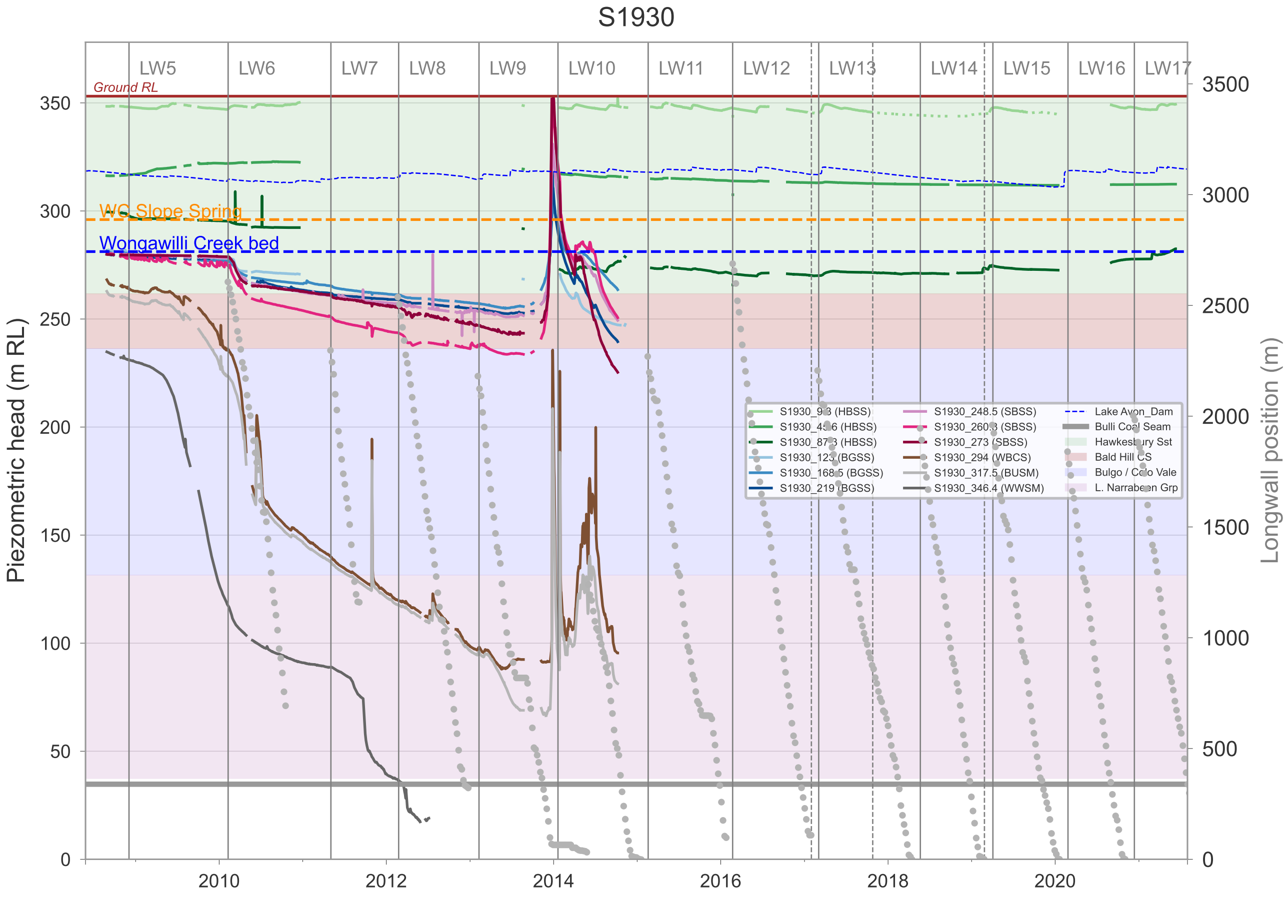

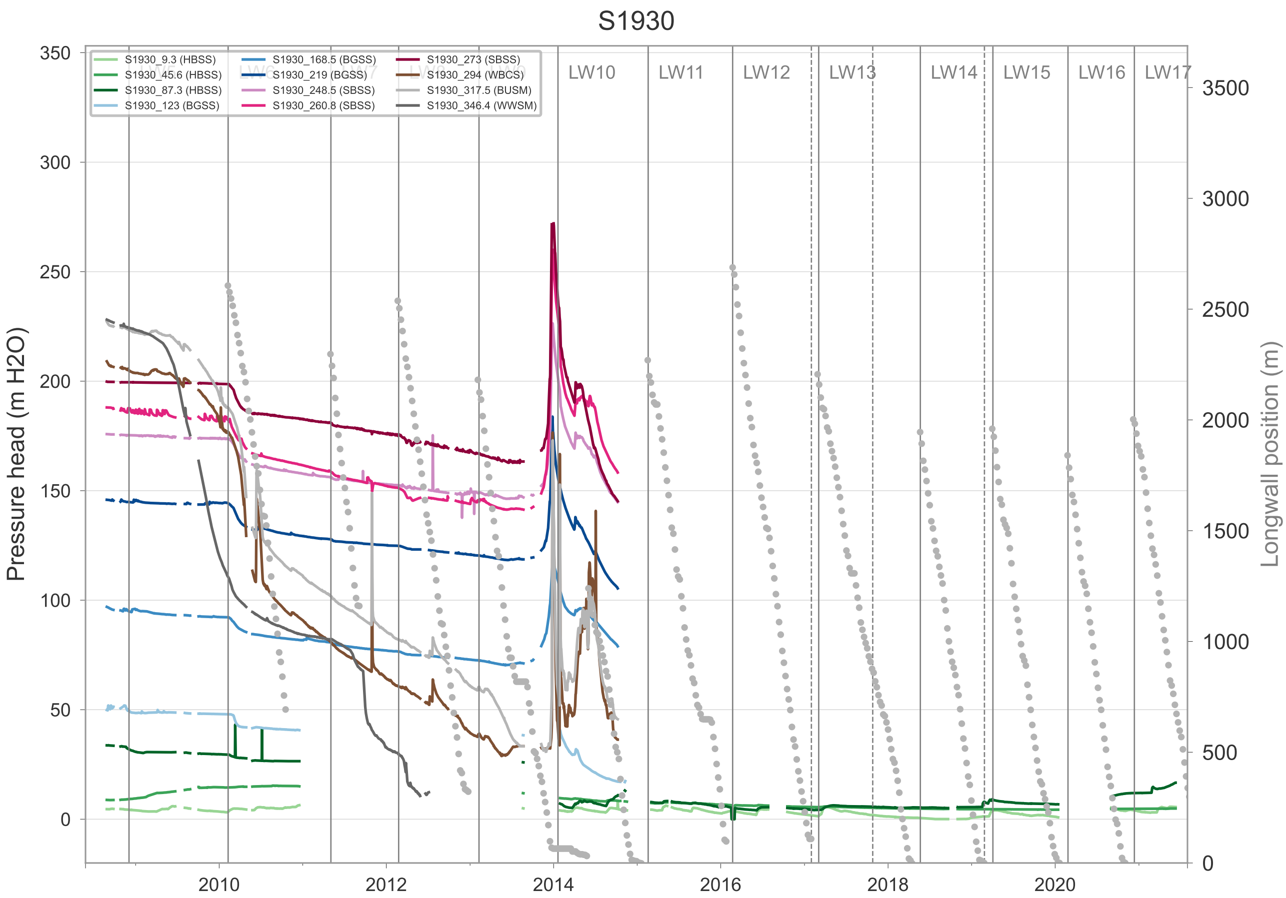

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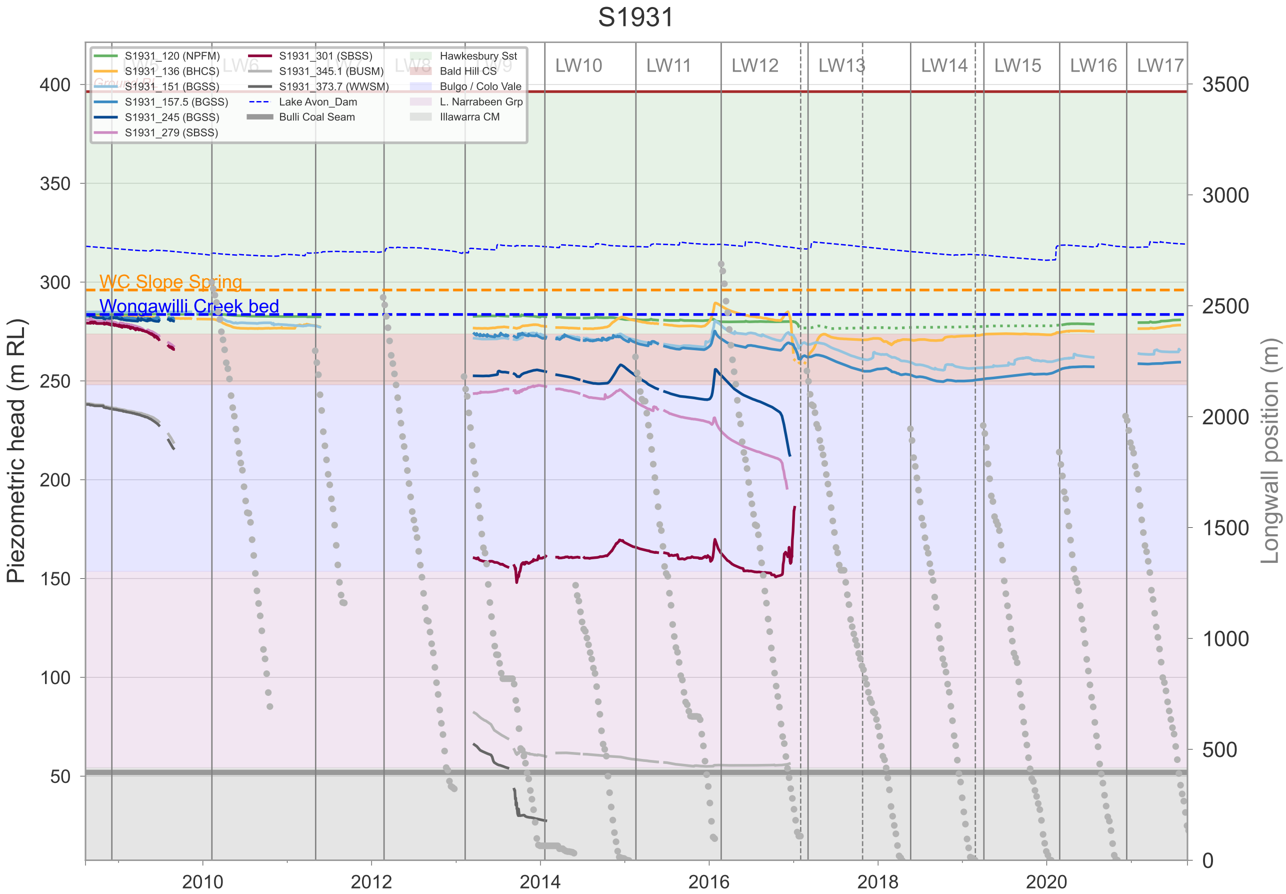

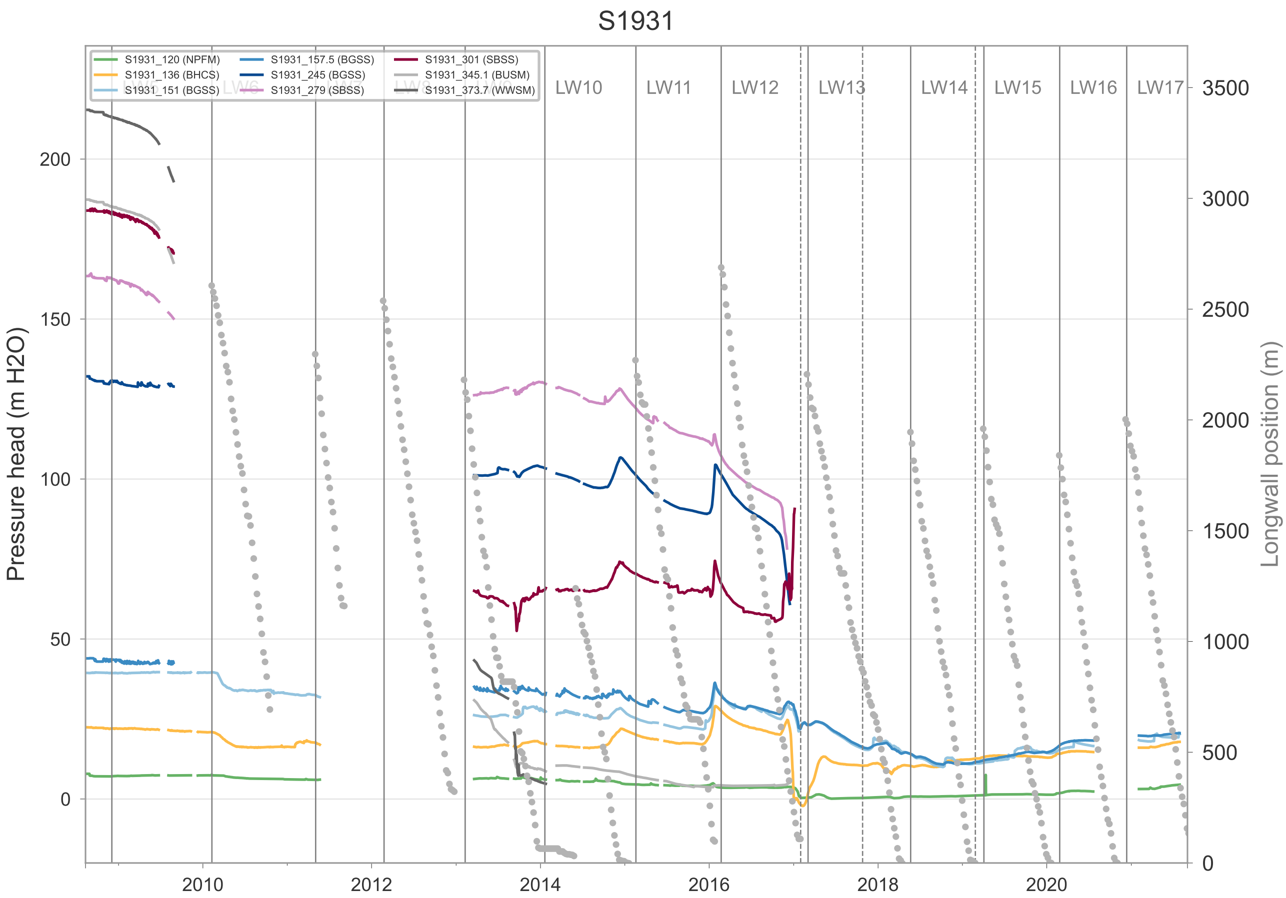

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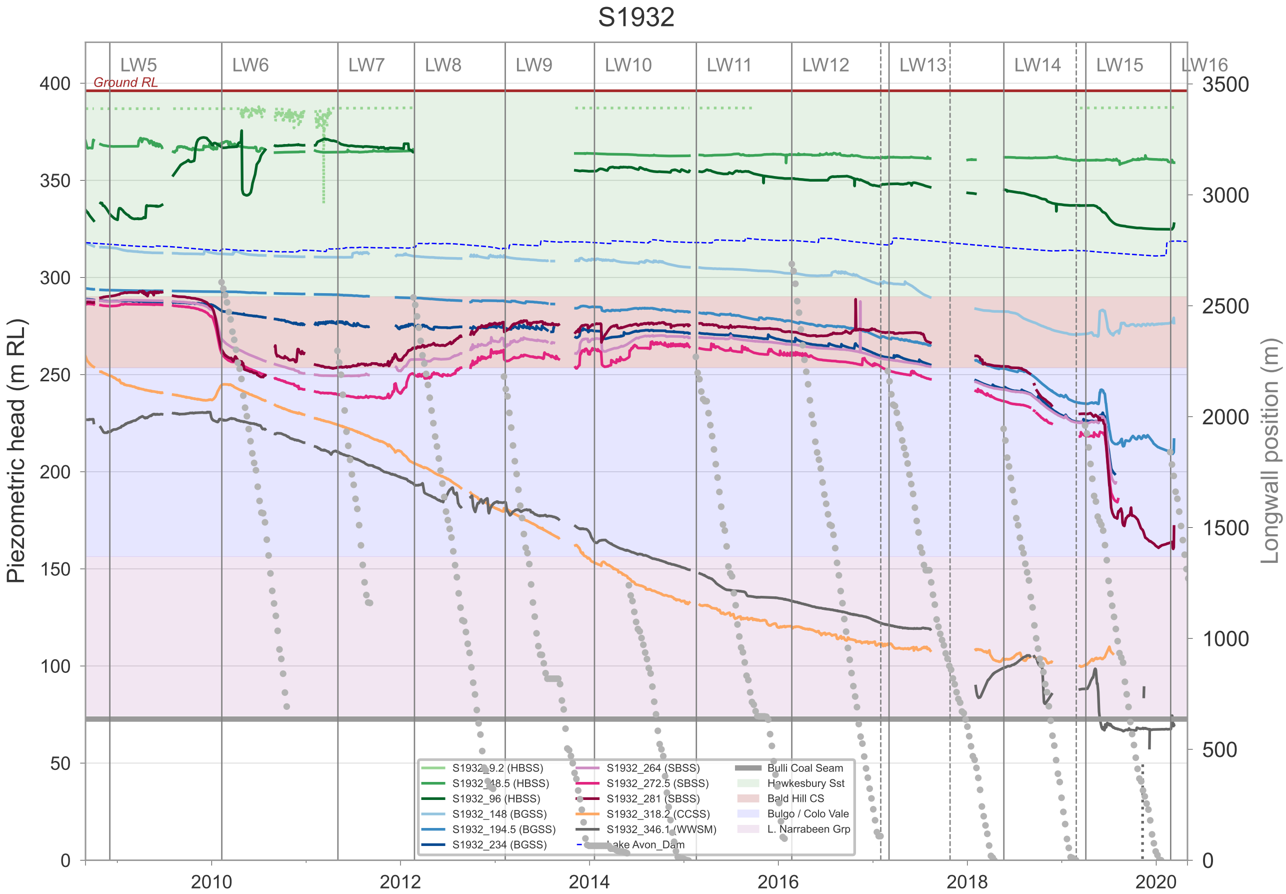

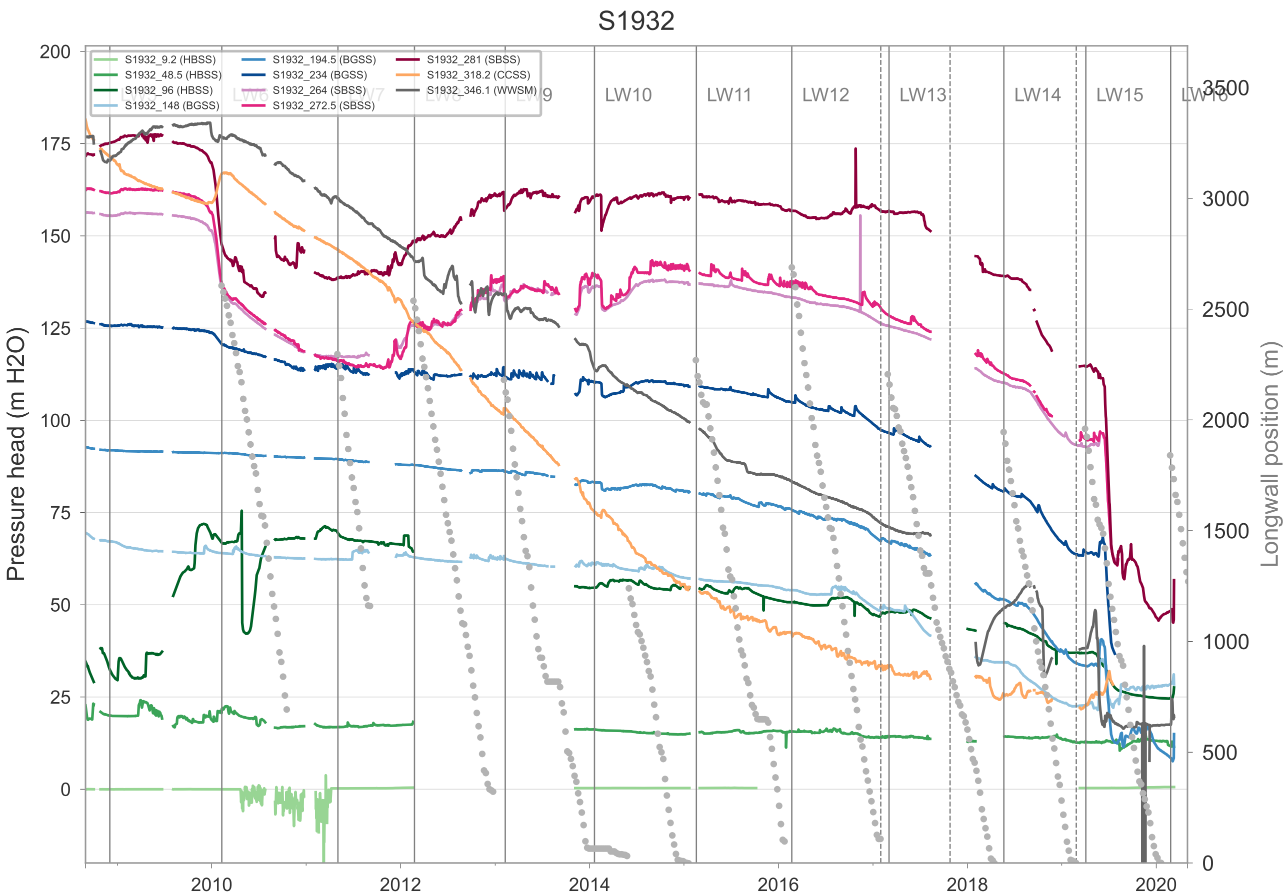

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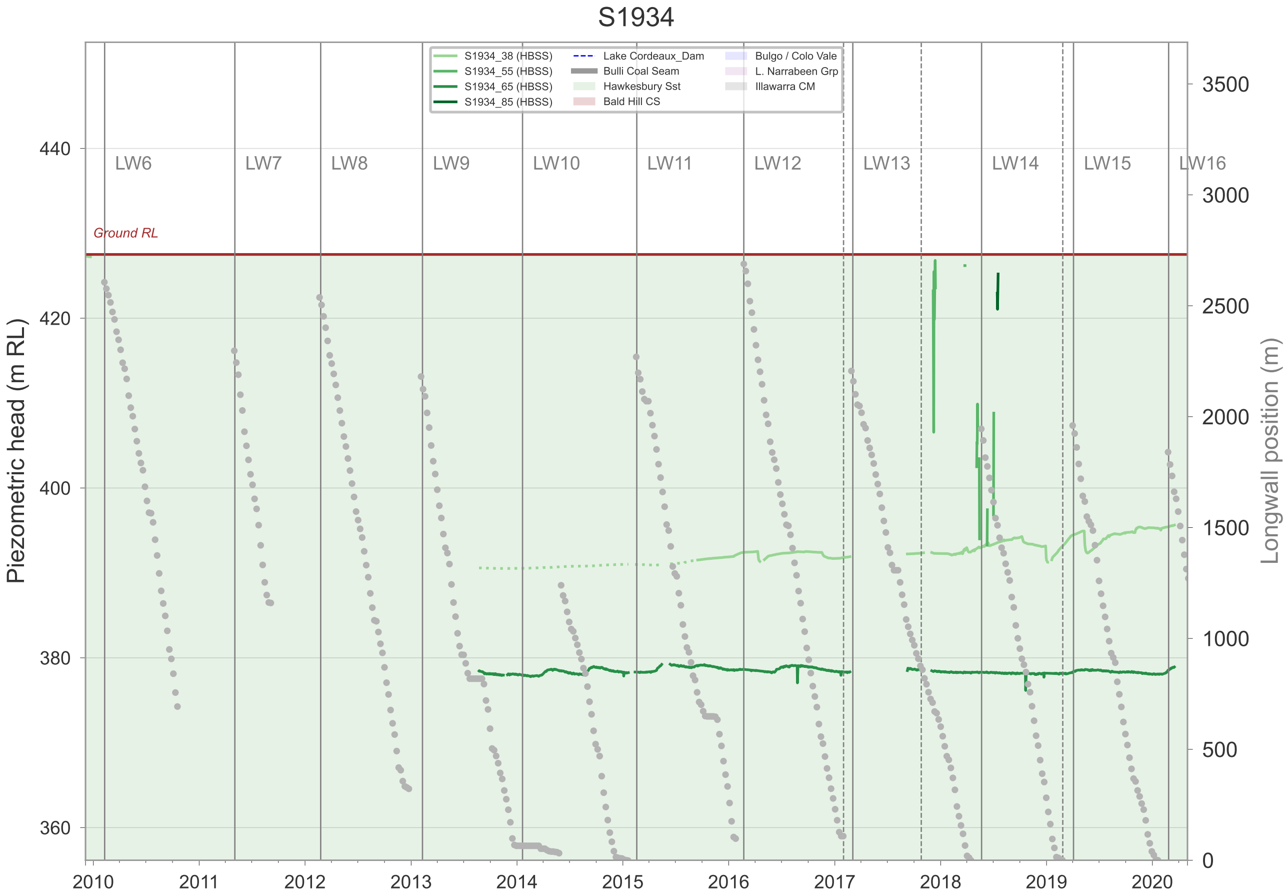

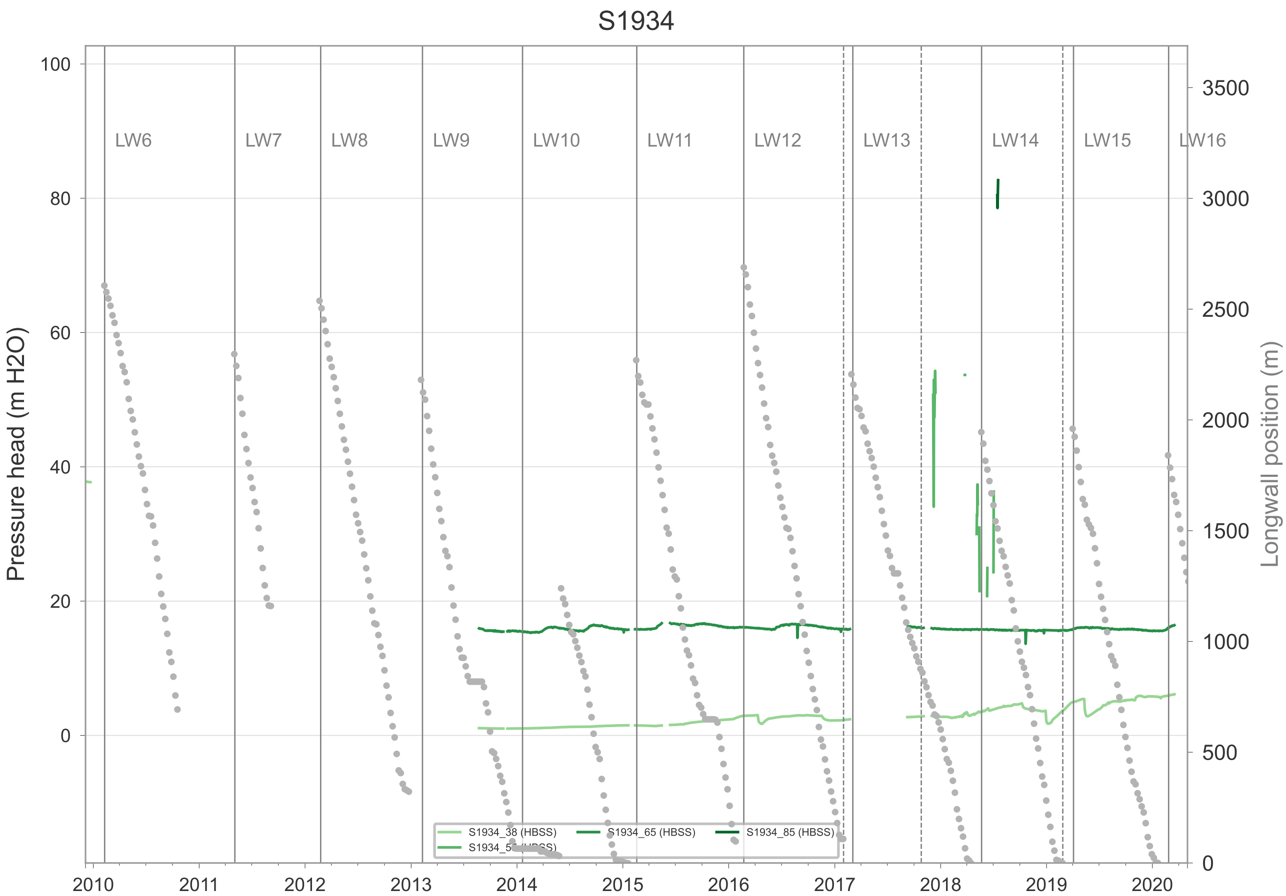

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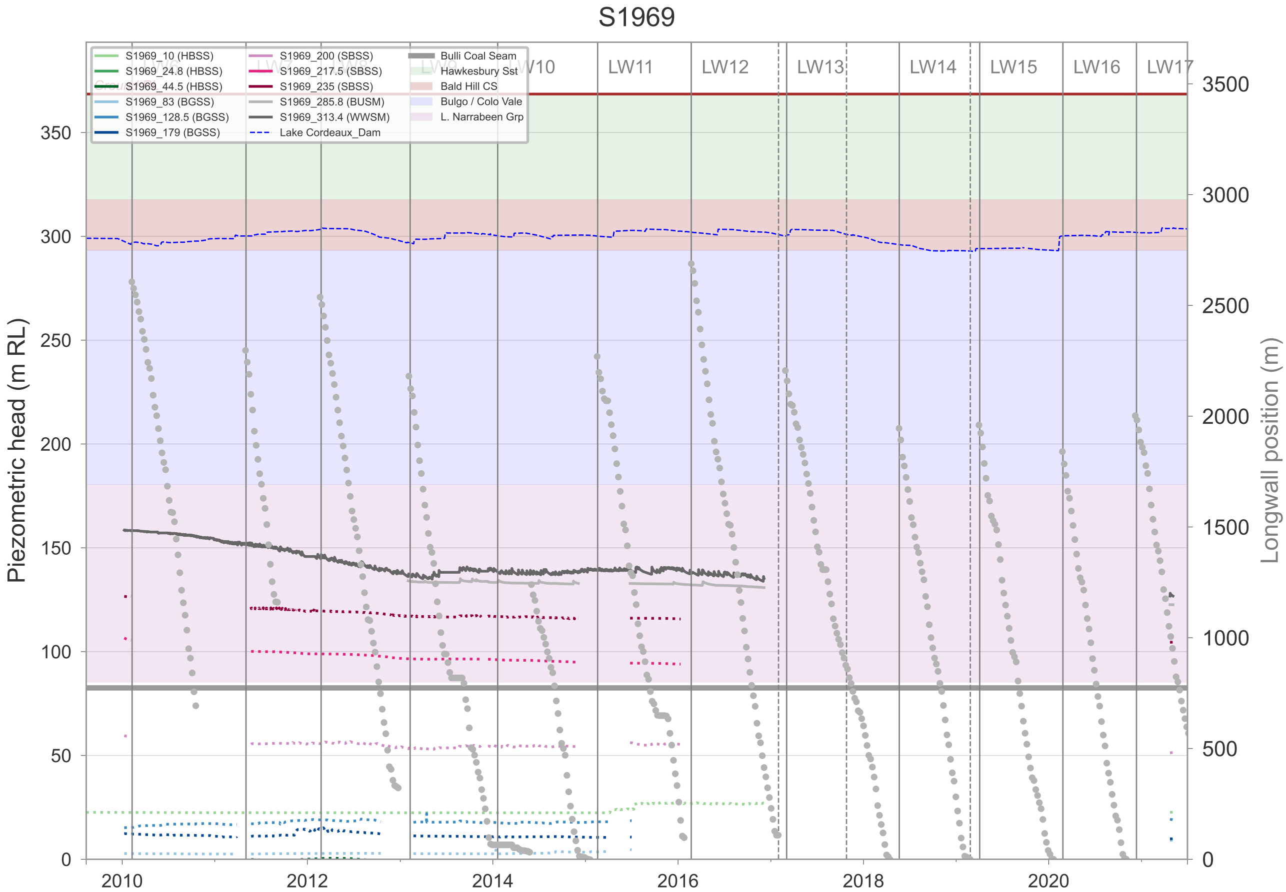

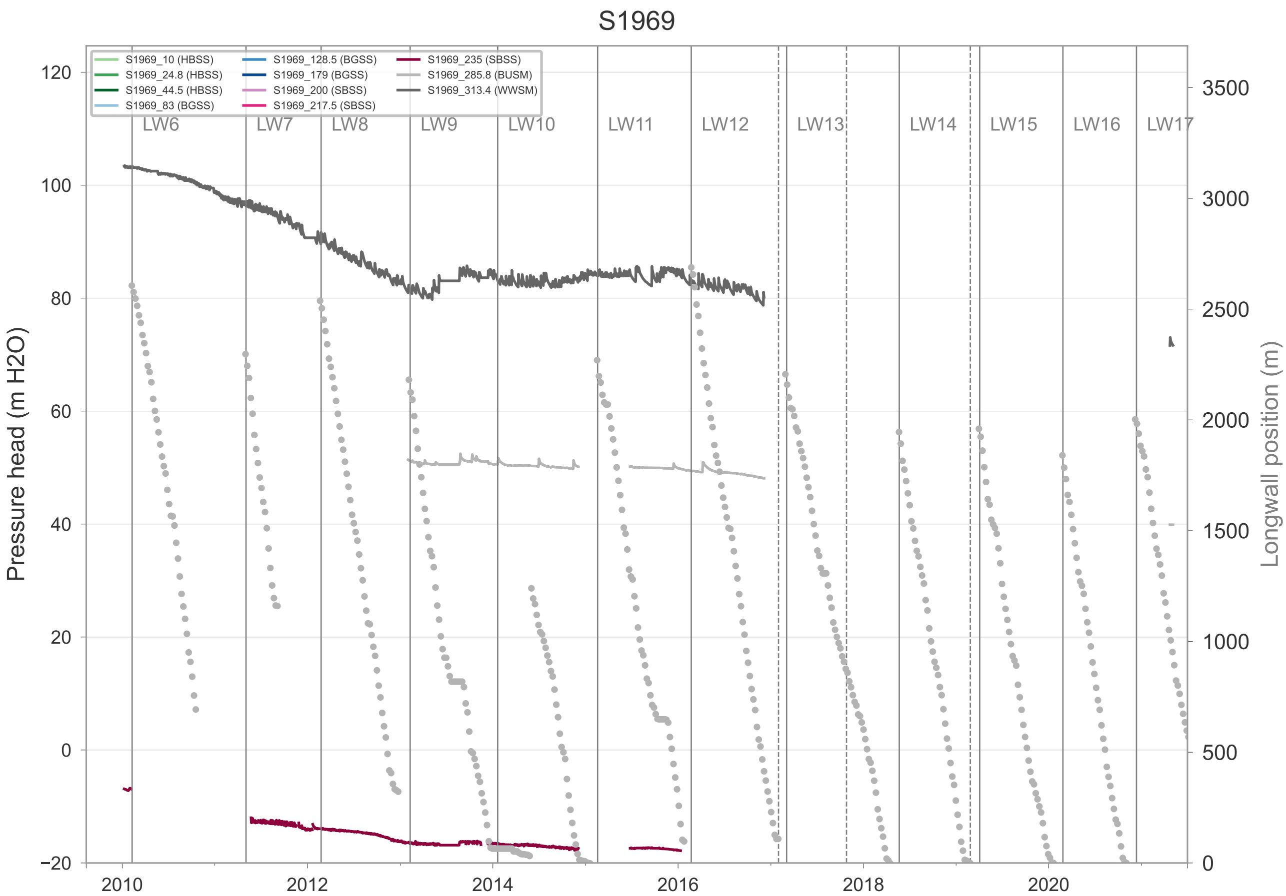

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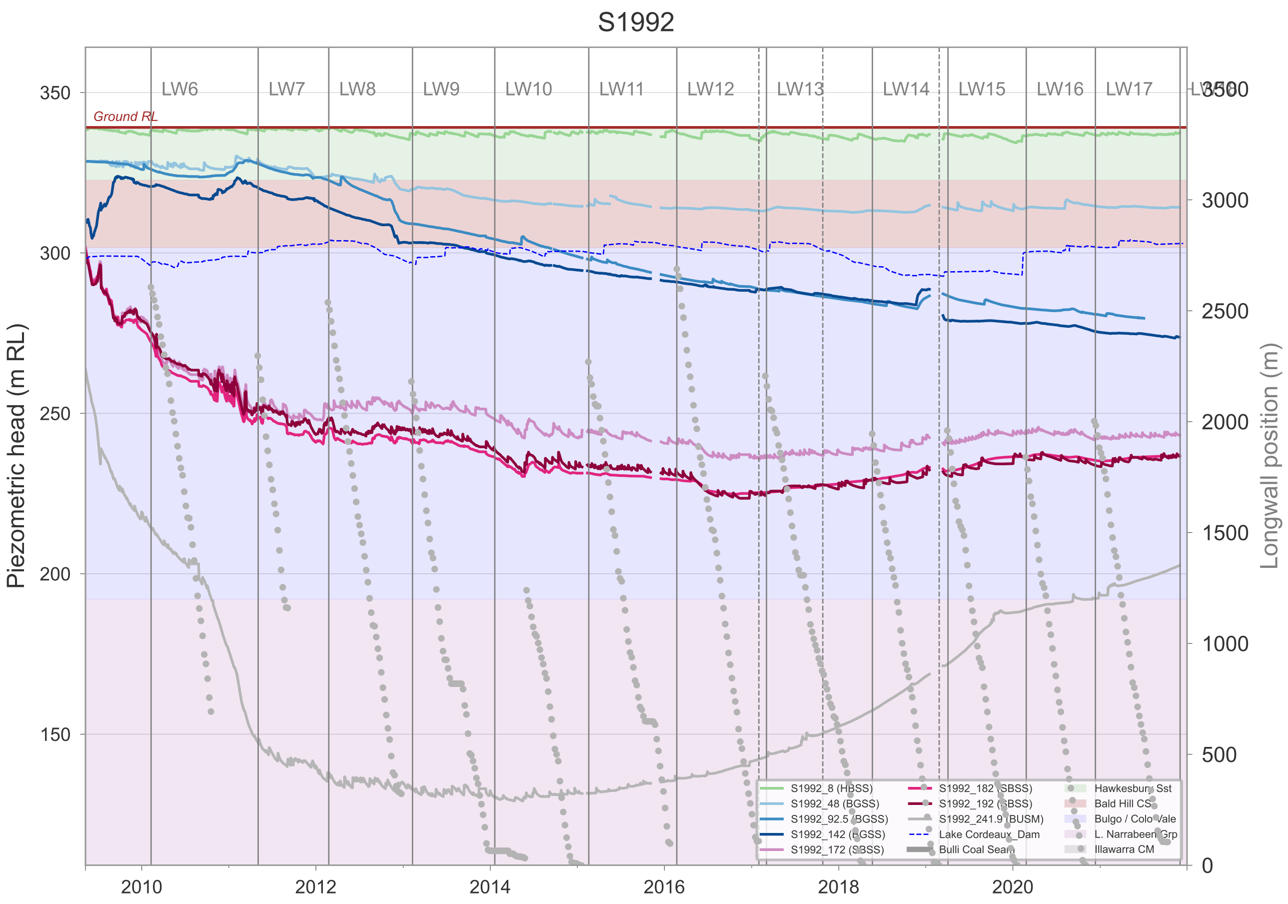

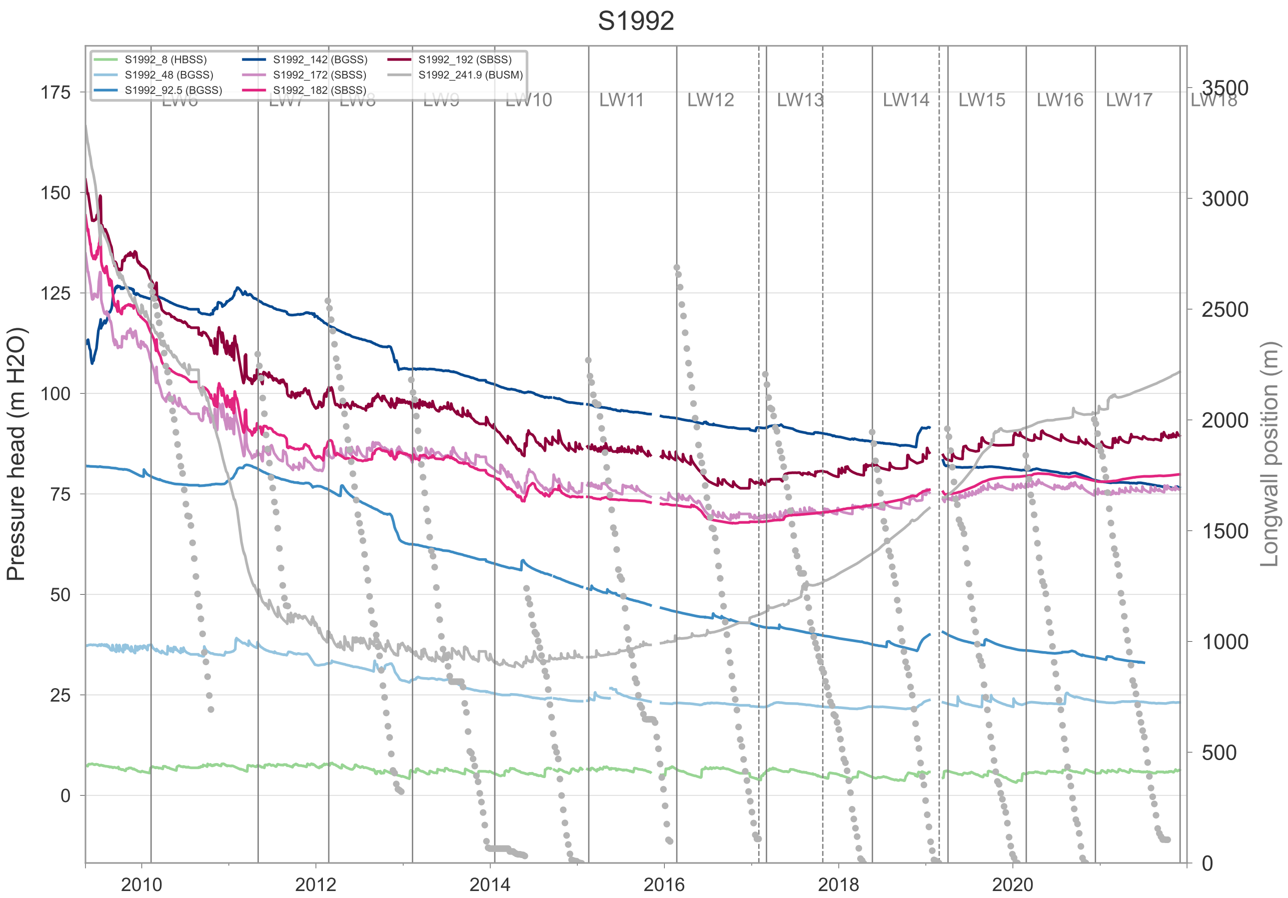

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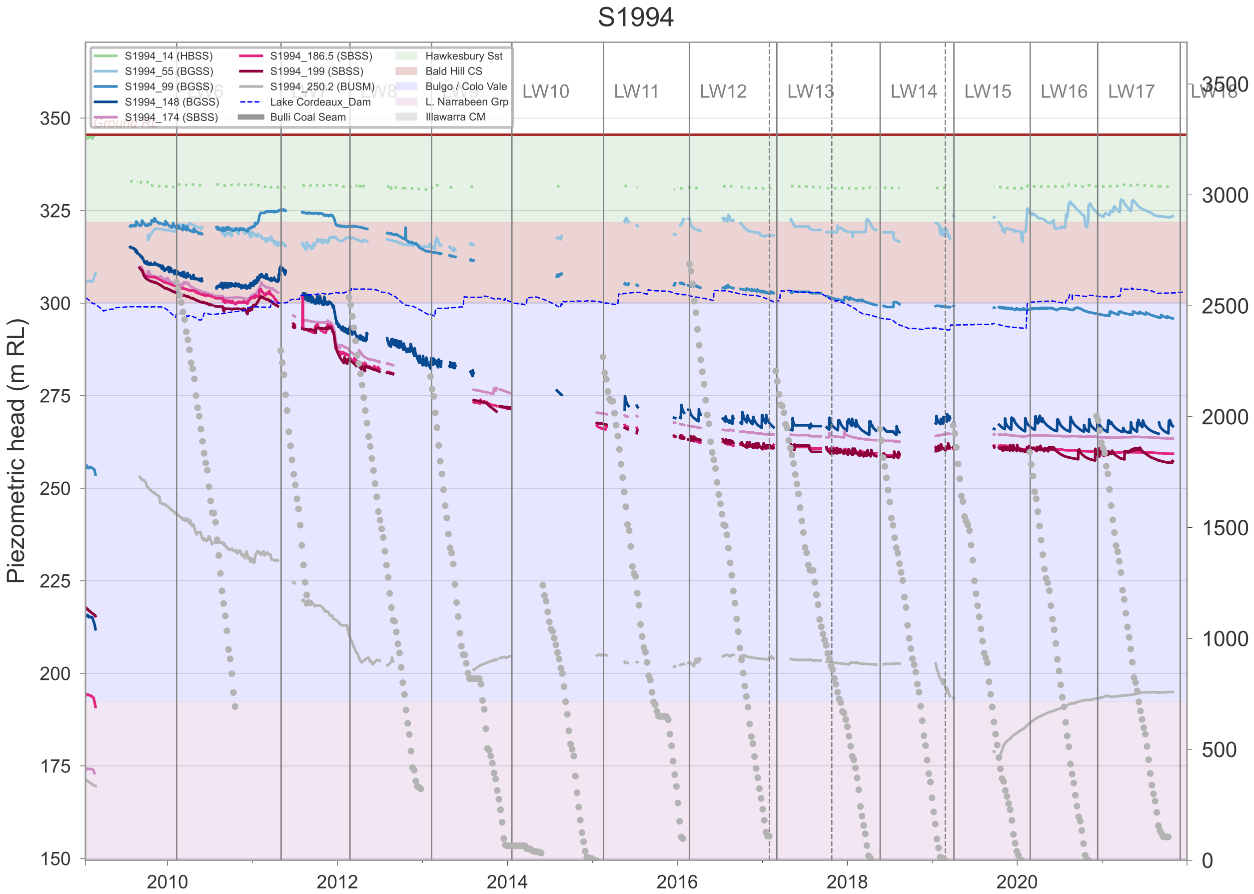

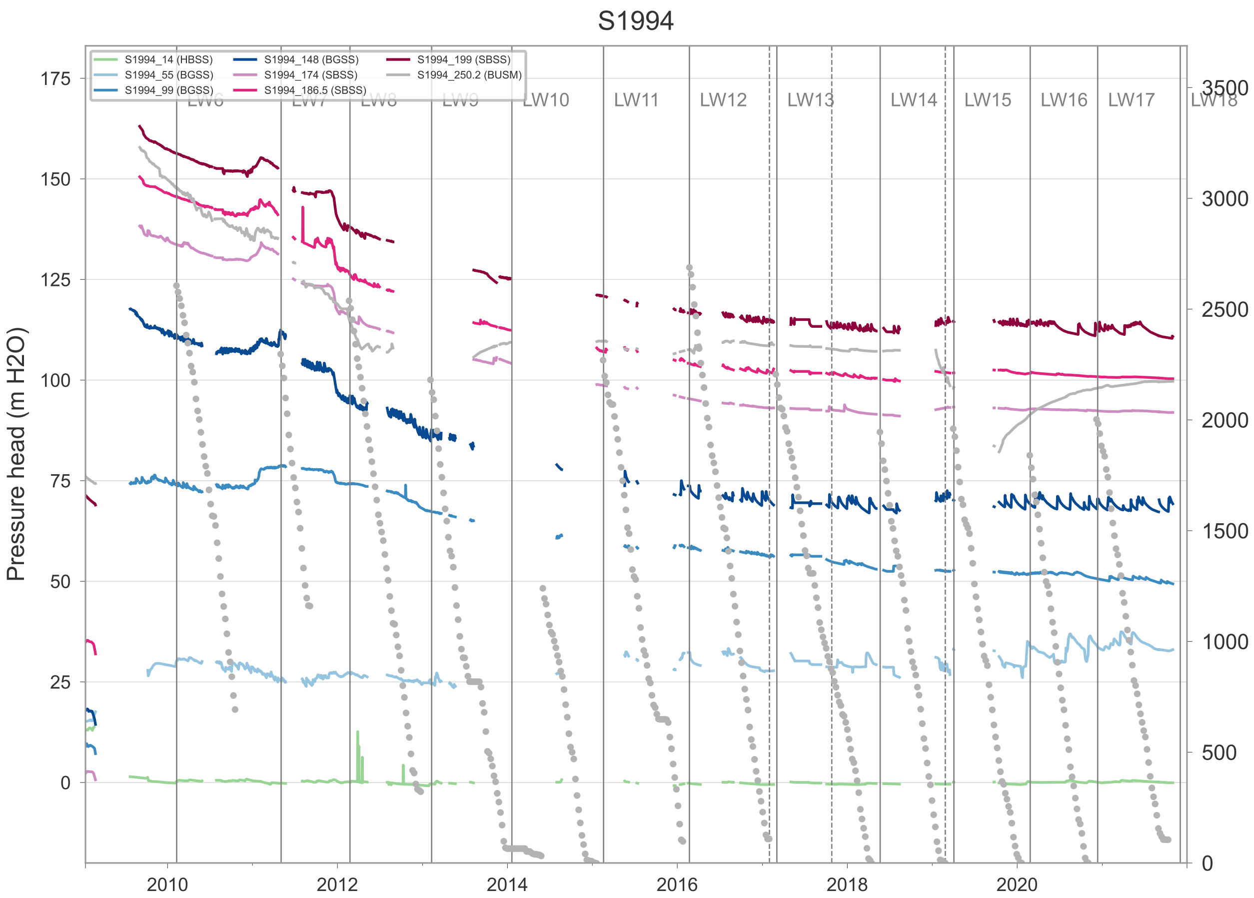

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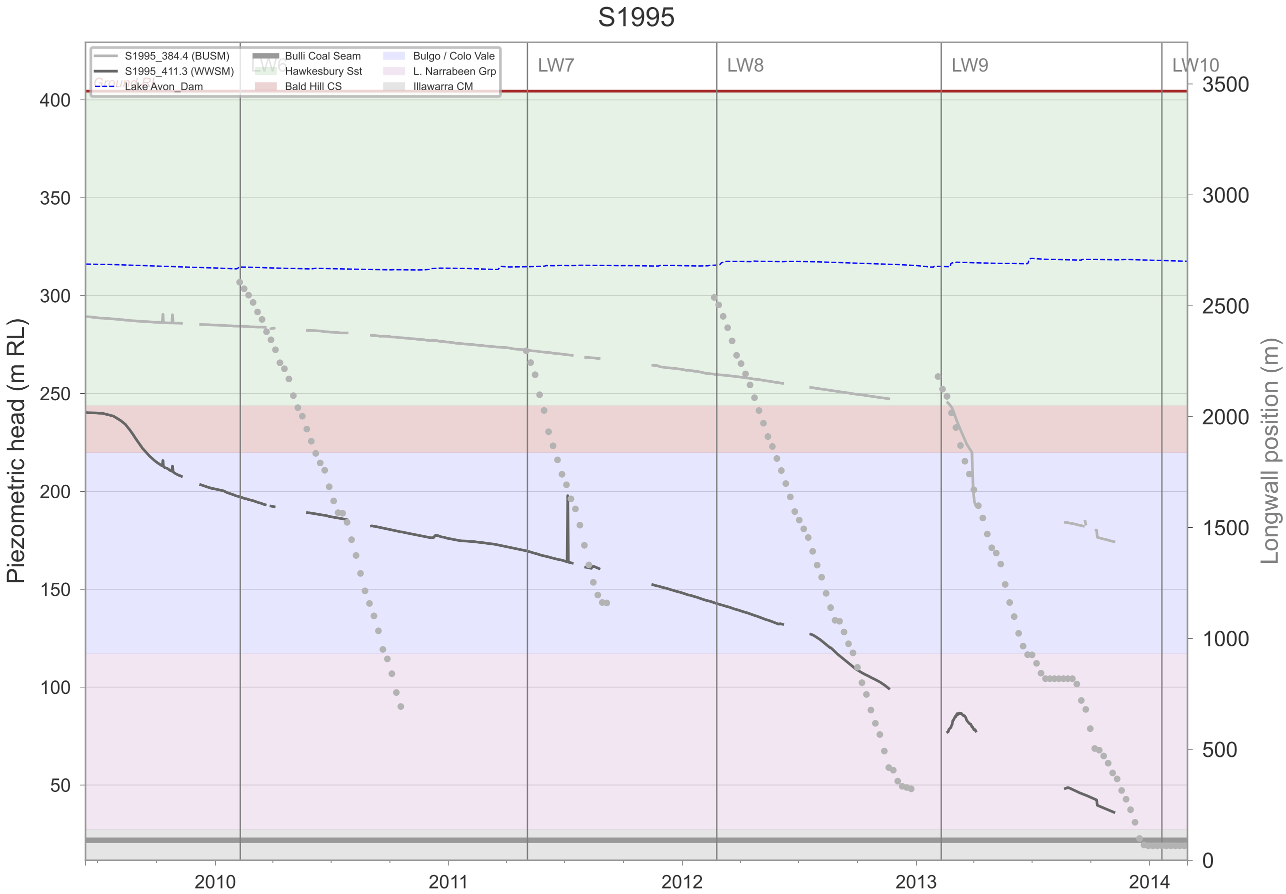

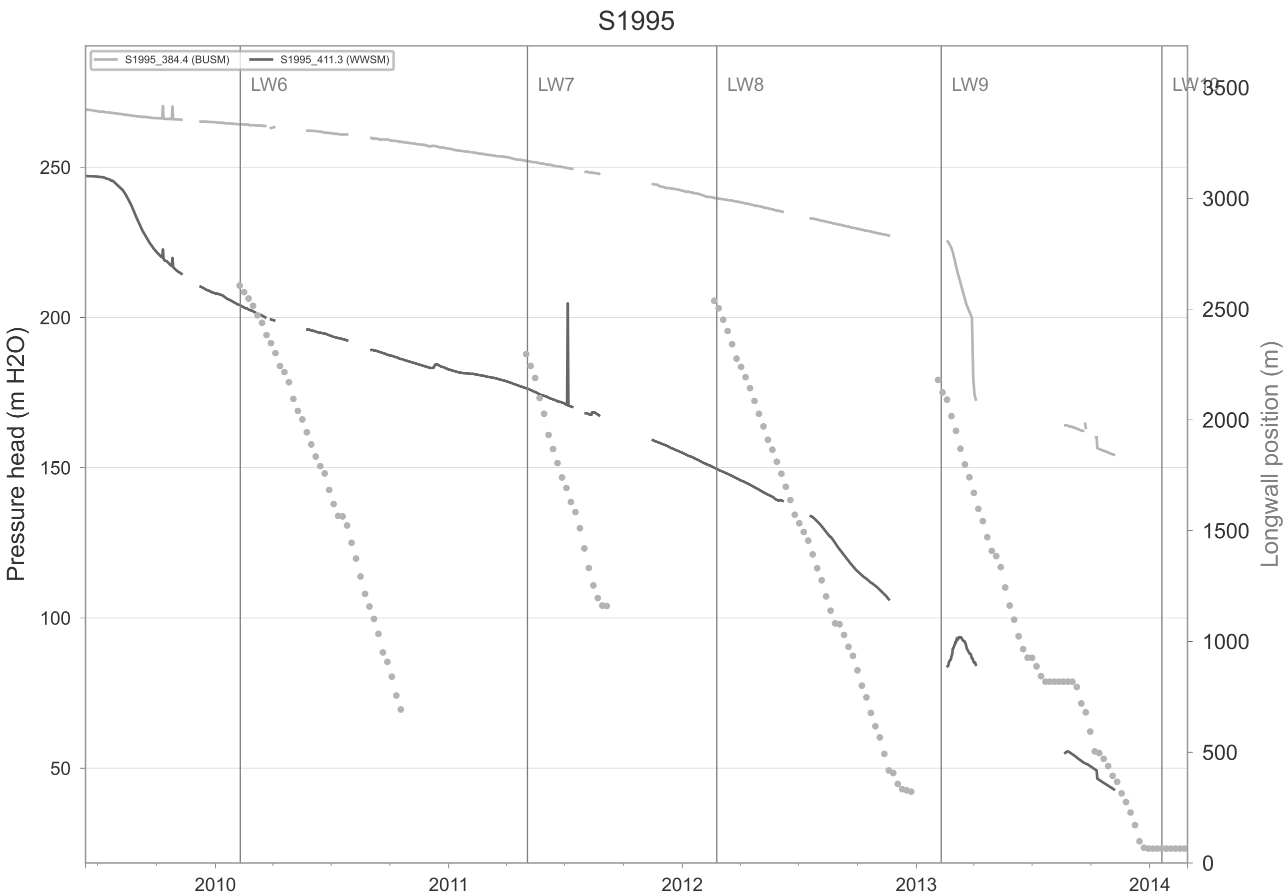

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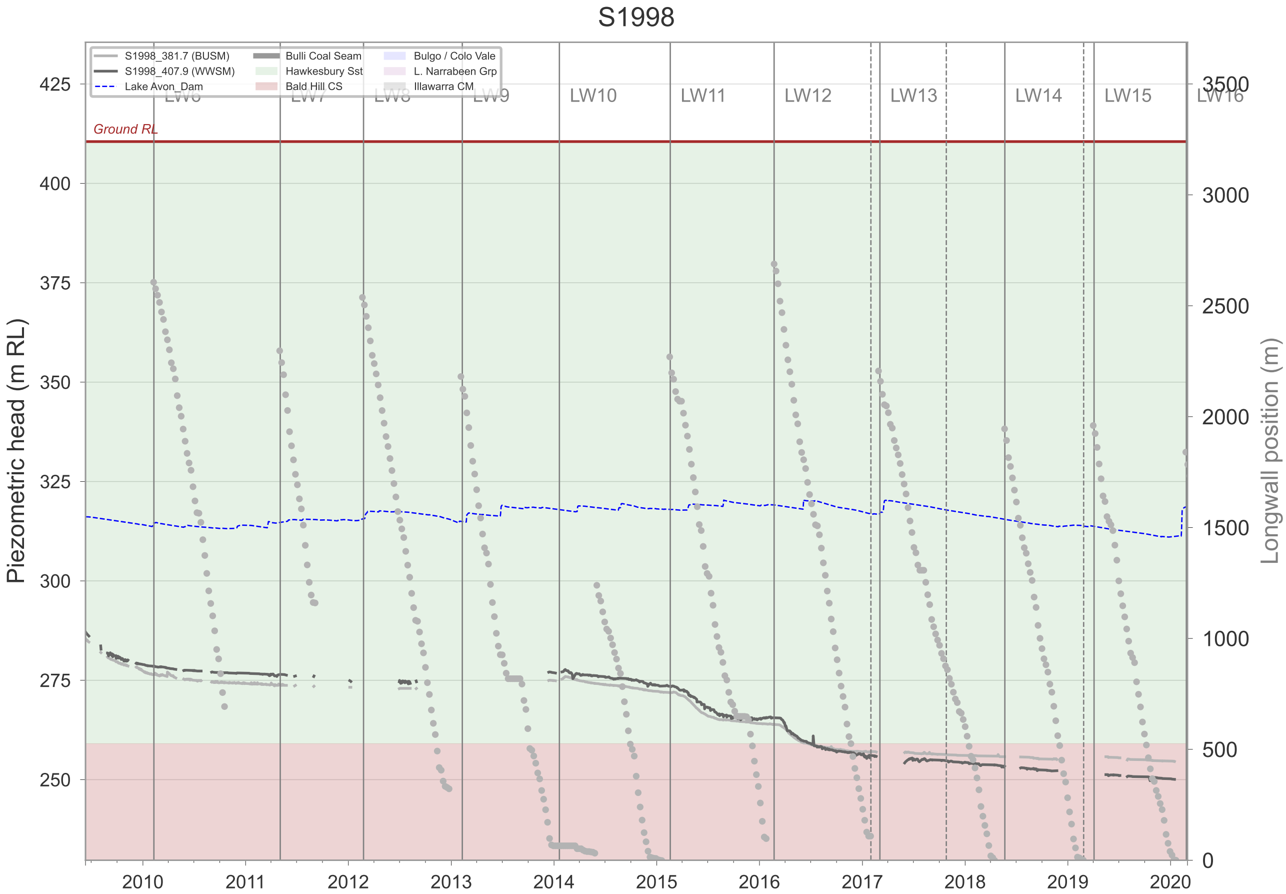

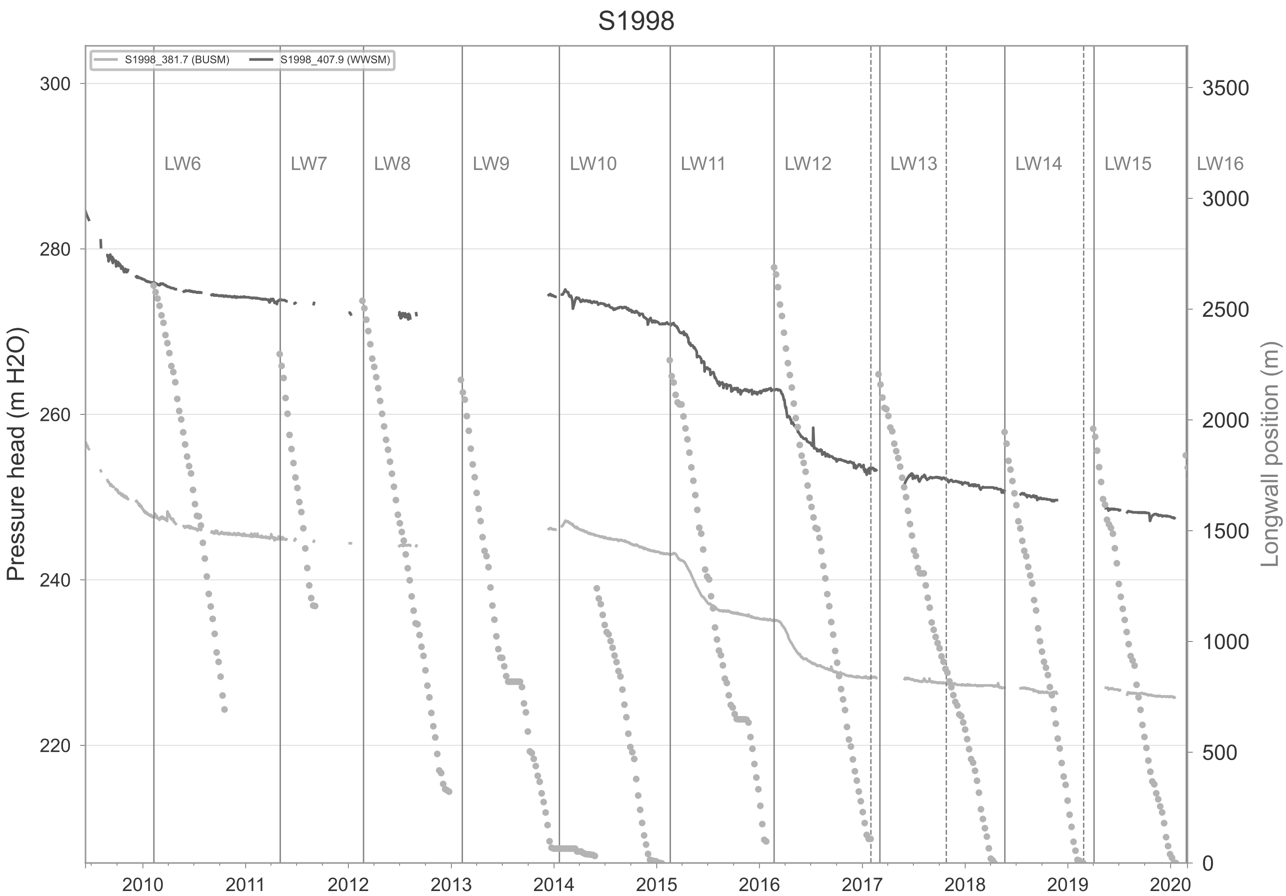

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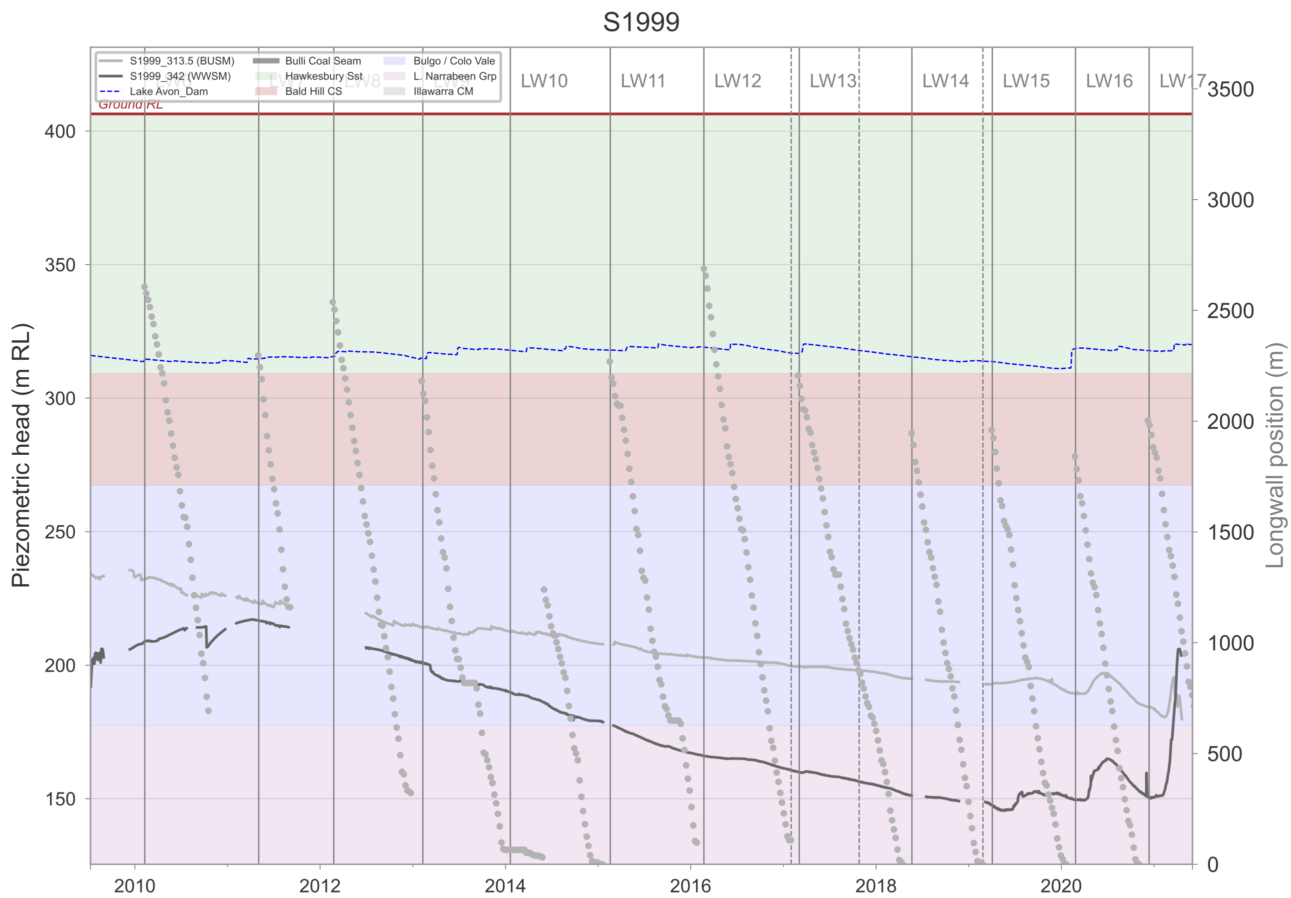

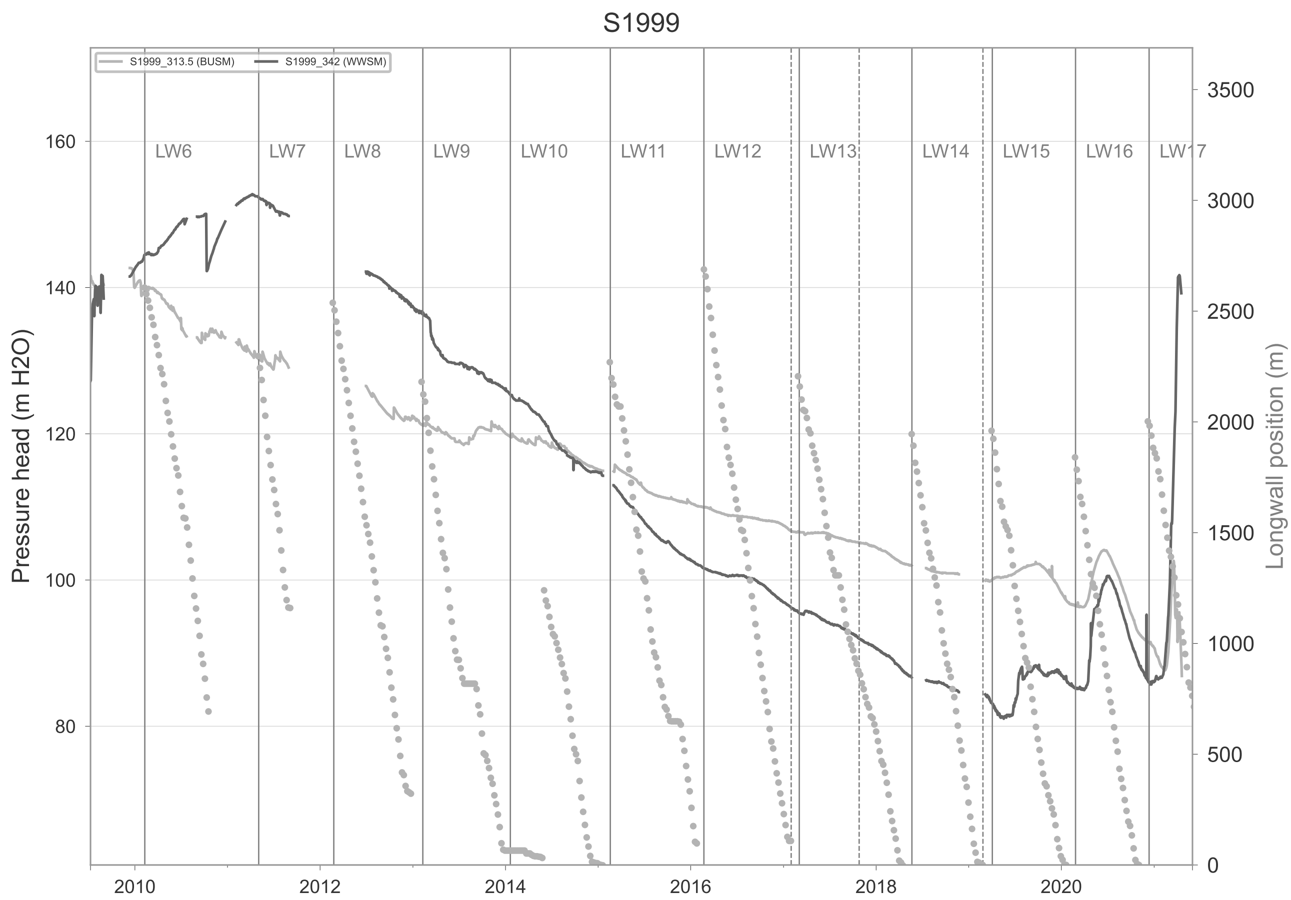

Groundwater hydrographs

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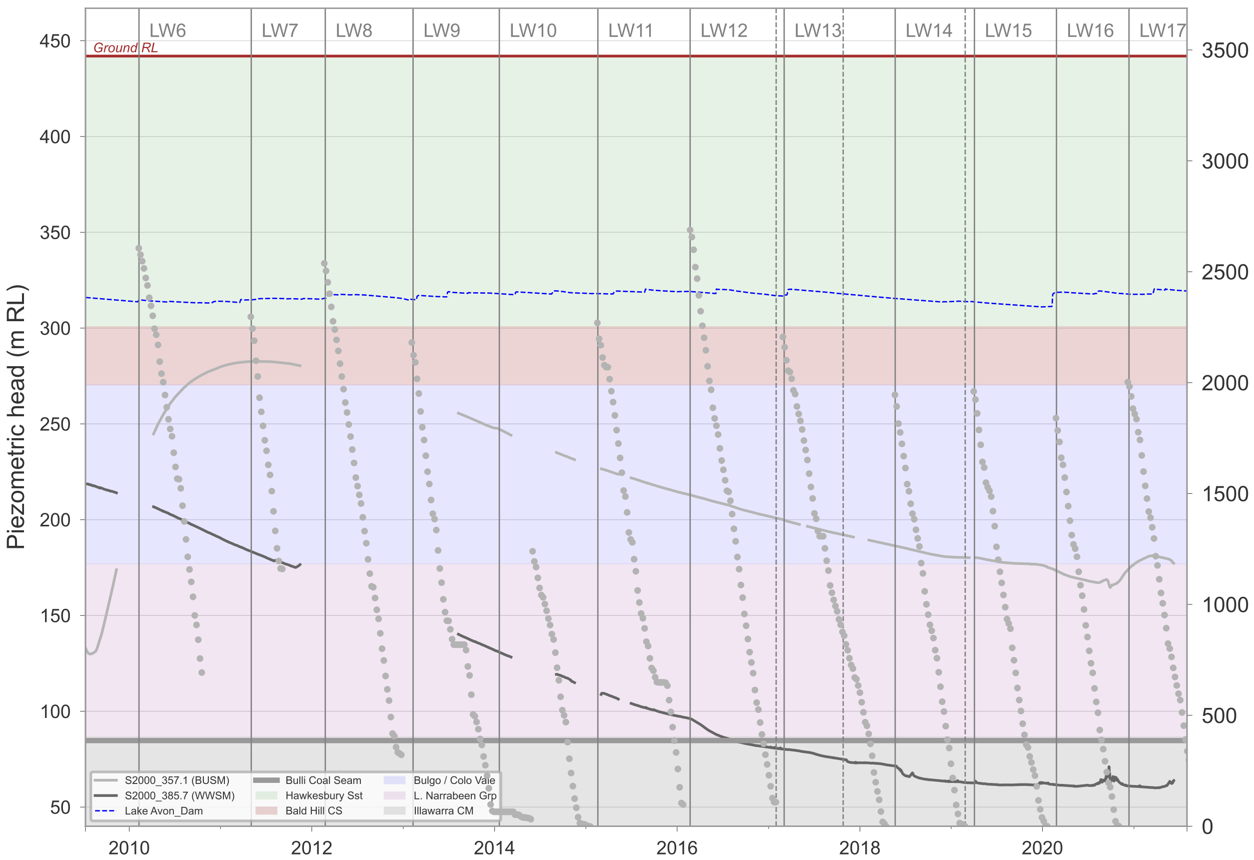

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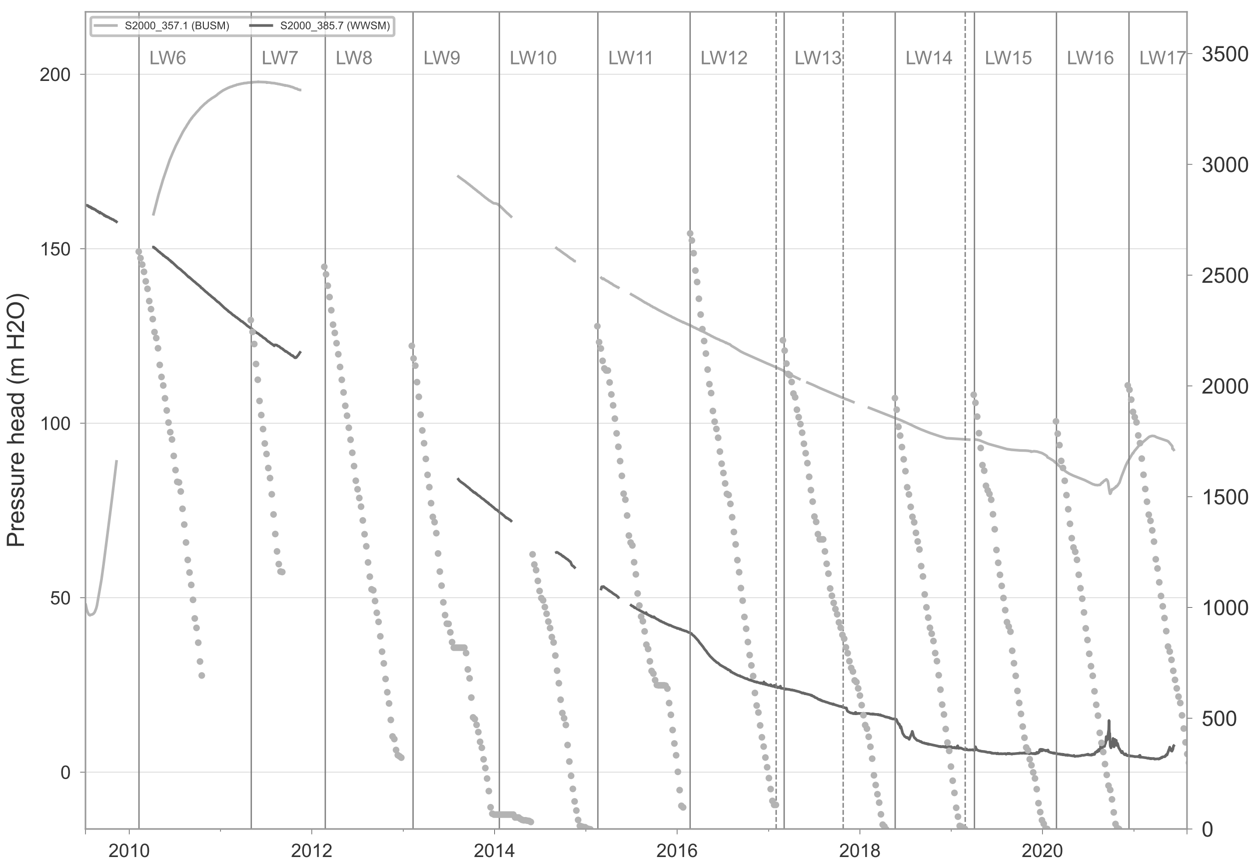
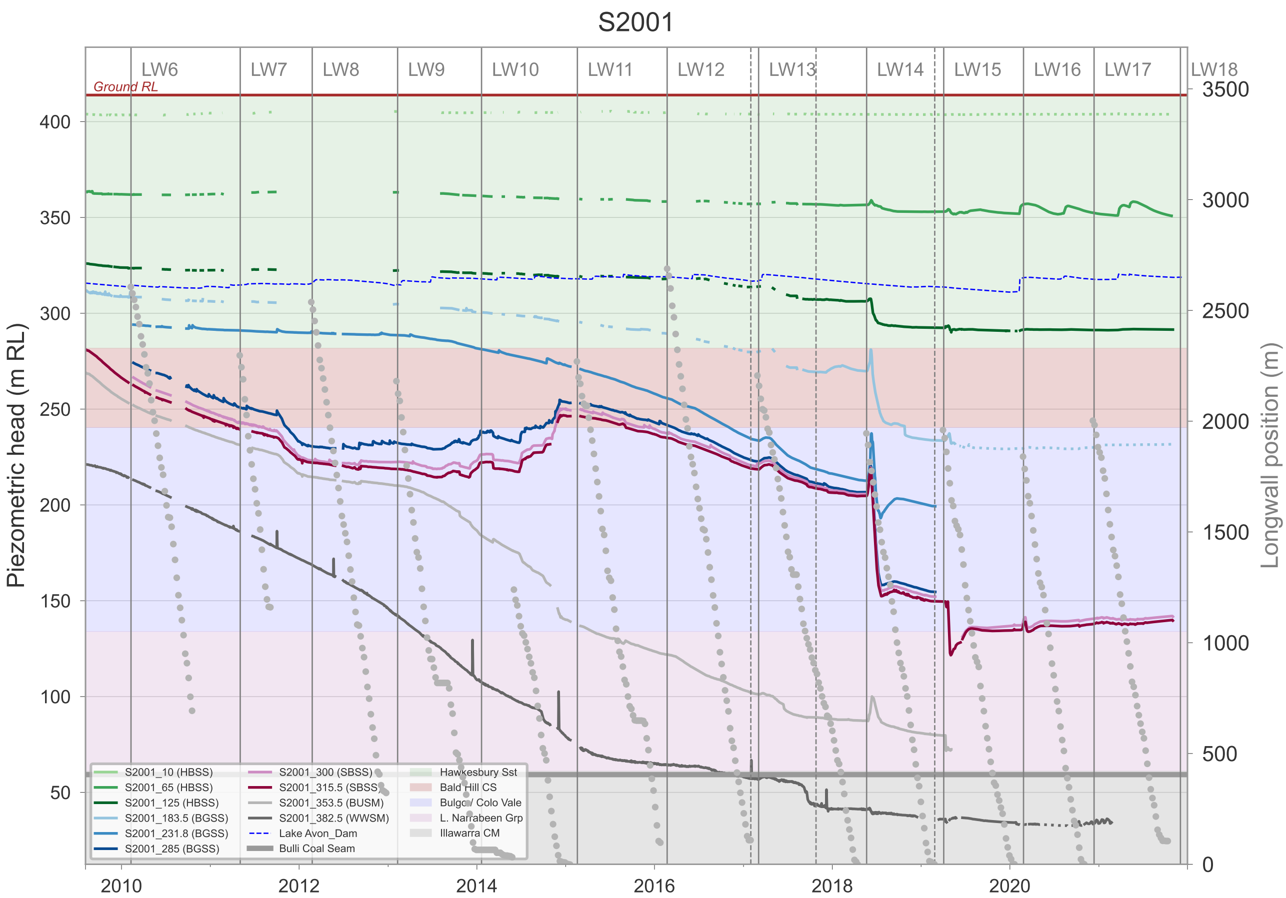
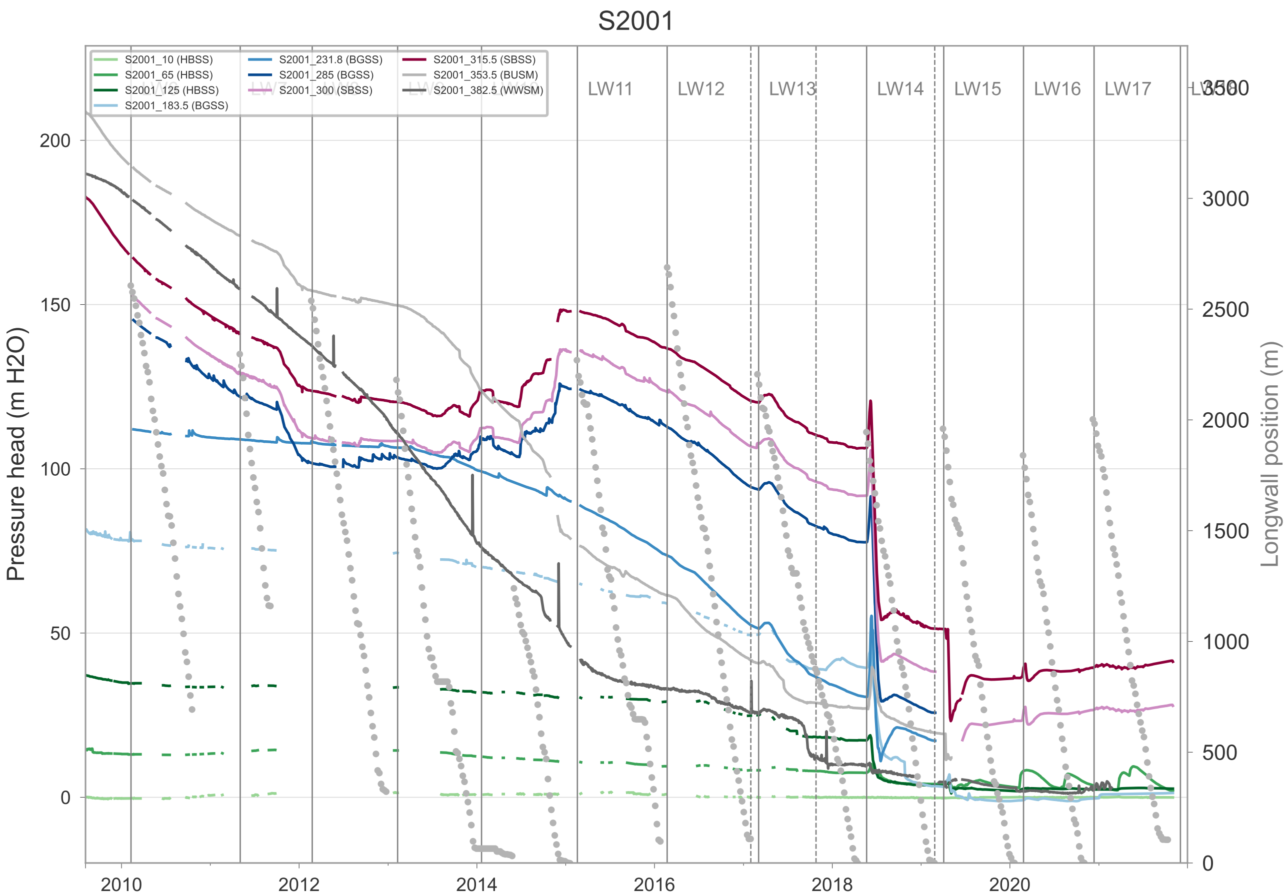
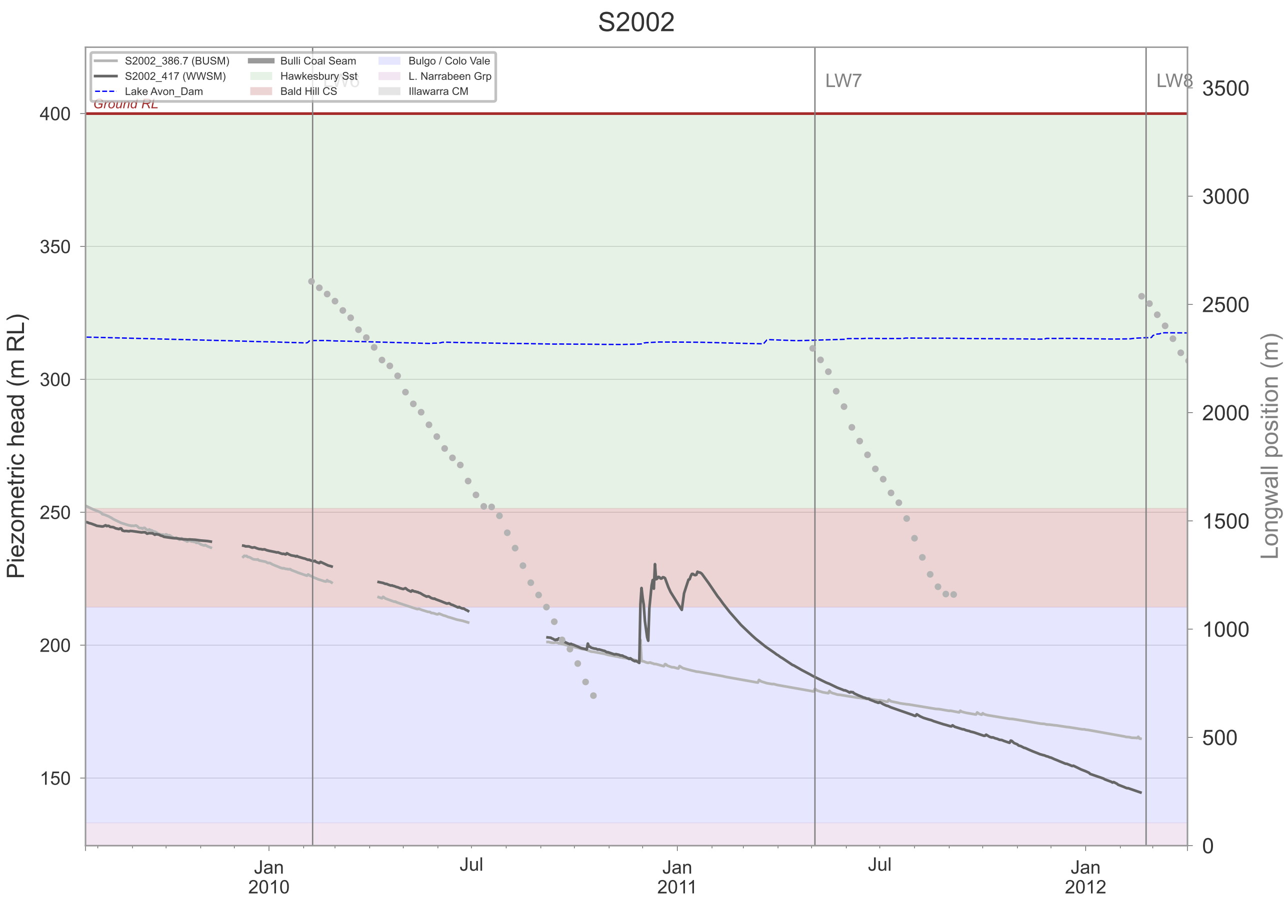


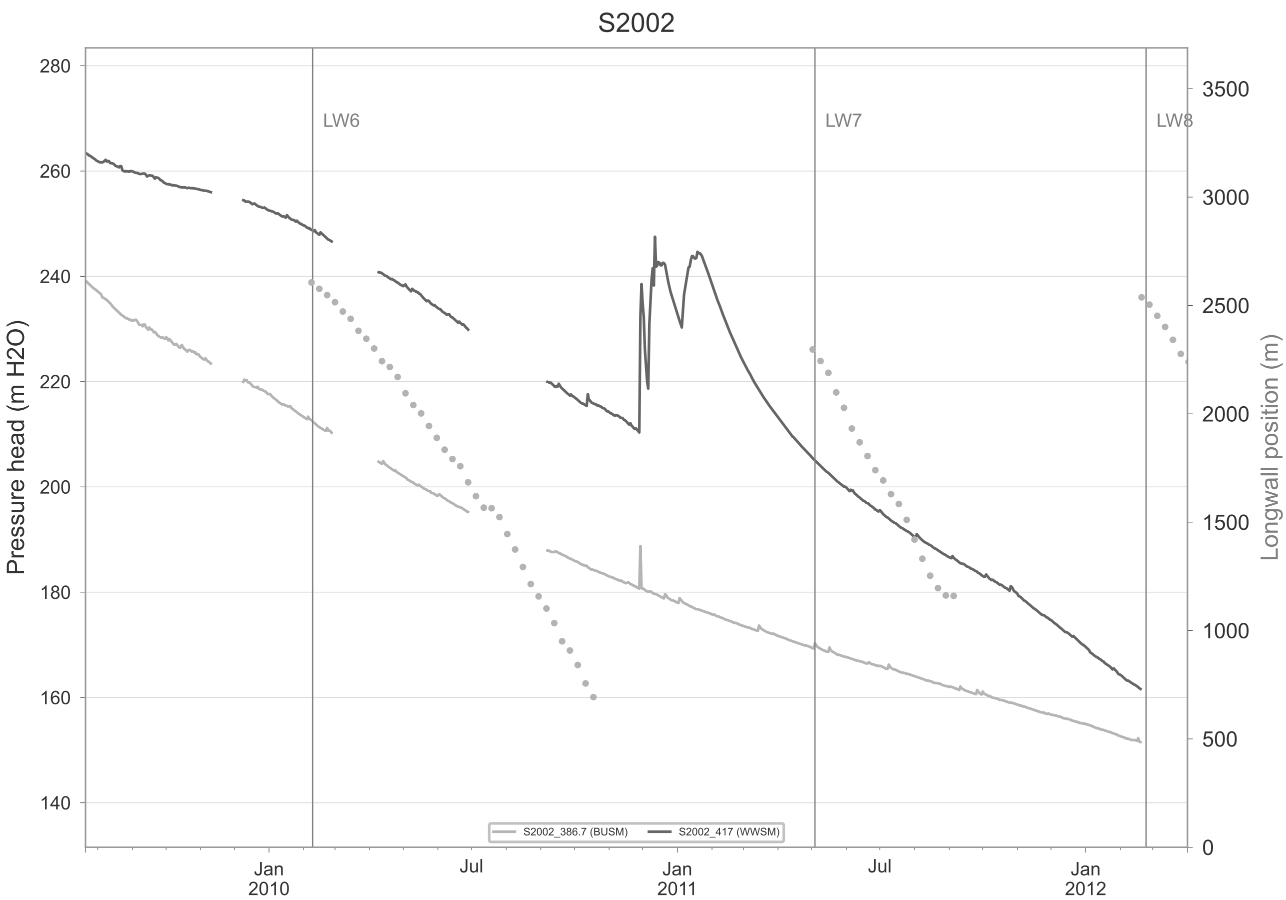
Groundwater hydrographs





Groundwater hydrographs





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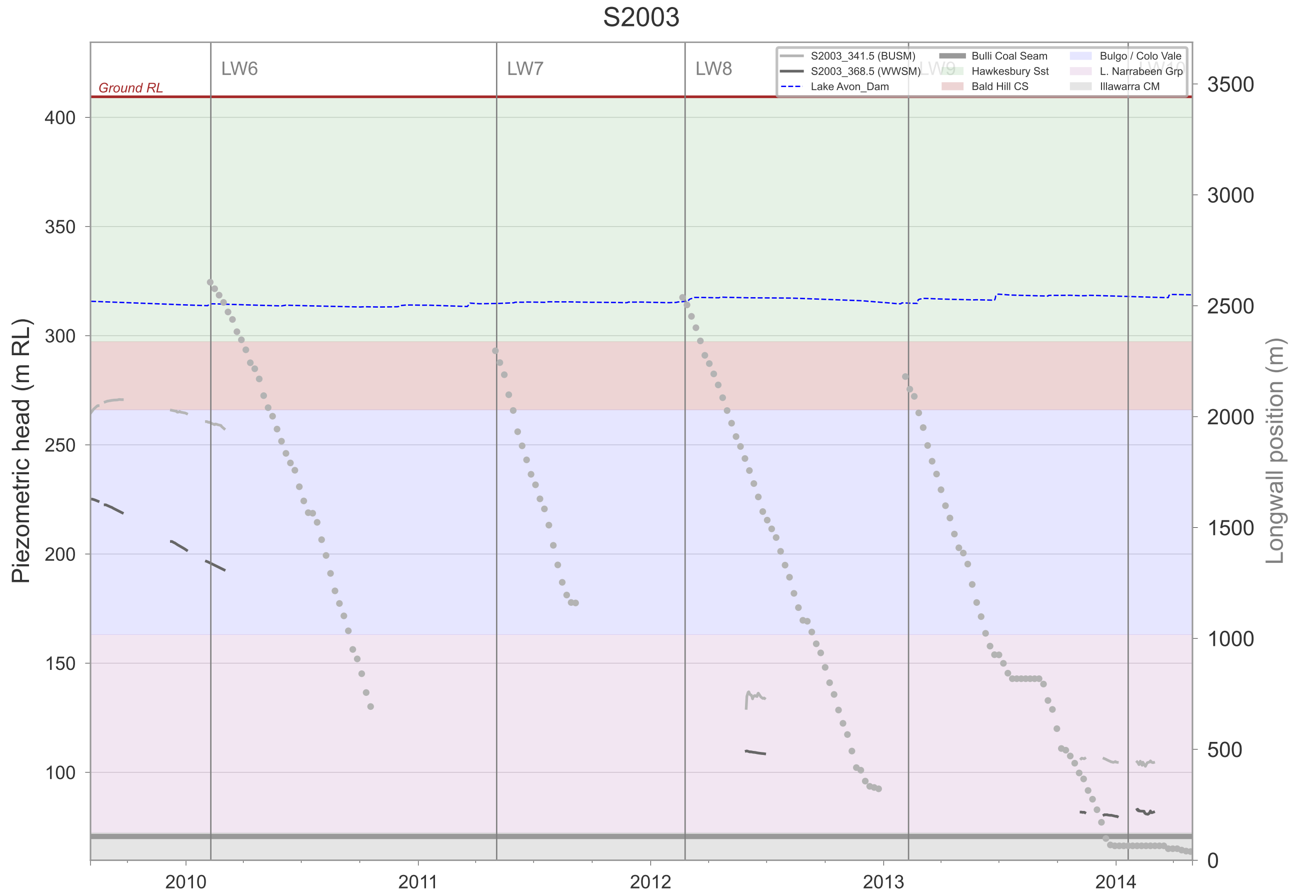

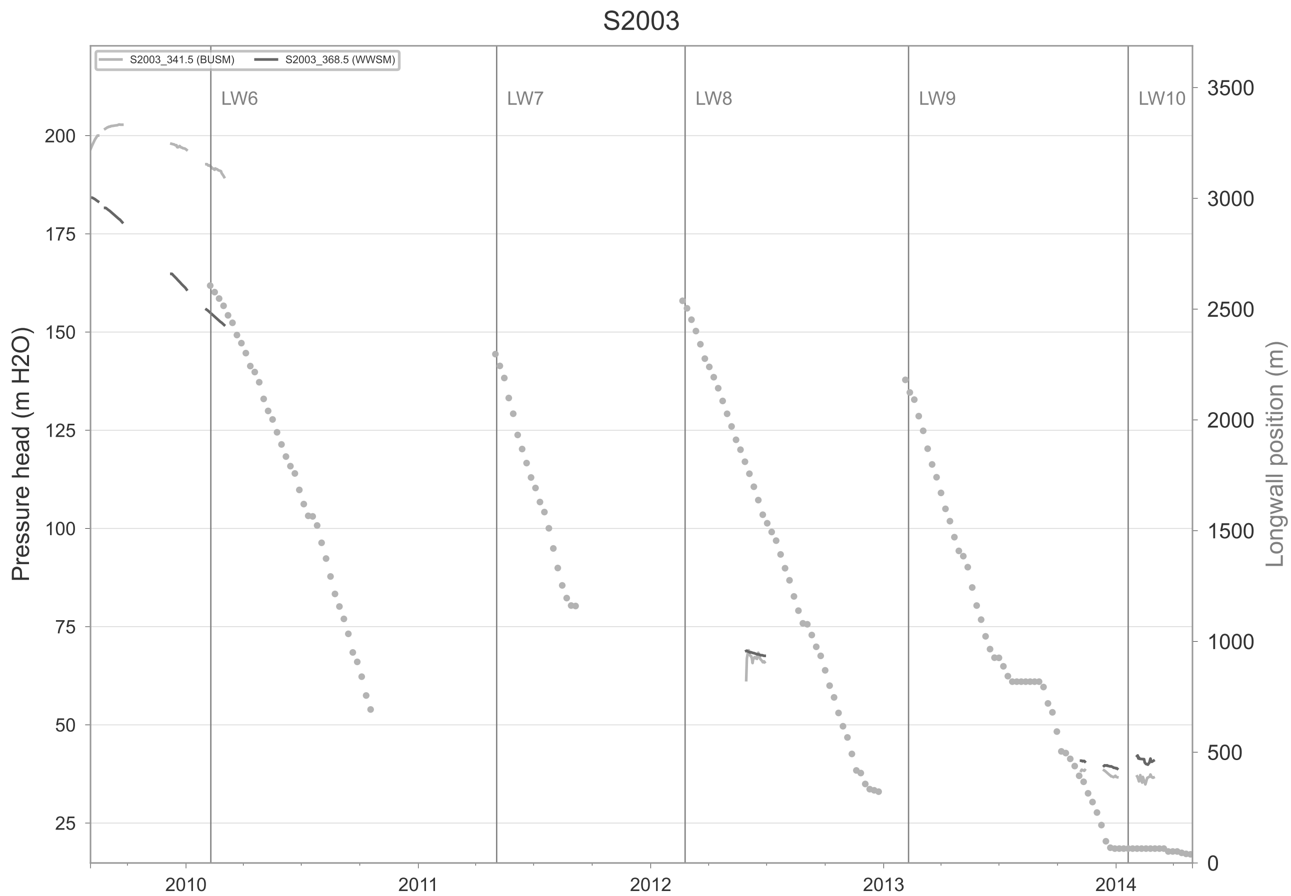

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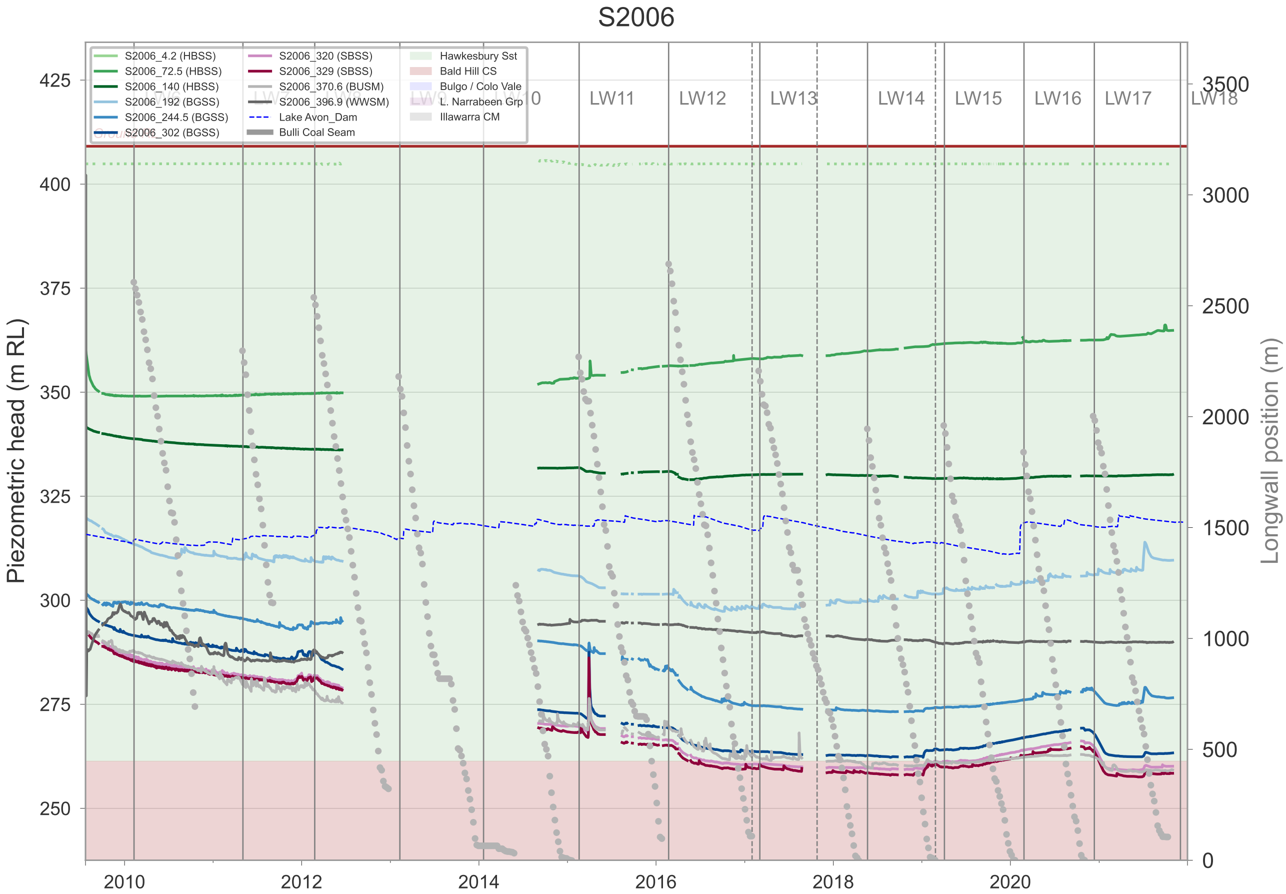

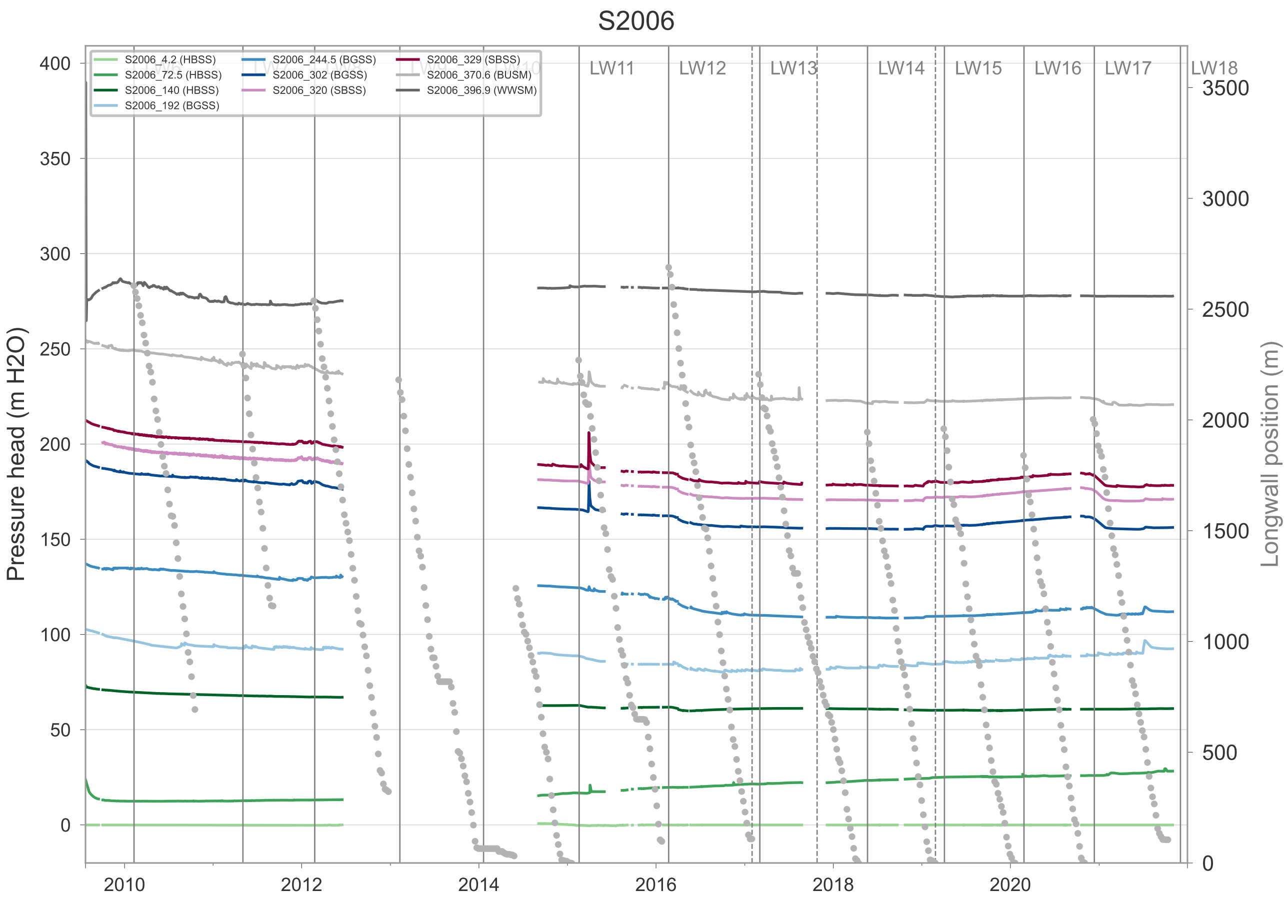

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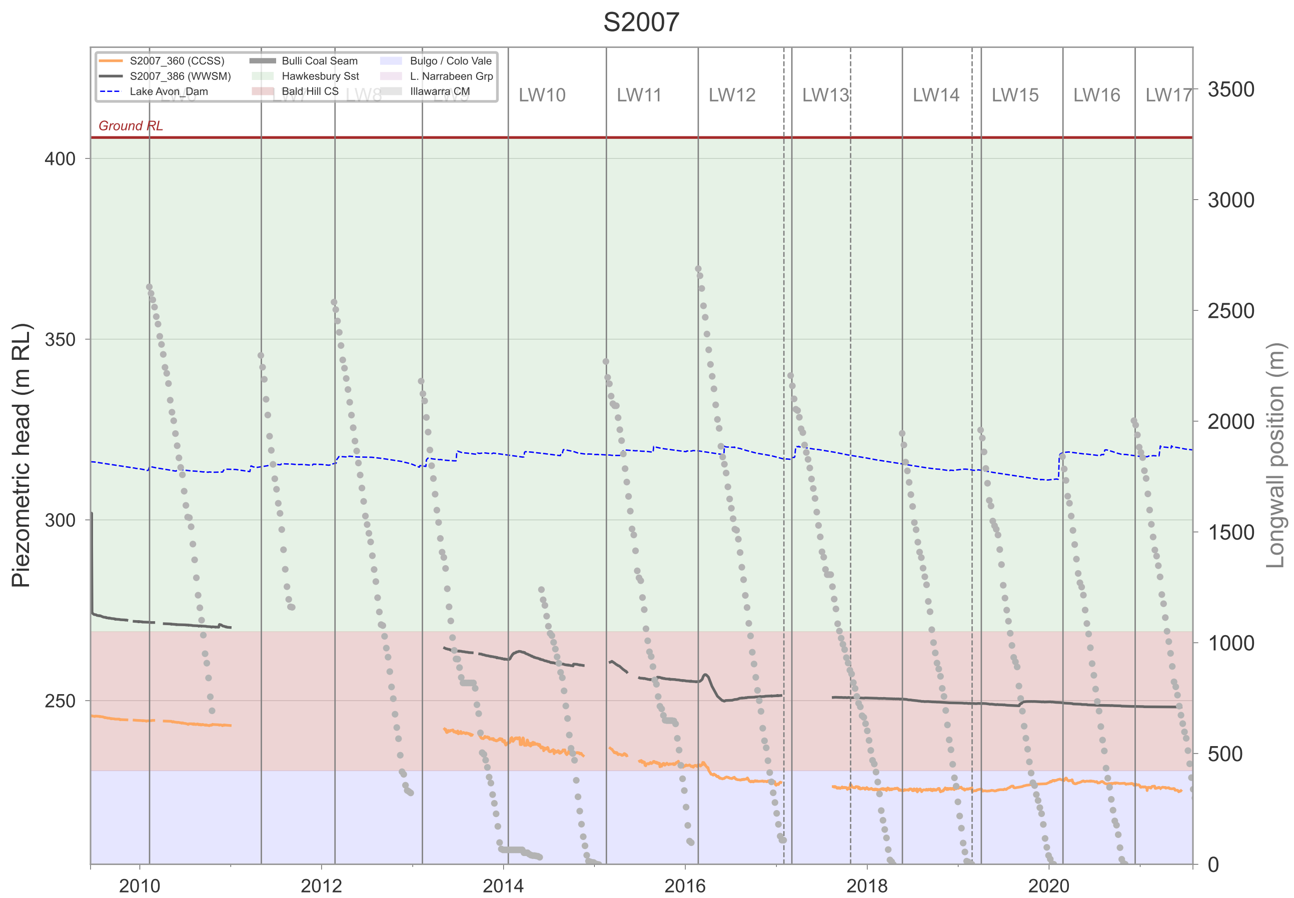

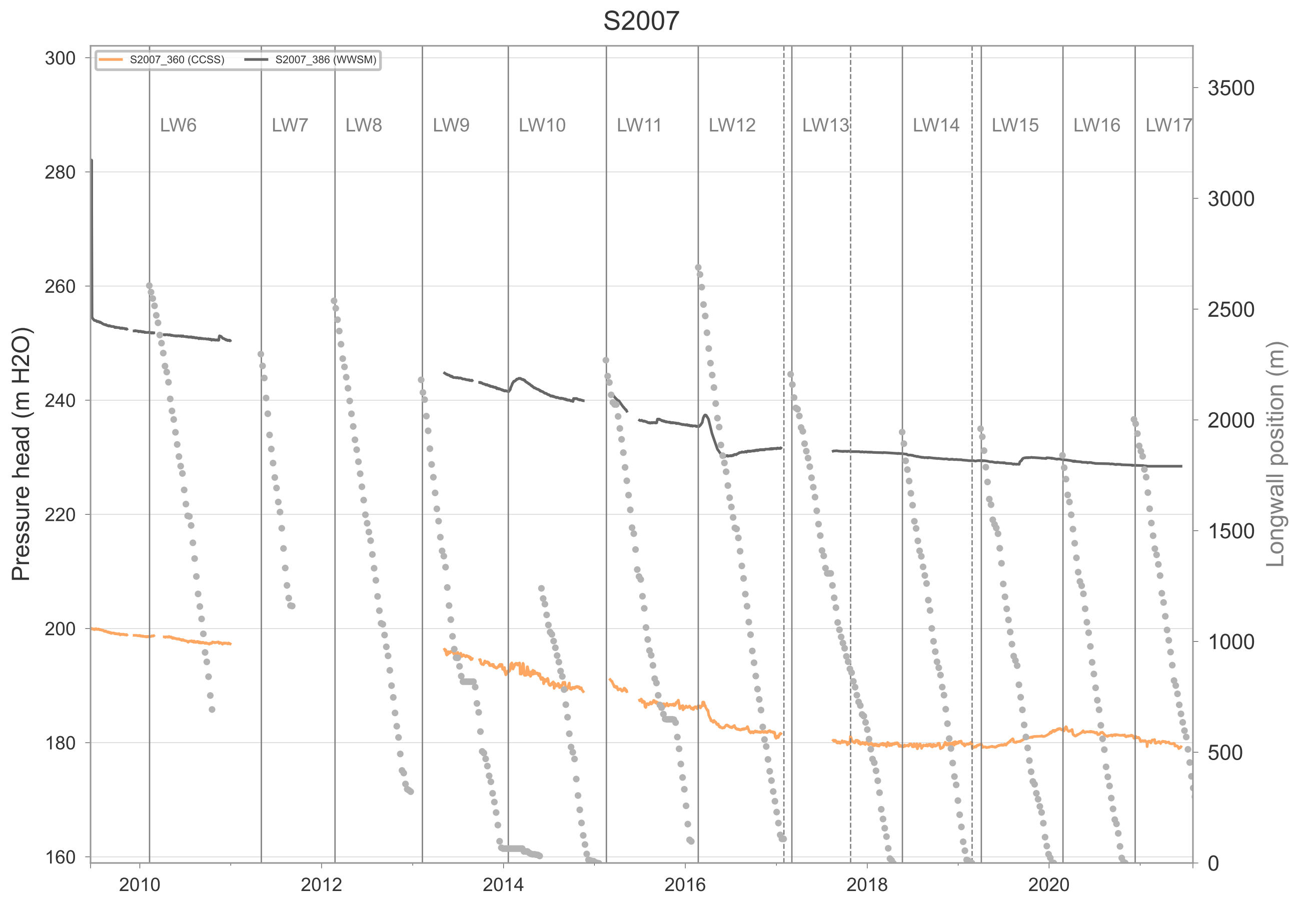

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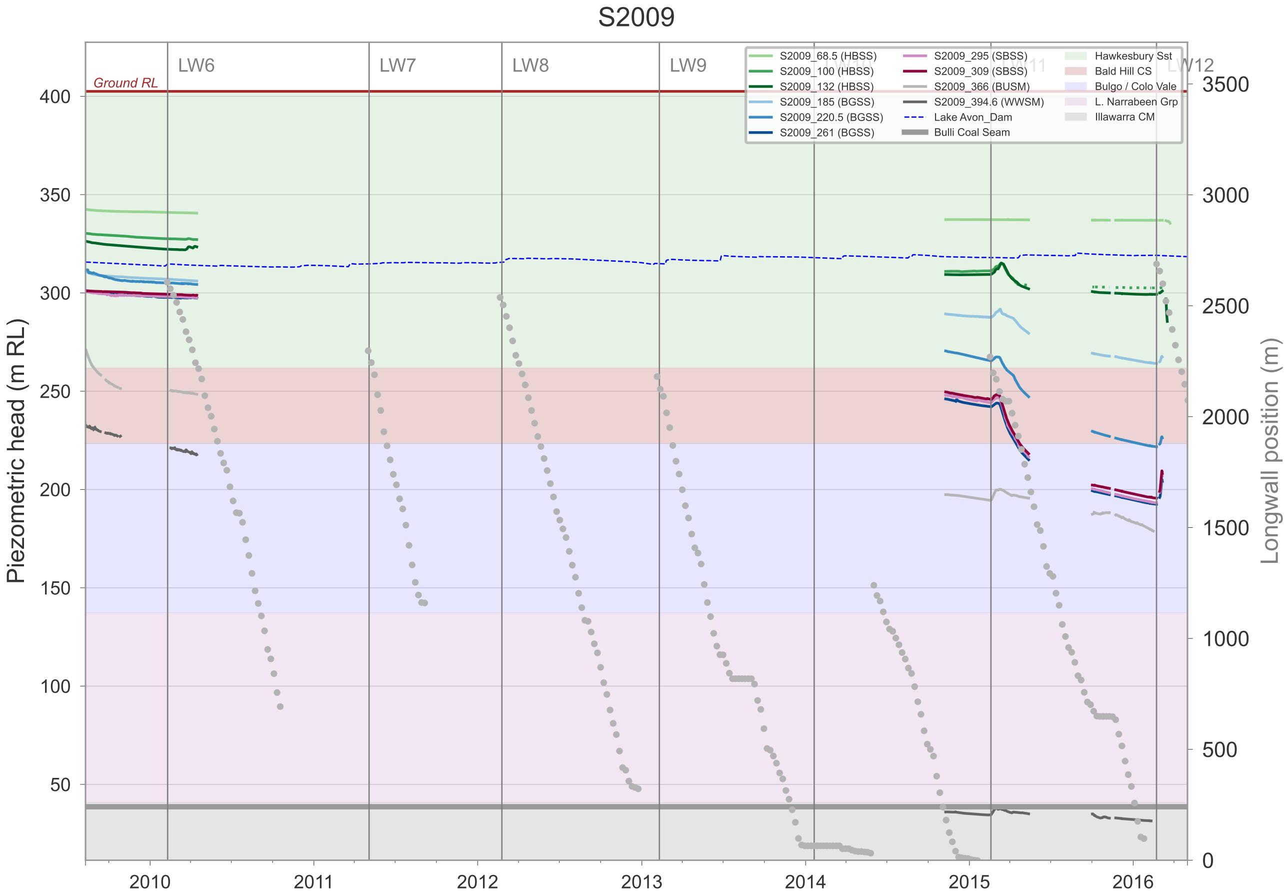

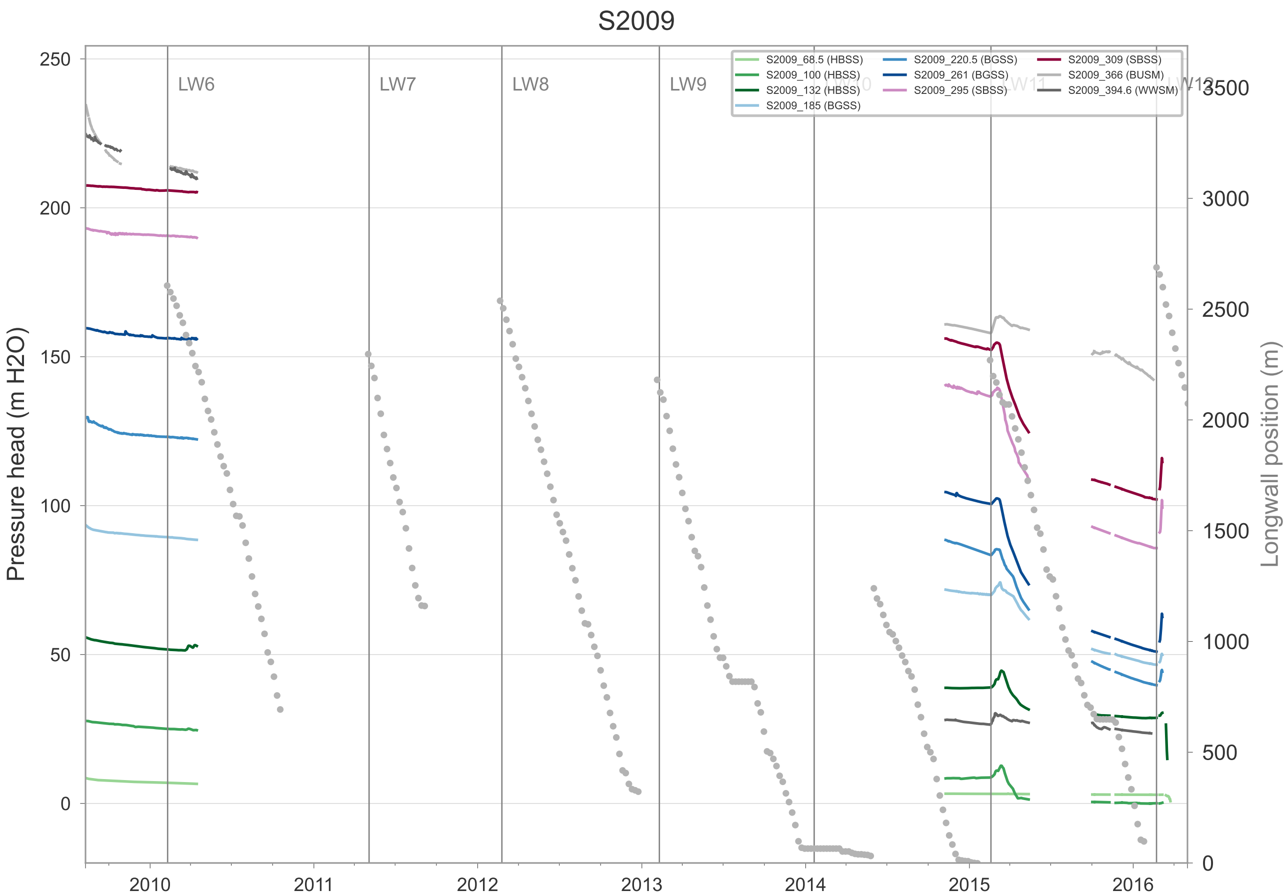

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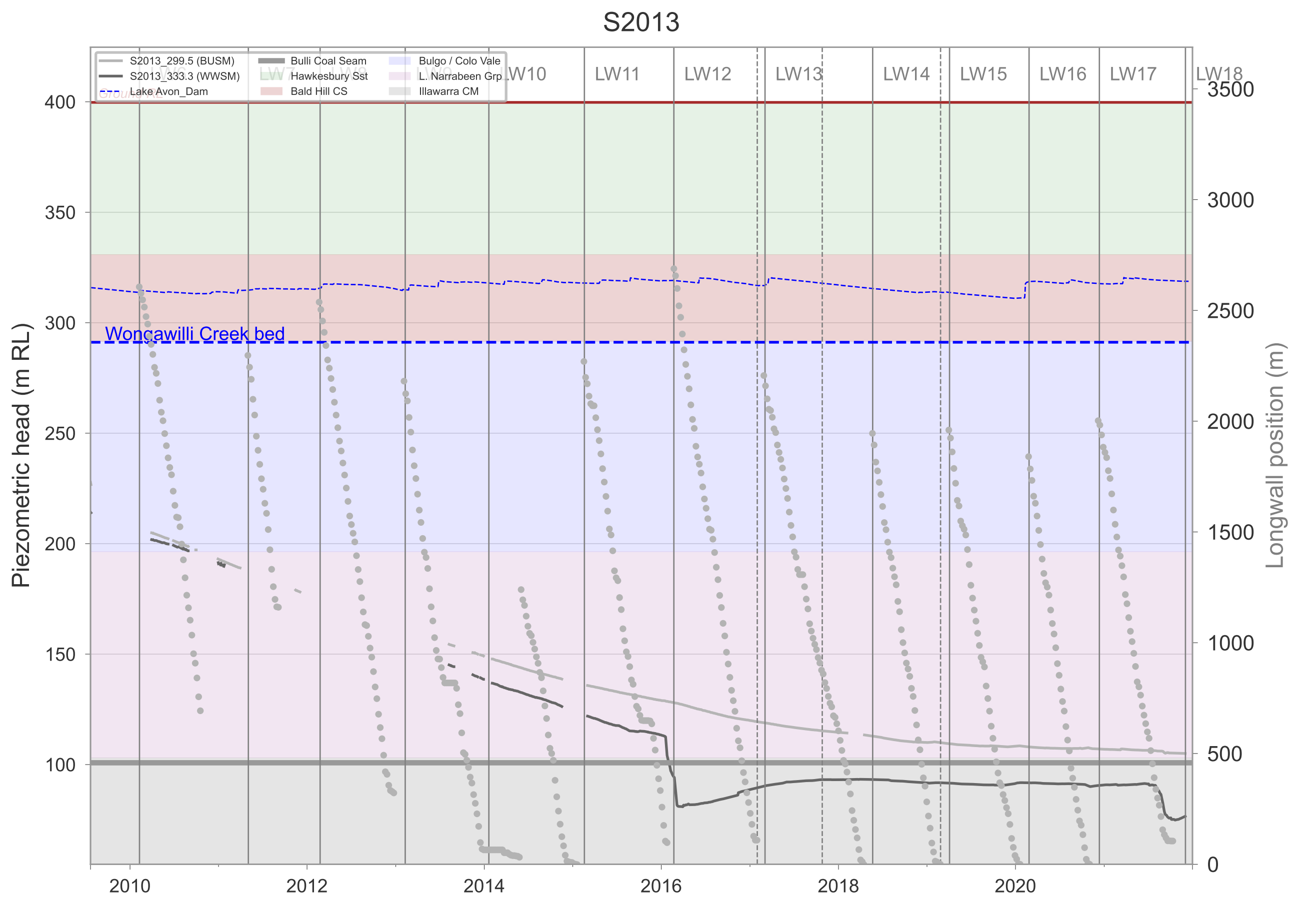

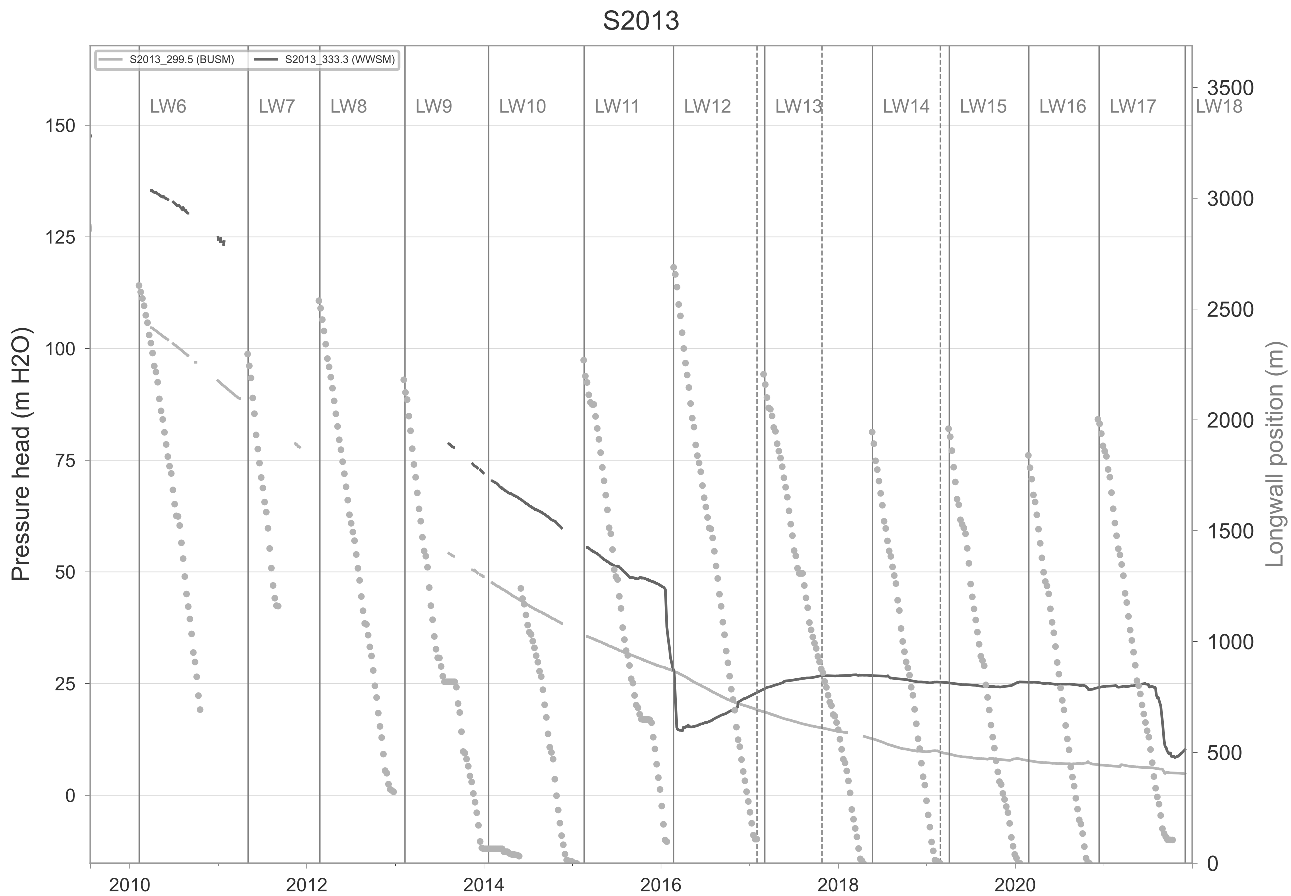

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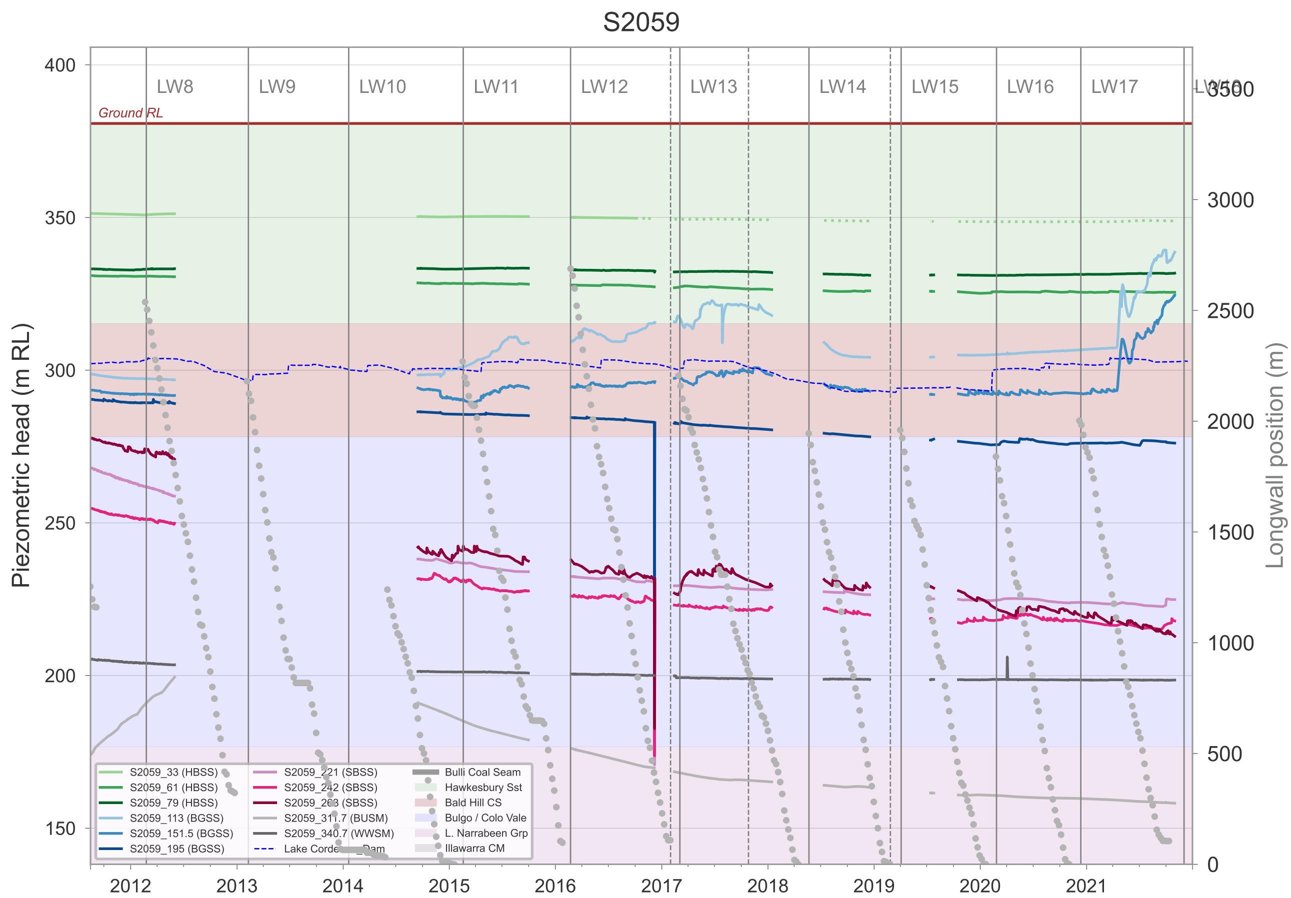

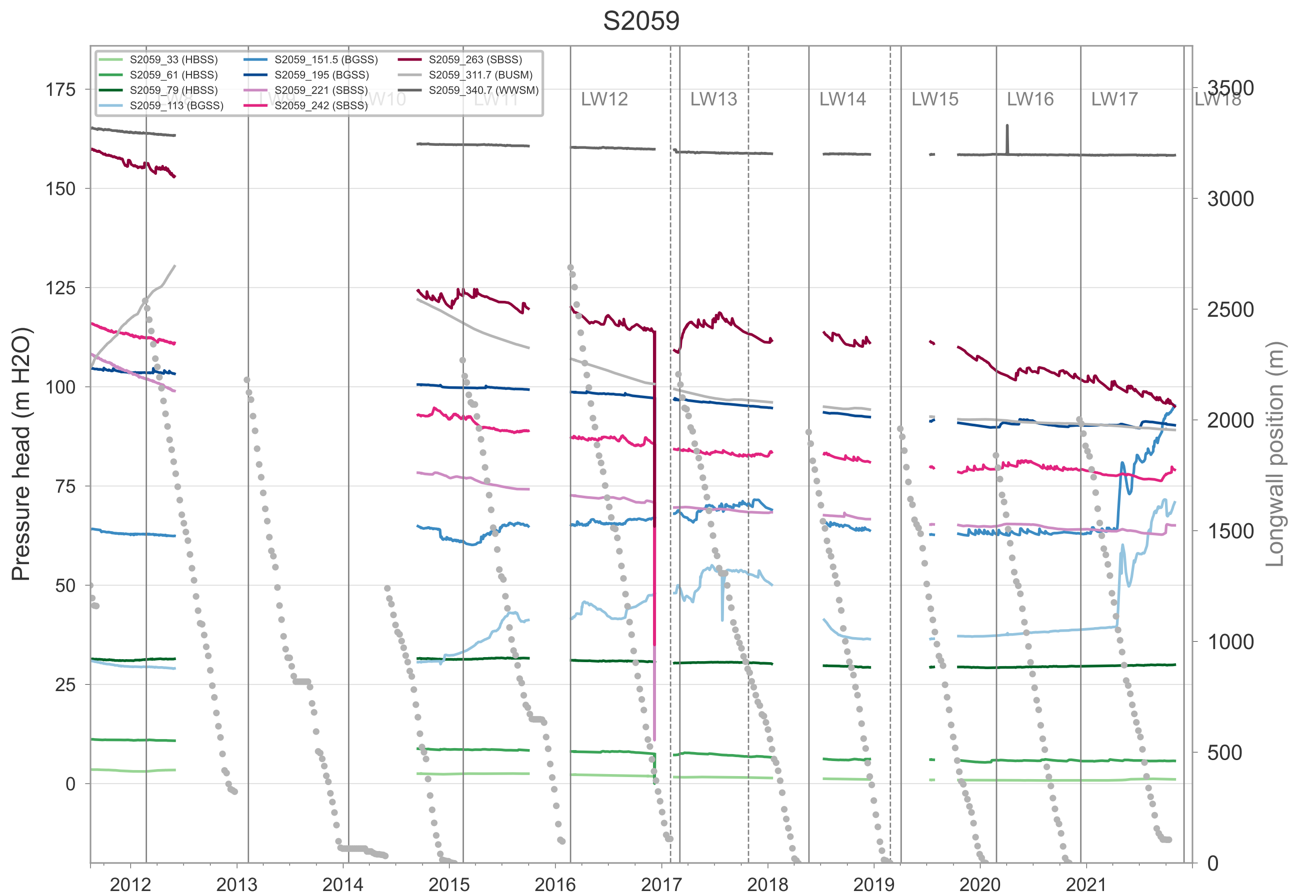

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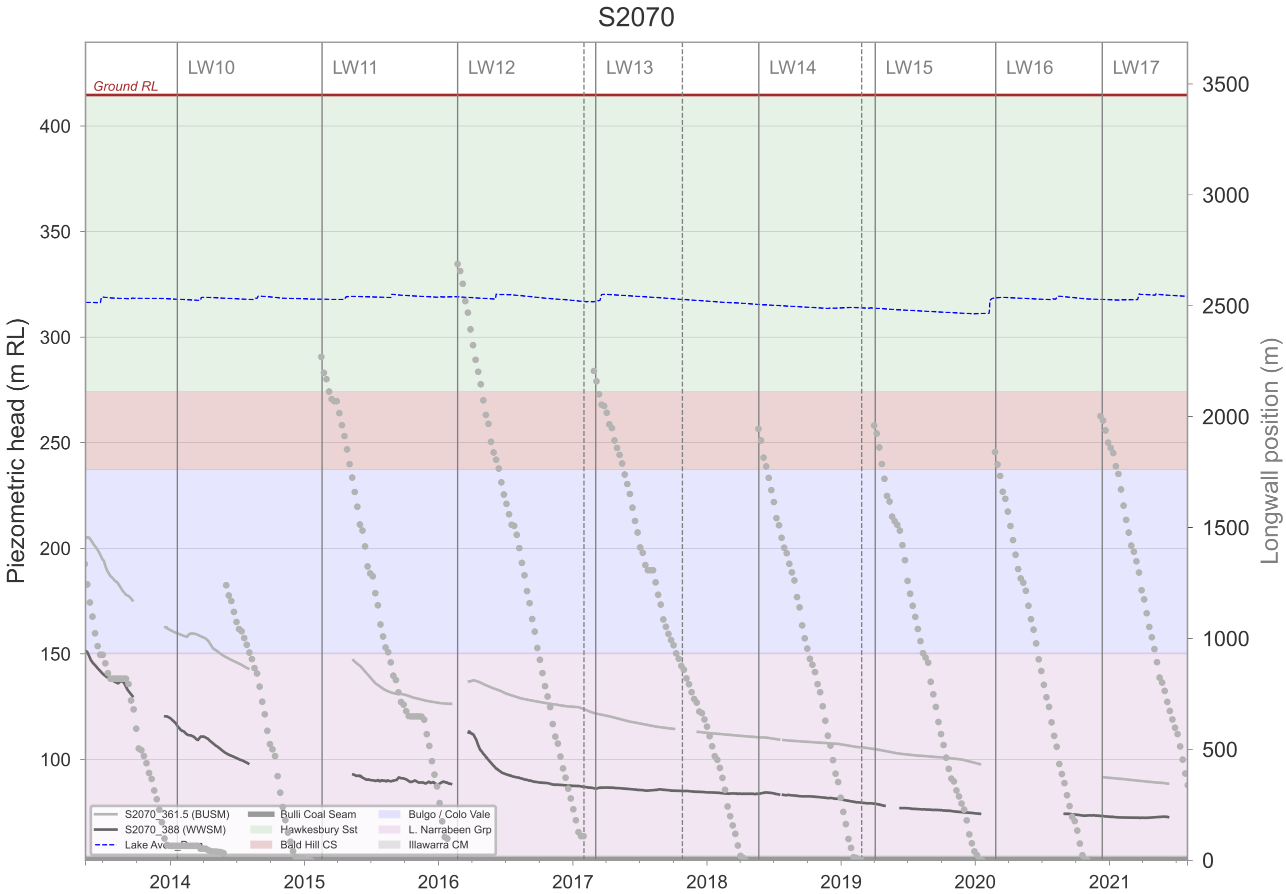

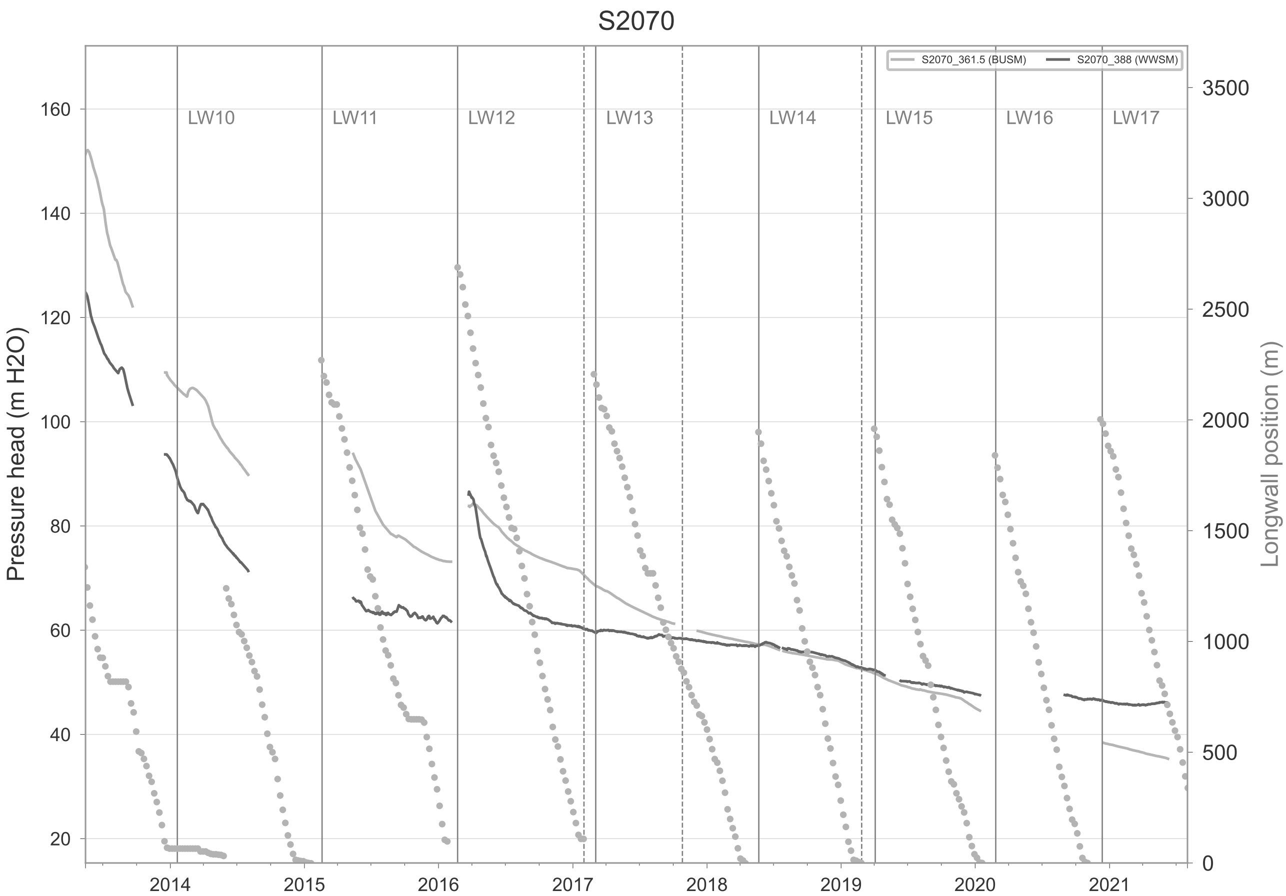

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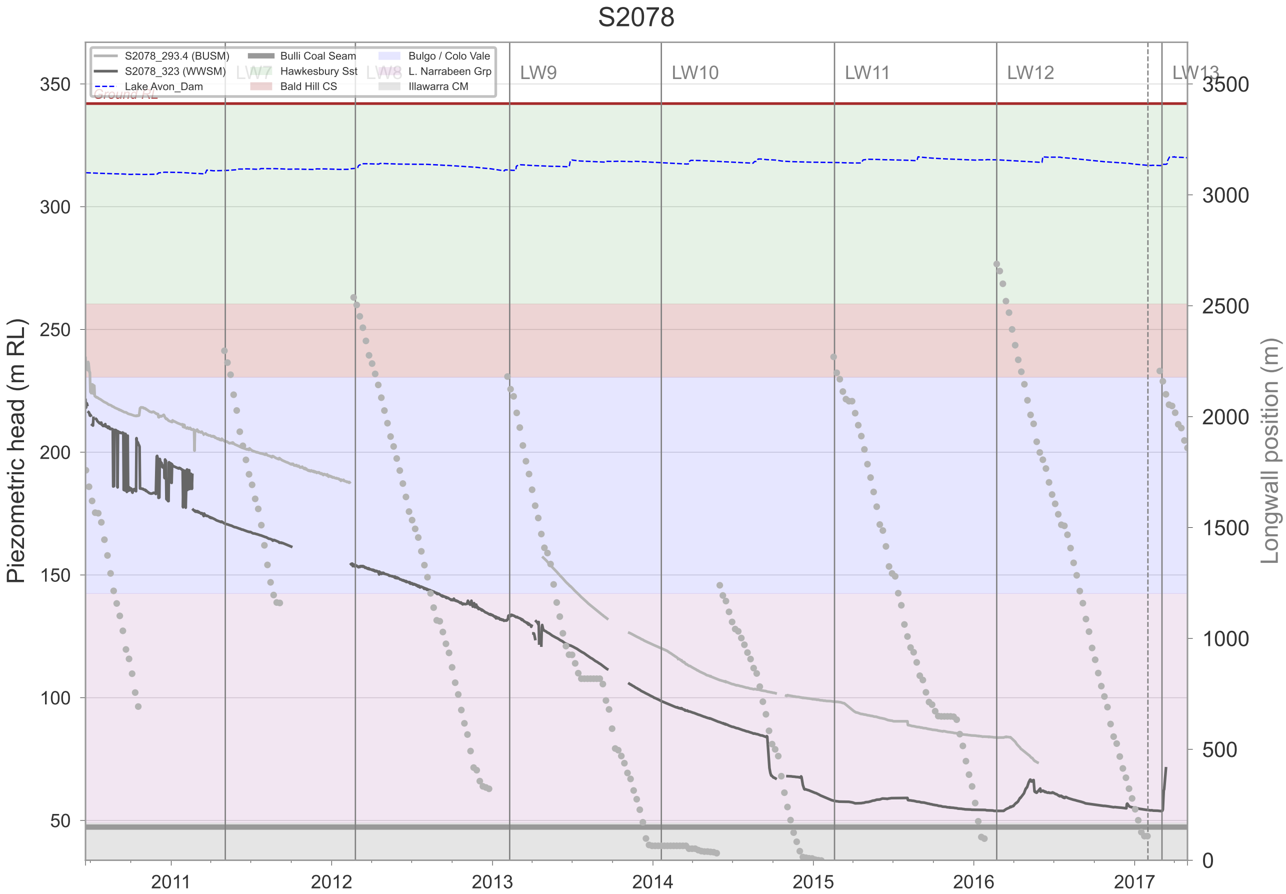

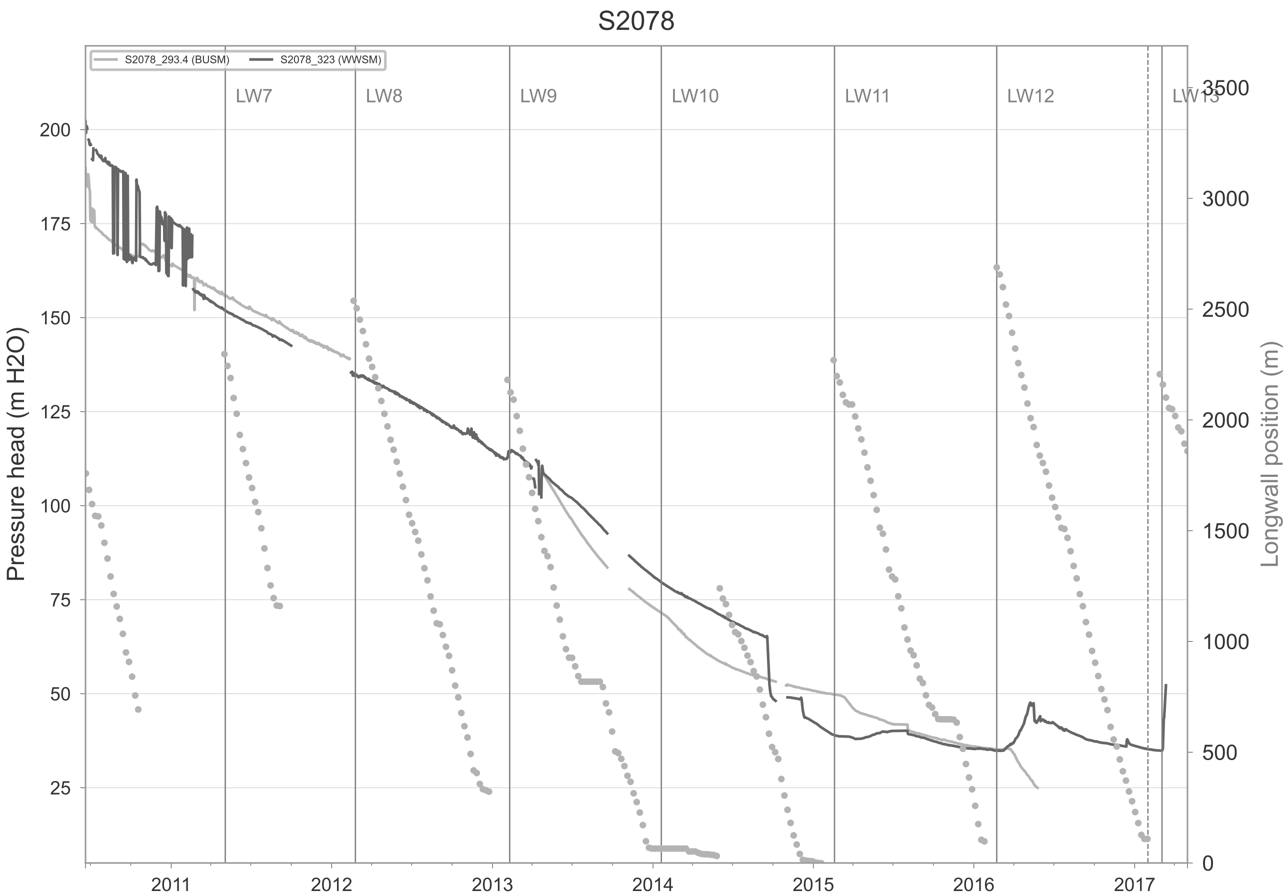

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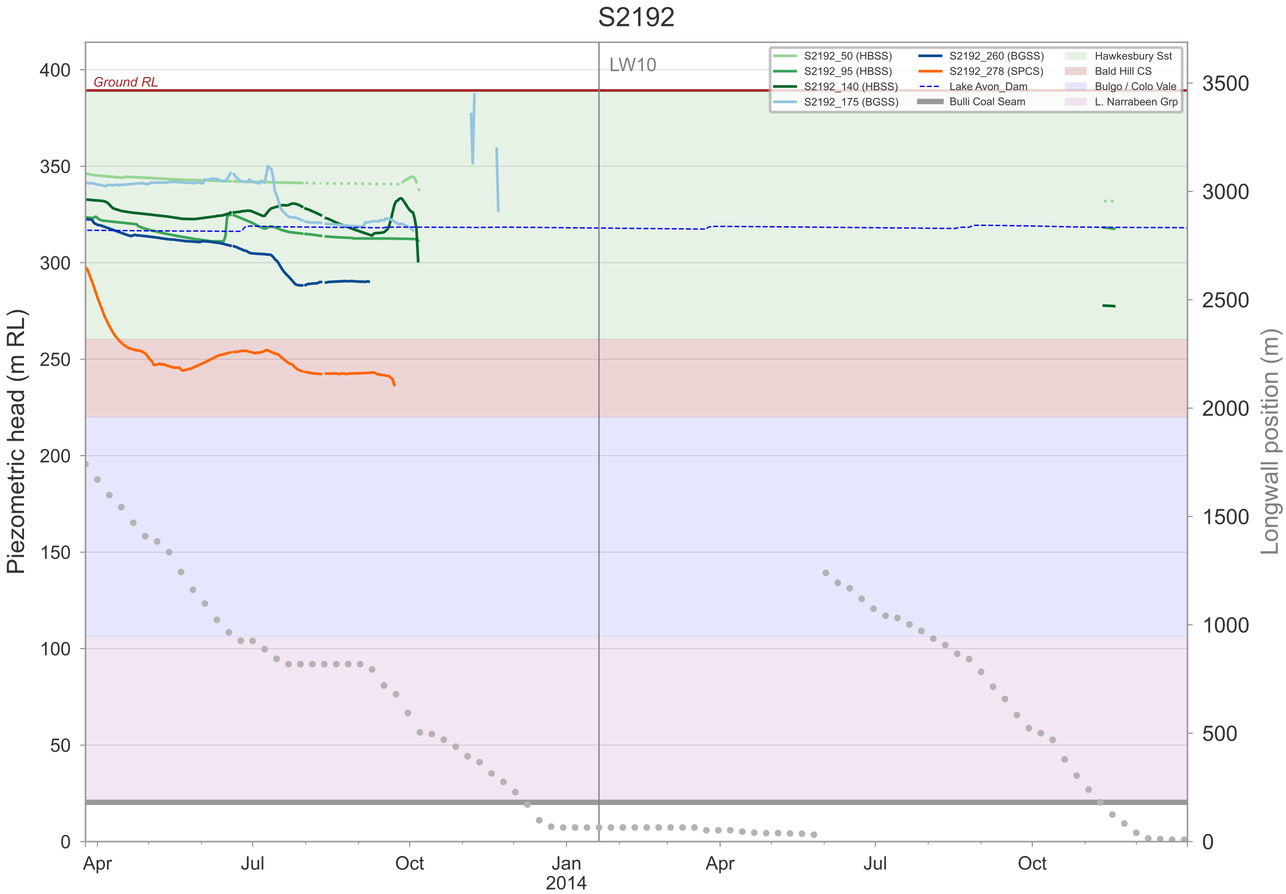

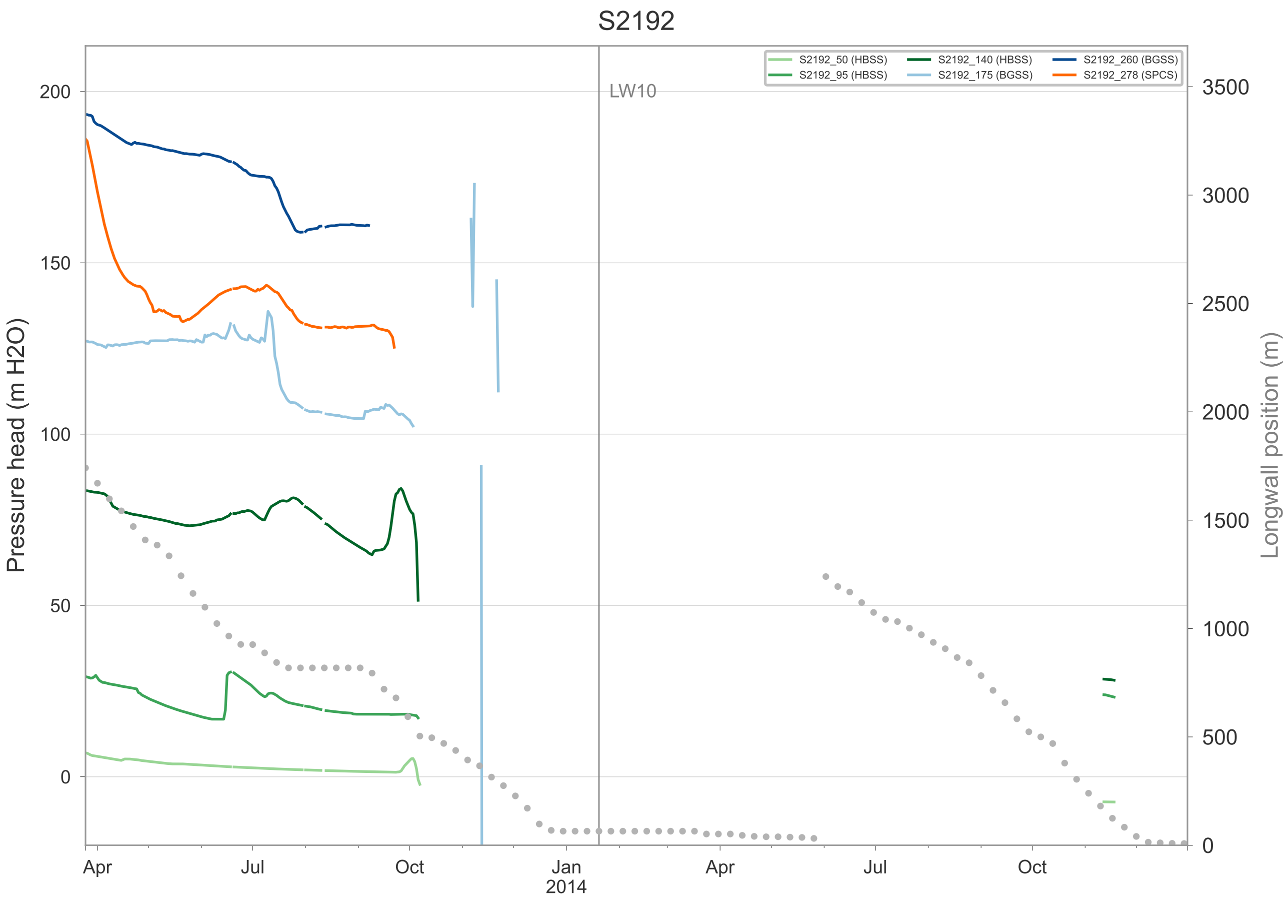

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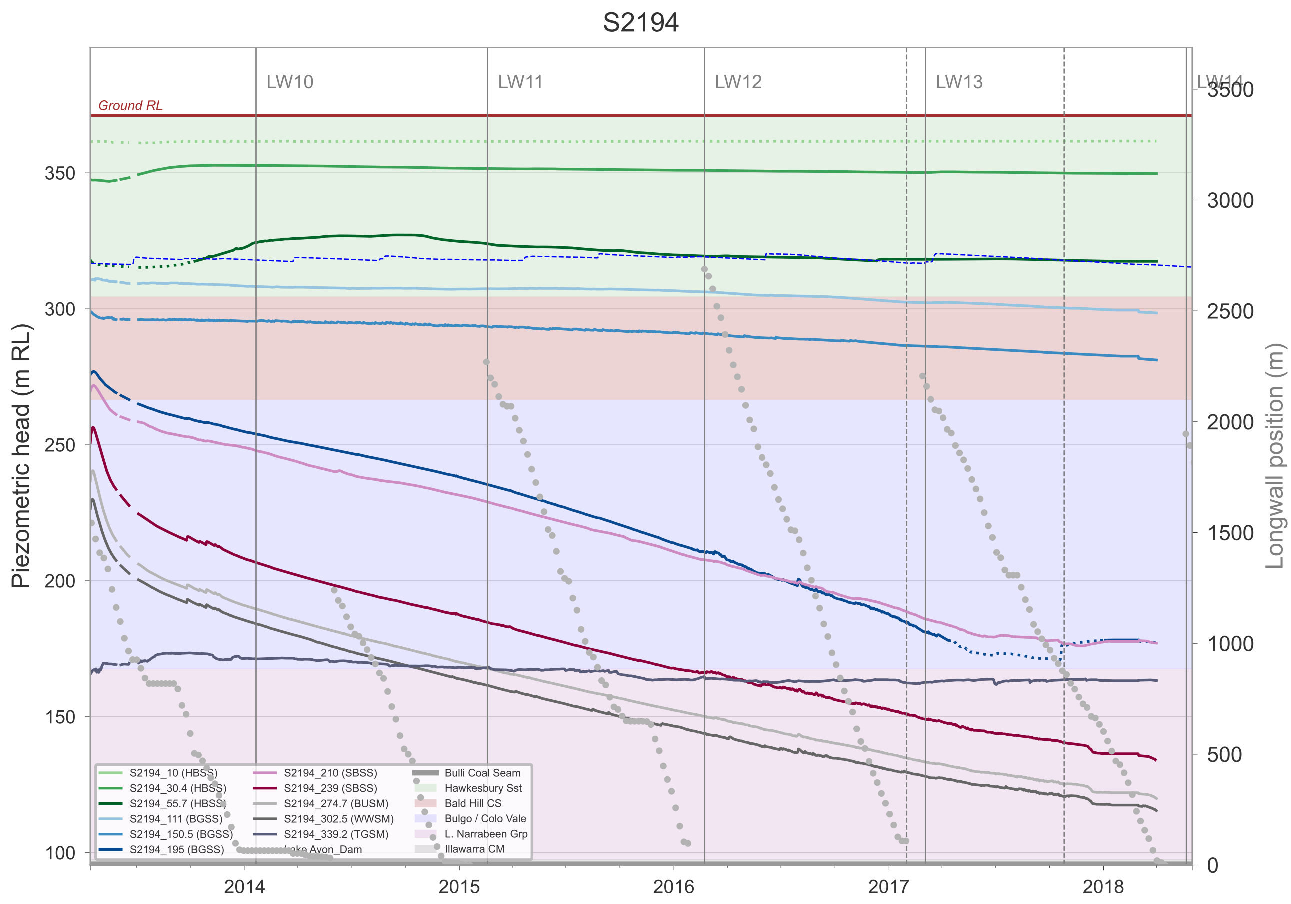

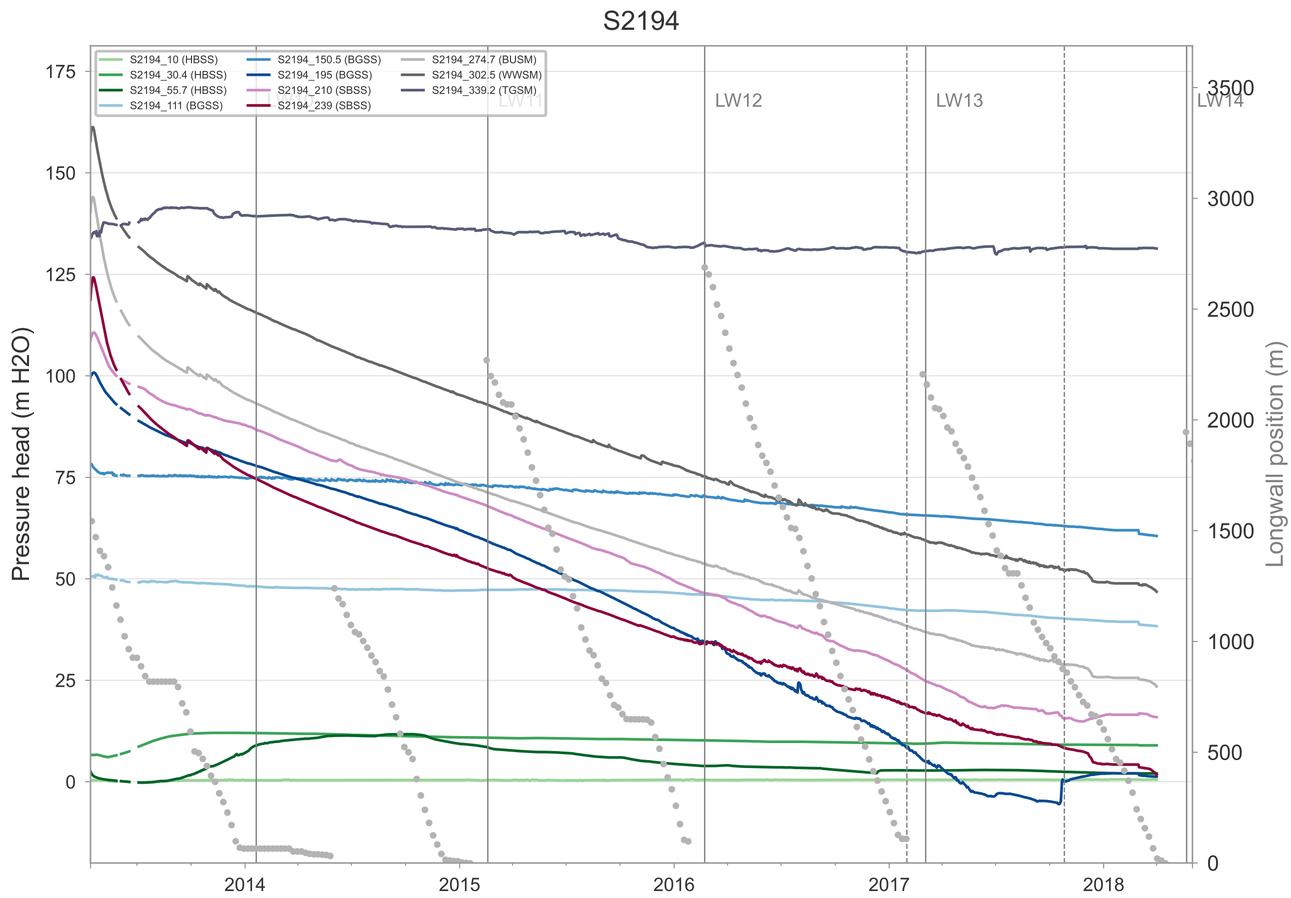

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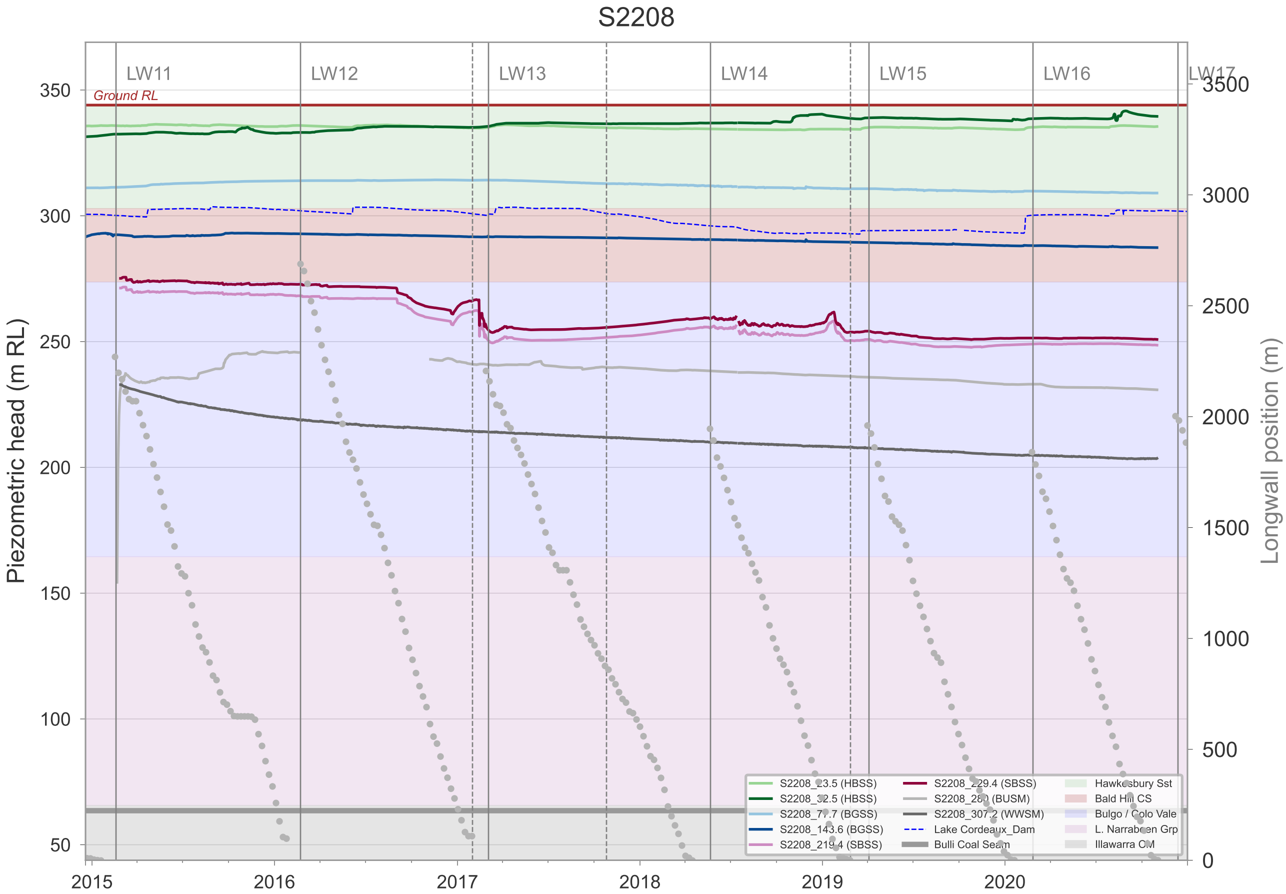

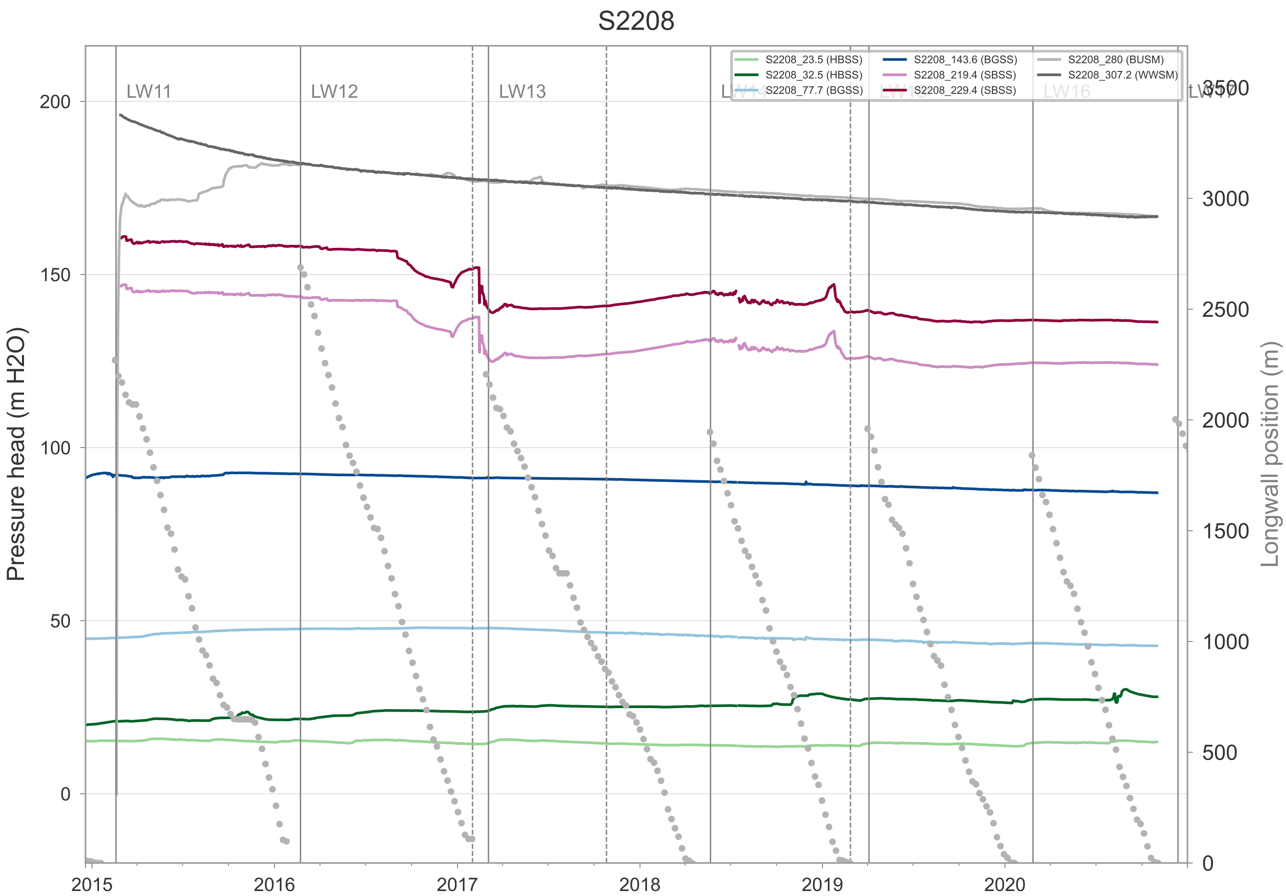

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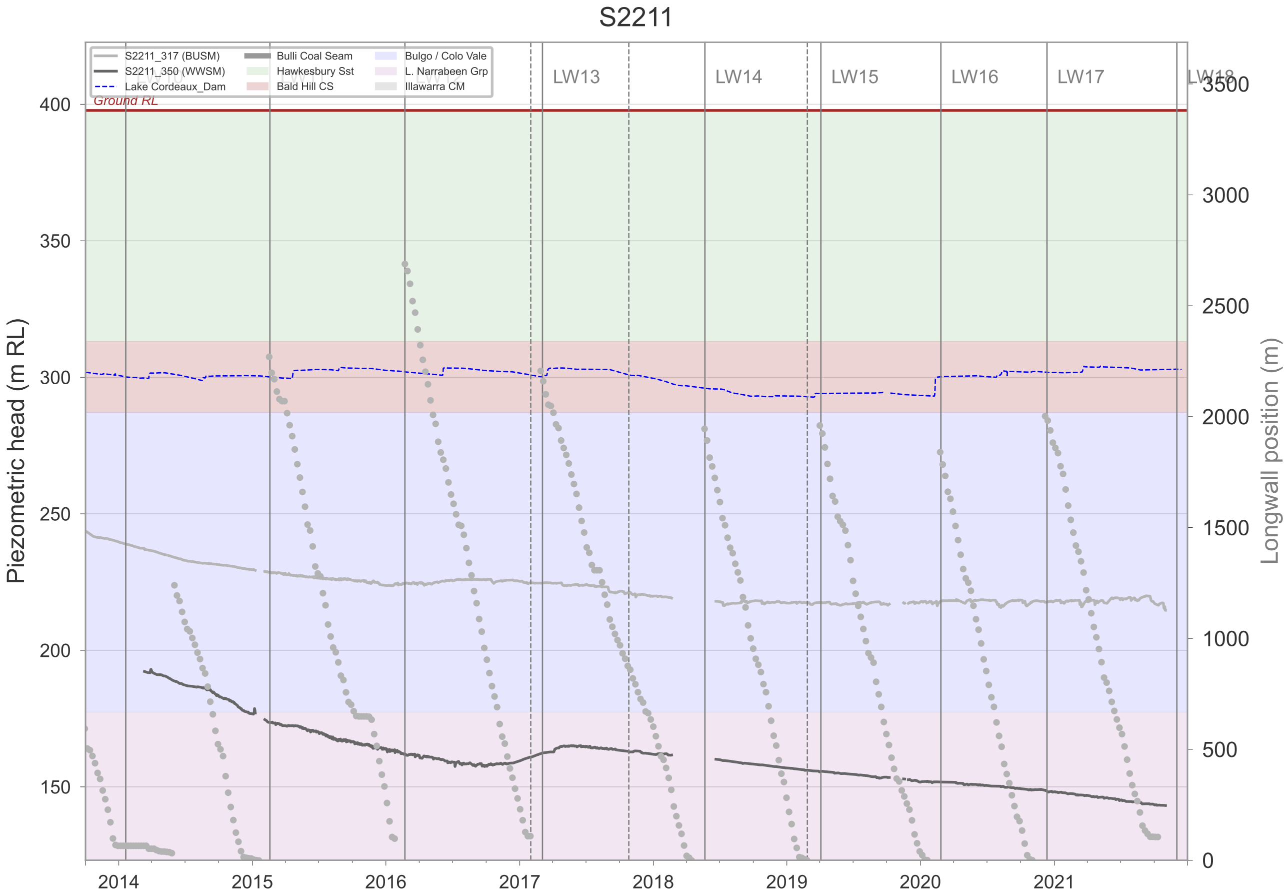

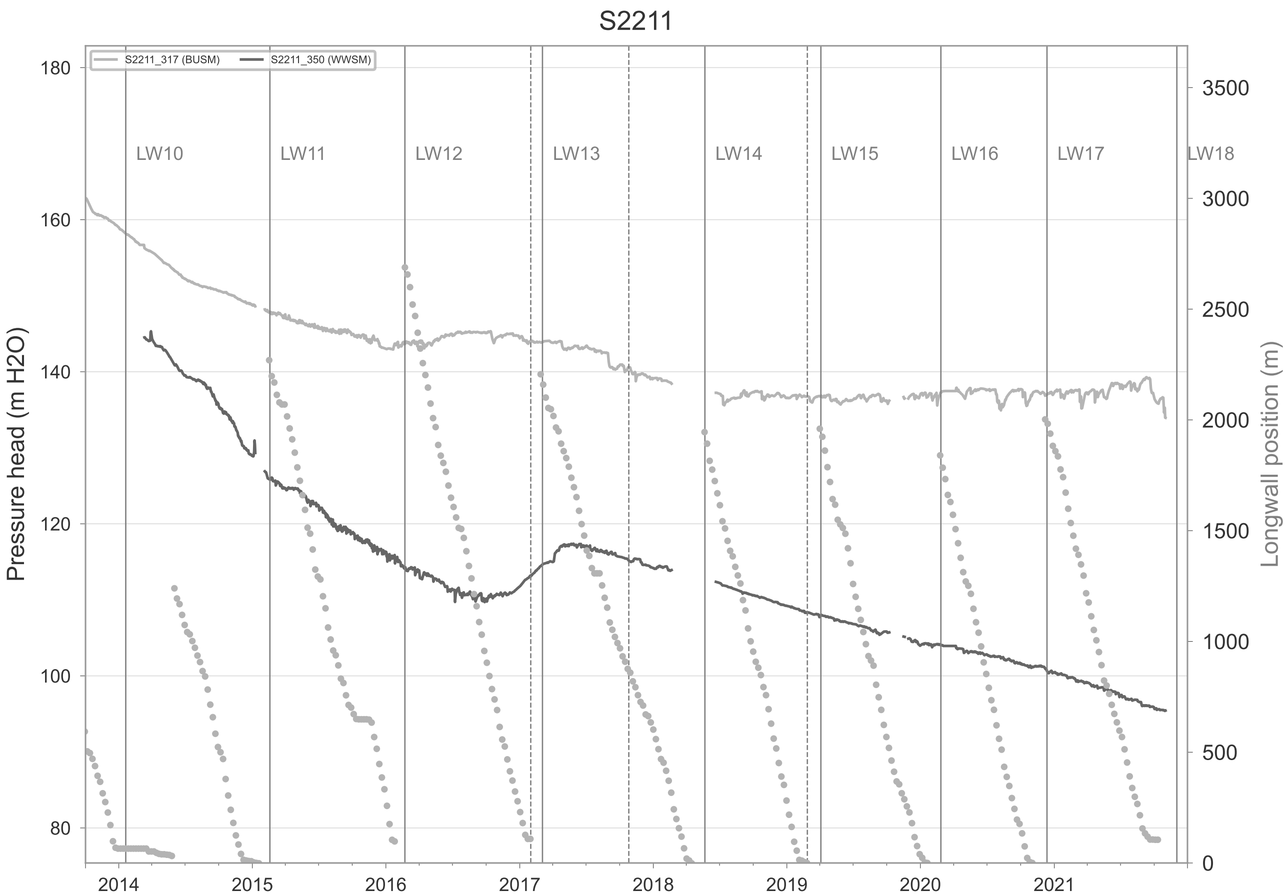

Groundwater hydrographs

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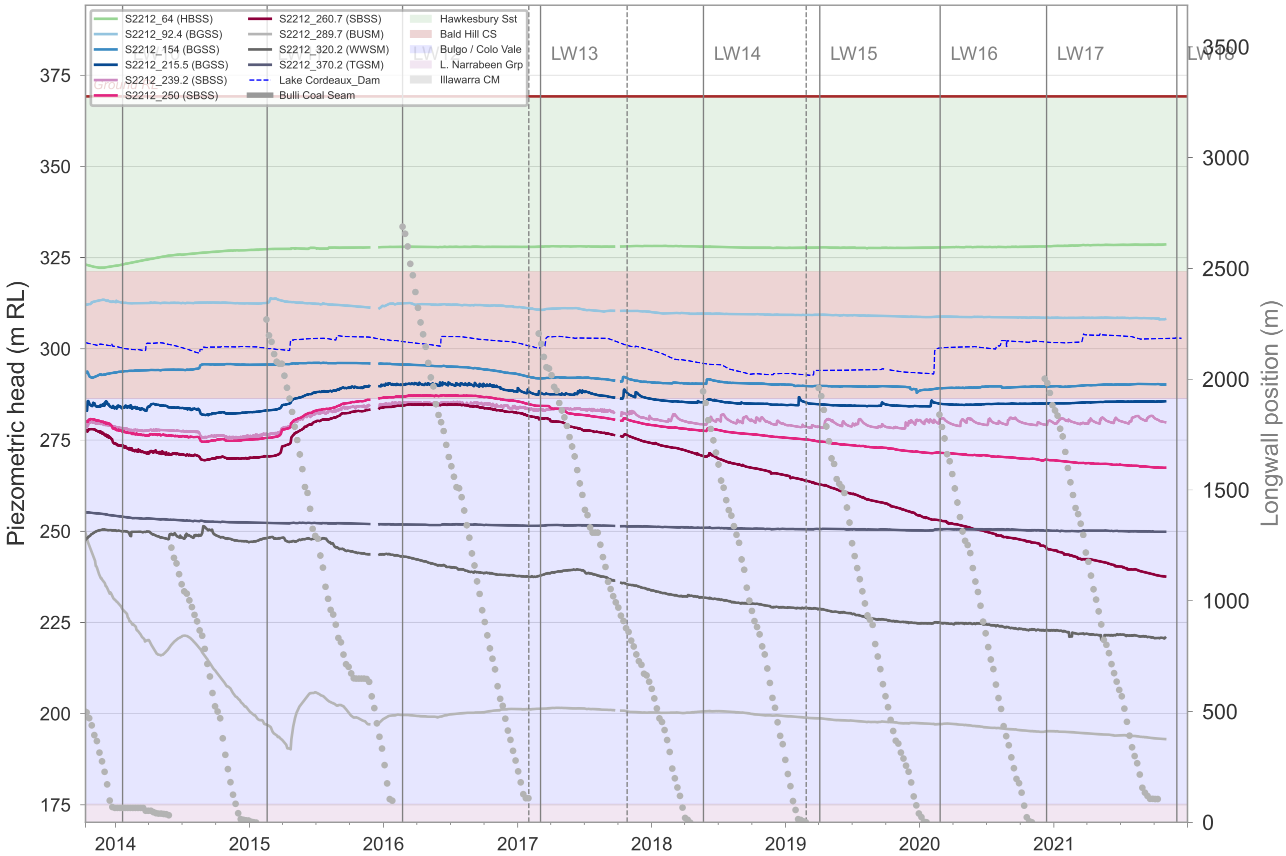

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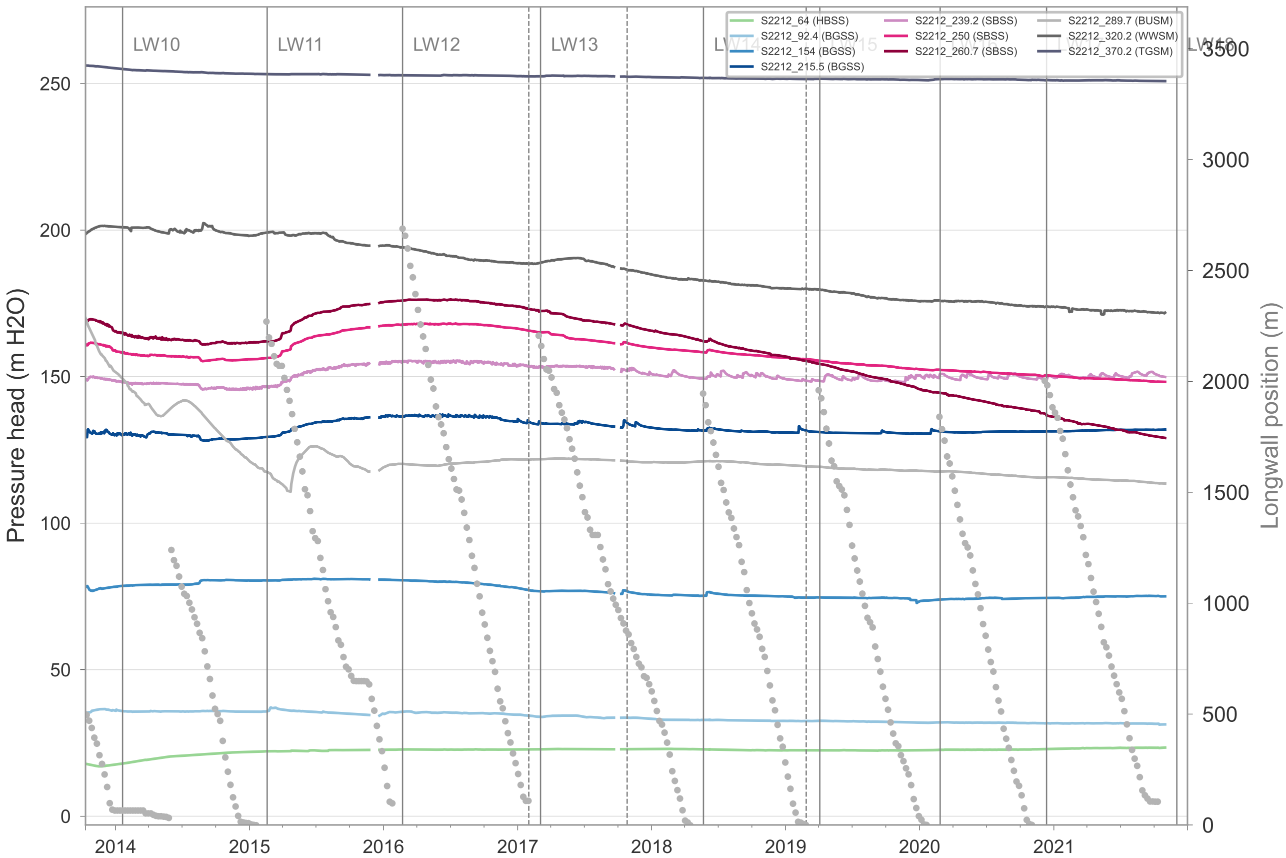

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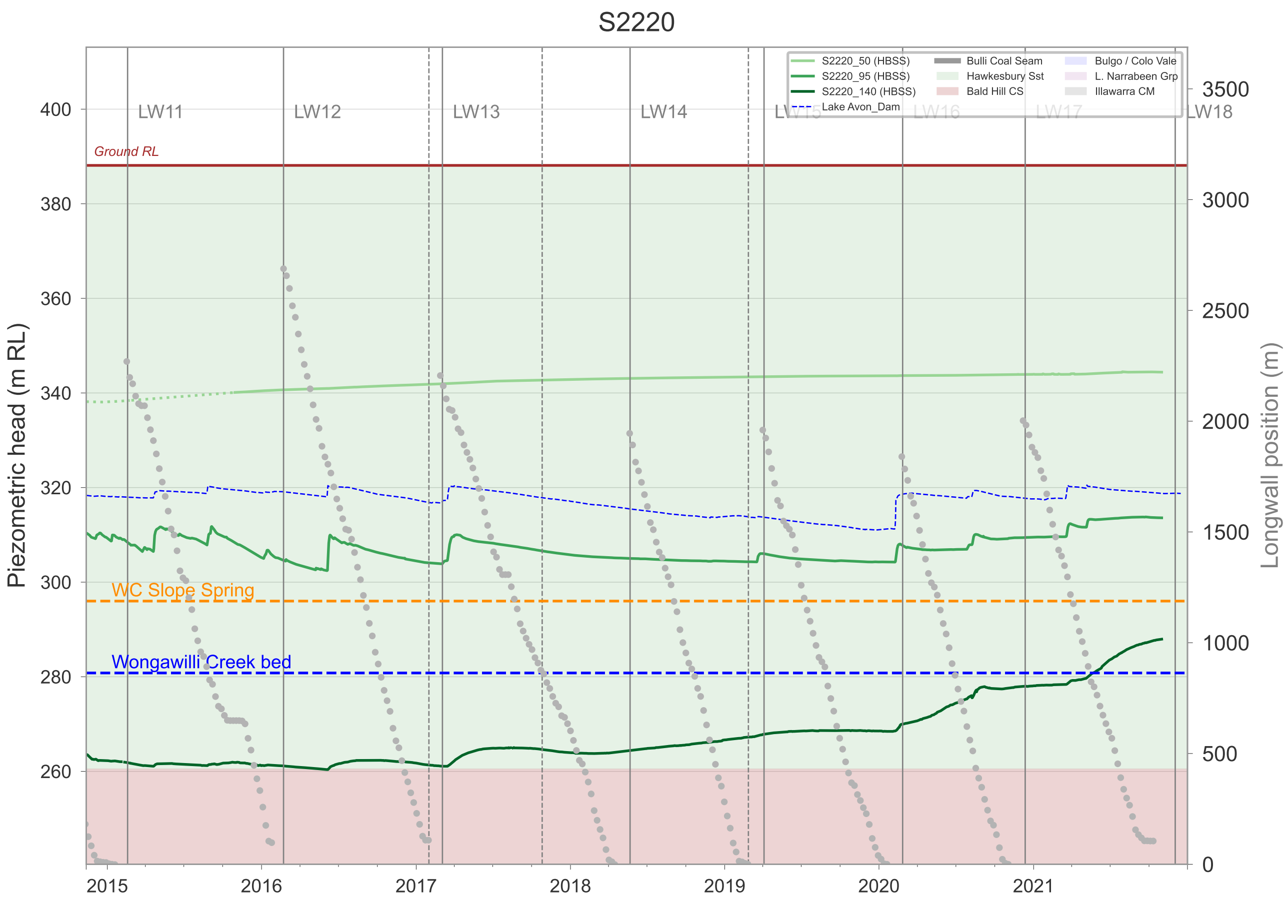

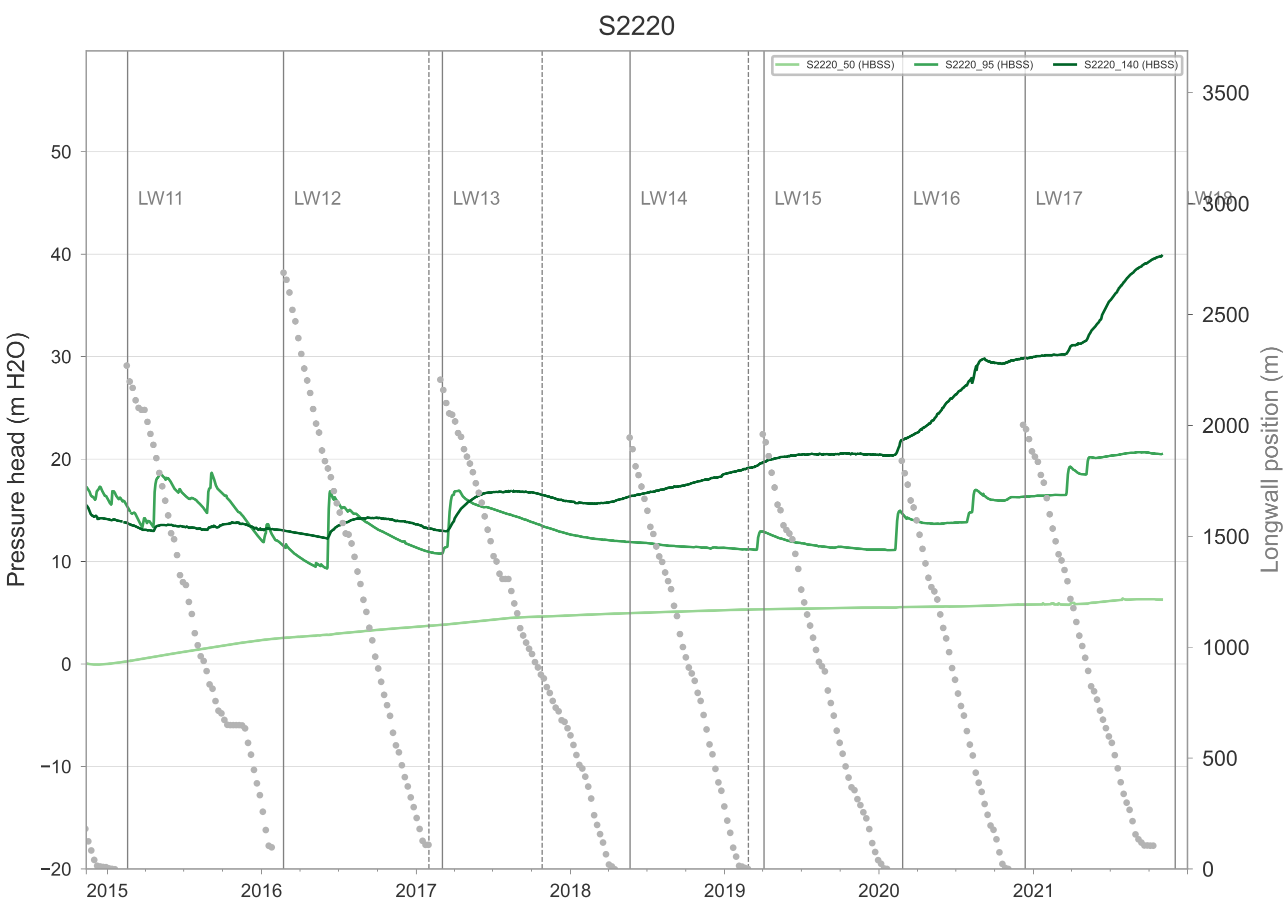

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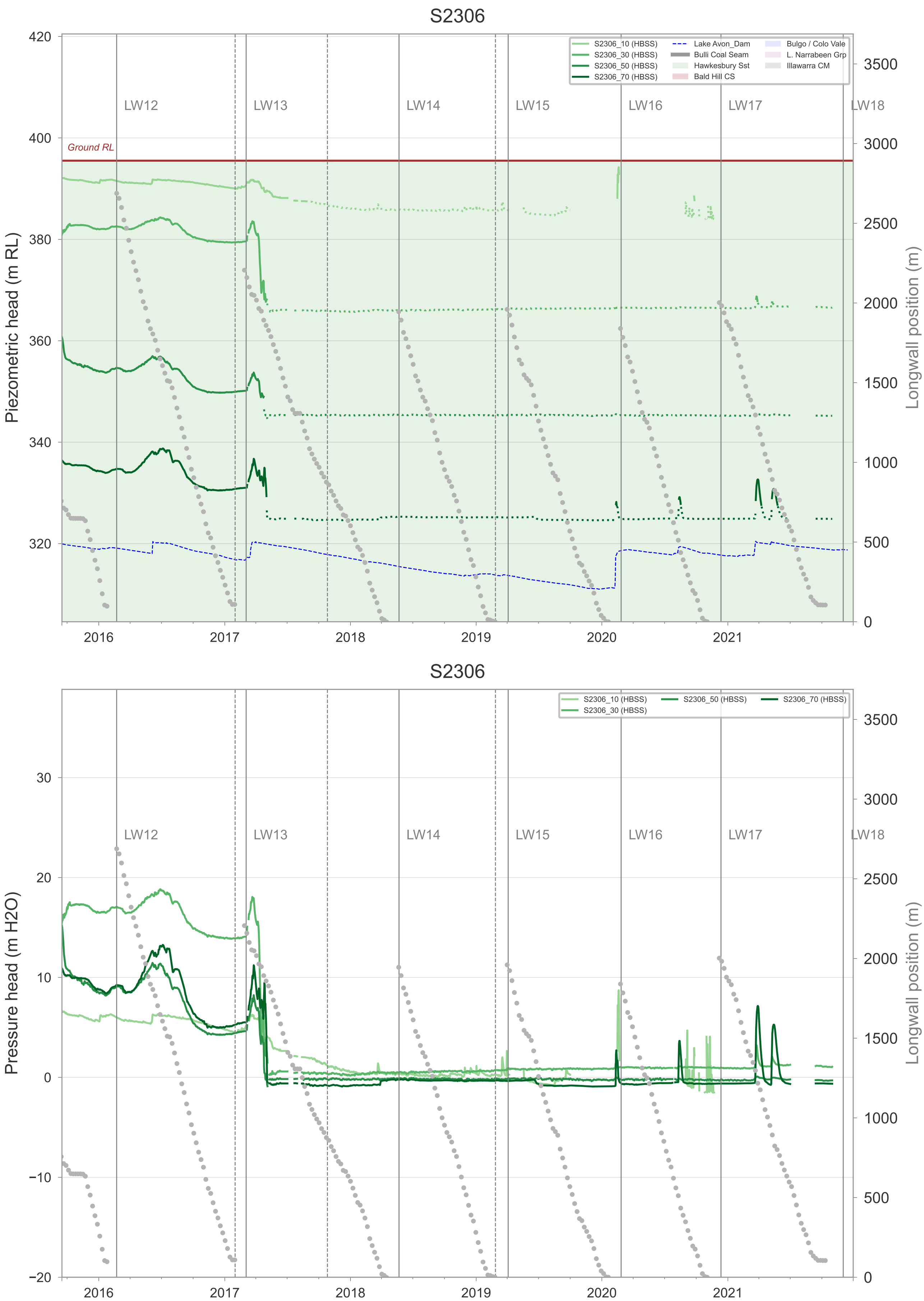

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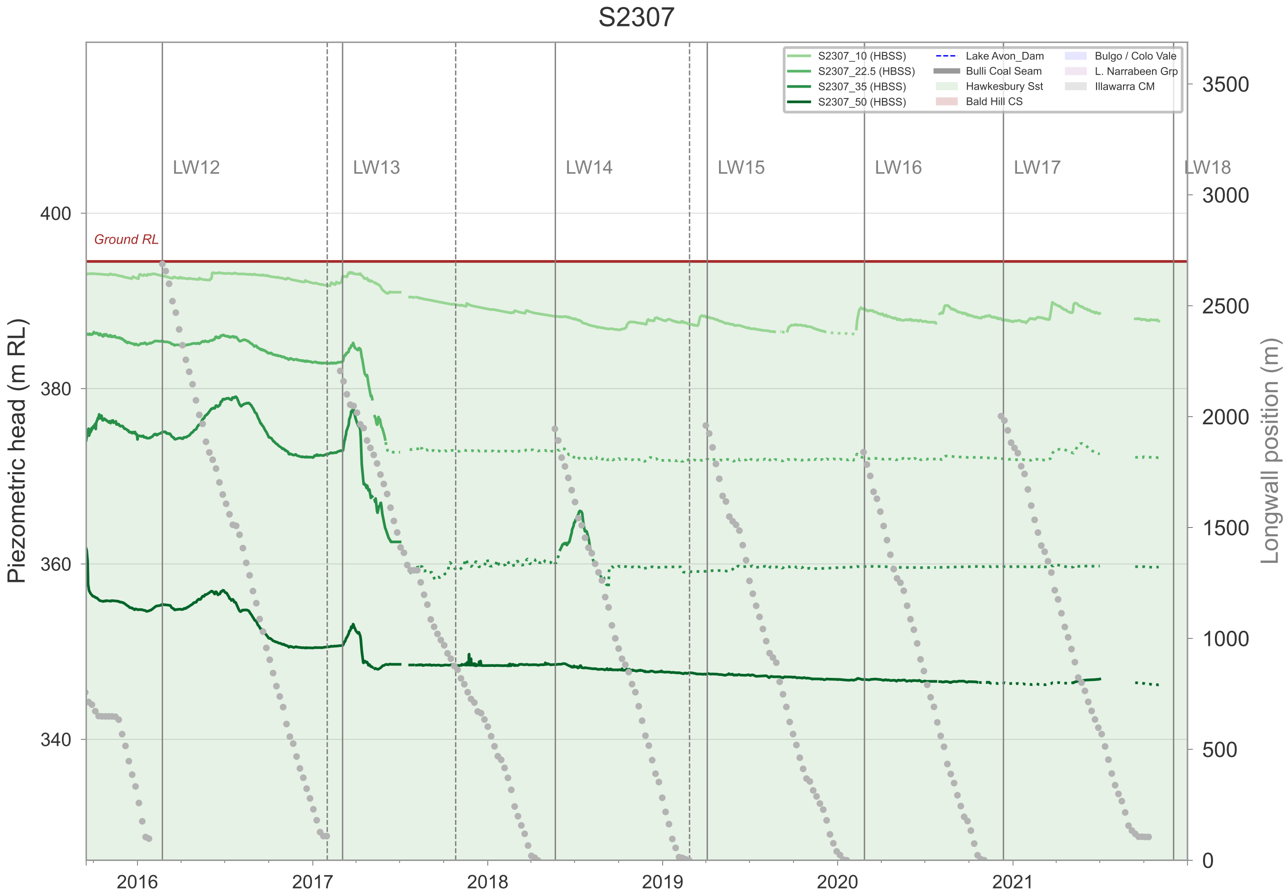

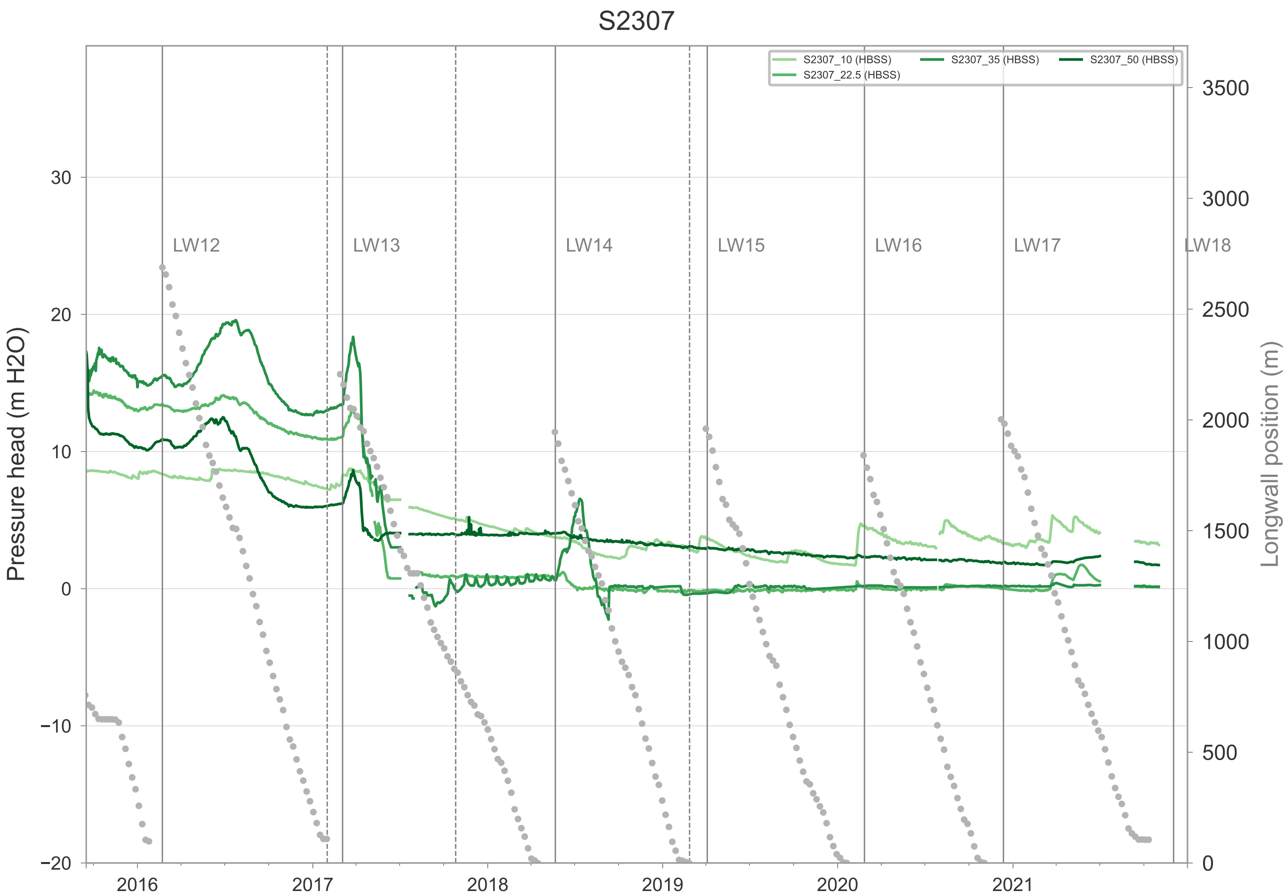

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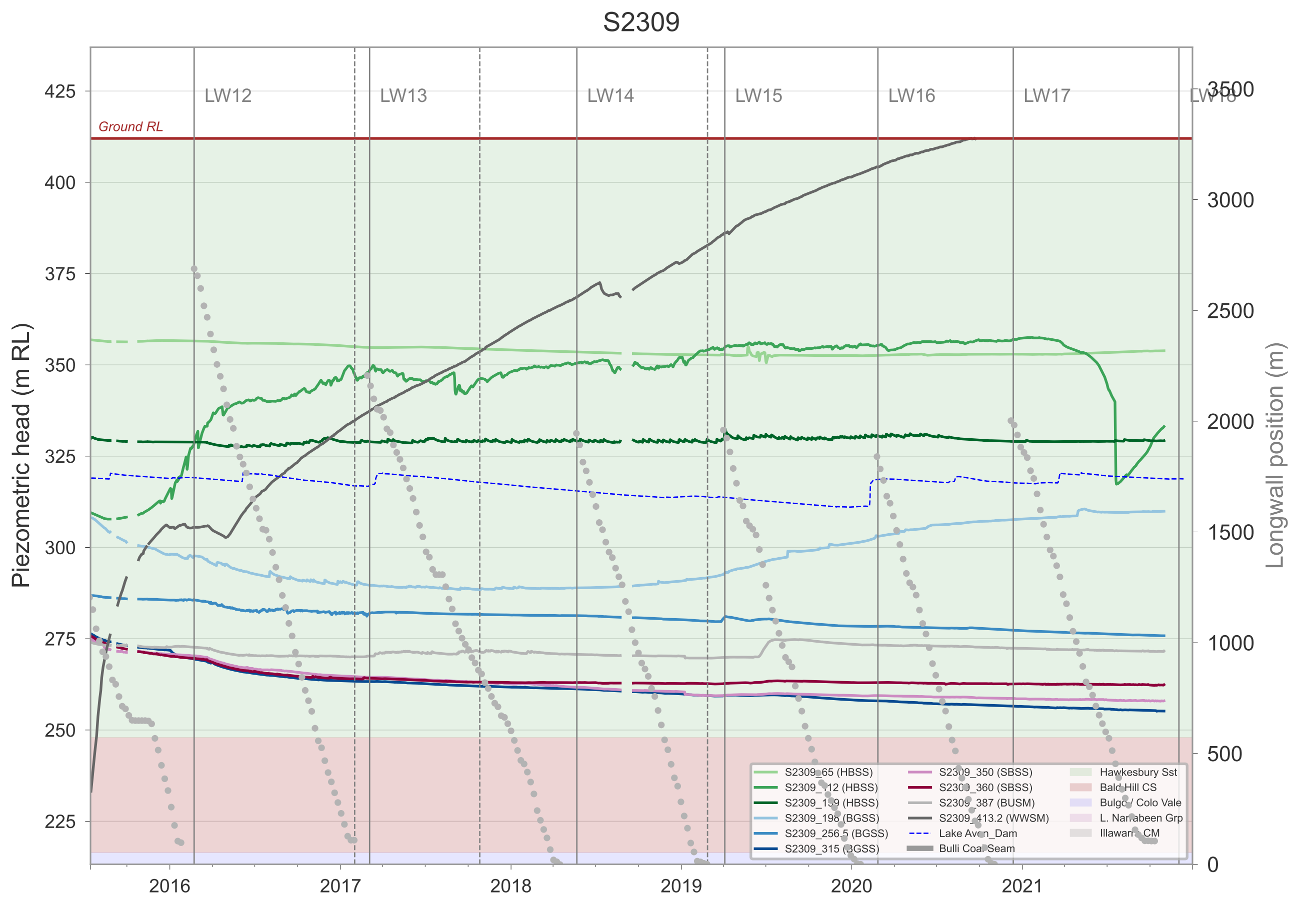

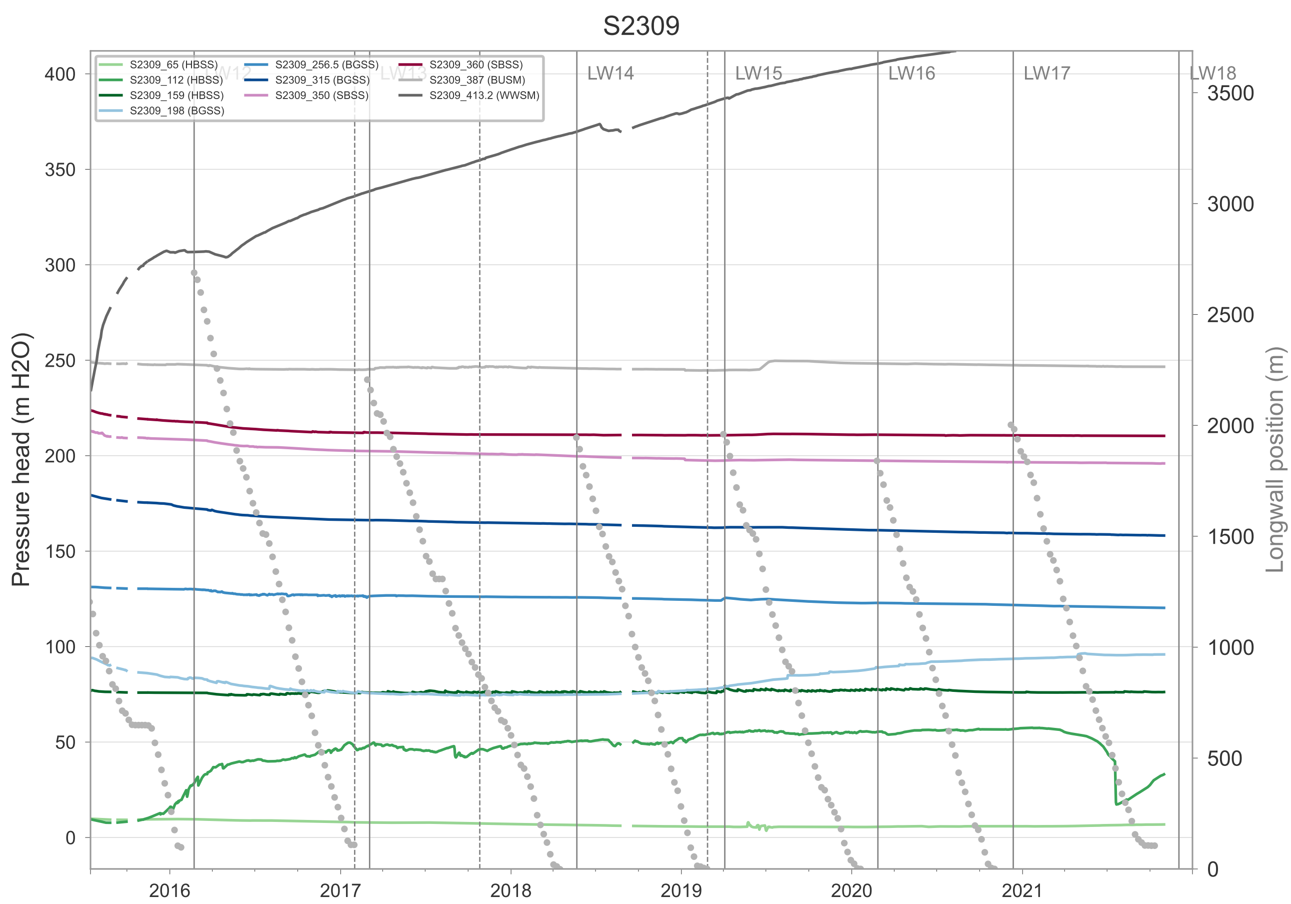

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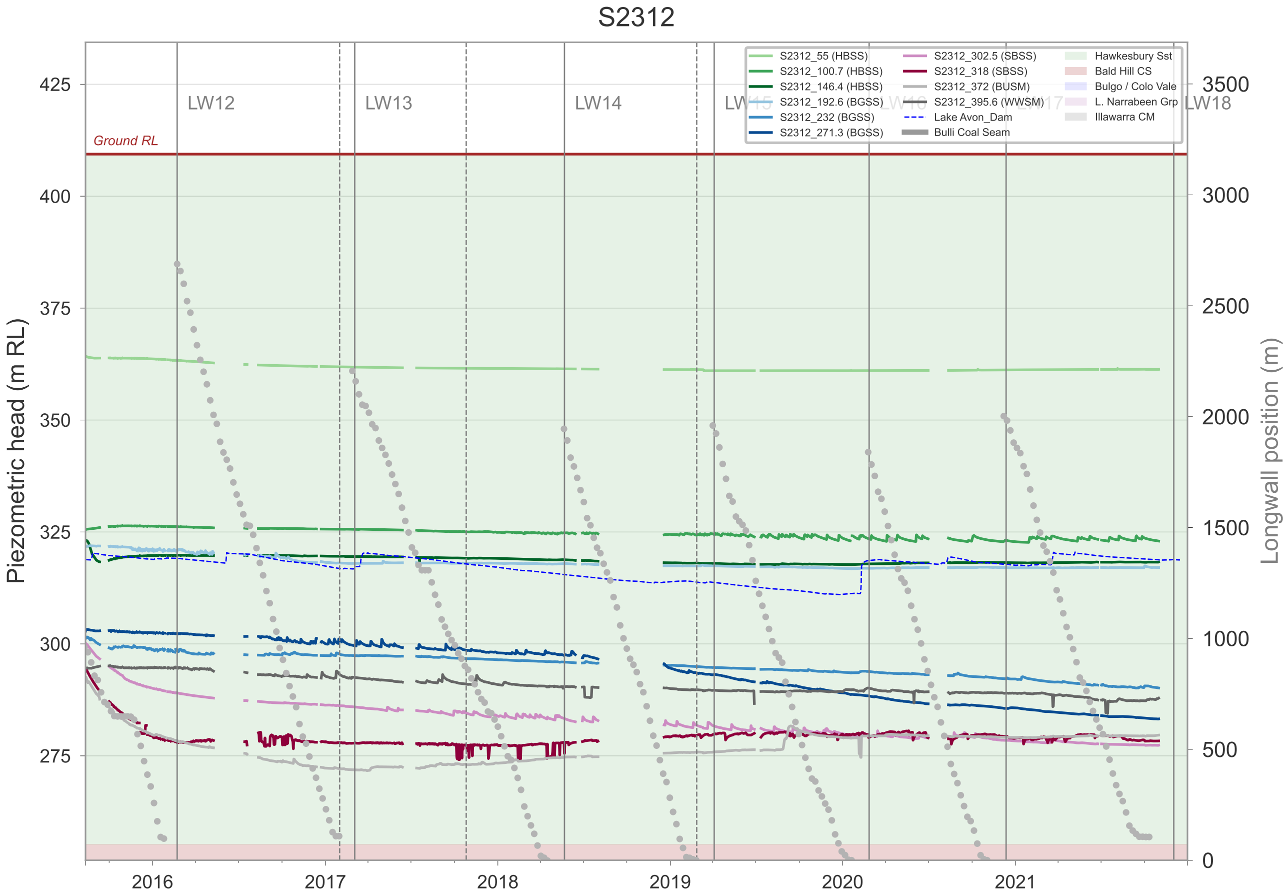

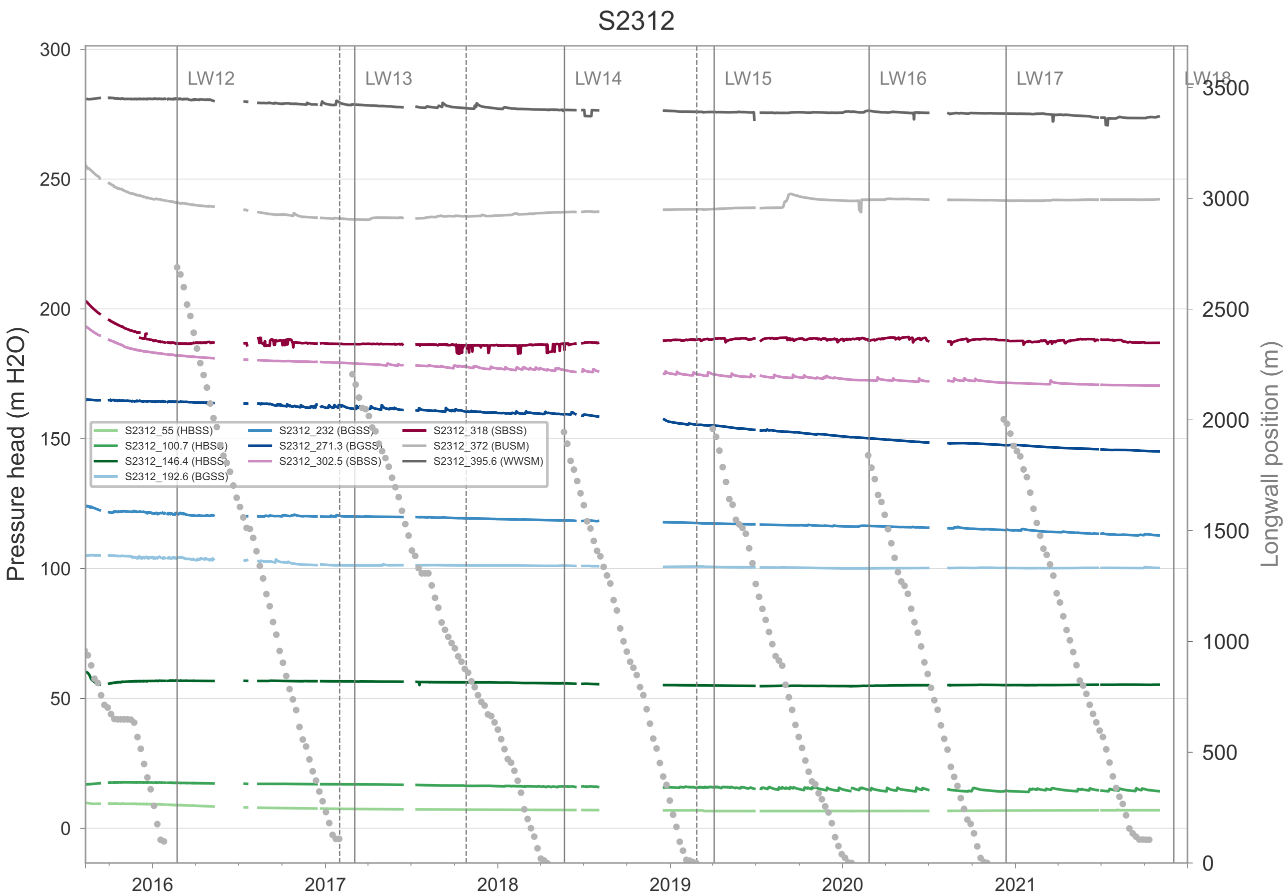

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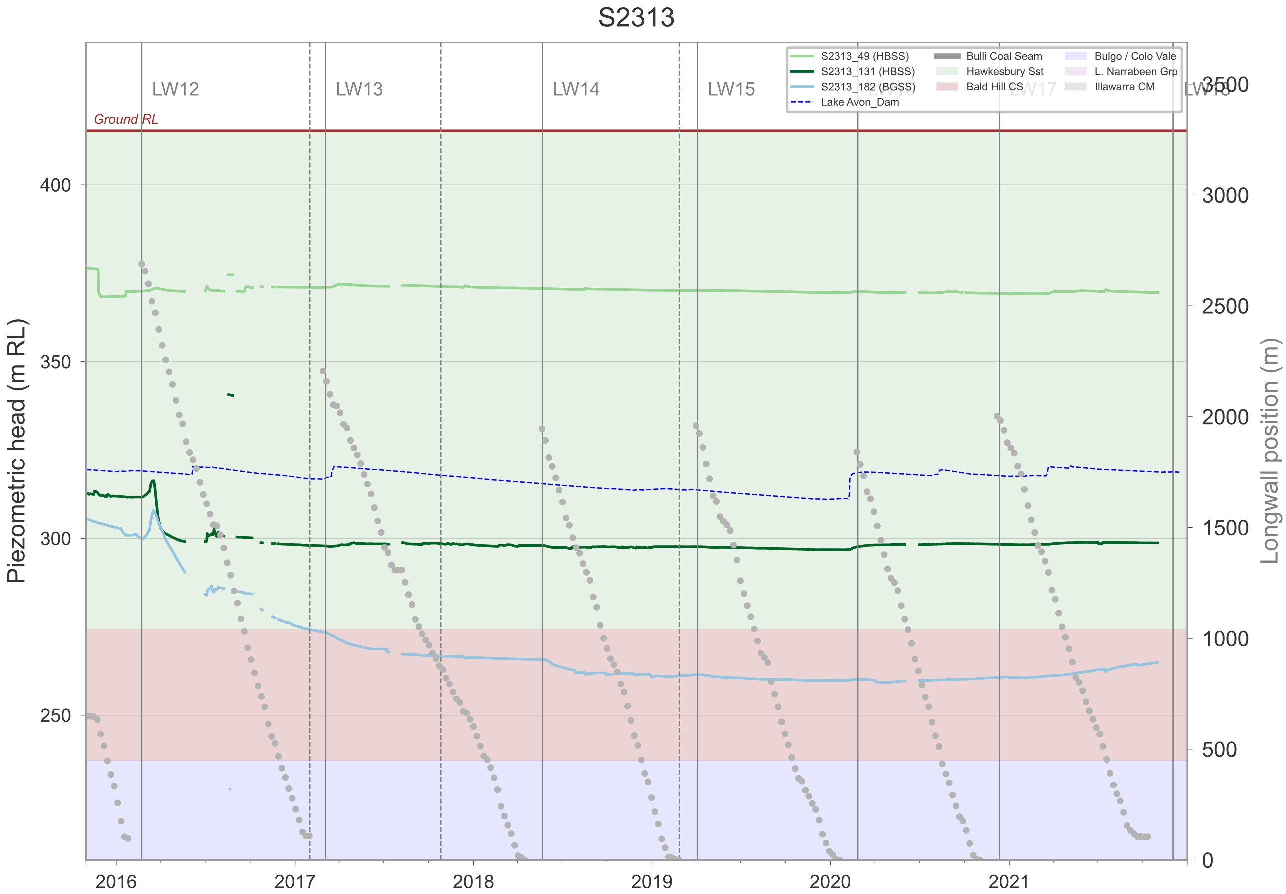

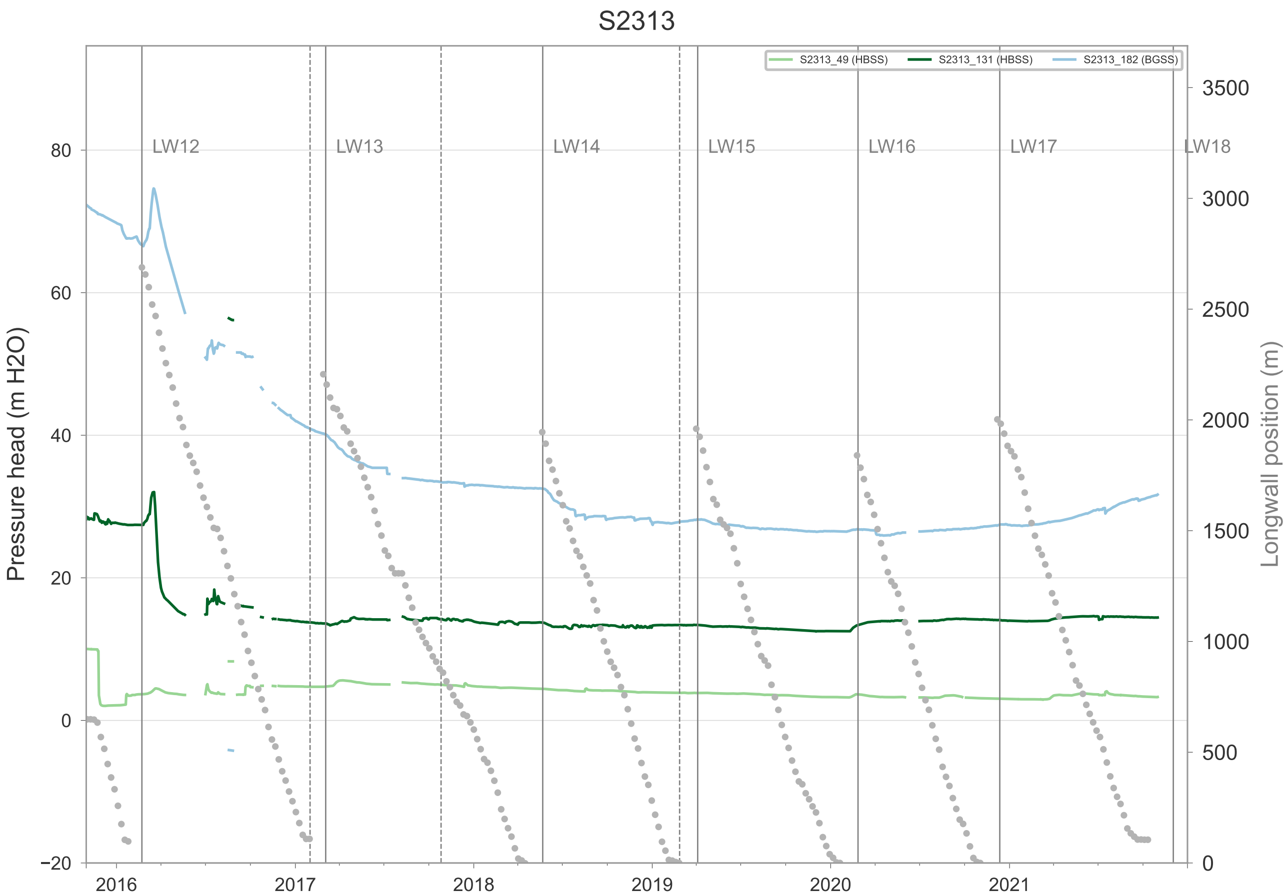

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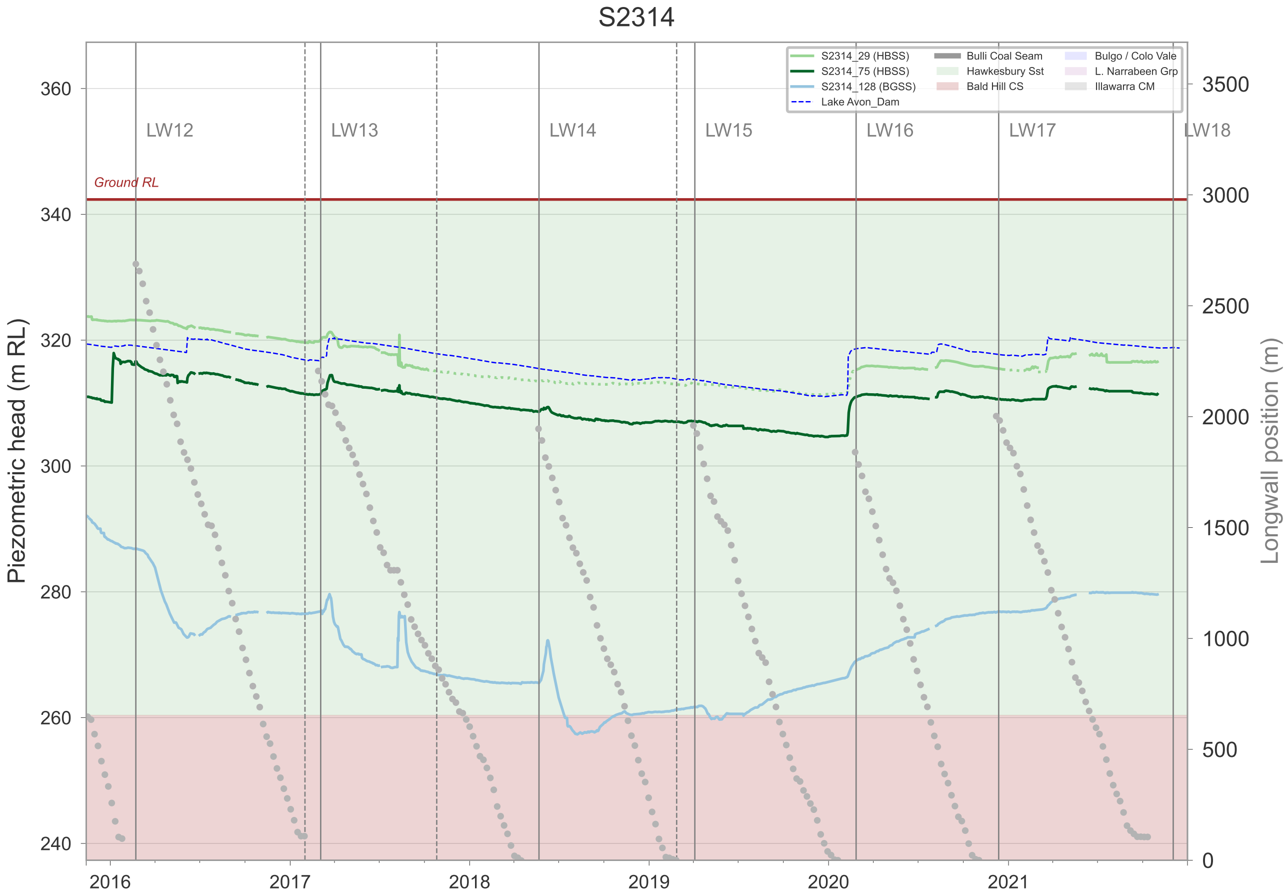

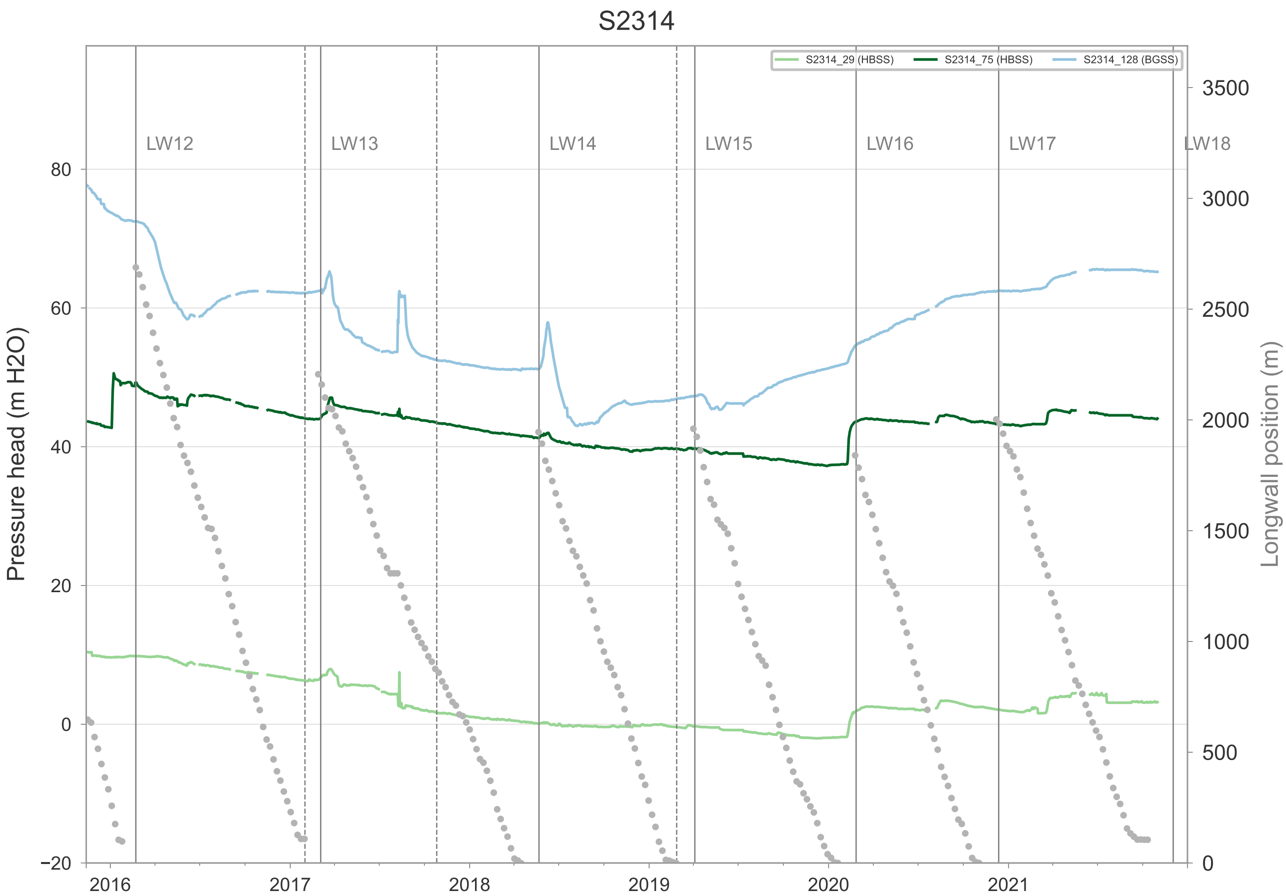

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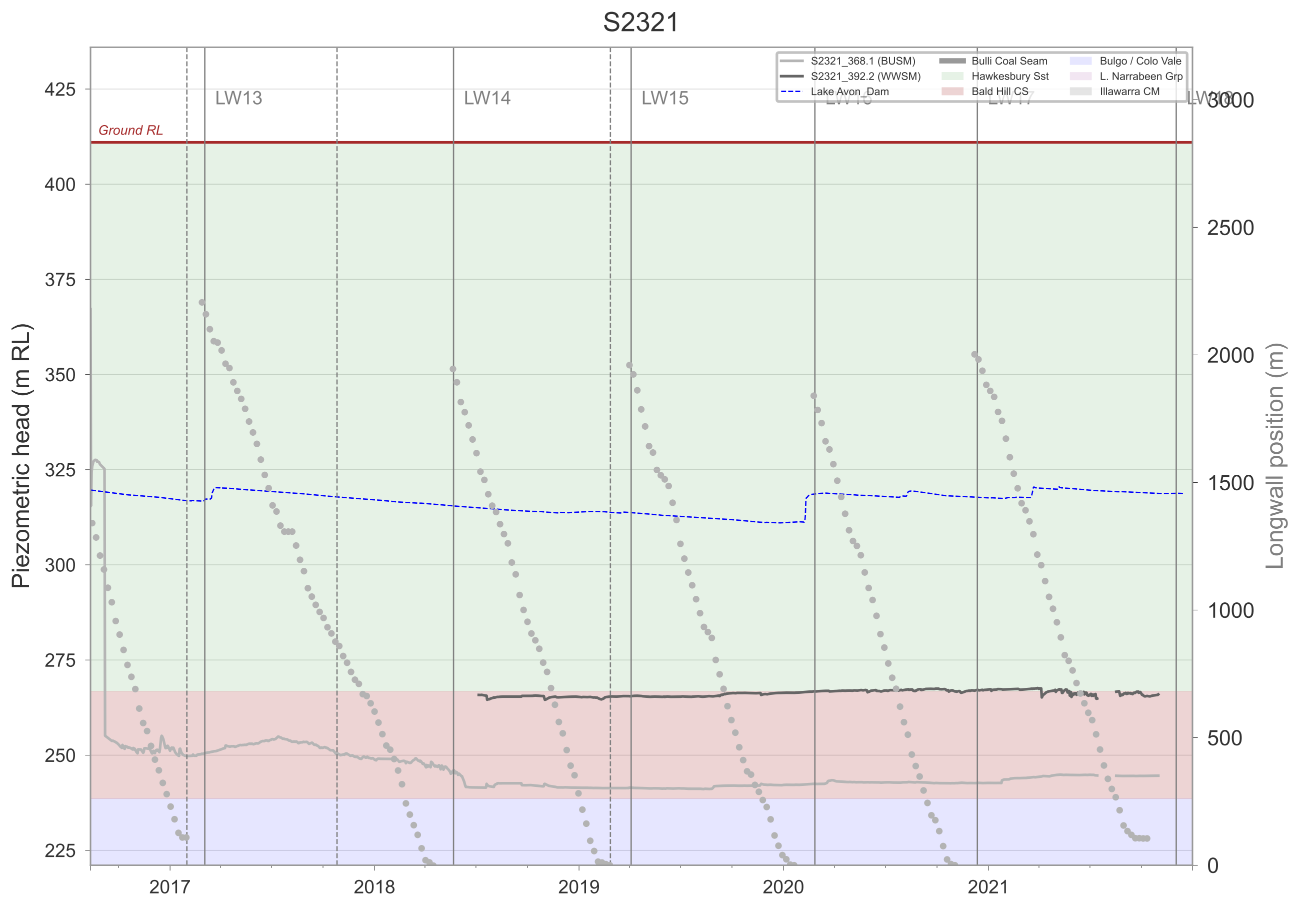

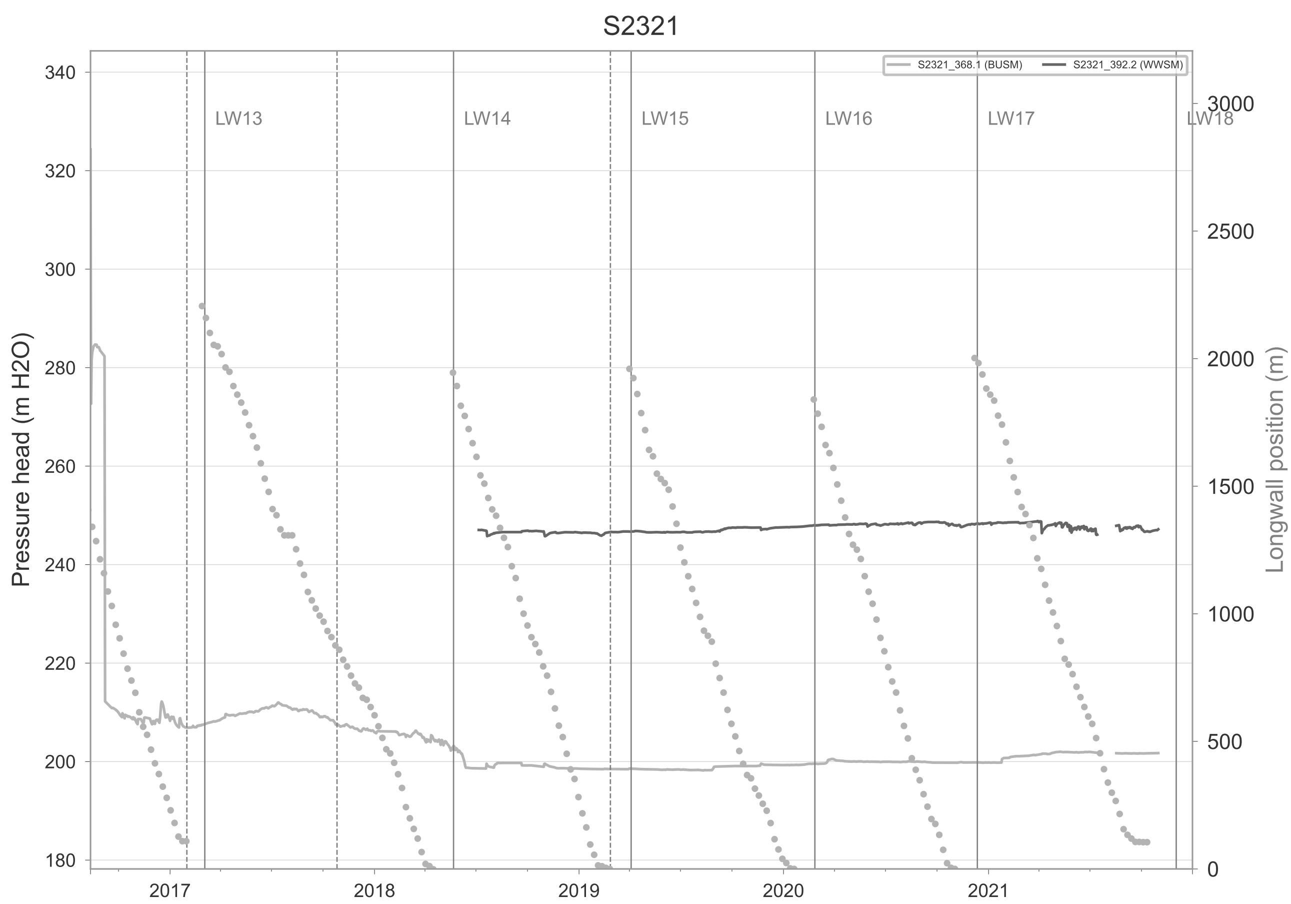

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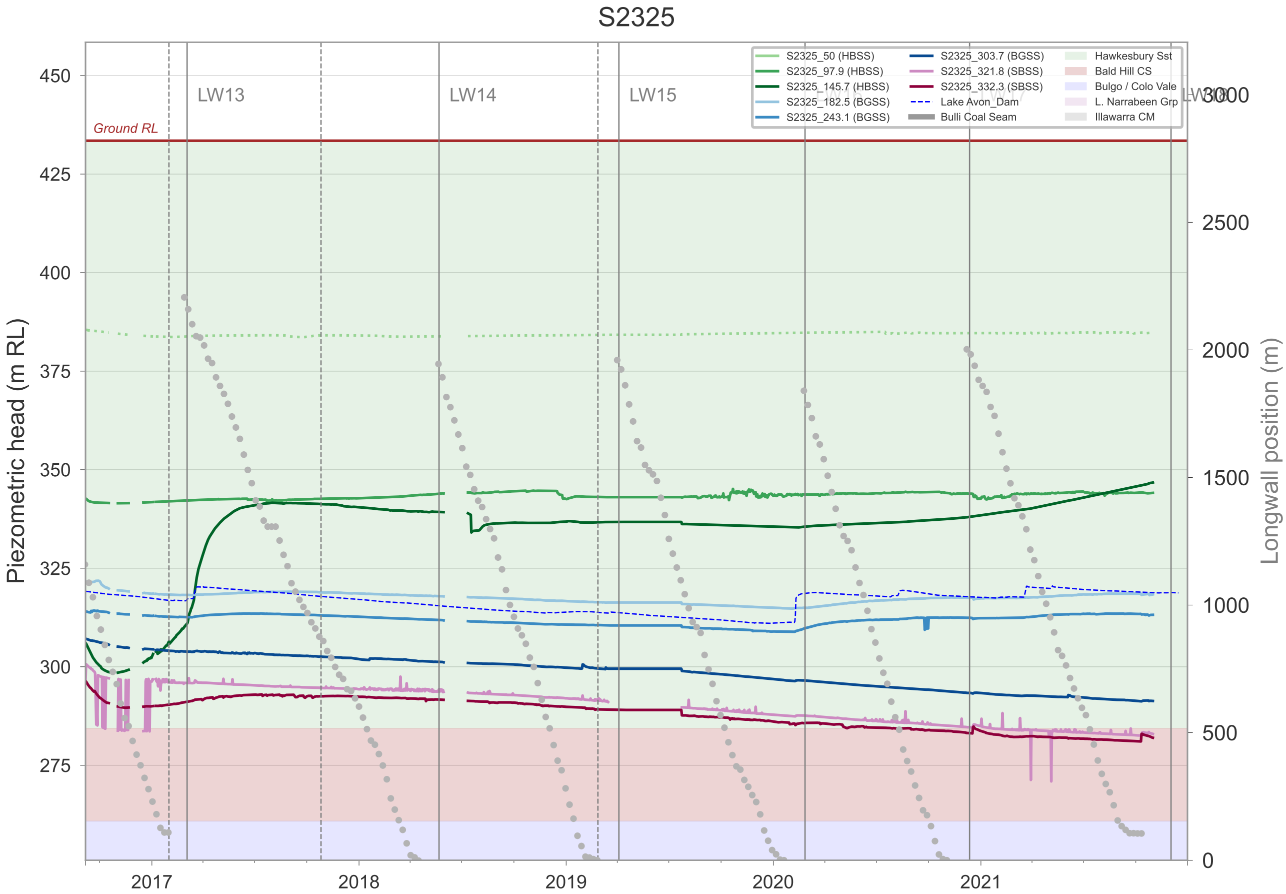

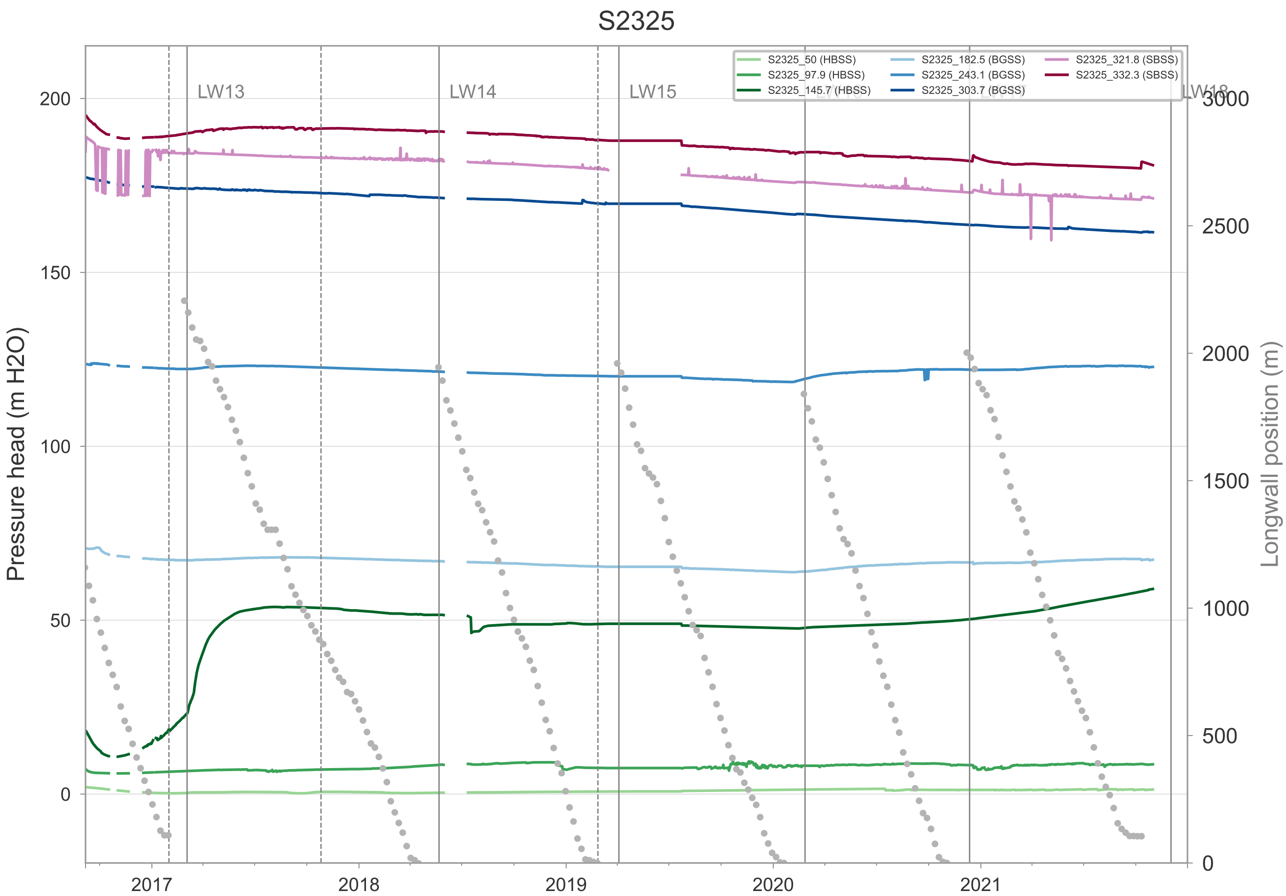

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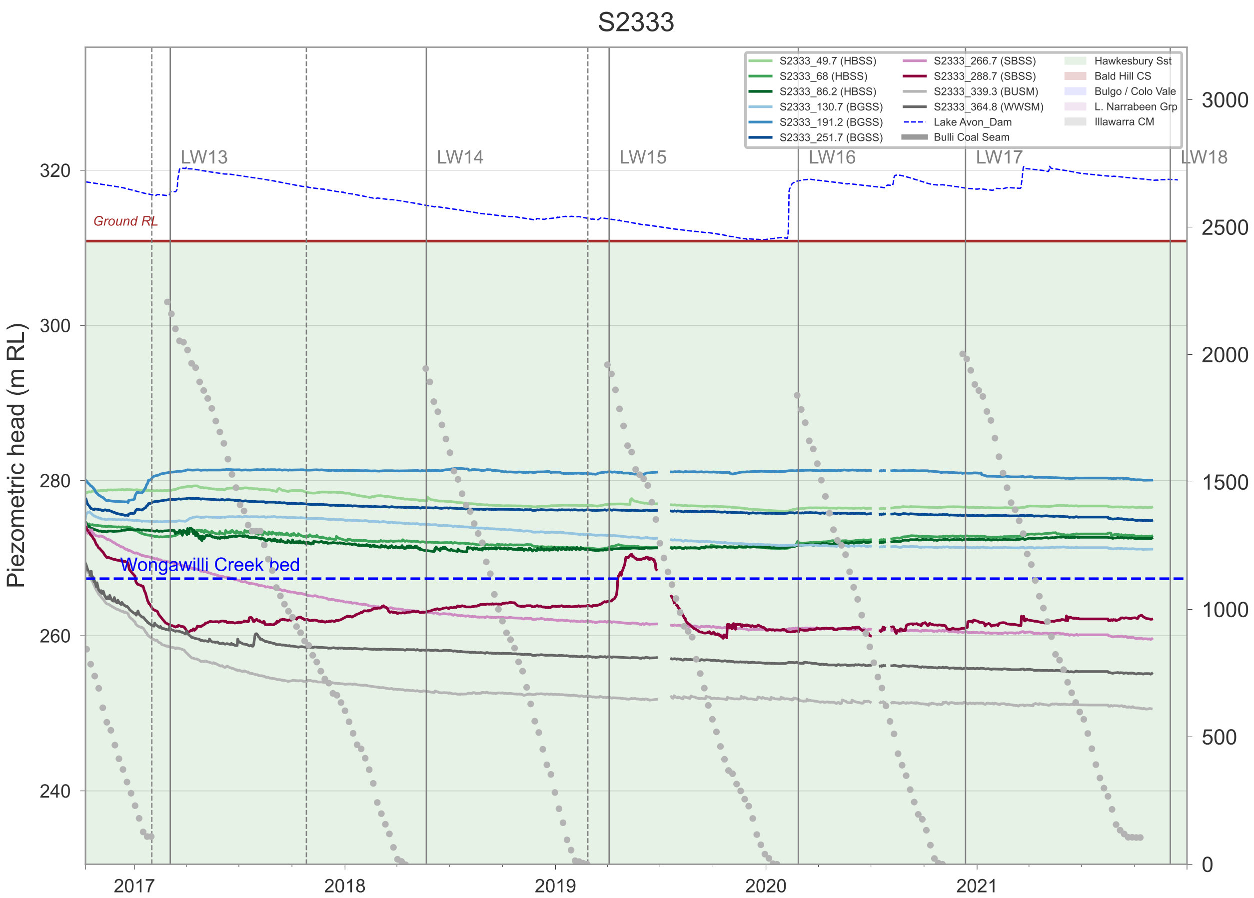

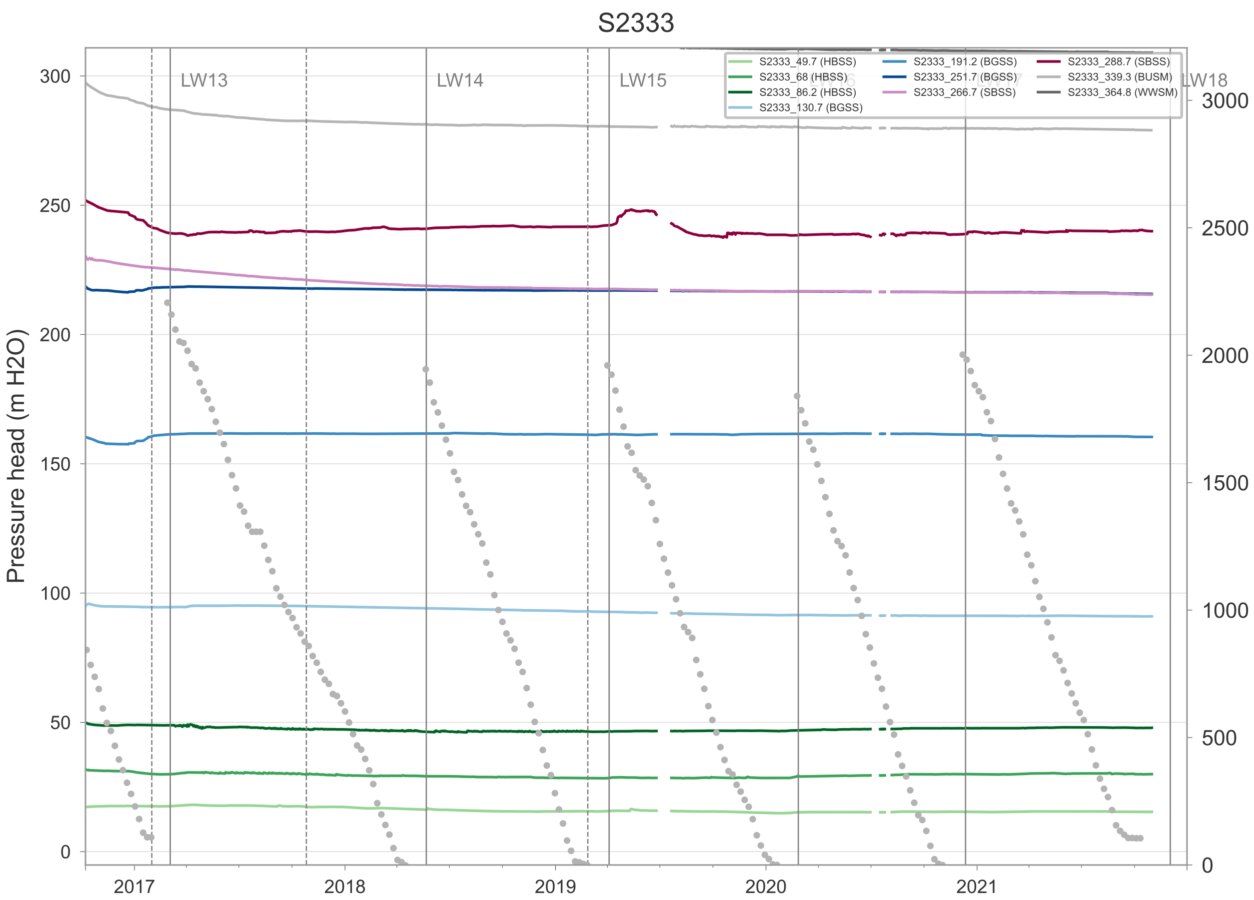

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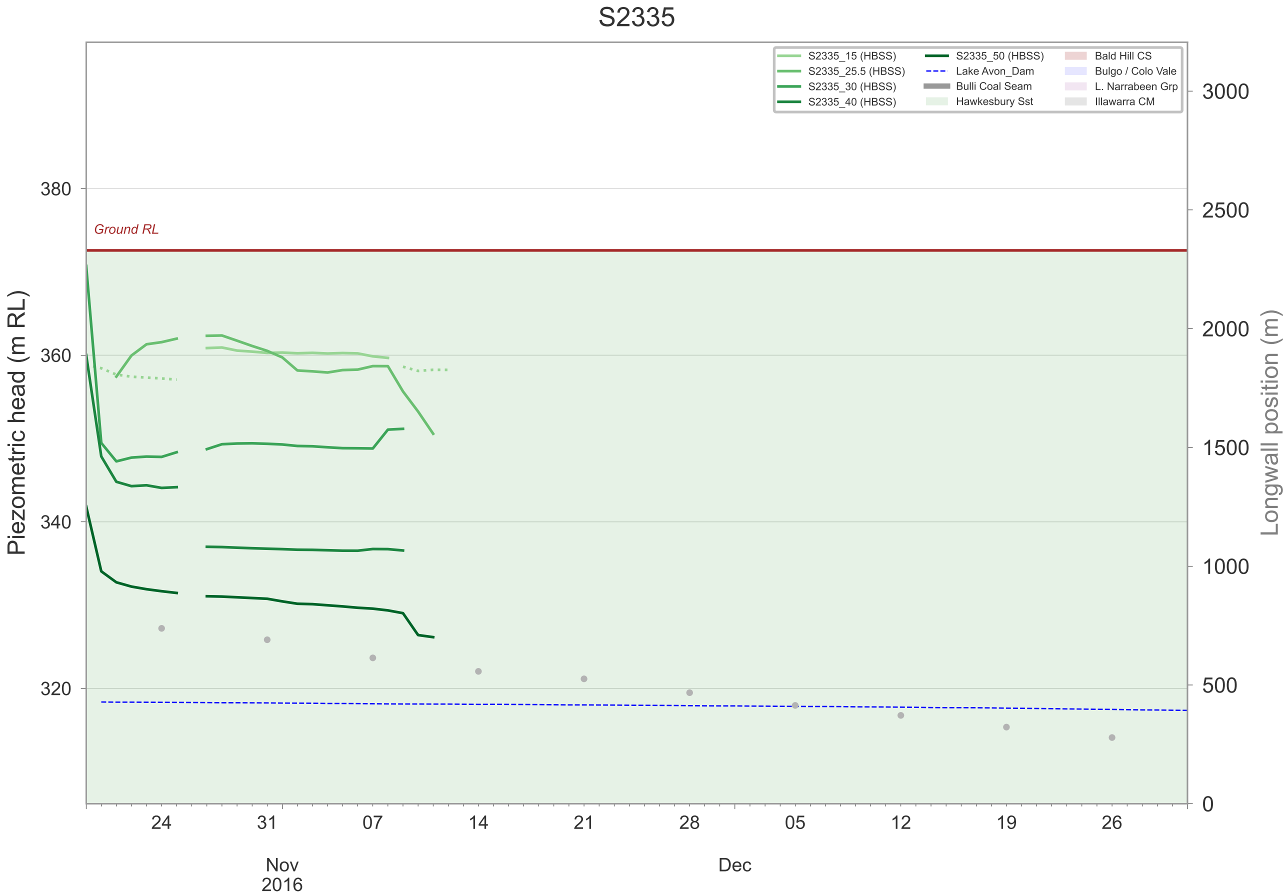

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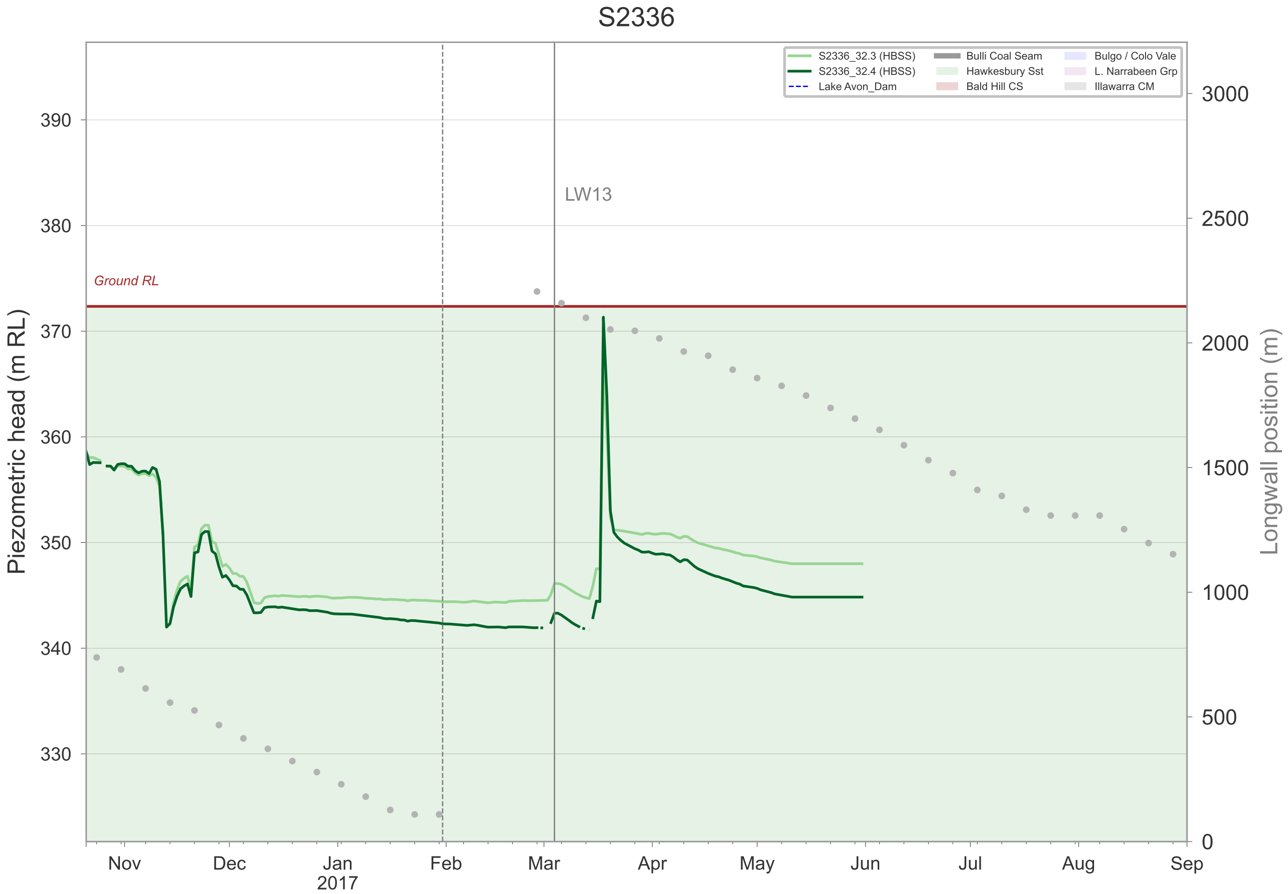

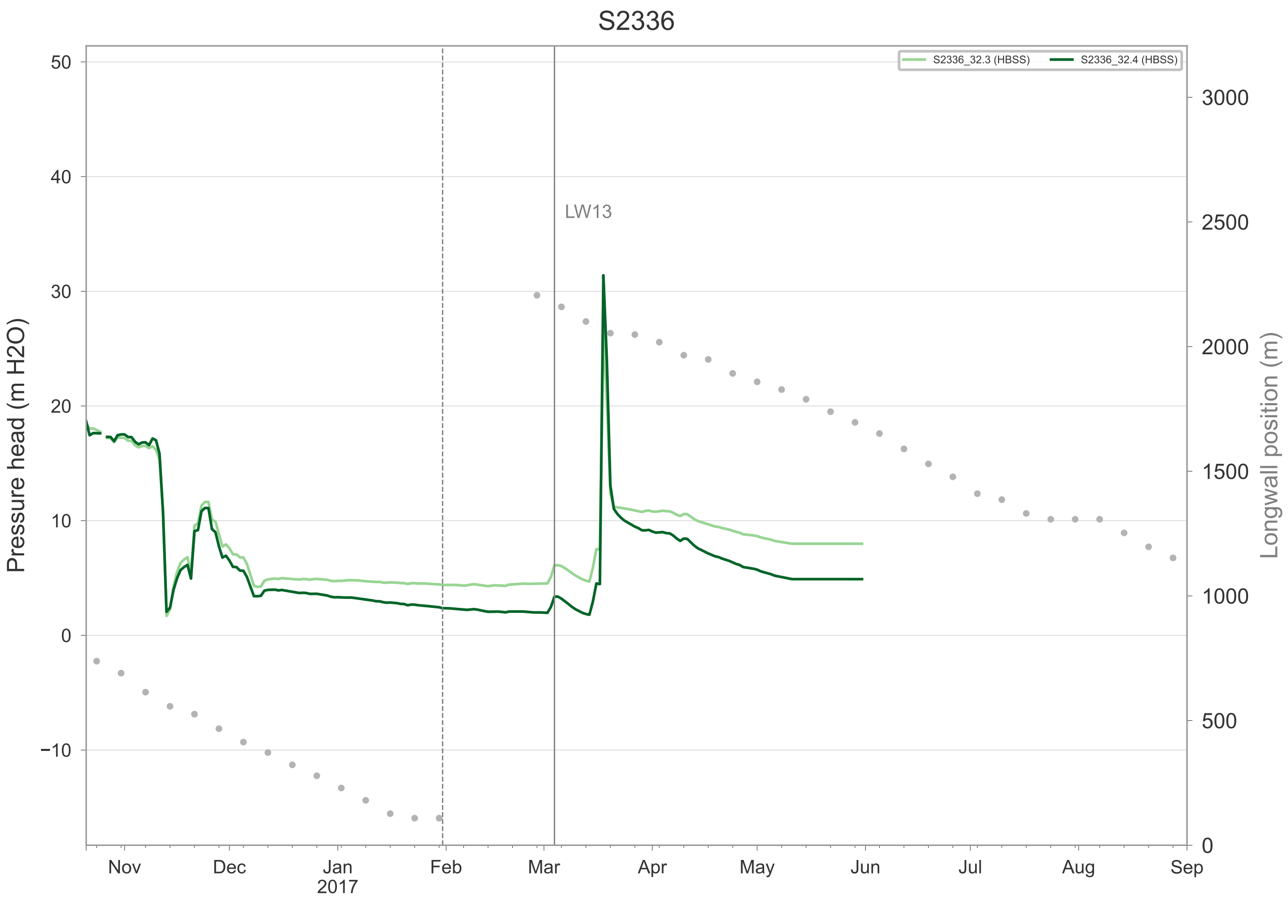

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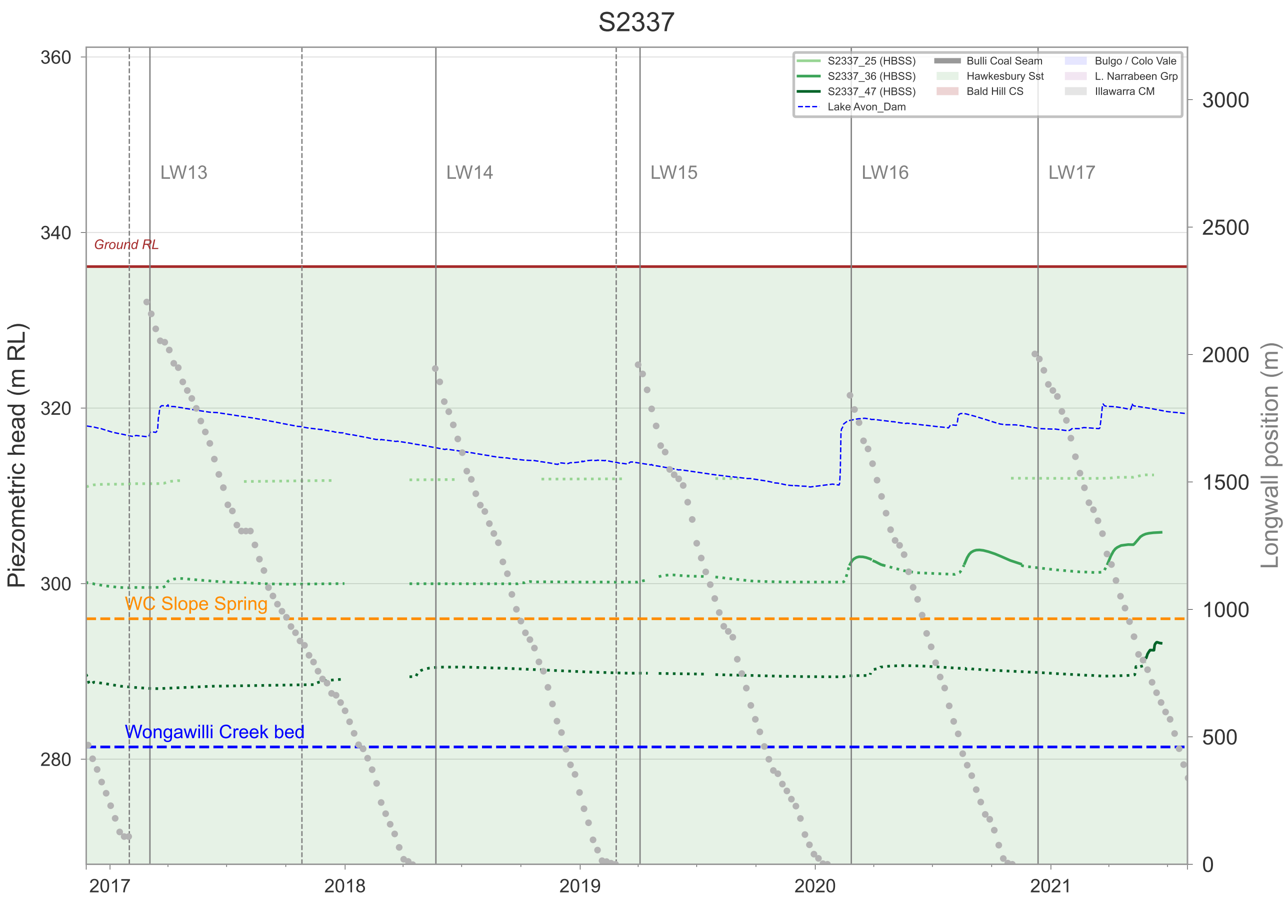

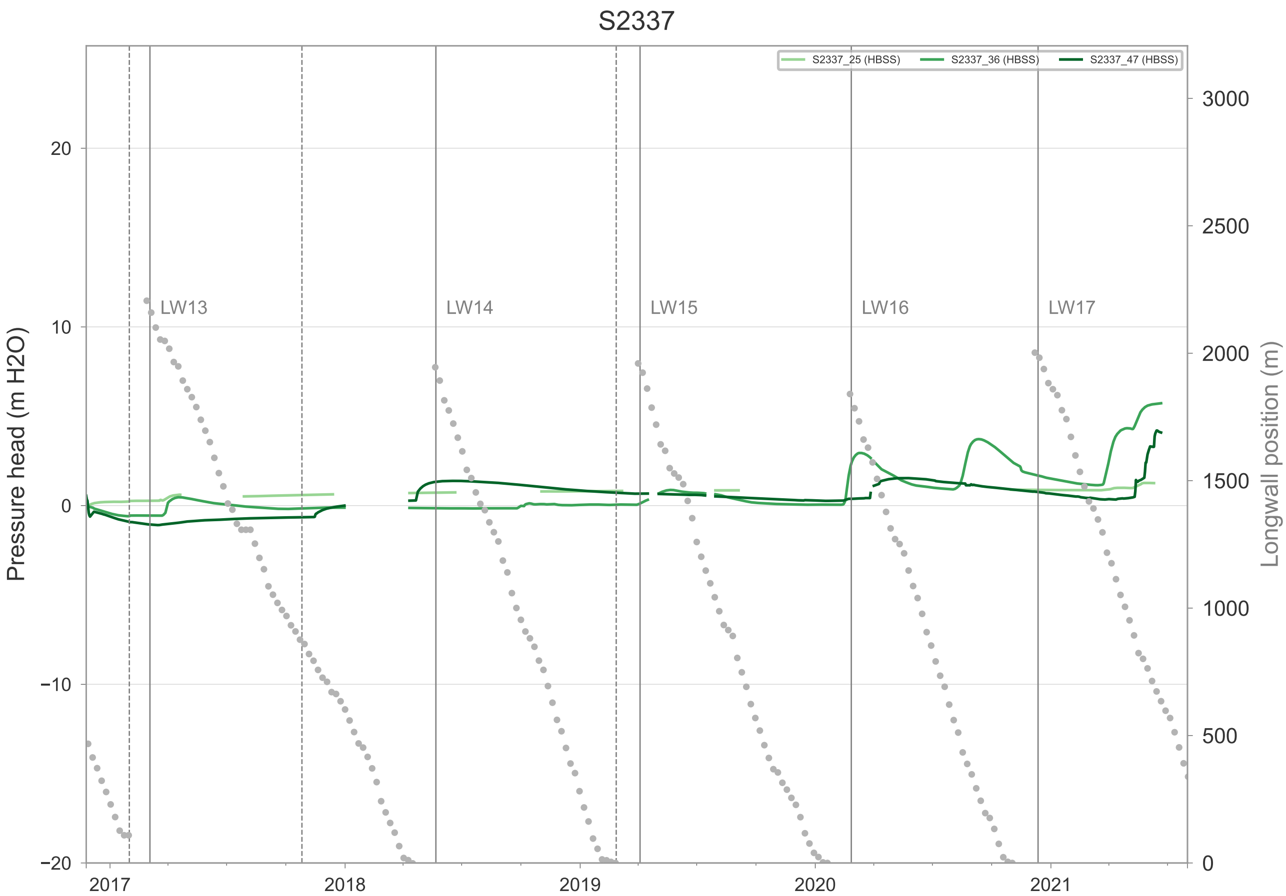

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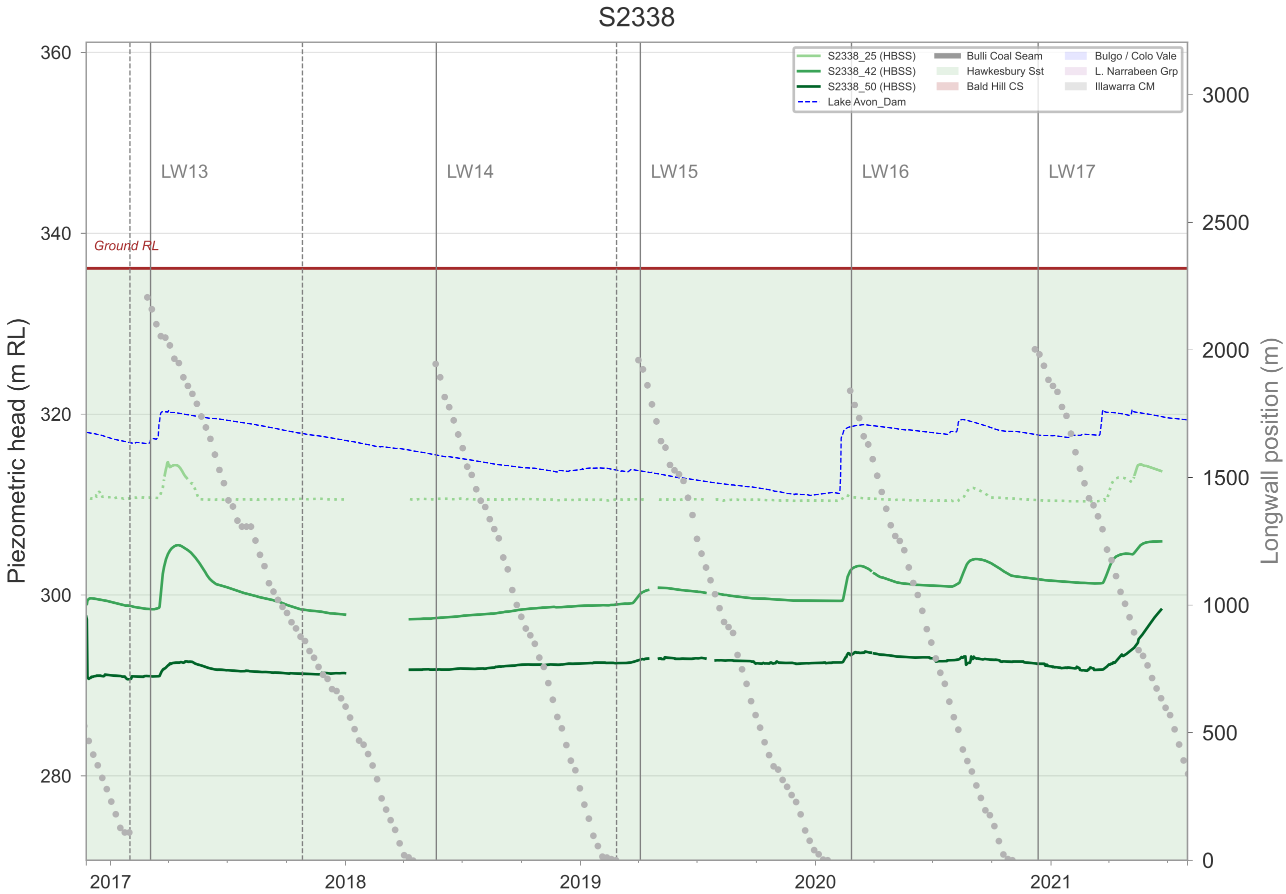

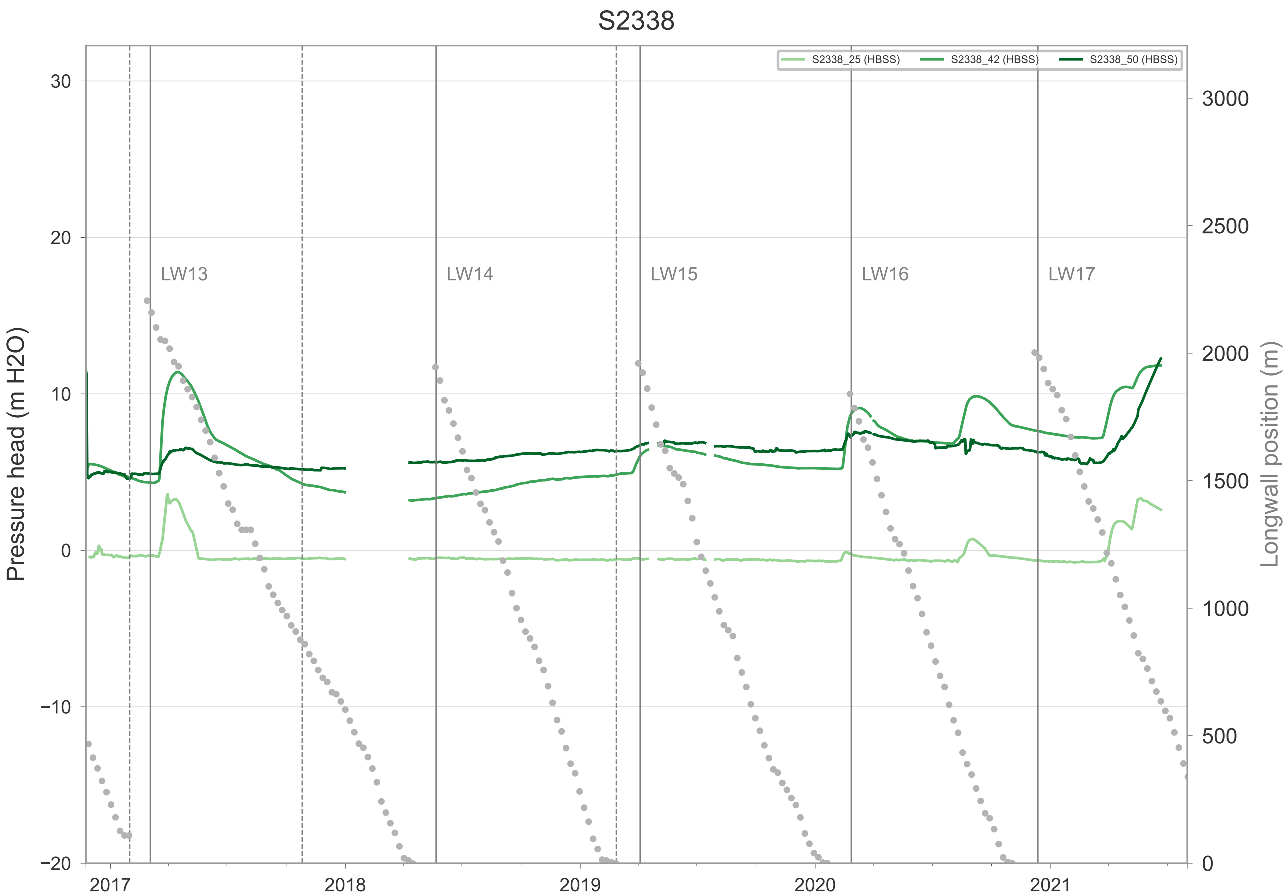

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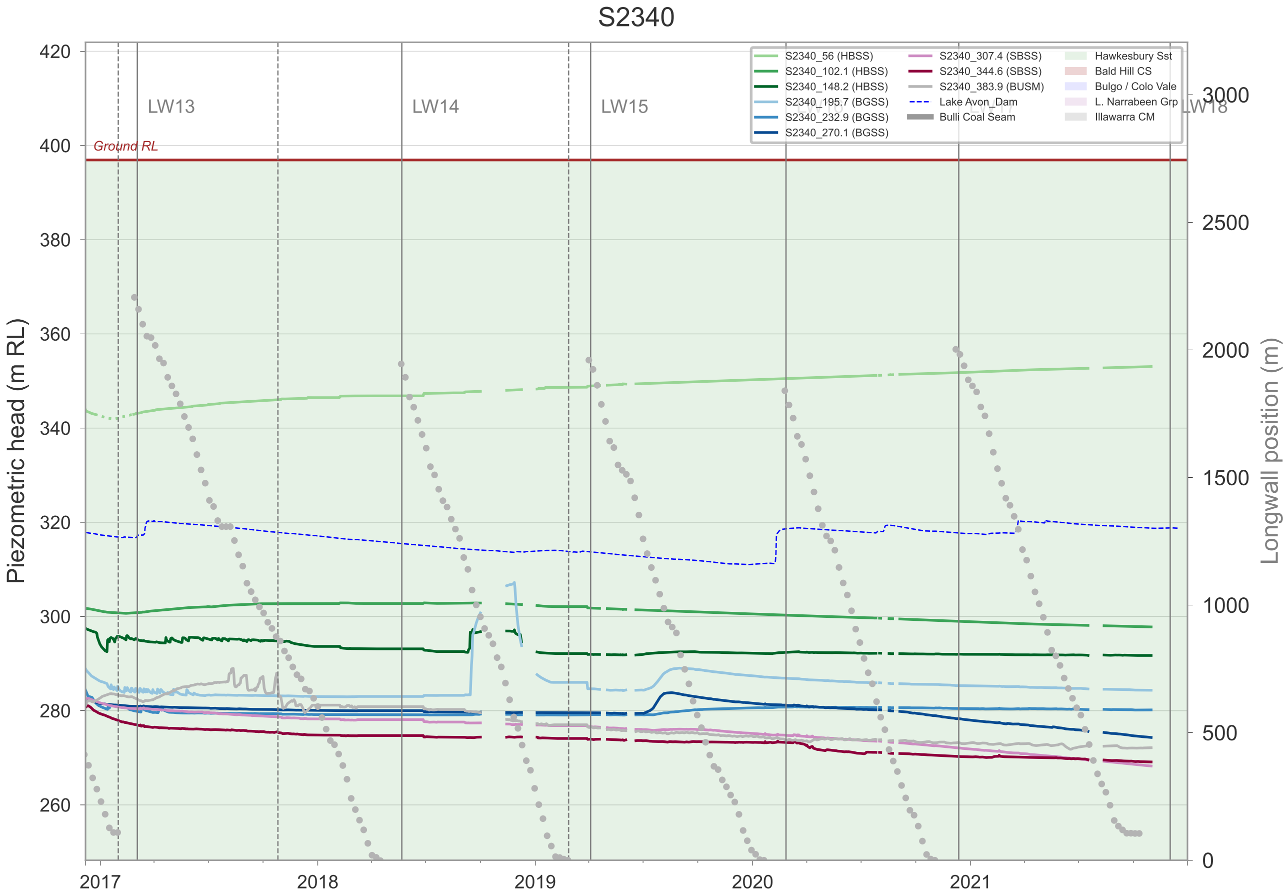

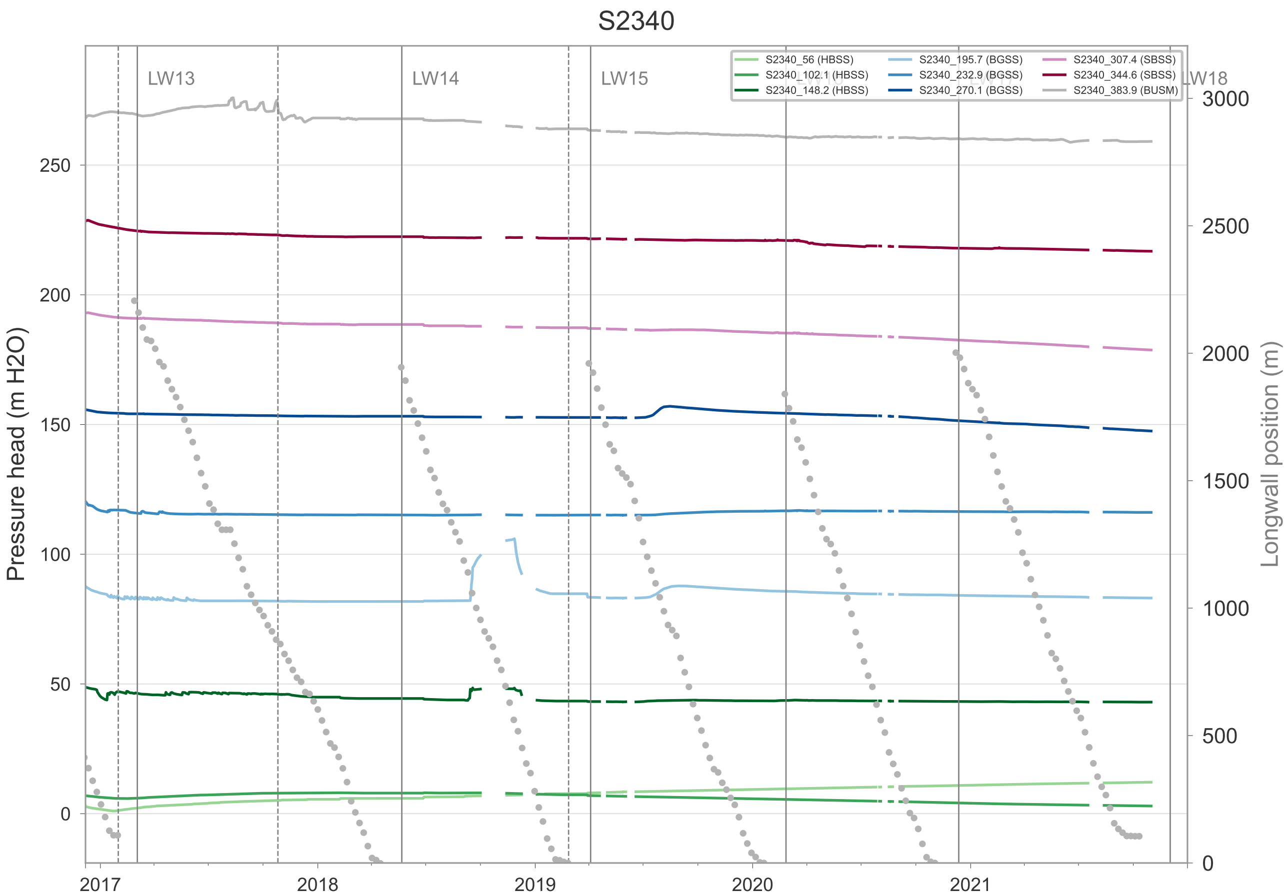

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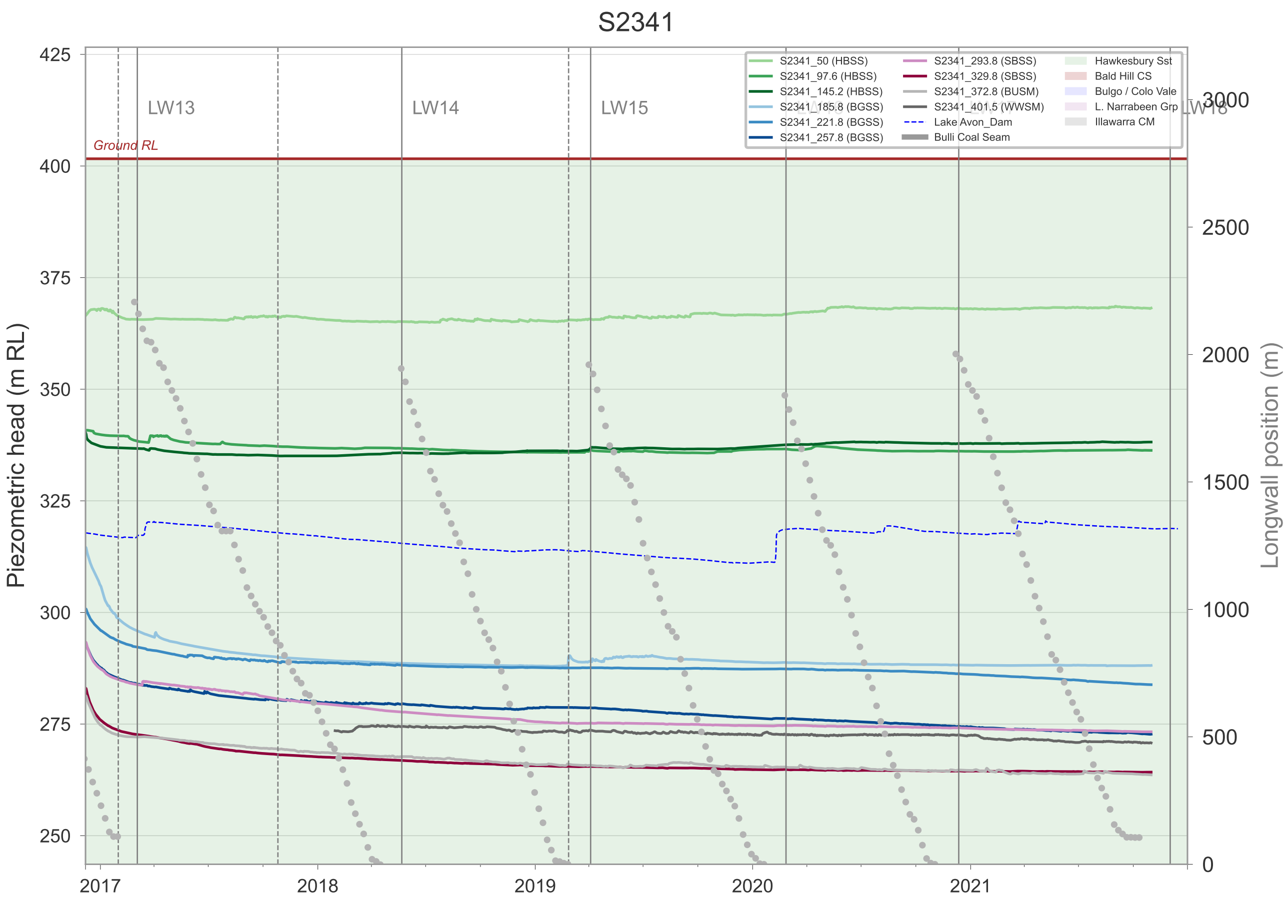

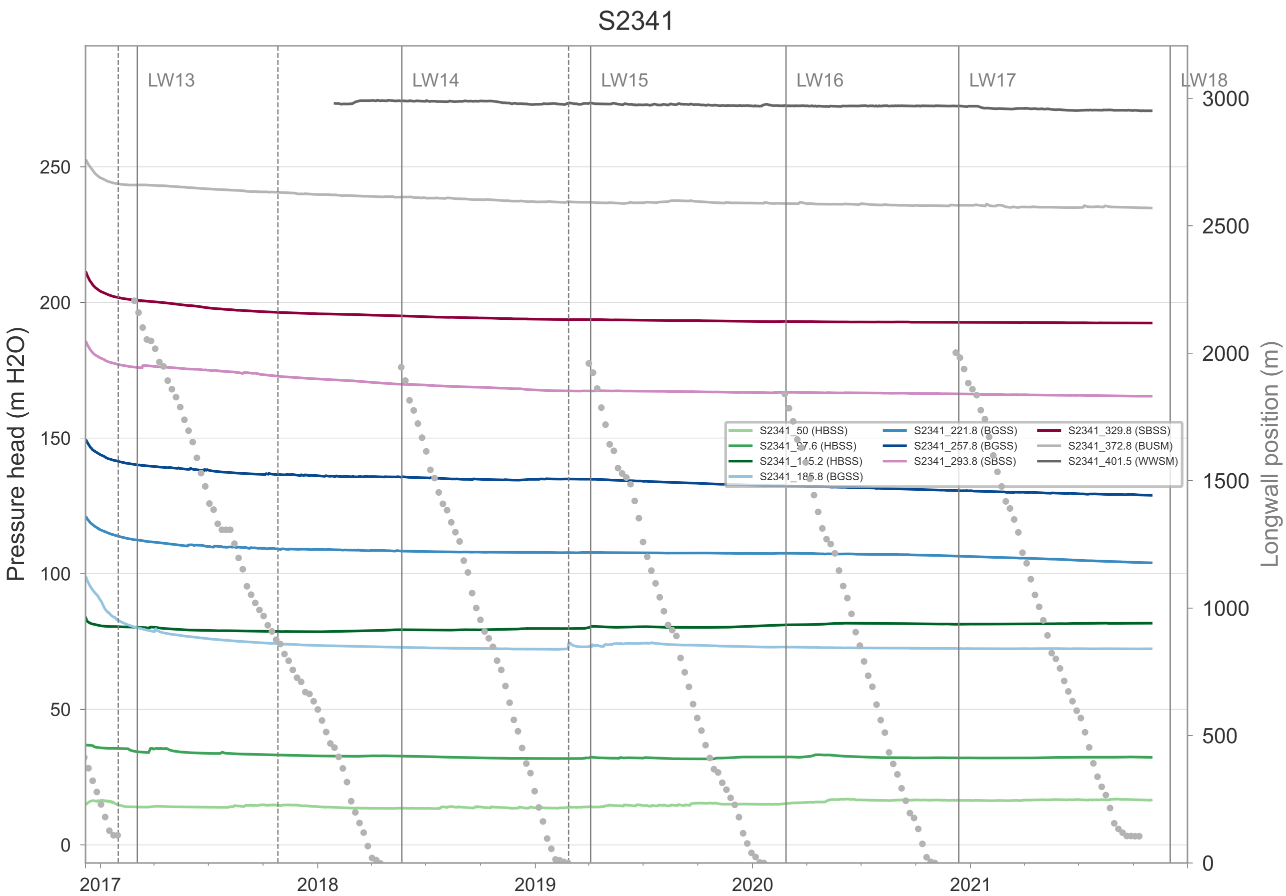

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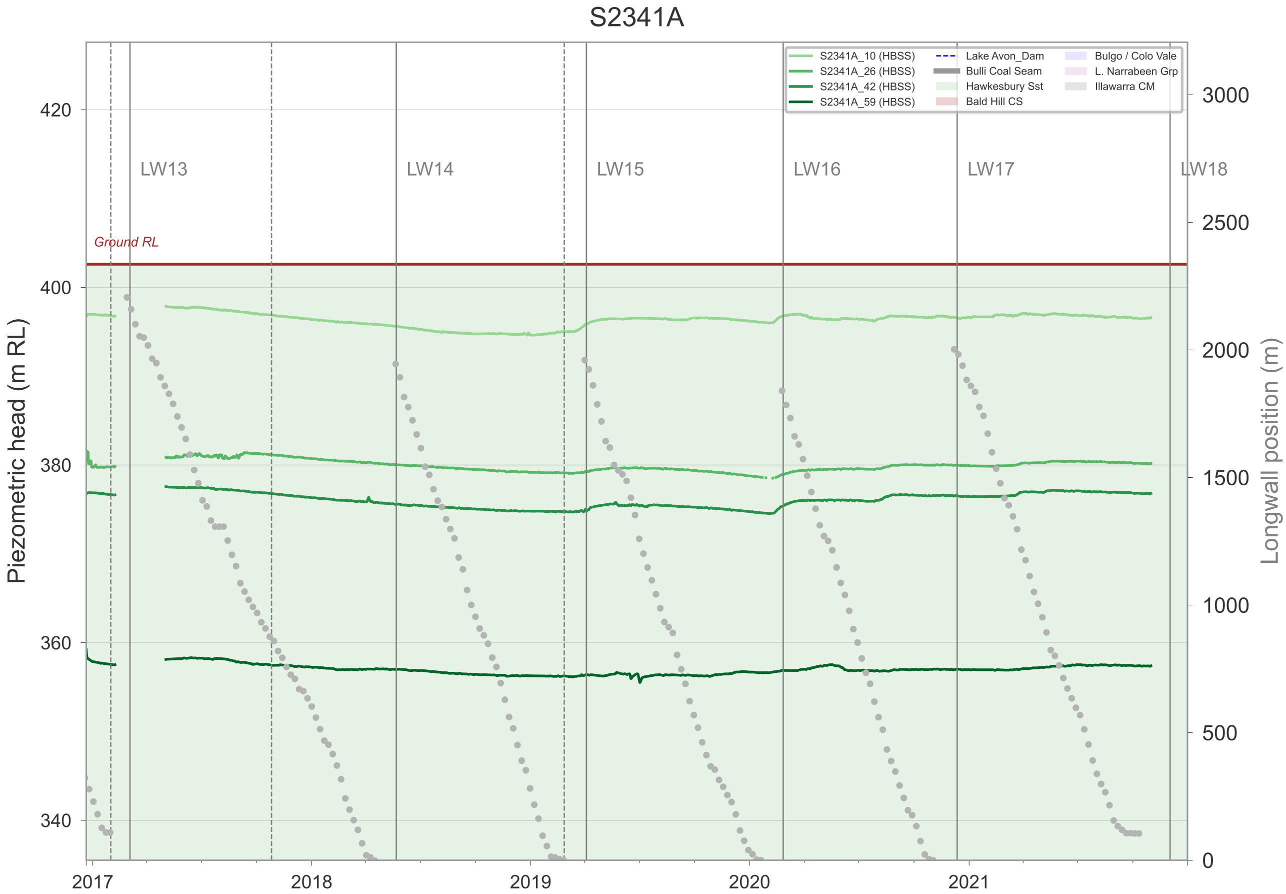

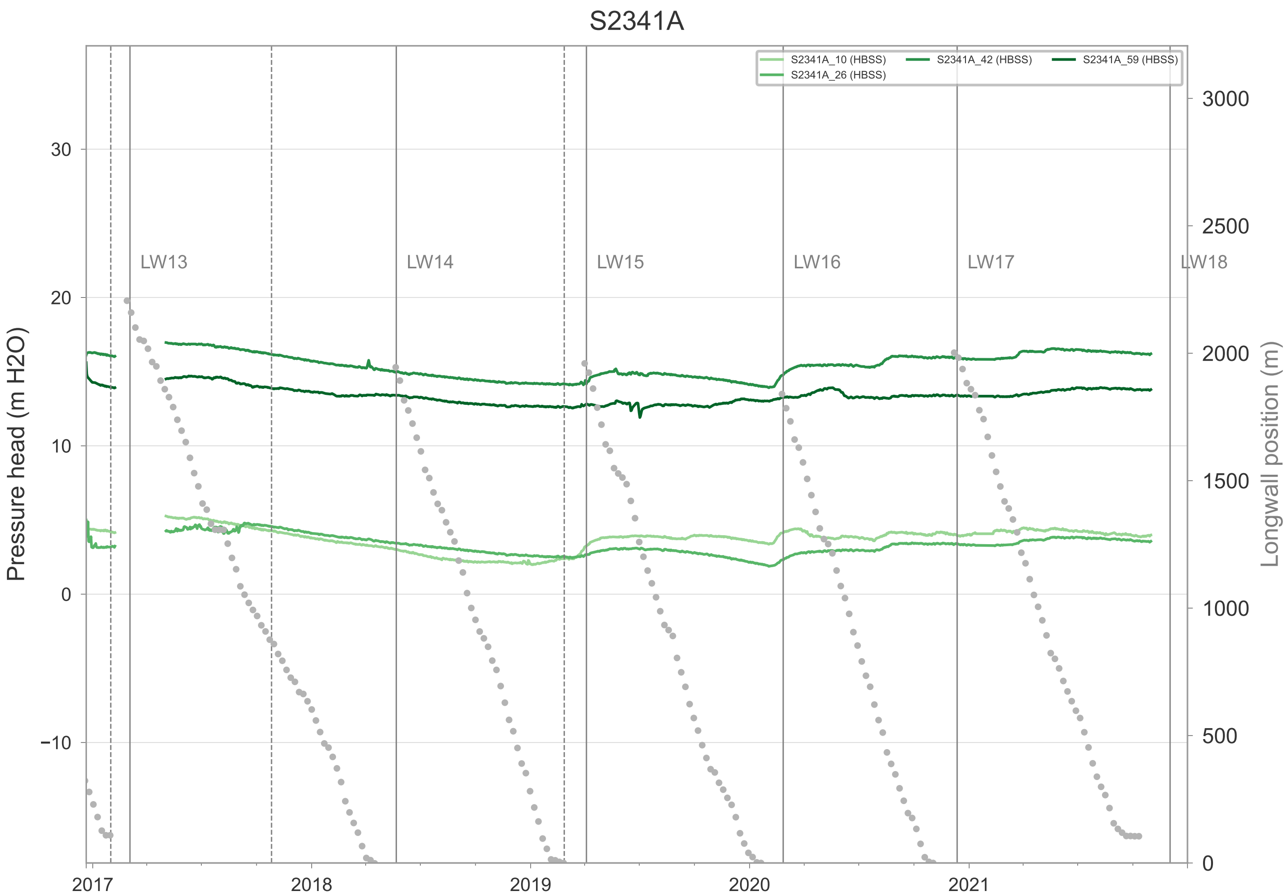

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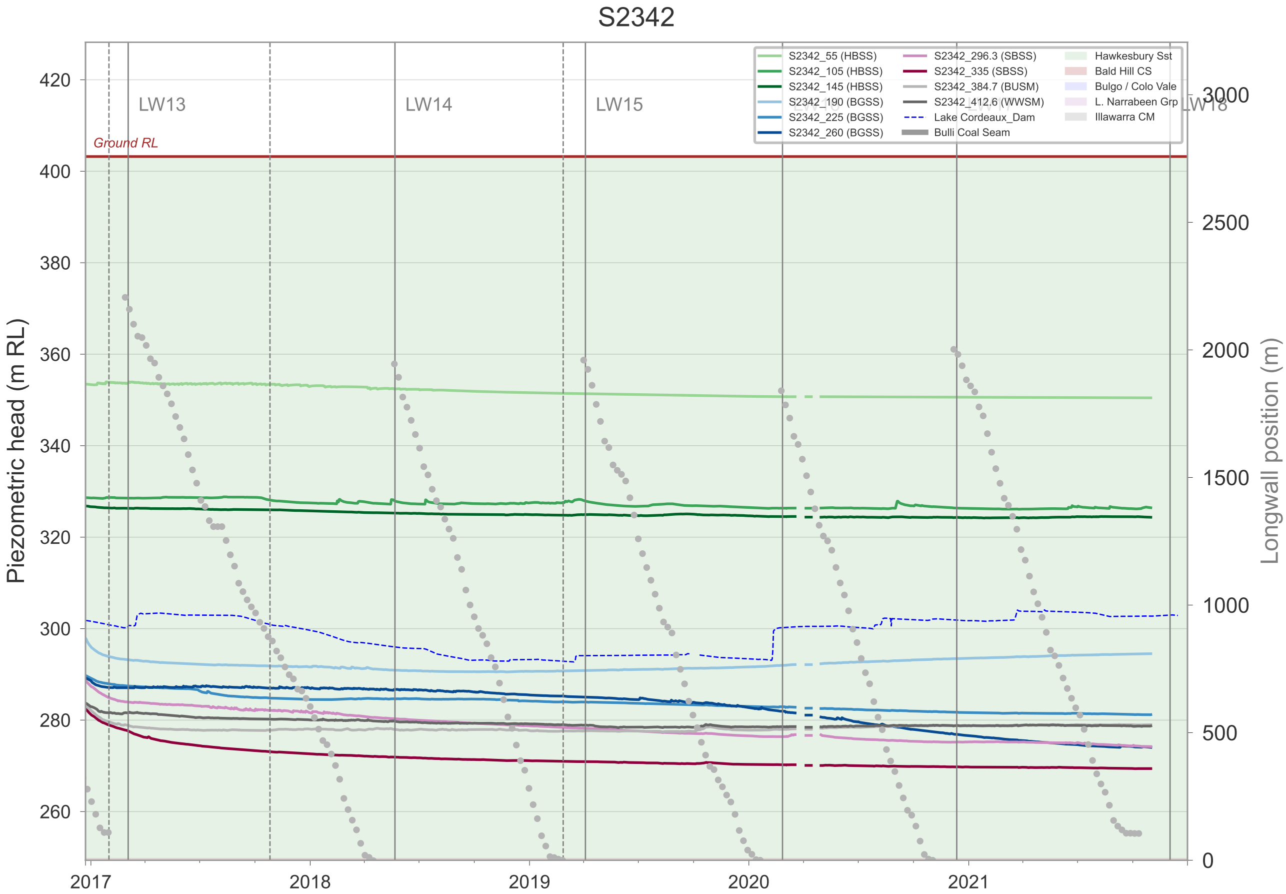

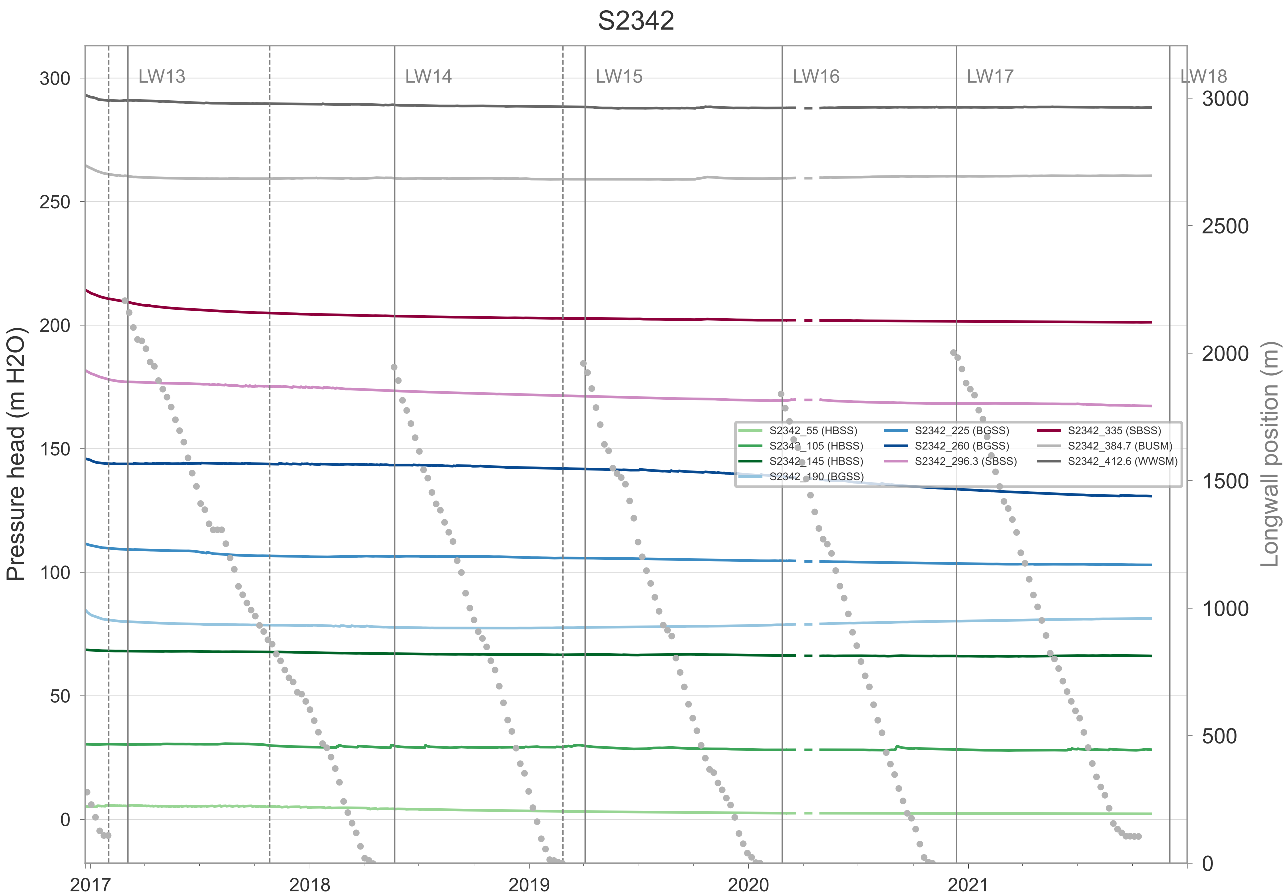

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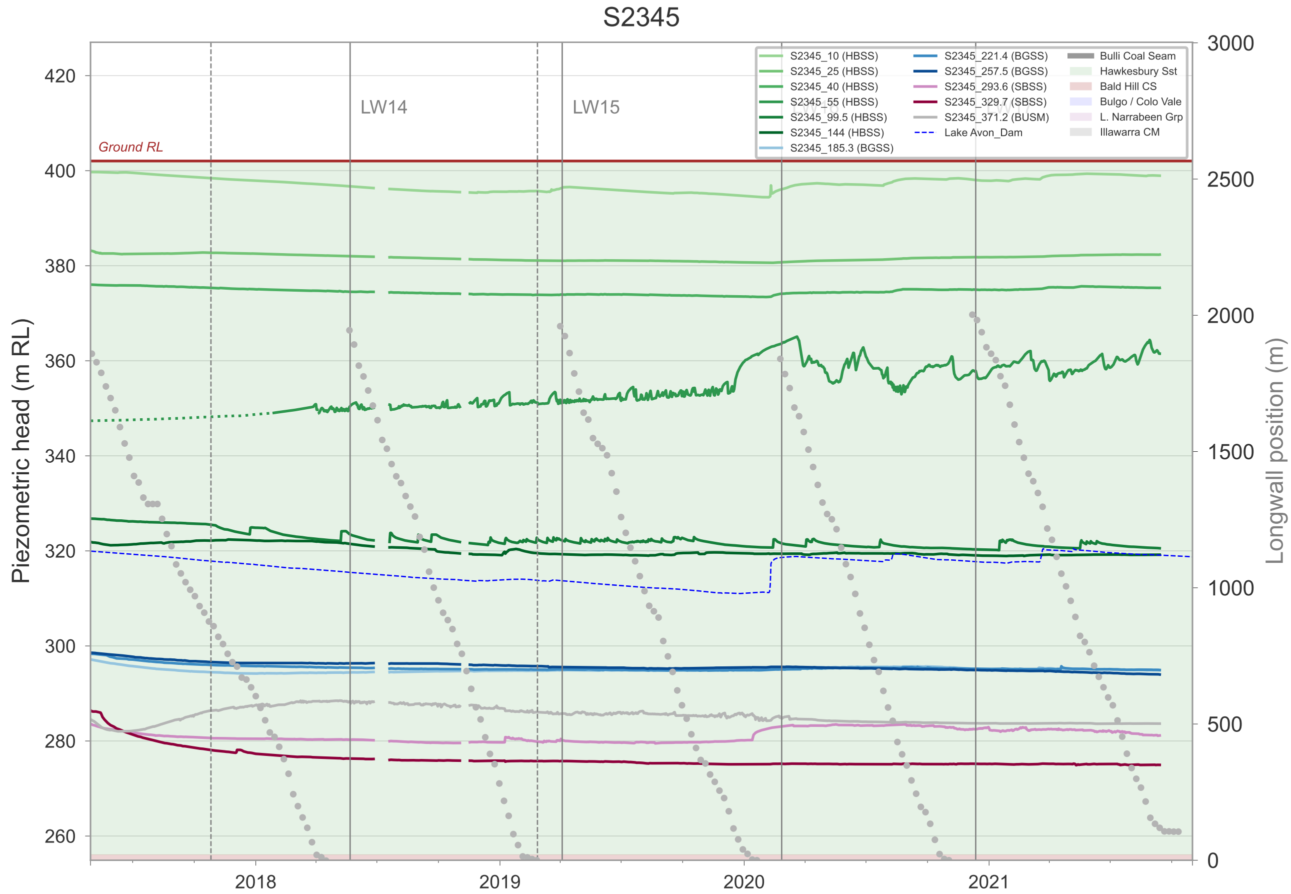

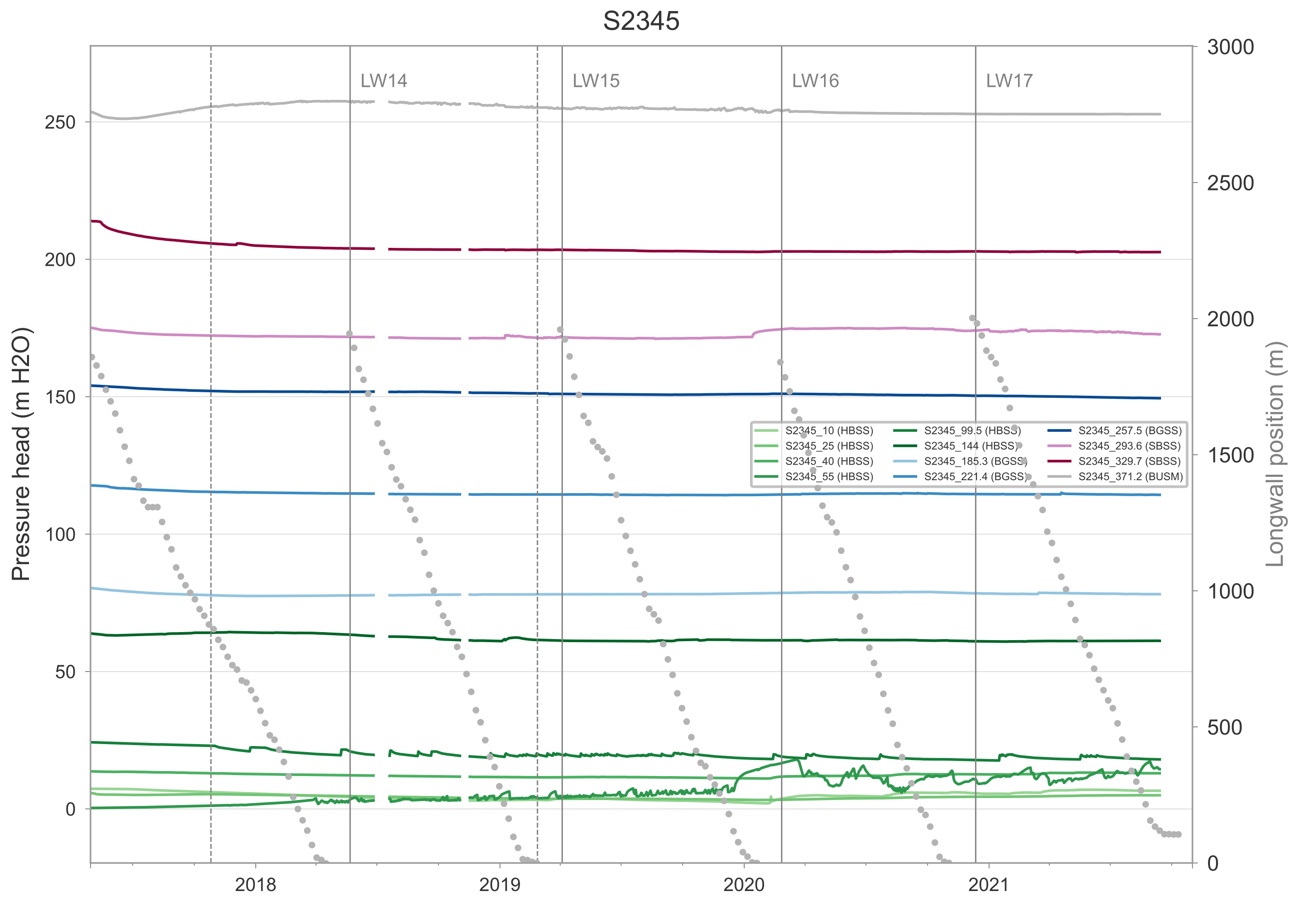

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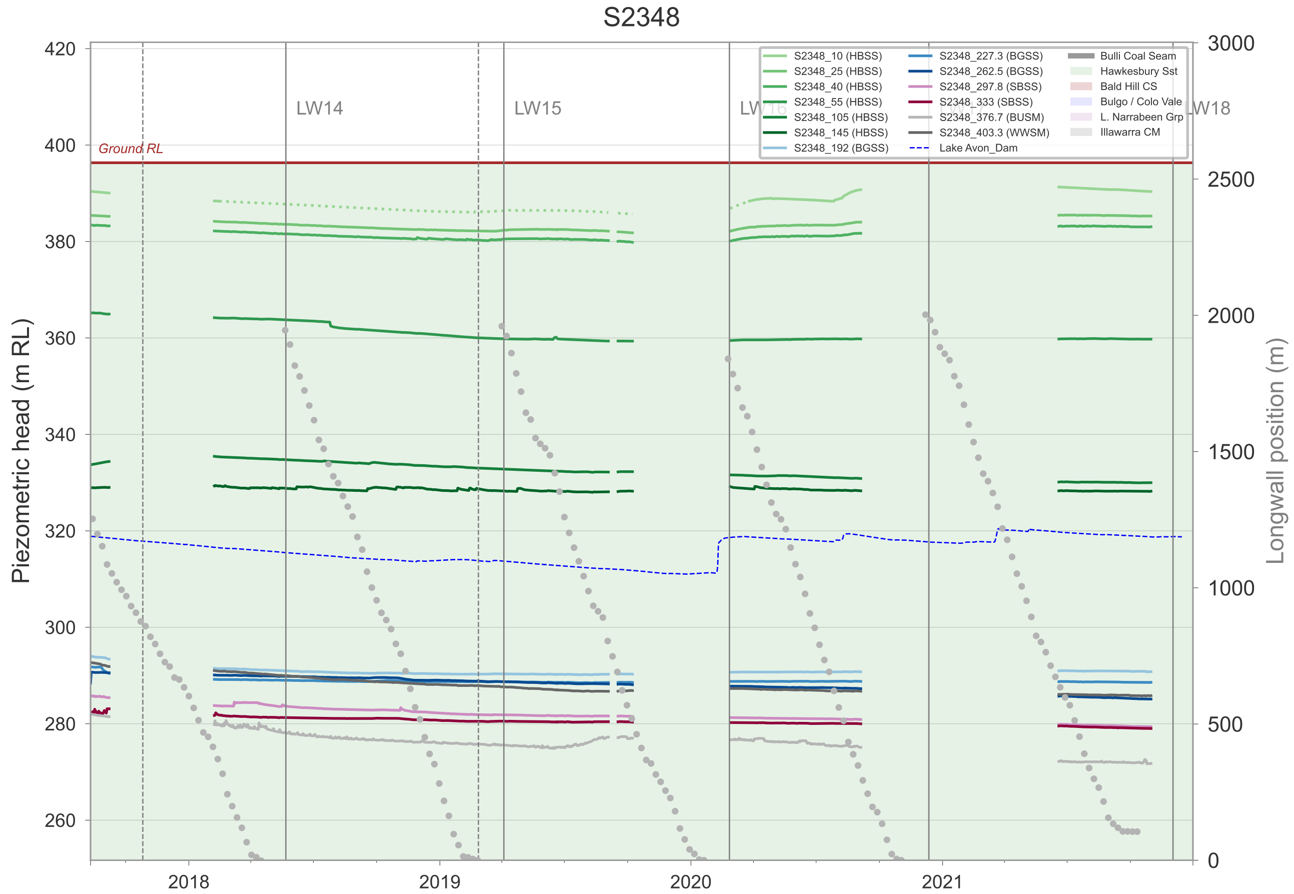

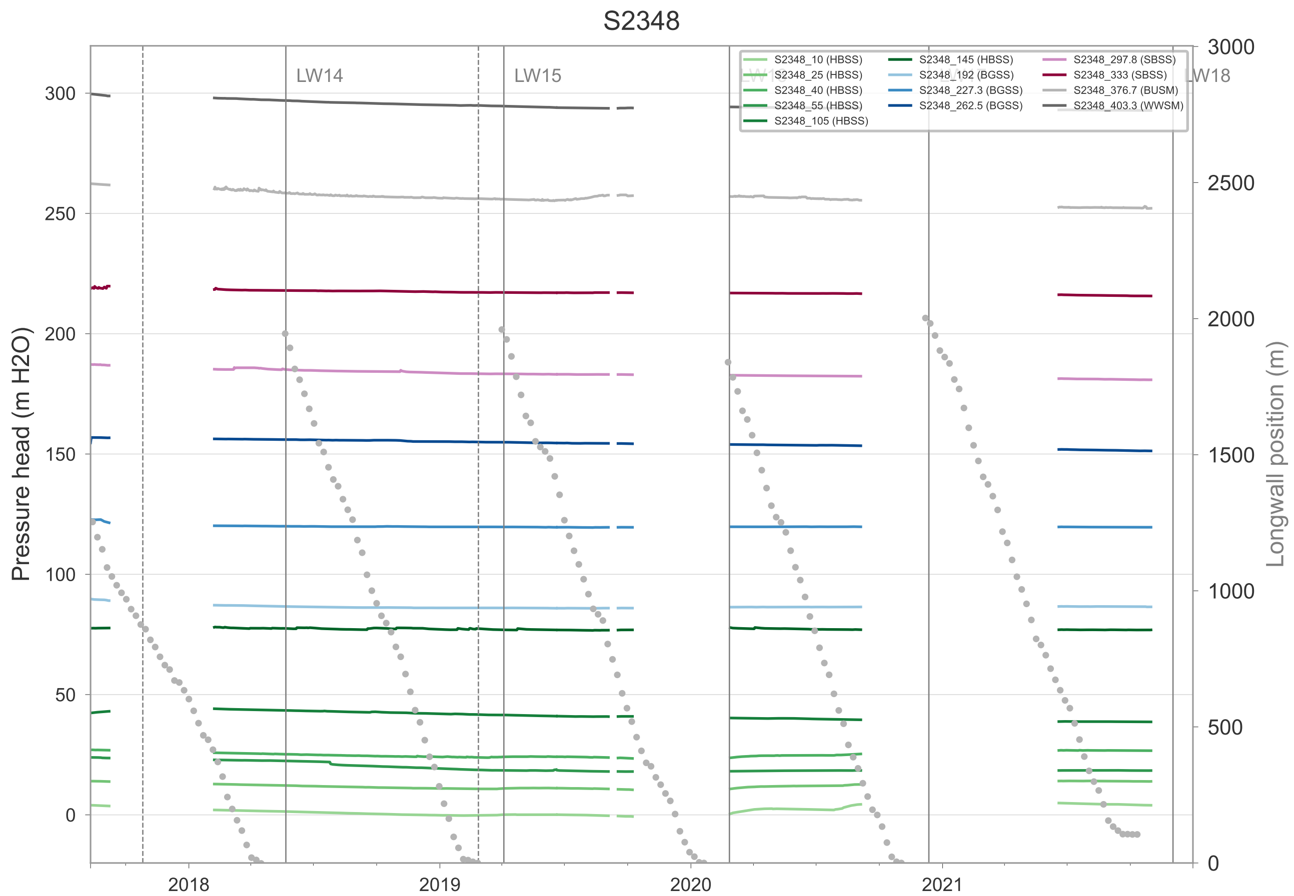

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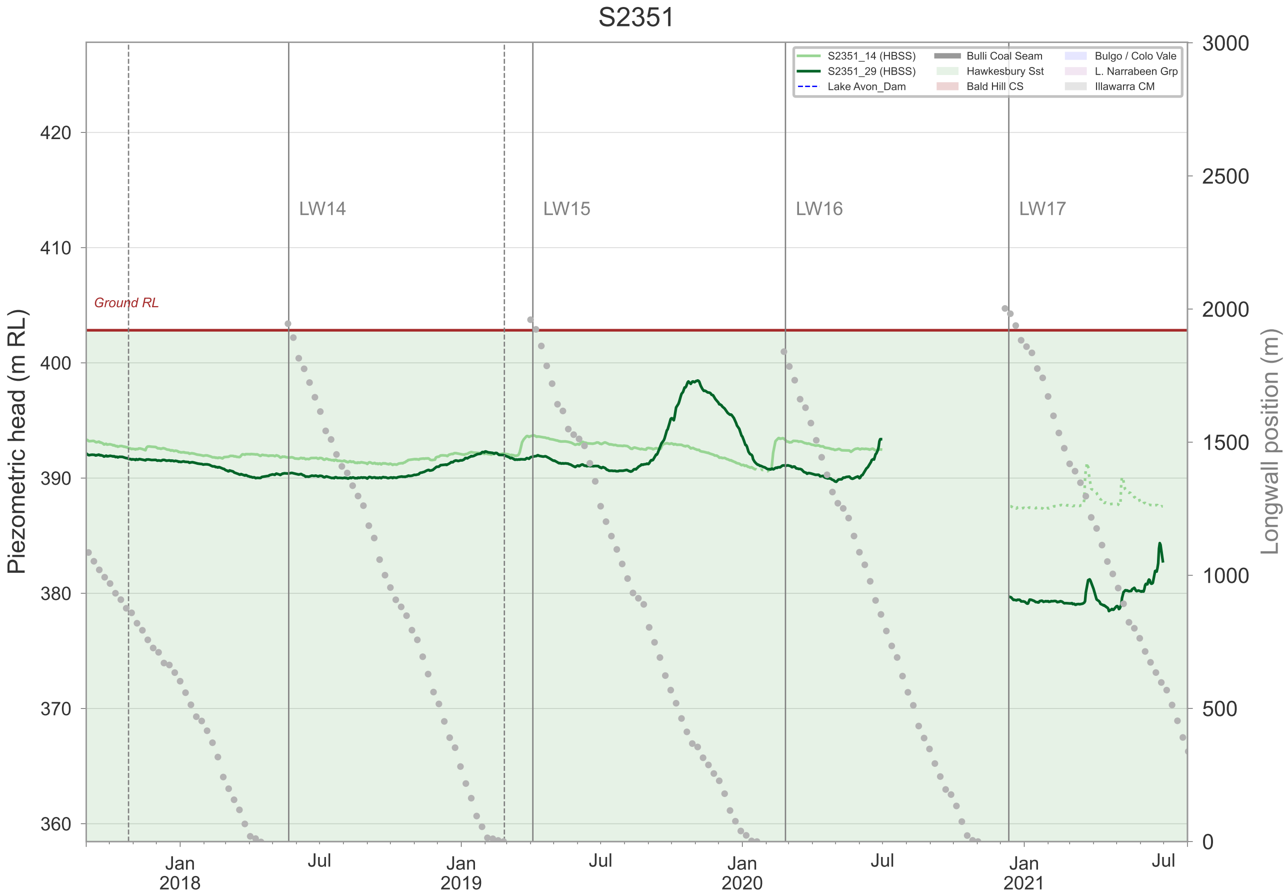

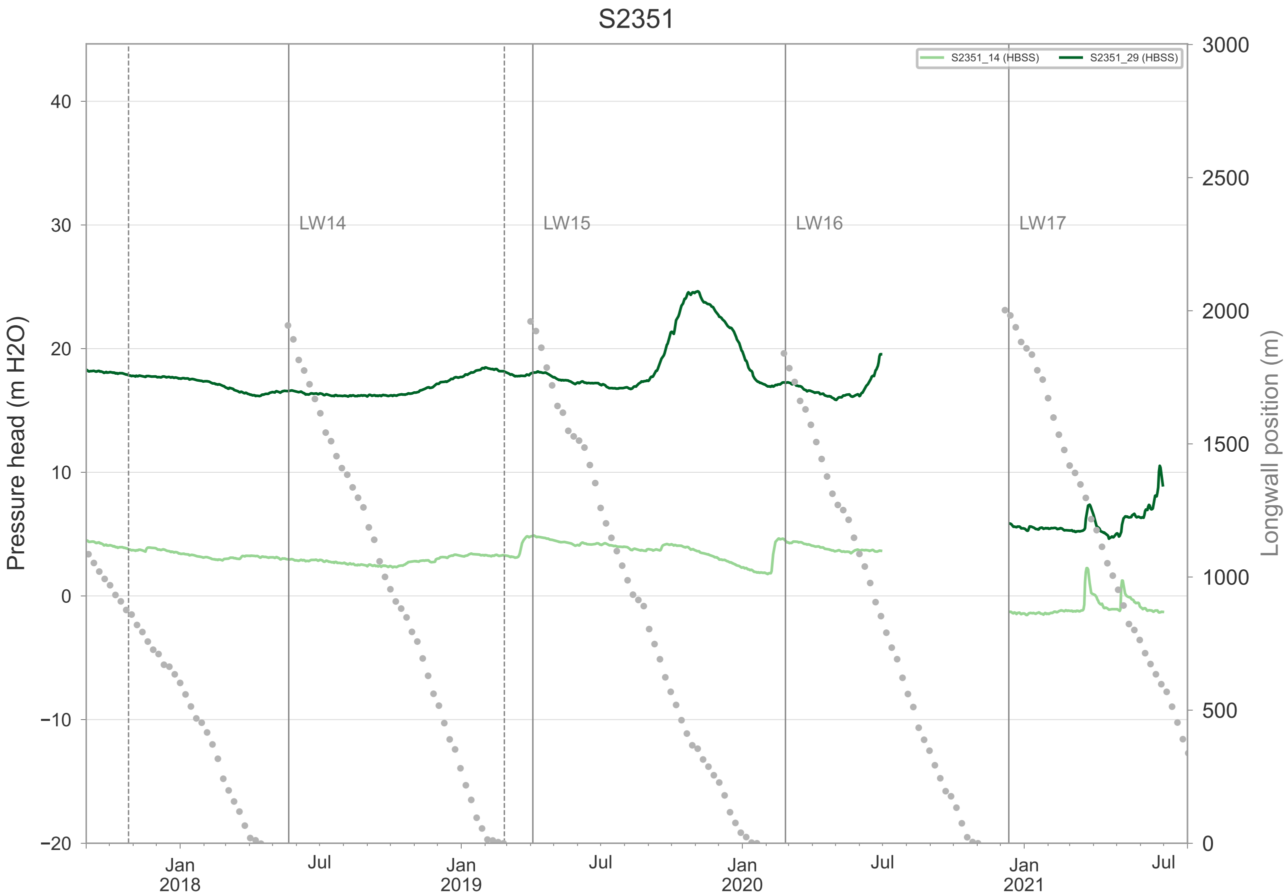

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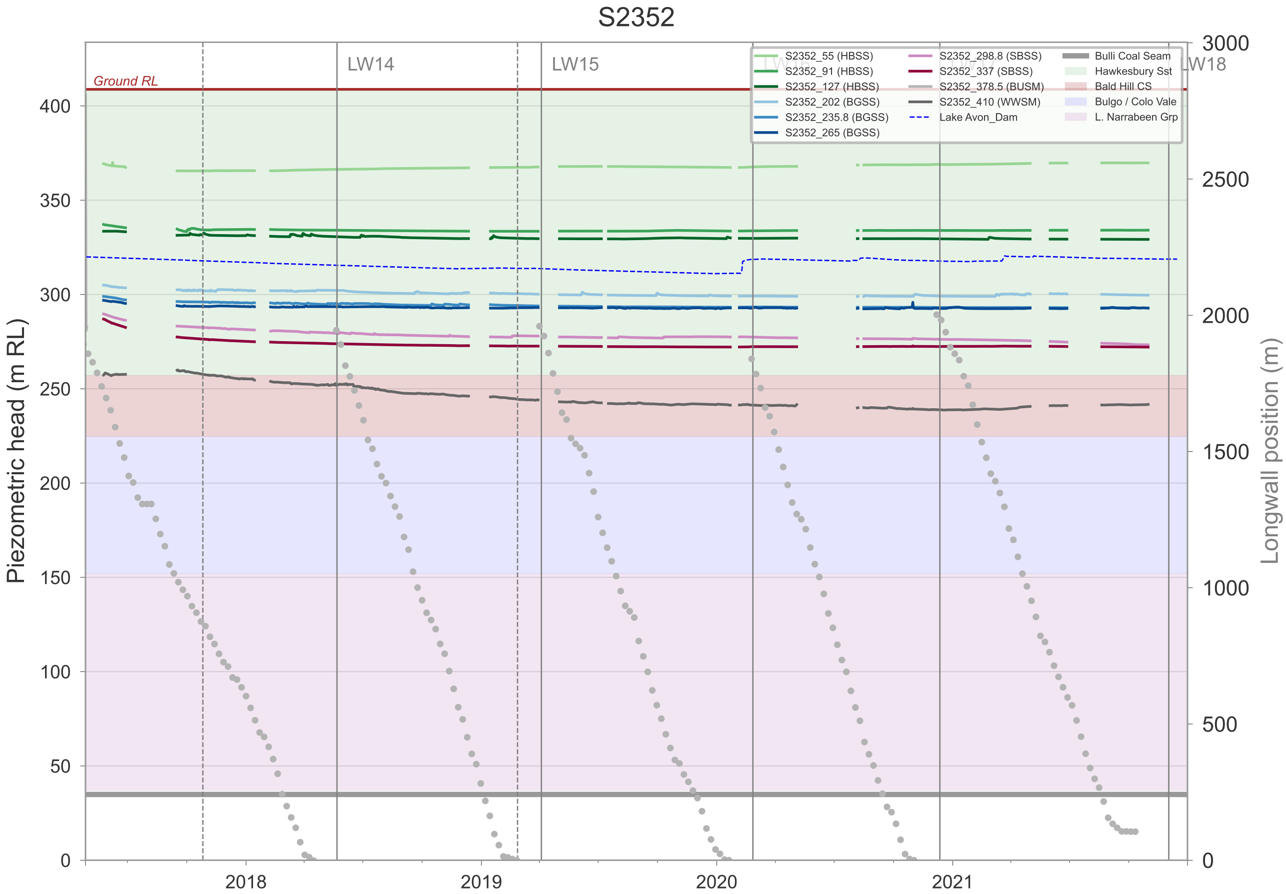

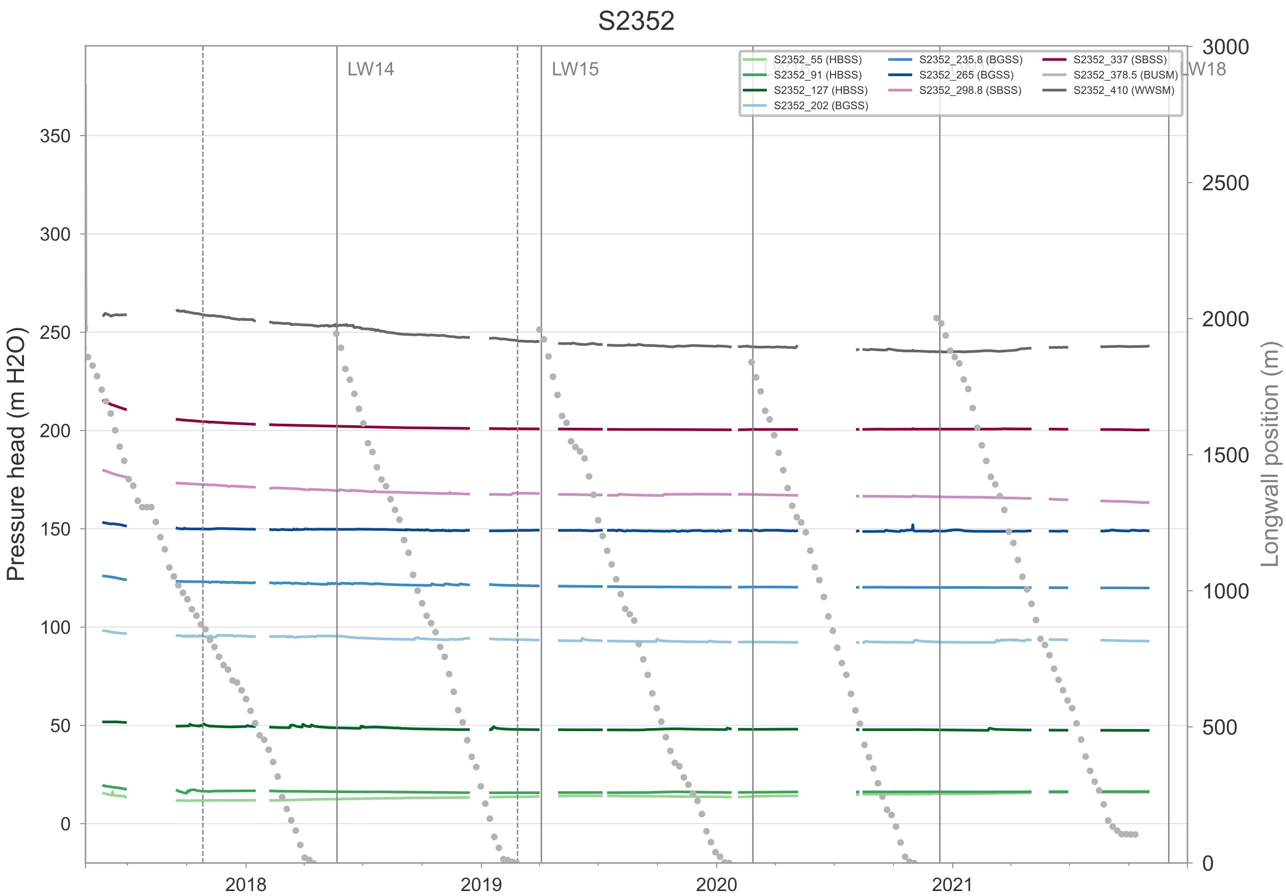

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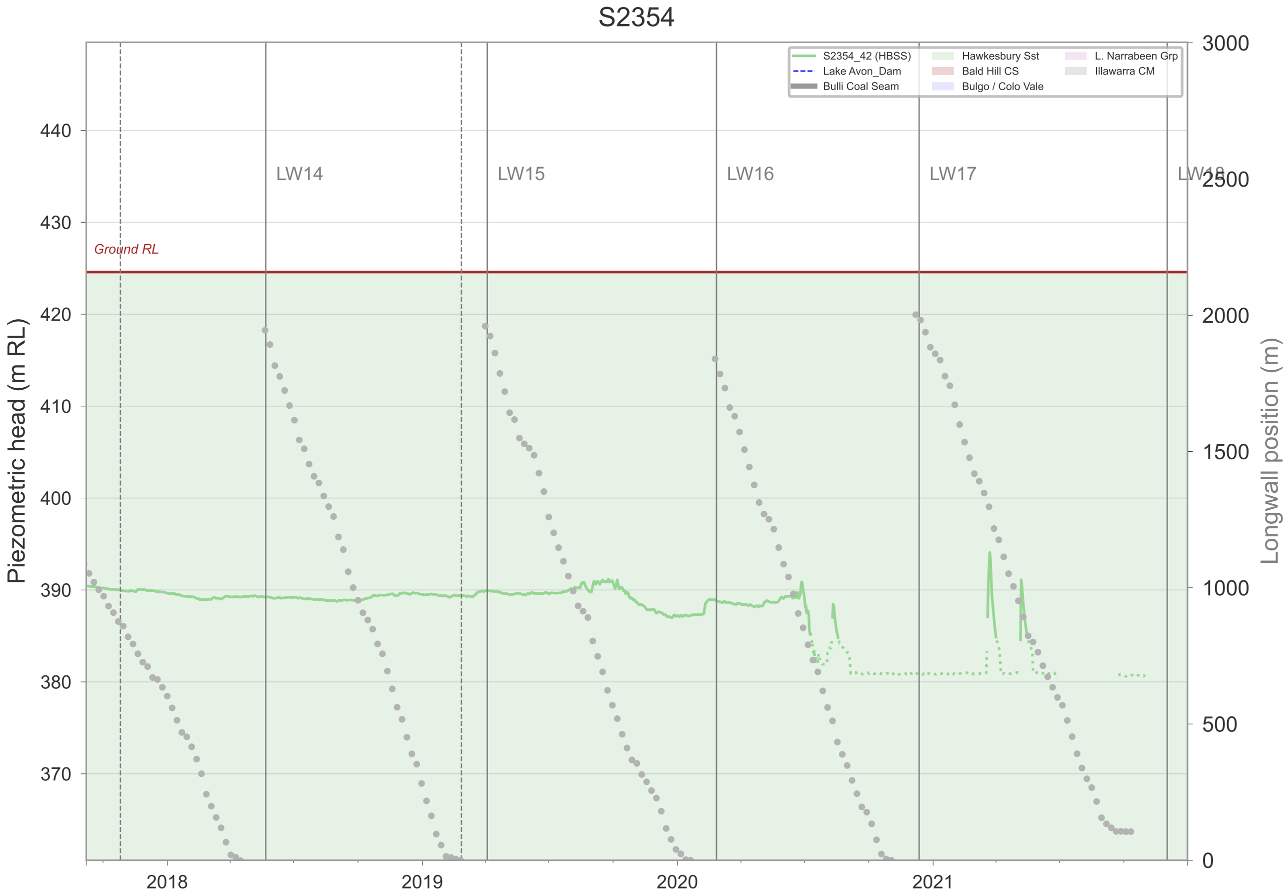

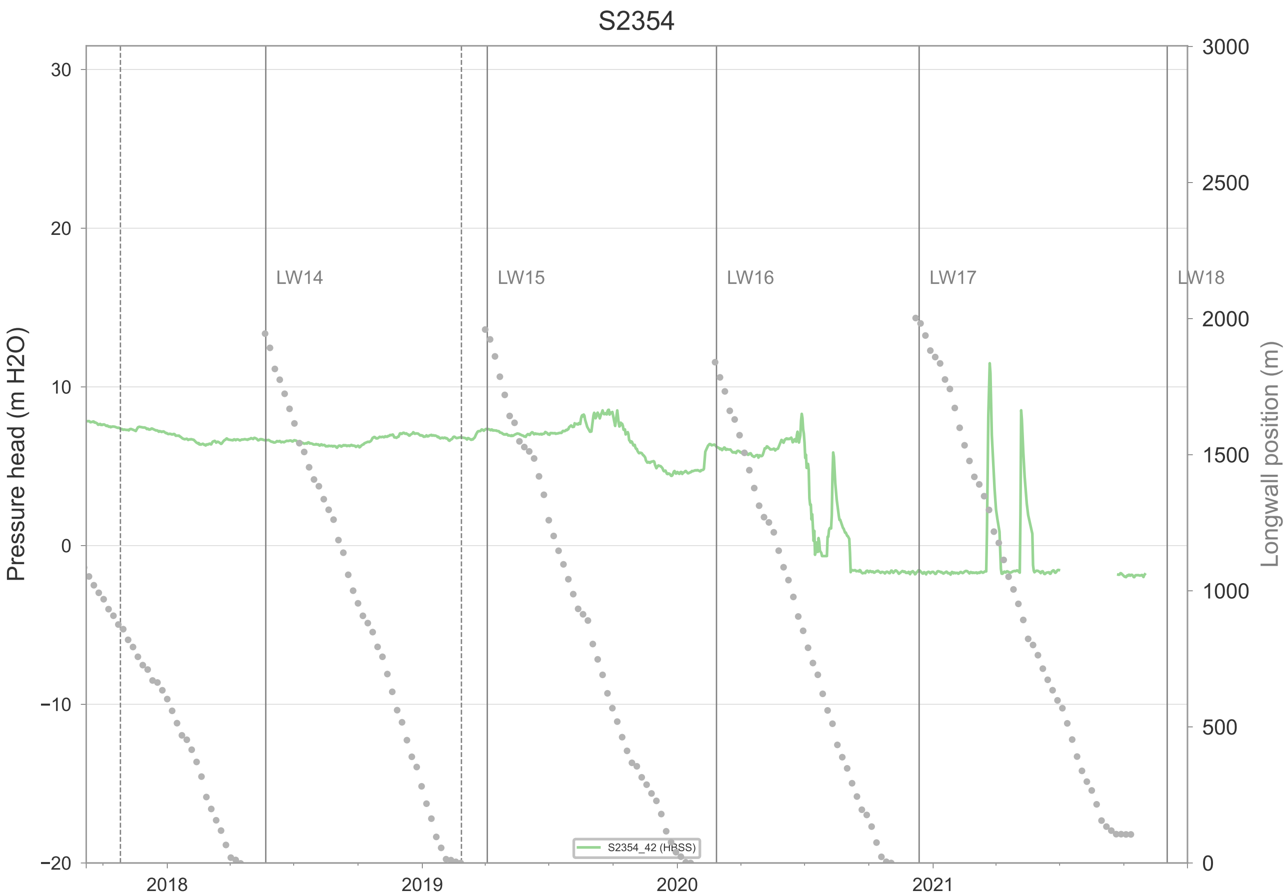

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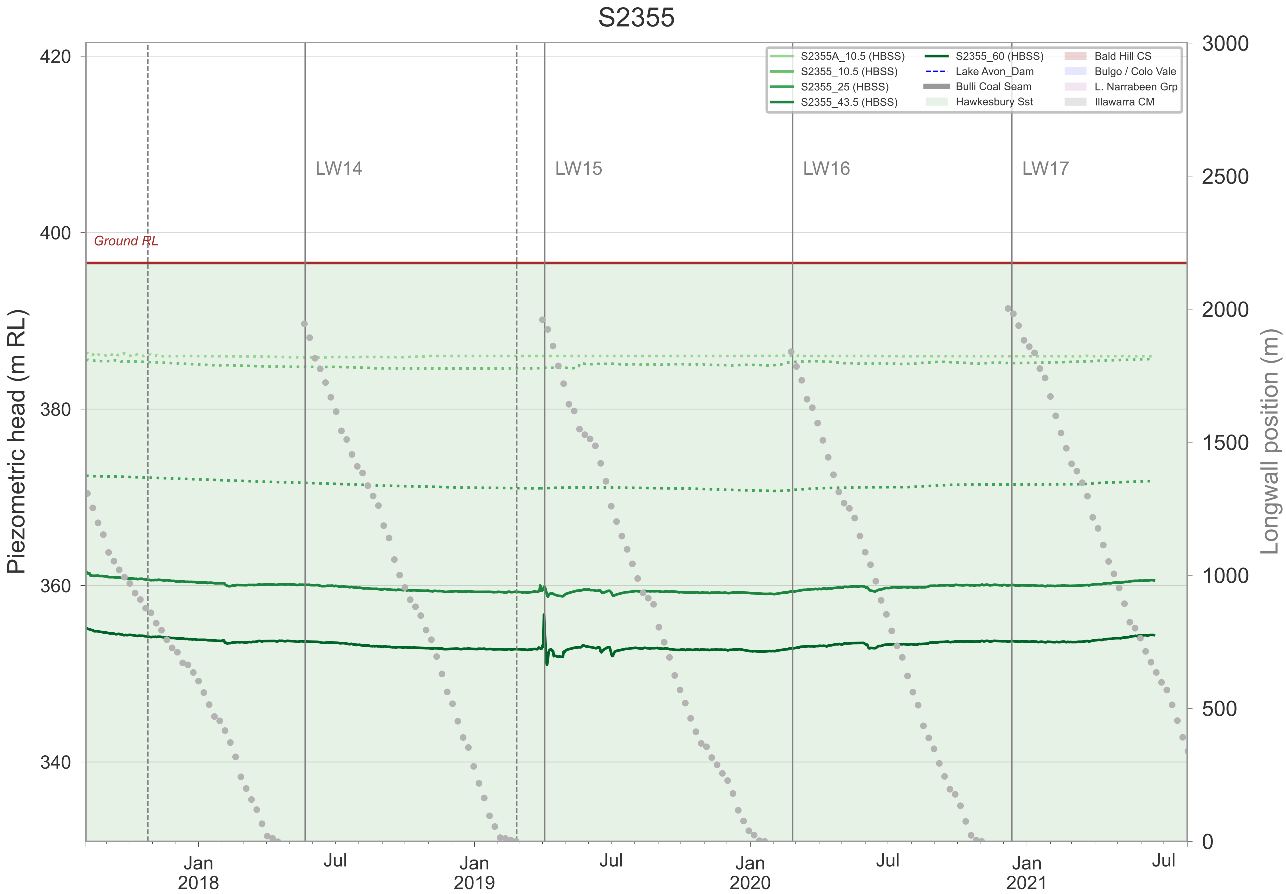

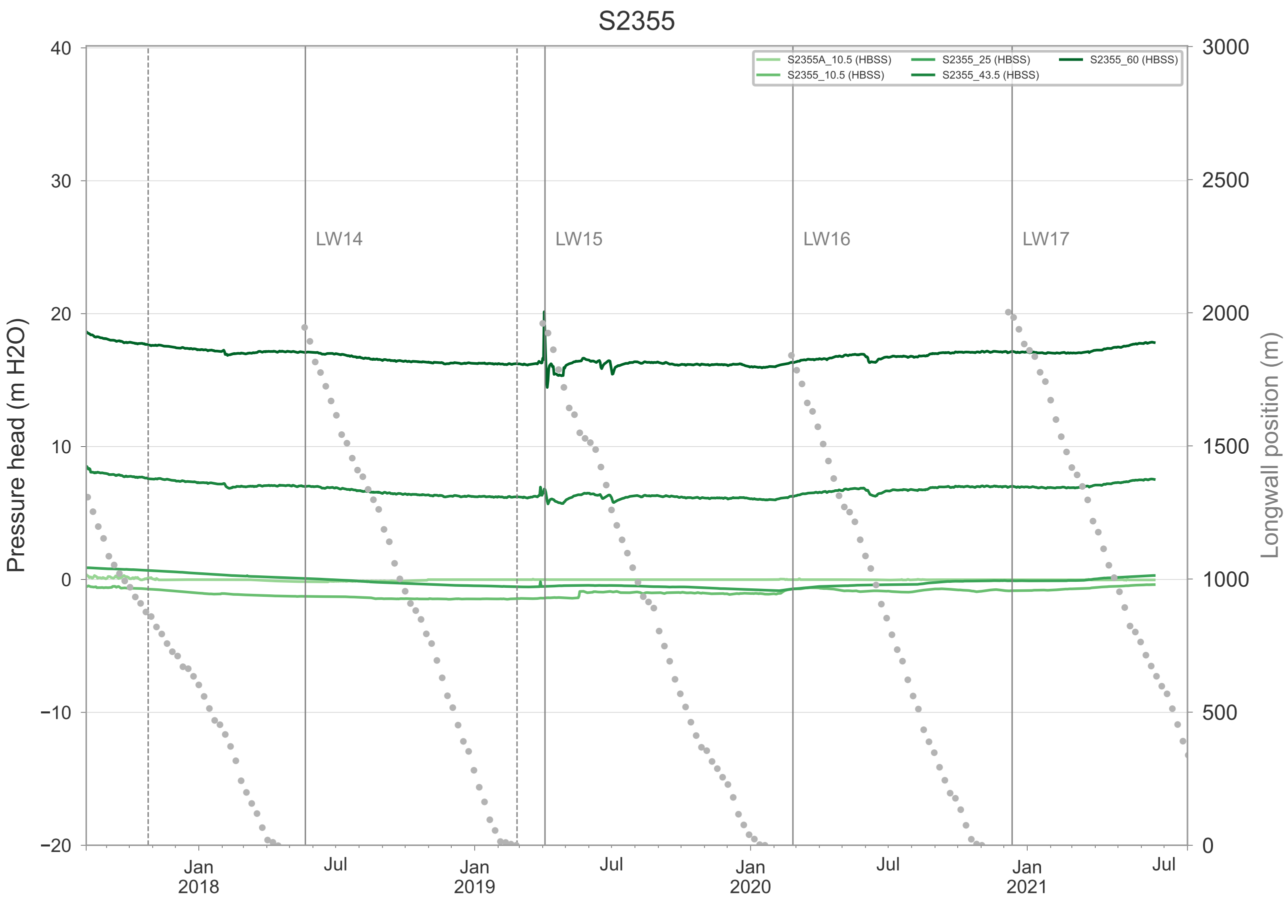

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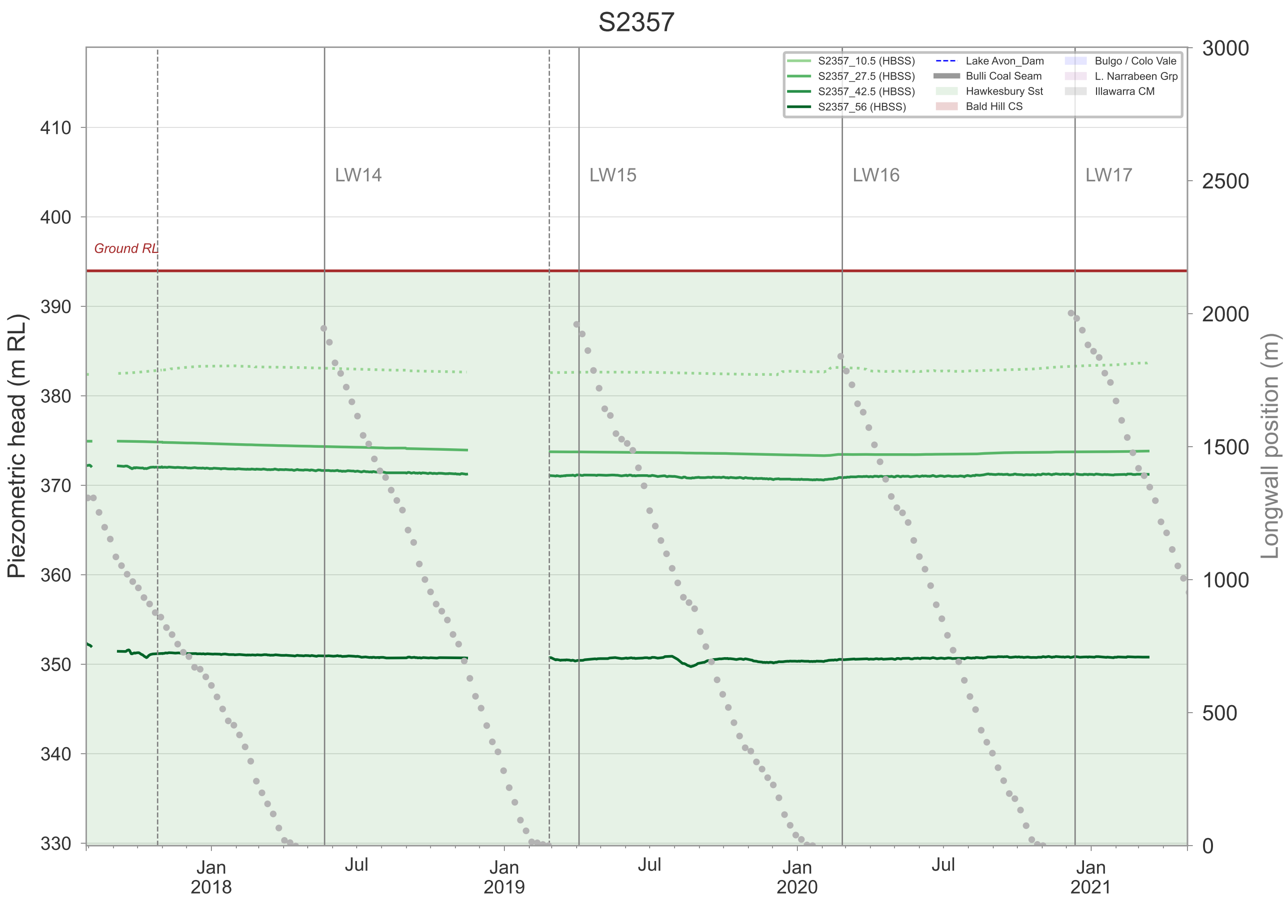

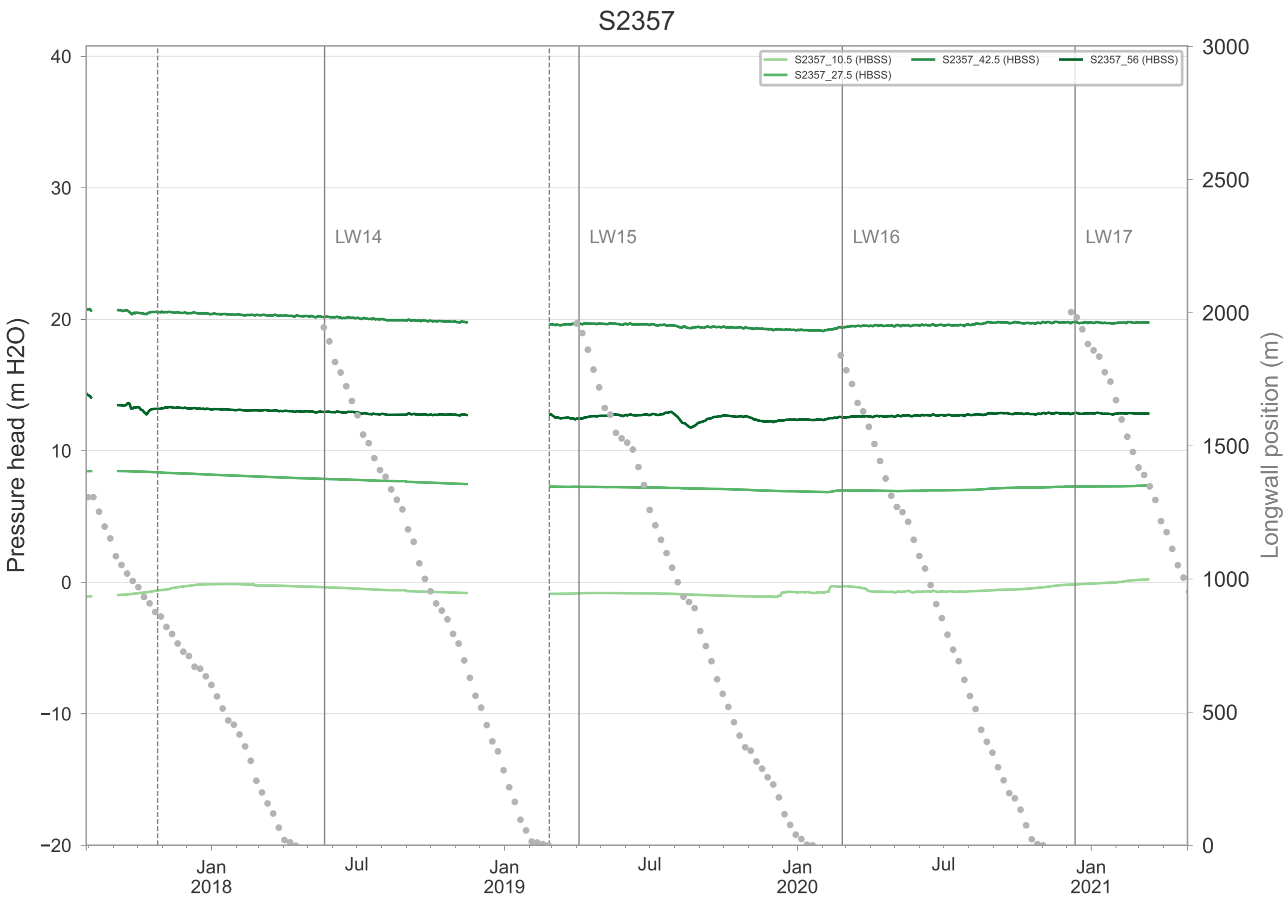

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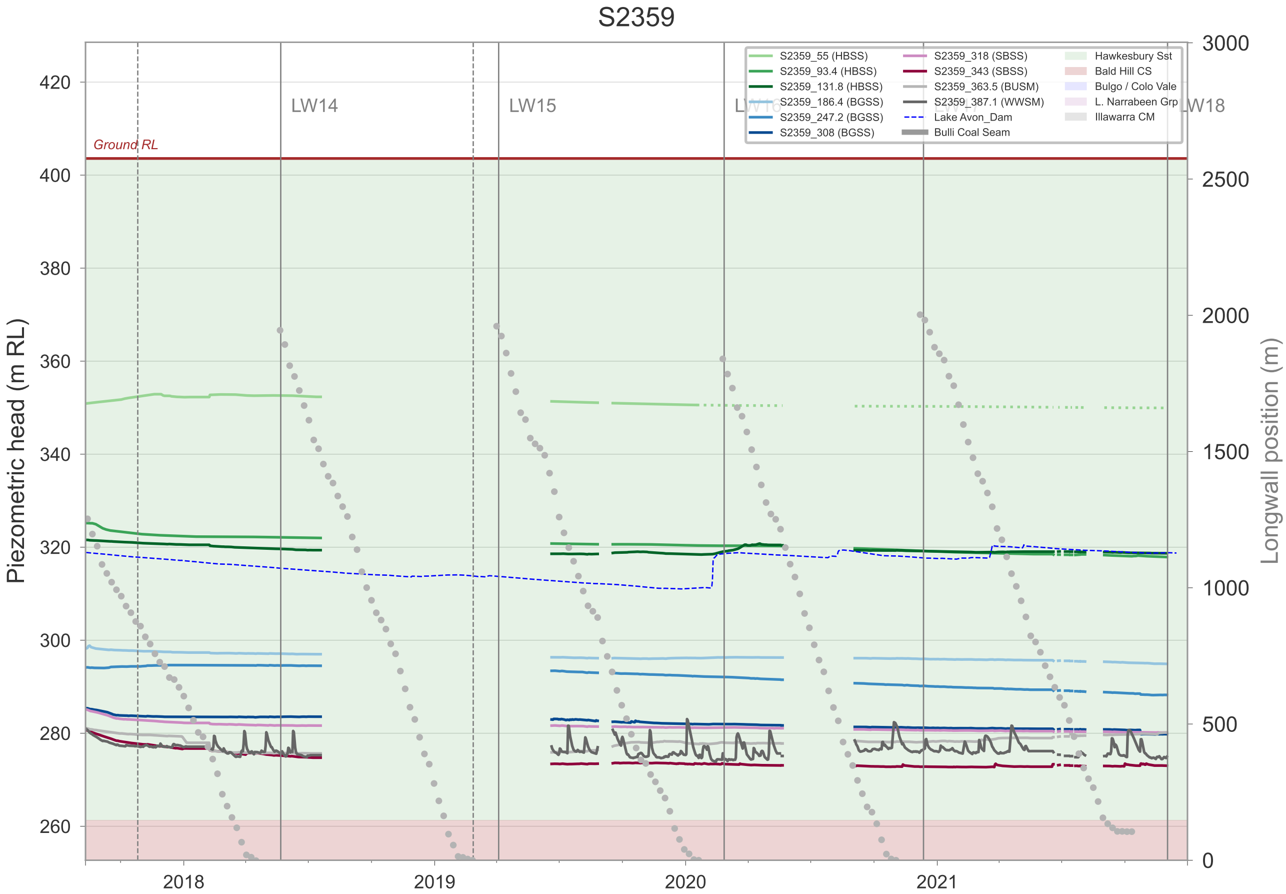

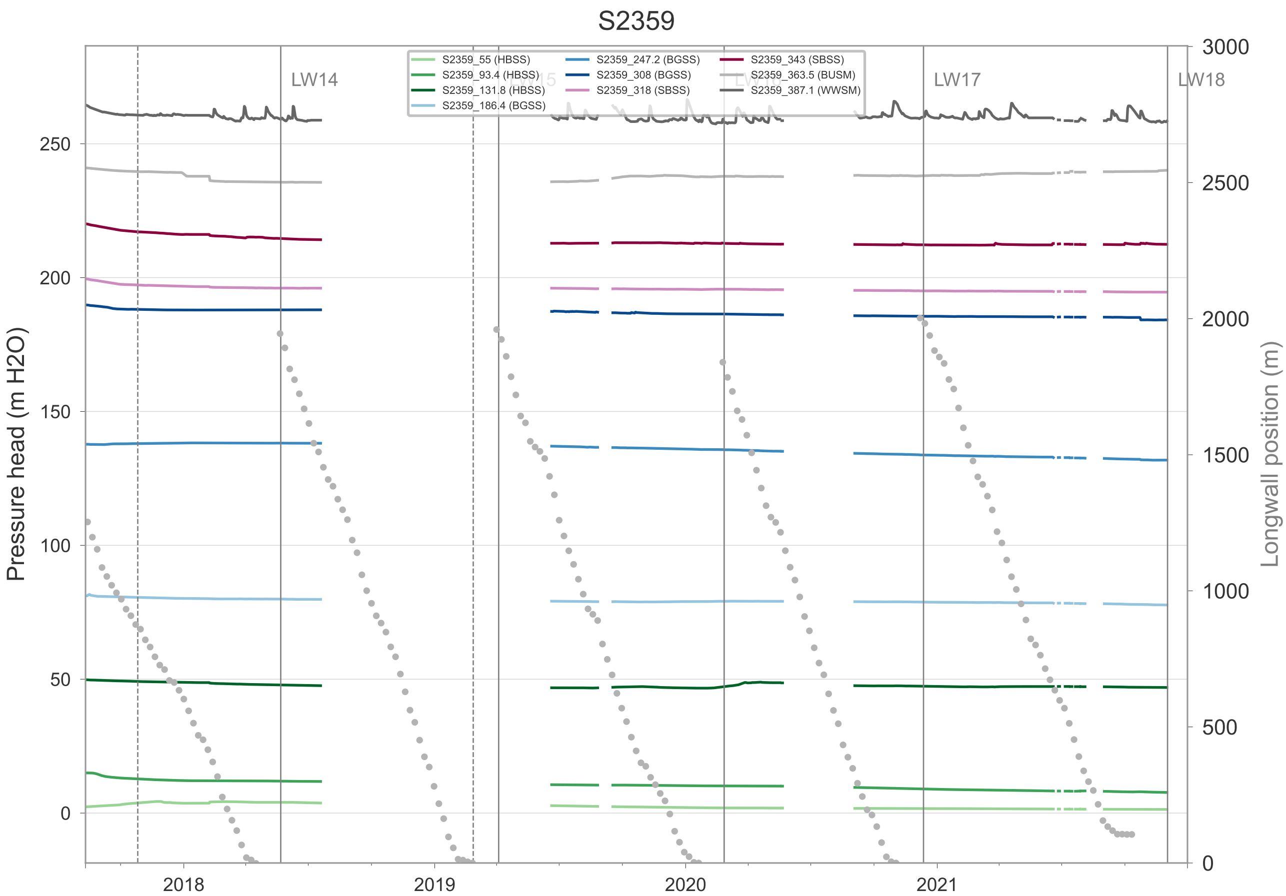

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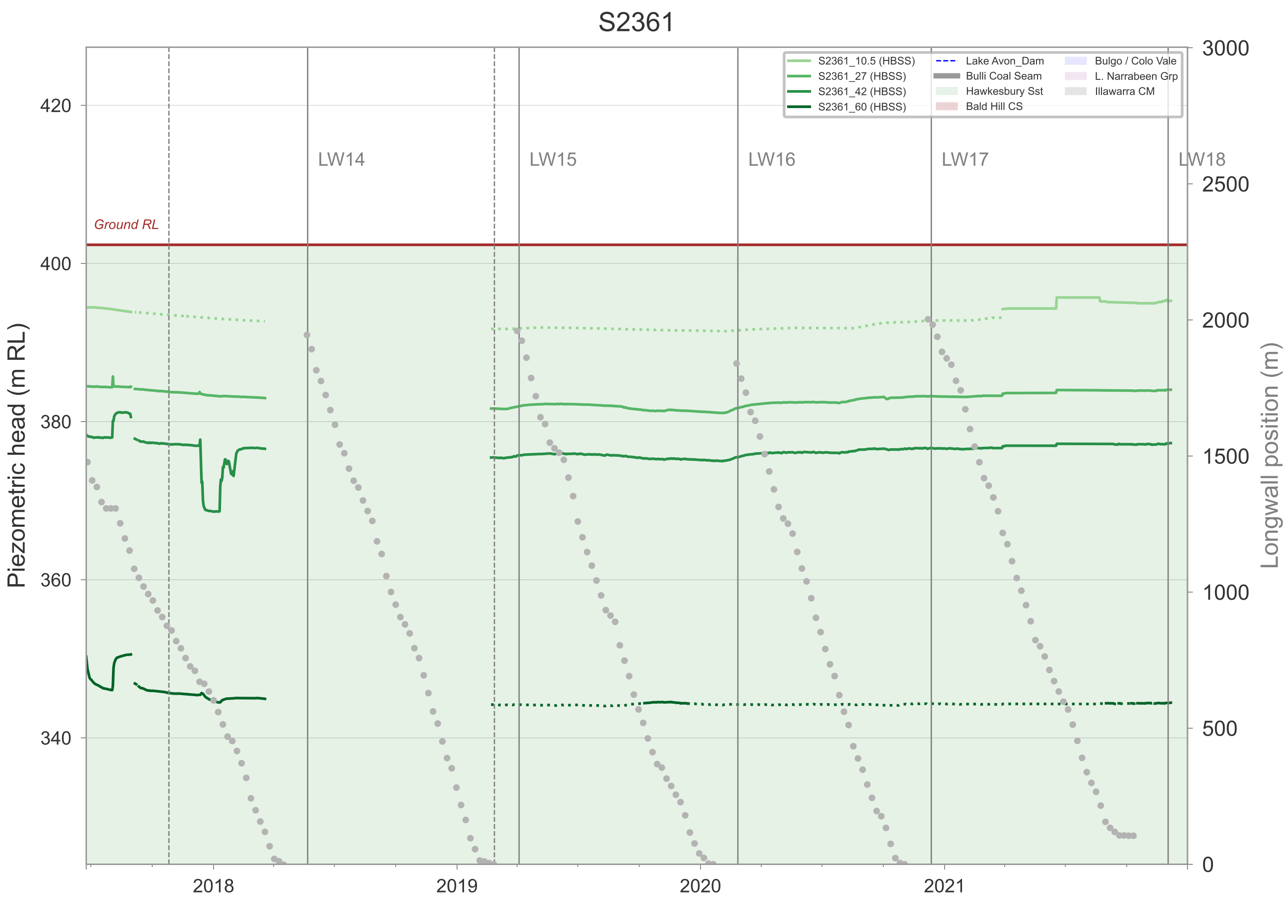

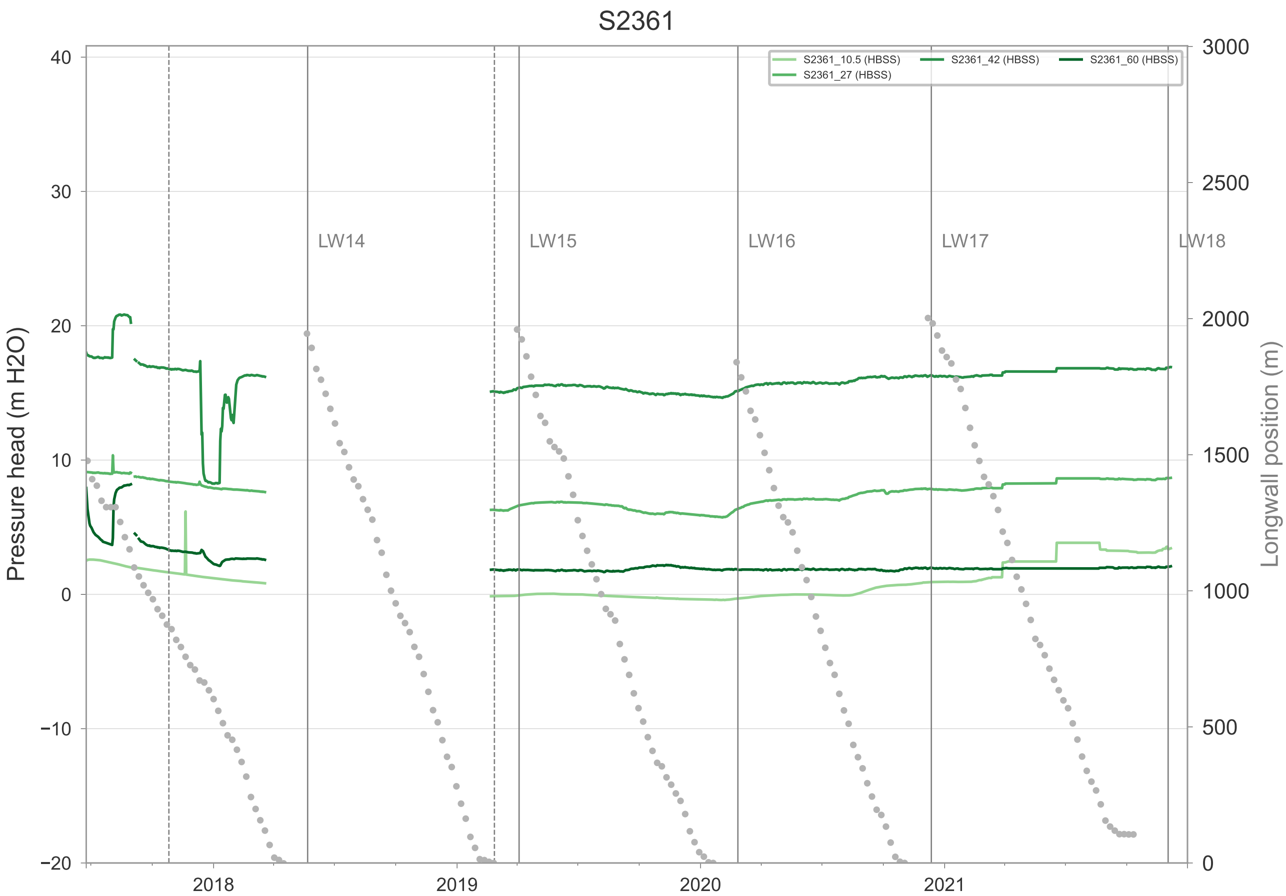

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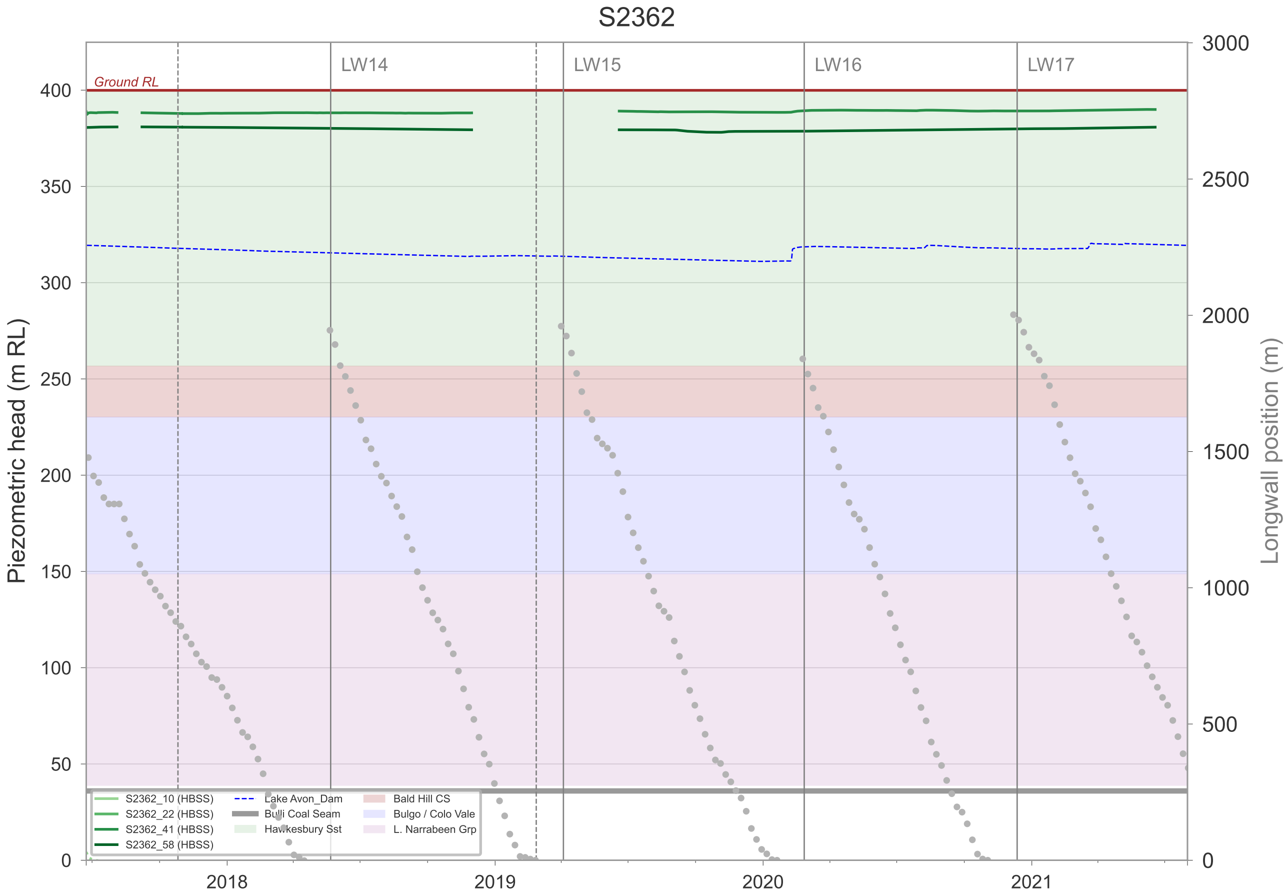

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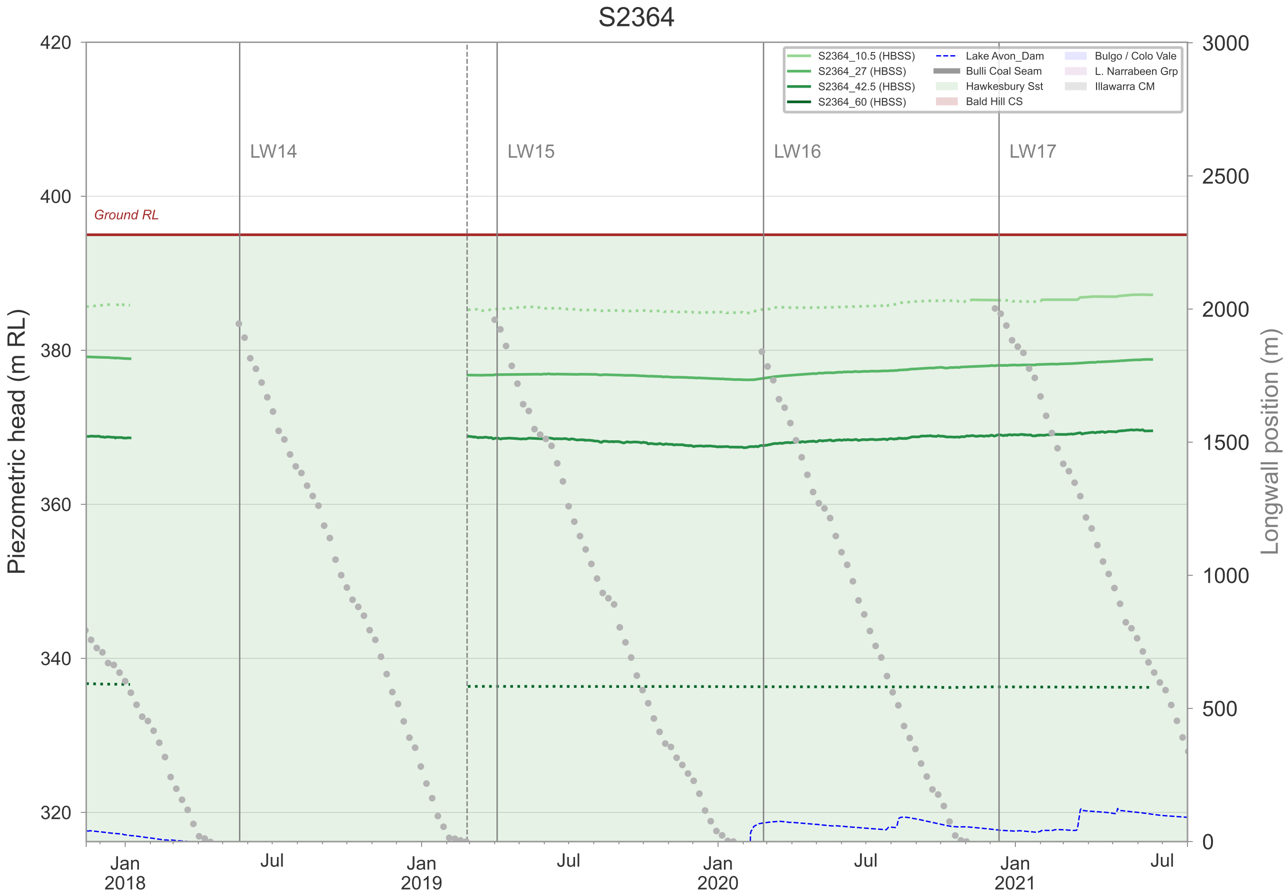

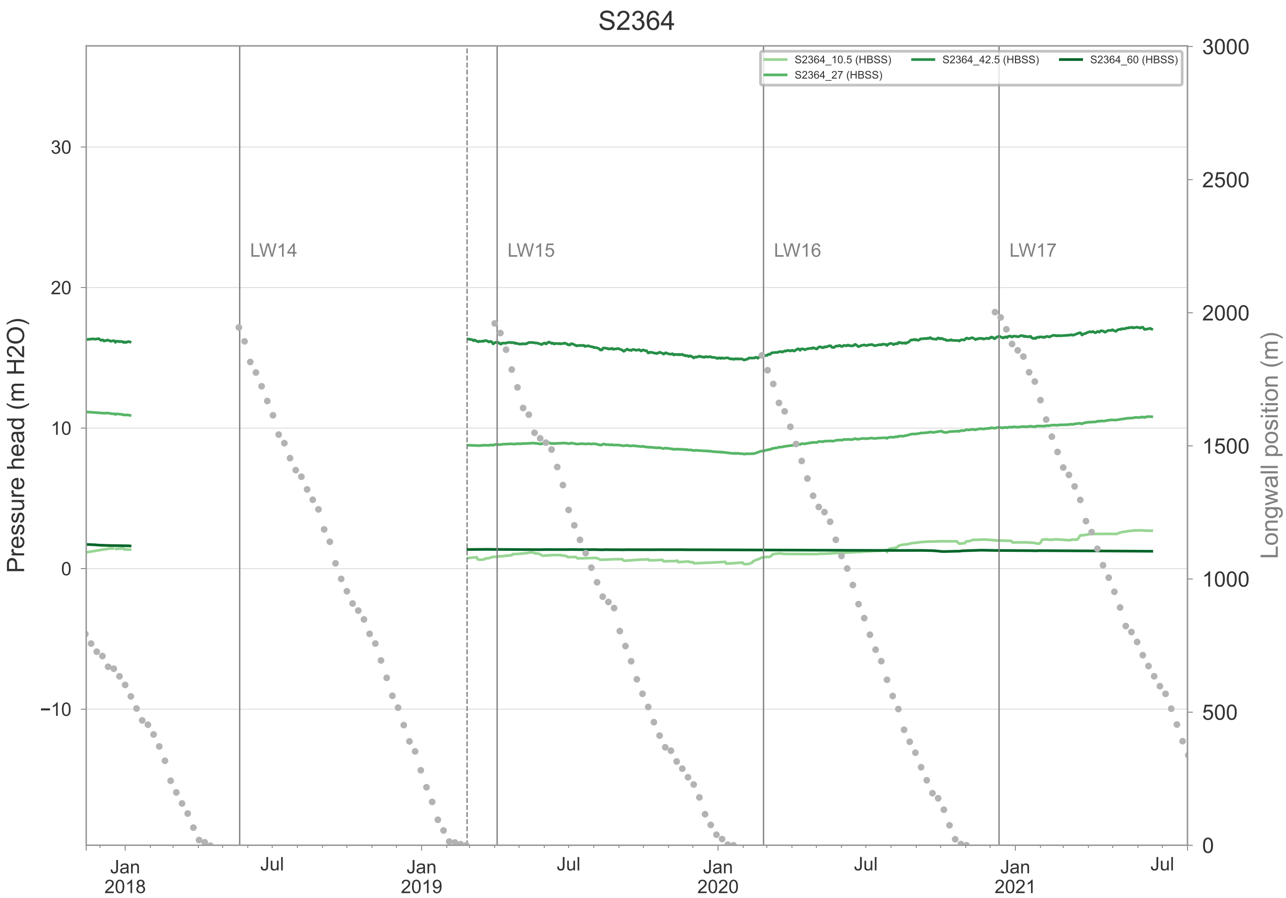

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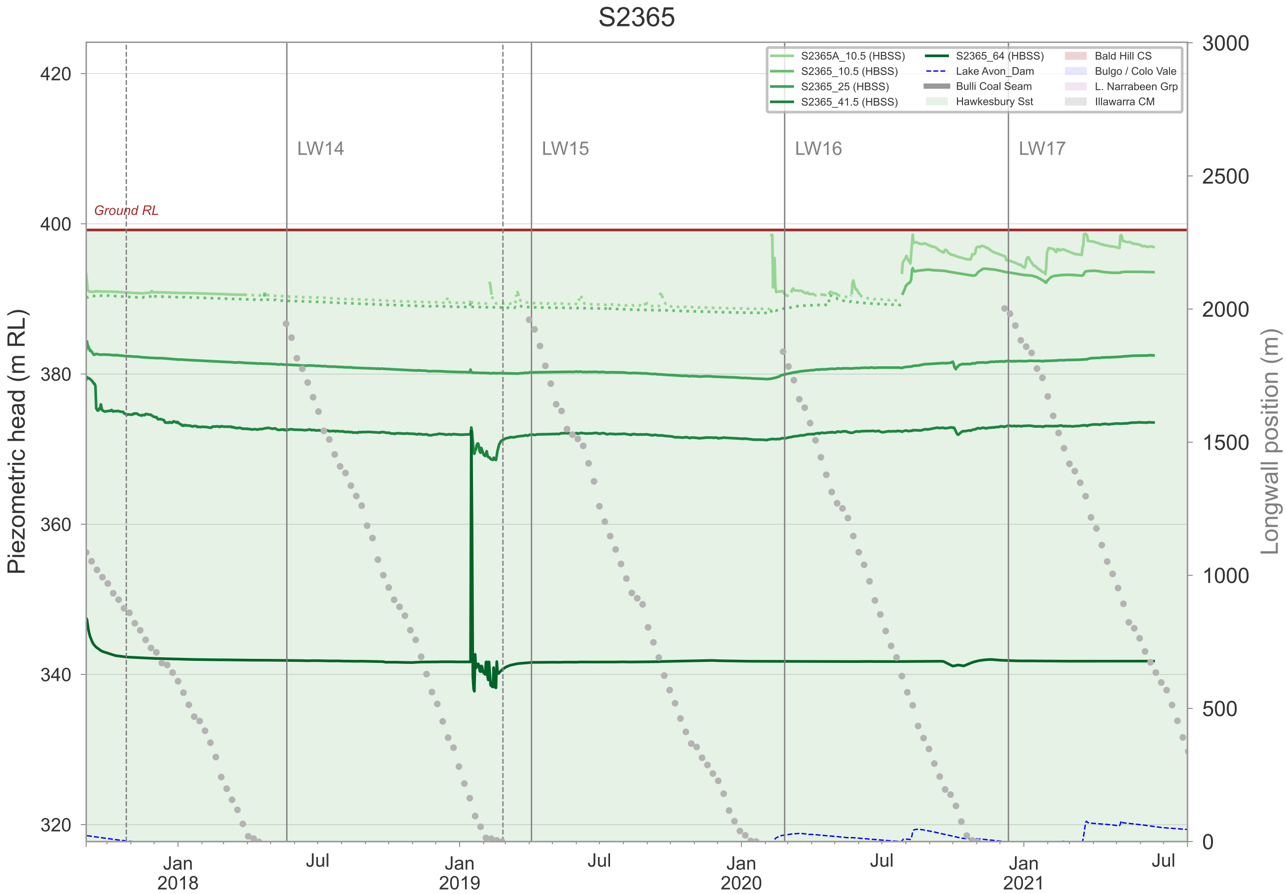

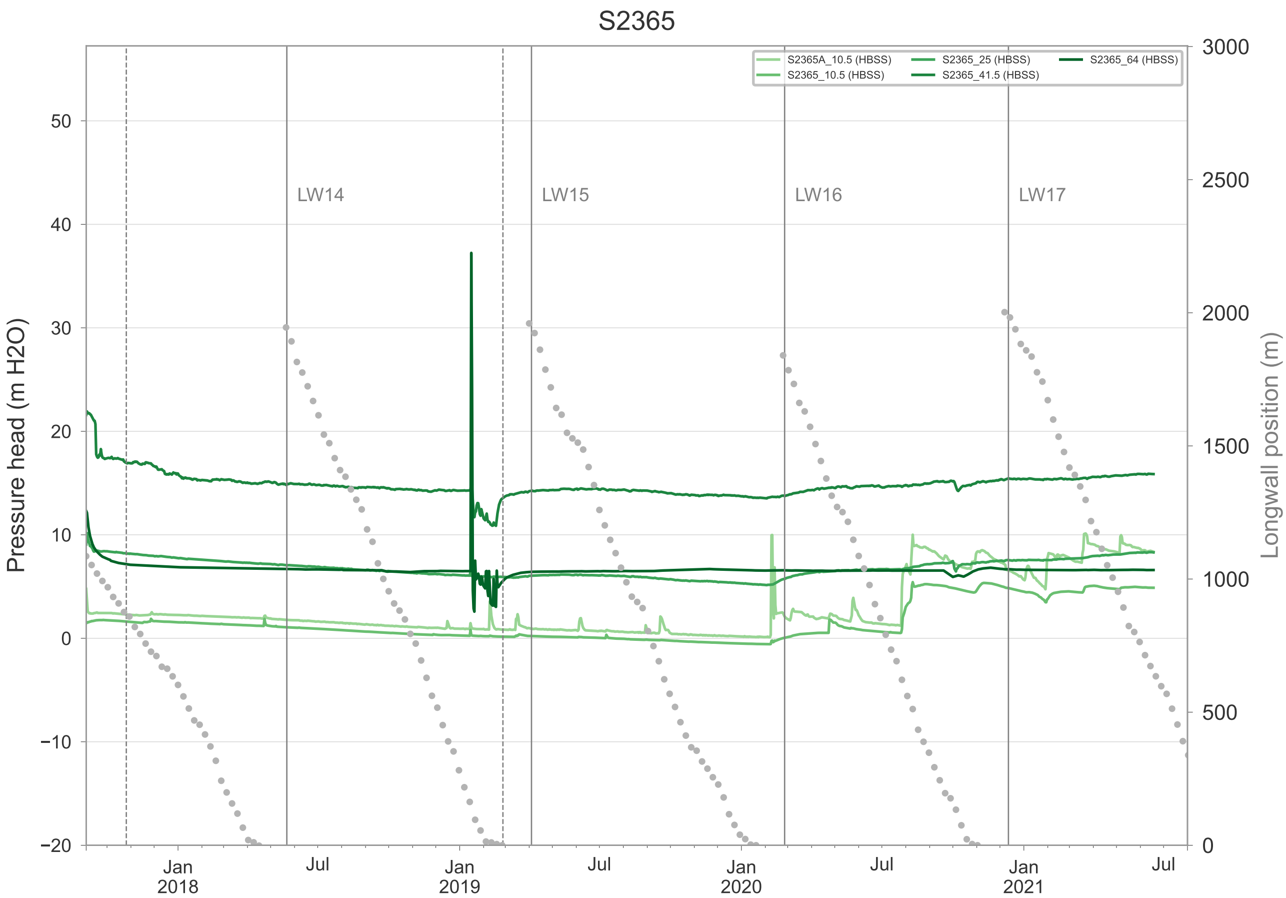

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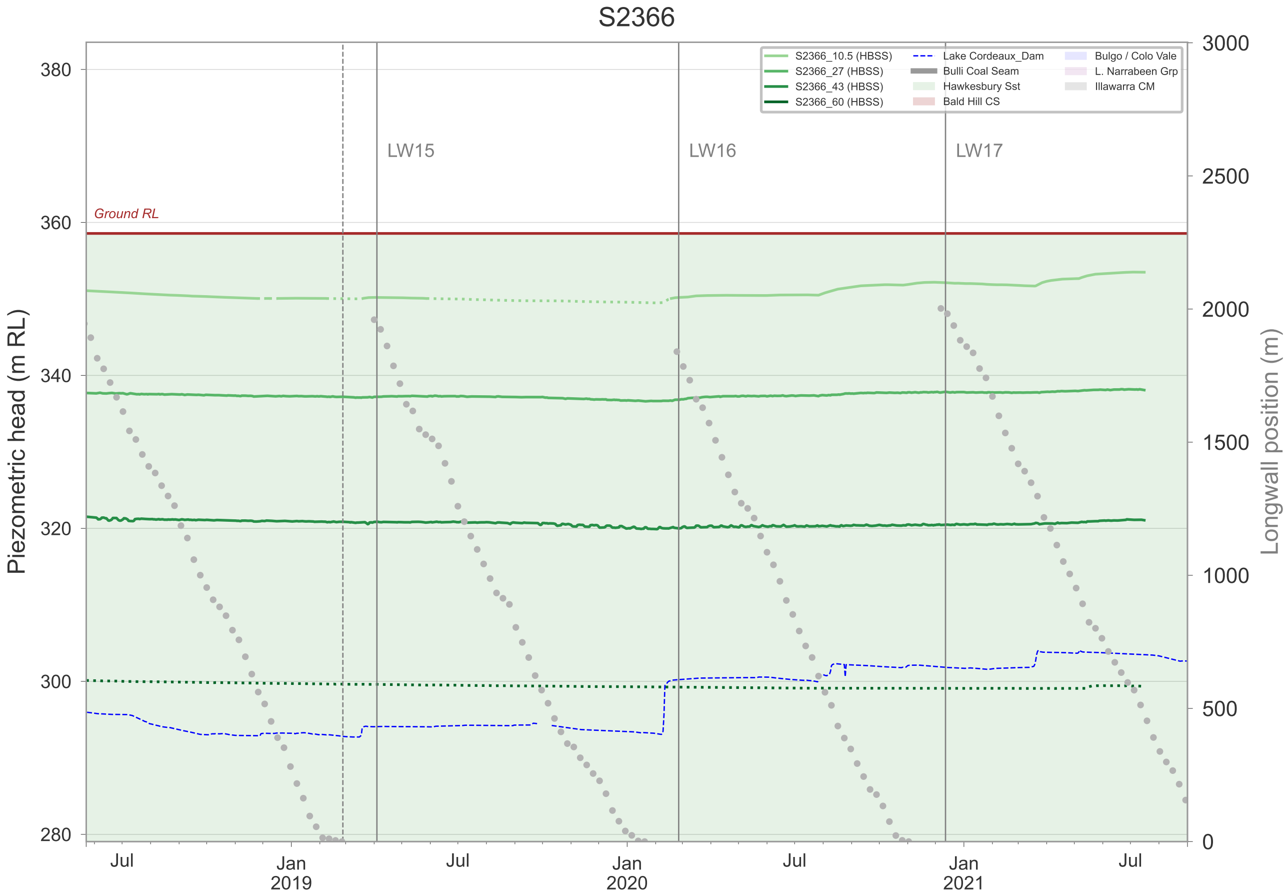

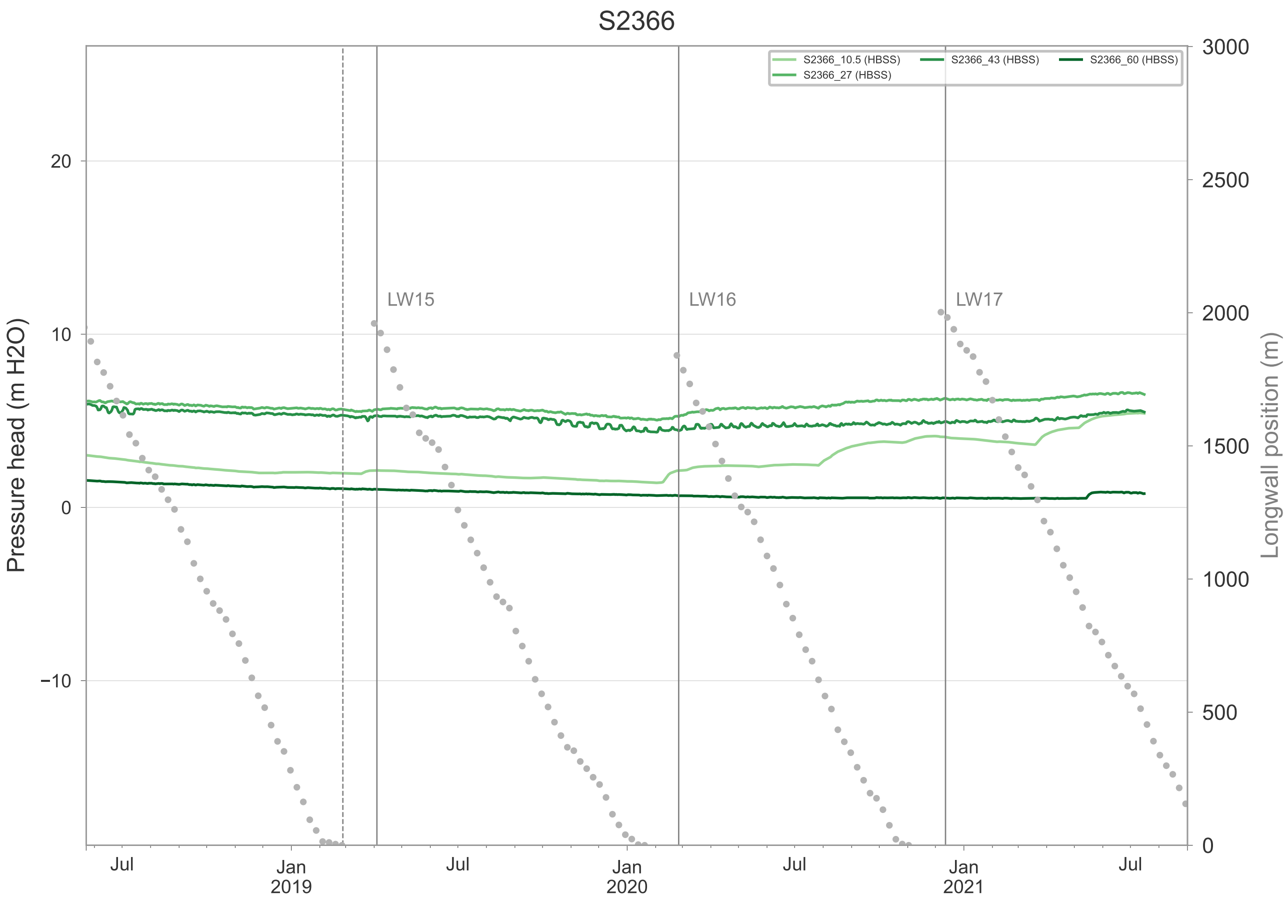

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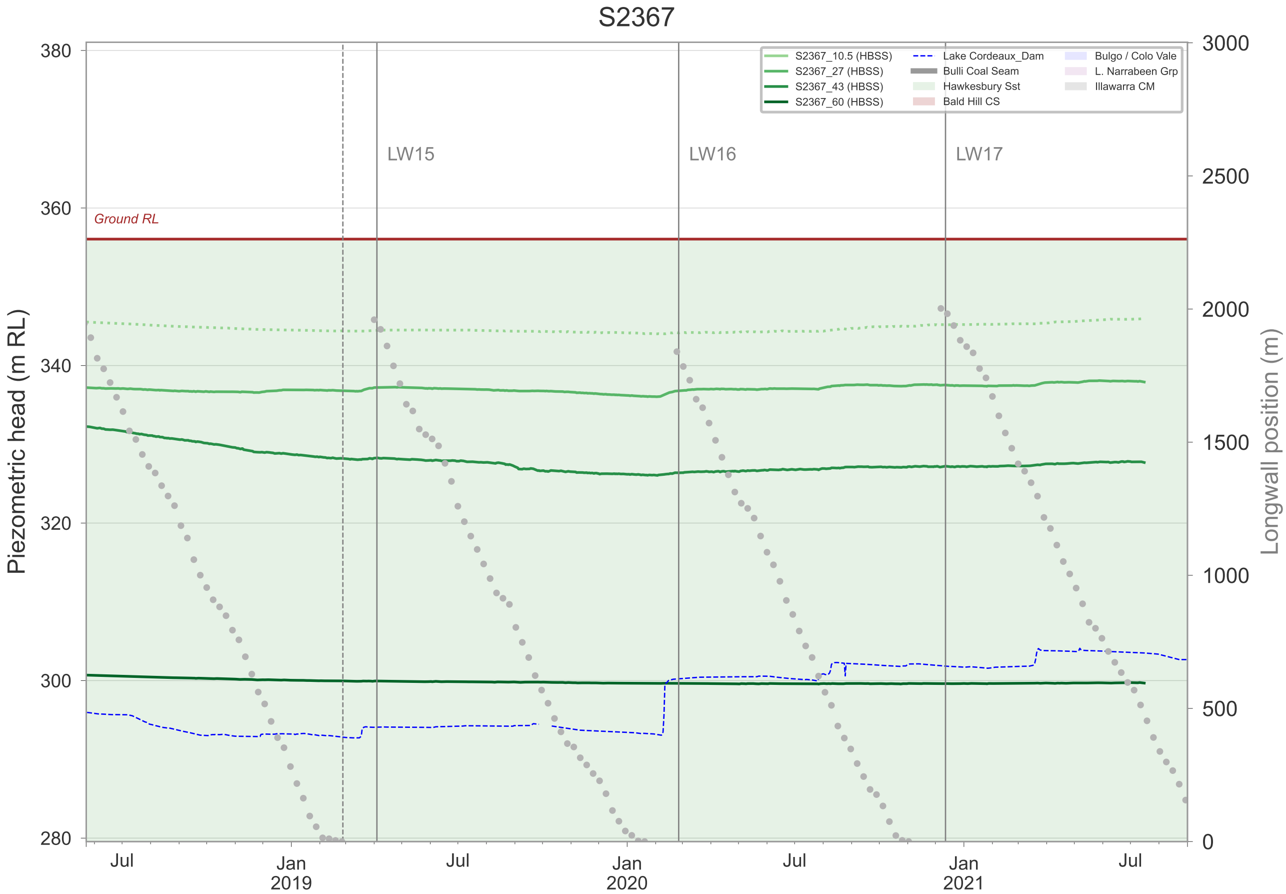

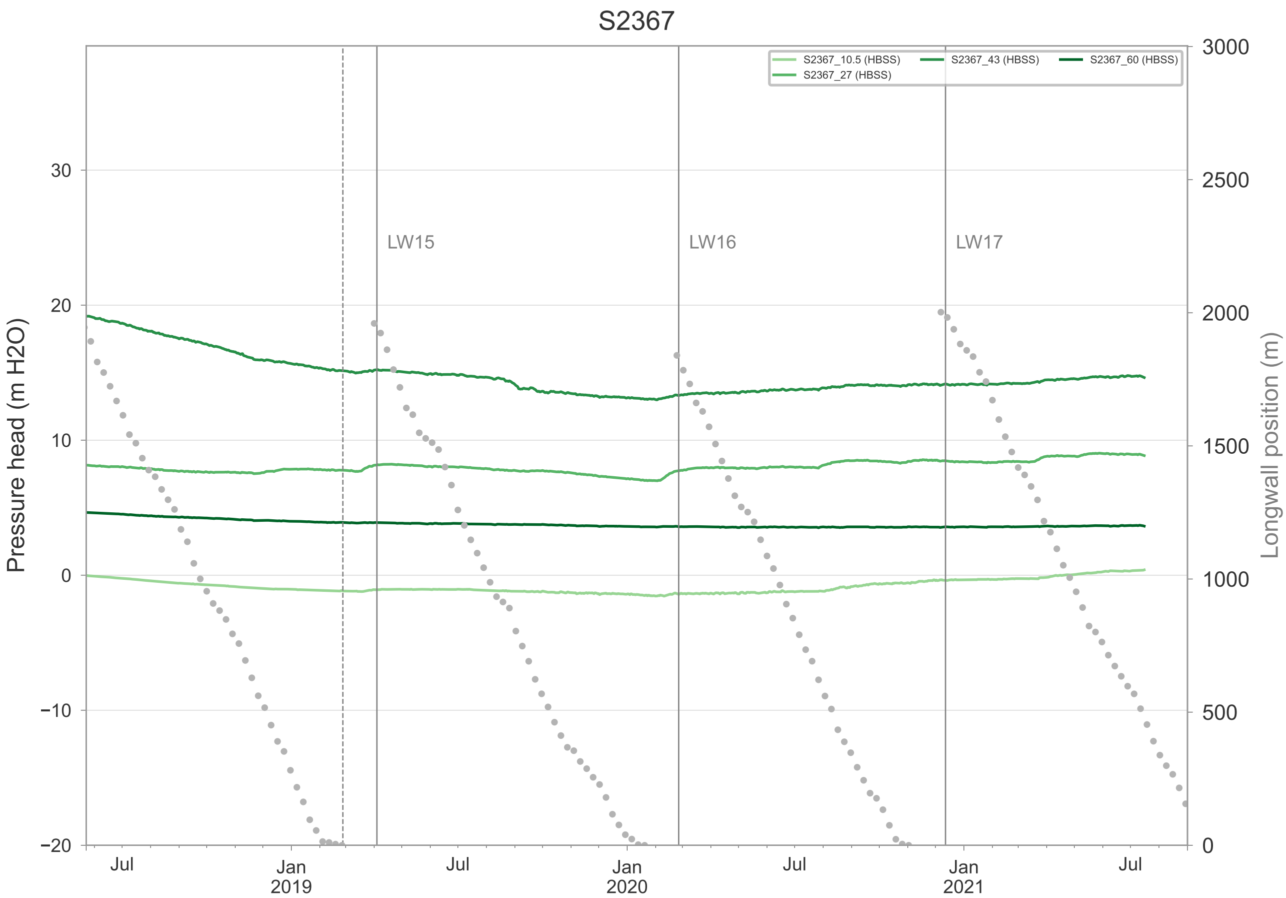

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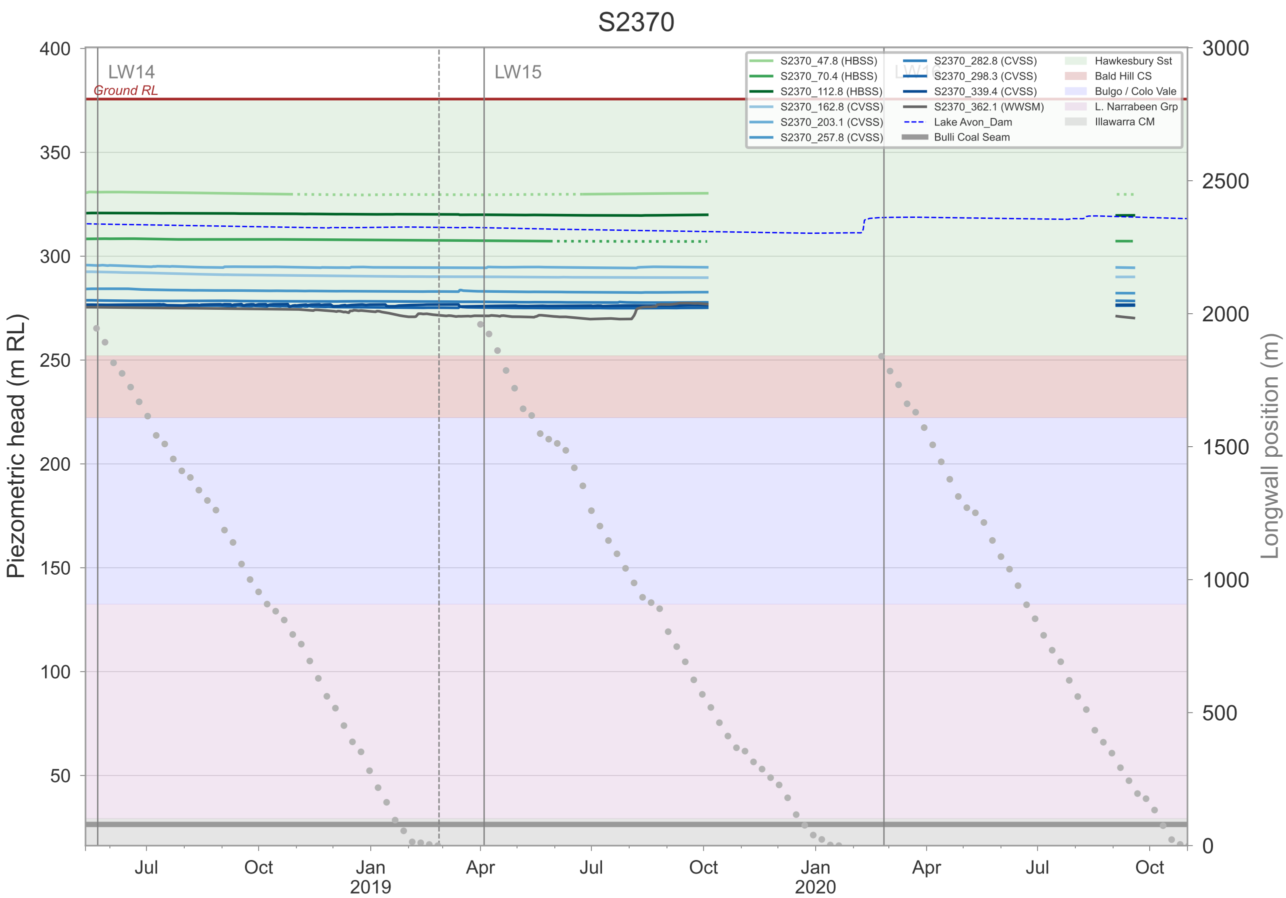

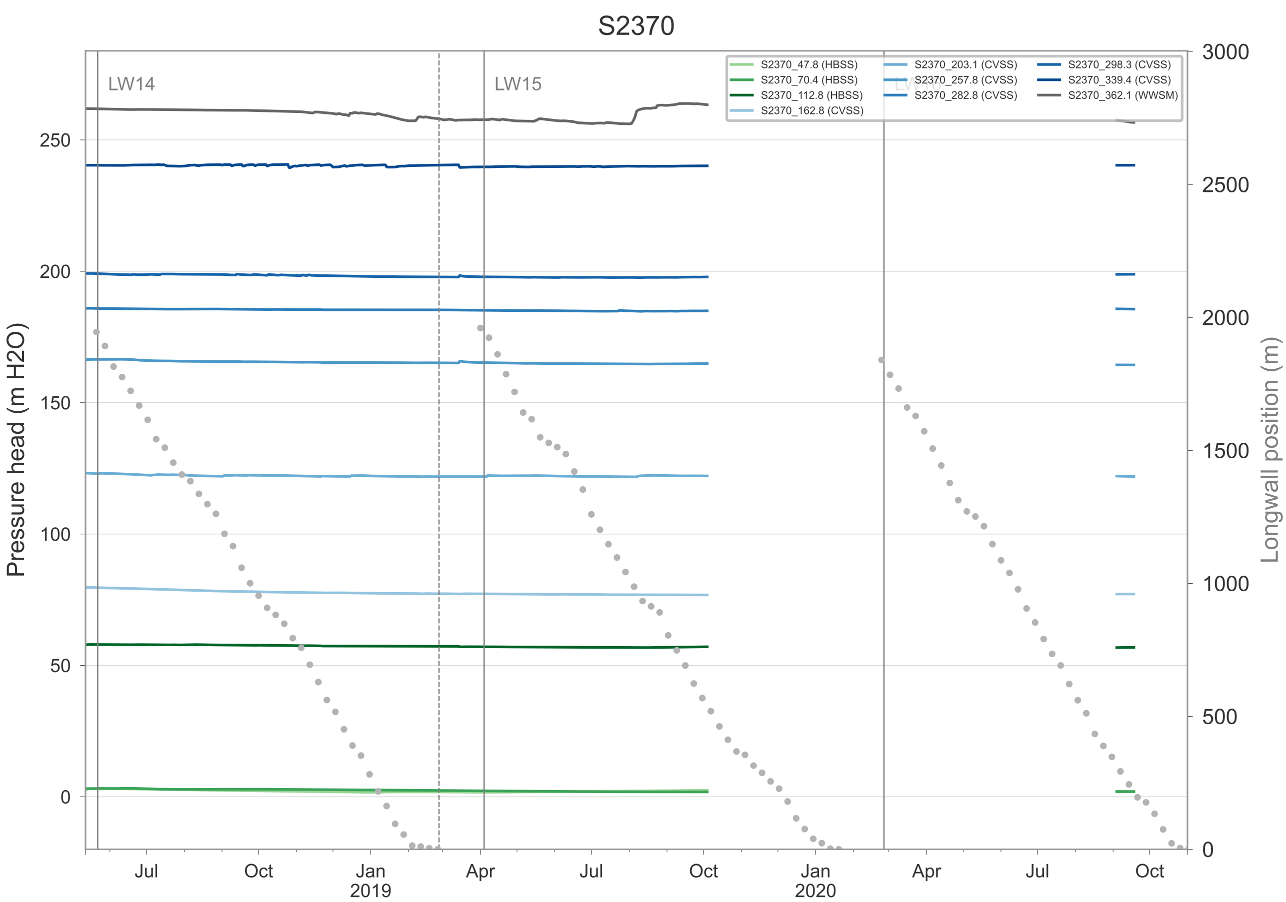

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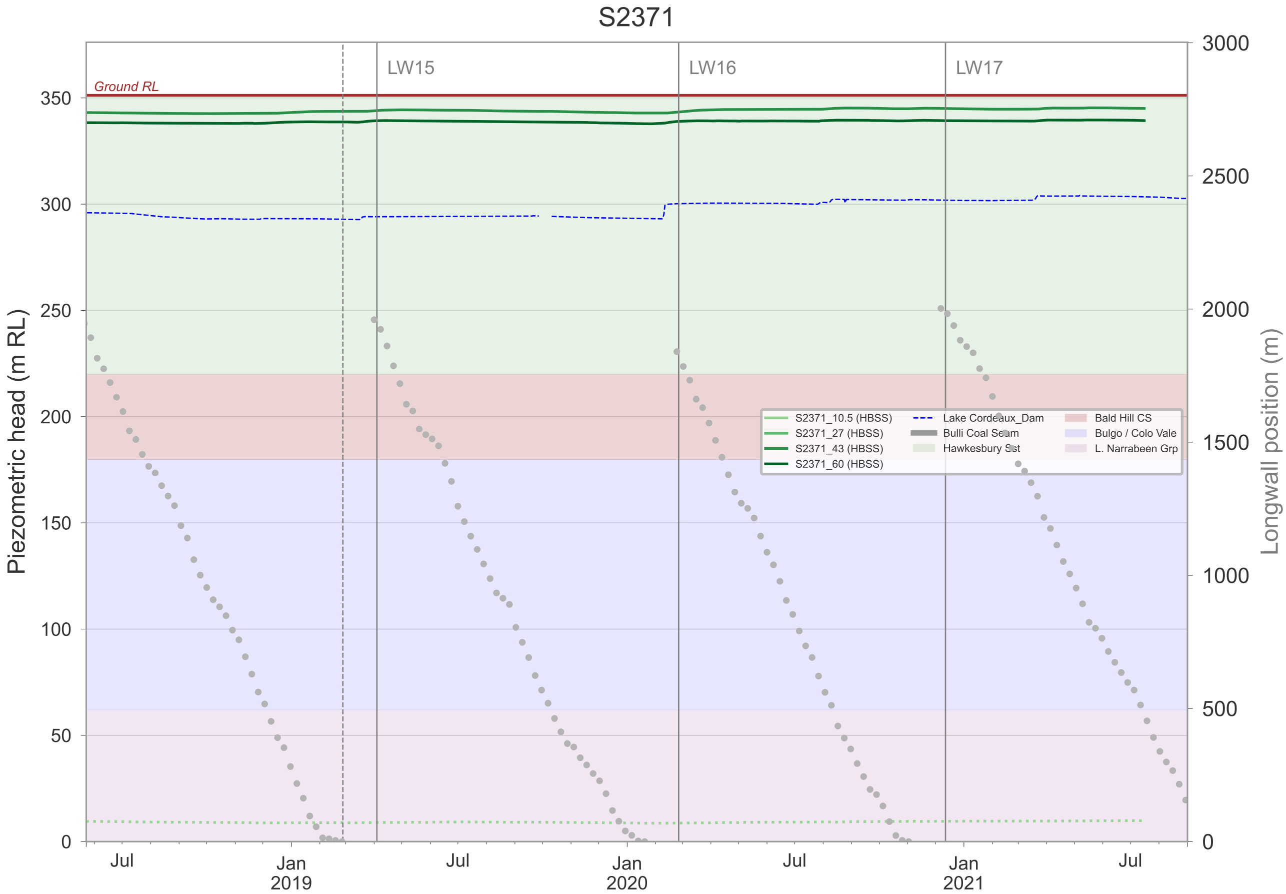

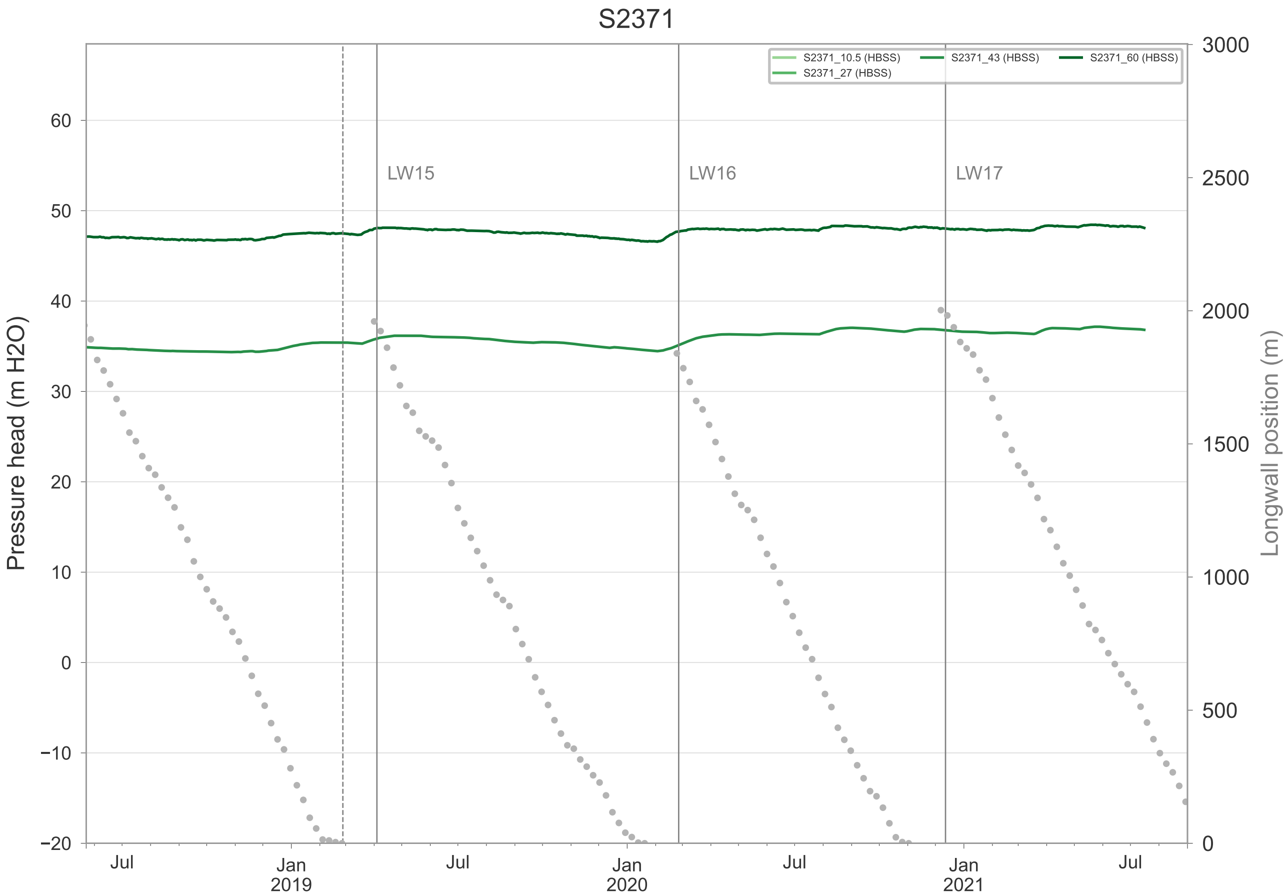

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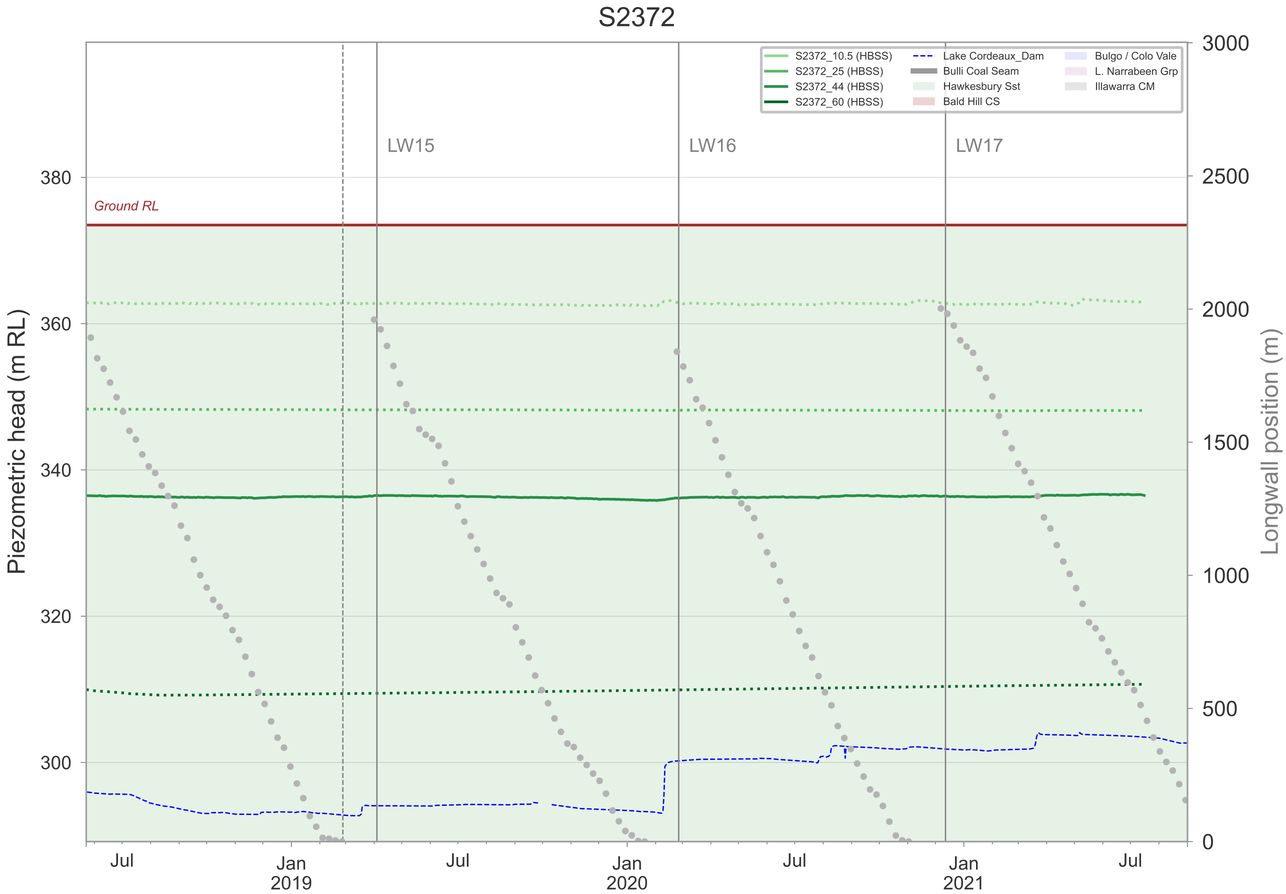

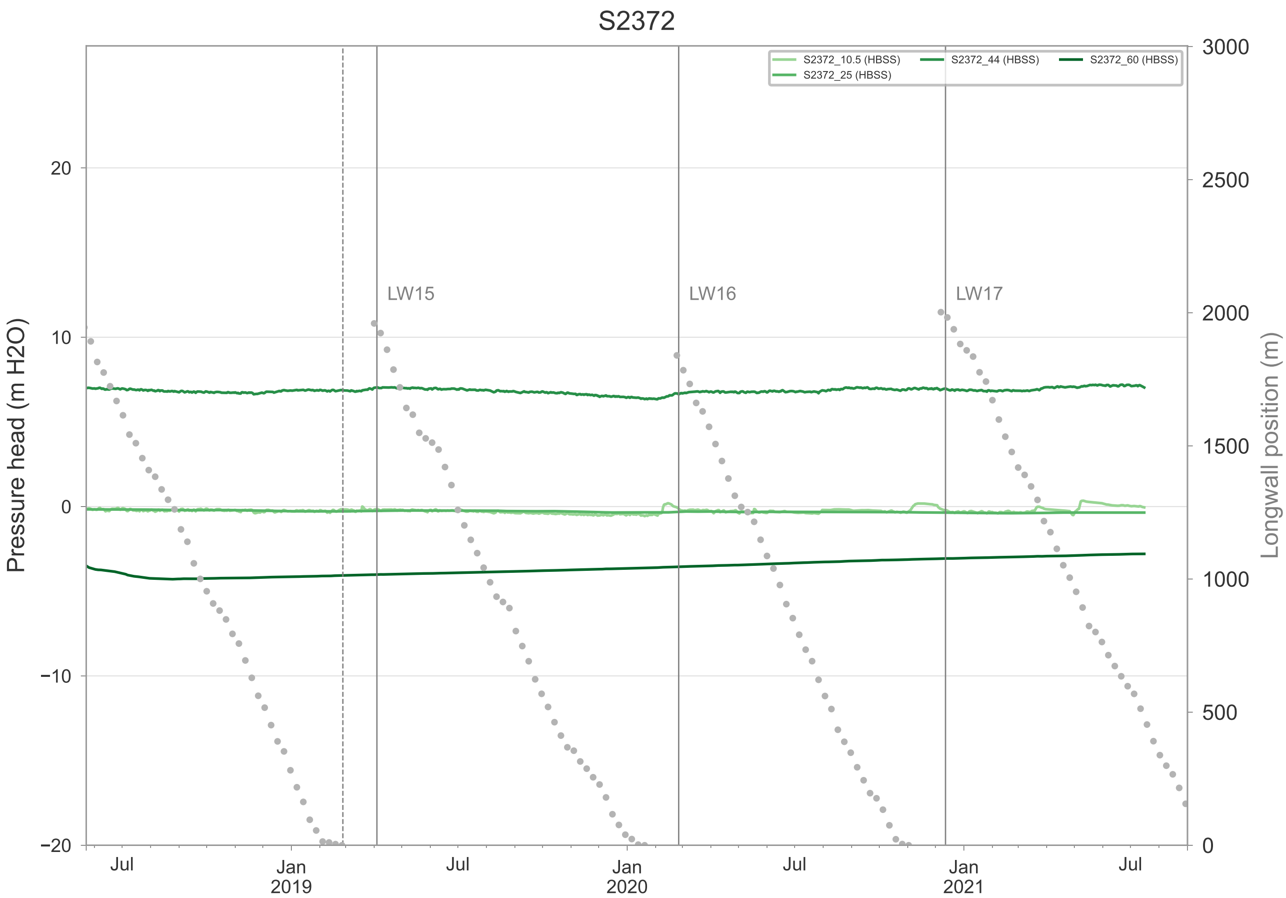

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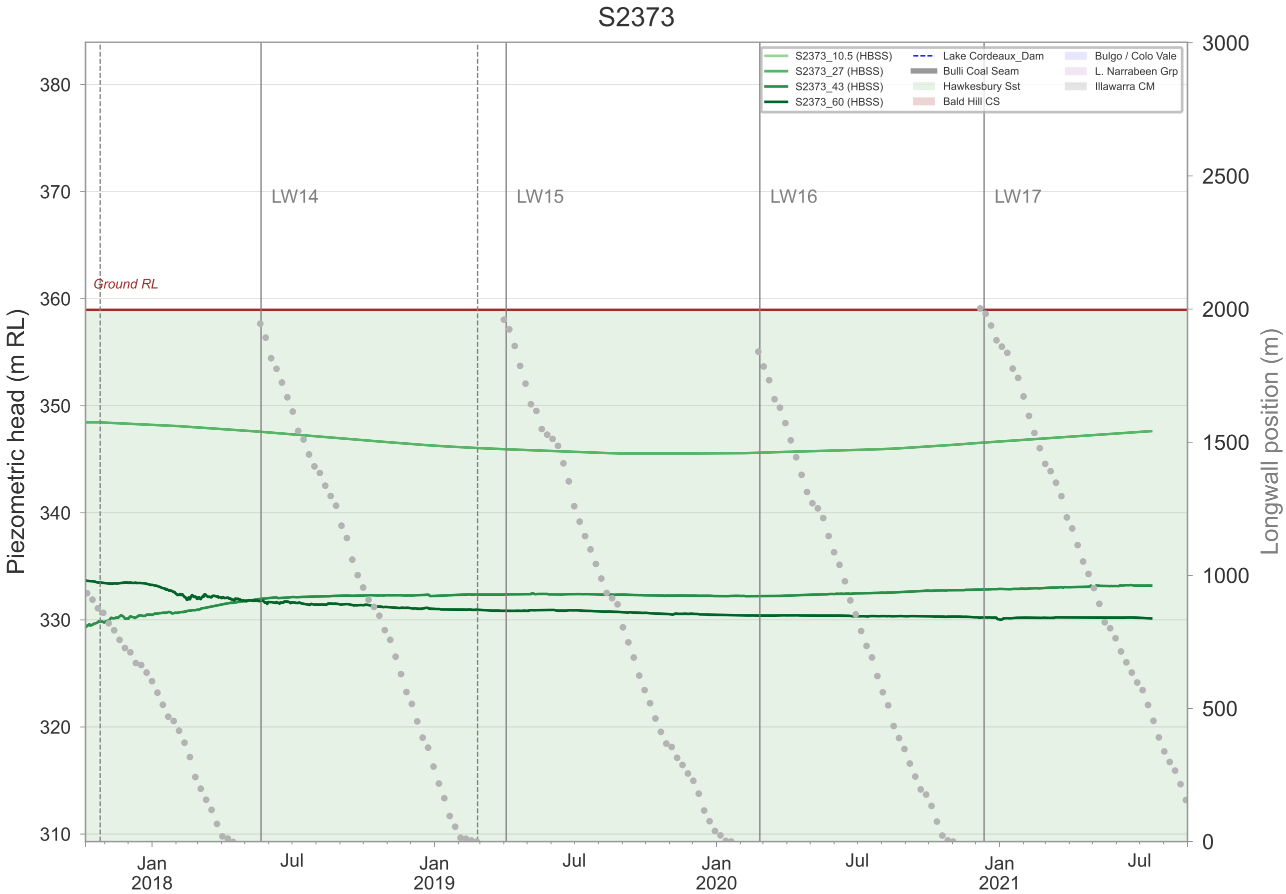

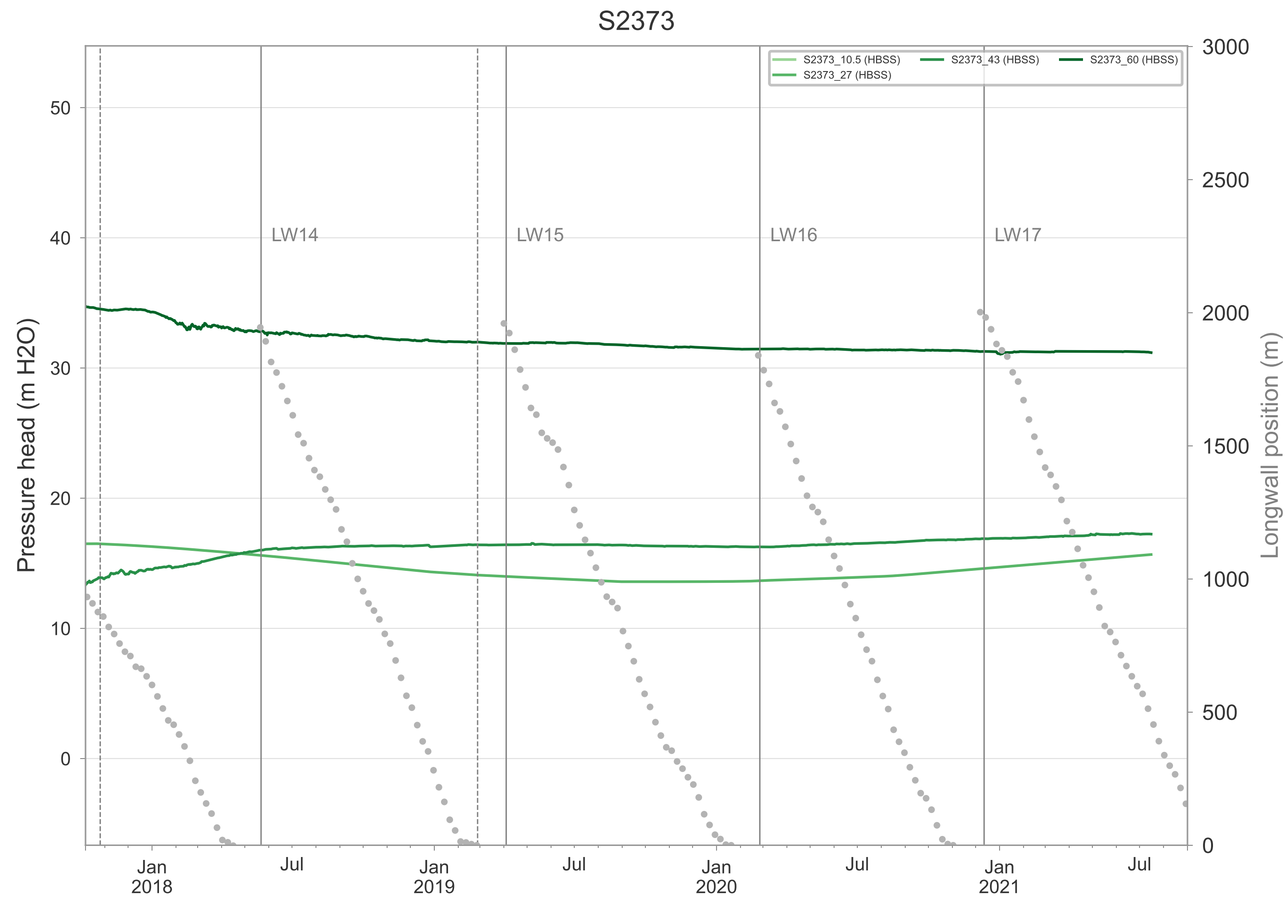

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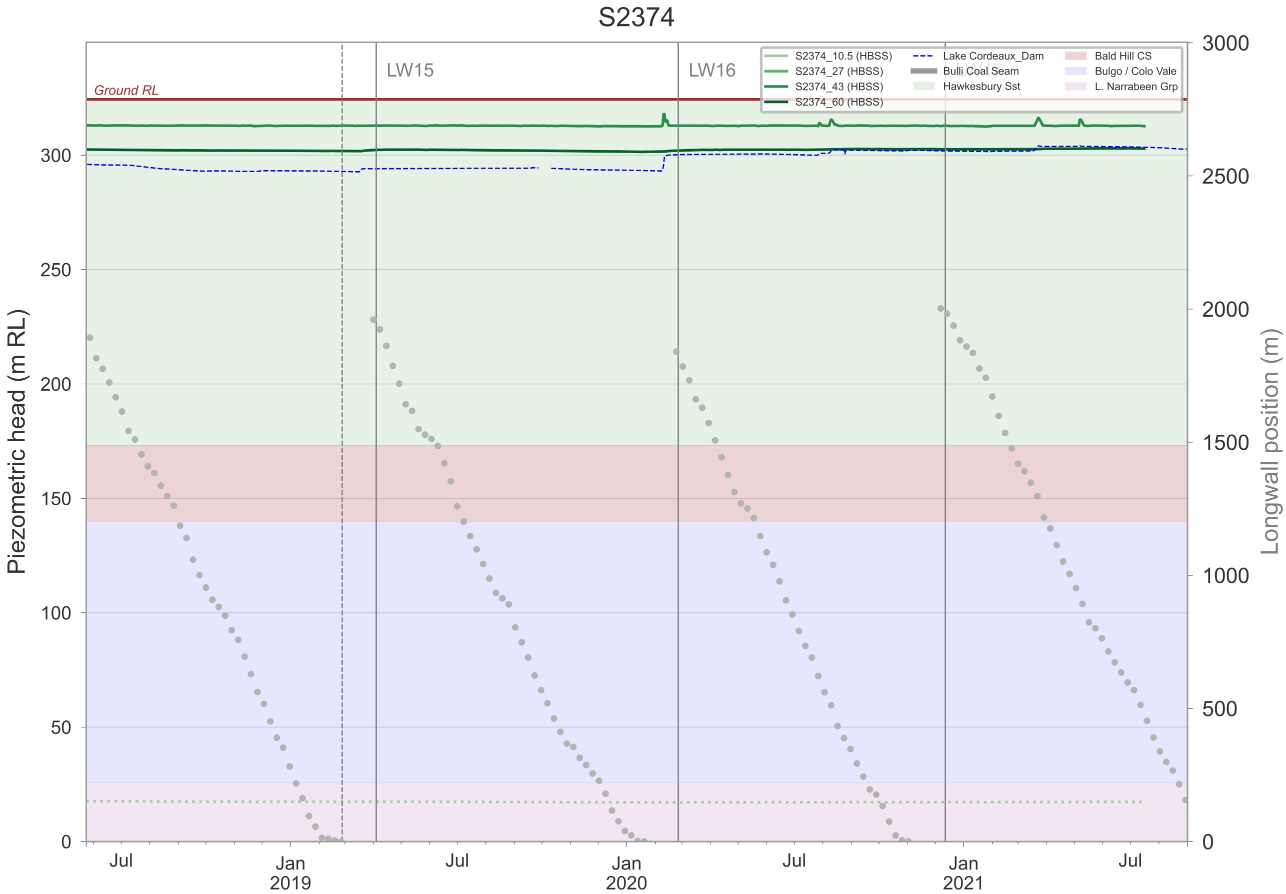

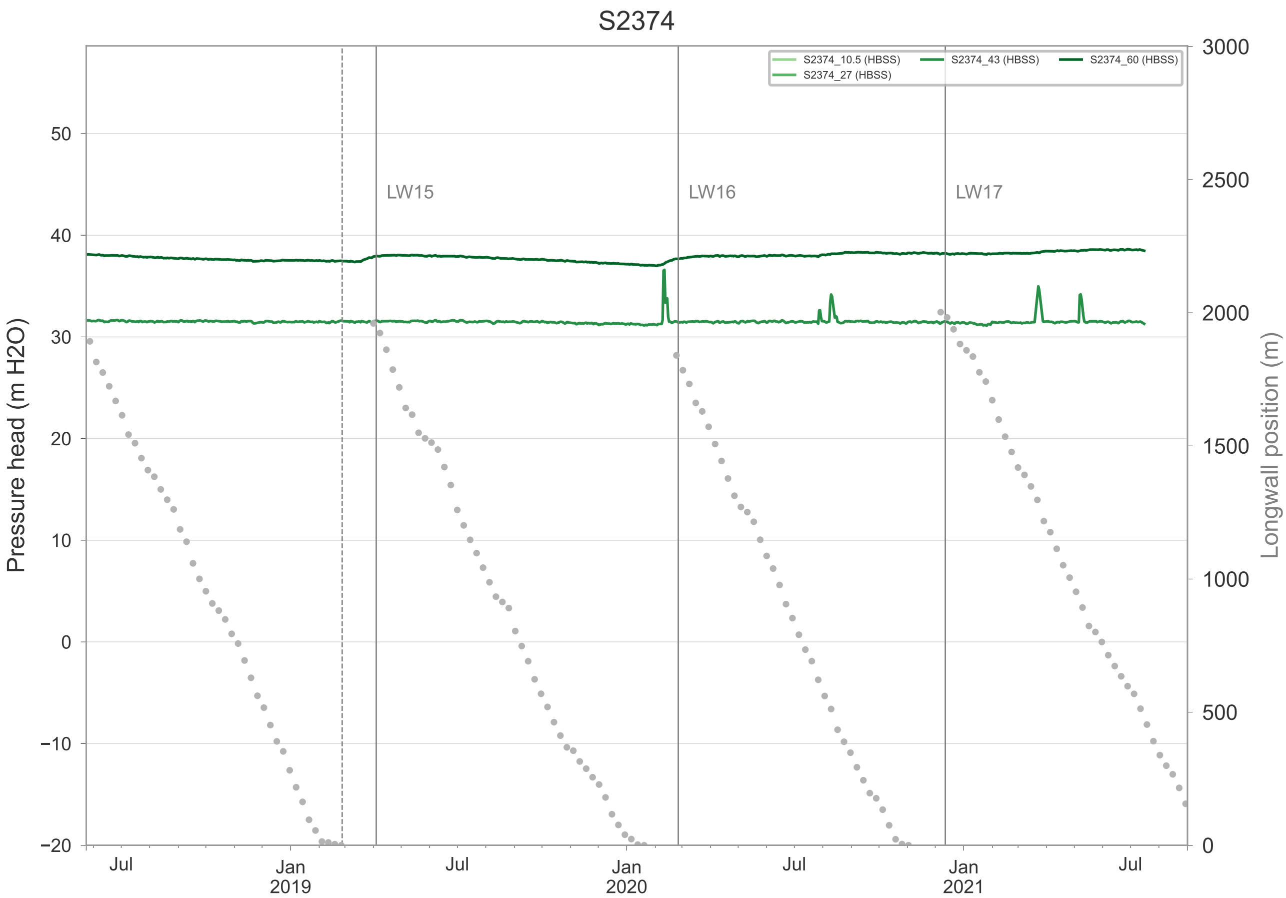

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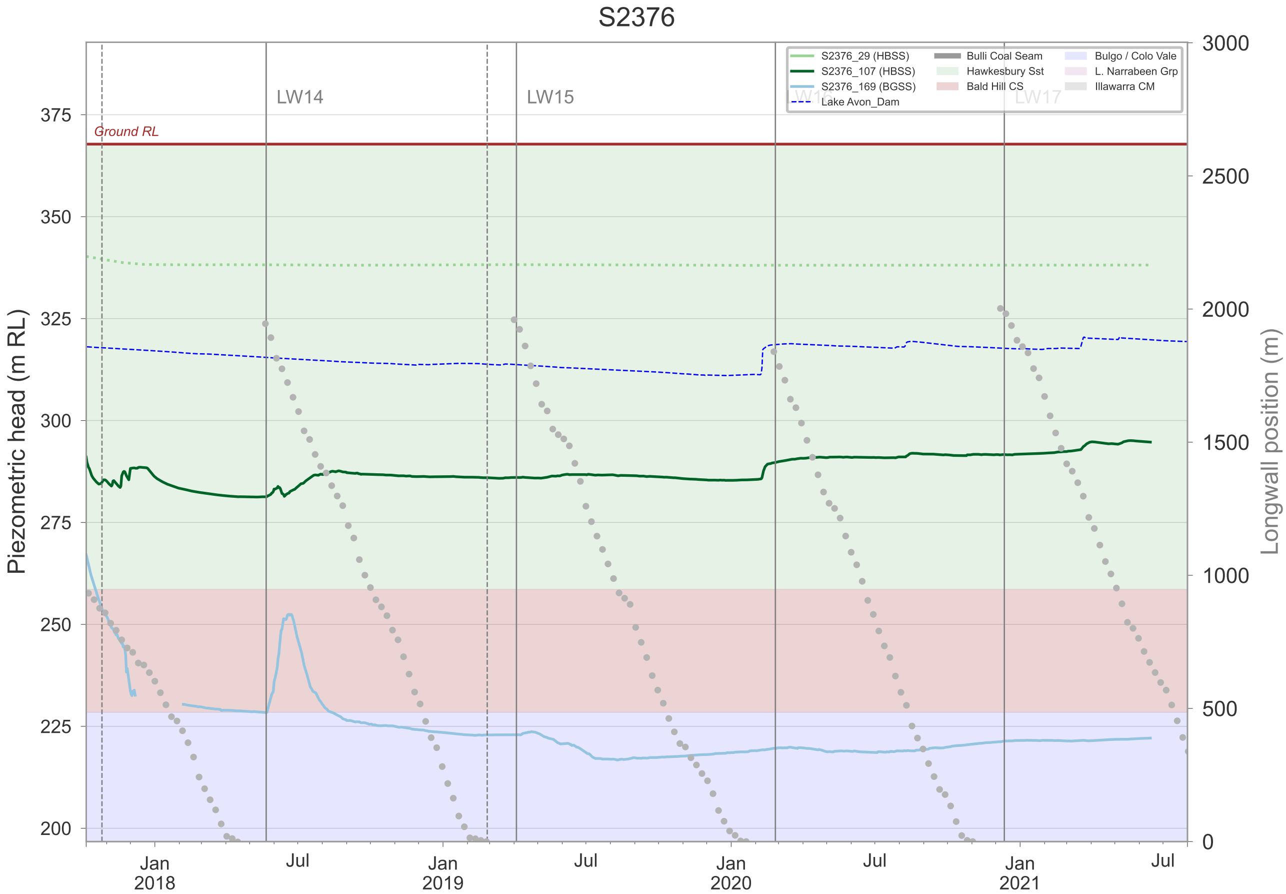

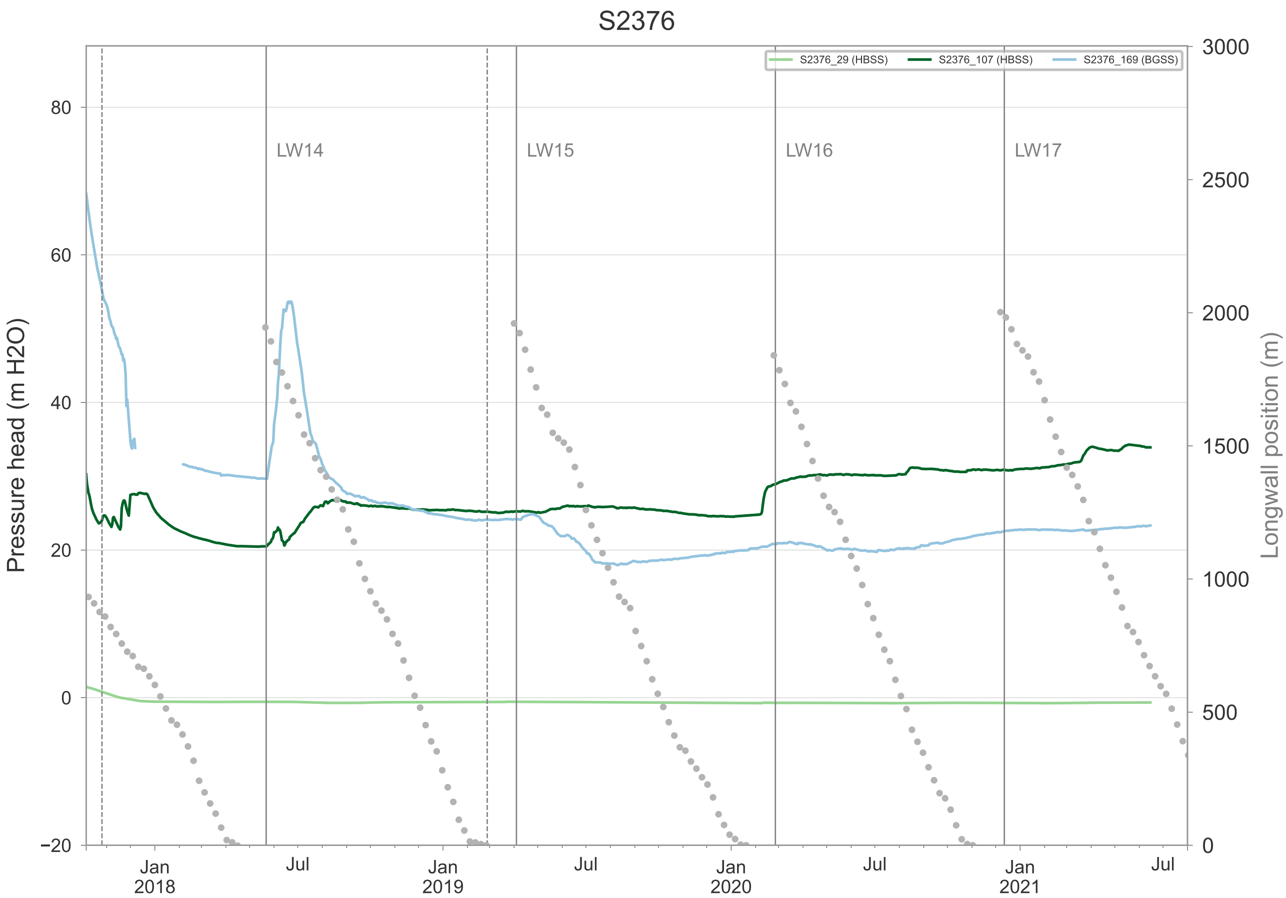

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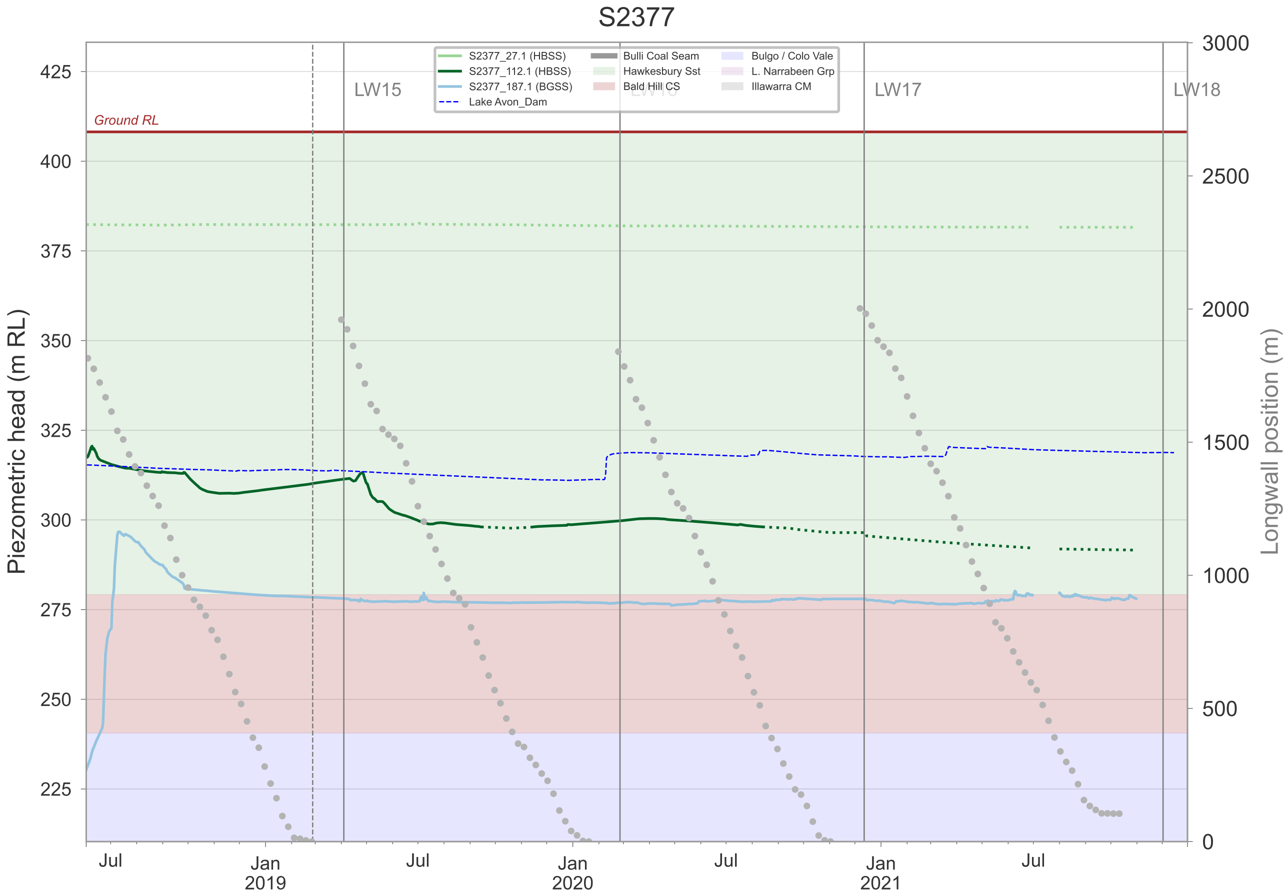

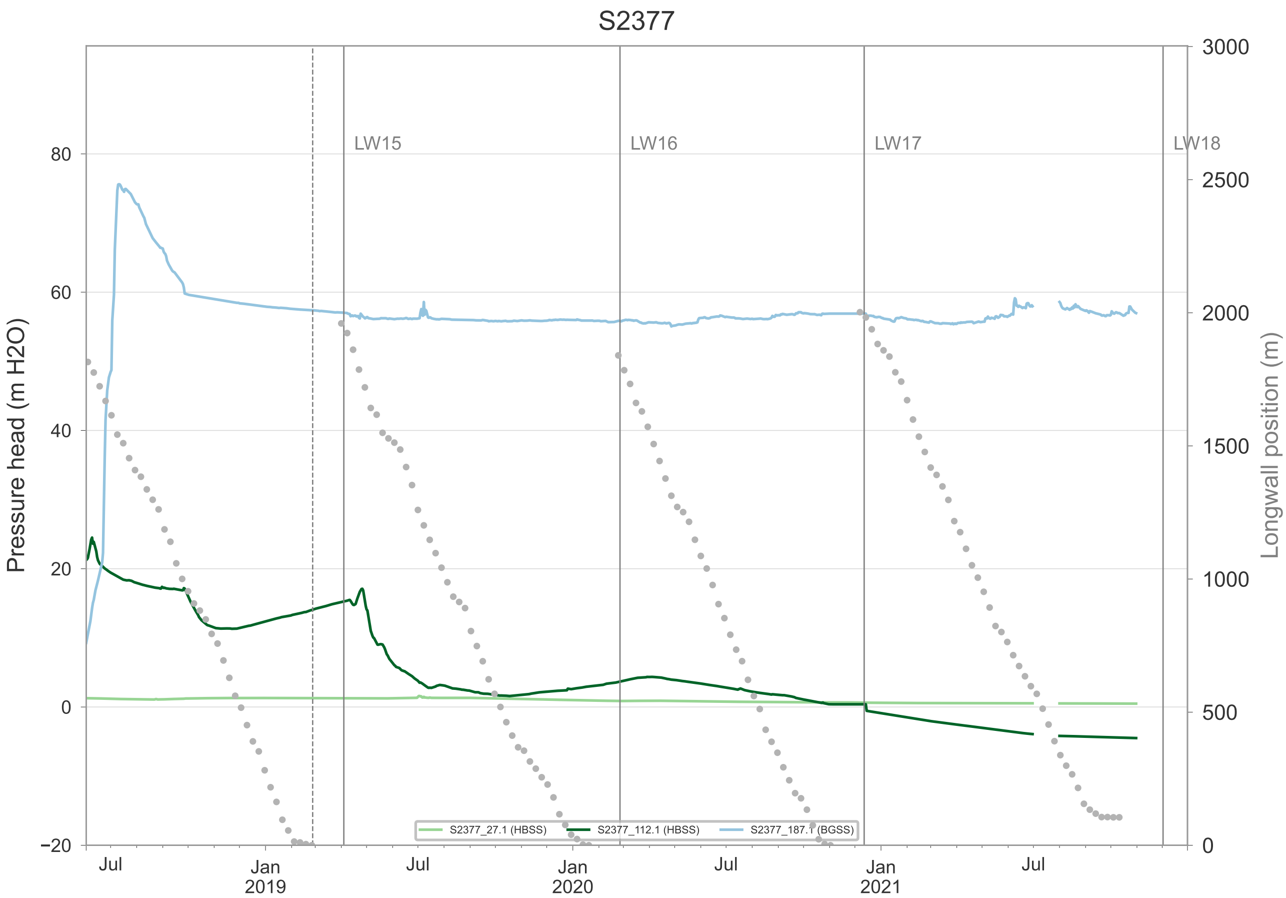

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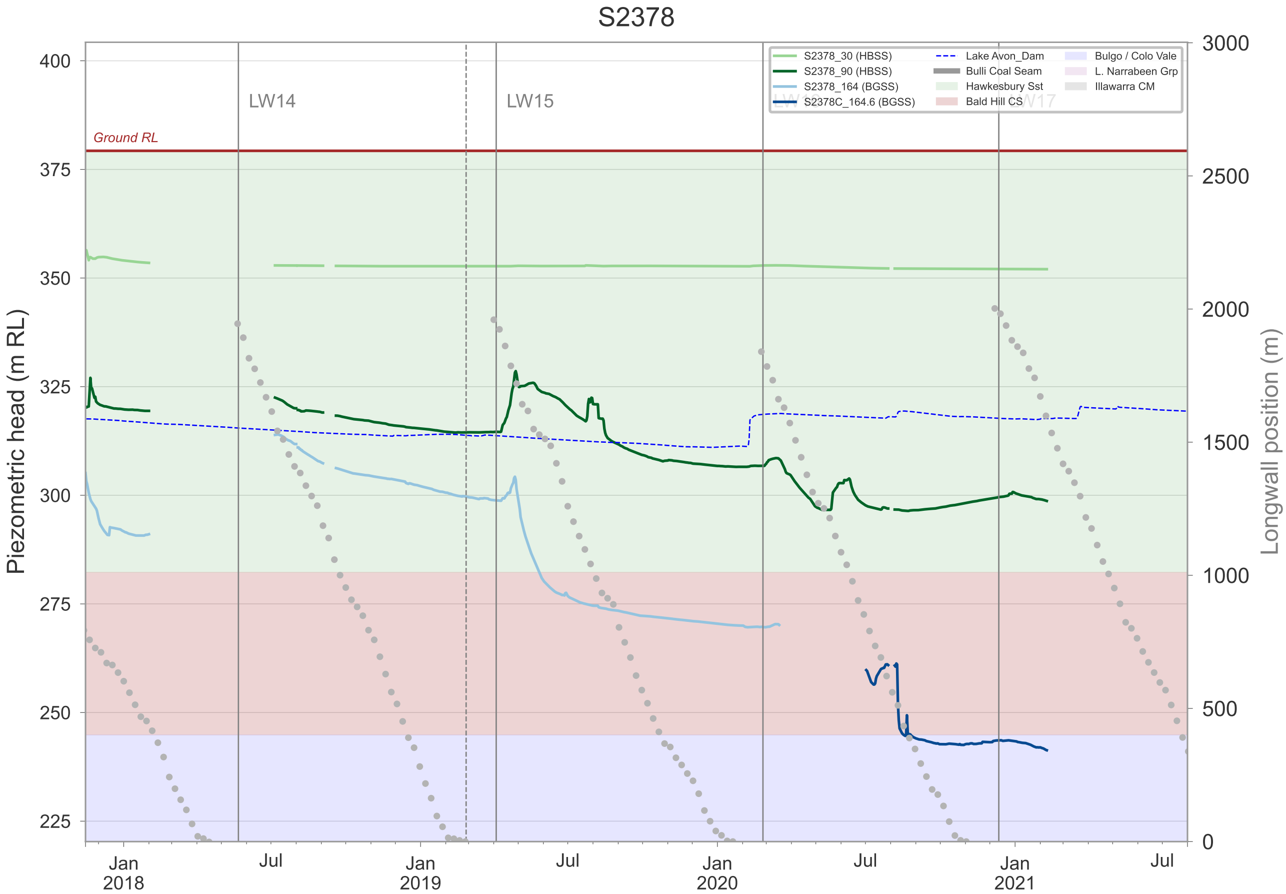

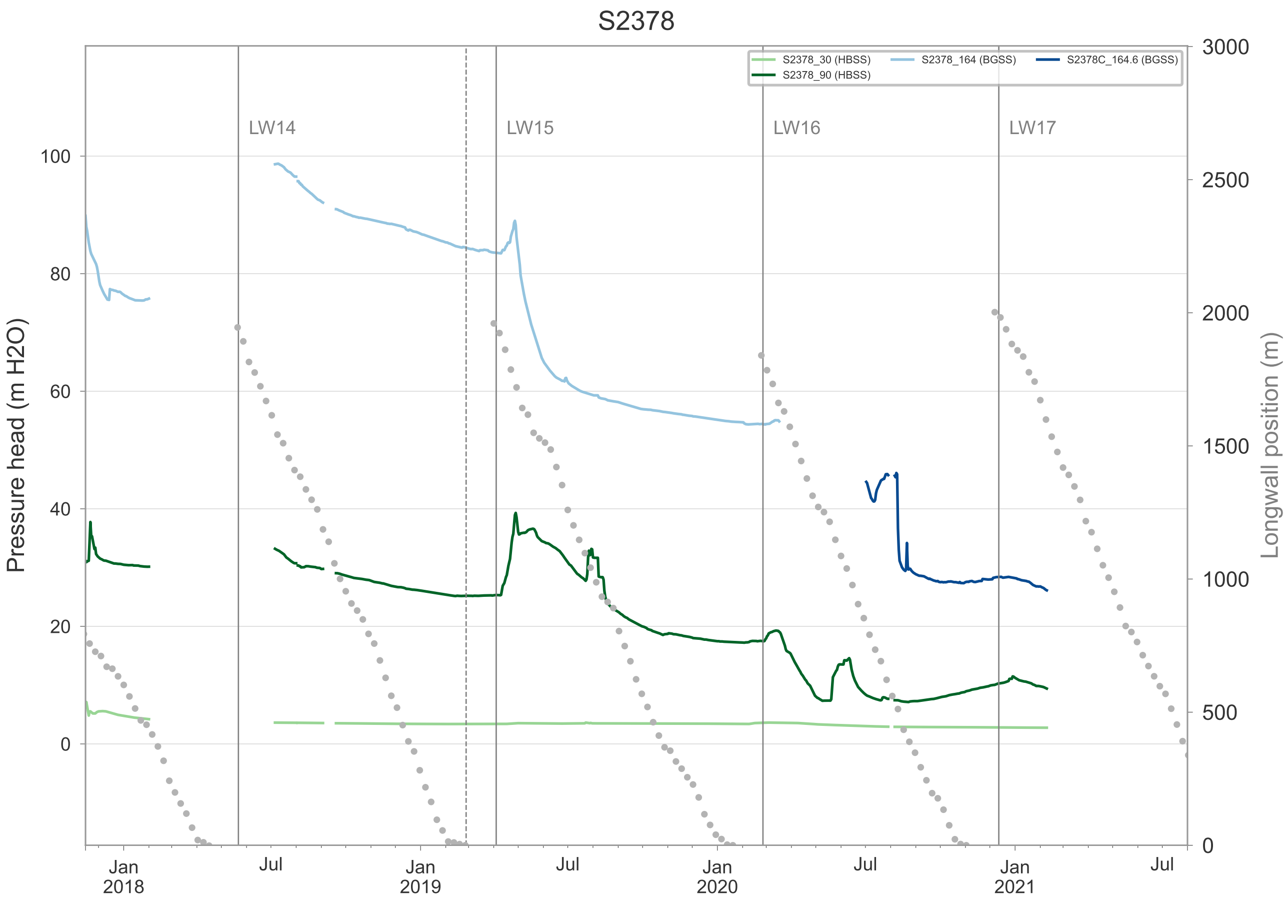

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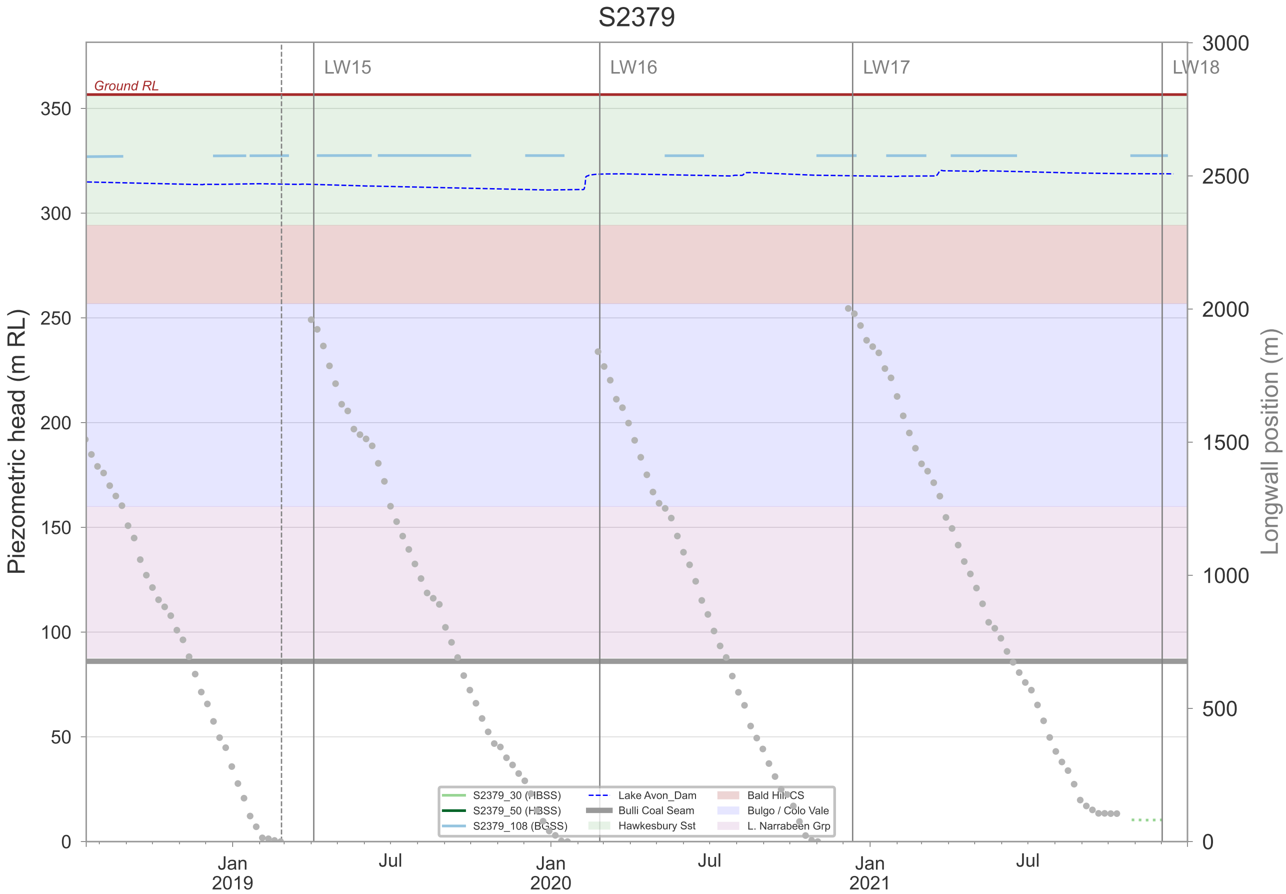

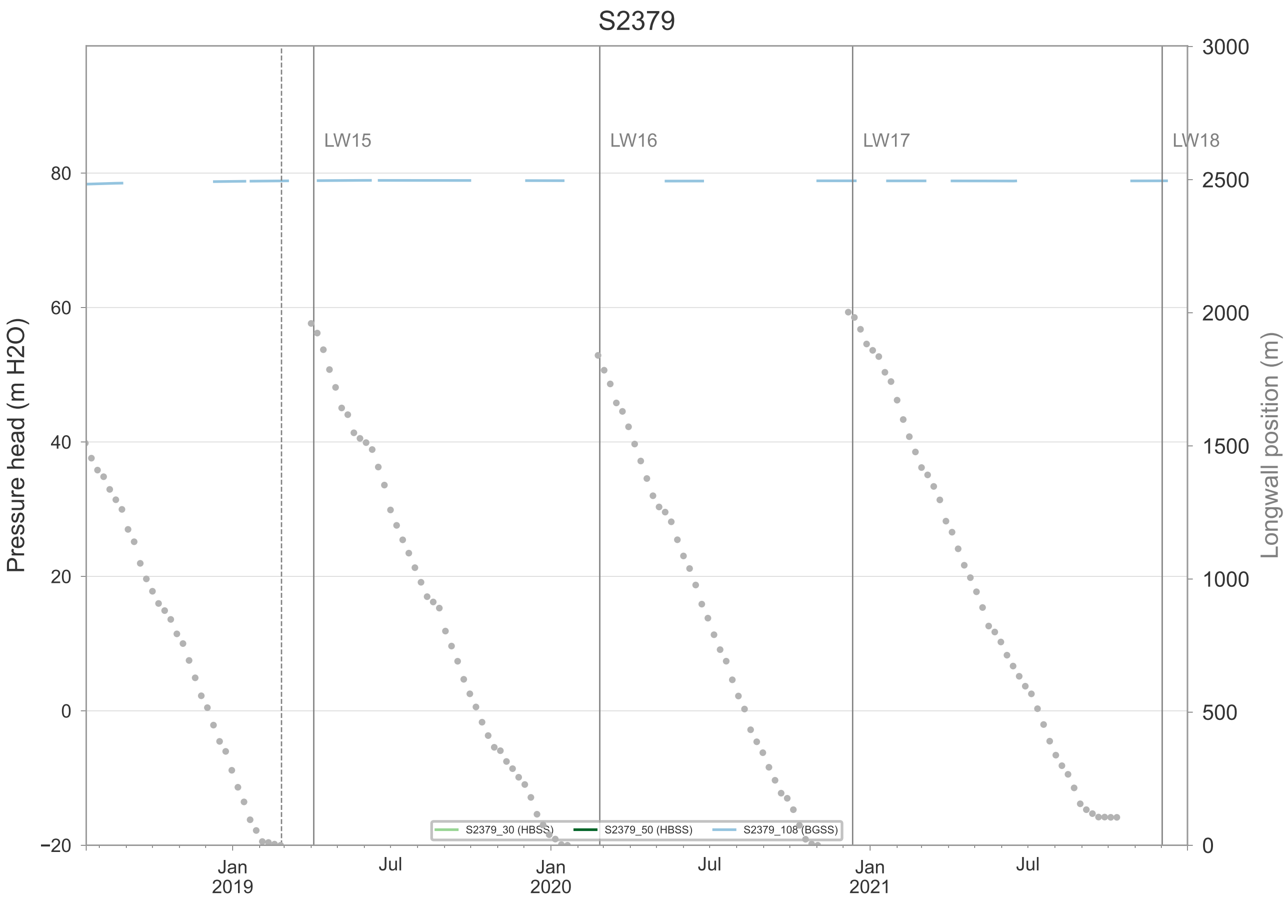

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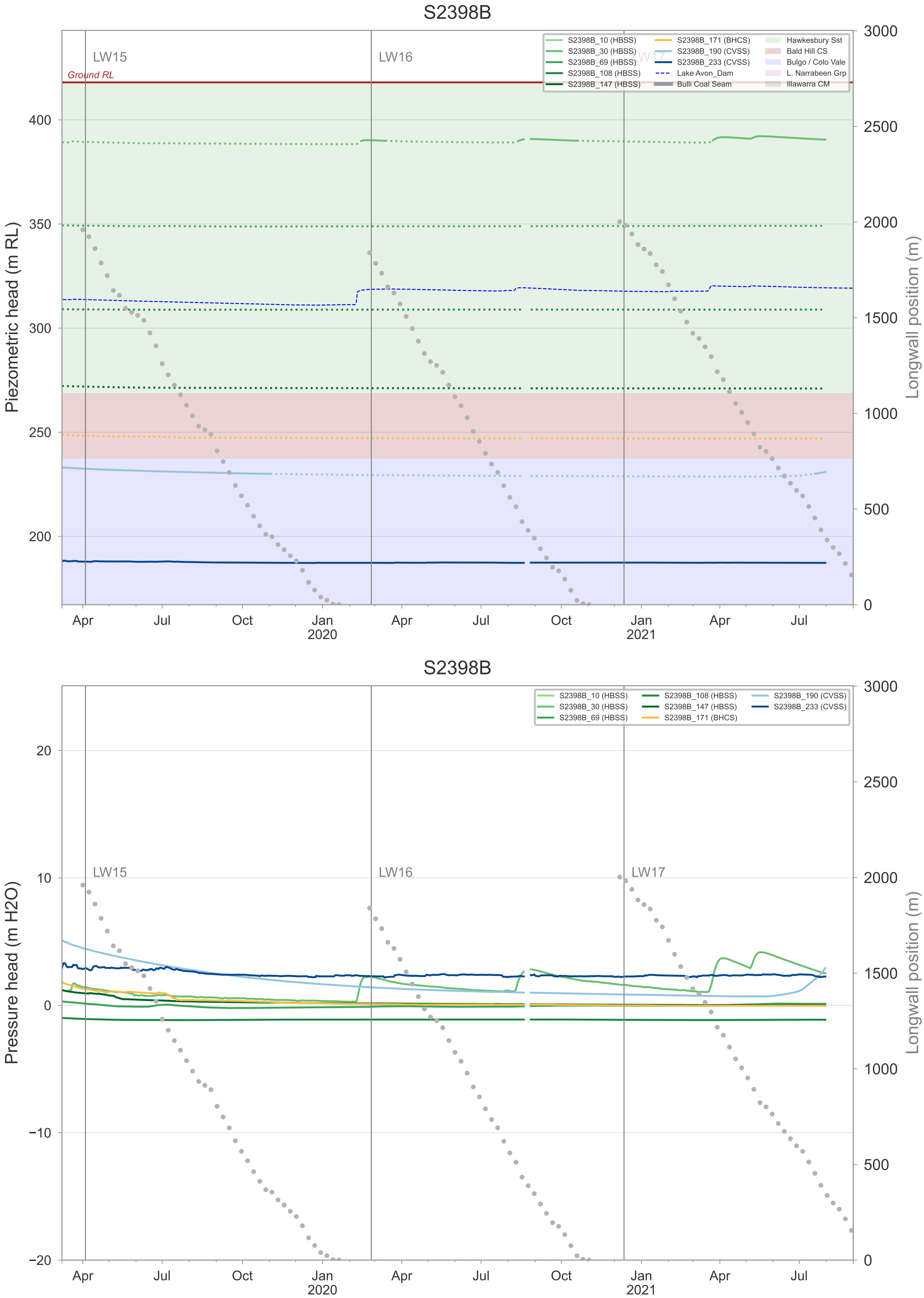

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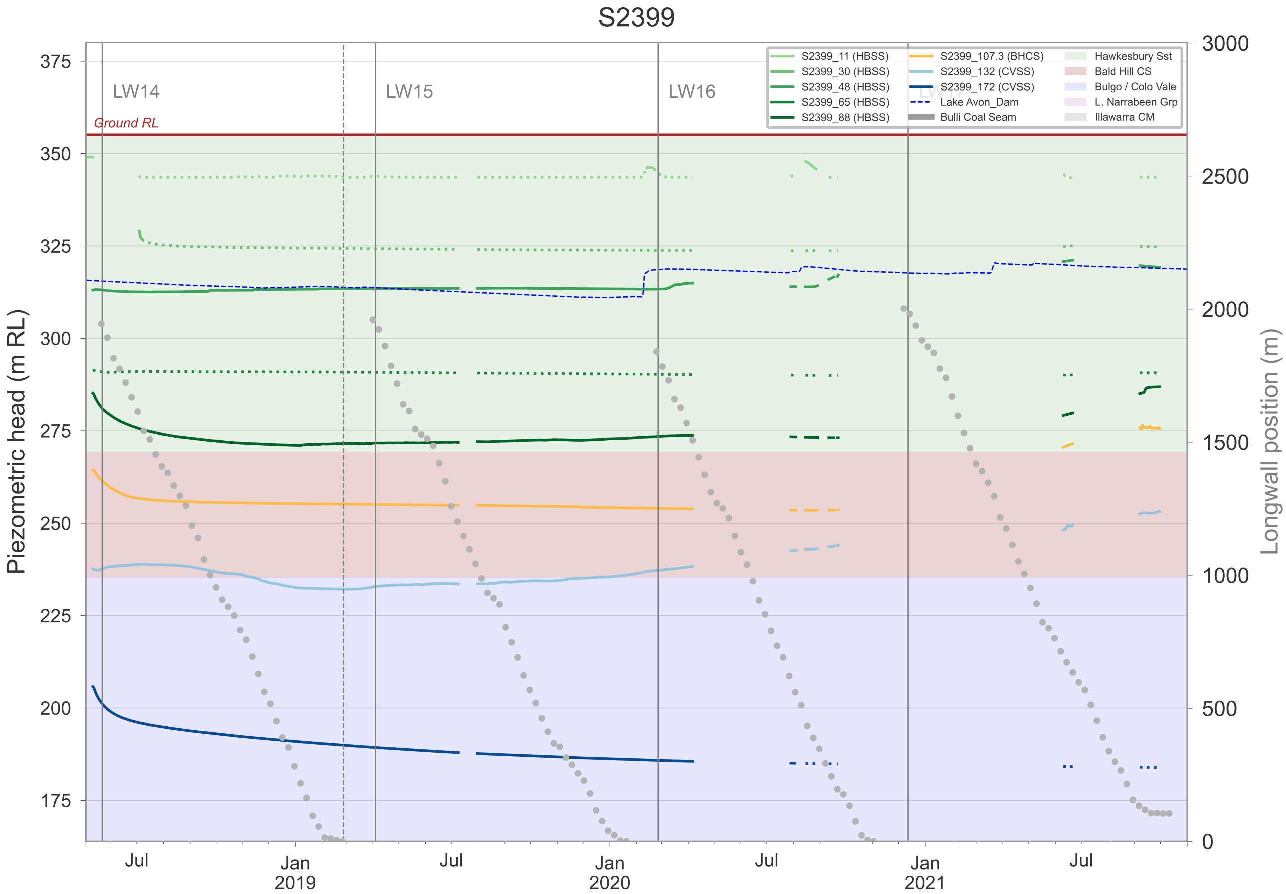

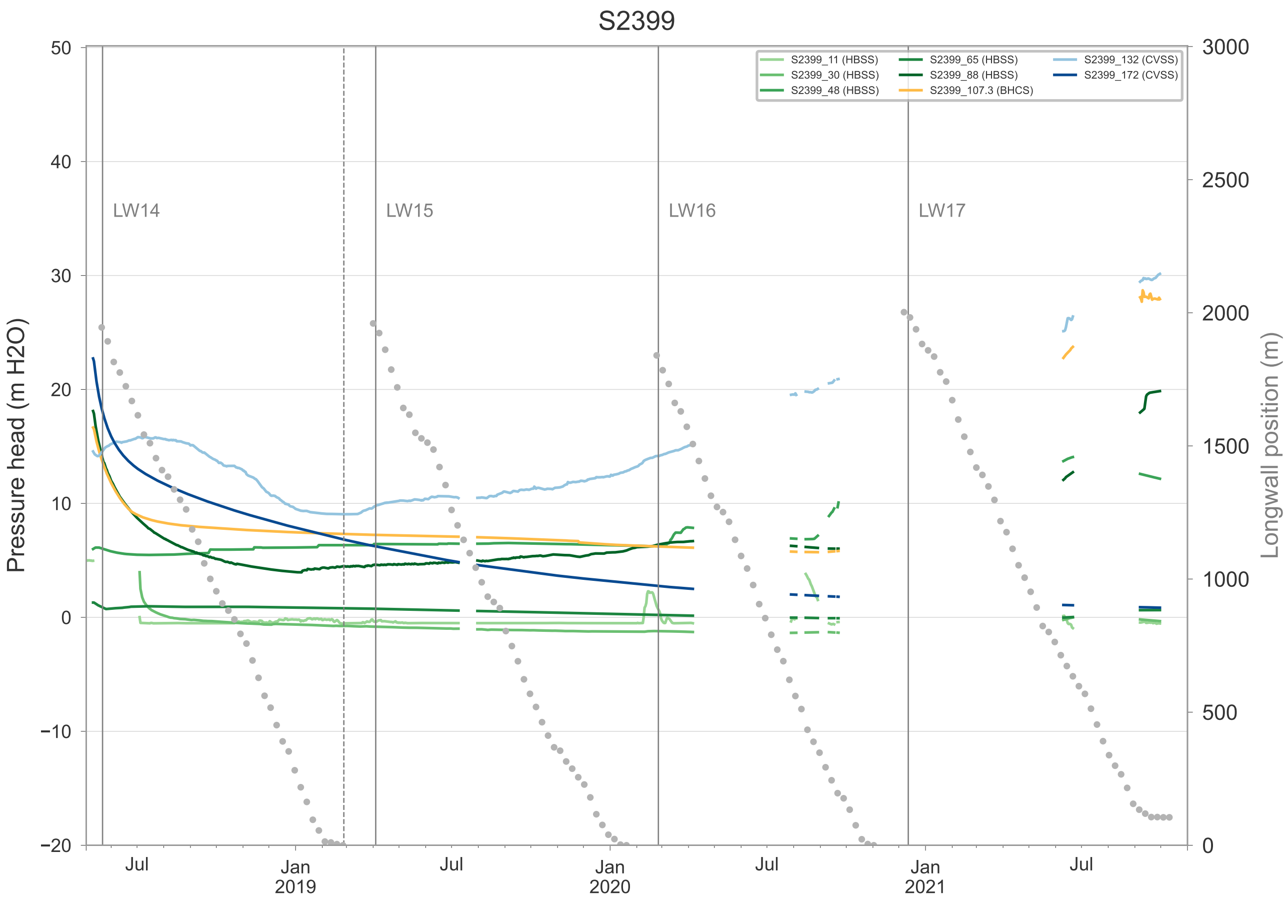

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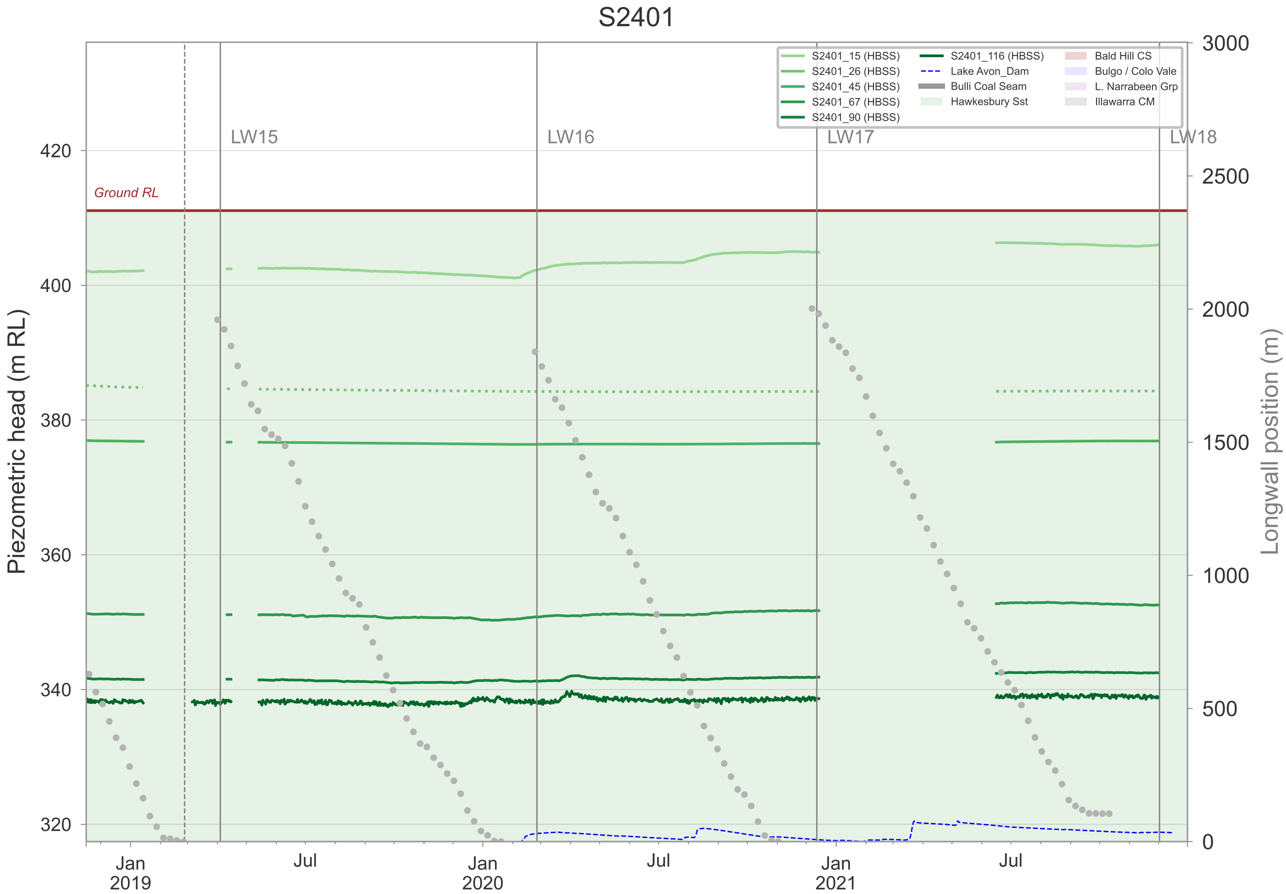

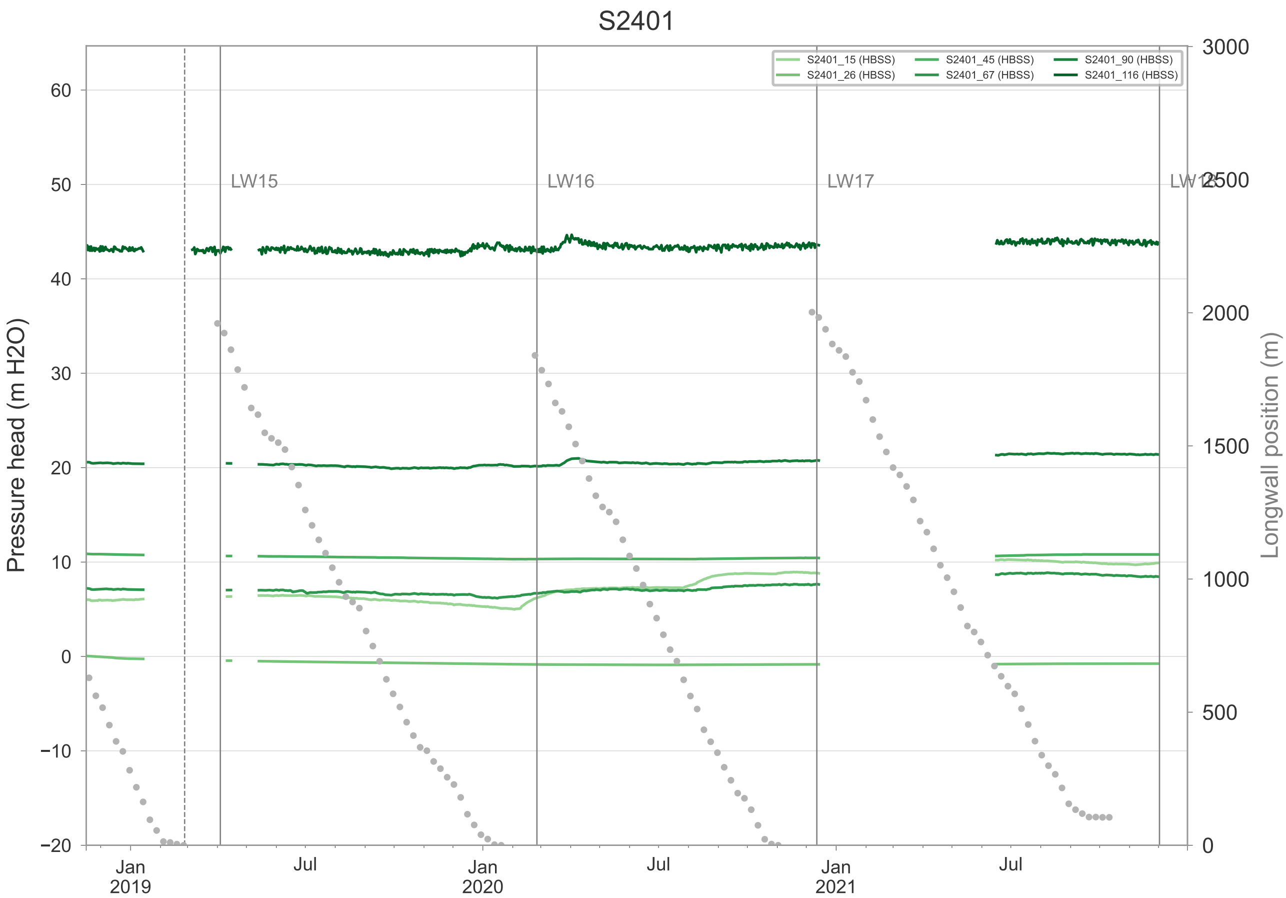

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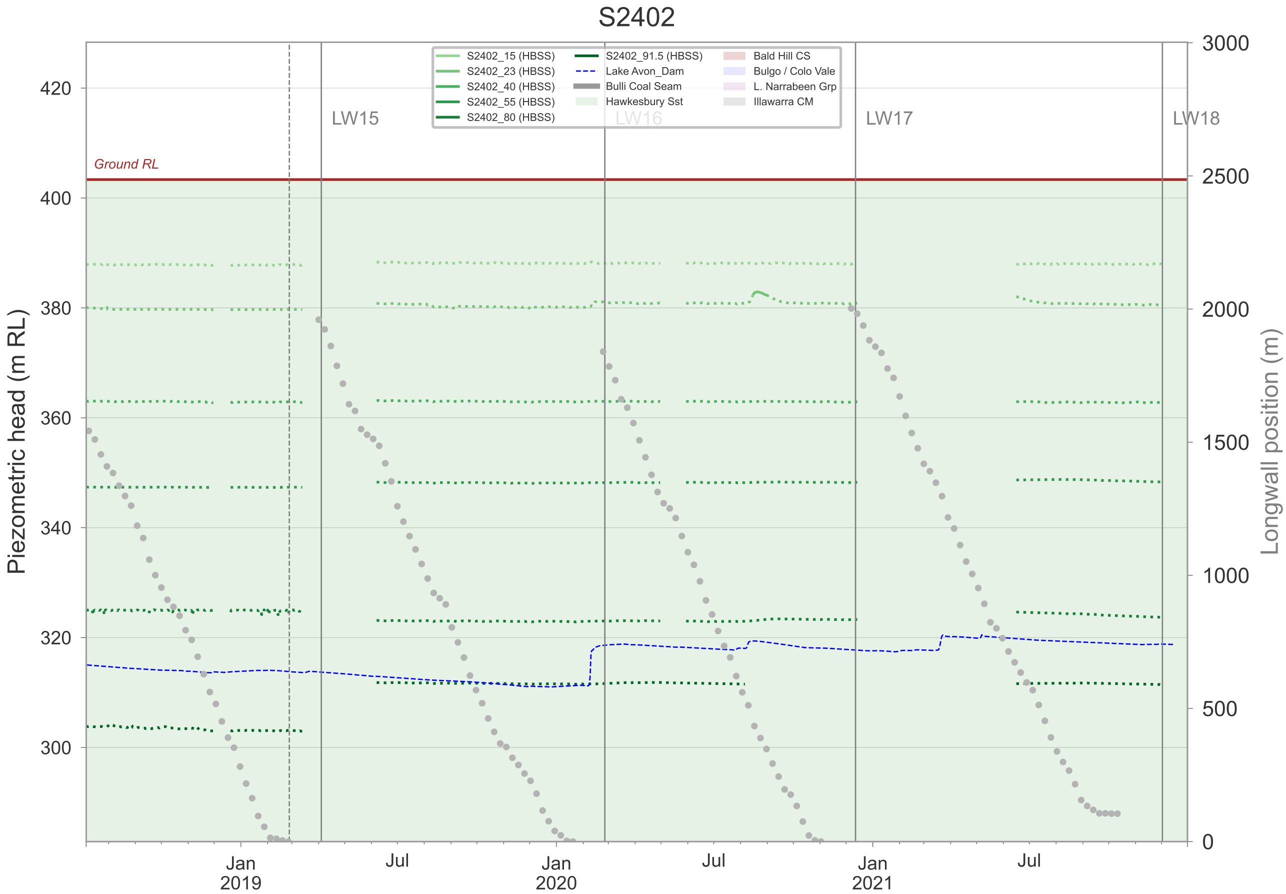

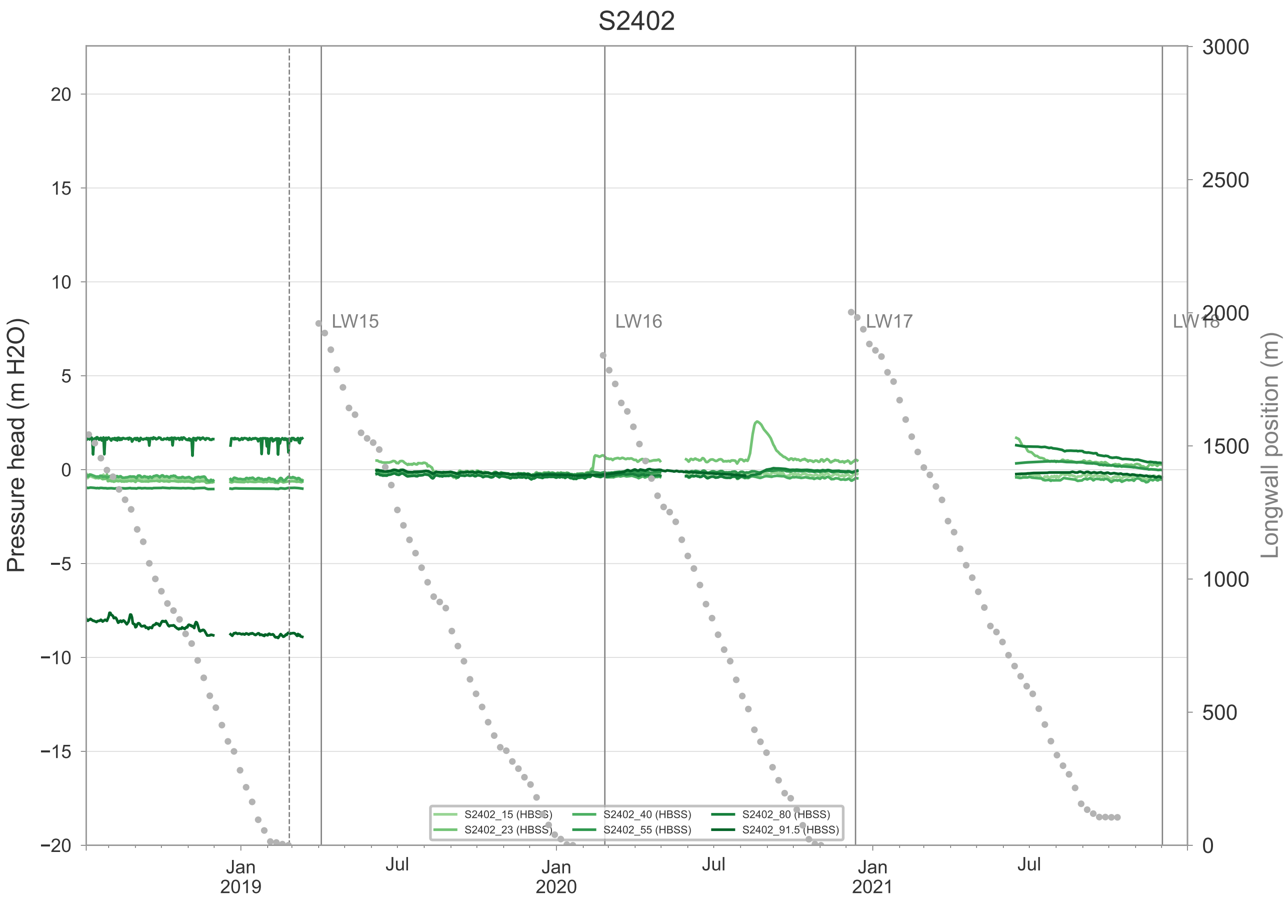

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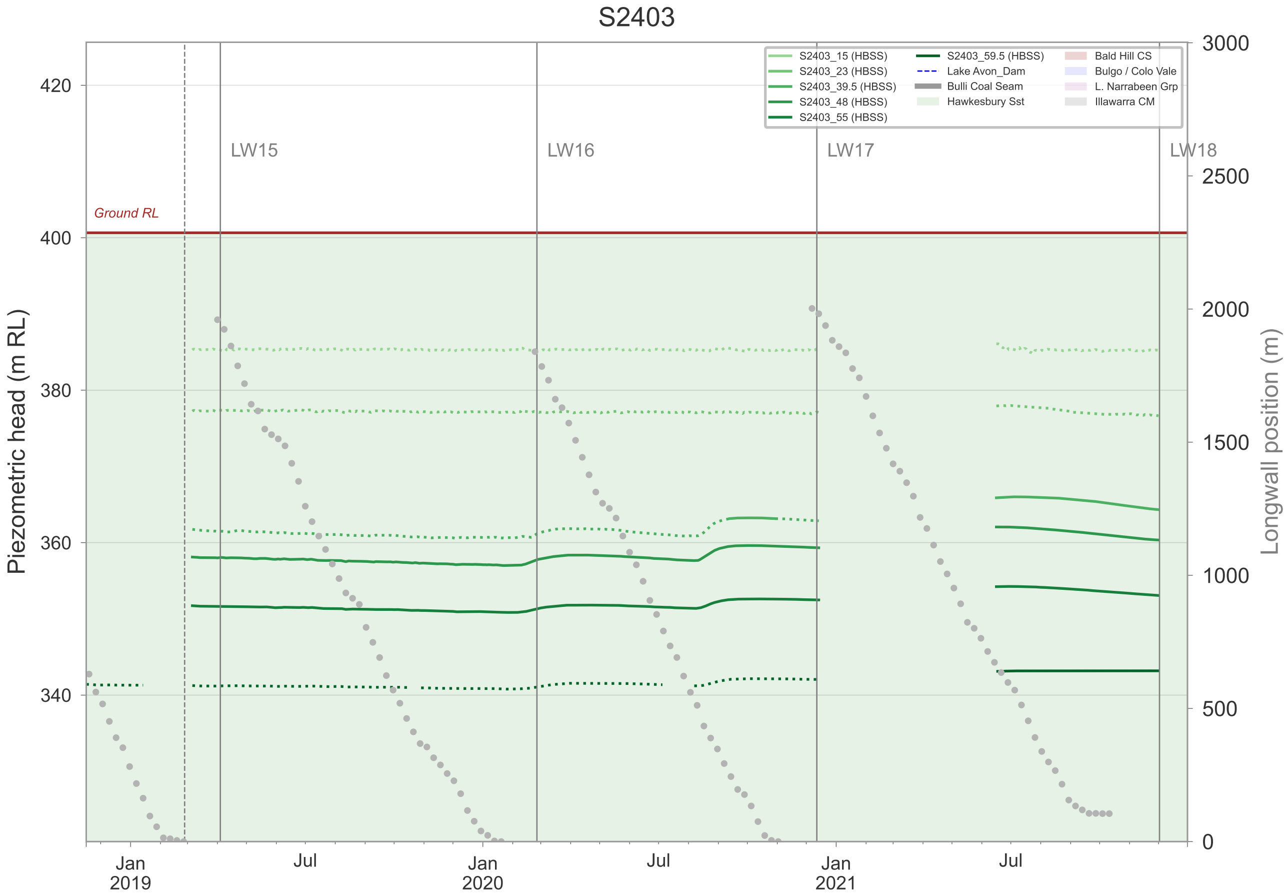

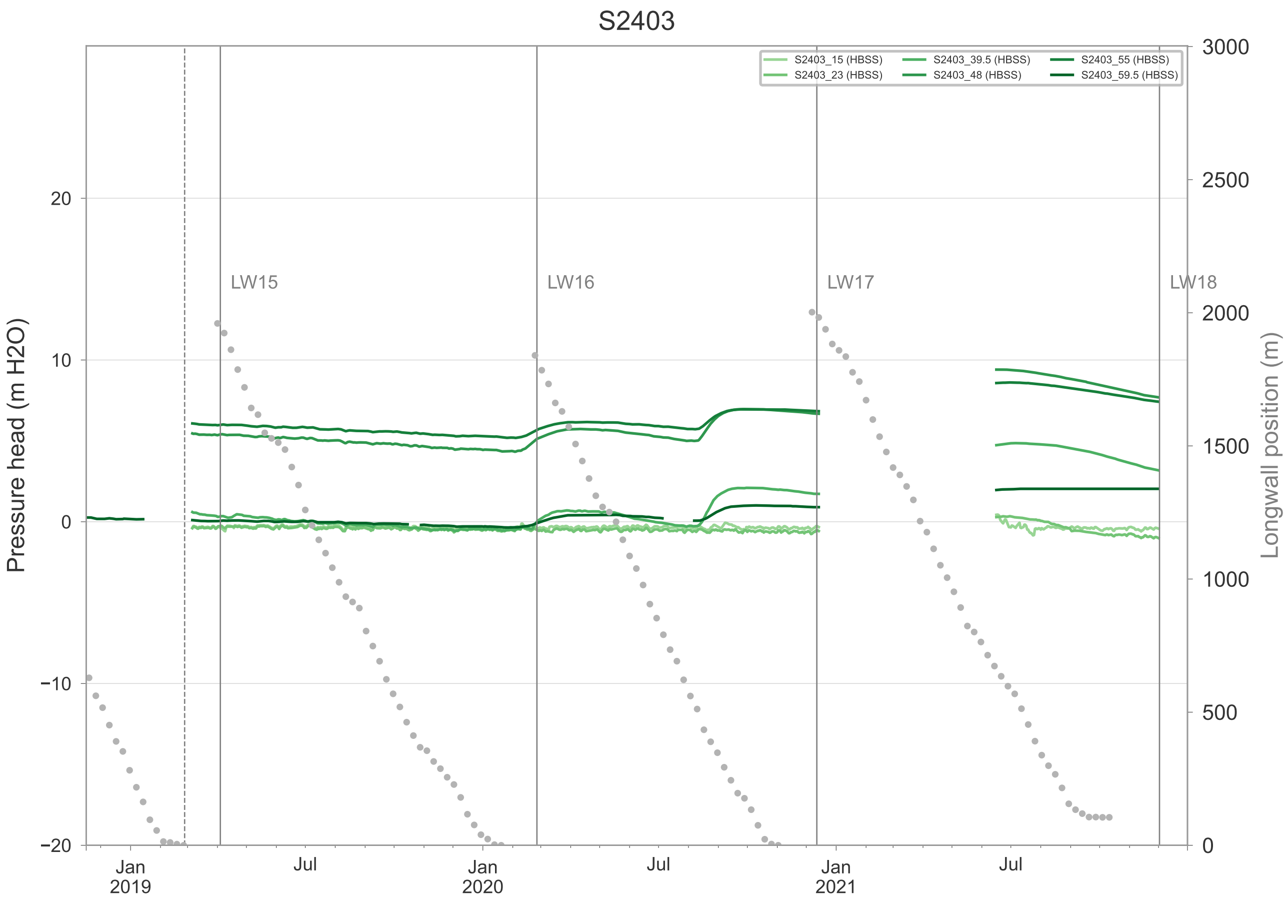

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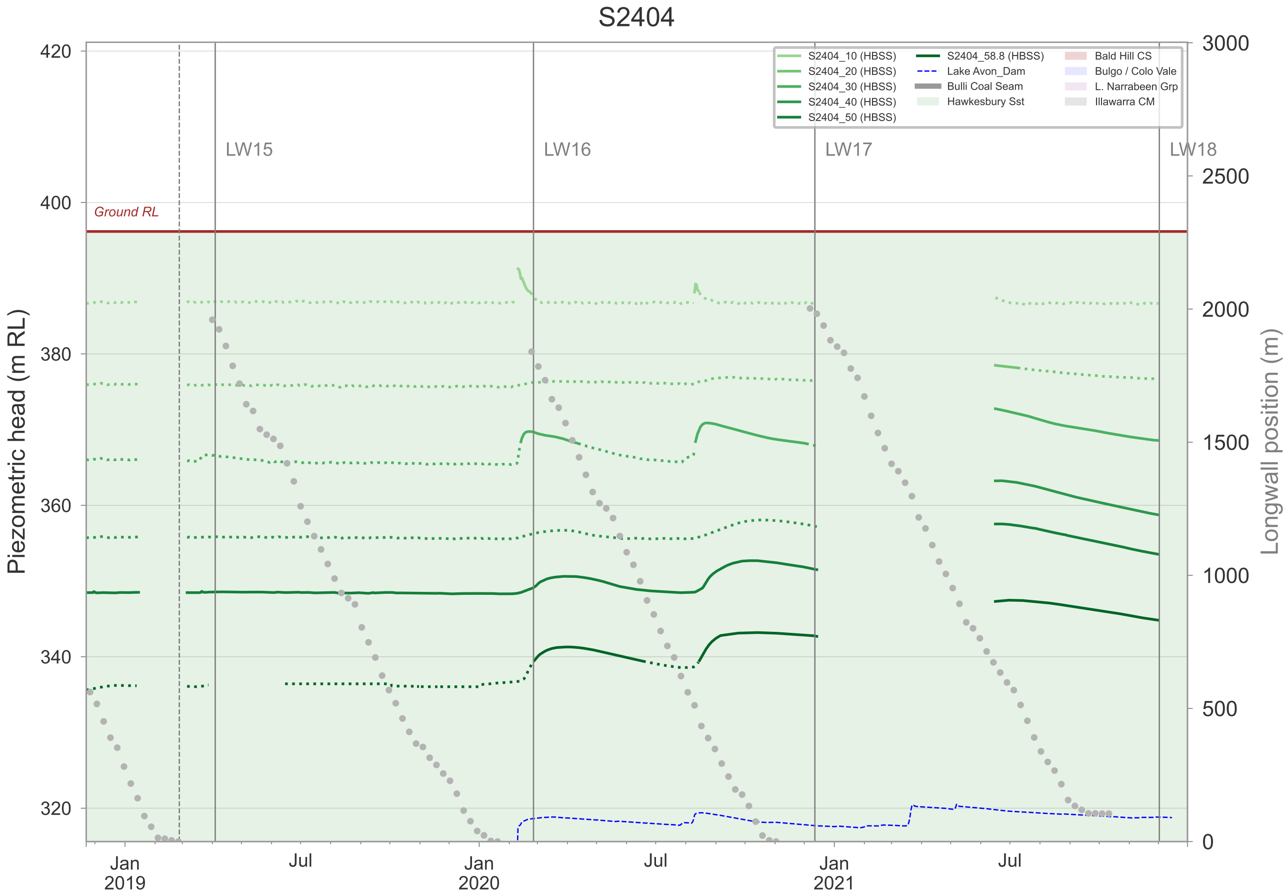

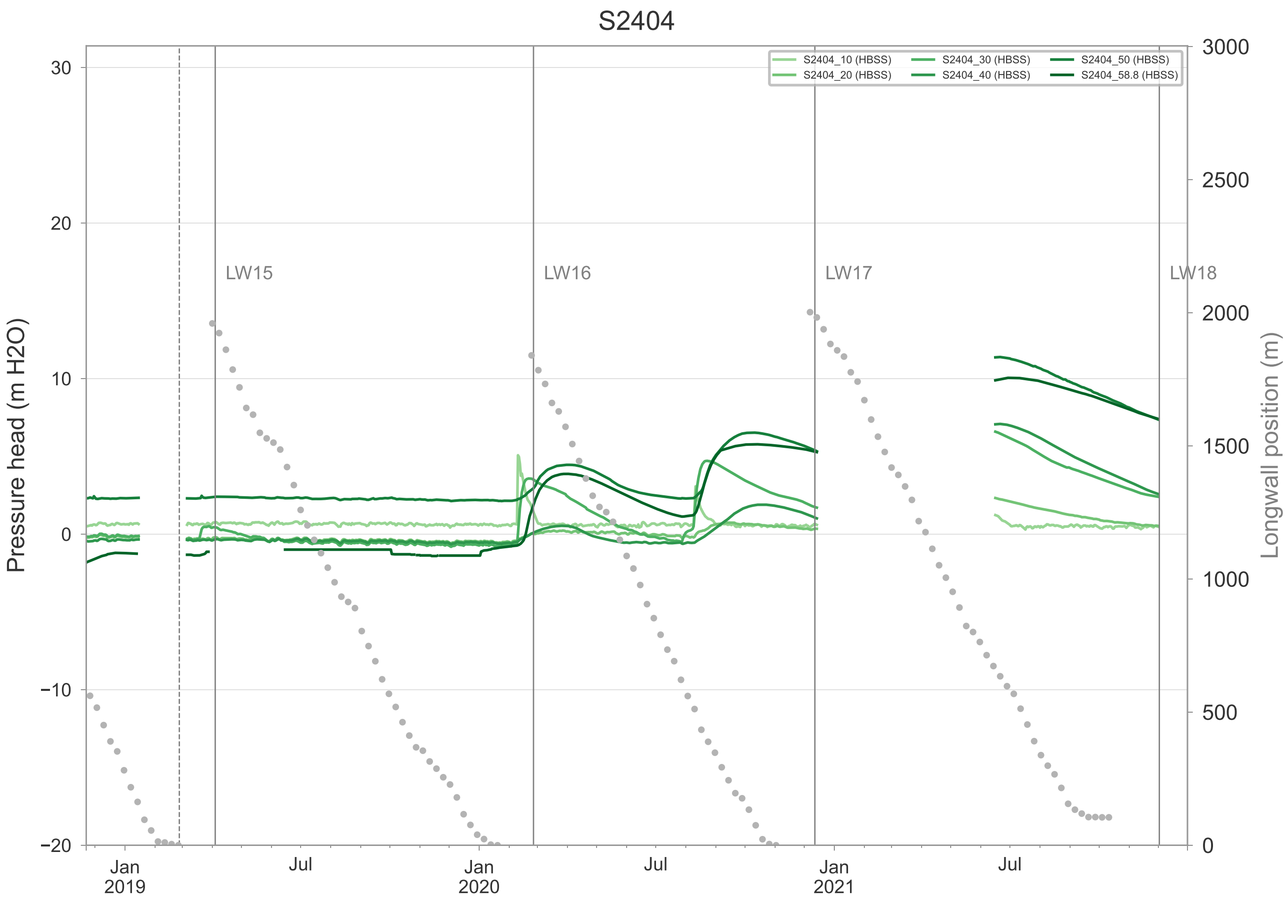

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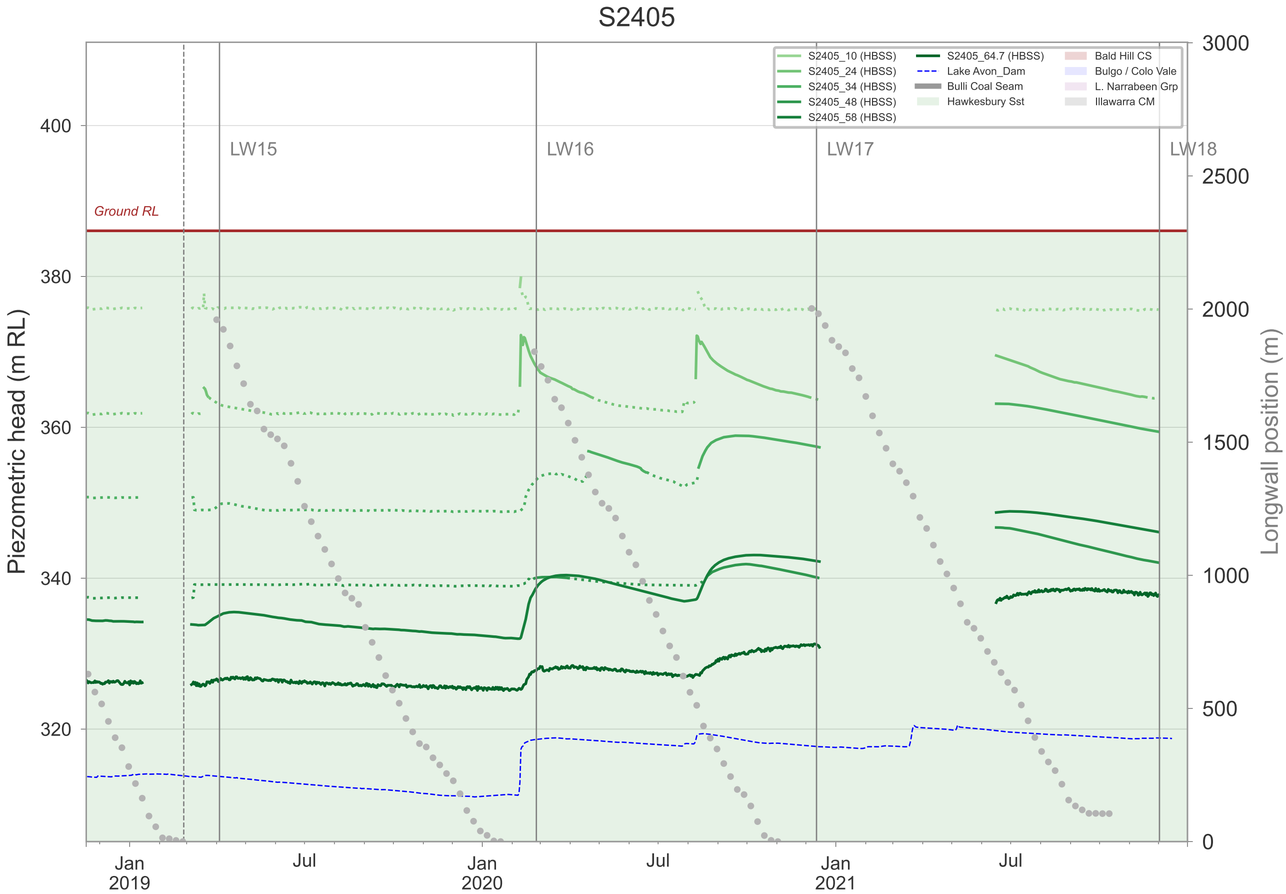

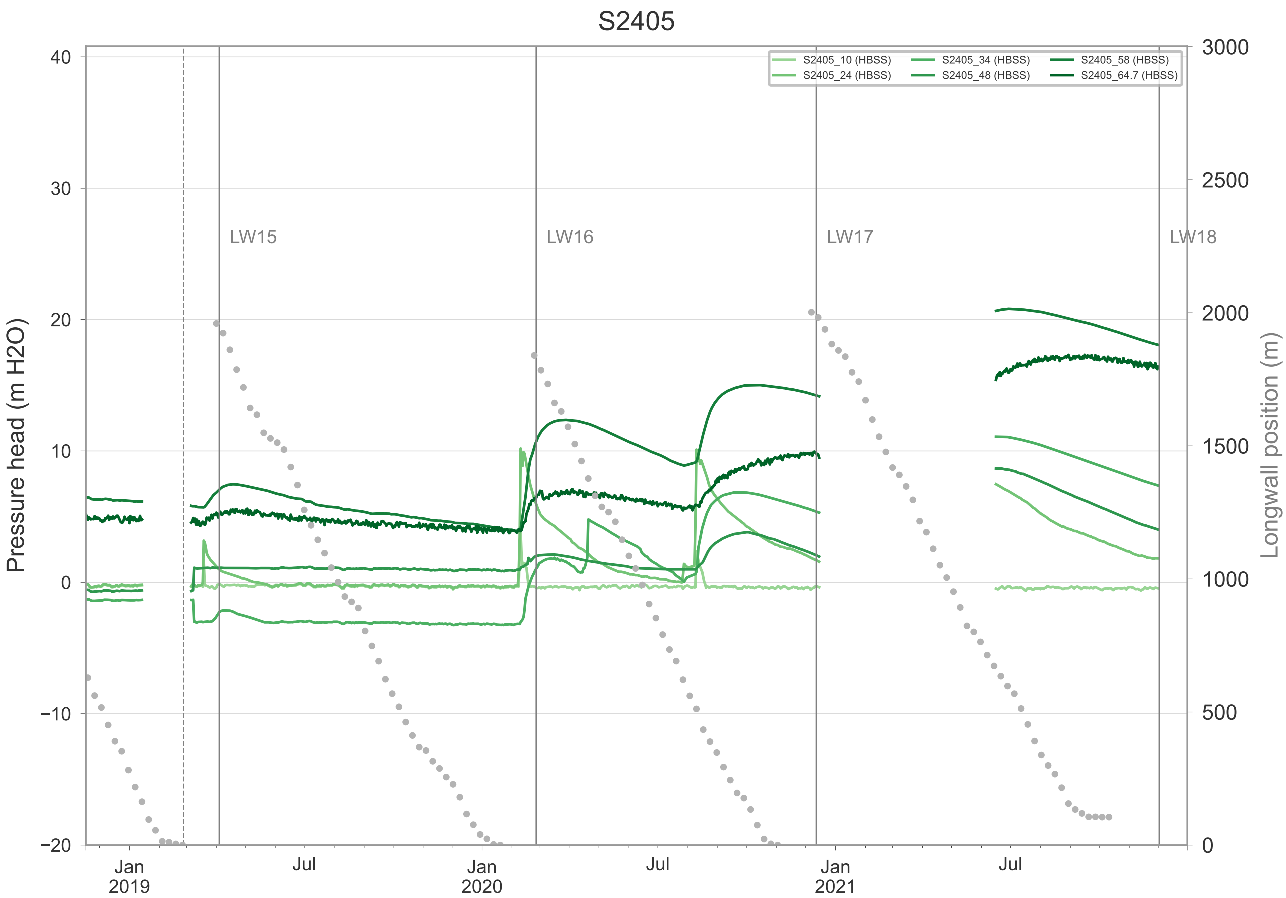

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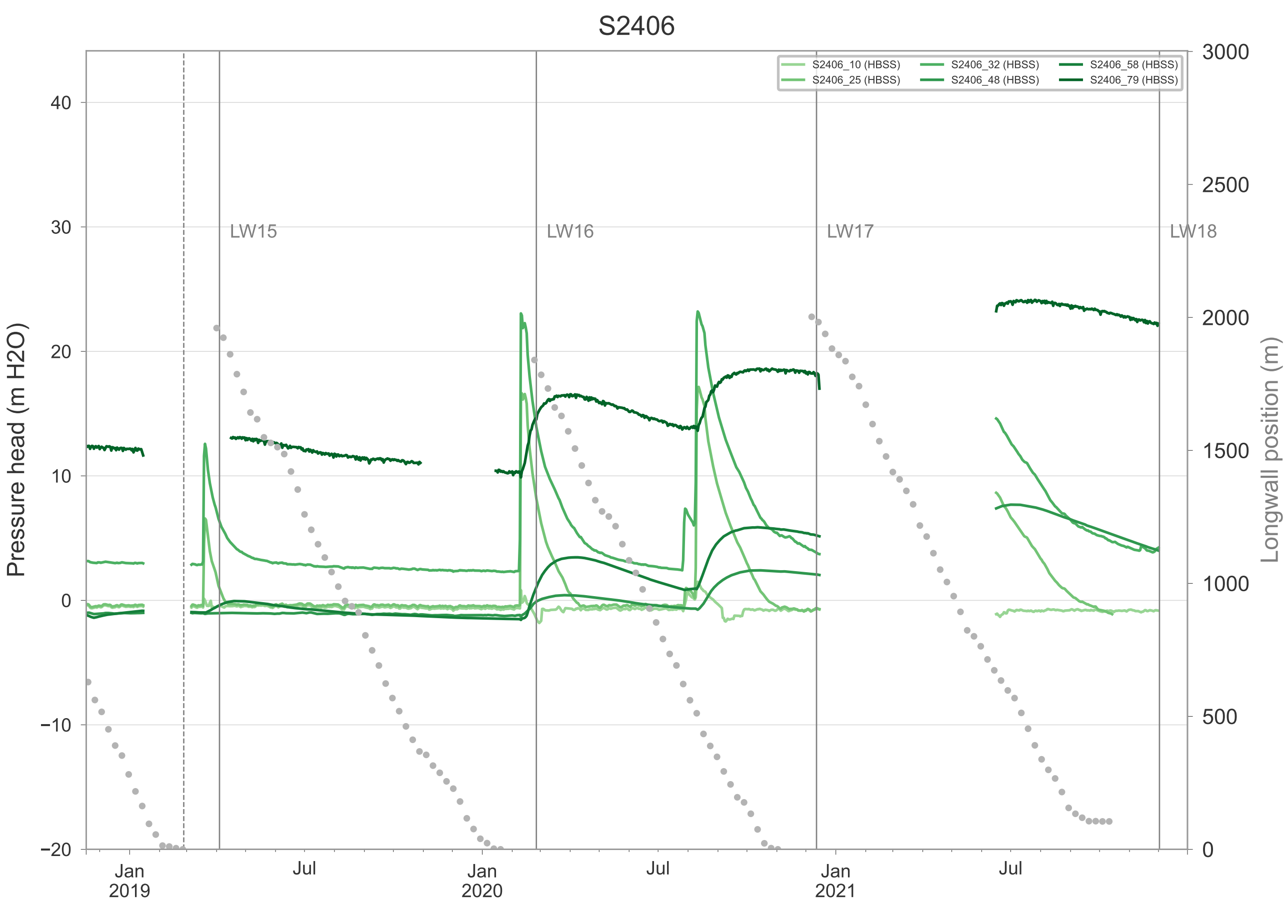

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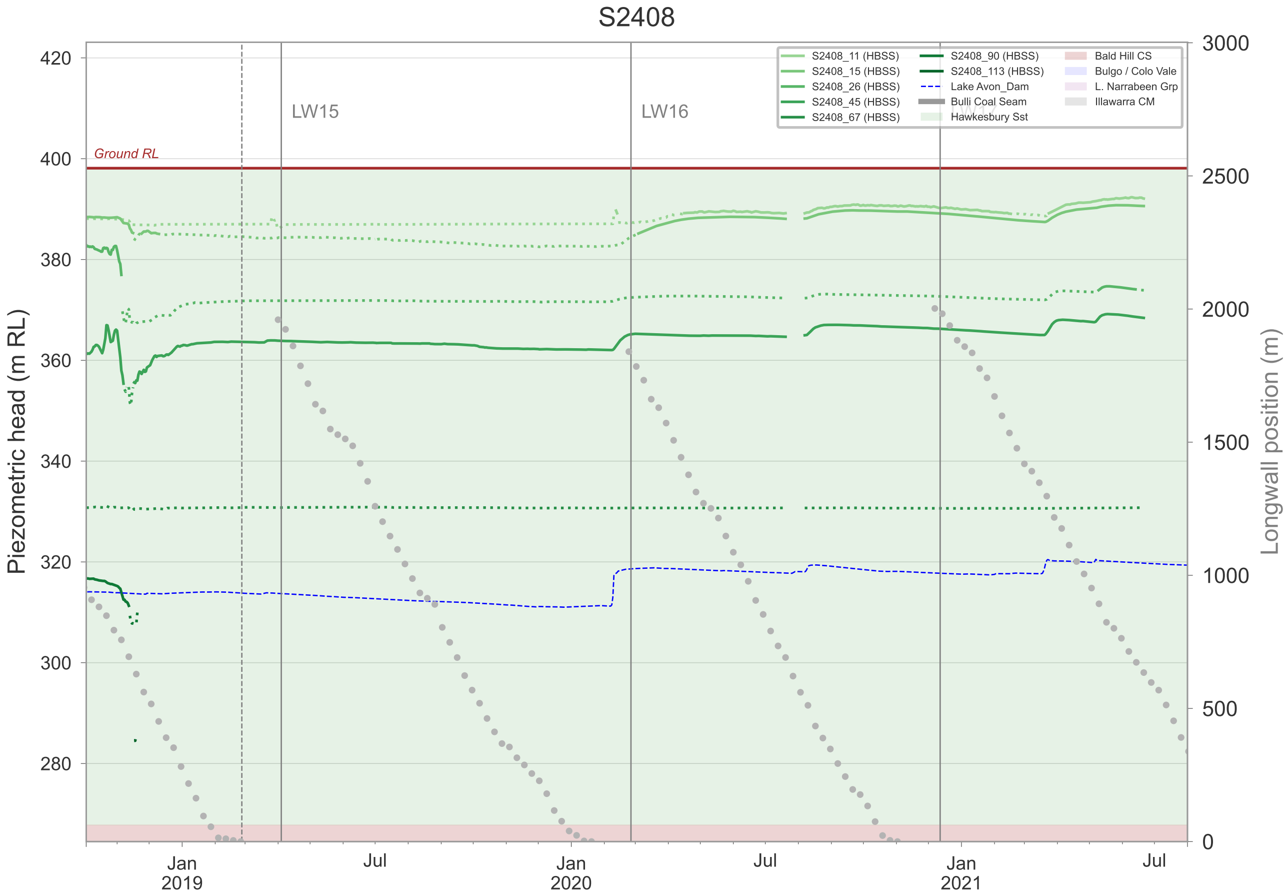

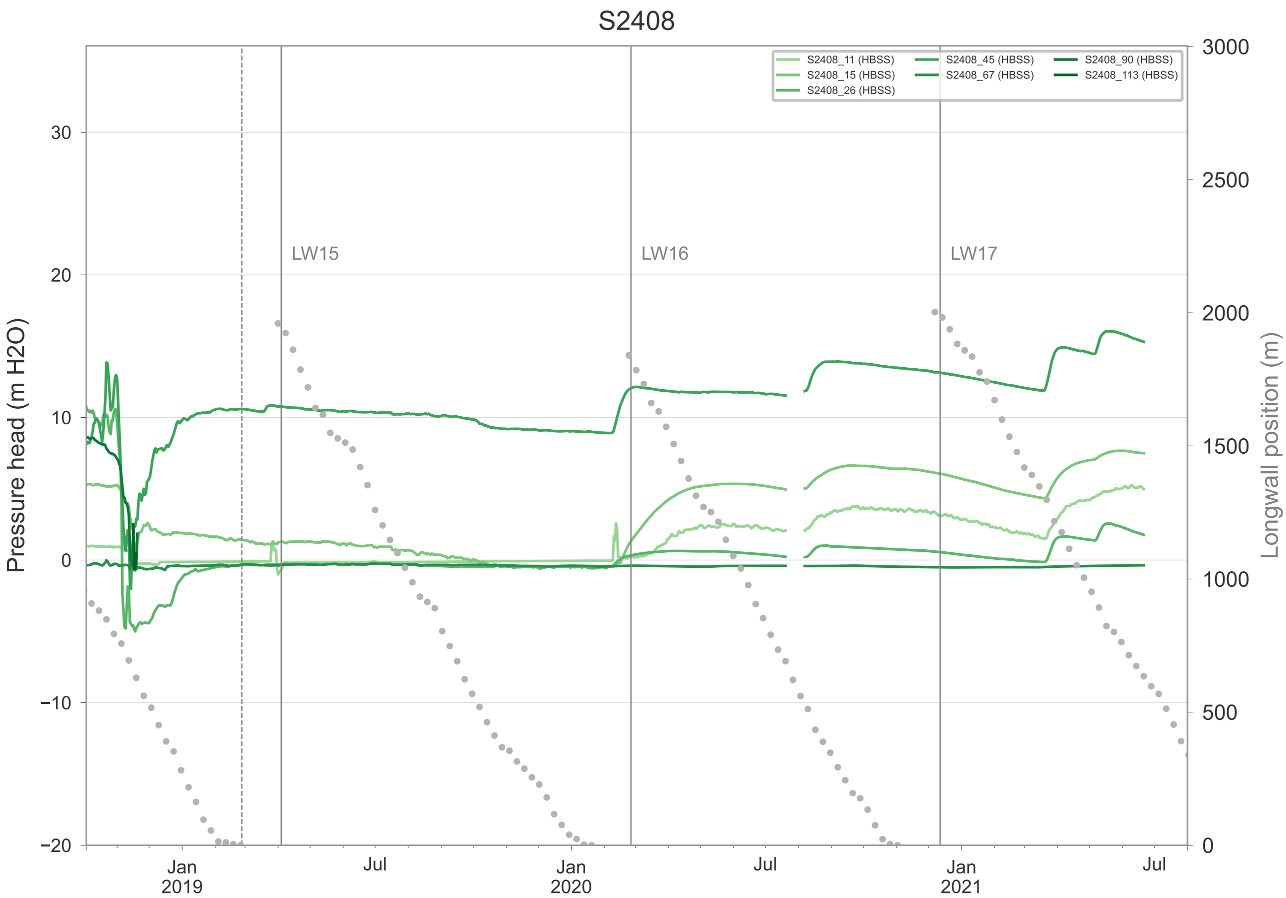

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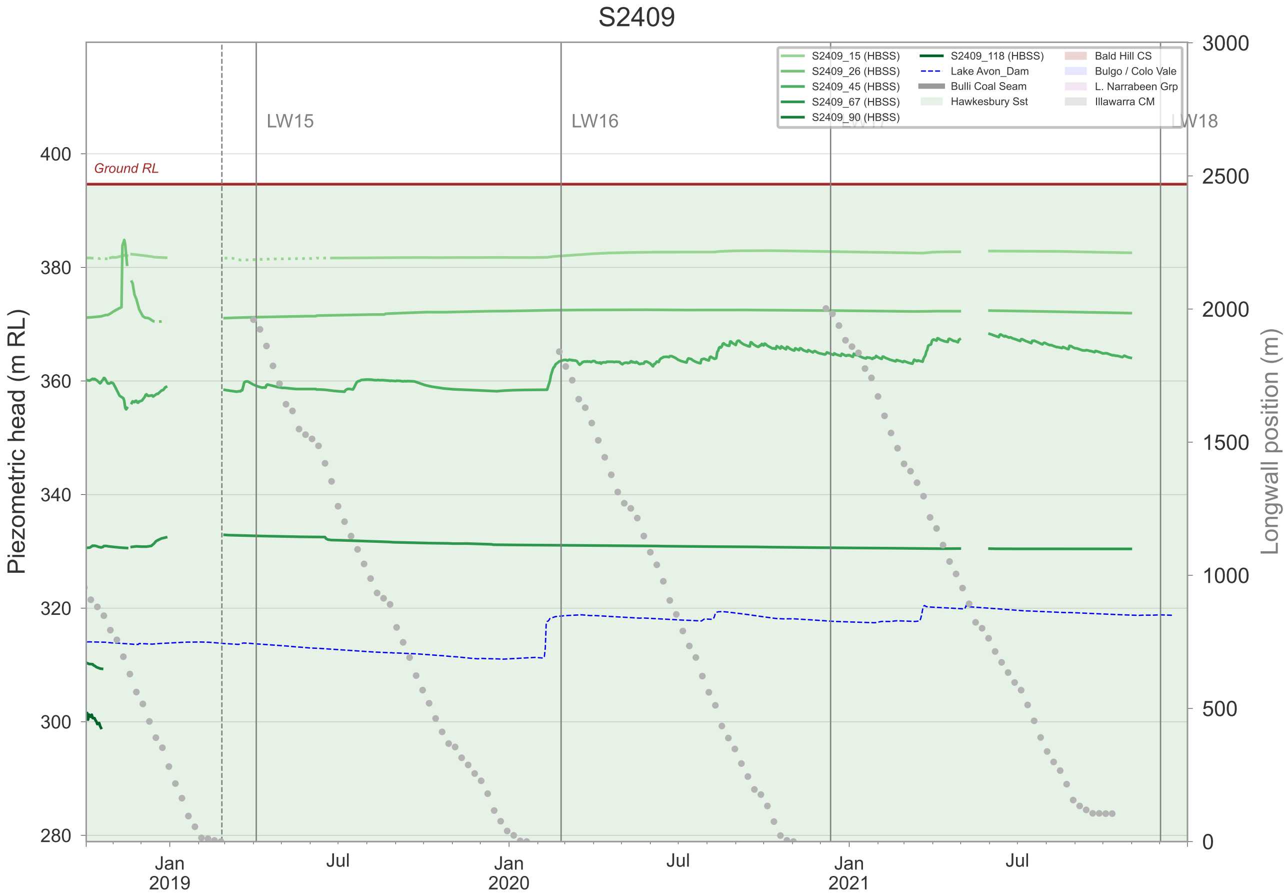

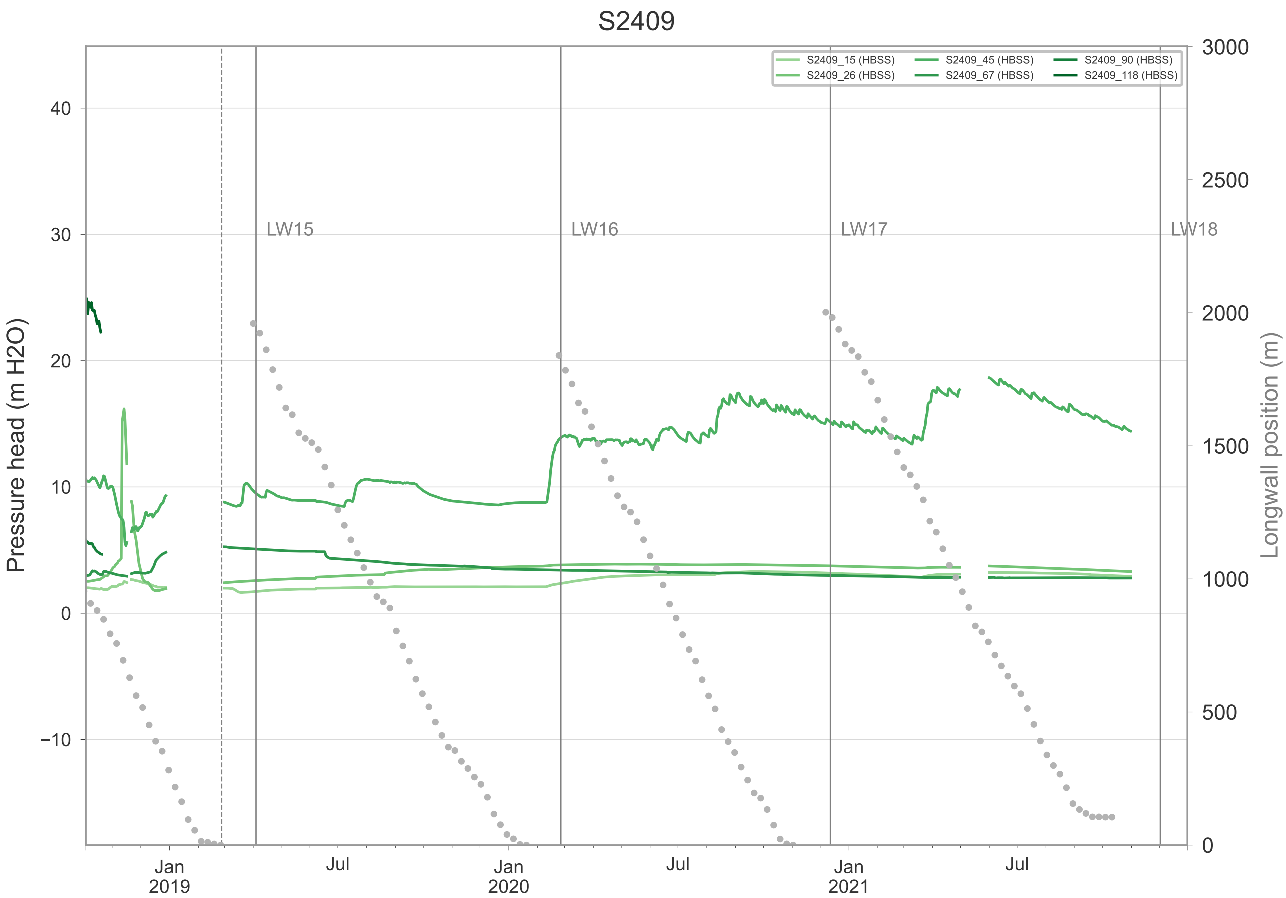

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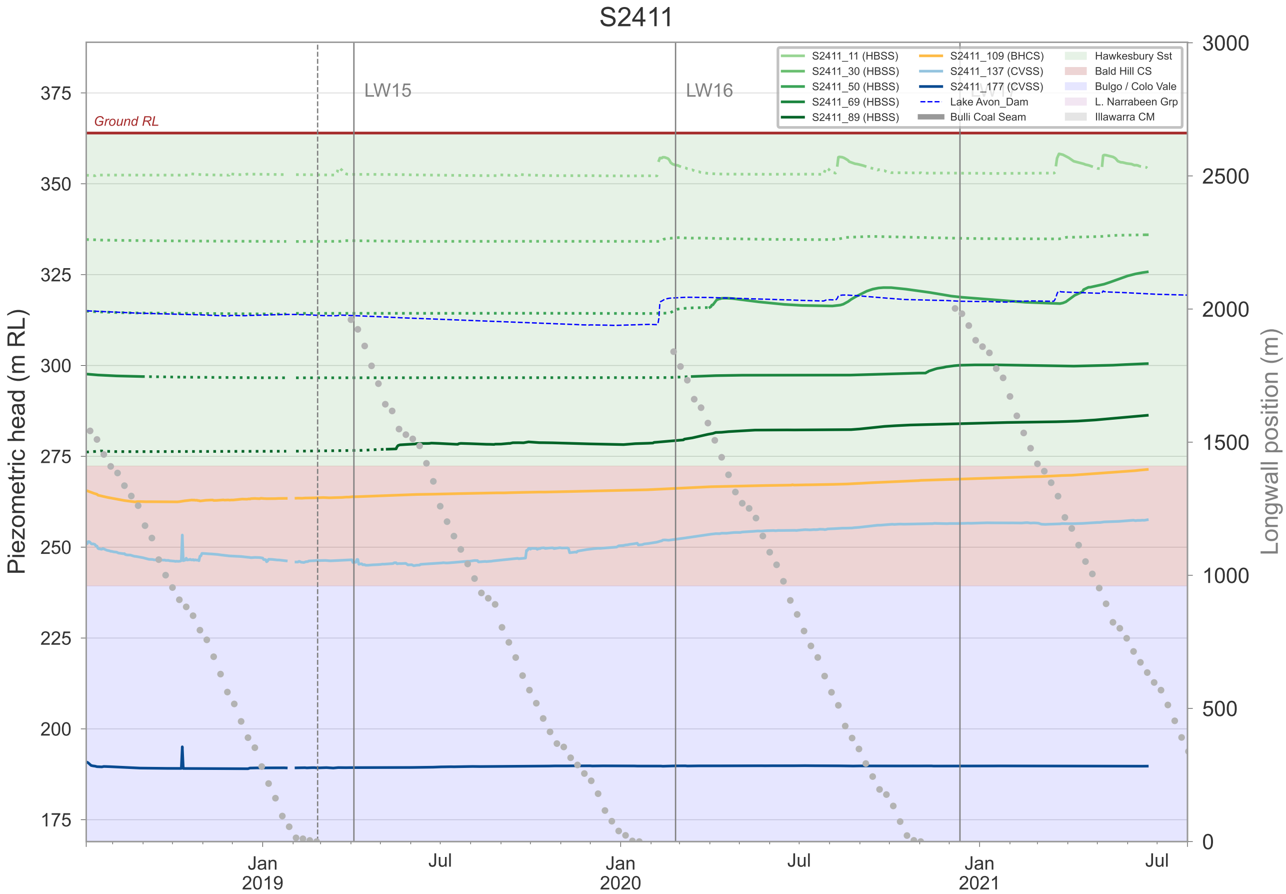

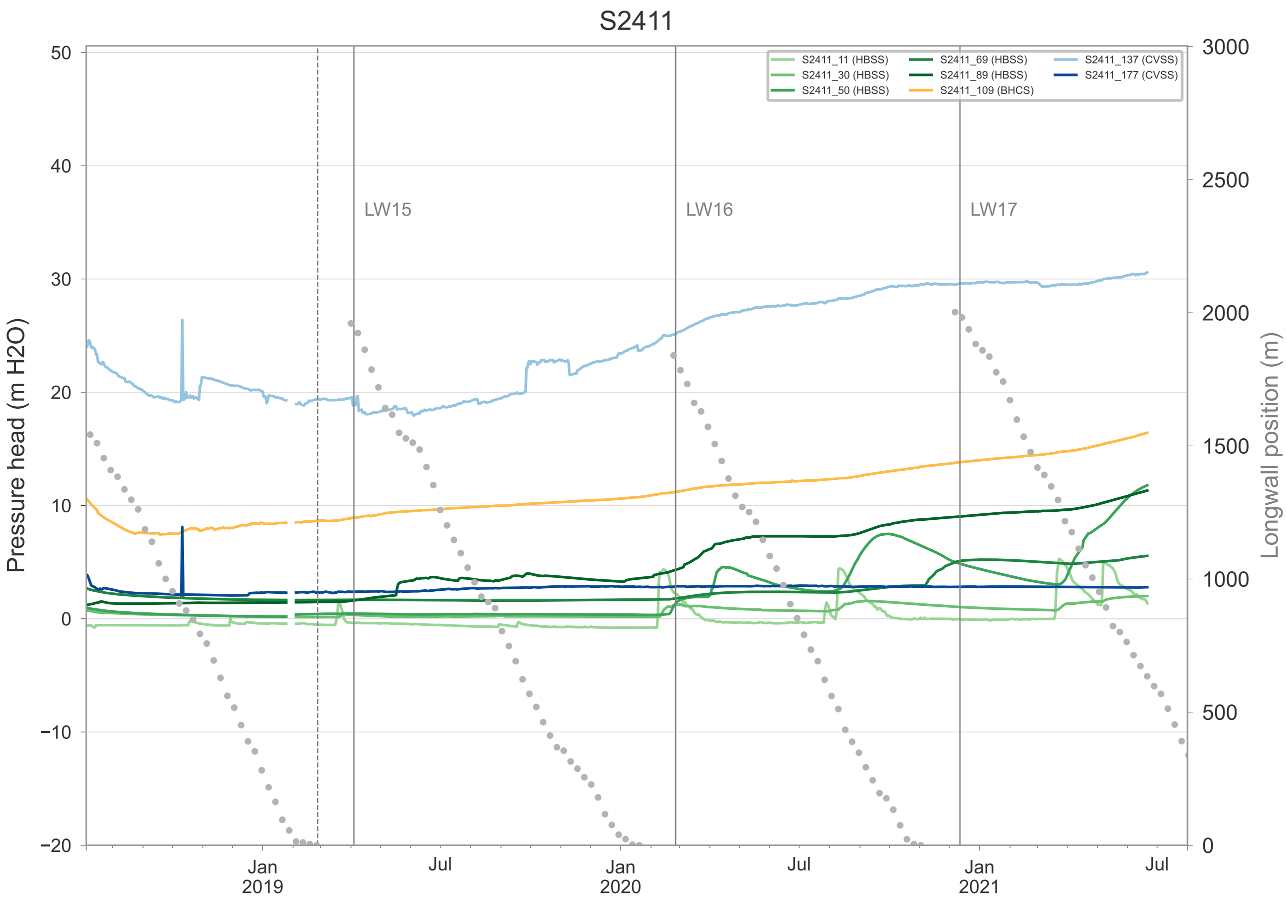

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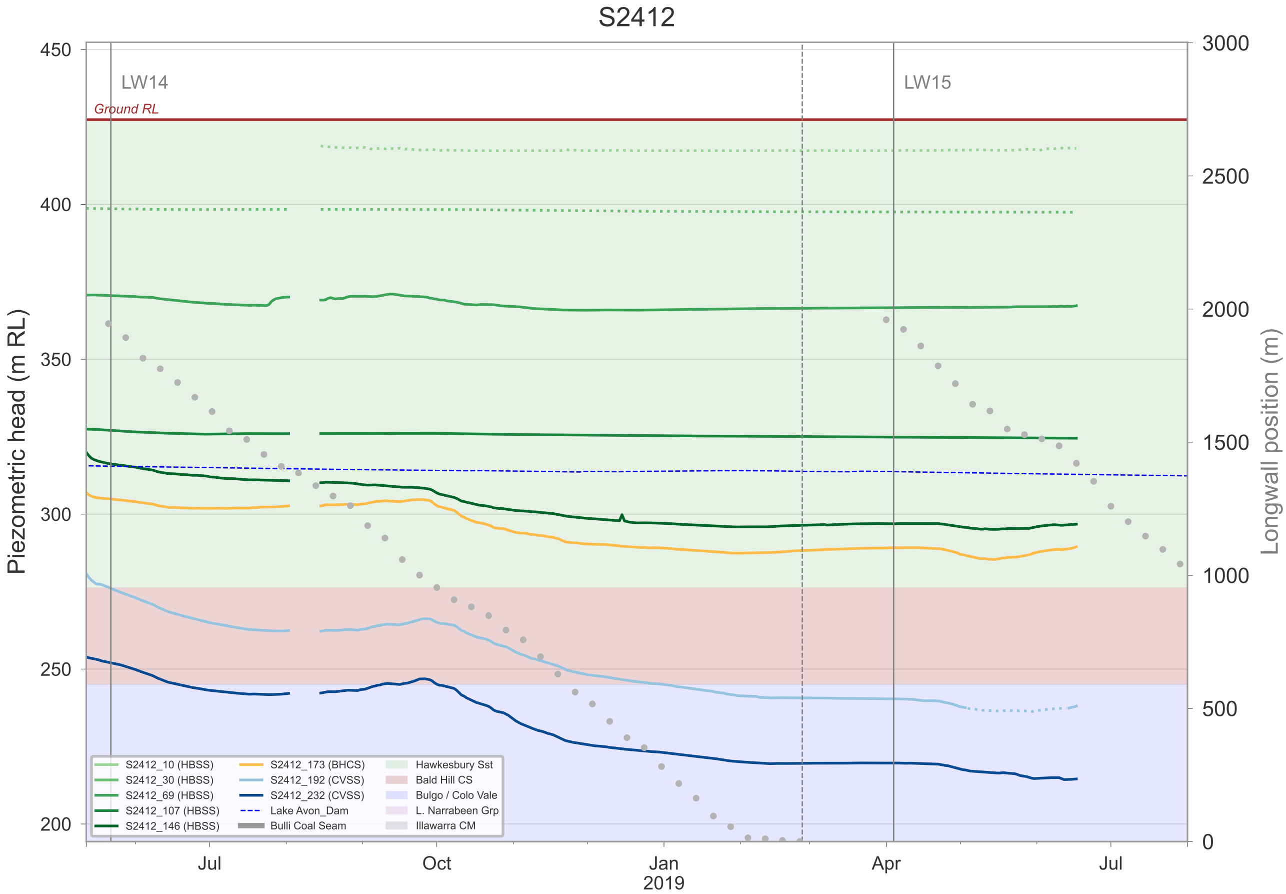

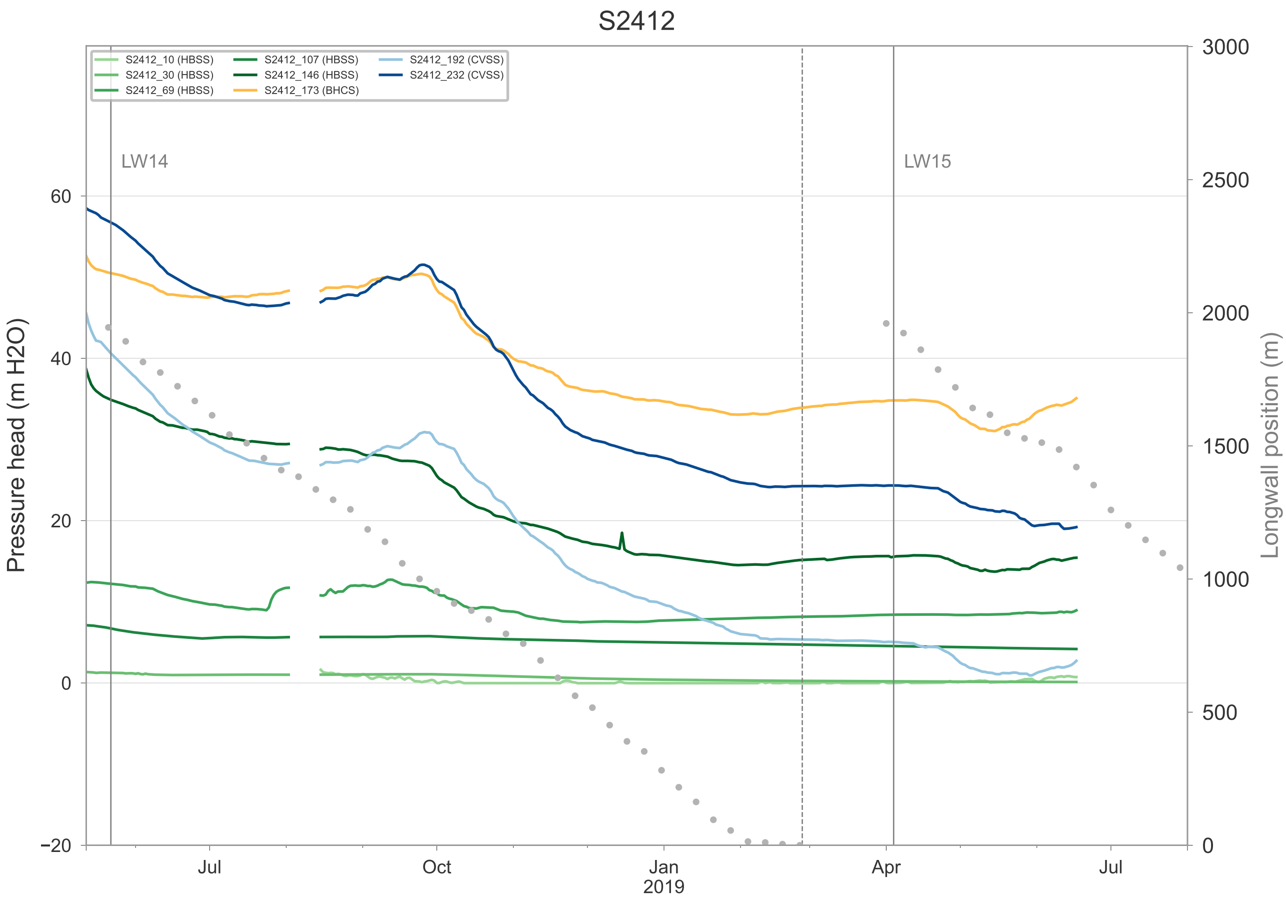

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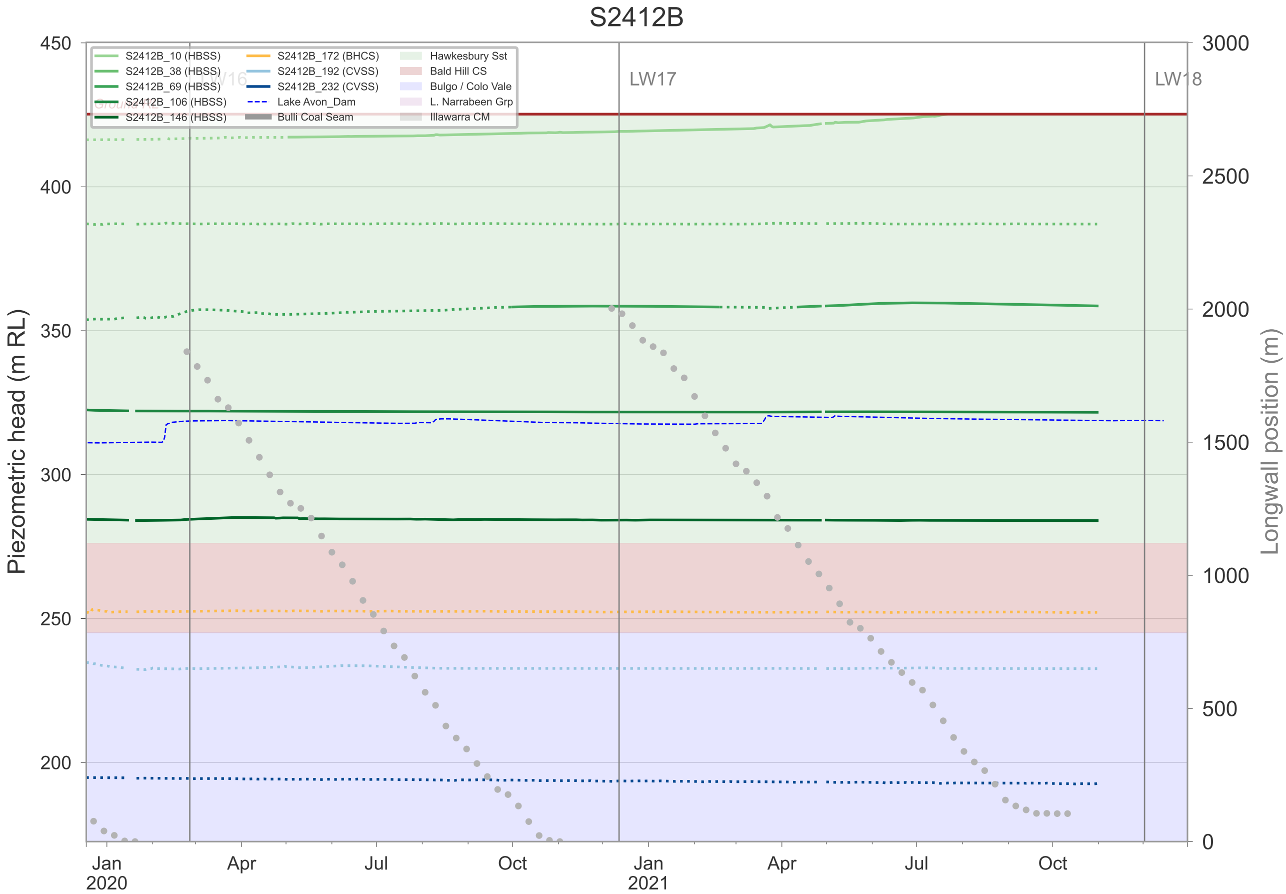

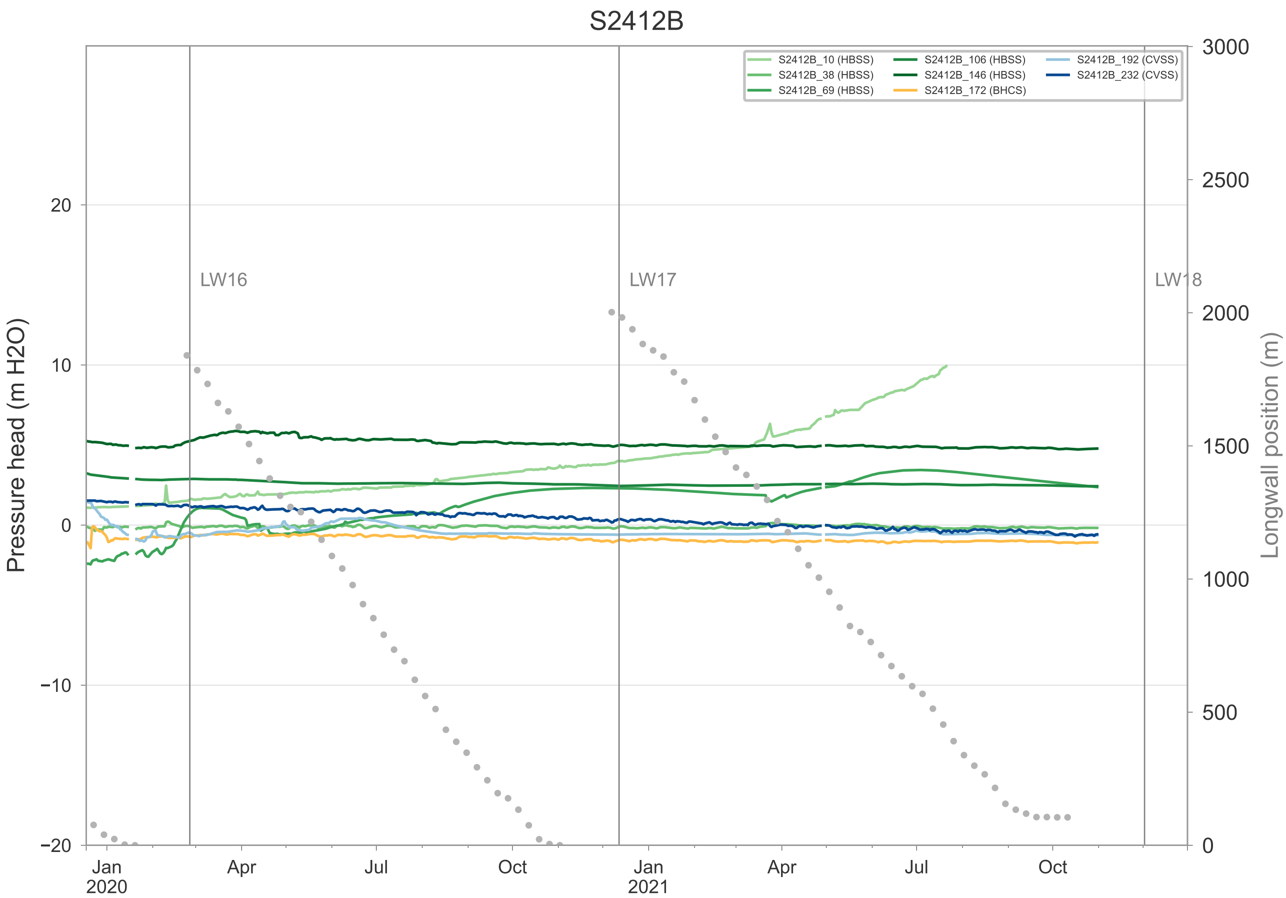

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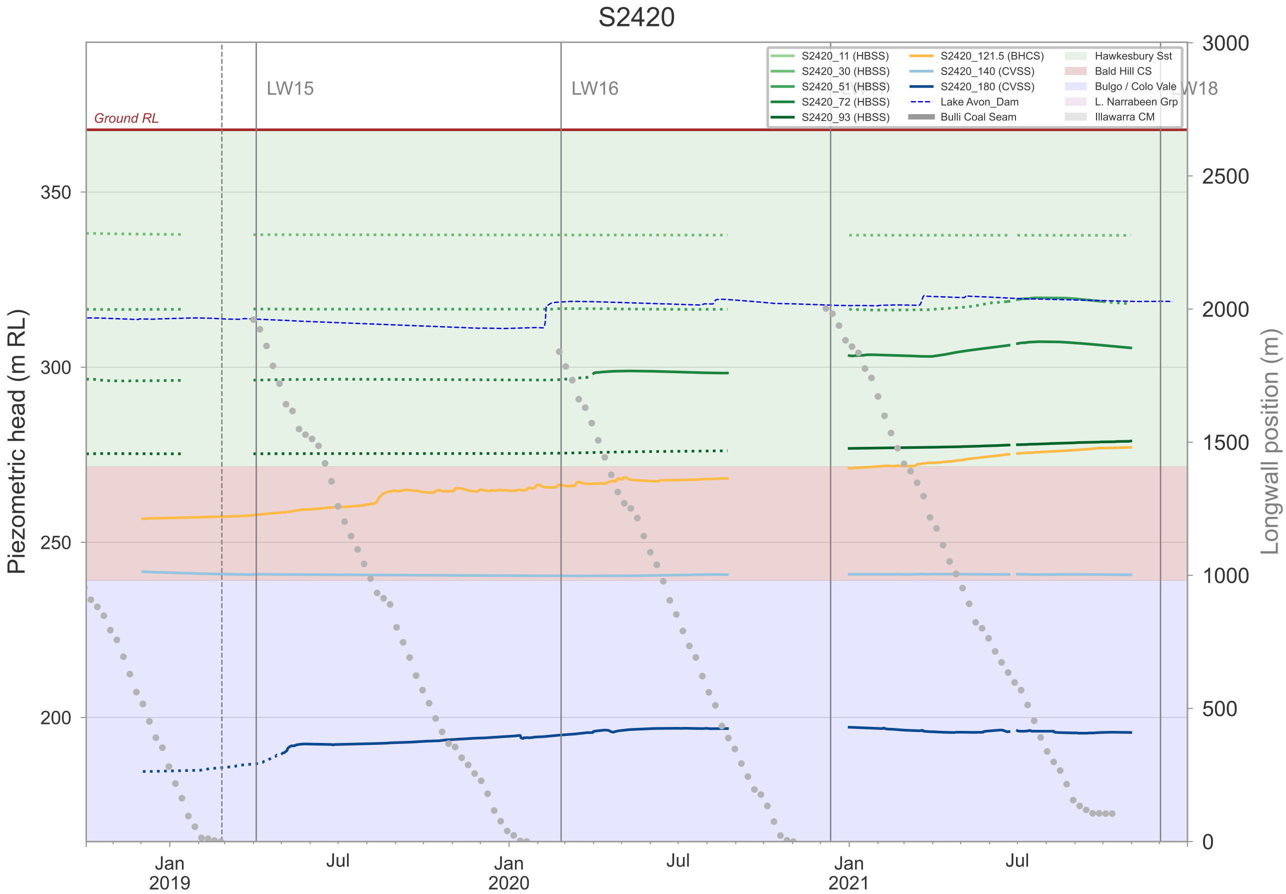

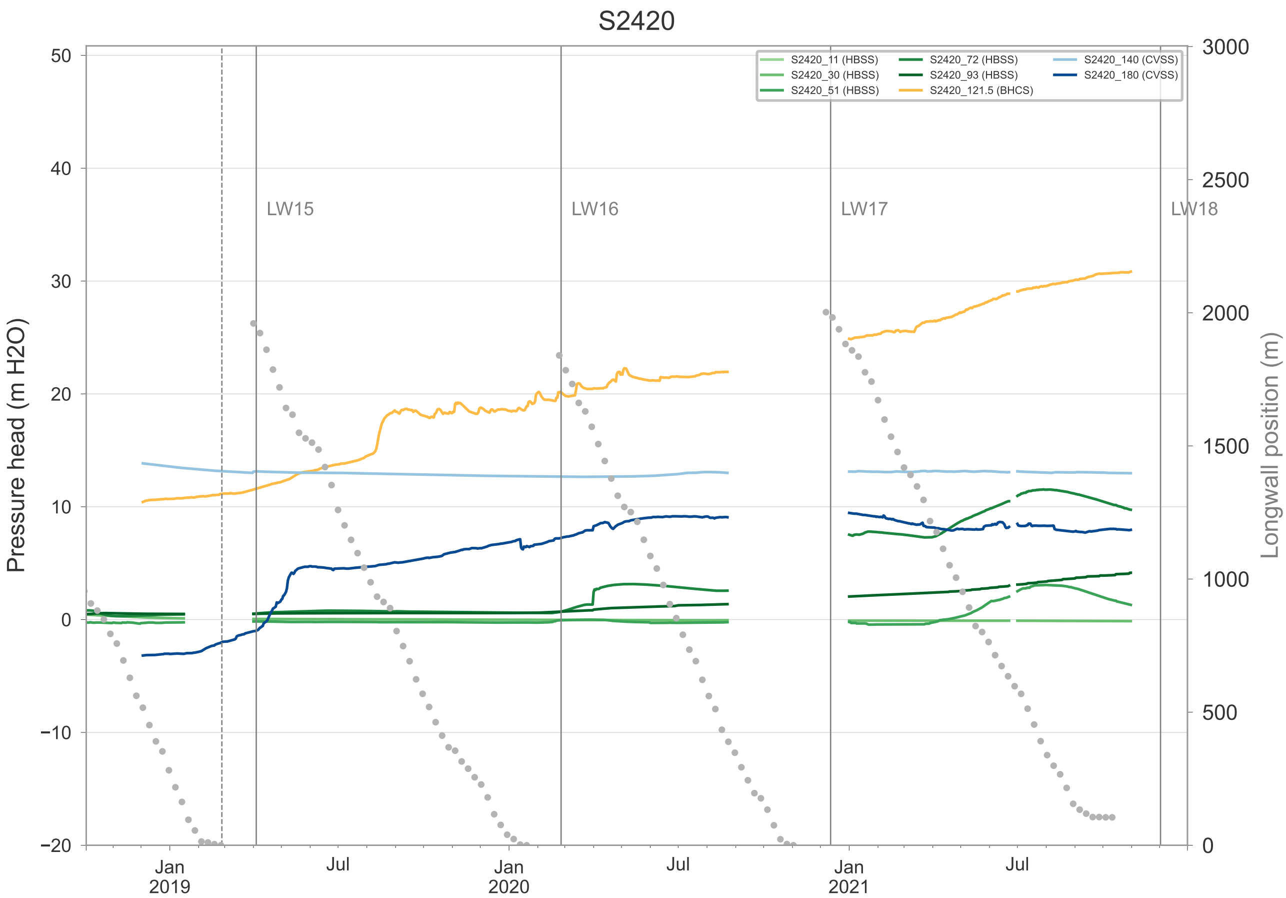

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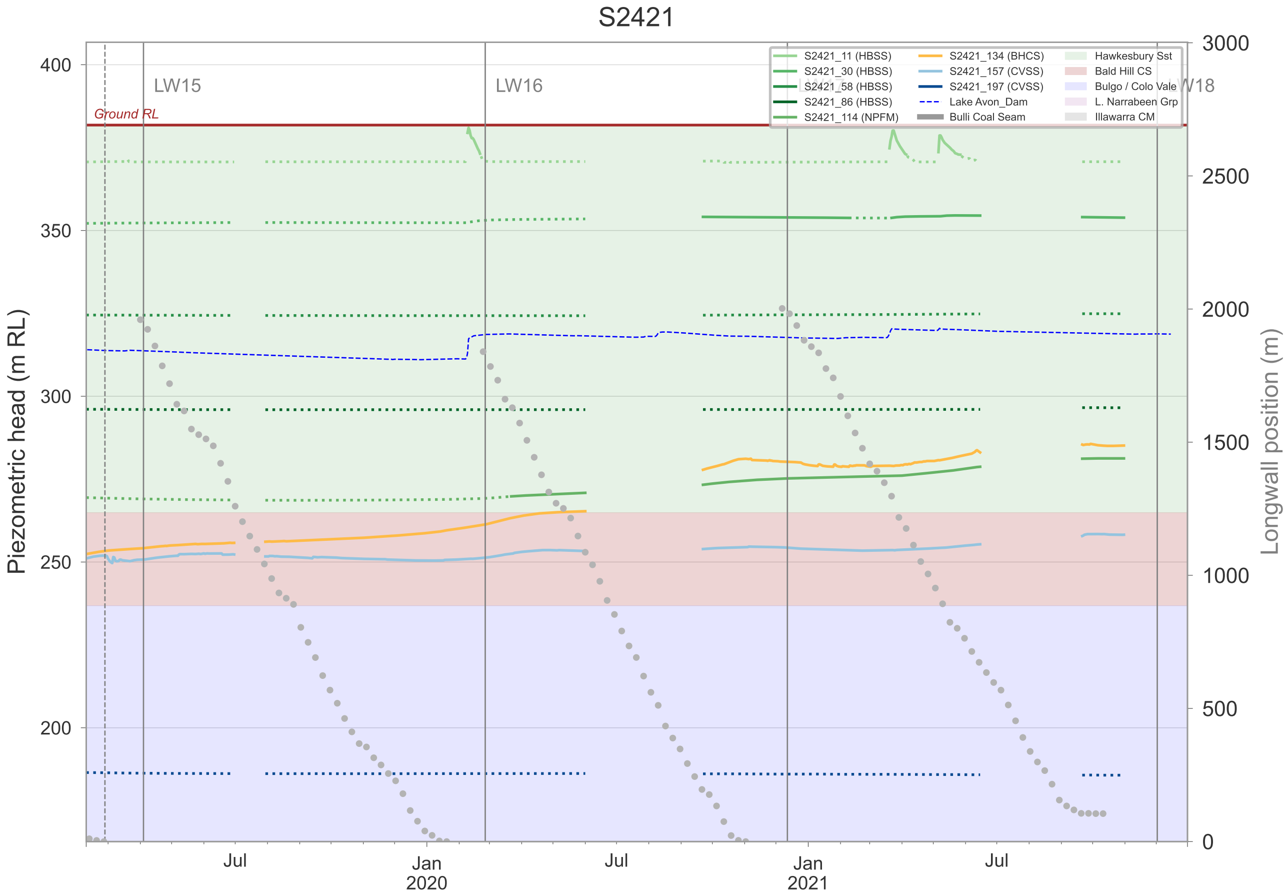

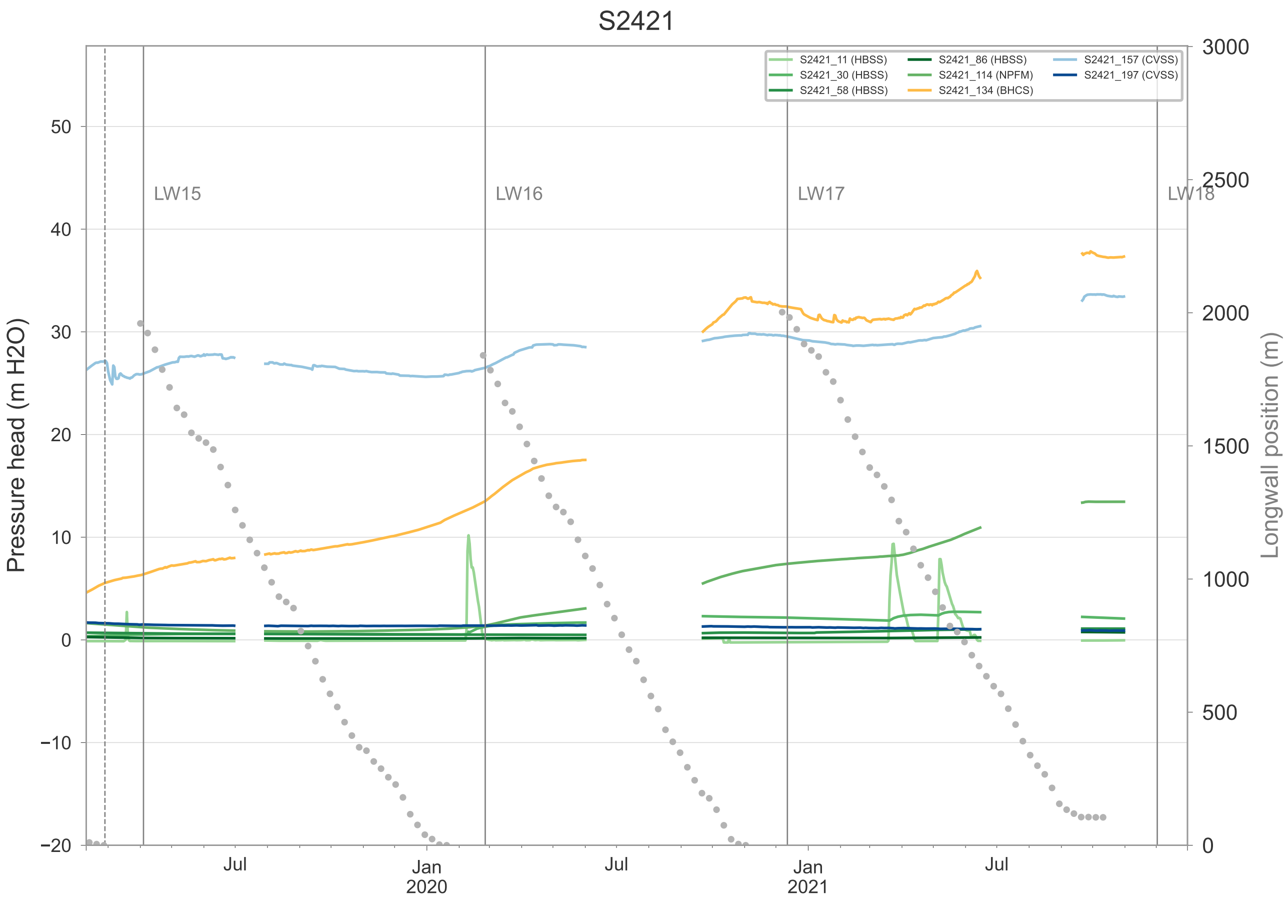

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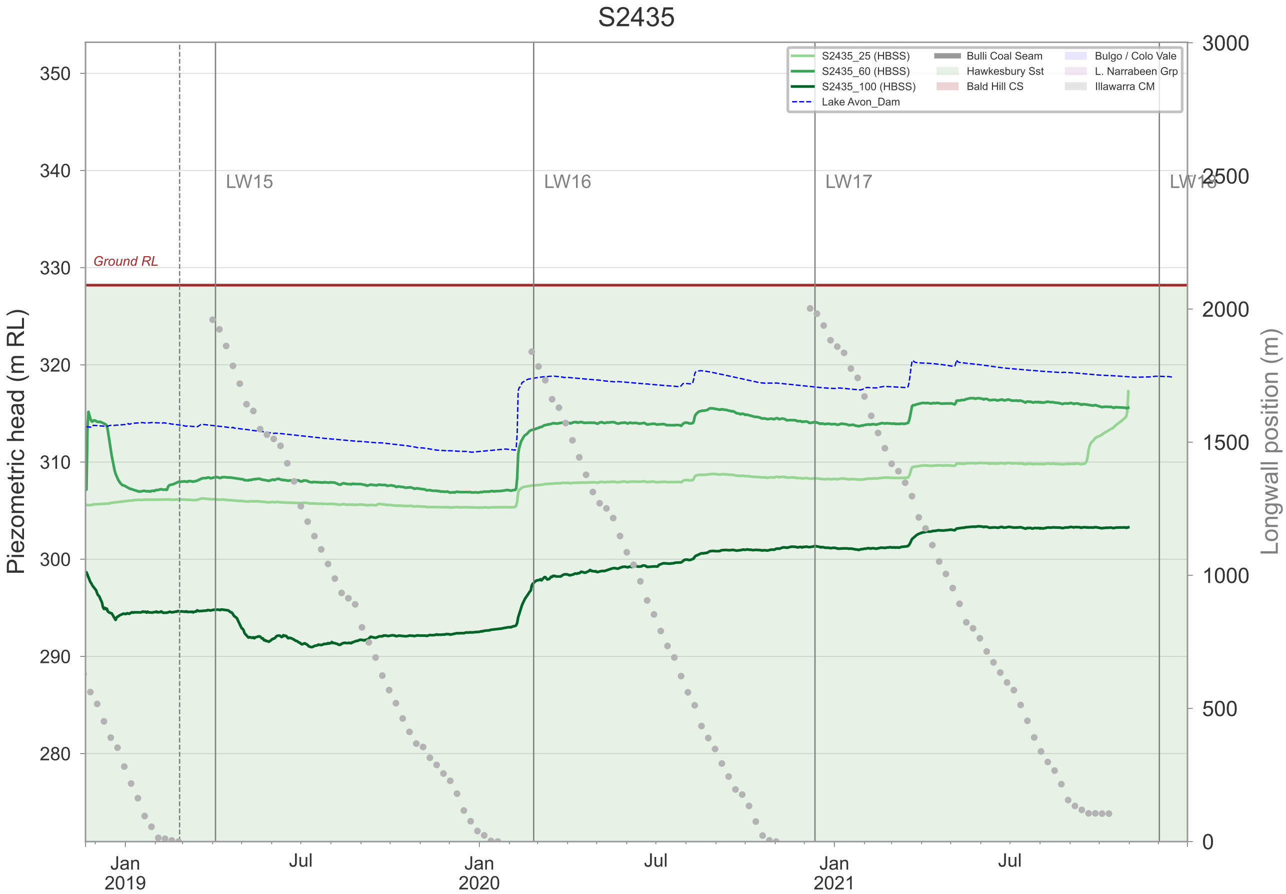

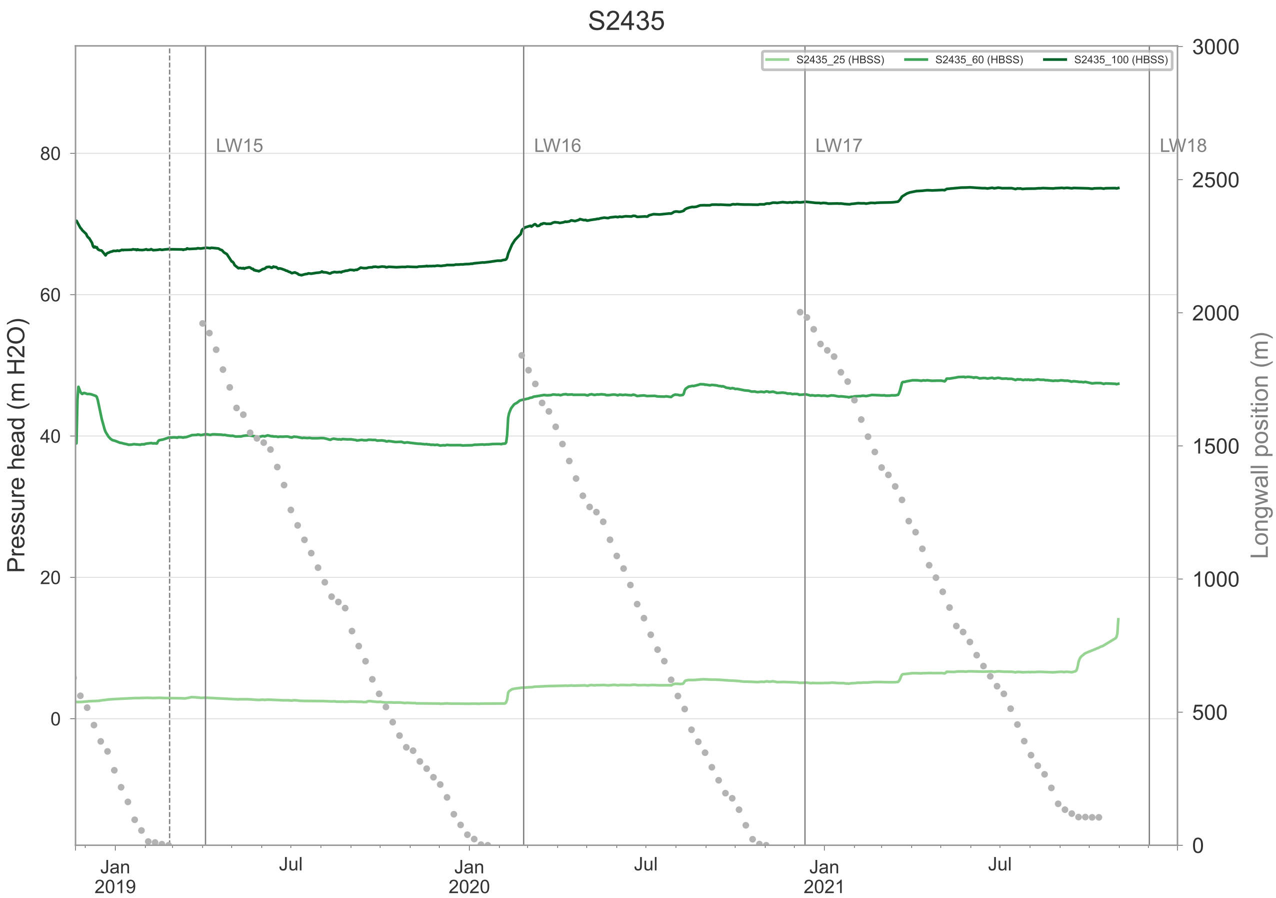

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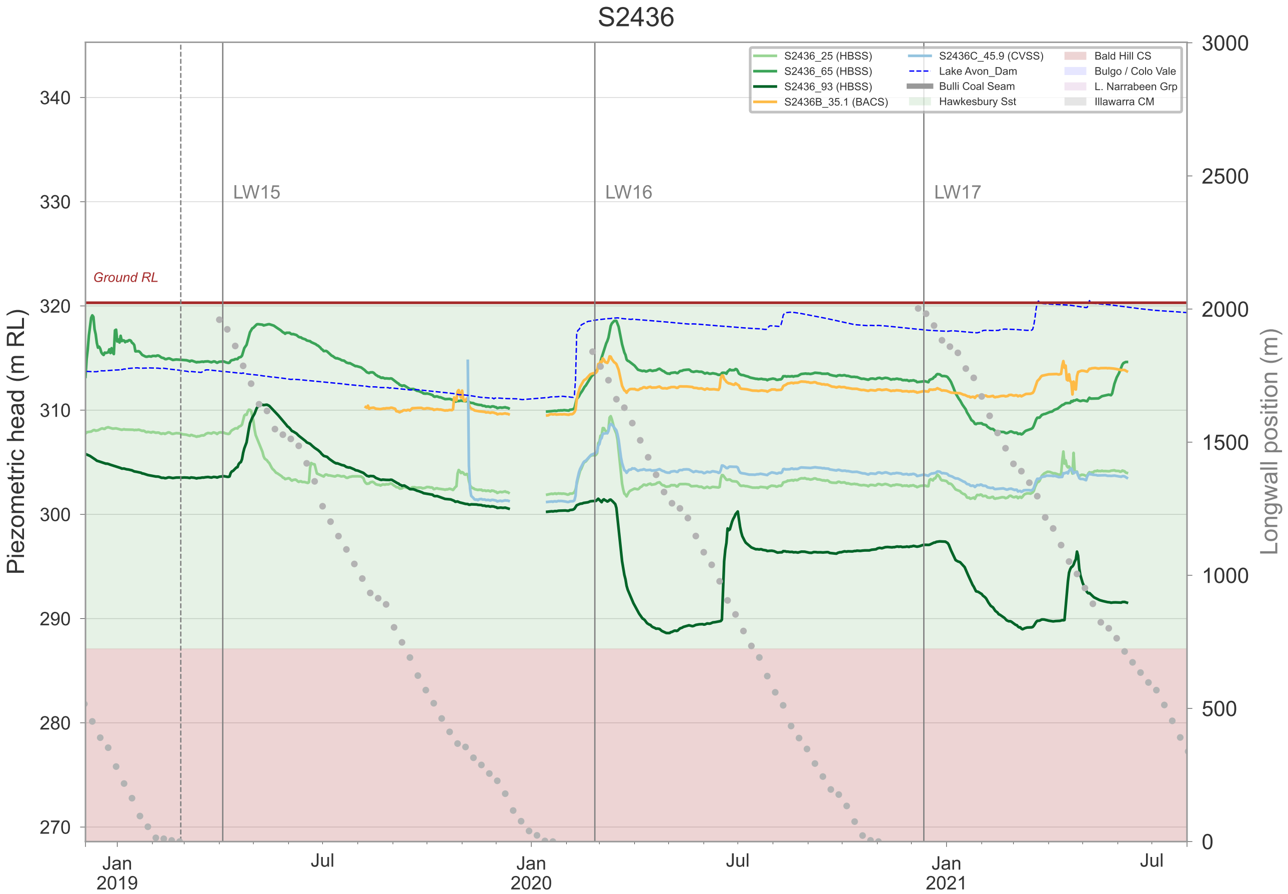

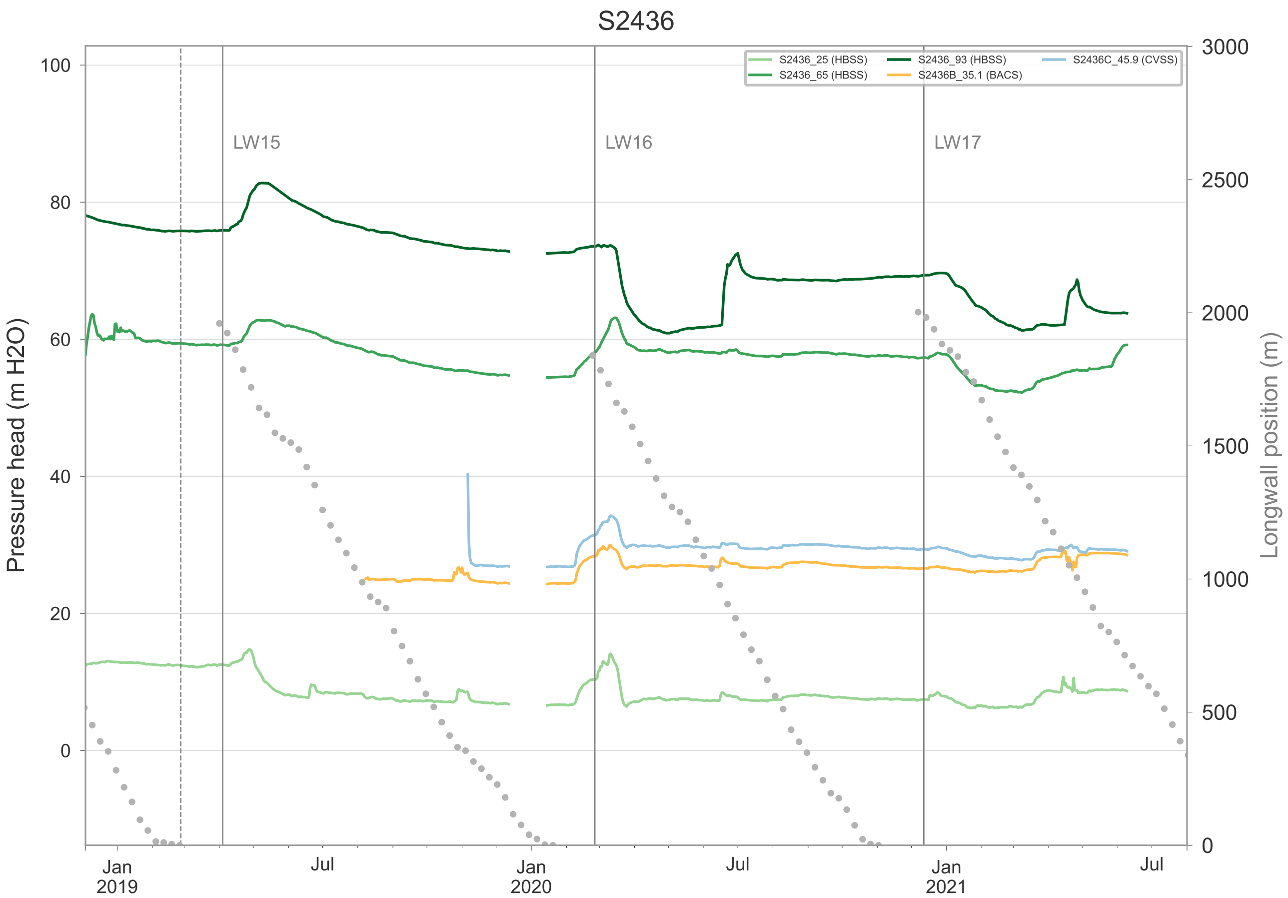

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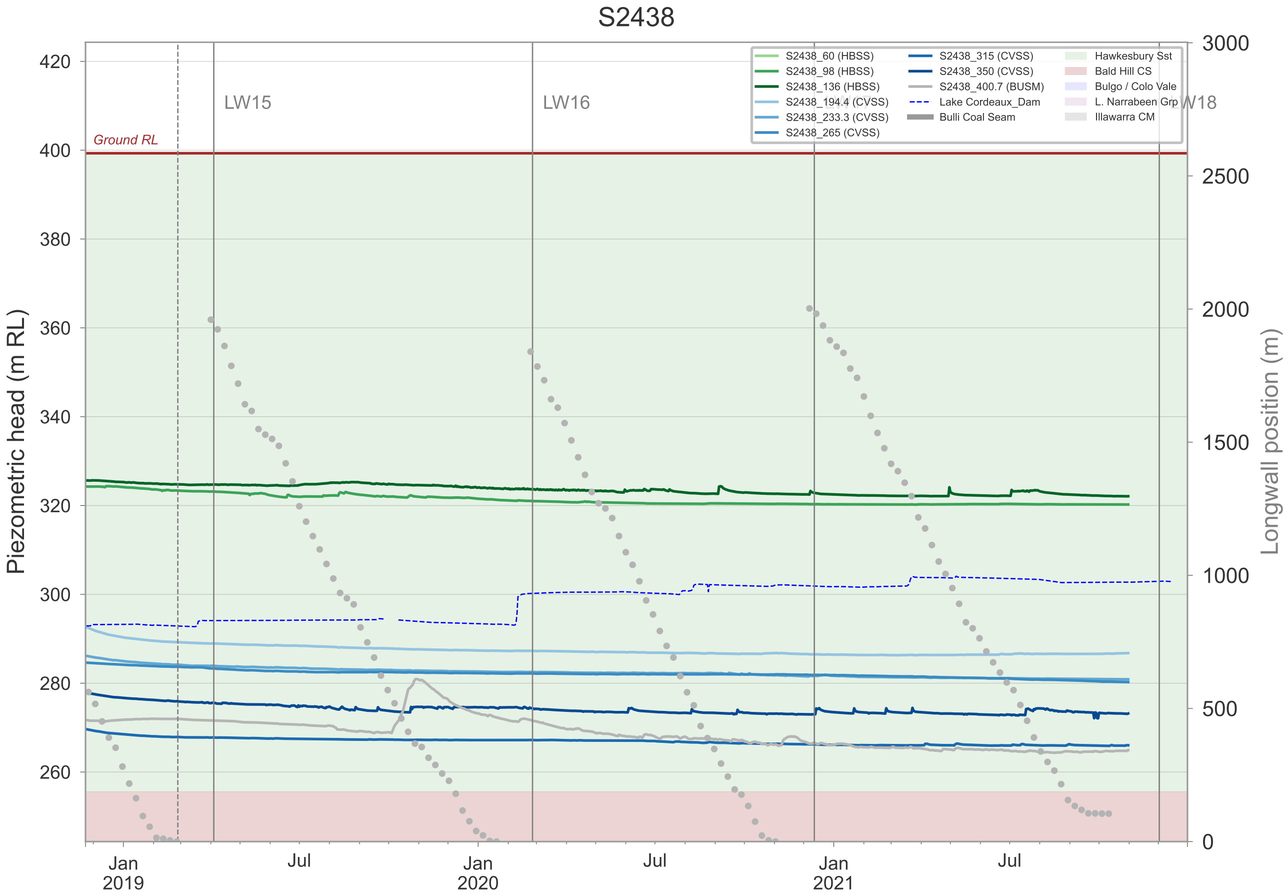

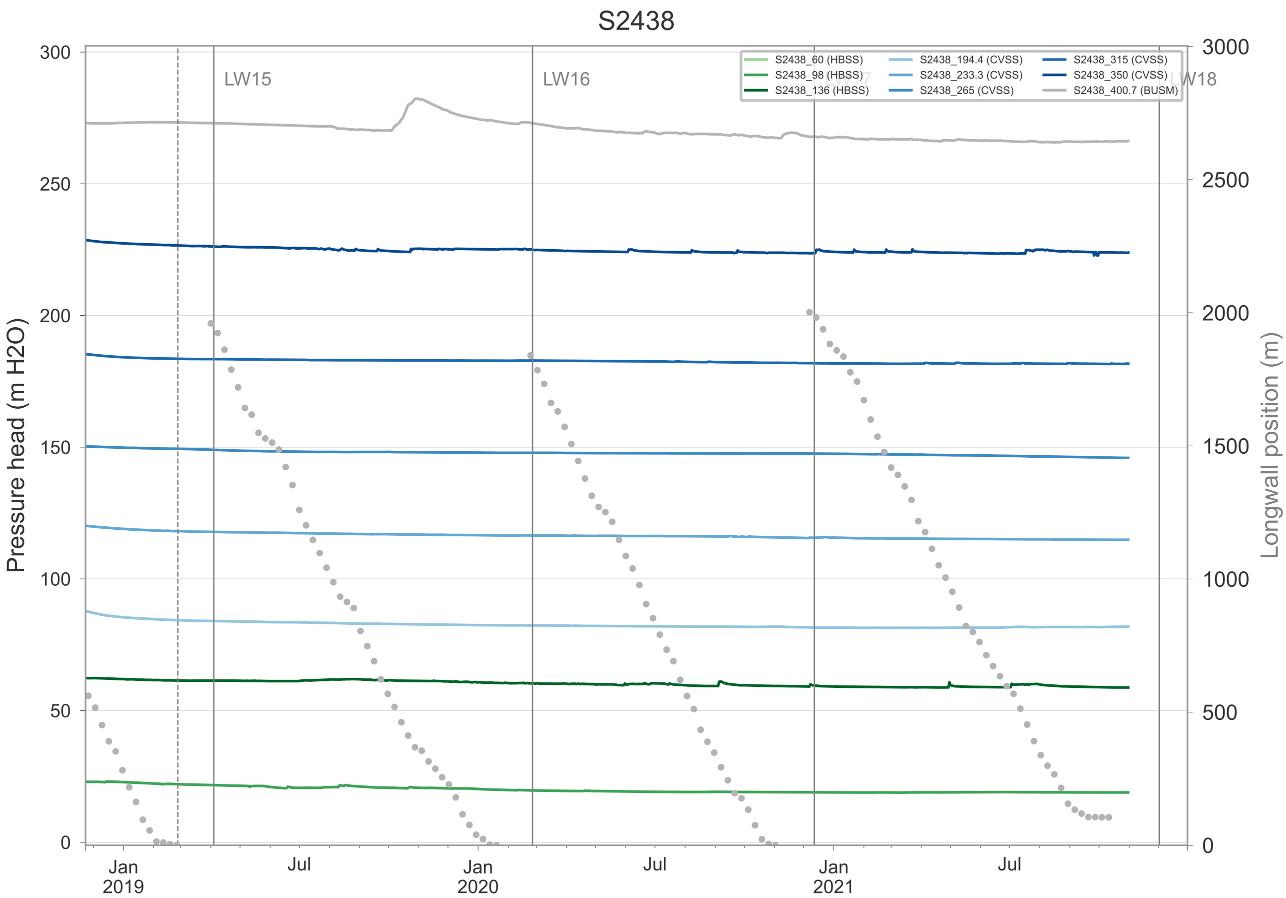

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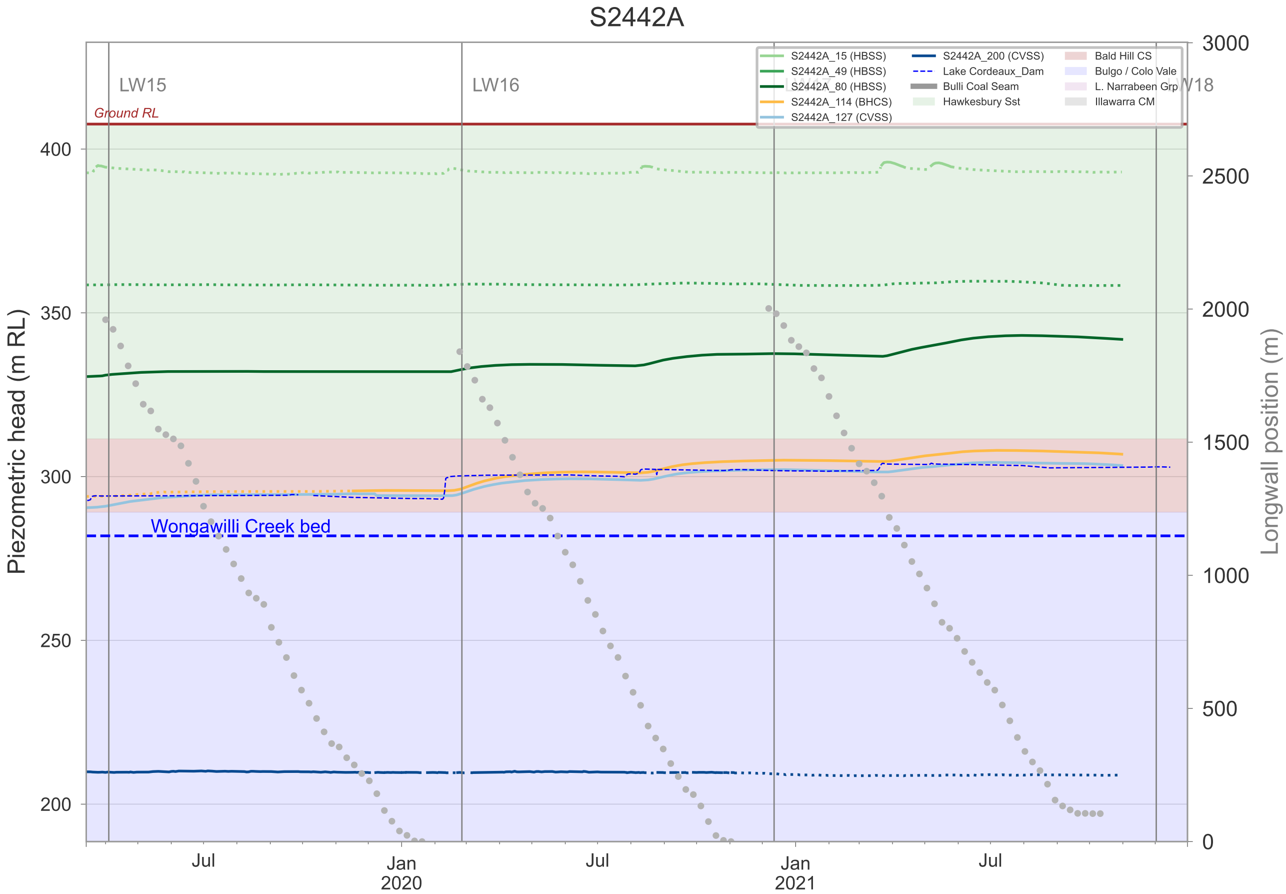

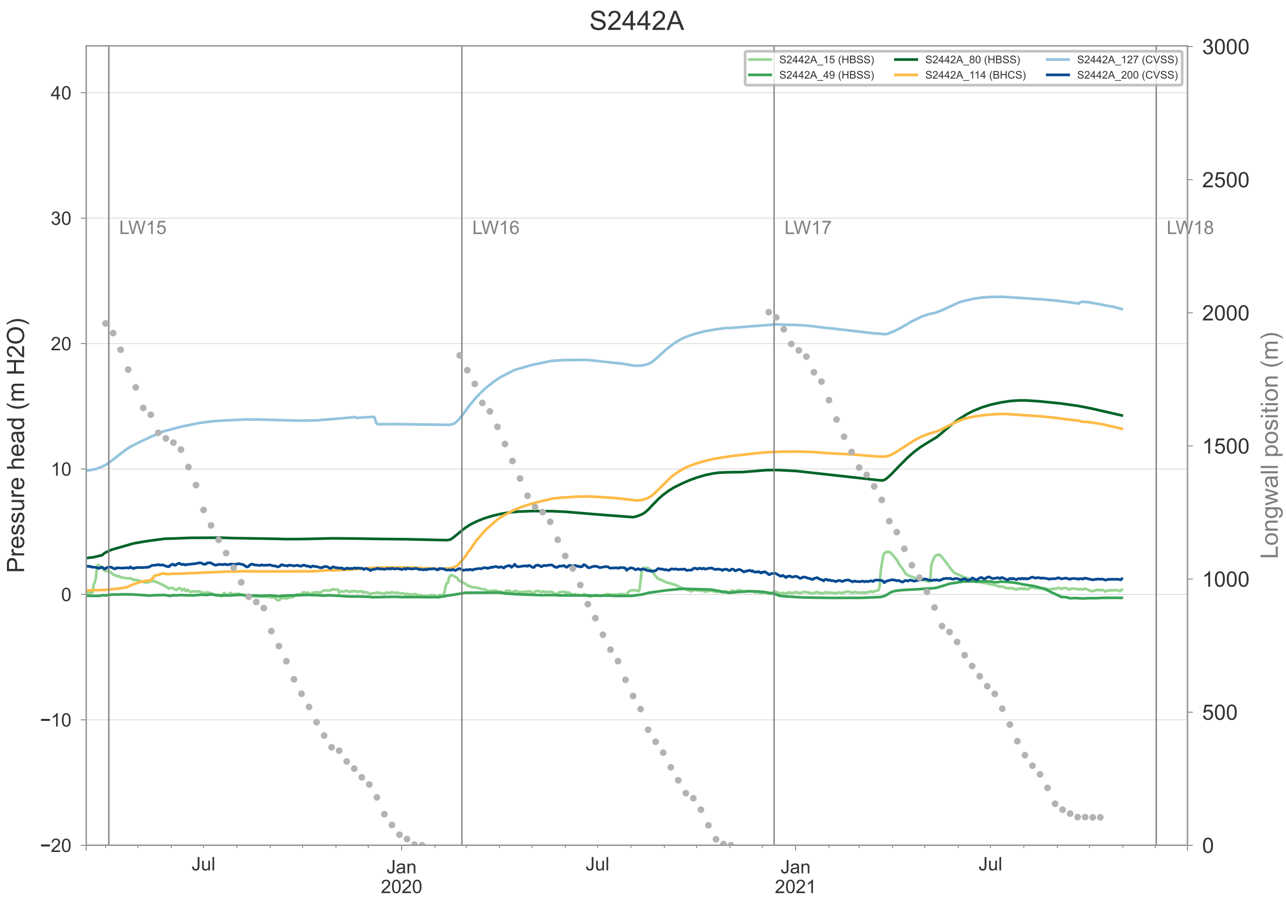

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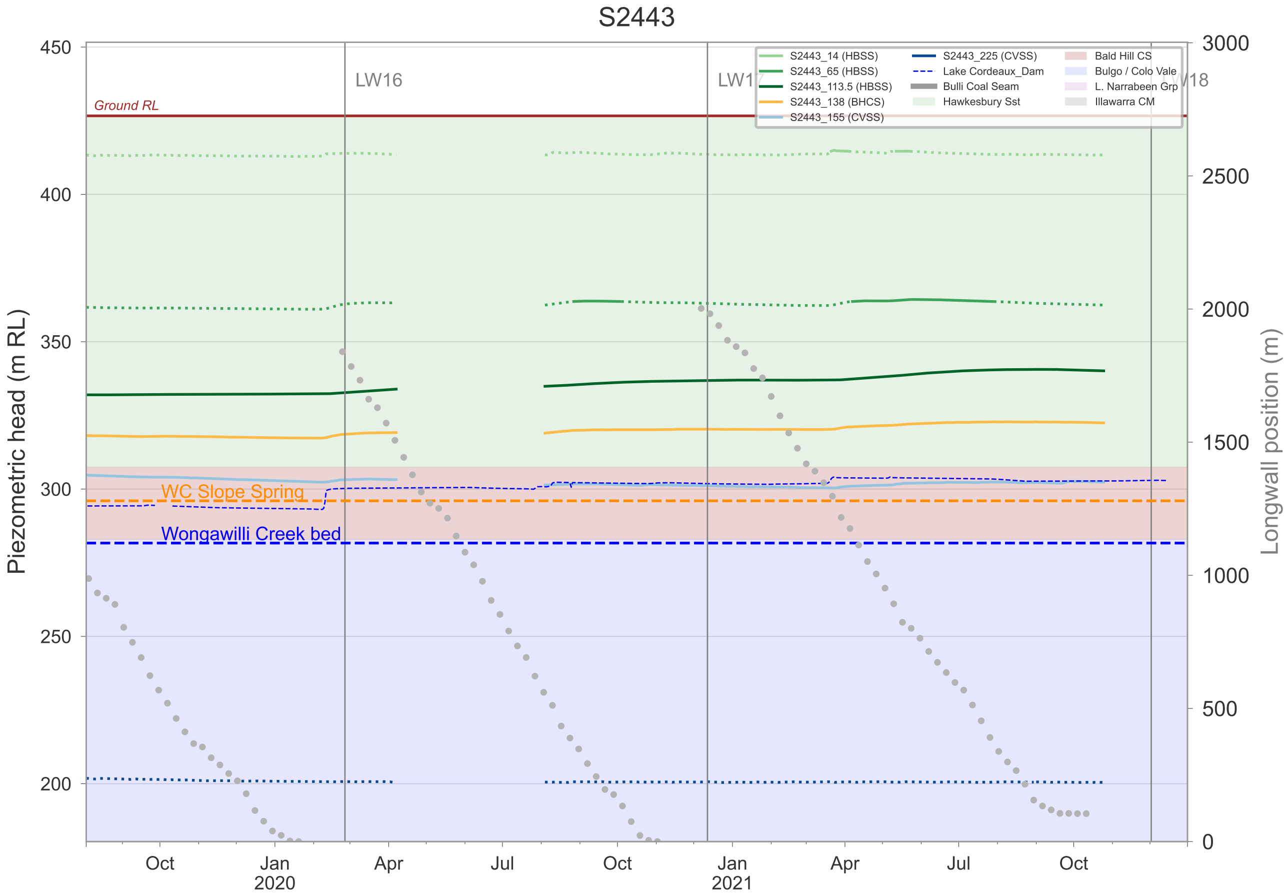

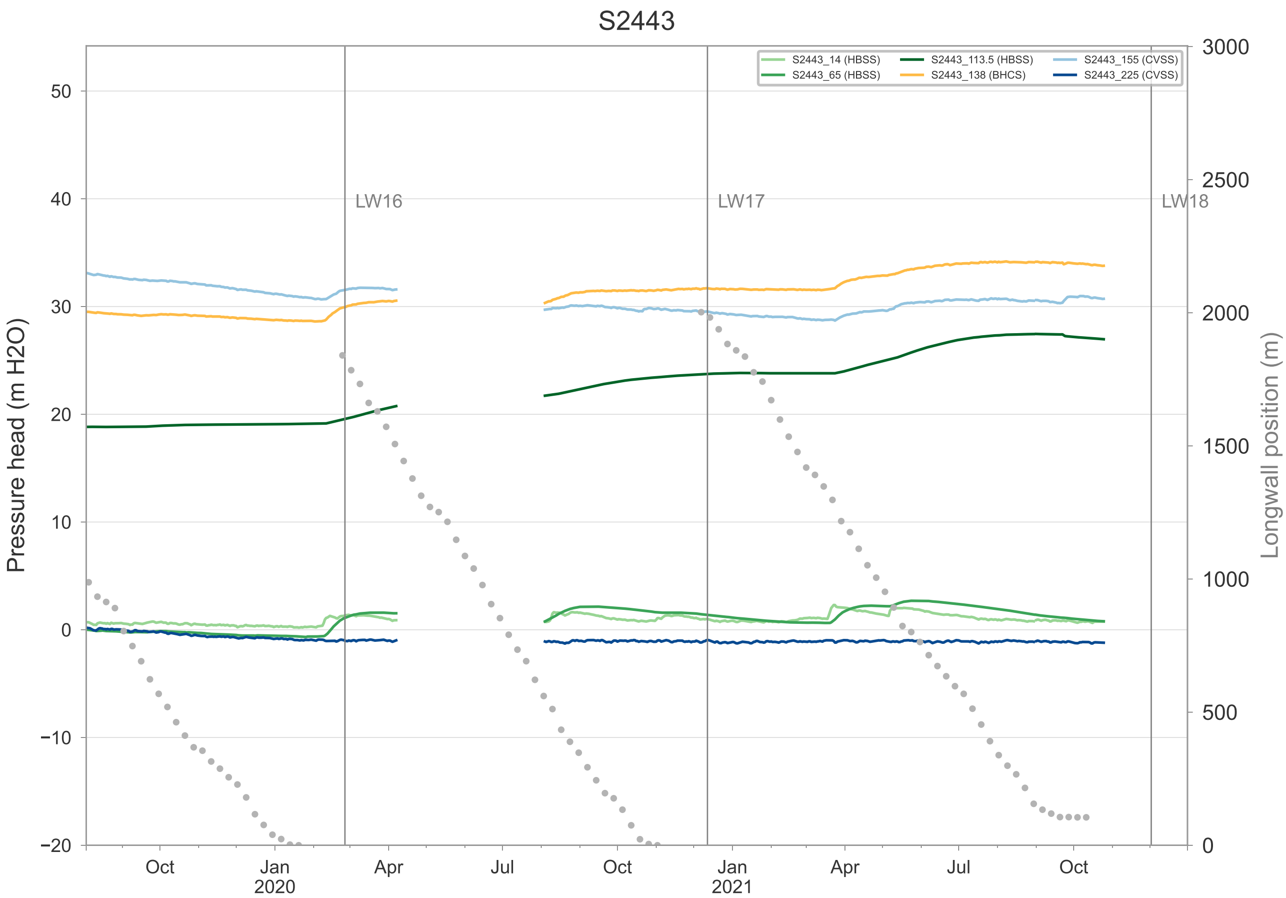

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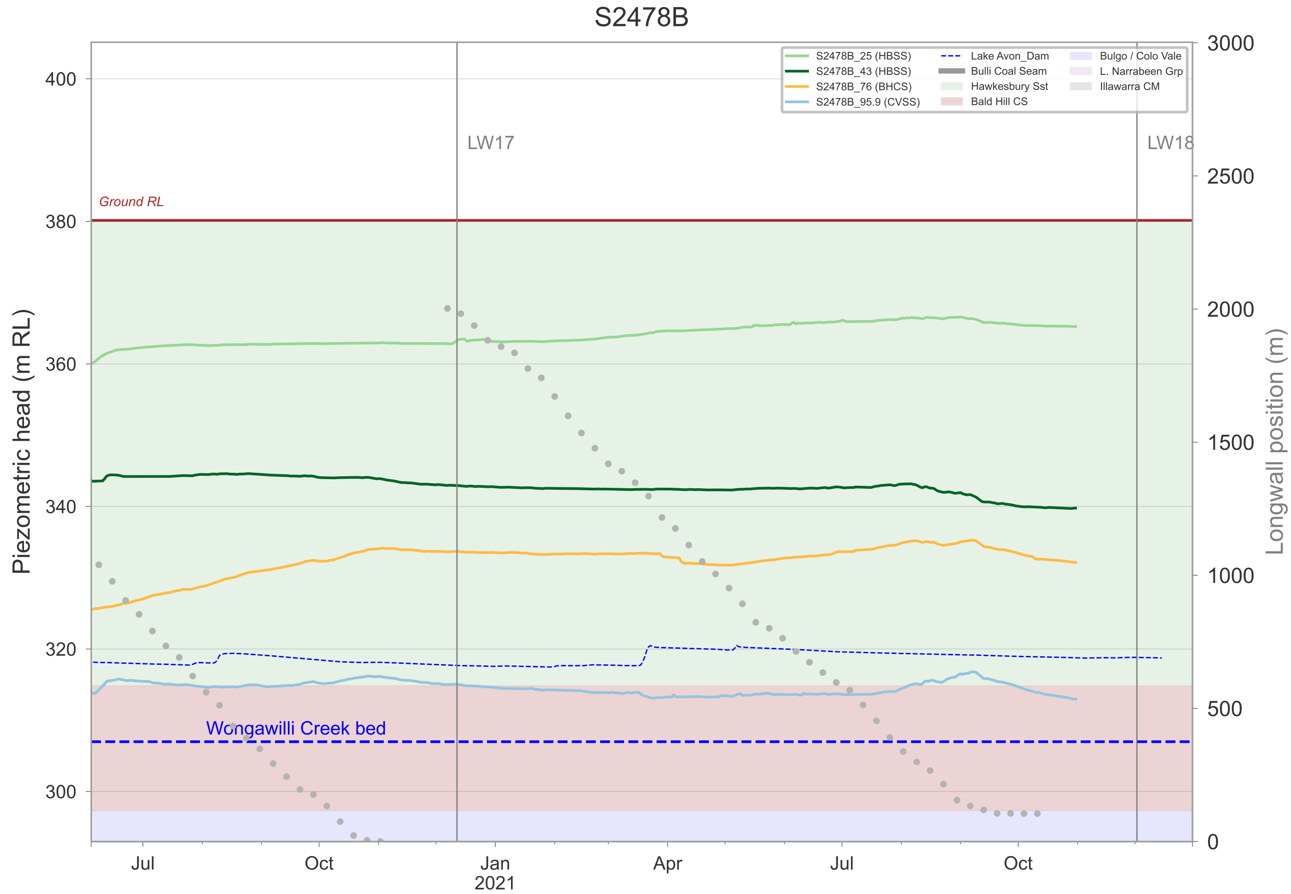

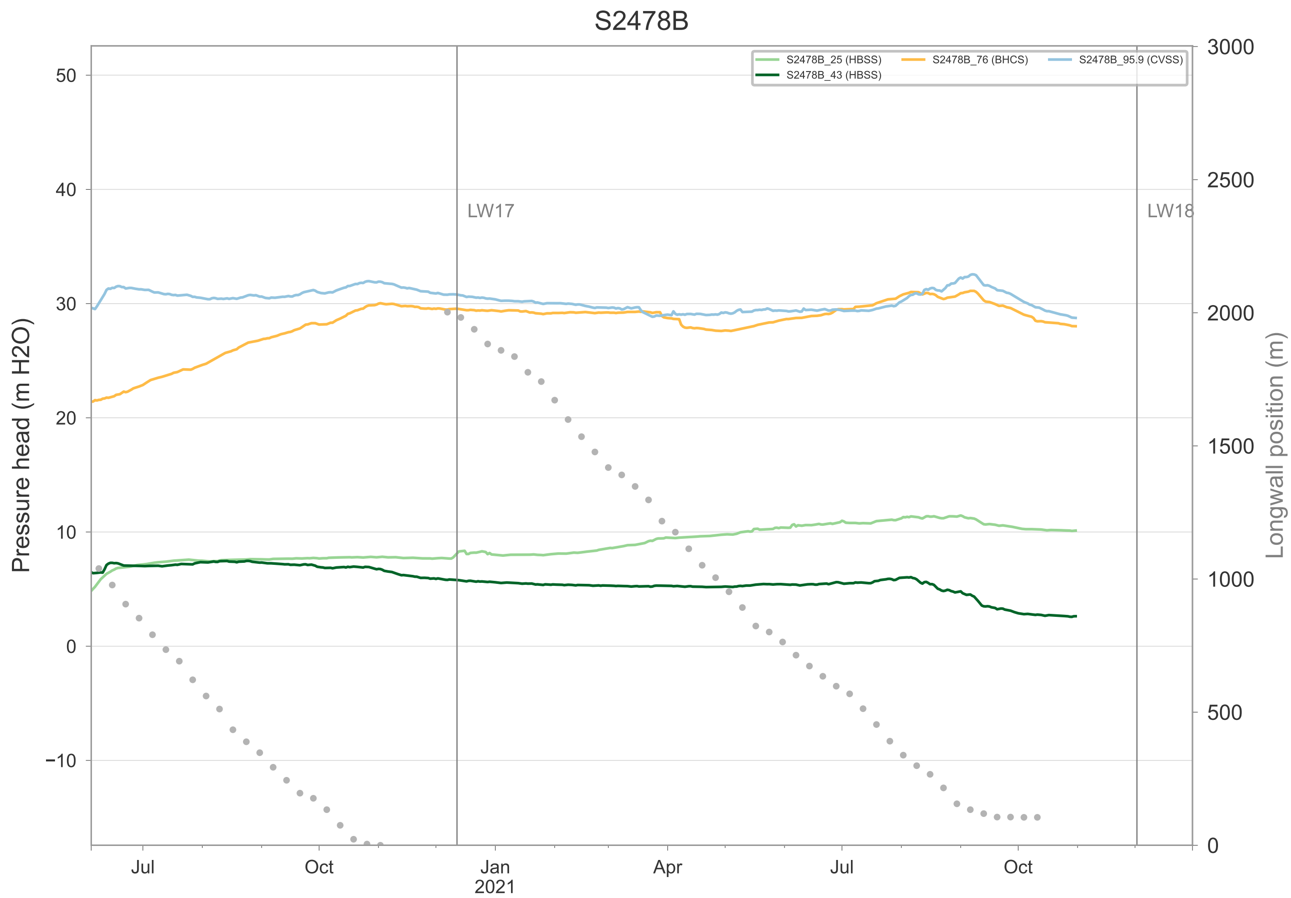

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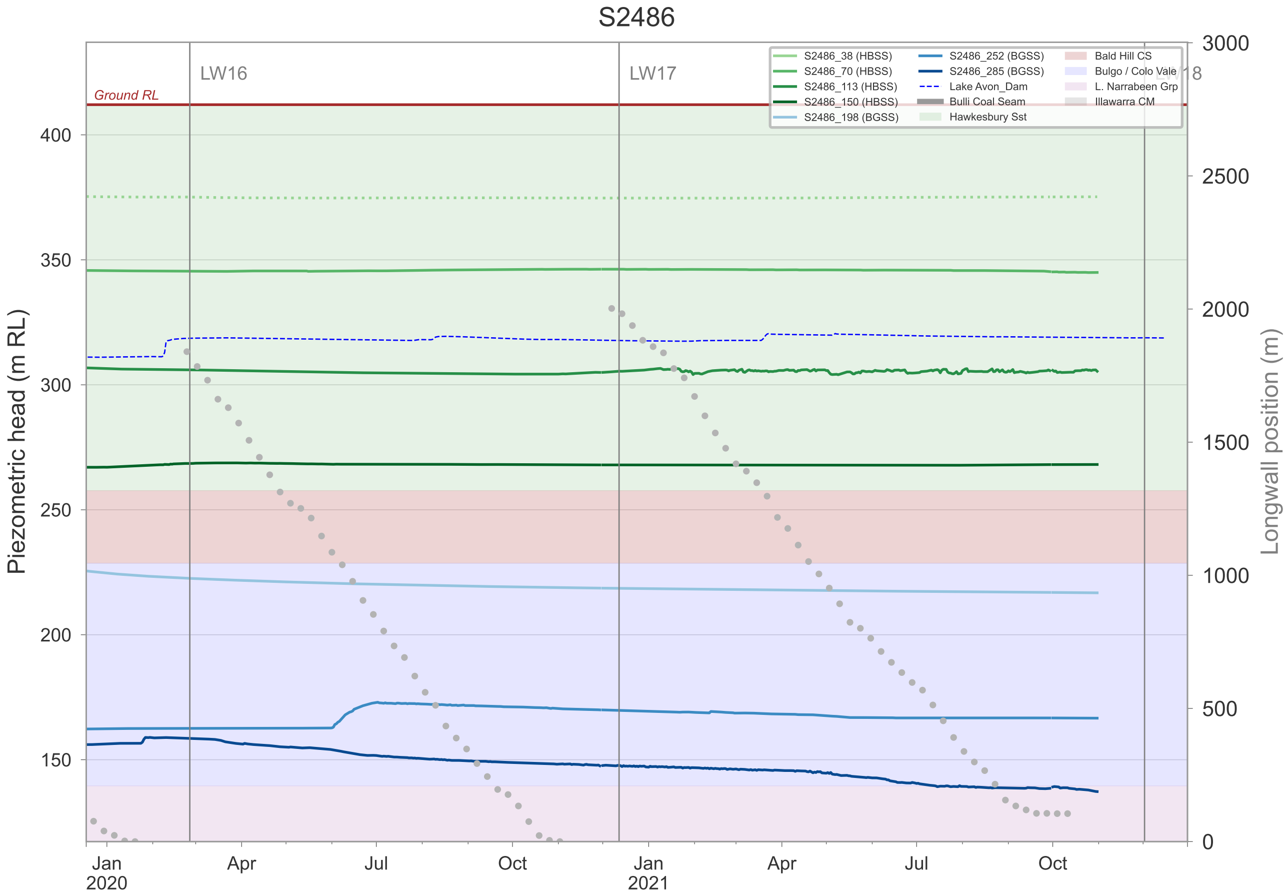

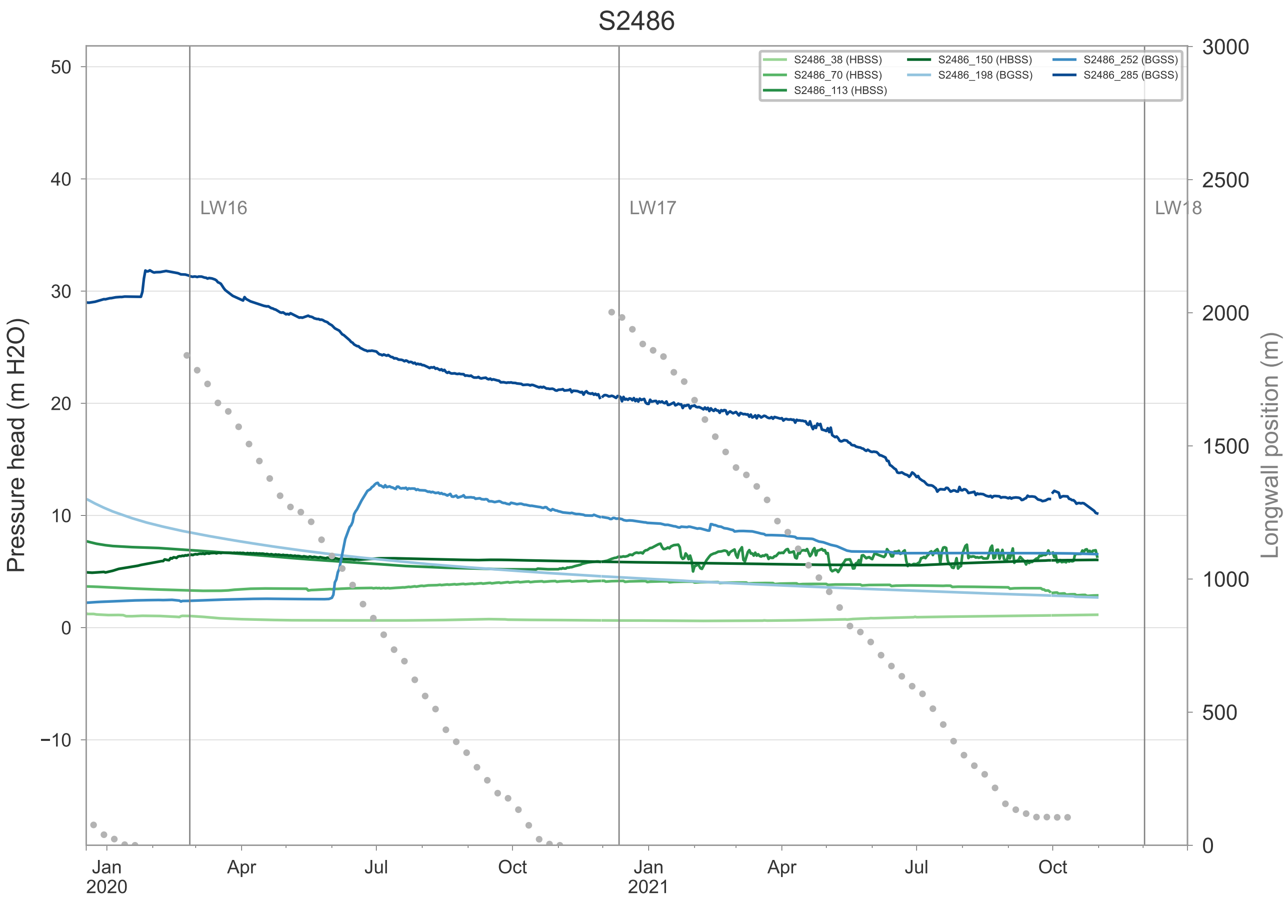

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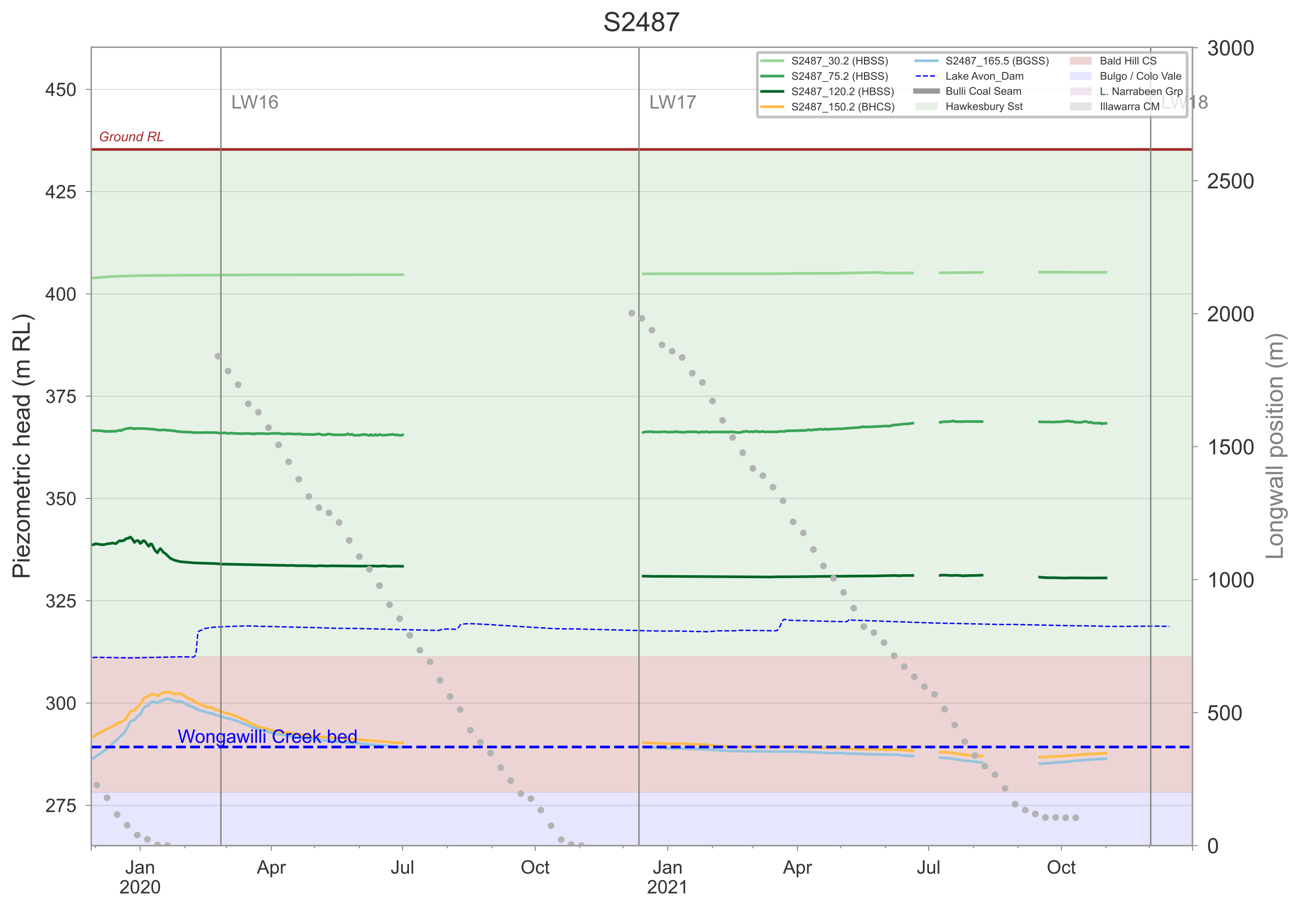

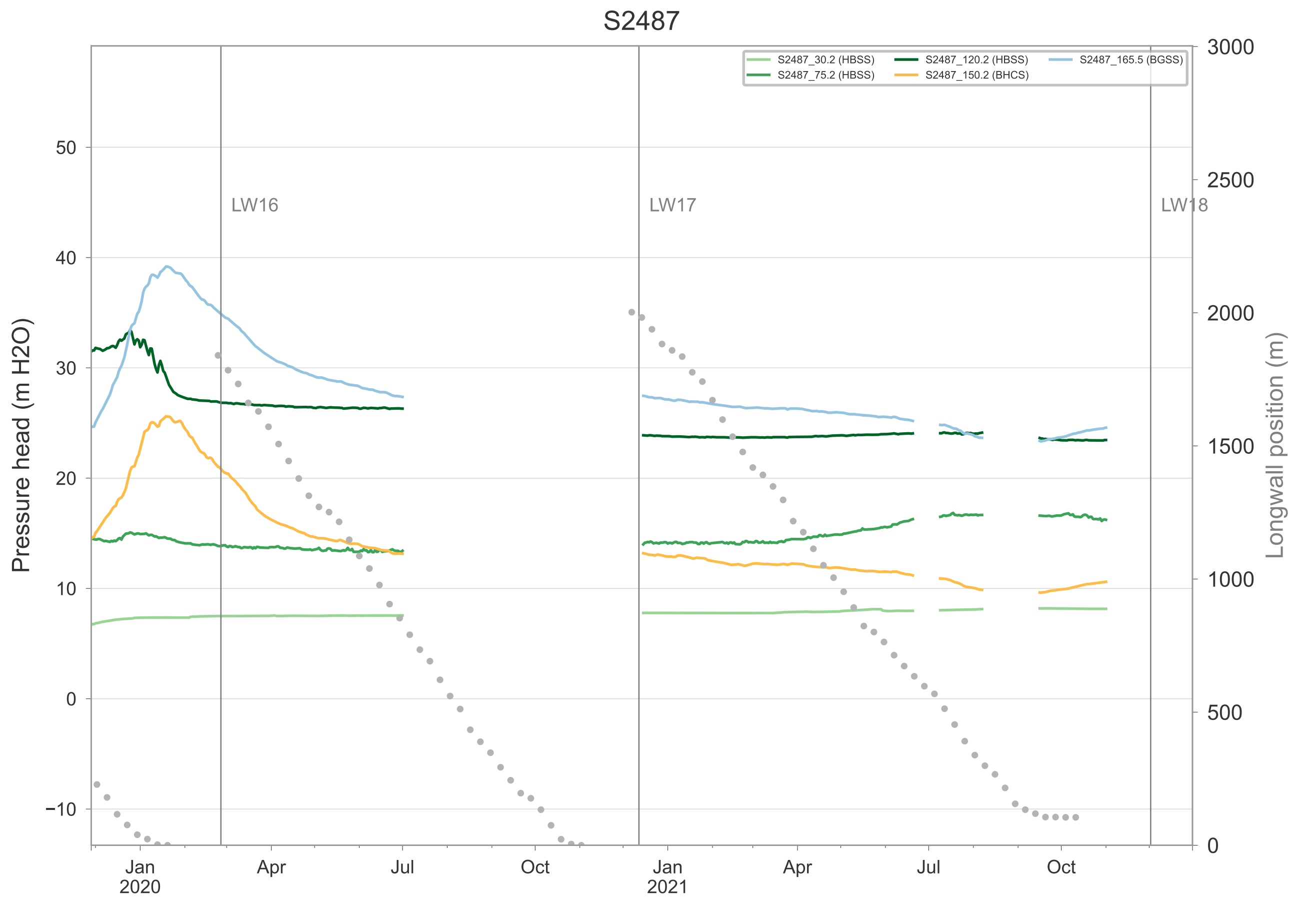

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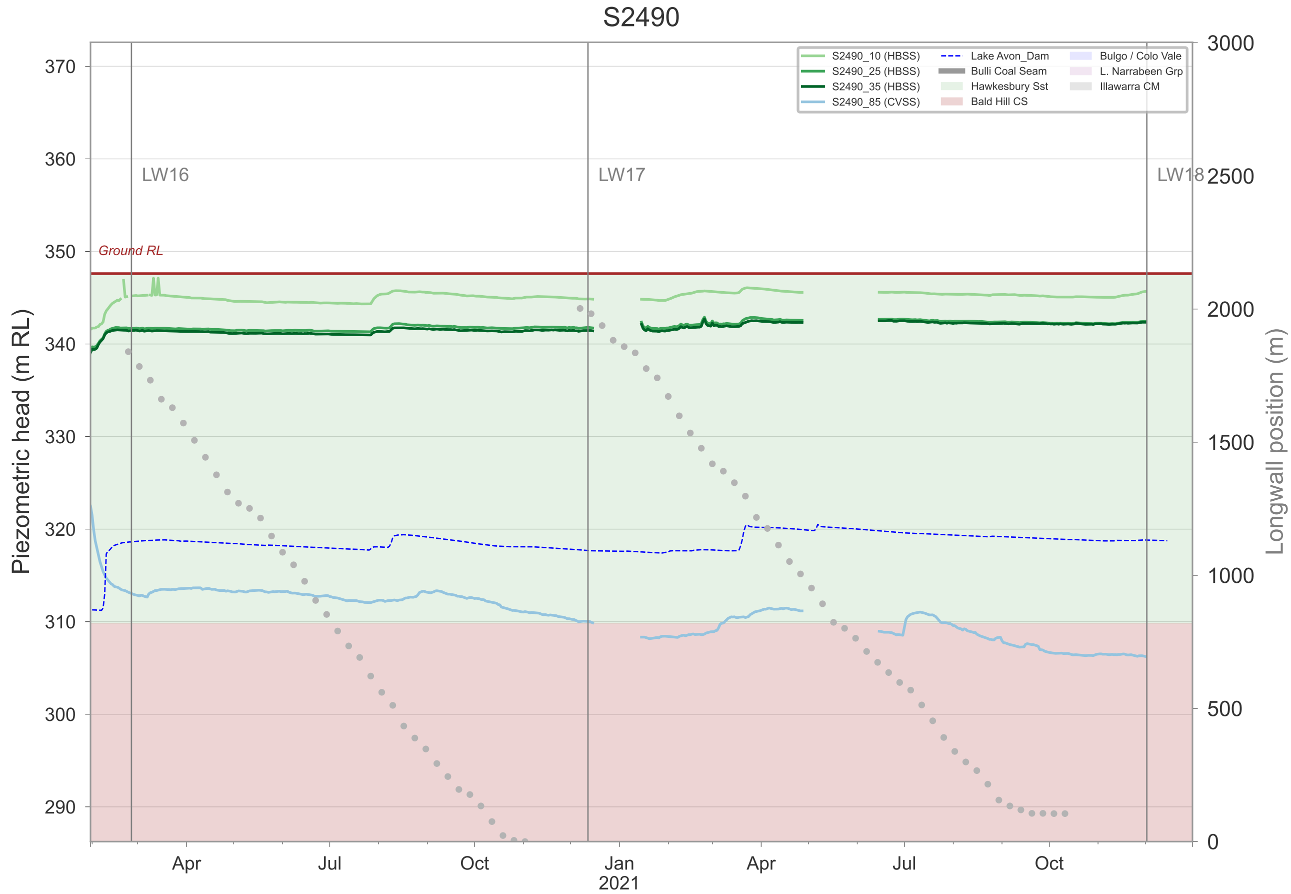

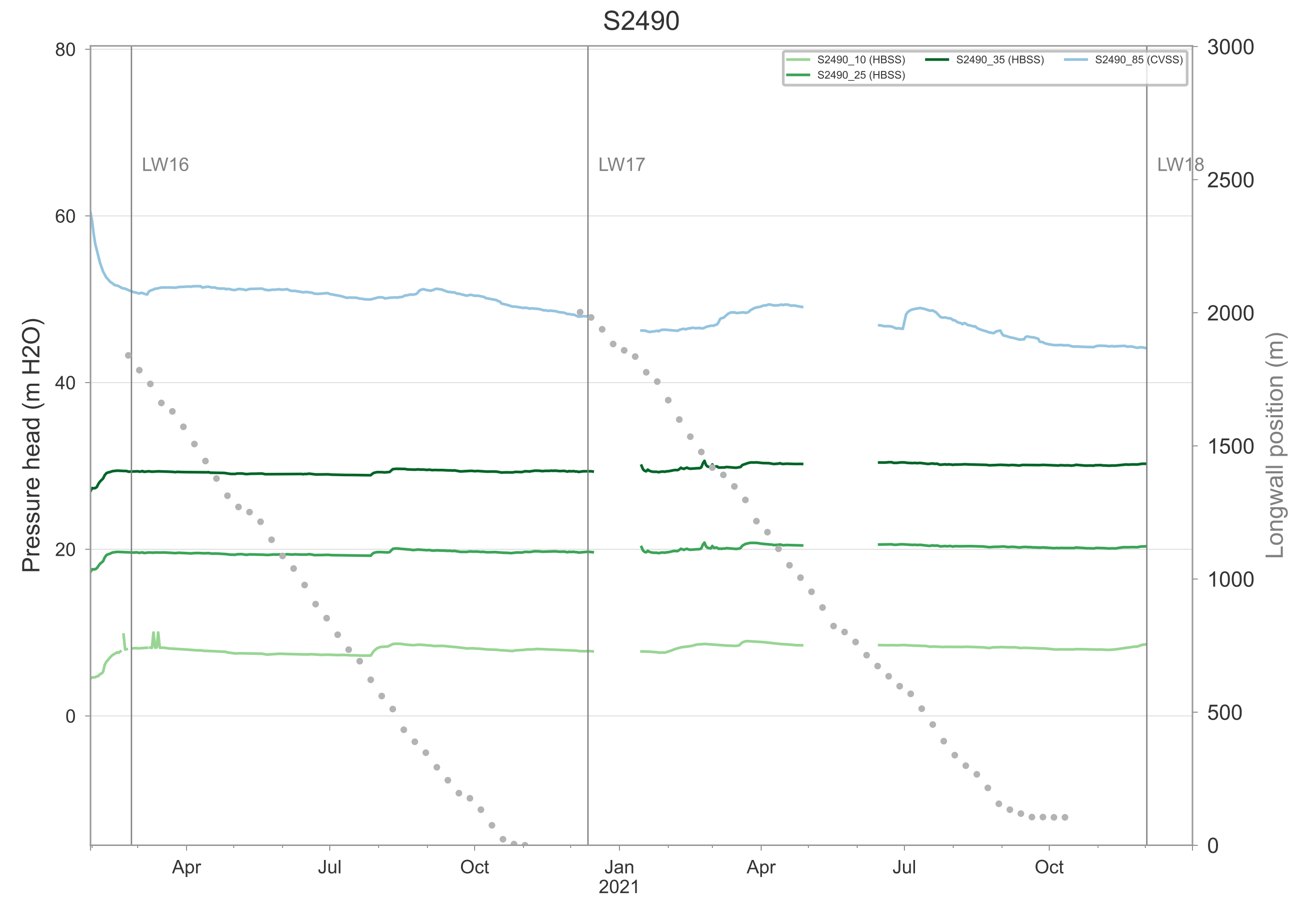

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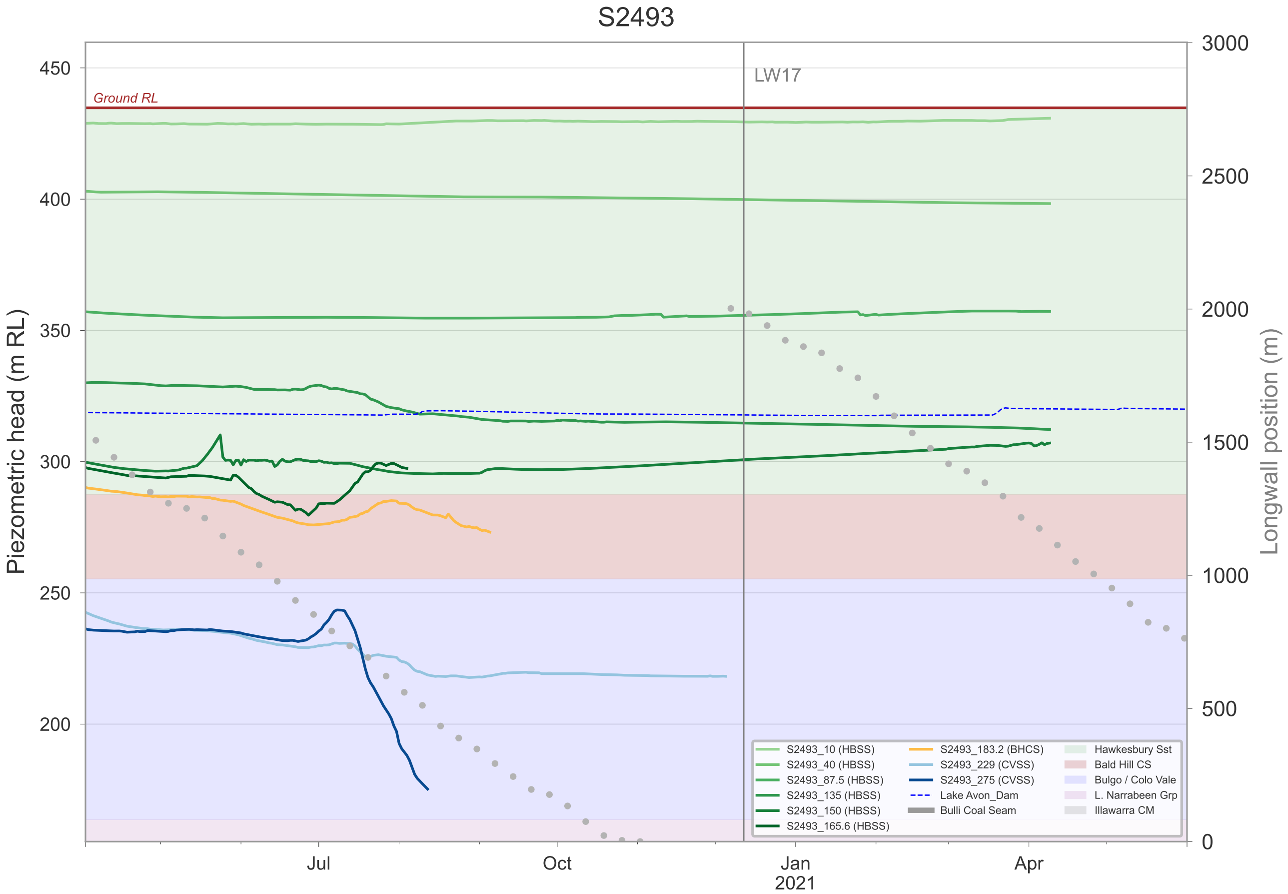

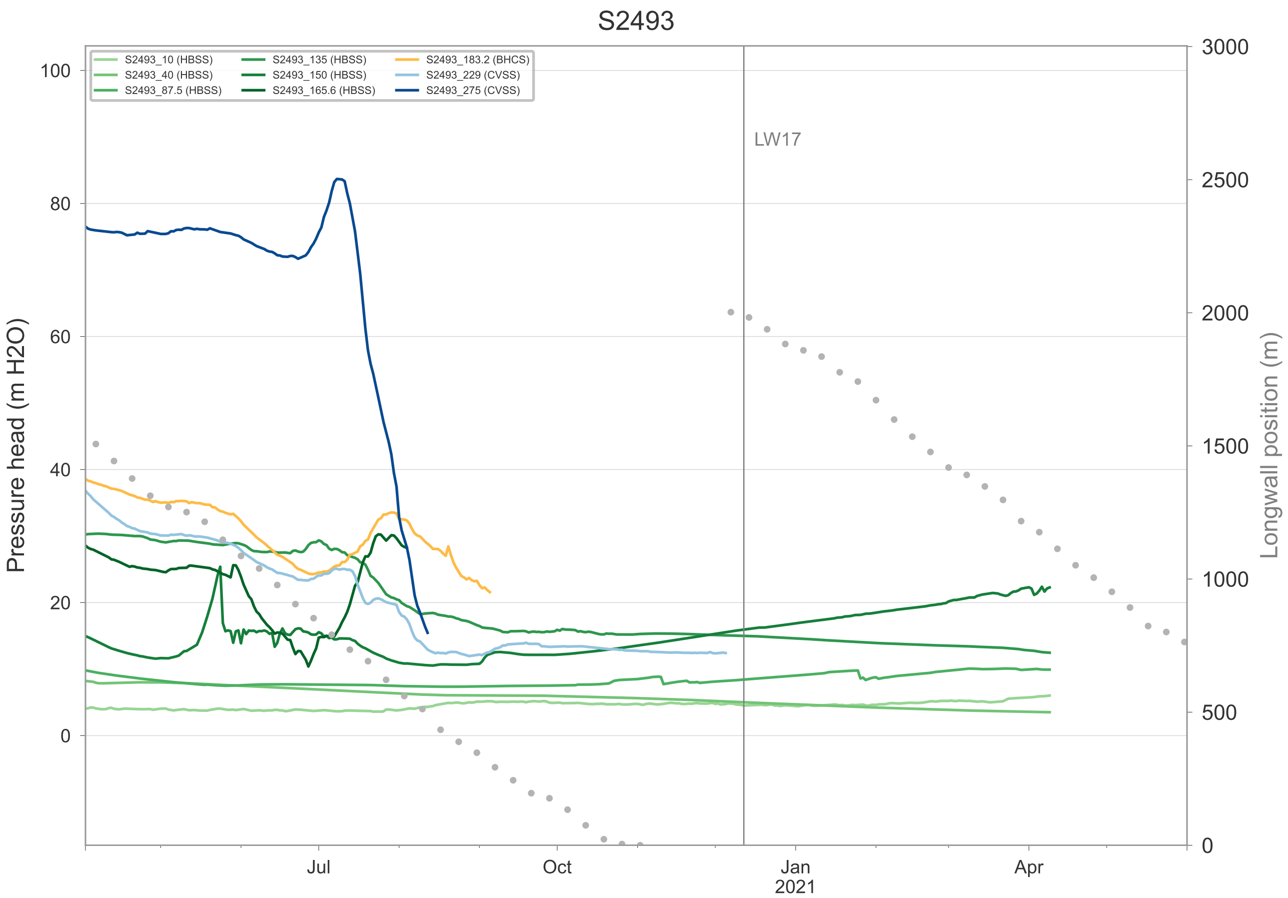

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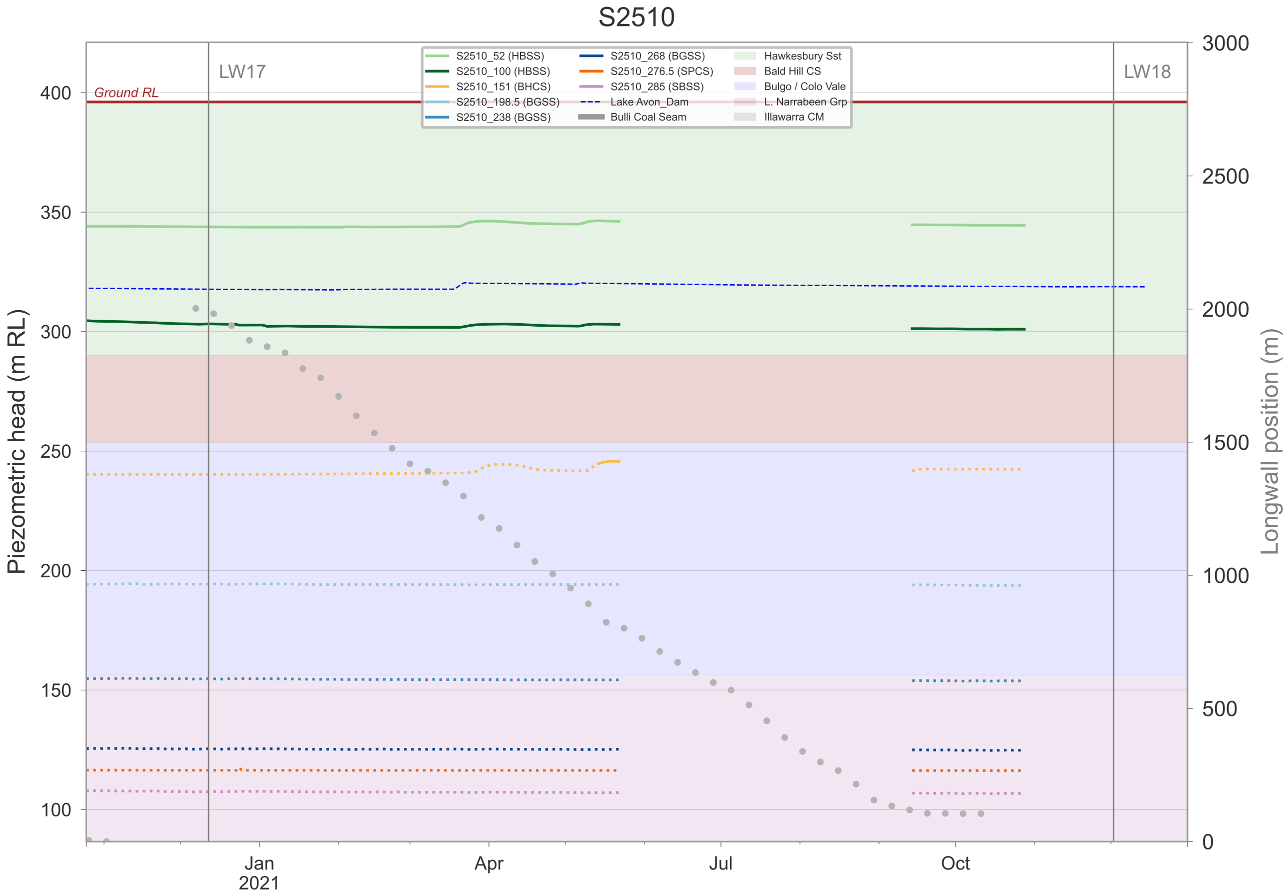

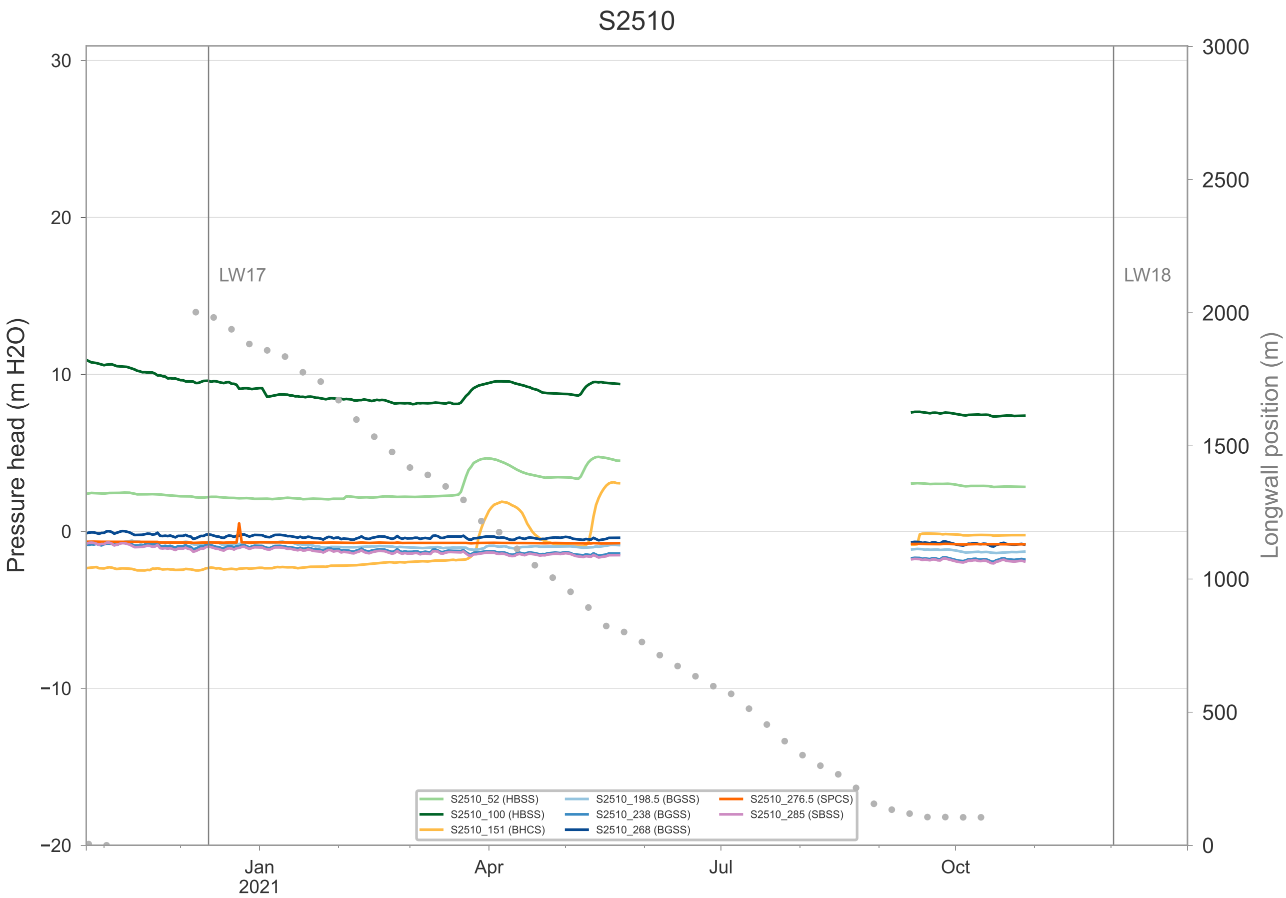

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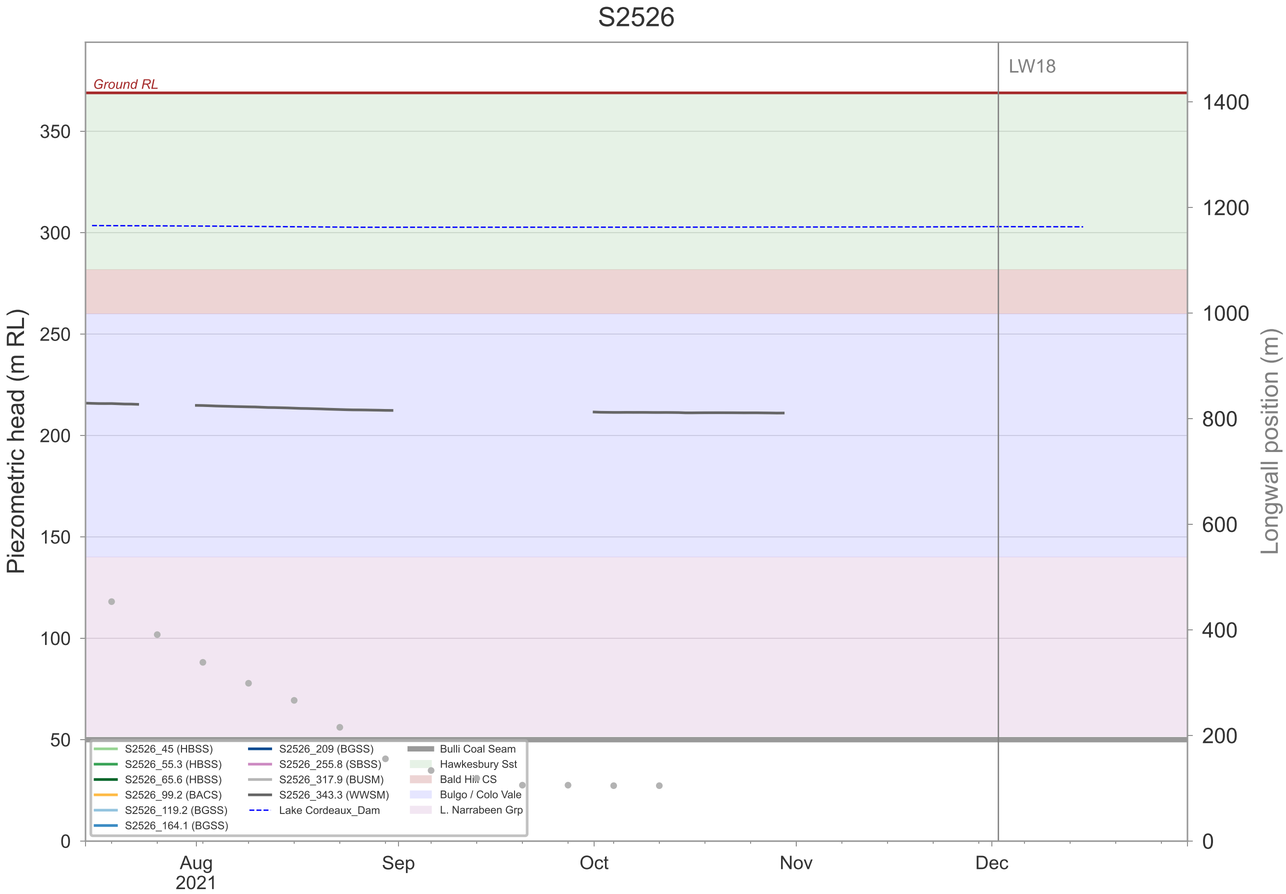
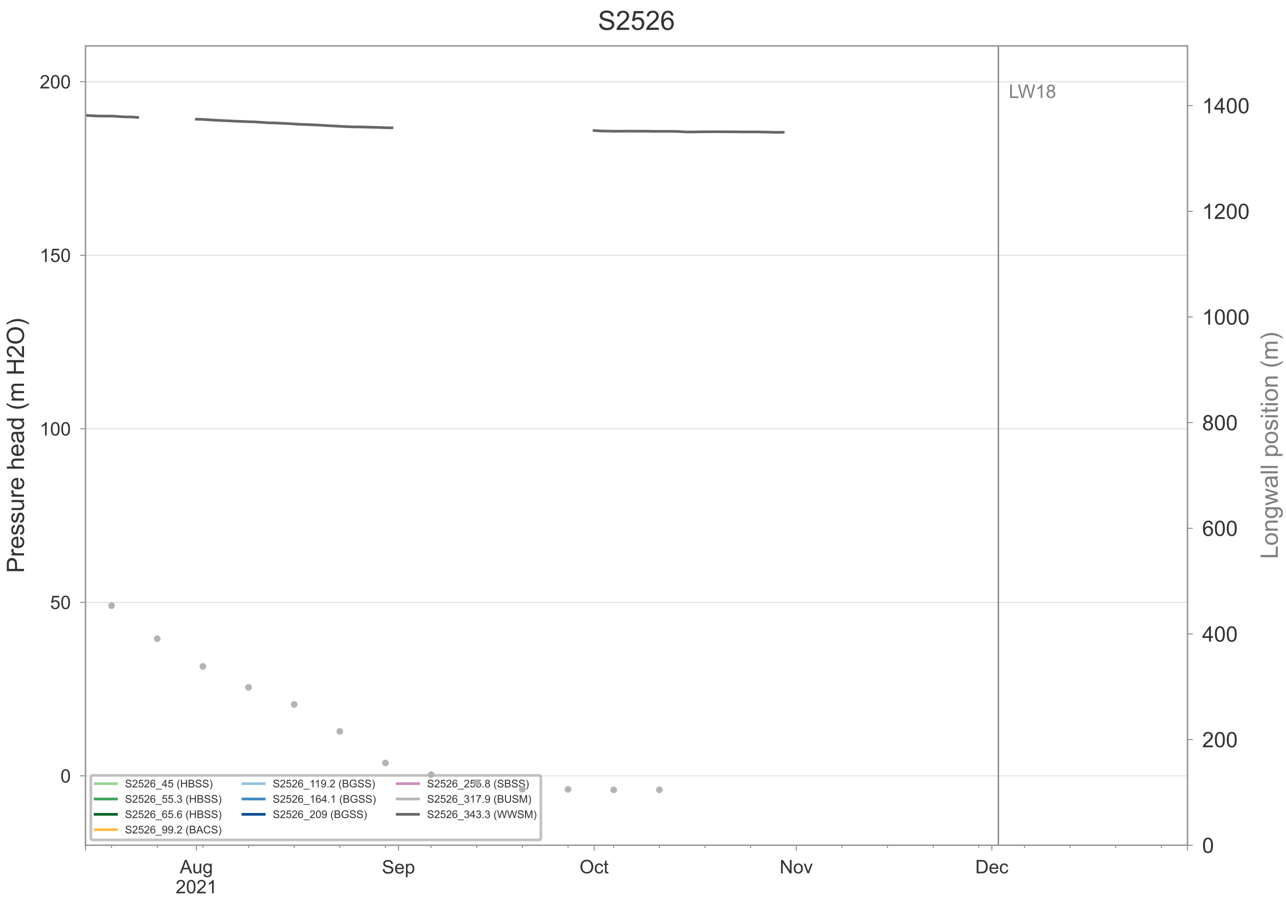
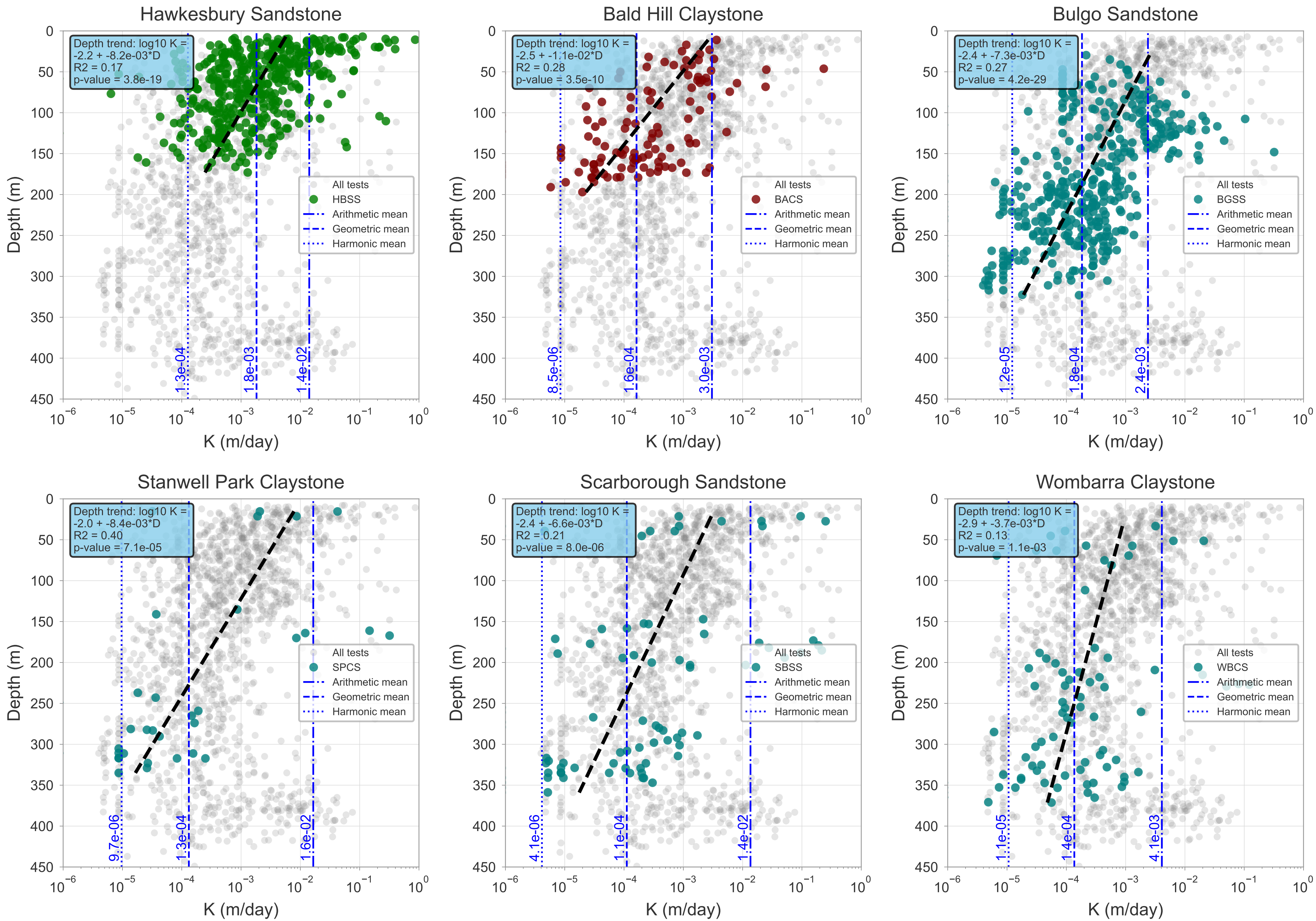
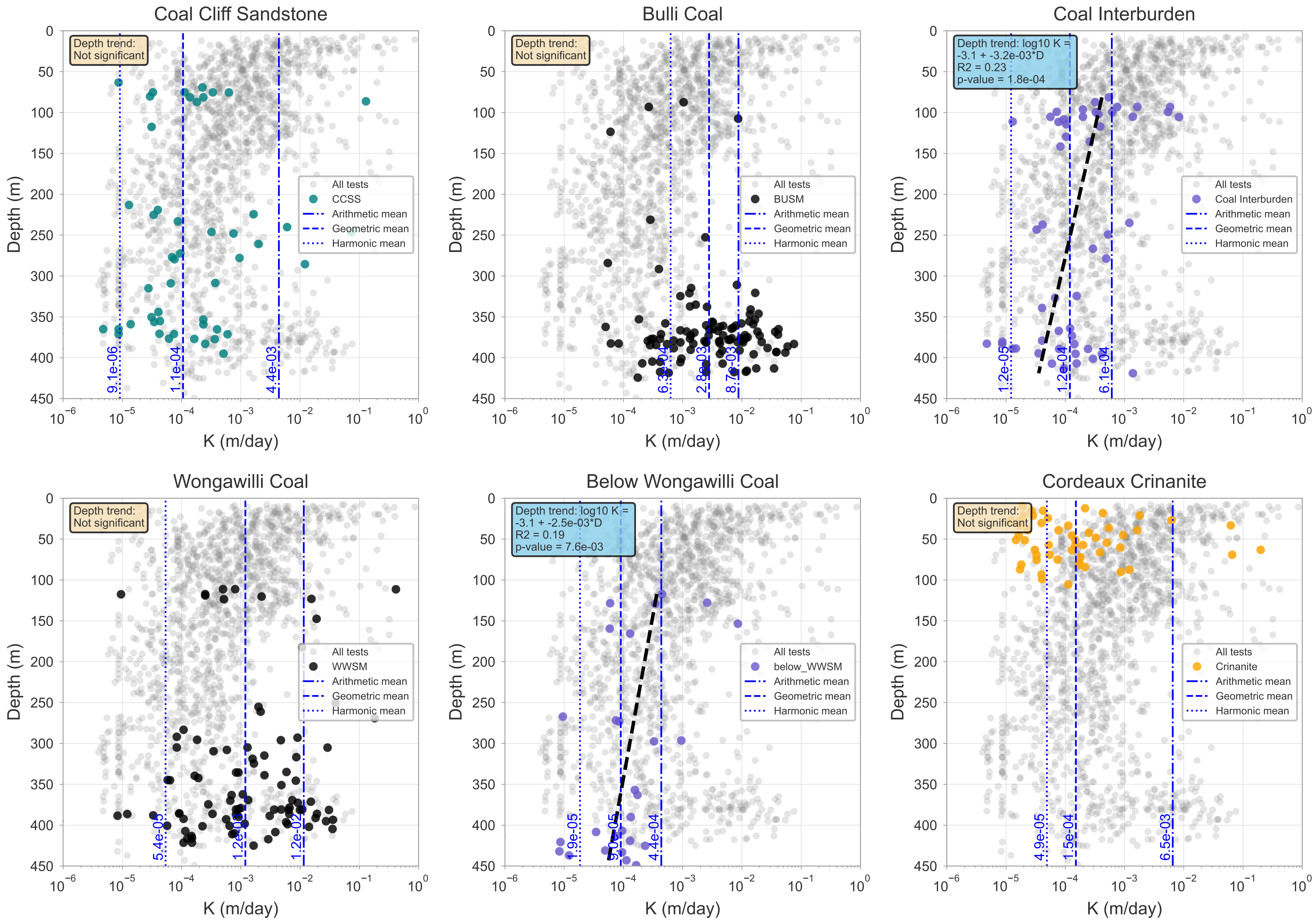


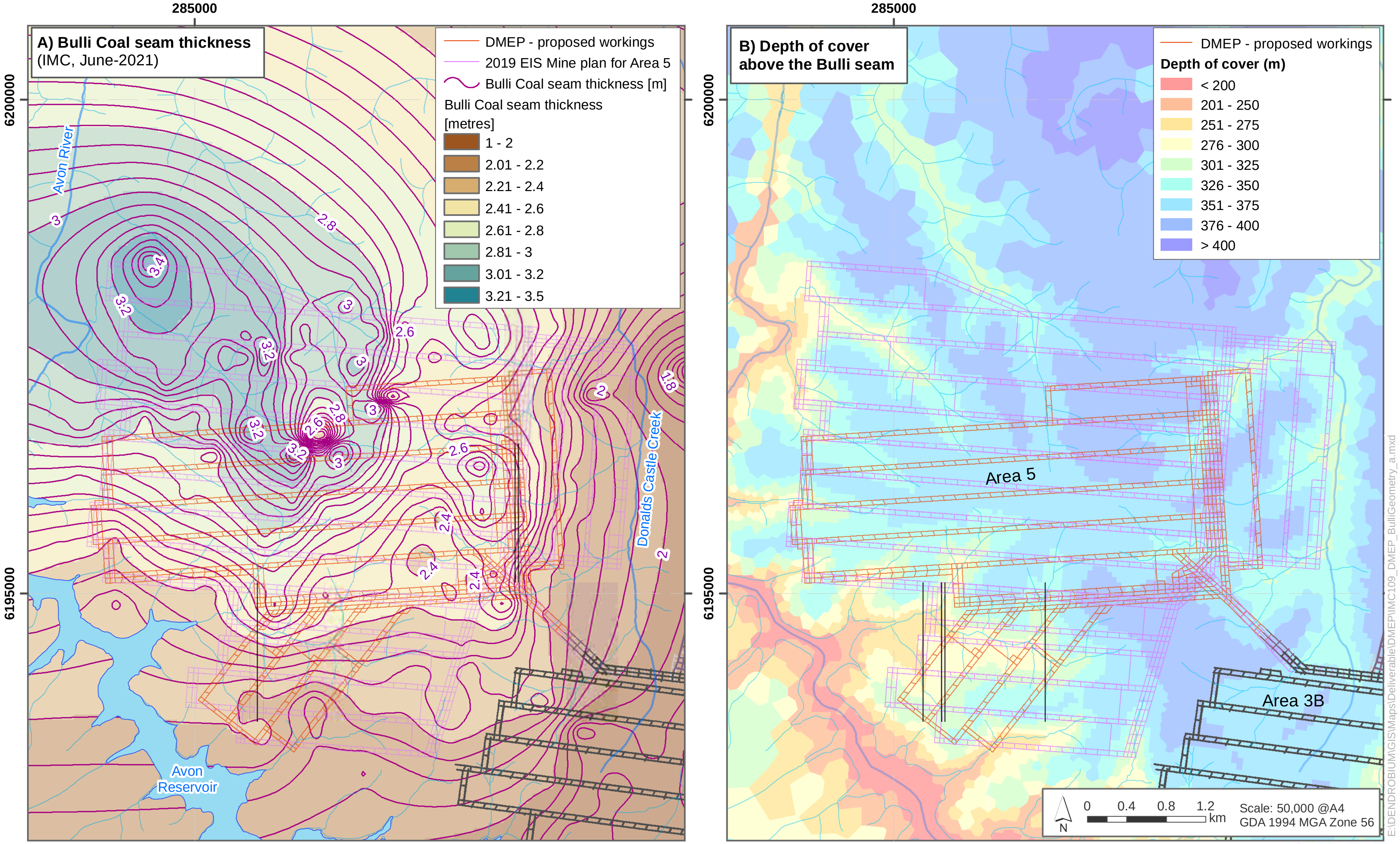


Appendix C: Variation in packer test permeability


Hawkesbury Sandstone
Depth trend: log10 K = -2.2 + -8.2e-03*D
R2 = 0.17
p-value = 3.8e-19
All tests
HBSS
Arithmetic mean
Geometric mean
Harmonic mean
1.3e-04
1.8e-03
1.4e-02
Bald Hill Claystone
Depth trend: log10 K = -2.5 + -1.1e-02*D
R2 = 0.28
p-value = 3.5e-10
BACS
8.5e-06
1.6e-04
3.0e-03
Bulgo Sandstone
Depth trend: log10 K = -2.4 + -7.3e-03*D
R2 = 0.27
p-value = 4.2e-29
BGSS
1.2e-05
1.8e-04
2.4e-03
Stanwell Park Claystone
Depth trend: log10 K = -2.0 + -8.4e-03*D
R2 = 0.40
p-value = 7.1e-05
SPCS
9.7e-06
1.3e-04
1.6e-02
Scarborough Sandstone
Depth trend: log10 K = -2.4 + -6.6e-03*D
R2 = 0.21
p-value = 8.0e-06
SBSS
4.1e-06
1.1e-04
1.4e-02
Wombarra Claystone
Depth trend: log10 K = -2.9 + -3.7e-03*D
R2 = 0.13
p-value = 1.1e-03
WBCS
1.1e-05
1.4e-04
4.1e-03
Depth (m)
K (m/day)


Coal Cliff Sandstone
Depth trend: Not significant
All tests
CCSS
Arithmetic mean
Geometric mean
Harmonic mean
9.1e-06
1.1e-04
4.4e-03
Bulli Coal
Depth trend: Not significant
All tests
BUSM
Arithmetic mean
Geometric mean
Harmonic mean
Coal Interburden
Depth trend: log10 K = -3.1 + -3.2e-03*D
R2 = 0.23
p-value = 1.8e-04
All tests
Coal Interburden
Arithmetic mean
Geometric mean
Harmonic mean
1.2e-05
1.2e-04
6.1e-04
Wongawilli Coal
Depth trend: Not significant
All tests
WWSM
Arithmetic mean
Geometric mean
Harmonic mean
Below Wongawilli Coal
Depth trend: log10 K = -3.1 + -2.5e-03*D
R2 = 0.19
p-value = 7.6e-03
All tests
below_WWSM
Arithmetic mean
Geometric mean
Harmonic mean
4.4e-04
Cordeaux Crinanite
Depth trend: Not significant
All tests
Crinanite
Arithmetic mean
Geometric mean
Harmonic mean
4.9e-05
1.5e-04
6.5e-03
Depth (m)
K (m/day)

Appendix D: Assessment of Height of Fracturing at Dendrobium



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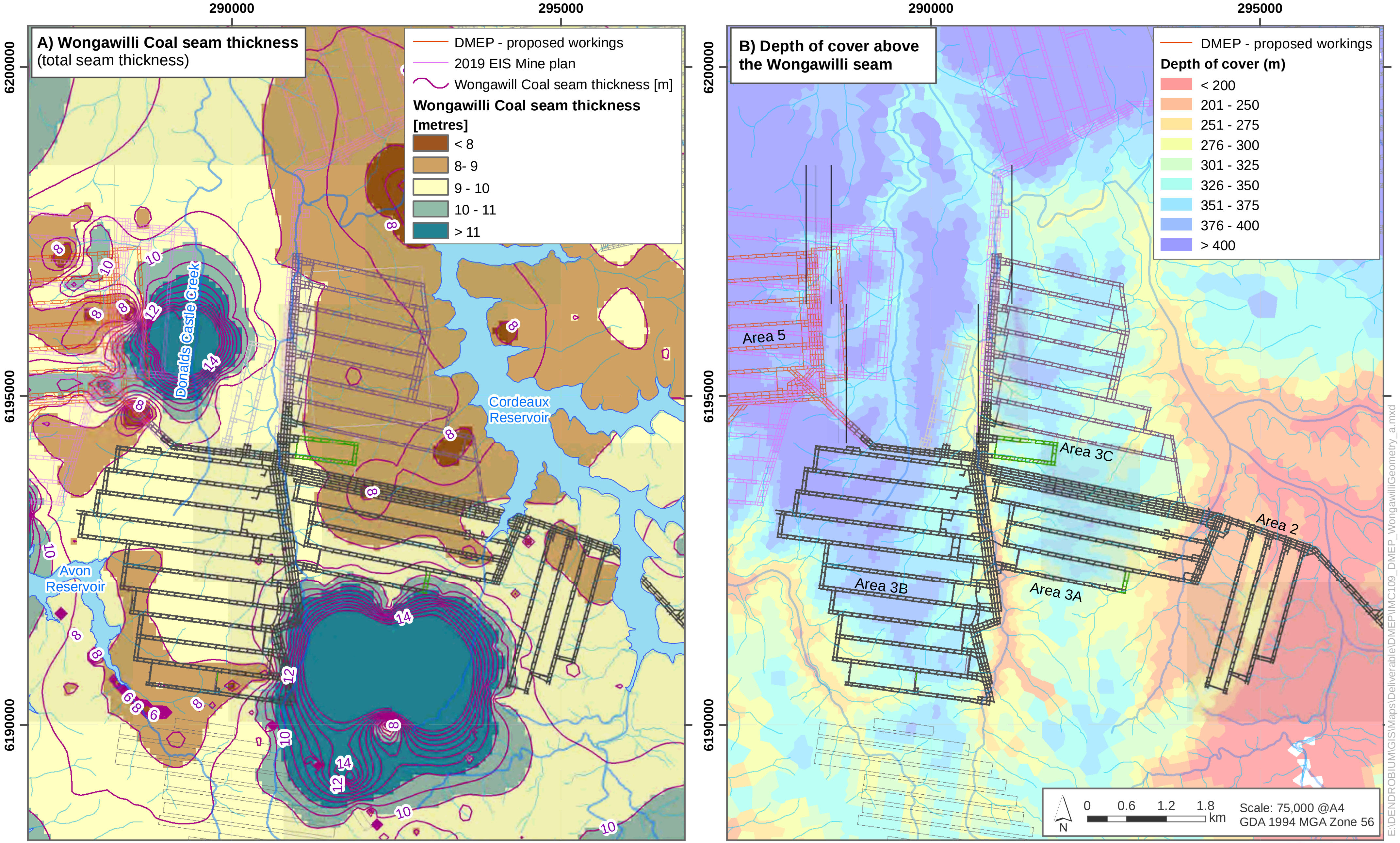
Lake
Watercourse
Tribs

IMC | Dendrobium Mine

Area 5 mine plan, Bulli Coal seam thickness and depth of cover

Figure D1



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Lake

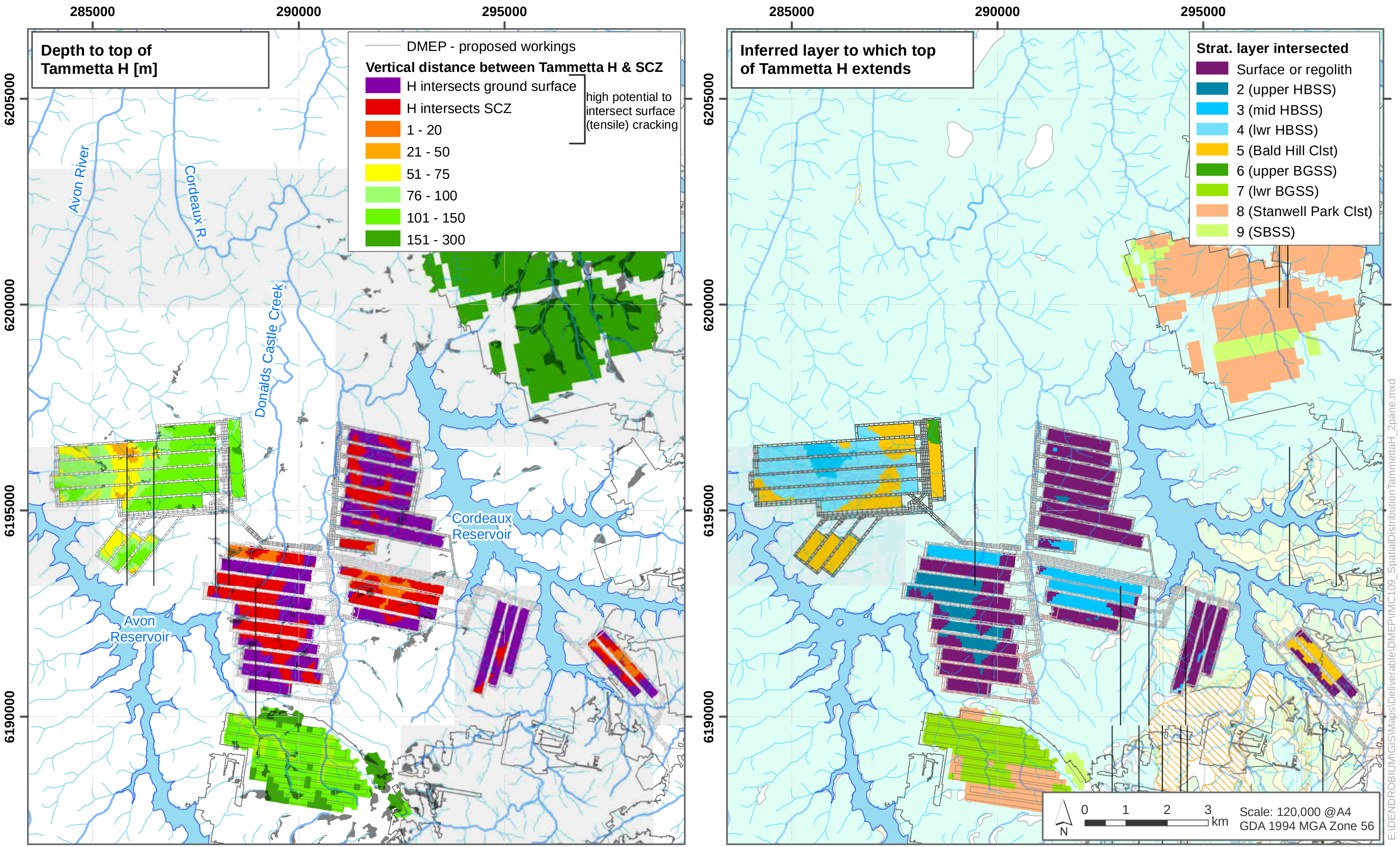
Watercourse

Tribs

IMC | Dendrobium Mine

Dendrobium mine plan, Wongawilli Coal seam thickness and depth of cover

Figure D2



Lake
Watercourse
Tribs
Upland Swamp
Mine workings

Outcrop geology

(Sthn Coalfield 1:100k)

Qa	alluvium	TRh	HBSS
Qt	talus	TRnz	BHCS (BACS)
		TRnbu	BUSS / CVSS
			Cordeaux Crinanite

notes:

* Tammetta (2012) model for H, the height of complete groundwater drainage. Sometimes used to also refer "to the region of (connected) fracturing which results in significant depressurisation of the strata" (IEPMC, 2019). While it is considered a useful tool to understand risk, recent evidence suggests that this is not equivalent to the height of connected fracturing at Dendrobium Mine.

* SCZ: Surface Cracking Zone, where the depth of this zone estimated conservatively as 12 x longwall cutting height.

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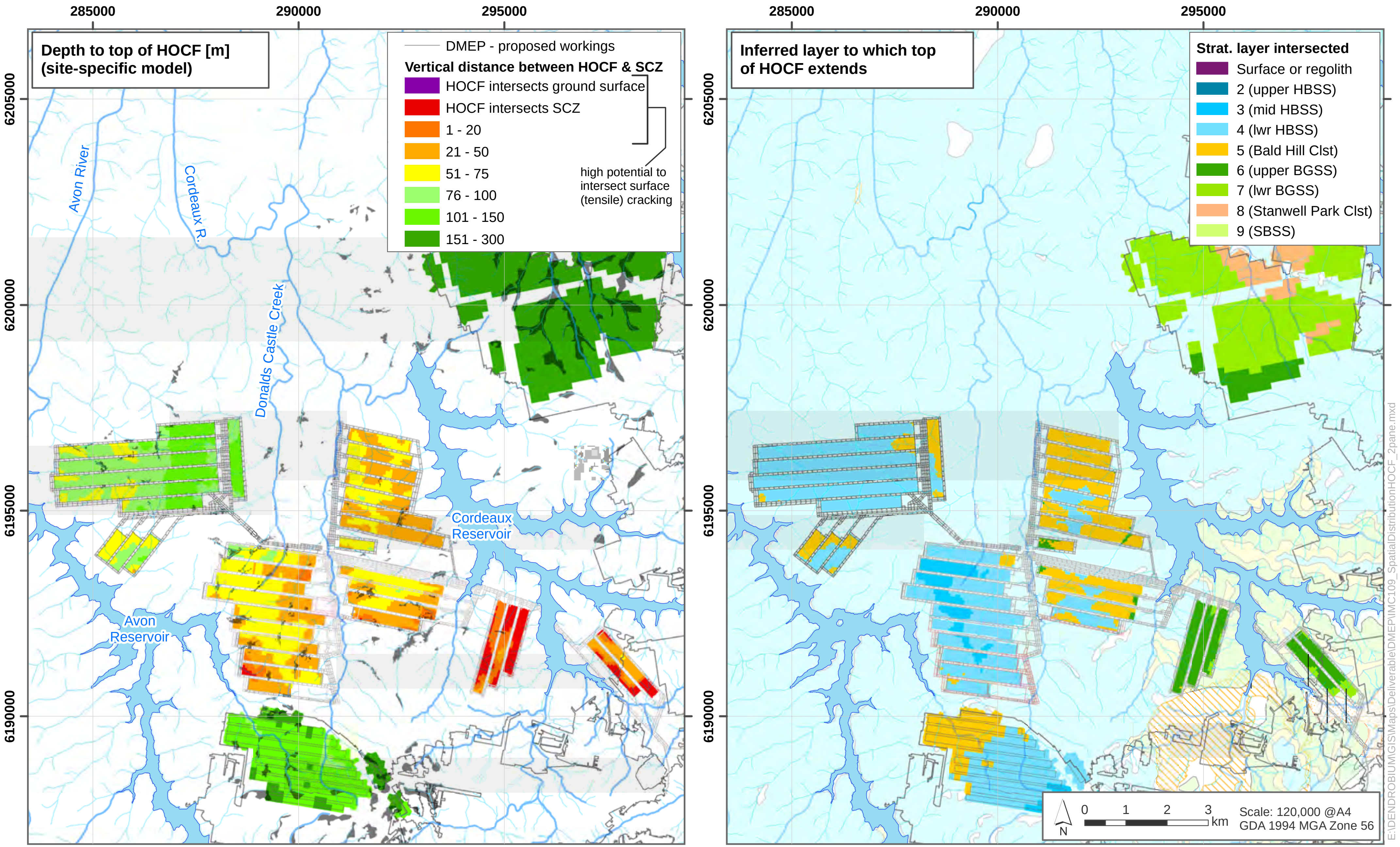
WATERSHED HYDROGEO

IMC | Dendrobium Mine

Spatial variation in inferred height and depth Tammetta H at Dendrobium and neighbouring mines

Figure D3



Lake
Watercourse
Tribs
Upland Swamp
Mine workings

Outcrop geology

(Sthn Coalfield 1:100k)

Qa	alluvium	TRh	HBSS
Qt	talus	TRnz	BHCS (BACS)
		TRnbu	BUSS / CVSS
		Cordeaux Crinanite	

notes:

* Site-specific model is that HOCF at Dendrobium is best estimated by empirical models of Ditton (Ditton A95).
* SCZ: Surface Cracking Zone, where the depth of this zone estimated conservatively as 12 x longwall cutting height.

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WATERSHED HYDROGEO

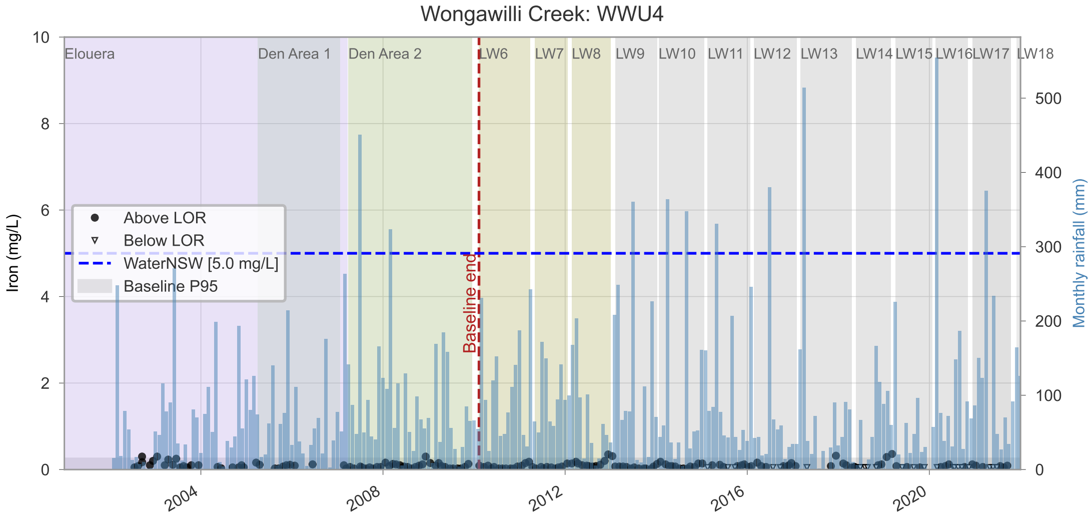
IMC | Dendrobium Mine

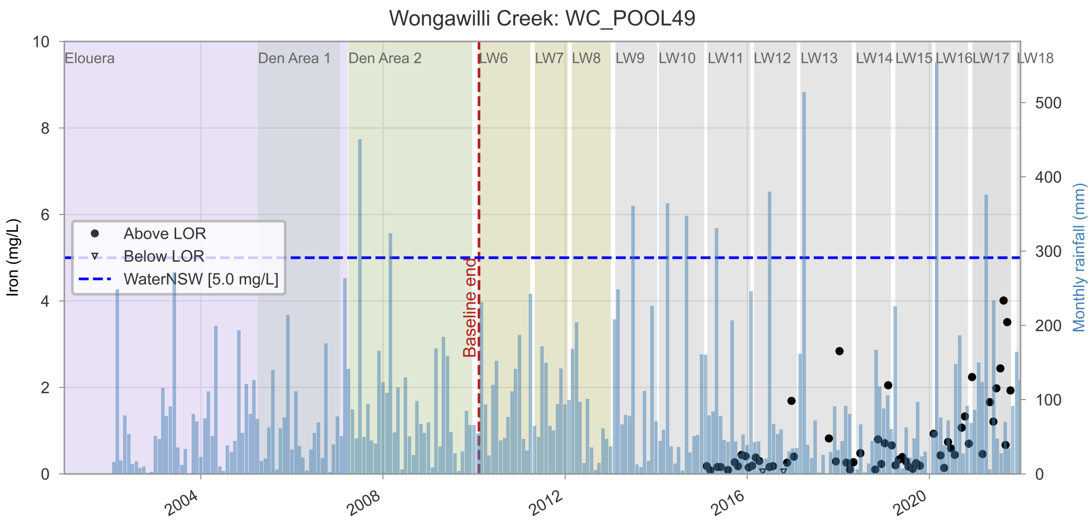
Spatial variation in inferred height and depth of Height of Connected Fracturing (HOCF) at Dendrobium and neighbouring mines

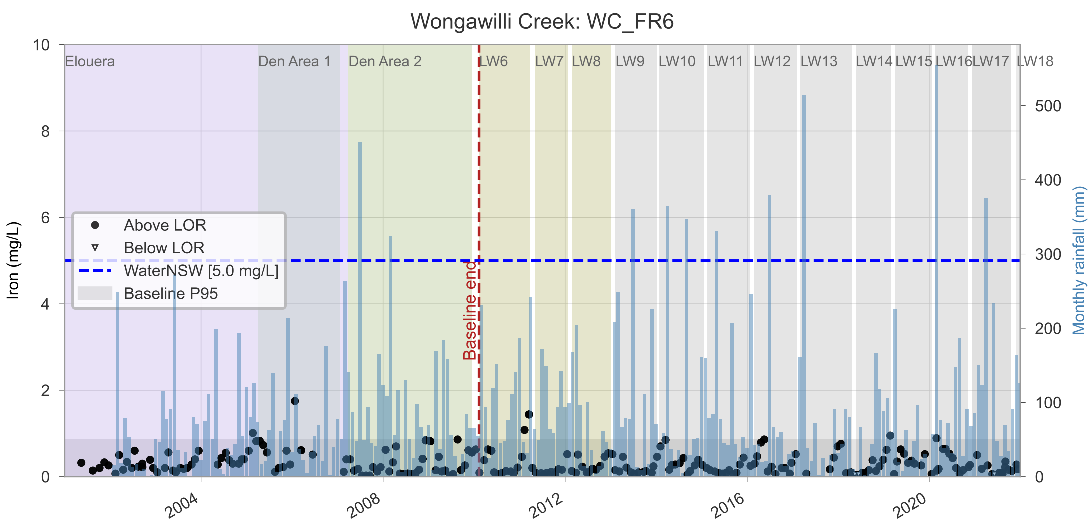
Figure D4

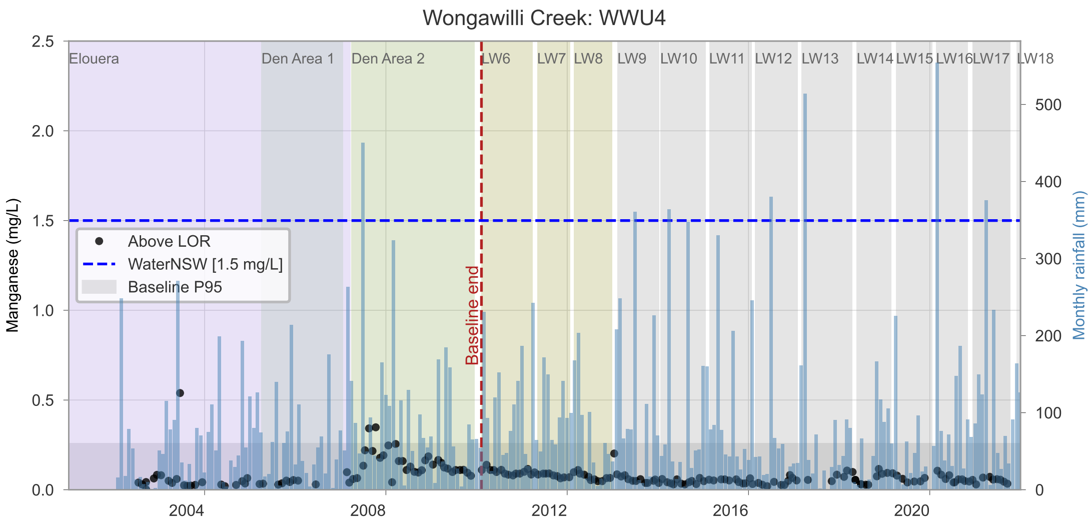
Appendix E: Timeseries of surface water quality (metals)

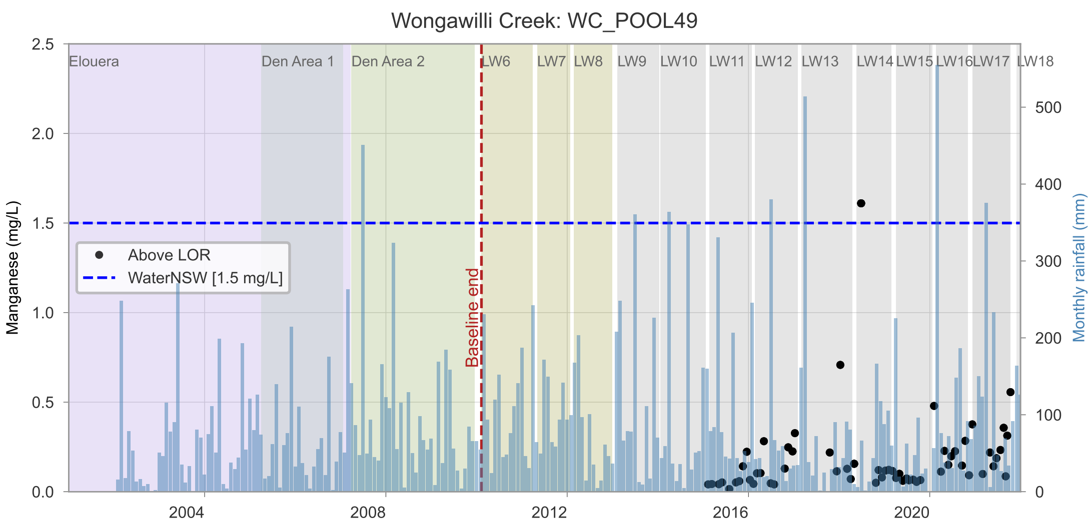
The charts in this appendix focus on dissolved metals previously identified by WaterNSW or elsewhere as of concern.

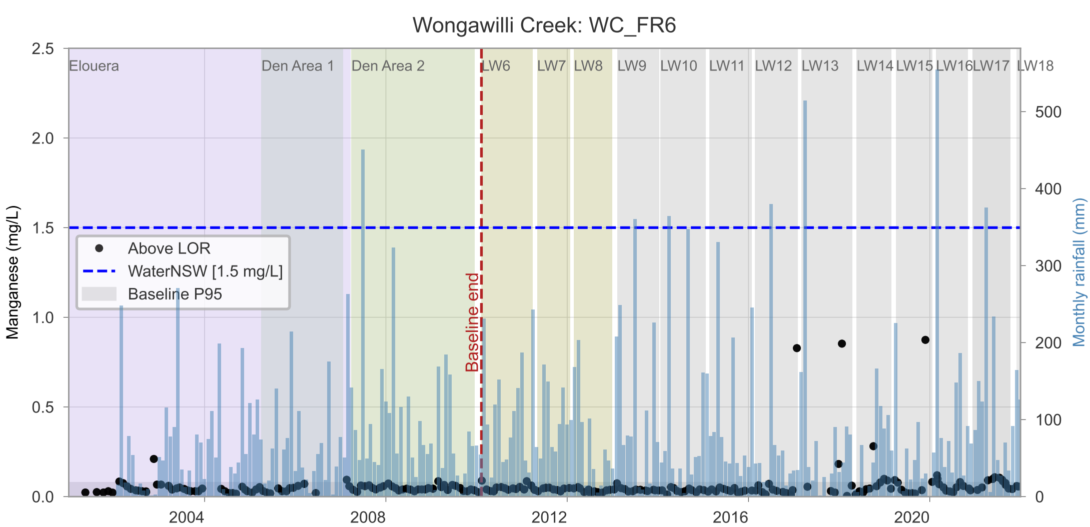

Wongawilli Creek: WWU4
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Above LOR
Below LOR
WaterNSW [5.0 mg/L]
Baseline P95
Baseline end
Iron (mg/L)
Monthly rainfall (mm)
0
2
4
6
8
10
100
200
300
400
500
2004
2008
2012
2016
2020

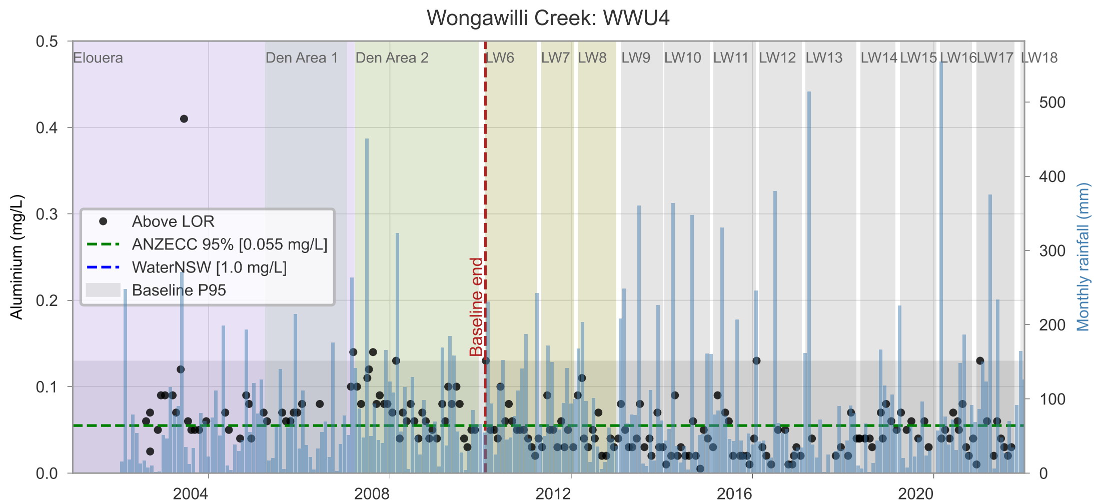

Wongawilli Creek: WC_POOL49
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Above LOR
Below LOR
WaterNSW [5.0 mg/L]
Baseline end
Iron (mg/L)
Monthly rainfall (mm)
0
2
4
6
8
10
100
200
300
400
500
2004
2008
2012
2016
2020

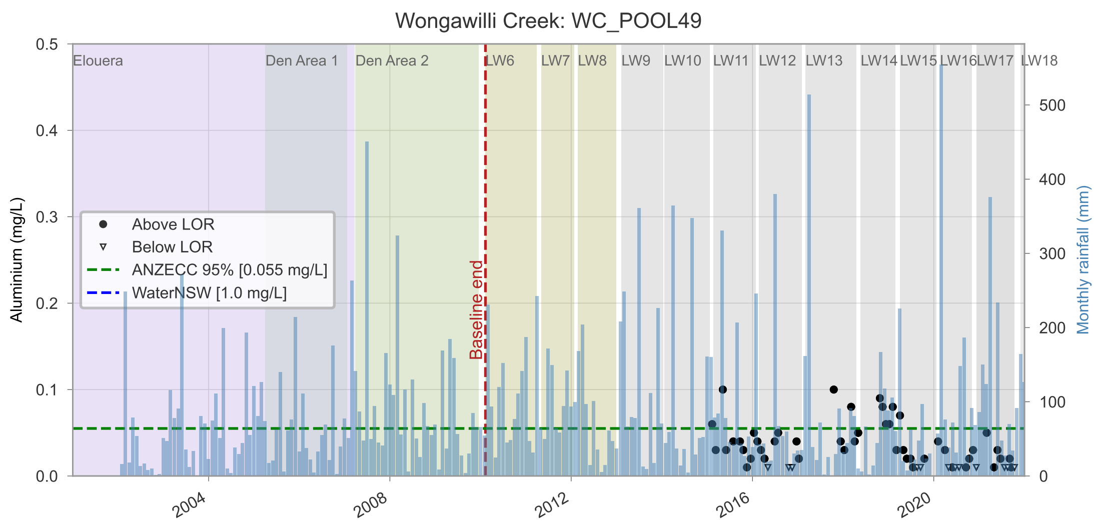

Wongawilli Creek: WC_FR6
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Above LOR
Below LOR
WaterNSW [5.0 mg/L]
Baseline P95
Baseline end
Iron (mg/L)
Monthly rainfall (mm)
0
2
4
6
8
10
100
200
300
400
500
2004
2008
2012
2016
2020

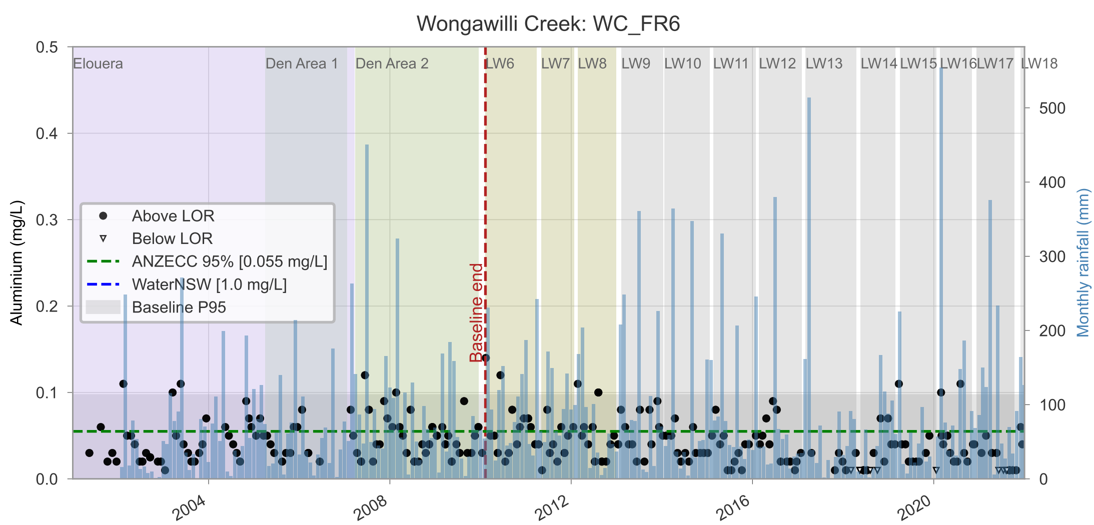

Wongawilli Creek: WWU4
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
WaterNSW [1.5 mg/L]
Baseline P95
Manganese (mg/L)
Monthly rainfall (mm)
2004
2008
2012
2016
2020


Wongawilli Creek: WC_POOL49
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
WaterNSW [1.5 mg/L]
Manganese (mg/L)
Monthly rainfall (mm)
2004
2008
2012
2016
2020

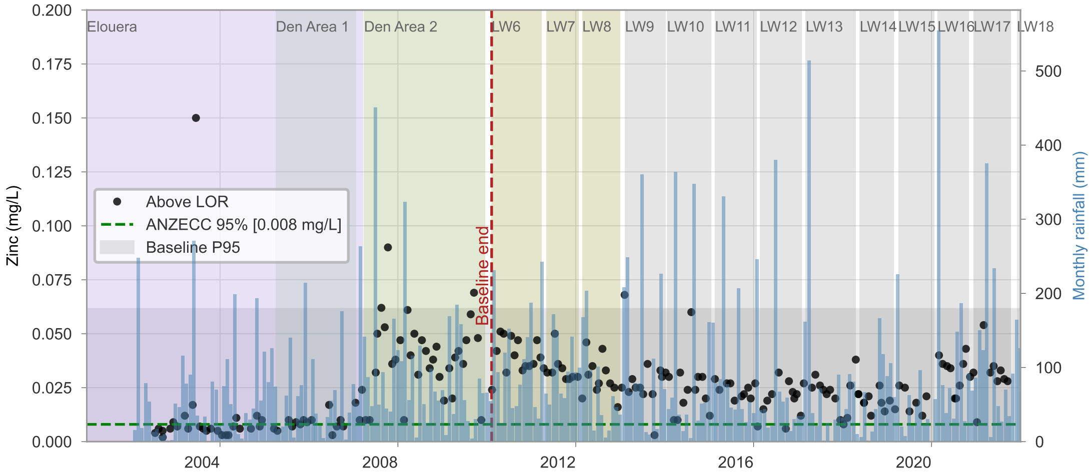

Wongawilli Creek: WC_FR6
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
WaterNSW [1.5 mg/L]
Baseline P95
Manganese (mg/L)
Monthly rainfall (mm)
2004
2008
2012
2016
2020


Wongawilli Creek: WWU4
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
ANZECC 95% [0.055 mg/L]
WaterNSW [1.0 mg/L]
Baseline P95
Aluminium (mg/L)
Monthly rainfall (mm)
0.0
0.1
0.2
0.3
0.4
0.5
0
100
200
300
400
500
2004
2008
2012
2016
2020

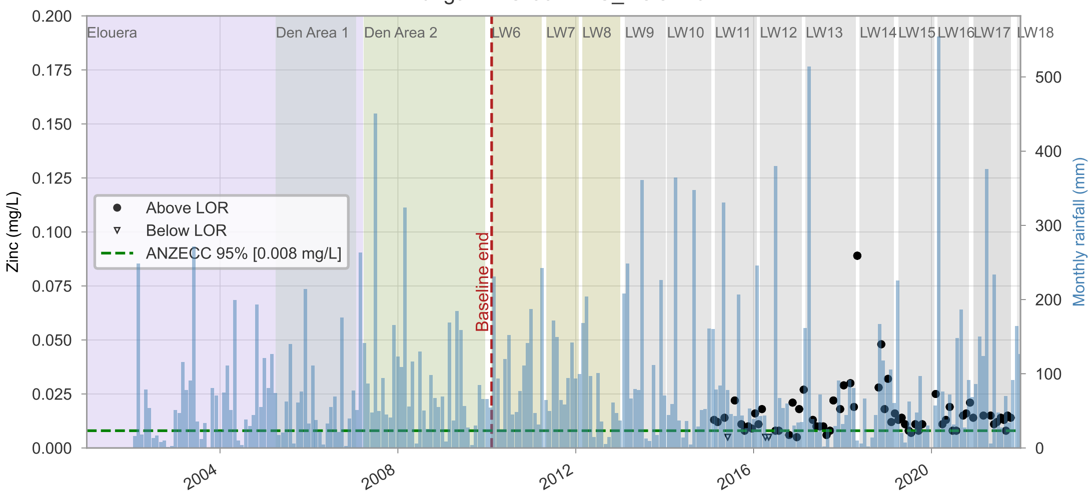

Wongawilli Creek: WC_POOL49
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
Below LOR
ANZECC 95% [0.055 mg/L]
WaterNSW [1.0 mg/L]
Aluminium (mg/L)
Monthly rainfall (mm)
0.0
0.1
0.2
0.3
0.4
0.5
0
100
200
300
400
500
2004
2008
2012
2016
2020


Wongawilli Creek: WC_FR6
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
Below LOR
ANZECC 95% [0.055 mg/L]
WaterNSW [1.0 mg/L]
Baseline P95
Aluminium (mg/L)
Monthly rainfall (mm)
0.0
0.1
0.2
0.3
0.4
0.5
0
100
200
300
400
500
2004
2008
2012
2016
2020

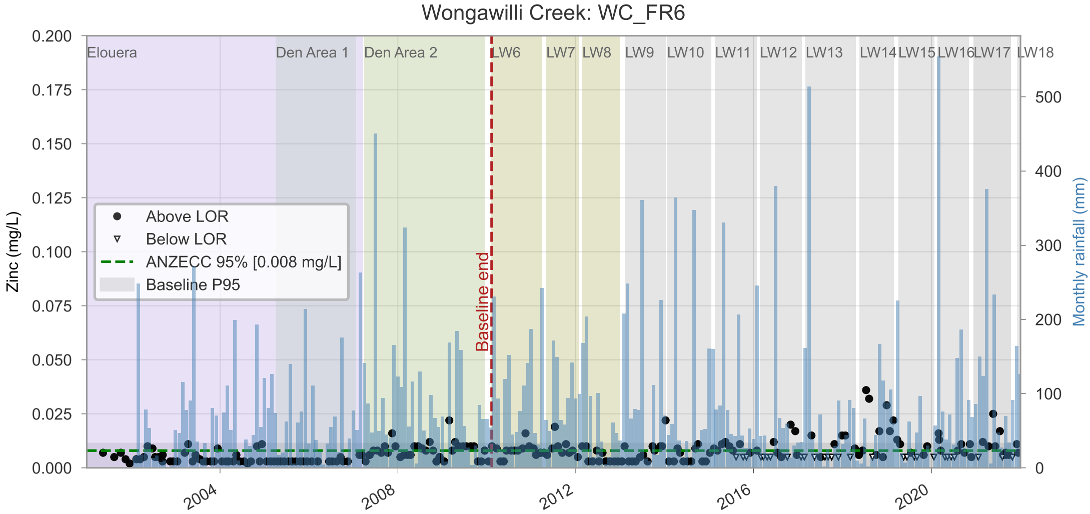
Wongawilli Creek: WWU4

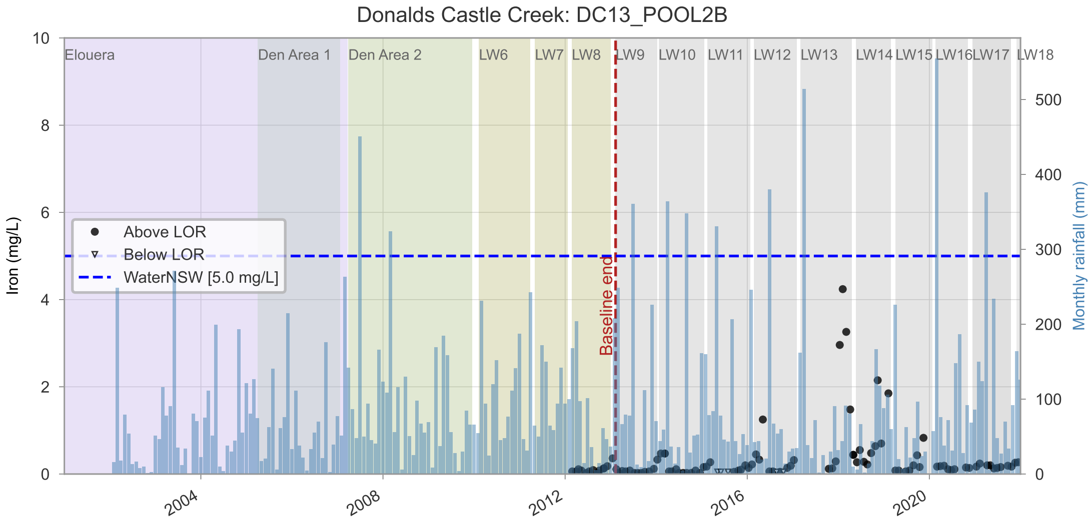


Wongawilli Creek: WC_POOL49

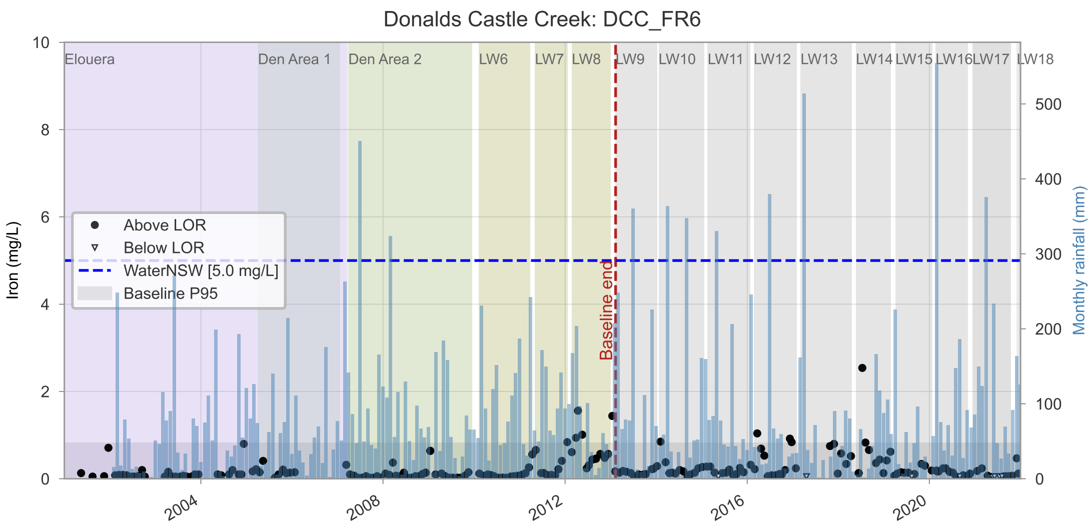


Wongawilli Creek: WC_FR6

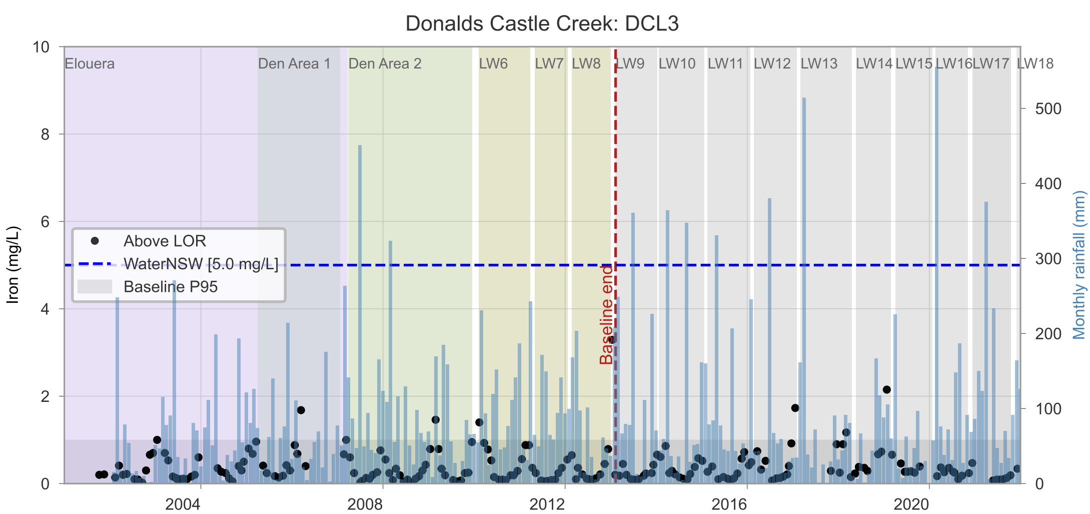




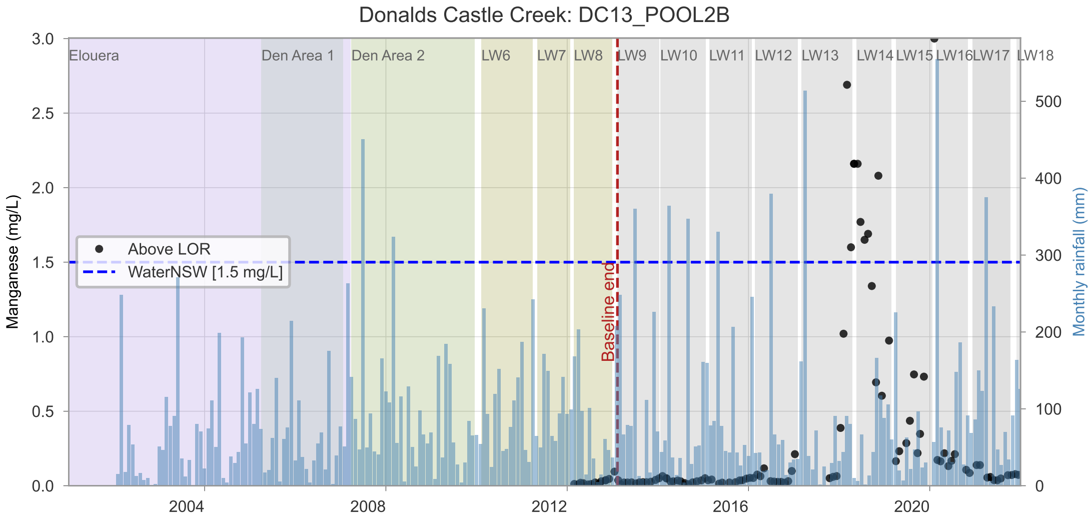
Donalds Castle Creek: DC13_POOL2B
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Above LOR
Below LOR
WaterNSW [5.0 mg/L]
Baseline end
Iron (mg/L)
Monthly rainfall (mm)
0
2
4
6
8
10
100
200
300
400
500
2004
2008
2012
2016
2020

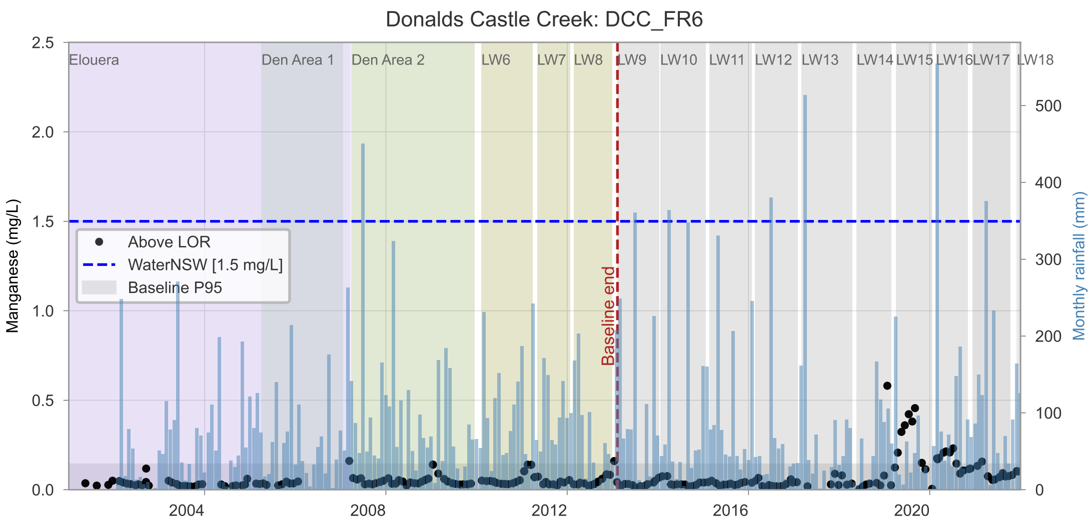


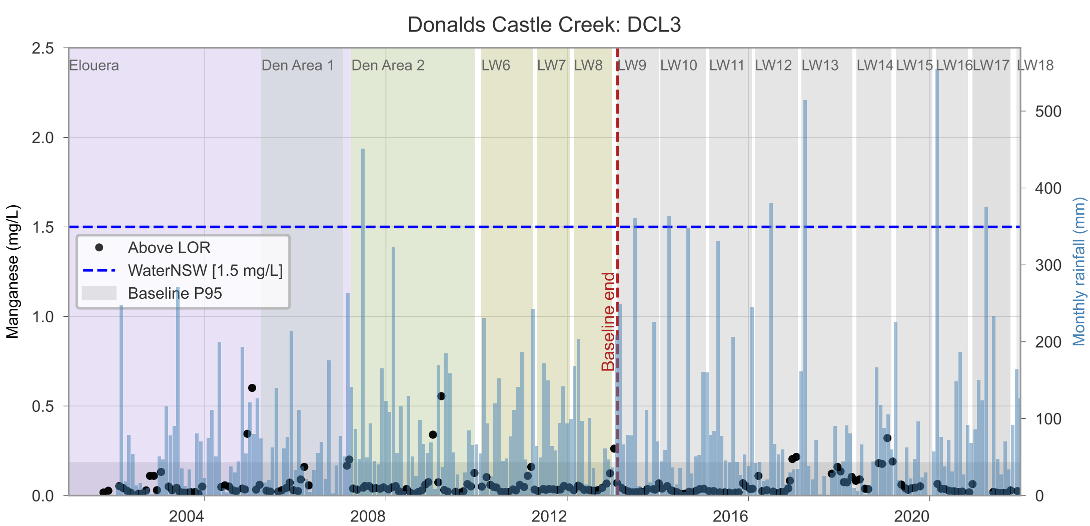
Donalds Castle Creek: DCC_FR6
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Above LOR
Below LOR
WaterNSW [5.0 mg/L]
Baseline P95
Baseline end
Iron (mg/L)
Monthly rainfall (mm)
0
2
4
6
8
10
100
200
300
400
500
2004
2008
2012
2016
2020

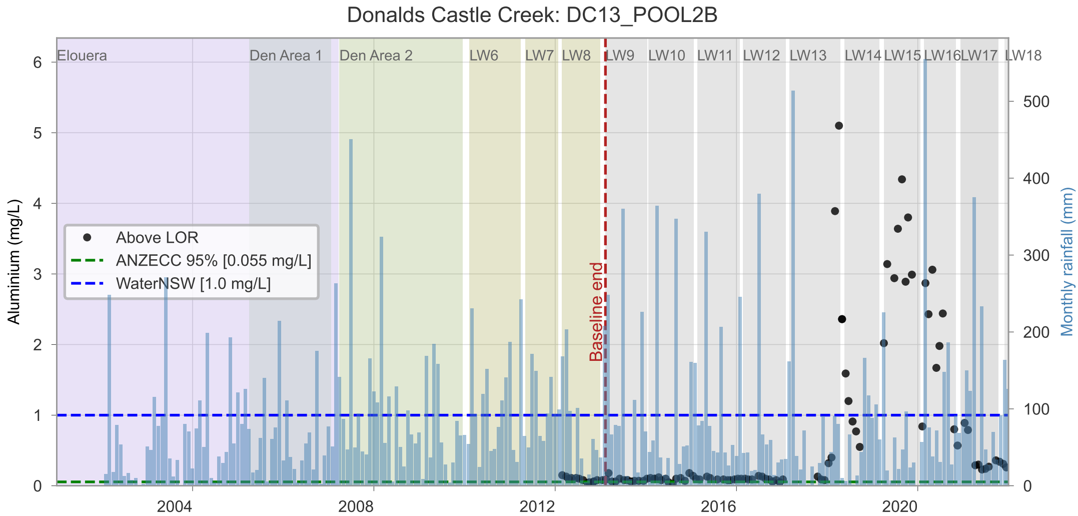


Donalds Castle Creek: DCL3
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Above LOR
WaterNSW [5.0 mg/L]
Baseline P95
Baseline end
Iron (mg/L)
Monthly rainfall (mm)
0
2
4
6
8
10
100
200
300
400
500
2004
2008
2012
2016
2020

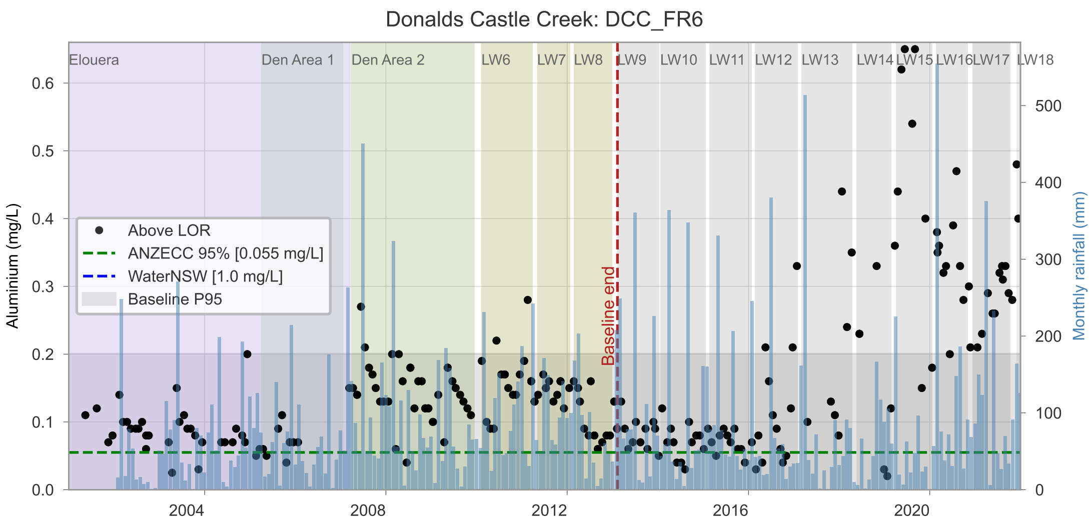

Donalds Castle Creek: DC13_POOL2B
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
WaterNSW [1.5 mg/L]
Manganese (mg/L)
Monthly rainfall (mm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
100
200
300
400
500
2004
2008
2012
2016
2020


Donalds Castle Creek: DCC_FR6
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
WaterNSW [1.5 mg/L]
Baseline P95
Manganese (mg/L)
Monthly rainfall (mm)
0.0
0.5
1.0
1.5
2.0
2.5
0
100
200
300
400
500
2004
2008
2012
2016
2020

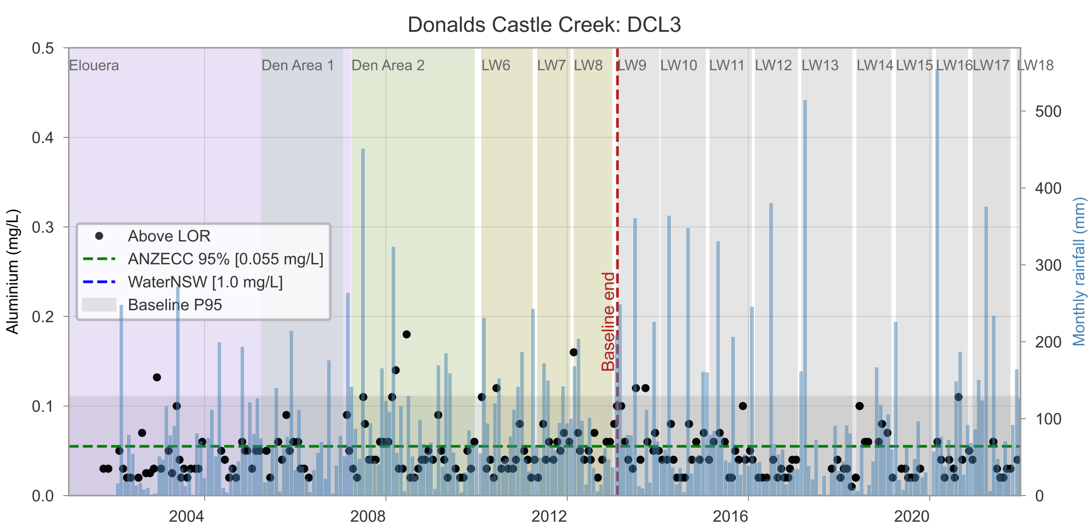

Donalds Castle Creek: DCL3
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
WaterNSW [1.5 mg/L]
Baseline P95
Manganese (mg/L)
Monthly rainfall (mm)
0.0
0.5
1.0
1.5
2.0
2.5
0
100
200
300
400
500
2004
2008
2012
2016
2020



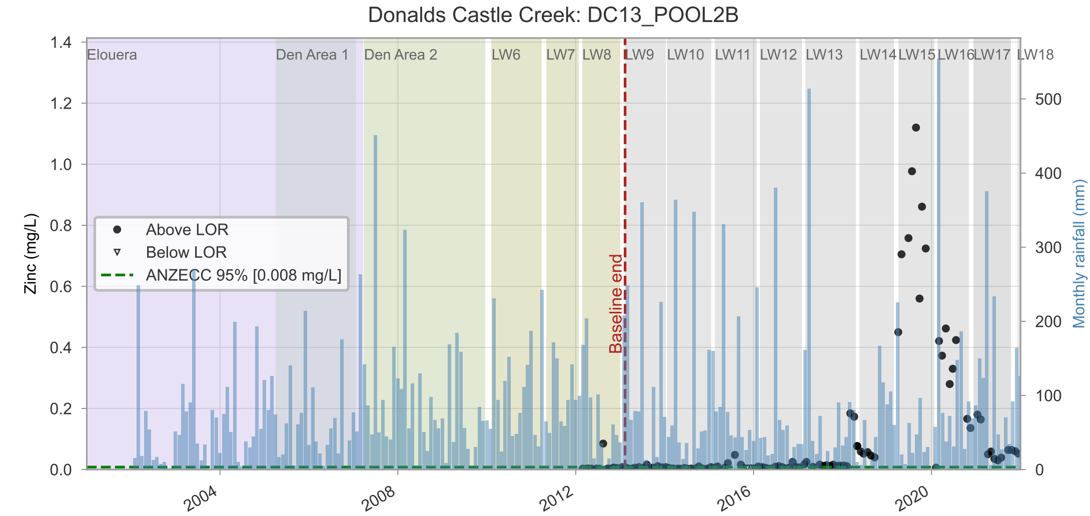
Donalds Castle Creek: DC13_POOL2B
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
ANZECC 95% [0.055 mg/L]
WaterNSW [1.0 mg/L]
Aluminium (mg/L)
Monthly rainfall (mm)

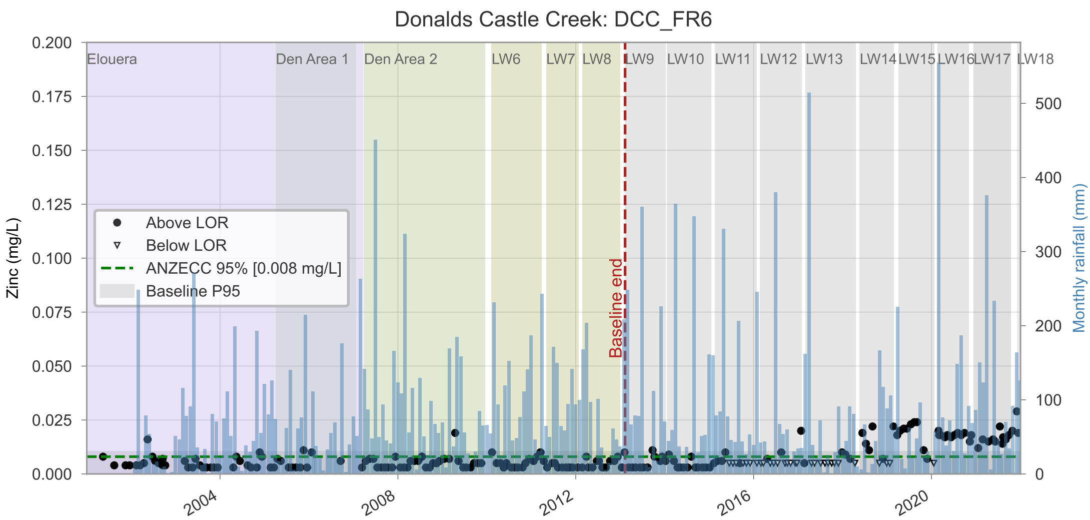


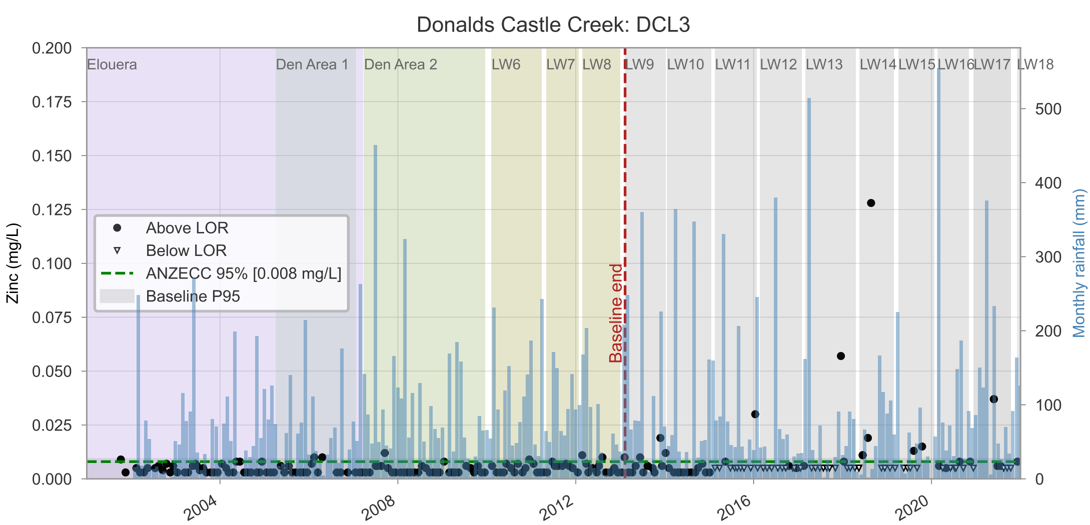
Donalds Castle Creek: DCC_FR6
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
ANZECC 95% [0.055 mg/L]
WaterNSW [1.0 mg/L]
Baseline P95
Aluminium (mg/L)
Monthly rainfall (mm)



Donalds Castle Creek: DCL3
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
ANZECC 95% [0.055 mg/L]
WaterNSW [1.0 mg/L]
Baseline P95
Aluminium (mg/L)
Monthly rainfall (mm)


Donalds Castle Creek: DC13_POOL2B
Zinc (mg/L)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
Below LOR
ANZECC 95% [0.008 mg/L]
2004
2008
2012
2016
2020


Donalds Castle Creek: DCC_FR6
Zinc (mg/L)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
Below LOR
ANZECC 95% [0.008 mg/L]
Baseline P95
2004
2008
2012
2016
2020


Donalds Castle Creek: DCL3
Zinc (mg/L)
Monthly rainfall (mm)
Elouera
Den Area 1
Den Area 2
LW6
LW7
LW8
LW9
LW10
LW11
LW12
LW13
LW14
LW15
LW16
LW17
LW18
Baseline end
Above LOR
Below LOR
ANZECC 95% [0.008 mg/L]
Baseline P95
2004
2008
2012
2016
2020

Appendix F: Model stress period schedule

Appendix E: Model Stress Period Schedule

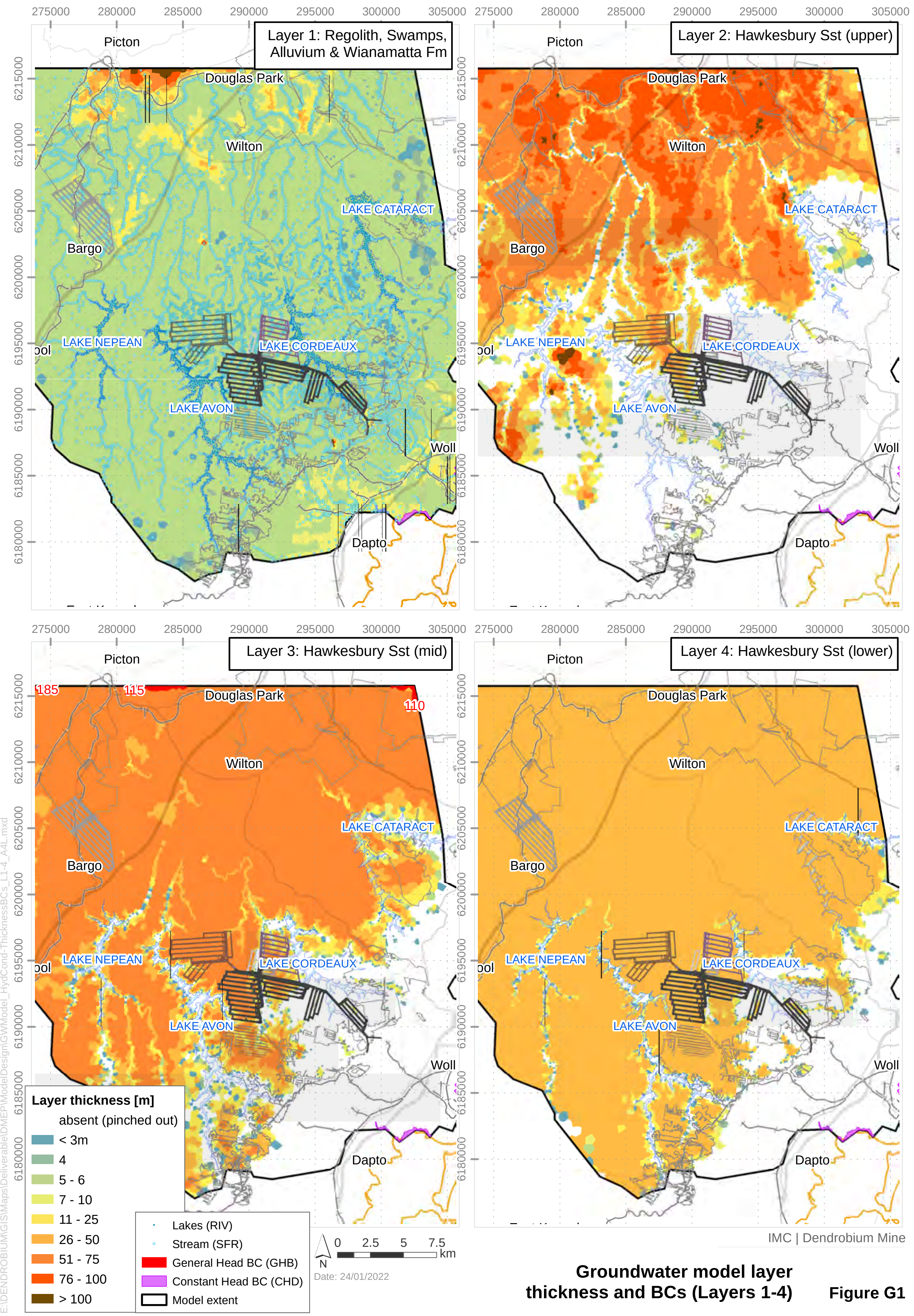
Stage	SP	Days	DateFrom	DateTo	Scheduled Mining	Event / Rainfall / Inflow signal	Total days	Elouera	other
	1		***Steady State***				1		
CALIBRATION	**2**	18993	1/01/1940	31/12/1991			18994		
	3	3608	1/01/1992	16/11/2001			22602		
	4	20	17/11/2001	6/12/2001			22622		
	5	20	7/12/2001	26/12/2001			22642		
	6	20	27/12/2001	15/01/2002			22662		
	7	40	16/01/2002	24/02/2002			22702		
	8	100	25/02/2002	4/06/2002			22802		
	9	100	5/06/2002	12/09/2002			22902		
	10	100	13/09/2002	21/12/2002			23002		
	11	200	22/12/2002	9/07/2003			23202		
	12	200	10/07/2003	25/01/2004			23402		
	13	200	26/01/2004	12/08/2004			23602		
	14	232	13/08/2004	1/04/2005			23834		
	15	90	2/04/2005	30/06/2005	Start LW1		23924		
	16	90	1/07/2005	28/09/2005			24014		
	17	74	29/09/2005	11/12/2005	End LW1		24088		
	18	60	12/12/2005	9/02/2006			24148		
	19	60	10/02/2006	10/04/2006	Start LW2		24208		
	20	95	11/04/2006	14/07/2006			24303		
	21	95	15/07/2006	17/10/2006			24398		
	22	96	18/10/2006	21/01/2007	End LW2	**End A1**	24494		
	23	99	22/01/2007	30/04/2007	Start LW3		24593	End Elouera LWs	
	24	44	1/05/2007	13/06/2007			24637		
	25	4	14/06/2007	17/06/2007		A2rain1	24641		
	26	8	18/06/2007	25/06/2007		A2week1	24649		
	27	43	26/06/2007	7/08/2007		A2inflow1	24692		
	28	100	8/08/2007	15/11/2007	End LW3		24792		
	29	33	16/11/2007	18/12/2007			24825		
	30	47	19/12/2007	3/02/2008	Start LW4		24872		
	31	6	4/02/2008	9/02/2008		A2 Rain2	24878		
	32	8	10/02/2008	17/02/2008		A2 week2	24886		
	33	36	18/02/2008	24/03/2008		A2 inflow2	24922		
	34	50	25/03/2008	13/05/2008			24972		
	35	32	14/05/2008	14/06/2008			25004		
	36	110	15/06/2008	2/10/2008	End LW4		25114		
	37	31	3/10/2008	2/11/2008			25145		
	38	30	3/11/2008	2/12/2008			25175		
	39	31	3/12/2008	2/01/2009	Start LW5		25206		
	40	60	3/01/2009	3/03/2009			25266		
	41	60	4/03/2009	2/05/2009			25326		
	42	17	3/05/2009	19/05/2009			25343		
	43	5	20/05/2009	24/05/2009		A2rain3	25348		
	44	8	25/05/2009	1/06/2009		A2week3	25356		
	45	22	2/06/2009	23/06/2009		A2inflow3	25378		
	46	88	24/06/2009	19/09/2009			25466		
	47	90	20/09/2009	18/12/2009	End LW5	**End A2**	25556		
	48	53	19/12/2009	9/02/2010			25609		
	49	105	10/02/2010	25/05/2010	Start LW6		25714		
	50	10	26/05/2010	4/06/2010		A2rain4	25724		
	51	8	5/06/2010	12/06/2010		A2week4	25732		
	52	22	13/06/2010	4/07/2010		A2inflow4	25754		
	53	75	5/07/2010	17/09/2010			25829		
	54	72	18/09/2010	28/11/2010			25901		
	55	9	29/11/2010	7/12/2010		A2rain5	25910		
	56	8	8/12/2010	15/12/2010		A2week5	25918		
	57	22	16/12/2010	6/01/2011		A2inflow5	25940		
	58	71	7/01/2011	18/03/2011			26011		
	59	4	19/03/2011	22/03/2011		A2rain6	26015		
	60	8	23/03/2011	30/03/2011	End LW6	A2week6	26023		
	61	60	31/03/2011	29/05/2011	StartLW7	A2inflow6	26083		
	62	4	30/05/2011	2/06/2011		A2rain7	26087		
	63	8	3/06/2011	10/06/2011		A2week7	26095		
	64	38	11/06/2011	18/07/2011		A2inflow7	26133		
	65	5	19/07/2011	23/07/2011		A2rain8	26138		
	66	8	24/07/2011	31/07/2011		A2inflow8	26146		
	67	22	1/08/2011	22/08/2011		A2inflow8	26168		
	68	69	23/08/2011	30/10/2011			26237		
	69	85	31/10/2011	23/01/2012	End LW7		26322		
	70	35	24/01/2012	27/02/2012	Start LW8		26357		
	71	11	28/02/2012	9/03/2012		A2rain9	26368		
	72	8	10/03/2012	17/03/2012		A2week9	26376		
	73	31	18/03/2012	17/04/2012		A2inflow9	26407		
	74	85	18/04/2012	11/07/2012			26492		
	75	85	12/07/2012	4/10/2012			26577		
	76	86	5/10/2012	29/12/2012	End LW8	**End A3A**	26663		
	77	41	30/12/2012	8/02/2013			26704		
	78	11	9/02/2013	19/02/2013	Start LW9		26715		
	79	12	20/02/2013	3/03/2013		A2rain10	26727		
	80	8	4/03/2013	11/03/2013		A2week10	26735		
	81	22	12/03/2013	2/04/2013		A2inflow10	26757		
	82	80	3/04/2013	21/06/2013			26837		
	83	9	22/06/2013	30/06/2013		A2rain11	26846	Longwall N2	
	84	8	1/07/2013	8/07/2013		A2week11	26854	Longwall N2	
	85	22	9/07/2013	30/07/2013		A2inflow11	26876	Longwall N2	
	86	48	31/07/2013	16/09/2013			26924	Longwall N2	
	87	106	17/09/2013	31/12/2013	End LW9		27030	Longwall N2	
	88	77	1/01/2014	18/03/2014	Start LW10		27107	Longwall N2	
	89	13	19/03/2014	31/03/2014		A2rain12	27120	Care and Maintenance	
	90	8	1/04/2014	8/04/2014		A2week12	27128		
	91	22	9/04/2014	30/04/2014		A2inflow12	27150		
	92	107	1/05/2014	15/08/2014			27257		
	93	12	16/08/2014	27/08/2014		A2rain13	27269		
	94	8	28/08/2014	4/09/2014		A2week13	27277		
	95	22	5/09/2014	26/09/2014		A2inflow13	27299		
	96	106	27/09/2014	10/01/2015	End LW10		27405		
	97	96	11/01/2015	16/04/2015	Start LW11		27501		
	98	16	17/04/2015	2/05/2015		A2rain14	27517		
	99	8	3/05/2015	10/05/2015		A2week14	27525		

Stage	SP	Days	DateFrom	DateTo	Scheduled Mining	Event / Rainfall / Inflow signal	Total days	Elouera	other
	100	45	11/05/2015	24/06/2015		A2inflow14	27570		
	101	196	25/06/2015	6/01/2016	End LW11		27766		
	102	149	7/01/2016	3/06/2016	Start LW 12		27915		
	103	7	4/06/2016	10/06/2016		rain15	27922		
	104	20	11/06/2016	30/06/2016			27942		
	105	233	1/07/2016	18/02/2017	End LW 12		28175		
	106	71	19/02/2017	30/04/2017	Start LW 13		28246		
	107	92	1/05/2017	31/07/2017			28338		
	108	92	1/08/2017	31/10/2017			28430		
	109	120	1/11/2017	28/02/2018	End LW 13		28550		
	110	61	1/03/2018	30/04/2018	Start LW 14		28611		
	111	92	1/05/2018	31/07/2018			28703		
	112	92	1/08/2018	31/10/2018			28795		
	113	61	1/11/2018	31/12/2018	End LW 14		28856		
	114	90	1/01/2019	31/03/2019	Start LW 15		28946		
	115	61	1/04/2019	31/05/2019			29007		
	116	61	1/06/2019	31/07/2019			29068		
	117	61	1/08/2019	30/09/2019			29129		
	118	92	1/10/2019	31/12/2019	End LW 15		29221		
	119	59	1/01/2020	28/02/2020			29280		
	120	62	29/02/2020	30/04/2020	Start LW 16		29342		
	121	61	1/05/2020	30/06/2020			29403		
	122	92	1/07/2020	30/09/2020			29495		
	123	61	1/10/2020	30/11/2020	End LW 16		29556		
	124	62	1/12/2020	31/01/2021	Start LW 17		29618		
	125	59	1/02/2021	31/03/2021			29677		
	126	61	1/04/2021	31/05/2021			29738		
	127	61	1/06/2021	31/07/2021			29799		
	128	61	1/08/2021	30/09/2021	End LW 17		29860		
PREDICTION	129	61	1/10/2021	30/11/2021	Start LW 18		29921		
	130	62	1/12/2021	31/01/2022			29983		
	131	58	1/02/2022	30/03/2022	End LW 18	**End A3B**	30041		
	132	31	31/03/2022	30/04/2022			30072		
	133	61	1/05/2022	30/06/2022	Start LW 19		30133		
	134	31	1/07/2022	31/07/2022			30164		
	135	61	1/08/2022	30/09/2022			30225	**End C & M?**	**Tahmoor Sth**
	136	92	1/10/2022	31/12/2022			30317		
	137	31	1/01/2023	31/01/2023	End LW 19	**End A3A** (LW19)	30348		
	138	59	1/02/2023	31/03/2023	Start LW 21		30407		
	139	45	1/04/2023	15/05/2023	End LW 21		30452		
	140	46	16/05/2023	30/06/2023			30498		
	141	62	1/07/2023	31/08/2023	Start LW 22		30560		
	142	122	1/09/2023	31/12/2023			30682		
	143	121	1/01/2024	30/04/2024	End LW 22		30803		
	144	61	1/05/2024	30/06/2024			30864		
	145	92	1/07/2024	30/09/2024	Start LW 23		30956		
	146	151	1/10/2024	28/02/2025			31107		
	147	92	1/03/2025	31/05/2025			31199		
	148	92	1/06/2025	31/08/2025	End LW 23		31291		
	149	61	1/09/2025	31/10/2025	Start LW20		31352		
	150	61	1/11/2025	31/12/2025			31413		
	151	90	1/01/2026	31/03/2026	End LW20	**End A3C** (part 1)	31503		
	152	91	1/04/2026	30/06/2026	Start LW501		31594		
	153	92	1/07/2026	30/09/2026			31686		
	154	92	1/10/2026	31/12/2026			31778		
	155	90	1/01/2027	31/03/2027			31868		
	156	91	1/04/2027	30/06/2027	Start LW502		31959		
	157	92	1/07/2027	30/09/2027			32051		
	158	92	1/10/2027	31/12/2027			32143		
	159	91	1/01/2028	31/03/2028			32234		
	160	91	1/04/2028	30/06/2028			32325		
	161	92	1/07/2028	30/09/2028	Start LW503		32417		
	162	92	1/10/2028	31/12/2028			32509		
	163	90	1/01/2029	31/03/2029			32599		
	164	91	1/04/2029	30/06/2029			32690		
	165	92	1/07/2029	30/09/2029	Start LW504		32782		
	166	92	1/10/2029	31/12/2029			32874		
	167	90	1/01/2030	31/03/2030			32964		
	168	91	1/04/2030	30/06/2030			33055		
	169	92	1/07/2030	30/09/2030	Start LW505		33147		
	170	92	1/10/2030	31/12/2030			33239		
	171	90	1/01/2031	31/03/2031			33329		
	172	91	1/04/2031	30/06/2031			33420		
	173	92	1/07/2031	30/09/2031			33512		
	174	92	1/10/2031	31/12/2031	Start LW506		33604		
	175	91	1/01/2032	31/03/2032			33695		
	176	91	1/04/2032	30/06/2032	Start LW507		33786		
	177	92	1/07/2032	30/09/2032	Start LW508		33878		
	178	92	1/10/2032	31/12/2032			33970		
	179	90	1/01/2033	31/03/2033	Start LW509		34060		
	180	91	1/04/2033	30/06/2033	Start LW510		34151		
	181	92	1/07/2033	30/09/2033			34243		
	182	92	1/10/2033	31/12/2033	End LW510	**End A5**	34335		
	183	90	1/01/2034	31/03/2034			34425		
	184	91	1/04/2034	30/06/2034			34516		
	185	92	1/07/2034	30/09/2034			34608		
	186	92	1/10/2034	31/12/2034			34700		
	187	90	1/01/2035	31/03/2035	End LW 506WC		34790		
	188	91	1/04/2035	30/06/2035	Start LW507W		34881		
	189	92	1/07/2035	30/09/2035			34973		
	190	92	1/10/2035	31/12/2035	End LW 506WC		35065		
	191	91	1/01/2036	31/03/2036	Start LW507W		35156		
	192	91	1/04/2036	30/06/2036			35247		
	193	92	1/07/2036	30/09/2036	End LW 506WC		35339		
	194	92	1/10/2036	31/12/2036	Start LW507W		35431		
	195	90	1/01/2037	31/03/2037			35521		
	196	91	1/04/2037	30/06/2037	End LW 506WC		35612		
	197	92	1/07/2037	30/09/2037	Start LW507W		35704		
	198	92	1/10/2037	31/12/2037			35796		
	199	90	1/01/2038	31/03/2038	End LW 506WC		35886		

Stage	SP	Days	DateFrom	DateTo	Scheduled Mining	Event / Rainfall / Inflow signal	Total days	Elouera	other
	200	91	1/04/2038	30/06/2038	Start LW507W		35977		
	201	92	1/07/2038	30/09/2038			36069		
	202	92	1/10/2038	31/12/2038	End LW 506WC	**End A3C** (part 2)	36161		
POST_MINING	**203**	90	1/01/2039	31/03/2039	Start LW507W		36251		
	204	91	1/04/2039	30/06/2039			36342		
	205	184	1/07/2039	31/12/2039	End LW 506WC		36526		
	206	366	1/01/2040	31/12/2040	Start LW507W		36892		
	207	365	1/01/2041	31/12/2041			37257		
	208	365	1/01/2042	31/12/2042	End LW 506WC		37622		
	209	365	1/01/2043	31/12/2043	Start LW507W		37987		
	210	366	1/01/2044	31/12/2044			38353		
	211	365	1/01/2045	31/12/2045	End LW 506WC		38718		
	212	1826	1/01/2046	31/12/2050	Start LW507W		40544		
	213	1826	1/01/2051	31/12/2055	~30 yrs post- A3B		42370		
	214	1827	1/01/2056	31/12/2060	~30 yrs post- A3C(a)		44197		
	215	5478	1/01/2061	31/12/2075	~30 yrs post- A5, A3C(b)		49675		
	216	9131	1/01/2076	31/12/2100			58806		
	217	18262	1/01/2101	31/12/2150	End LW 506WC		77068		
	218	18262	1/01/2151	31/12/2200	Start LW507W		95330		

E:\DENDROBIUM\Model\GWmodel\Construction\Time\[StressPeriods_DND6v1_Oct2021.xlsx]Timing_DNDv6_DMEP

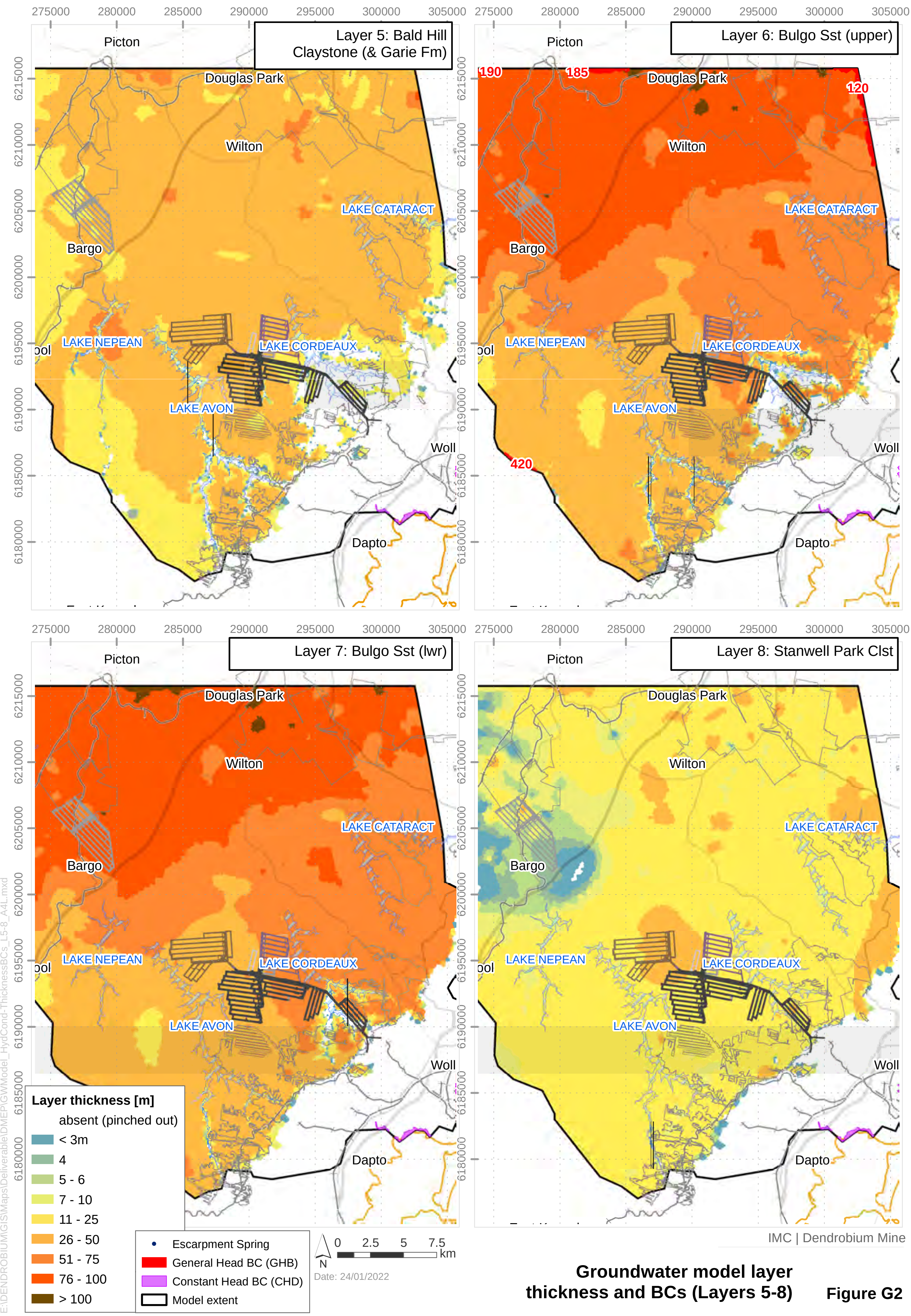
Appendix G: Model geometry and boundary conditions



IMC | Dendrobium Mine

Groundwater model layer thickness and BCs (Layers 1-4)

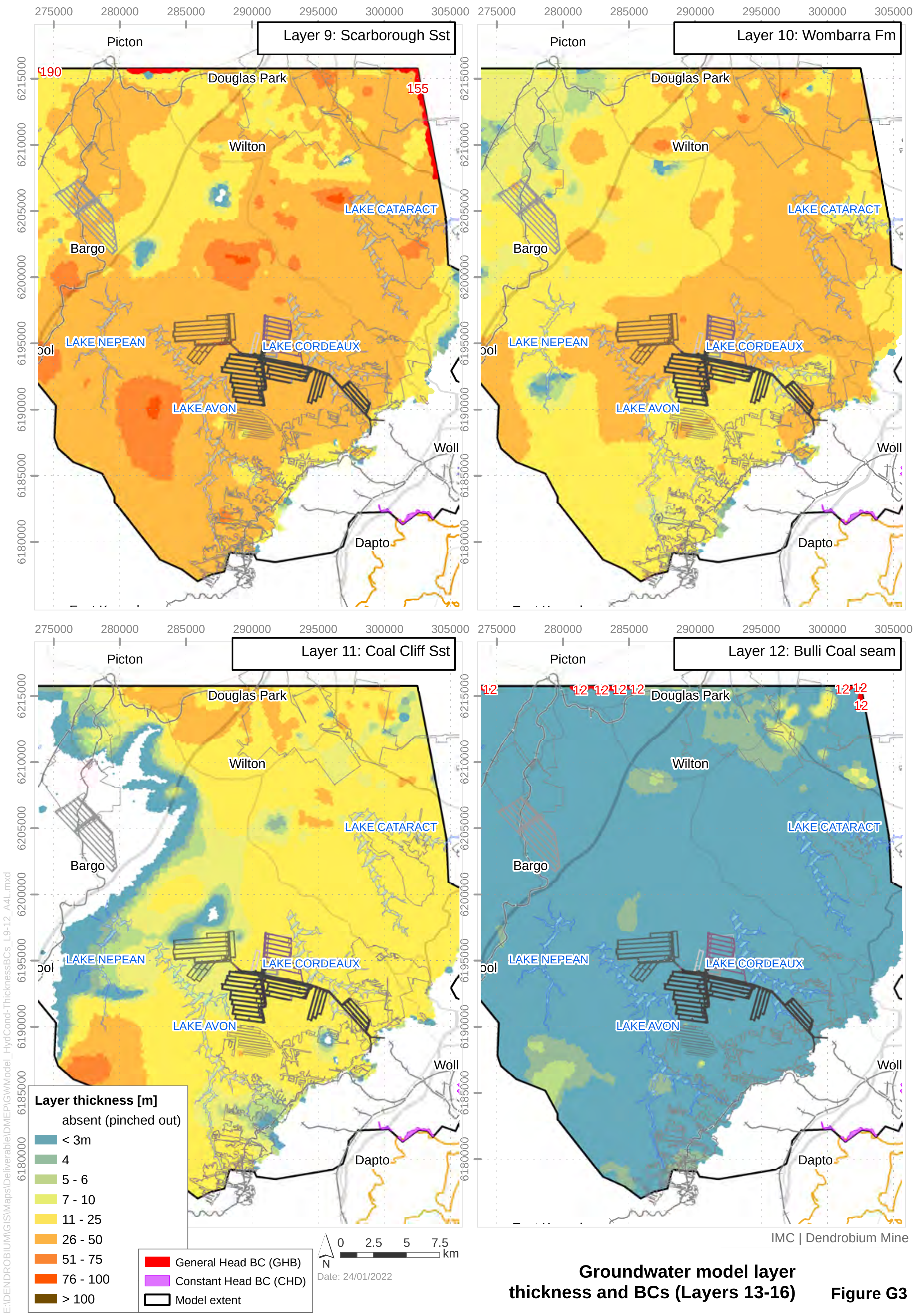
Figure G1



IMC | Dendrobium Mine

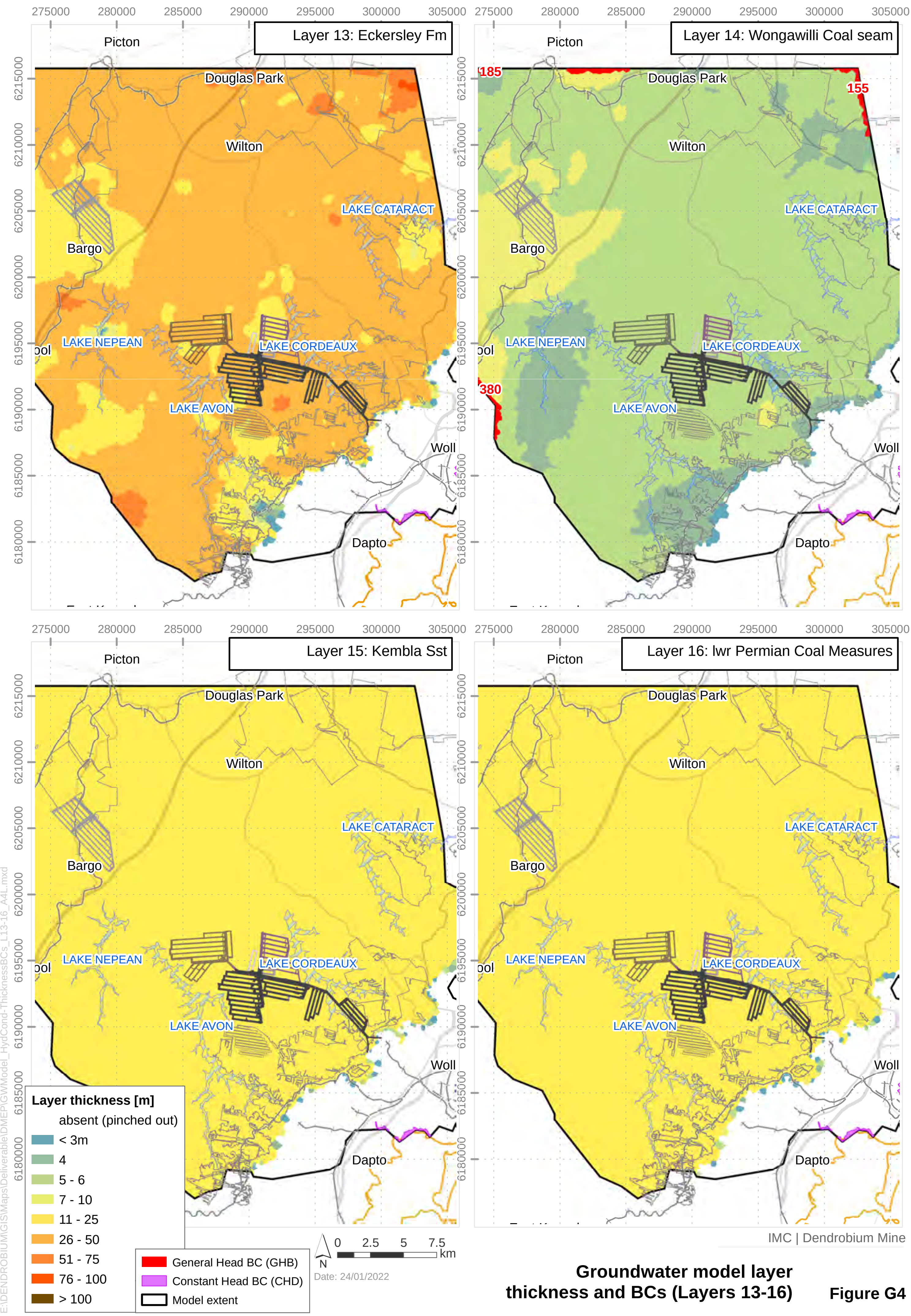
Groundwater model layer thickness and BCs (Layers 5-8)

Figure G2



Groundwater model layer thickness and BCs (Layers 13-16)

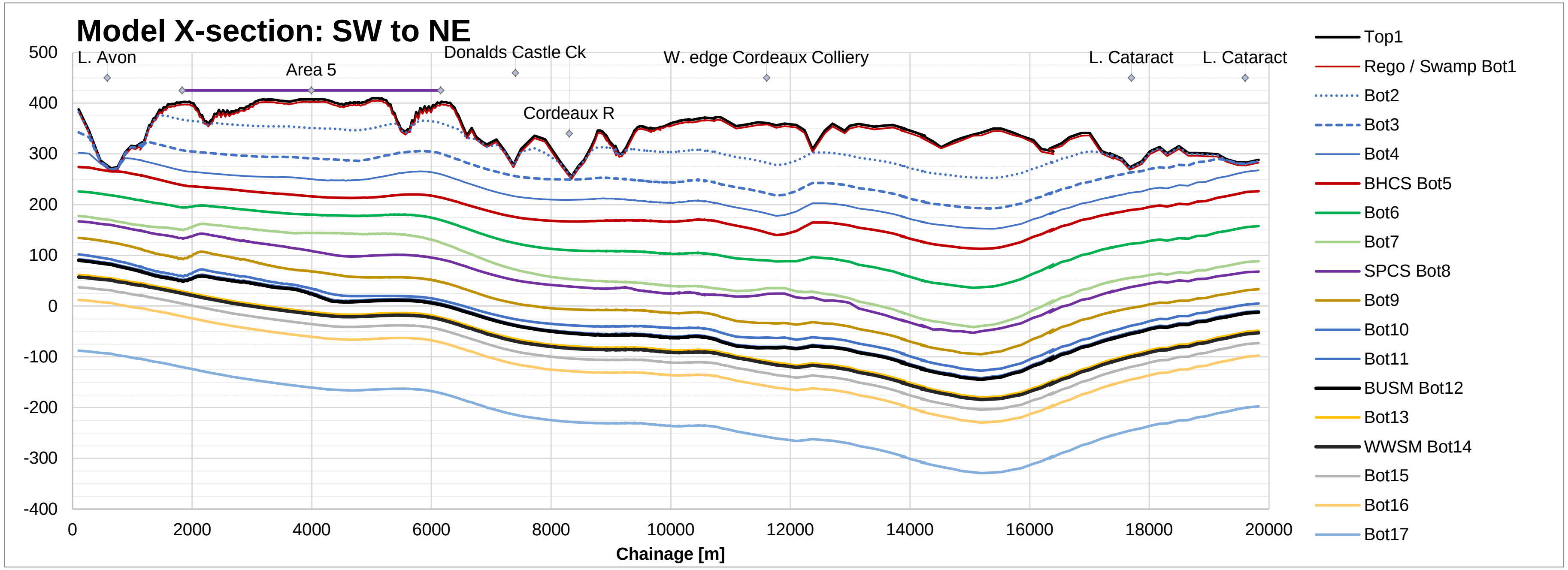
Figure G3



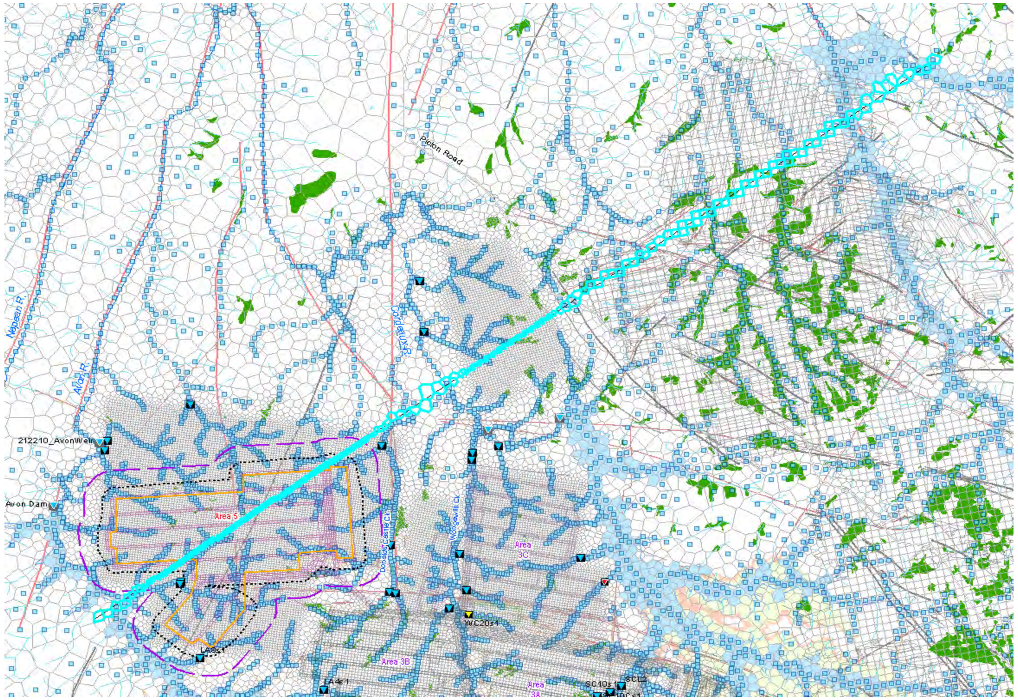
IMC | Dendrobium Mine

Groundwater model layer thickness and BCs (Layers 13-16)

Figure G4

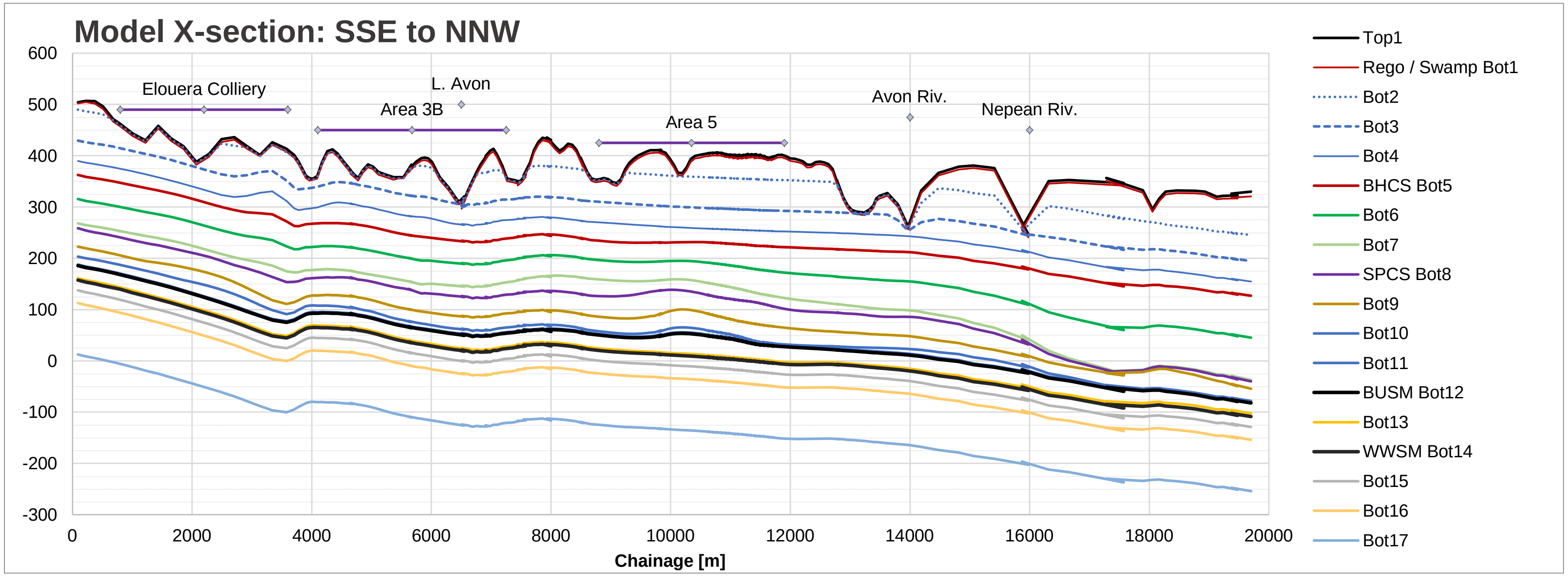


E:\DENDROBIUM\Model\GWmodel\Construction\Geometry\DND6\[ModelSection_SW-NE.xlsx]FIGURE_SW-NE



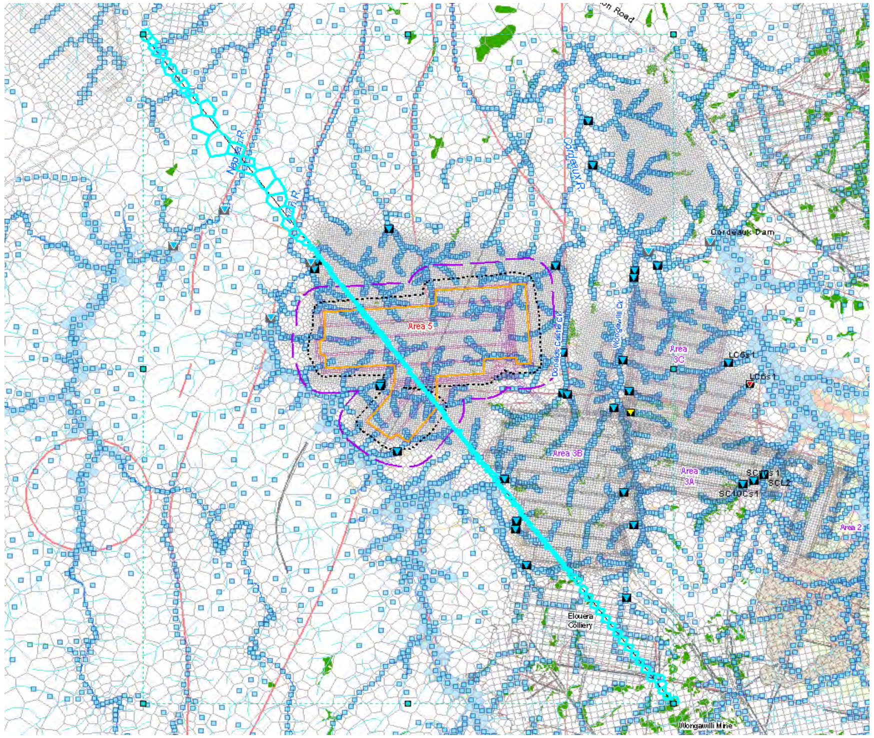
Cross-section through GW model:
SW-NE through Area 5
(approximately perpendicular
to regional GW flow)

Figure G5



E:\DENDROBIUM\Model\GWmodel\Construction\Geometry\DND6\[ModelSection_S-N.xlsx]FIGURE_SSE-NNW

E:\DENDROBIUM\GIS\Maps\Deliverable\DMEP\IMC109_DMEP_ModelMesh-WORKING2.mxd



Cross-section through GW model:
SSE-NNW through Area 5
(approximately parallel
to regional GW flow)

Figure G6

Appendix H: Model hydraulic conductivity and storage properties

Modelled Hydraulic Properties (K and S)

Layer	Zone#	Geology	abbrev.	K_h m/d	Kh factor	K_v m/d	Ss m-1	Sy
1	11	Swamps		1	n/a	0.05		0.3
	1, 3	Alluvium		10, 3	n/a	0.3, 5e-3		0.1
	2	Wianamatta Formation	WMFM	0.015	n/a	2.0E-05		0.1
	10	Regolith		0.03	n/a	0.03		0.1
2	20	Hawkesbury Sst (upper)	HBSS	*K-depth*	1.3	1E-05	5E-03	0.05
3	30	Hawkesbury Sst (mid)	HBSS	*K-depth*	0.6	1E-04	1E-06	0.025
4	40	Hawkesbury Sst (lower)	HBSS	*K-depth*	1	3E-05	1E-06	0.012
5	50	Bald Hill Claystone	BACS	*K-depth*	0.03	3E-06	1E-06	0.006
	51	Crinanite (weathered)		*K-depth*	0.8	3E-03	5E-04	0.01
6-11	multiple	Crinanite		*K-depth*	0.05	5E-05	5E-04	0.01
6	60	Bulgo Sst (upper)	BGSS	*K-depth*	0.2	1E-04	9E-07	0.008
	61	Bulgo Sst (upper)	BGSS	*K-depth*	0.25	5E-05	9E-07	0.008
	62	Bulgo Sst (upper) / CVSS	BGSS	*K-depth*	0.14	1E-06	9E-07	0.008
	64	Bulgo Sst (upper) (A2 outcrop)	BGSS	*K-depth*	0.3	2E-06	9E-07	0.008
7	70	Bulgo Sst (lower)	BGSS	*K-depth*	0.3	2E-05	8E-07	0.007
	71	Bulgo Sst (lower)	BGSS	*K-depth*	0.2	5E-05	8E-07	0.007
	72	Bulgo Sst (lower) / CVSS	BGSS	*K-depth*	0.2	2E-06	8E-07	0.007
	74	BGSS (lwr) near A2/crinanite	BGSS	*K-depth*	0.6	6E-06	8E-07	0.007
8	80	Stanwell Park Claystone	SPCS	*K-depth*	0.25	3E-05	7E-07	0.005
	81	Stanwell Park Claystone	SPCS	*K-depth*	0.25	2E-06	7E-07	0.005
	83	SPCS, near A2	SPCS	*K-depth*	2	4E-06	7E-07	0.005
9	90-92	Scarborough Sst	SBSS	*K-depth*	2	1E-06	6E-06	0.01
10	100	Wombarra Claystone	WBCS	*K-depth*	0.25	5E-06	5E-07	0.0035
11	110	Coalcliff Sandstone	CCSS	*K-depth*	1	7E-06	4E-07	0.004
	111	Coalcliff Sandstone	CCSS	*K-depth*	0.5	5E-06	4E-07	0.004
12	120	Bulli Seam	BUSM	*K-depth*	20	1E-06	2E-07	0.004
	121	Bulli Seam – cindered	BUSM	*K-depth*	0.4	6E-06	1E-06	0.016
	123	Bulli Seam – faulted (mylonite)	BUSM	*K-depth*	0.1	3E-05	1E-06	0.016
13	130	Lawrence and Loddon Ssts	LDSS	*K-depth*	1	1E-06	2E-07	0.004
	131	Nepheline syenite		*K-depth*	0.4	2E-06	3E-07	0.005
	132	Fault/mylonite		*K-depth*	0.3	9E-06	3E-07	0.005
14	140	Wongawilli Seam	WWSM	*K-depth*	40	1E-06	2E-07	0.004
	141	Nepheline syenite		*K-depth*	0.4	3E-06	4E-06	0.02
	142	Wongawilli Seam – cindered	WWSM	*K-depth*	0.5	2E-06	3E-06	0.012
	143	Fault/mylonite		*K-depth*	0.5	9E-06	1E-06	0.015
15	150	Kembla Sandstone	KBSS	*K-depth*	1	3E-05	3E-07	0.0045
	151	Kembla Sandstone – outcrop	KBSS	*K-depth*	1	1E-05	1E-04	0.02
	152	Kembla Sandstone – outcrop	KBSS	*K-depth*	1	8E-04	1E-04	0.02
16	160	lower Permian Coal Meas.	lPCM	*K-depth*	1	1E-05	3E-07	0.004
	161	lower Permian Coal Meas.	lPCM	*K-depth*	1	8E-04	3E-06	0.03
17	170	Shoalhaven Group		*K-depth*	1	2E-06	3E-07	0.005

"K-depth" = means that Kh is primarily determined by depth of mid-point of model cell (see Equation 1 and 2) and figures in Section 4.5.1.
Kh factor used to provide additional control based on lithology, facies variation. The K from the K-w-depth relationship is multiplied by this factor.
DND5_mesh_Kwdepth_5v25.xlsx

The K-depth relationship is based on the formulation from AGC (1984):

$$\mathrm{K} = \mathrm{K}_o . \exp{(-cz)}$$ **Equation 1**

- where,

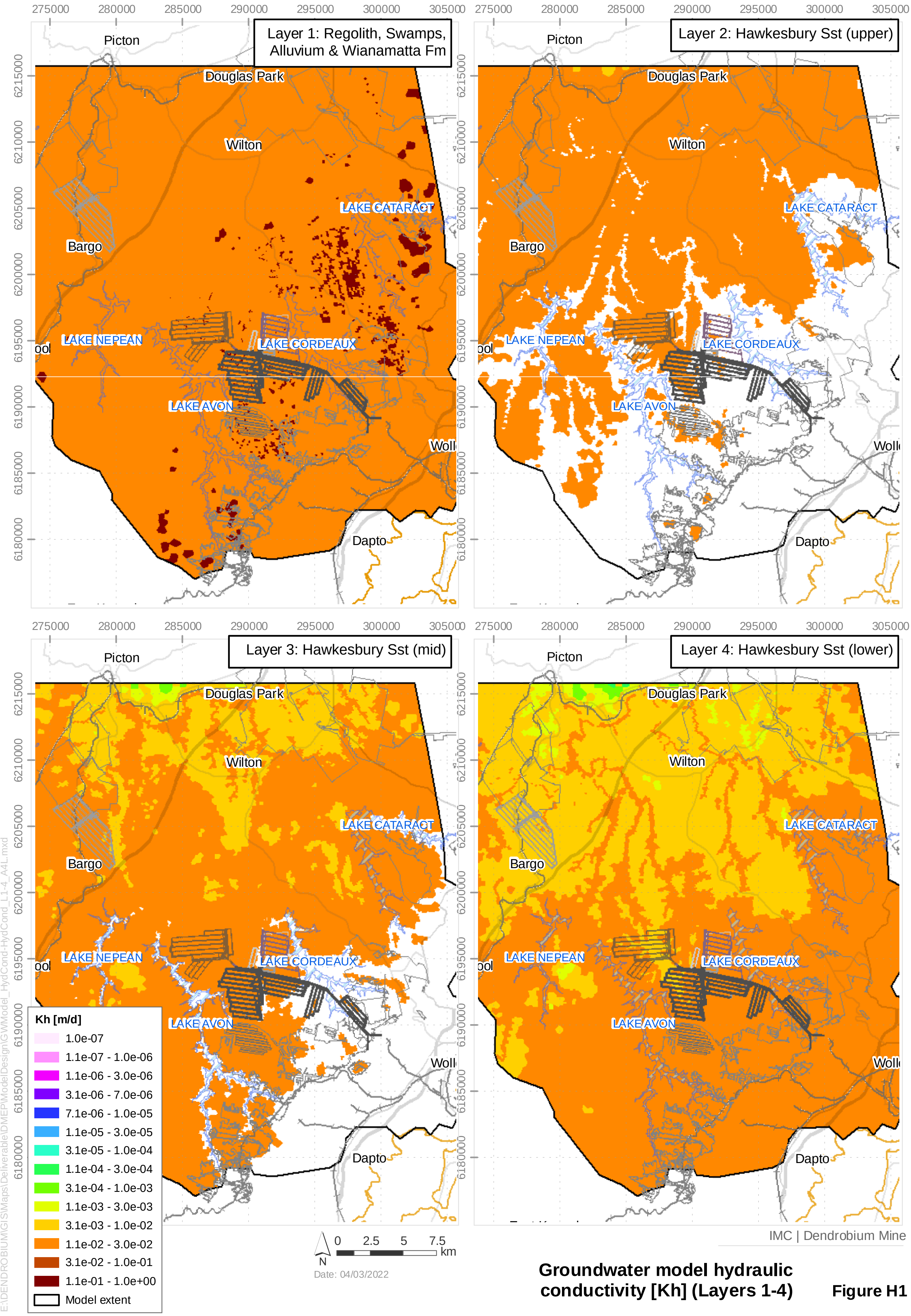
  c = gradient; z = depth [m].

The broad Kh-depth relationship at Dendrobium was calculated to be:

$$\mathrm{K} = 0.022 \exp{(-80 - z)}$$ **Equation 2**

- where,

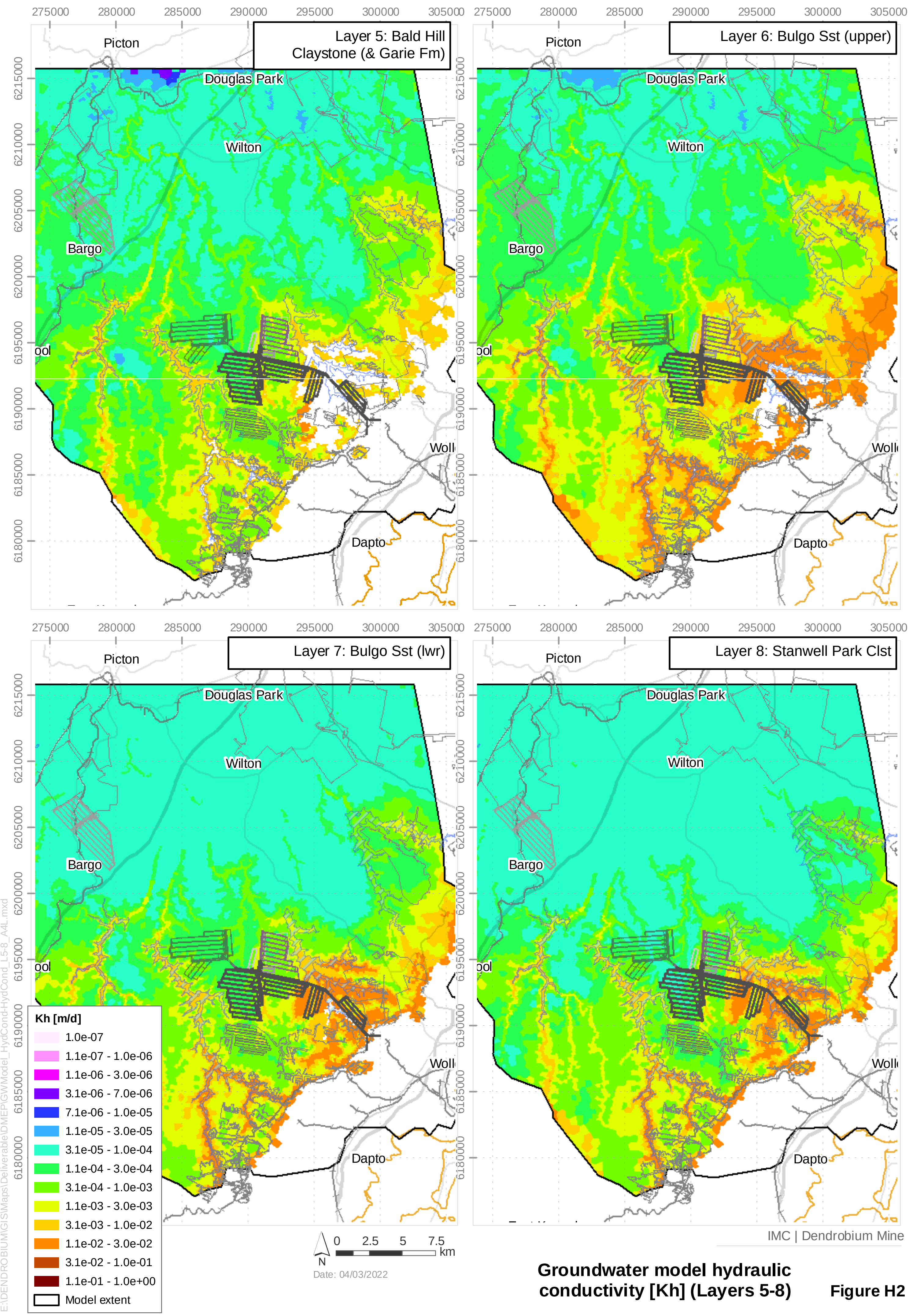
  the hydraulic conductivity K calculated by this relationship is limited to the range 2E-4 to 2.5E-2 m/d



IMC | Dendrobium Mine

Groundwater model hydraulic conductivity [Kh] (Layers 1-4)

Figure H1



Date: 04/03/2022

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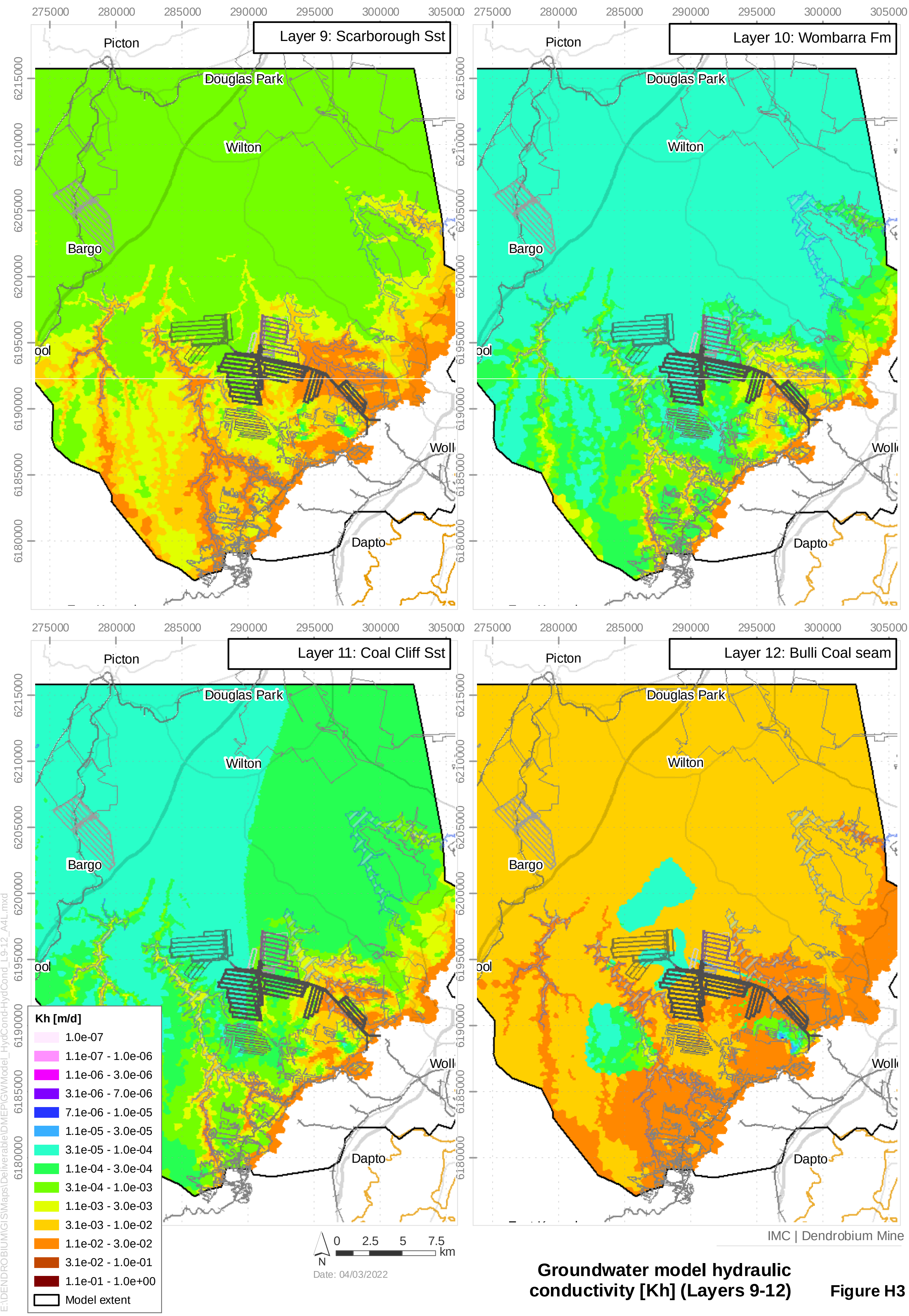
IMC | Dendrobium Mine

Groundwater model hydraulic conductivity [Kh] (Layers 5-8)

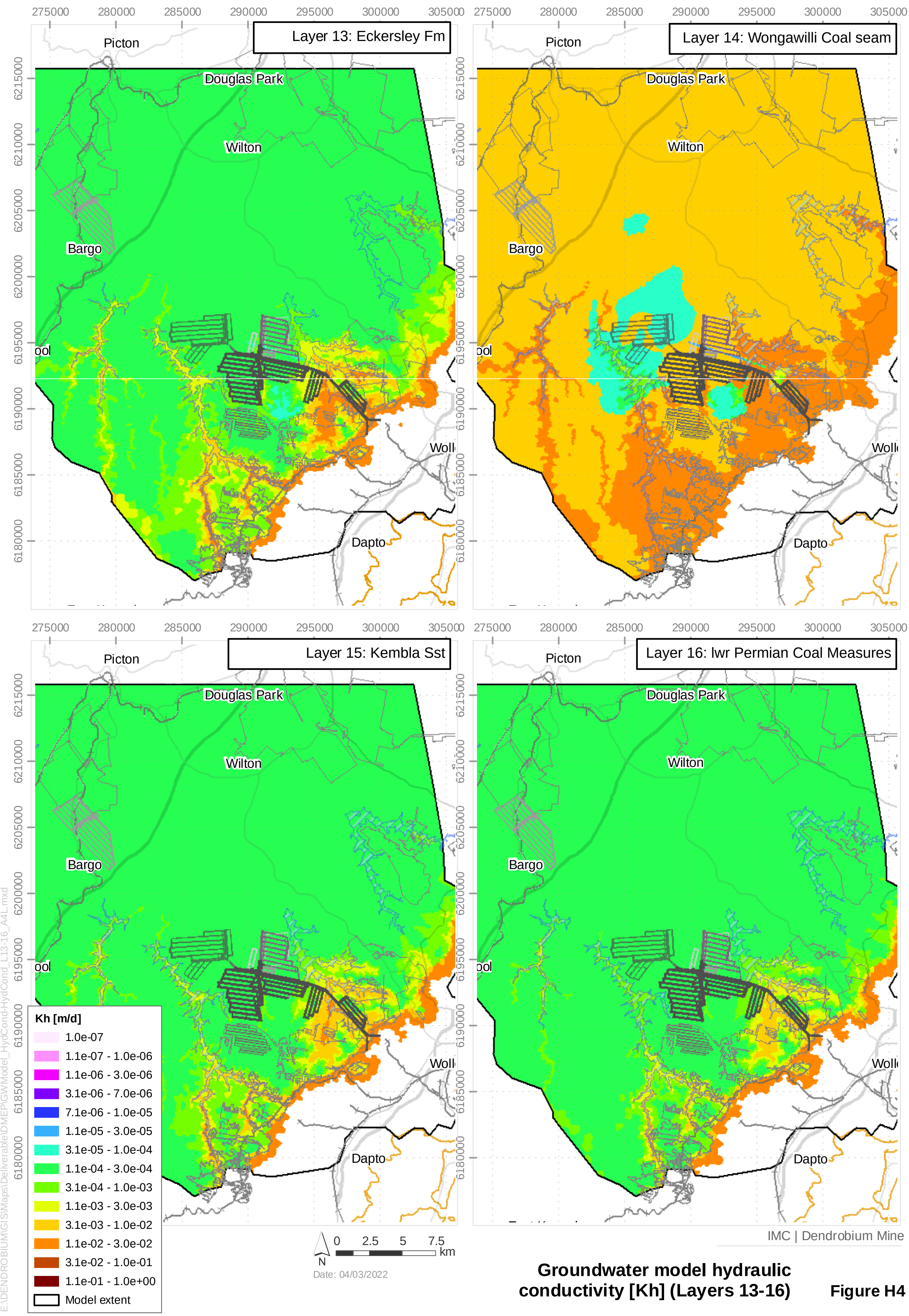
Figure H2



IMC | Dendrobium Mine

Groundwater model hydraulic conductivity [Kh] (Layers 9-12)

Figure H3

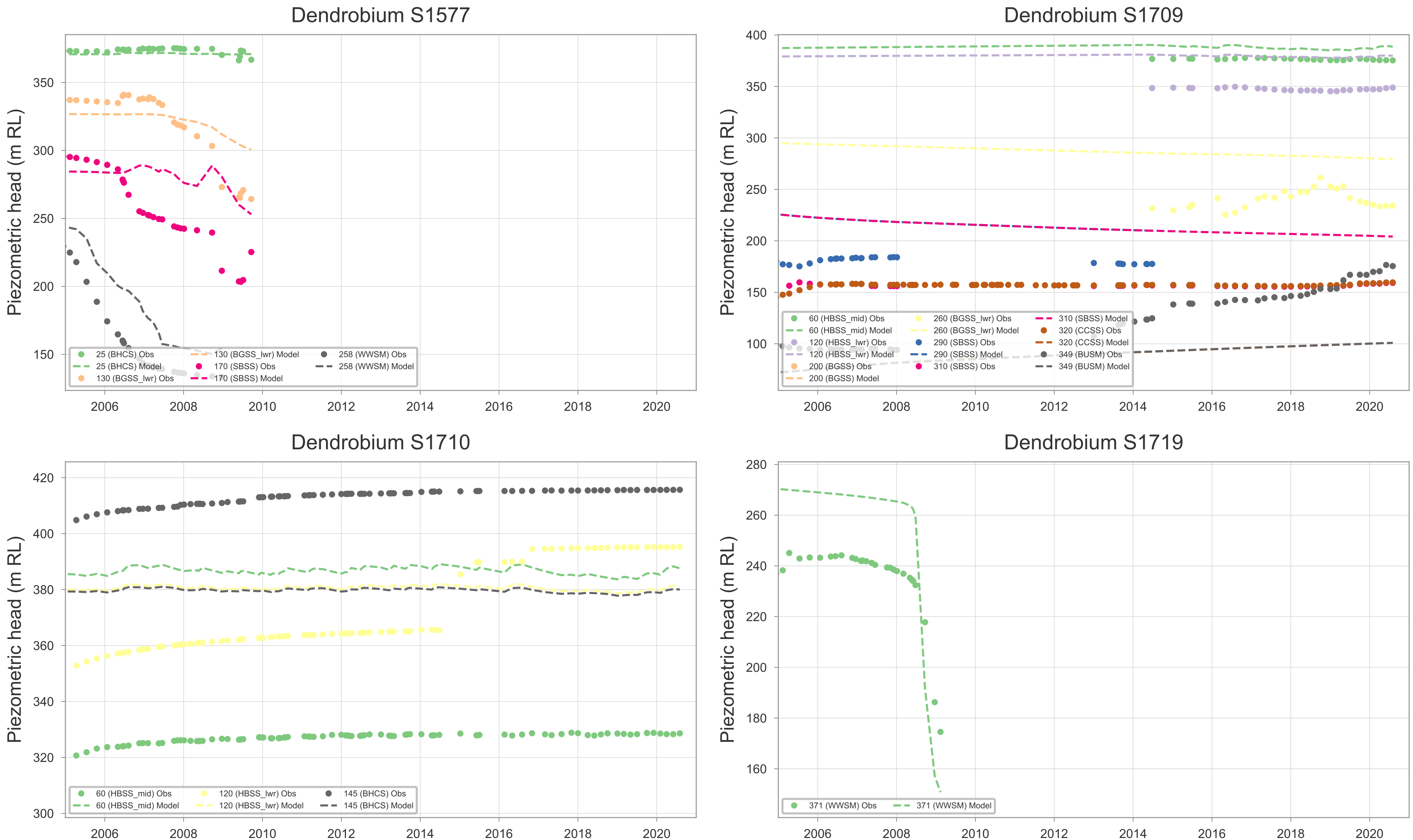


IMC | Dendrobium Mine

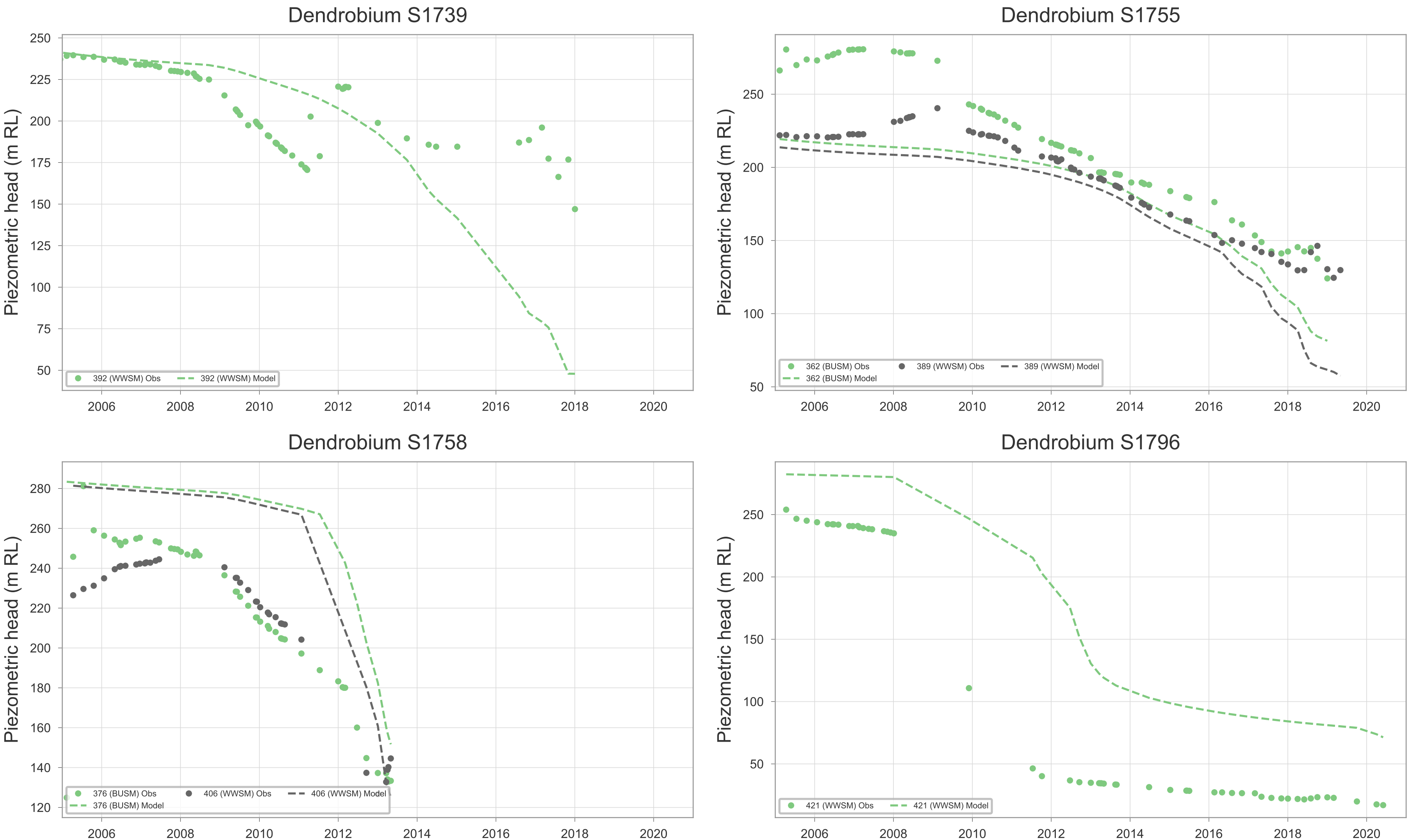
Groundwater model hydraulic conductivity [Kh] (Layers 13-16)

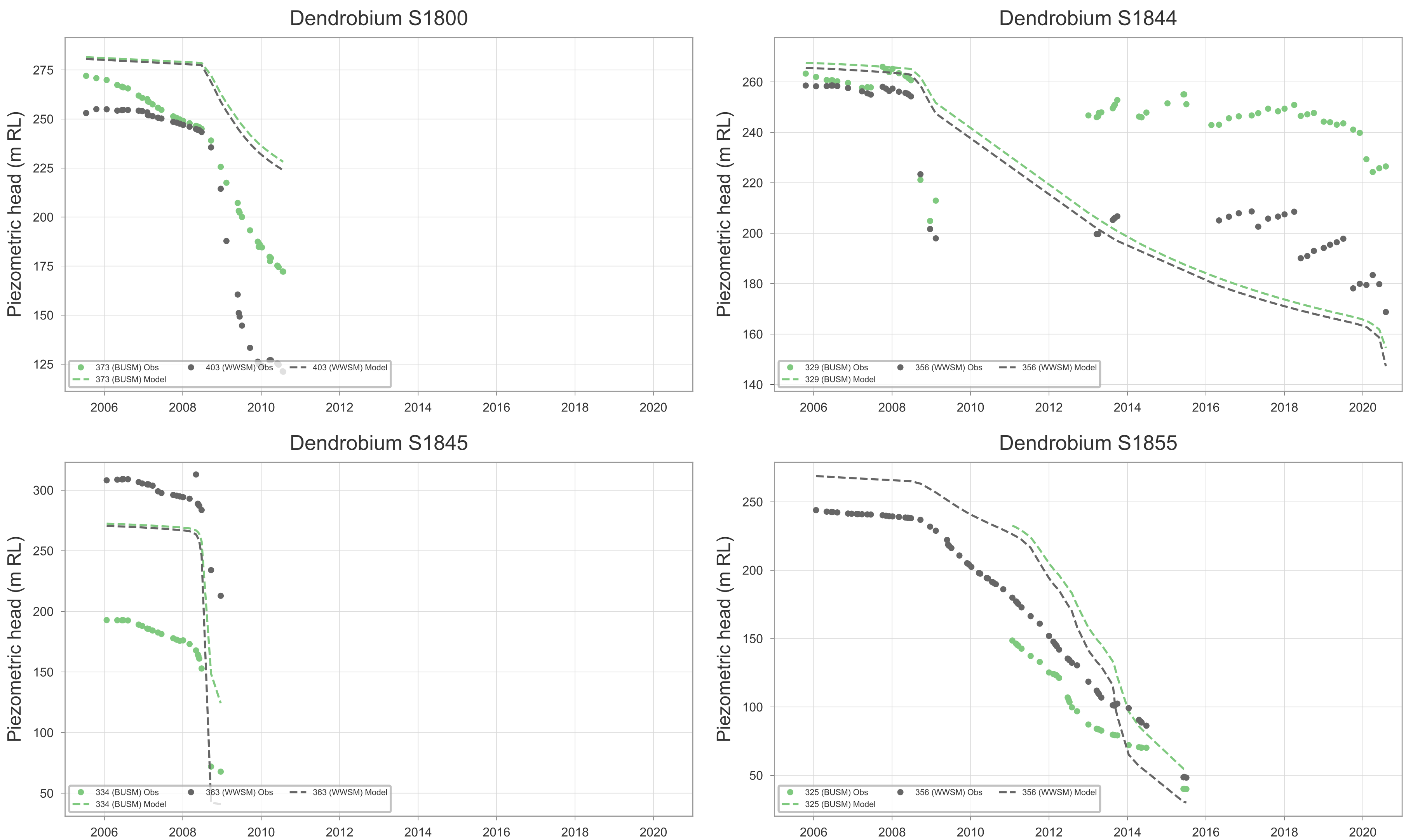
Figure H4

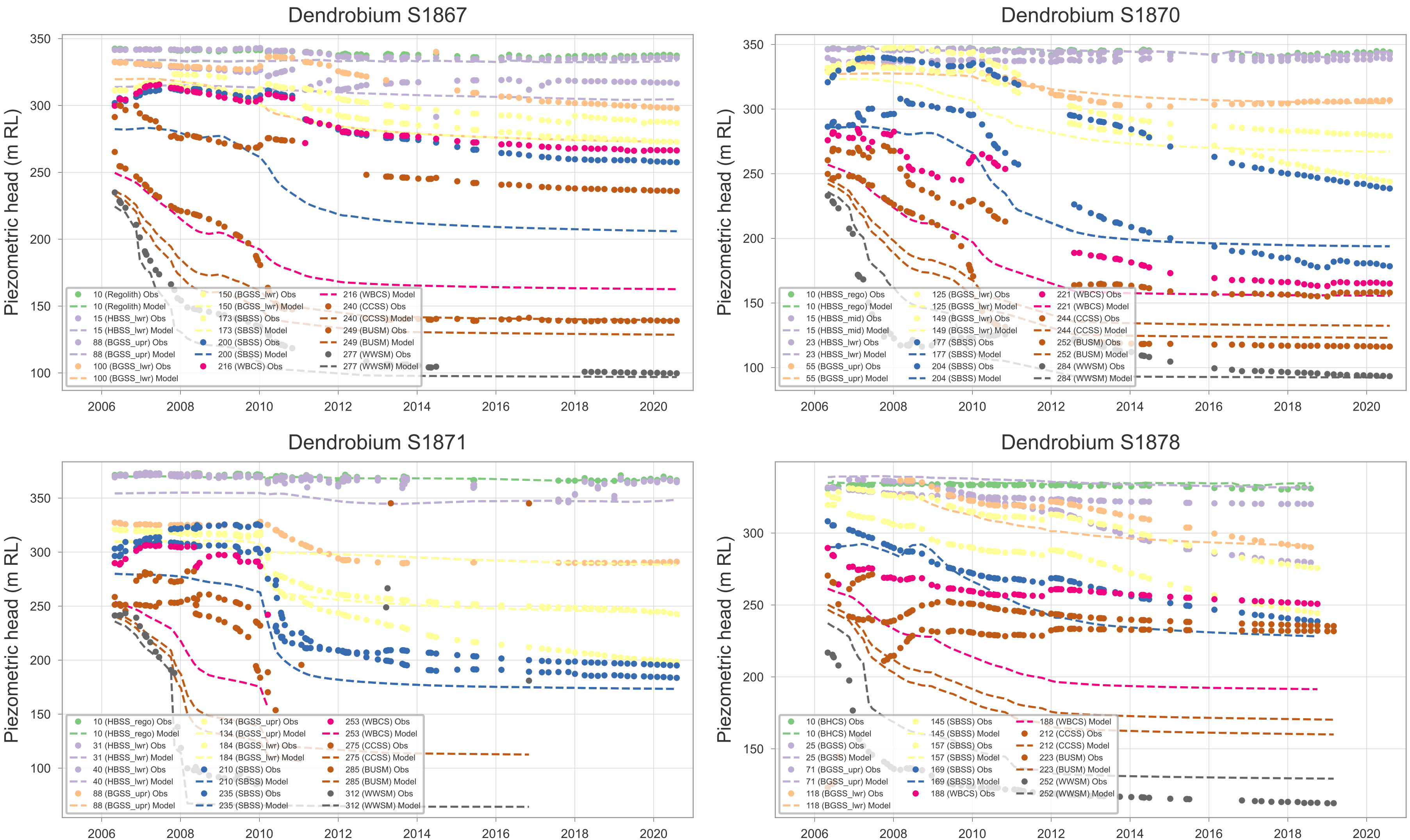
Appendix I: Groundwater model calibration hydrographs



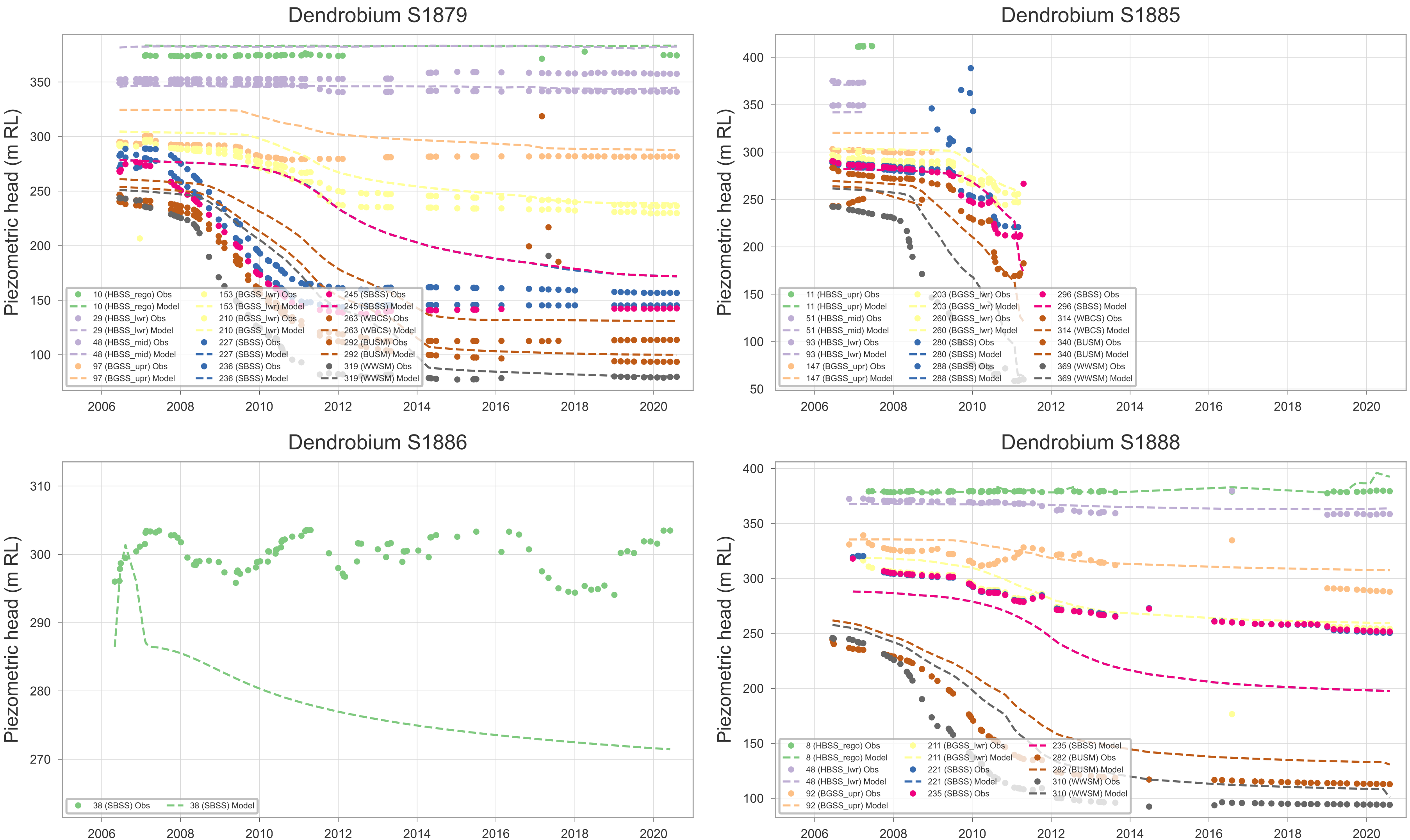
E:\DENDROBIUM\Model\GWmodel\Runs\DND6\DND6TR017\Proc\Heads\MOD2OBS\
GV Model Calibration Target Export File Hydrographs V3 DMEP EIS 2022.py

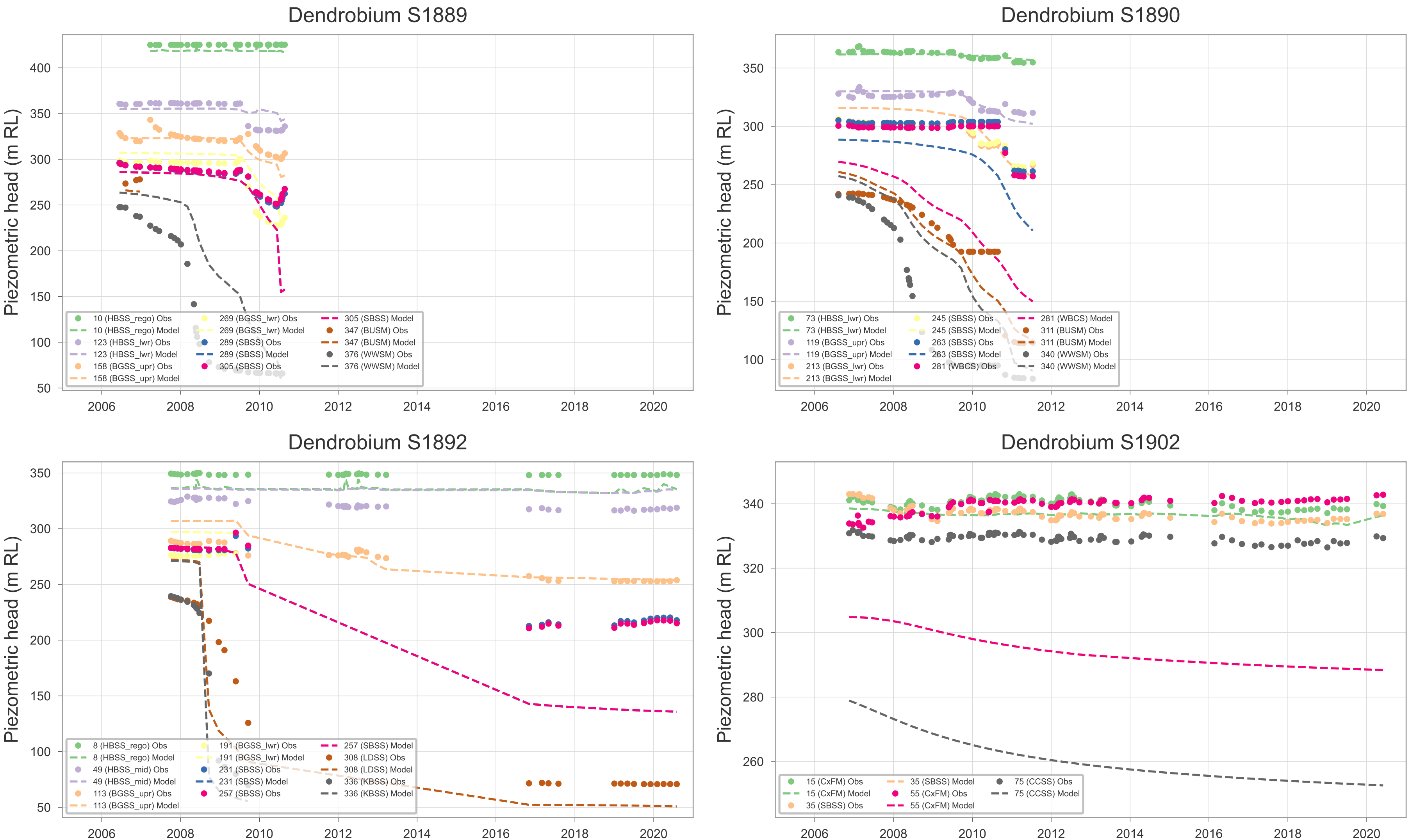

Dendrobium S1739
Piezometric head (m RL)
392 (WWSM) Obs
392 (WWSM) Model
Dendrobium S1755
Piezometric head (m RL)
362 (BUSM) Obs
389 (WWSM) Obs
389 (WWSM) Model
362 (BUSM) Model
Dendrobium S1758
Piezometric head (m RL)
376 (BUSM) Obs
406 (WWSM) Obs
406 (WWSM) Model
376 (BUSM) Model
Dendrobium S1796
Piezometric head (m RL)
421 (WWSM) Obs
421 (WWSM) Model


Dendrobium S1800
Dendrobium S1844
Dendrobium S1845
Dendrobium S1855
Piezometric head (m RL)
373 (BUSM) Obs
373 (BUSM) Model
403 (WWSM) Obs
403 (WWSM) Model
329 (BUSM) Obs
329 (BUSM) Model
356 (WWSM) Obs
356 (WWSM) Model
334 (BUSM) Obs
334 (BUSM) Model
363 (WWSM) Obs
363 (WWSM) Model
325 (BUSM) Obs
325 (BUSM) Model
356 (WWSM) Obs
356 (WWSM) Model

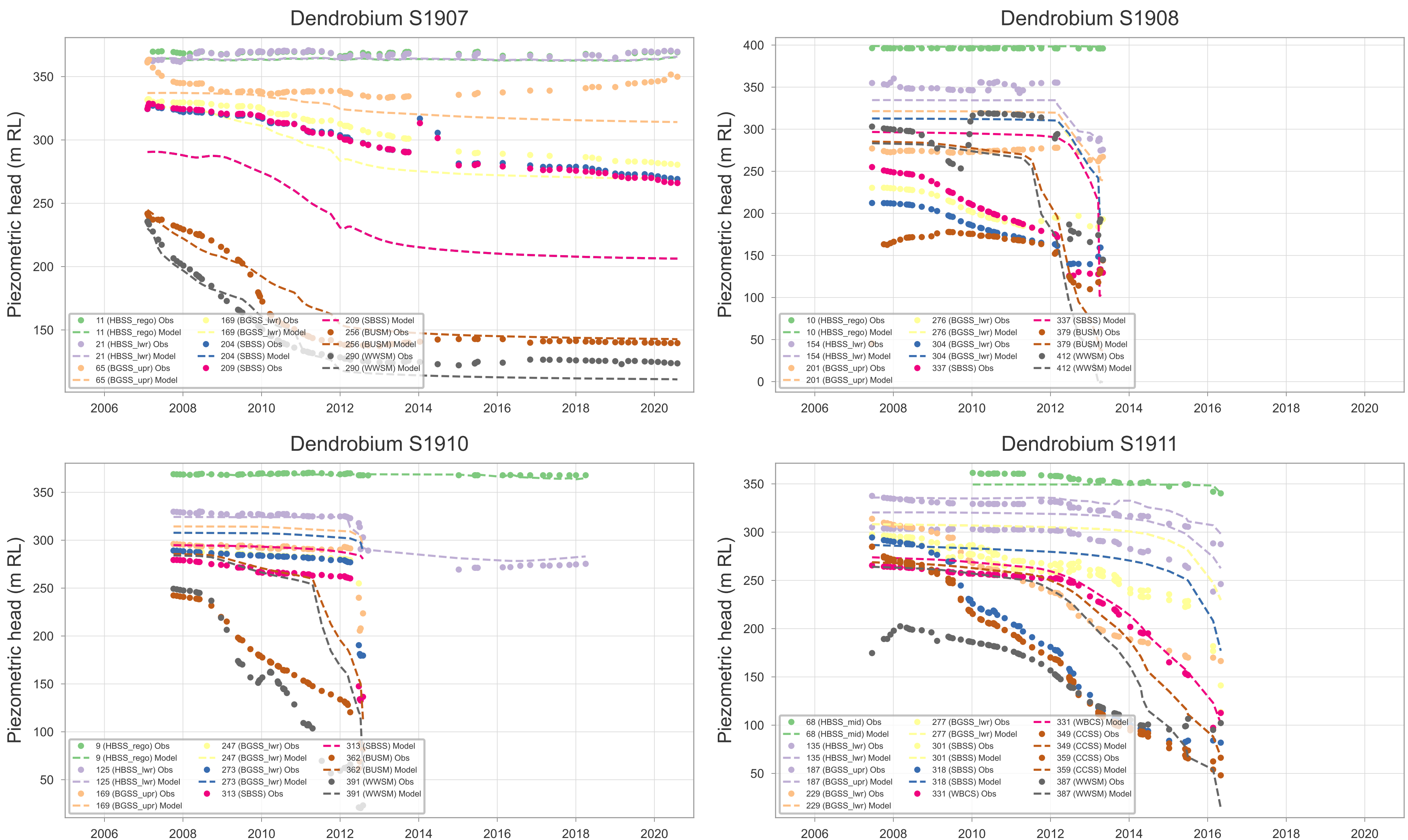


Dendrobium S1867
Piezometric head (m RL)
350
300
250
200
150
100
2006
2008
2010
2012
2014
2016
2018
2020
10 (Regolith) Obs
10 (Regolith) Model
15 (HBSS_lwr) Obs
15 (HBSS_lwr) Model
88 (BGSS_upr) Obs
88 (BGSS_upr) Model
100 (BGSS_lwr) Obs
100 (BGSS_lwr) Model
150 (BGSS_lwr) Obs
150 (BGSS_lwr) Model
173 (SBSS) Obs
173 (SBSS) Model
200 (SBSS) Obs
200 (SBSS) Model
216 (WBCS) Obs
216 (WBCS) Model
240 (CCSS) Obs
240 (CCSS) Model
249 (BUSM) Obs
249 (BUSM) Model
277 (WWSM) Obs
277 (WWSM) Model
Dendrobium S1870
Piezometric head (m RL)
350
300
250
200
150
100
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
15 (HBSS_mid) Obs
15 (HBSS_mid) Model
23 (HBSS_lwr) Obs
23 (HBSS_lwr) Model
55 (BGSS_upr) Obs
55 (BGSS_upr) Model
125 (BGSS_lwr) Obs
125 (BGSS_lwr) Model
149 (BGSS_lwr) Obs
149 (BGSS_lwr) Model
177 (SBSS) Obs
177 (SBSS) Model
204 (SBSS) Obs
204 (SBSS) Model
221 (WBCS) Obs
221 (WBCS) Model
244 (CCSS) Obs
244 (CCSS) Model
252 (BUSM) Obs
252 (BUSM) Model
284 (WWSM) Obs
284 (WWSM) Model
Dendrobium S1871
Piezometric head (m RL)
350
300
250
200
150
100
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
31 (HBSS_lwr) Obs
31 (HBSS_lwr) Model
40 (HBSS_lwr) Obs
40 (HBSS_lwr) Model
88 (BGSS_upr) Obs
88 (BGSS_upr) Model
134 (BGSS_upr) Obs
134 (BGSS_upr) Model
184 (BGSS_lwr) Obs
184 (BGSS_lwr) Model
210 (SBSS) Obs
210 (SBSS) Model
235 (SBSS) Obs
235 (SBSS) Model
253 (WBCS) Obs
253 (WBCS) Model
275 (CCSS) Obs
275 (CCSS) Model
285 (BUSM) Obs
285 (BUSM) Model
312 (WWSM) Obs
312 (WWSM) Model
Dendrobium S1878
Piezometric head (m RL)
300
250
200
150
2006
2008
2010
2012
2014
2016
2018
2020
10 (BHCS) Obs
10 (BHCS) Model
25 (BGSS) Obs
25 (BGSS) Model
71 (BGSS_upr) Obs
71 (BGSS_upr) Model
118 (BGSS_lwr) Obs
118 (BGSS_lwr) Model
145 (SBSS) Obs
145 (SBSS) Model
157 (SBSS) Obs
157 (SBSS) Model
169 (SBSS) Obs
169 (SBSS) Model
188 (WBCS) Obs
188 (WBCS) Model
212 (CCSS) Obs
212 (CCSS) Model
223 (BUSM) Obs
223 (BUSM) Model
252 (WWSM) Obs
252 (WWSM) Model

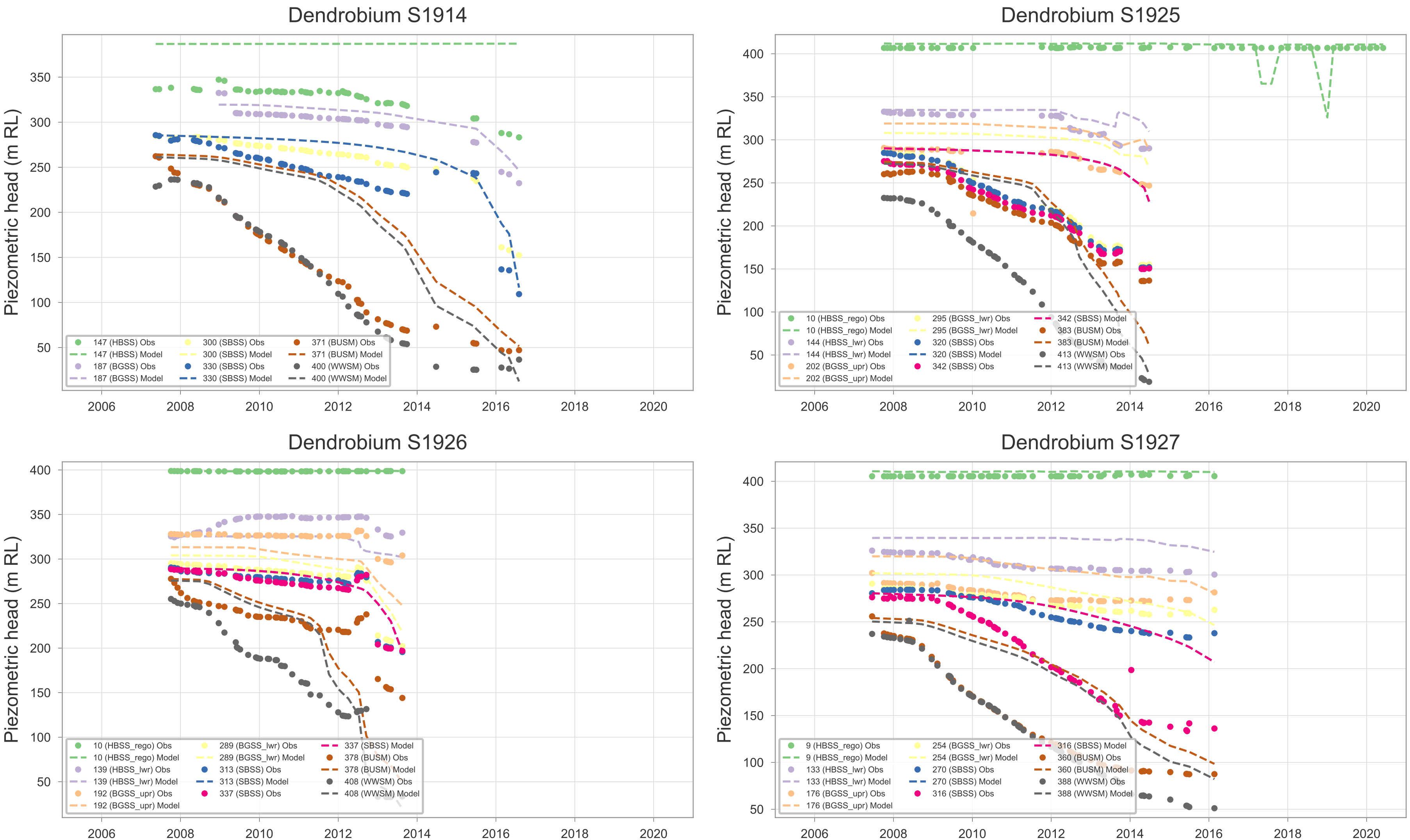

Dendrobium S1879
Piezometric head (m RL)
350
300
250
200
150
100
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
29 (HBSS_lwr) Obs
29 (HBSS_lwr) Model
48 (HBSS_mid) Obs
48 (HBSS_mid) Model
97 (BGSS_upr) Obs
97 (BGSS_upr) Model
153 (BGSS_lwr) Obs
153 (BGSS_lwr) Model
210 (BGSS_lwr) Obs
210 (BGSS_lwr) Model
227 (SBSS) Obs
227 (SBSS) Model
236 (SBSS) Obs
236 (SBSS) Model
245 (SBSS) Obs
245 (SBSS) Model
263 (WBCS) Obs
263 (WBCS) Model
292 (BUSM) Obs
292 (BUSM) Model
319 (WWSM) Obs
319 (WWSM) Model
Dendrobium S1885
Piezometric head (m RL)
400
350
300
250
200
150
100
50
2006
2008
2010
2012
2014
2016
2018
2020
11 (HBSS_upr) Obs
11 (HBSS_upr) Model
51 (HBSS_mid) Obs
51 (HBSS_mid) Model
93 (HBSS_lwr) Obs
93 (HBSS_lwr) Model
147 (BGSS_upr) Obs
147 (BGSS_upr) Model
203 (BGSS_lwr) Obs
203 (BGSS_lwr) Model
260 (BGSS_lwr) Obs
260 (BGSS_lwr) Model
280 (SBSS) Obs
280 (SBSS) Model
288 (SBSS) Obs
288 (SBSS) Model
296 (SBSS) Obs
296 (SBSS) Model
314 (WBCS) Obs
314 (WBCS) Model
340 (BUSM) Obs
340 (BUSM) Model
369 (WWSM) Obs
369 (WWSM) Model
Dendrobium S1886
Piezometric head (m RL)
310
300
290
280
270
2006
2008
2010
2012
2014
2016
2018
2020
38 (SBSS) Obs
38 (SBSS) Model
Dendrobium S1888
Piezometric head (m RL)
400
350
300
250
200
150
100
2006
2008
2010
2012
2014
2016
2018
2020
8 (HBSS_rego) Obs
8 (HBSS_rego) Model
48 (HBSS_lwr) Obs
48 (HBSS_lwr) Model
92 (BGSS_upr) Obs
92 (BGSS_upr) Model
211 (BGSS_lwr) Obs
211 (BGSS_lwr) Model
221 (SBSS) Obs
221 (SBSS) Model
235 (SBSS) Obs
235 (SBSS) Model
282 (BUSM) Obs
282 (BUSM) Model
310 (WWSM) Obs
310 (WWSM) Model

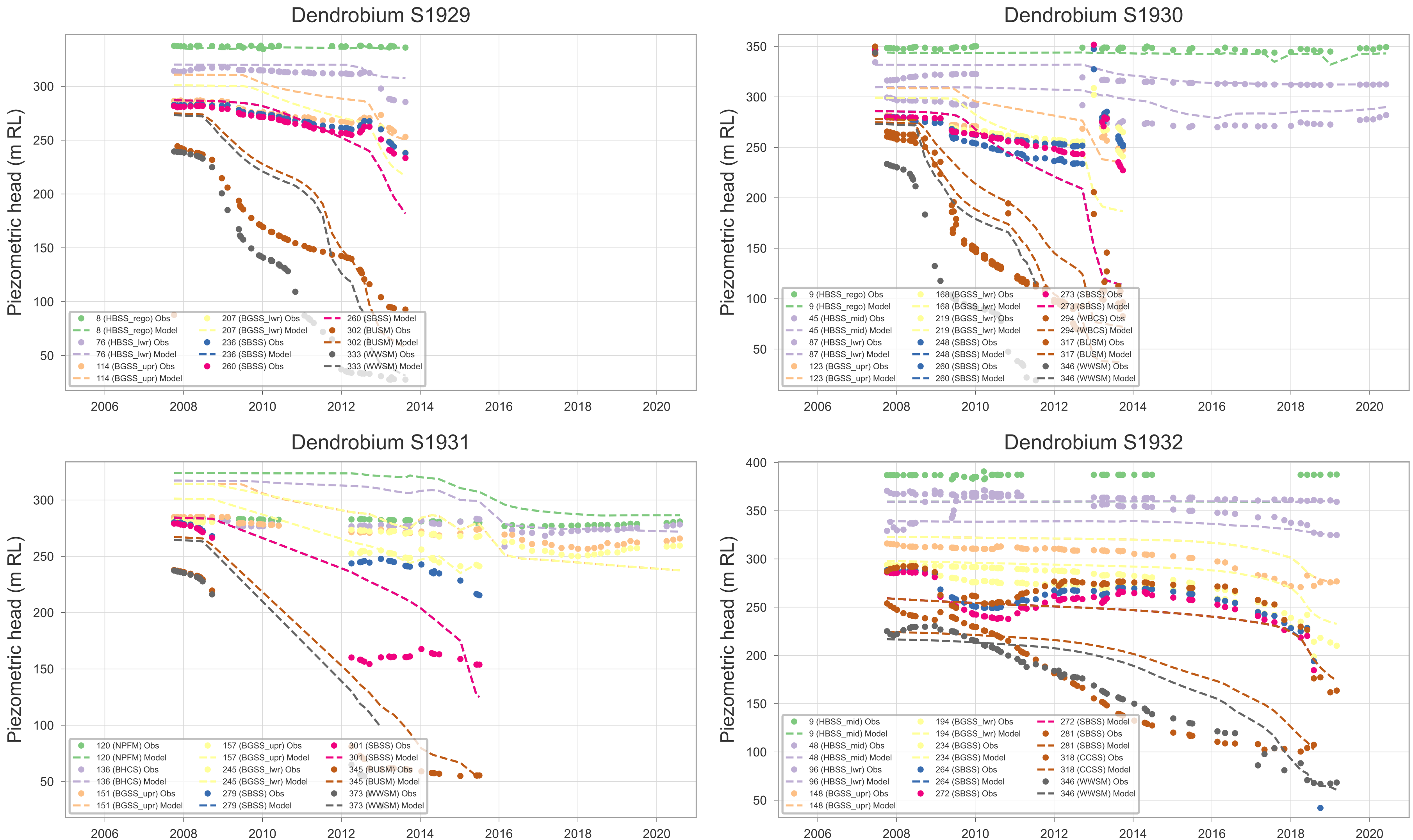


Dendrobium S1889
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
123 (HBSS_lwr) Obs
123 (HBSS_lwr) Model
158 (BGSS_upr) Obs
158 (BGSS_upr) Model
269 (BGSS_lwr) Obs
269 (BGSS_lwr) Model
289 (SBSS) Obs
289 (SBSS) Model
305 (SBSS) Obs
305 (SBSS) Model
347 (BUSM) Obs
347 (BUSM) Model
376 (WWSM) Obs
376 (WWSM) Model
Dendrobium S1890
Piezometric head (m RL)
73 (HBSS_lwr) Obs
73 (HBSS_lwr) Model
119 (BGSS_upr) Obs
119 (BGSS_upr) Model
213 (BGSS_lwr) Obs
213 (BGSS_lwr) Model
245 (SBSS) Obs
245 (SBSS) Model
263 (SBSS) Obs
263 (SBSS) Model
281 (WBCS) Obs
281 (WBCS) Model
311 (BUSM) Obs
311 (BUSM) Model
340 (WWSM) Obs
340 (WWSM) Model
Dendrobium S1892
Piezometric head (m RL)
8 (HBSS_rego) Obs
8 (HBSS_rego) Model
49 (HBSS_mid) Obs
49 (HBSS_mid) Model
113 (BGSS_upr) Obs
113 (BGSS_upr) Model
191 (BGSS_lwr) Obs
191 (BGSS_lwr) Model
231 (SBSS) Obs
231 (SBSS) Model
257 (SBSS) Obs
257 (SBSS) Model
308 (LDSS) Obs
308 (LDSS) Model
336 (KBSS) Obs
336 (KBSS) Model
Dendrobium S1902
Piezometric head (m RL)
15 (CxFM) Obs
15 (CxFM) Model
35 (SBSS) Obs
35 (SBSS) Model
55 (CxFM) Obs
55 (CxFM) Model
75 (CCSS) Obs
75 (CCSS) Model

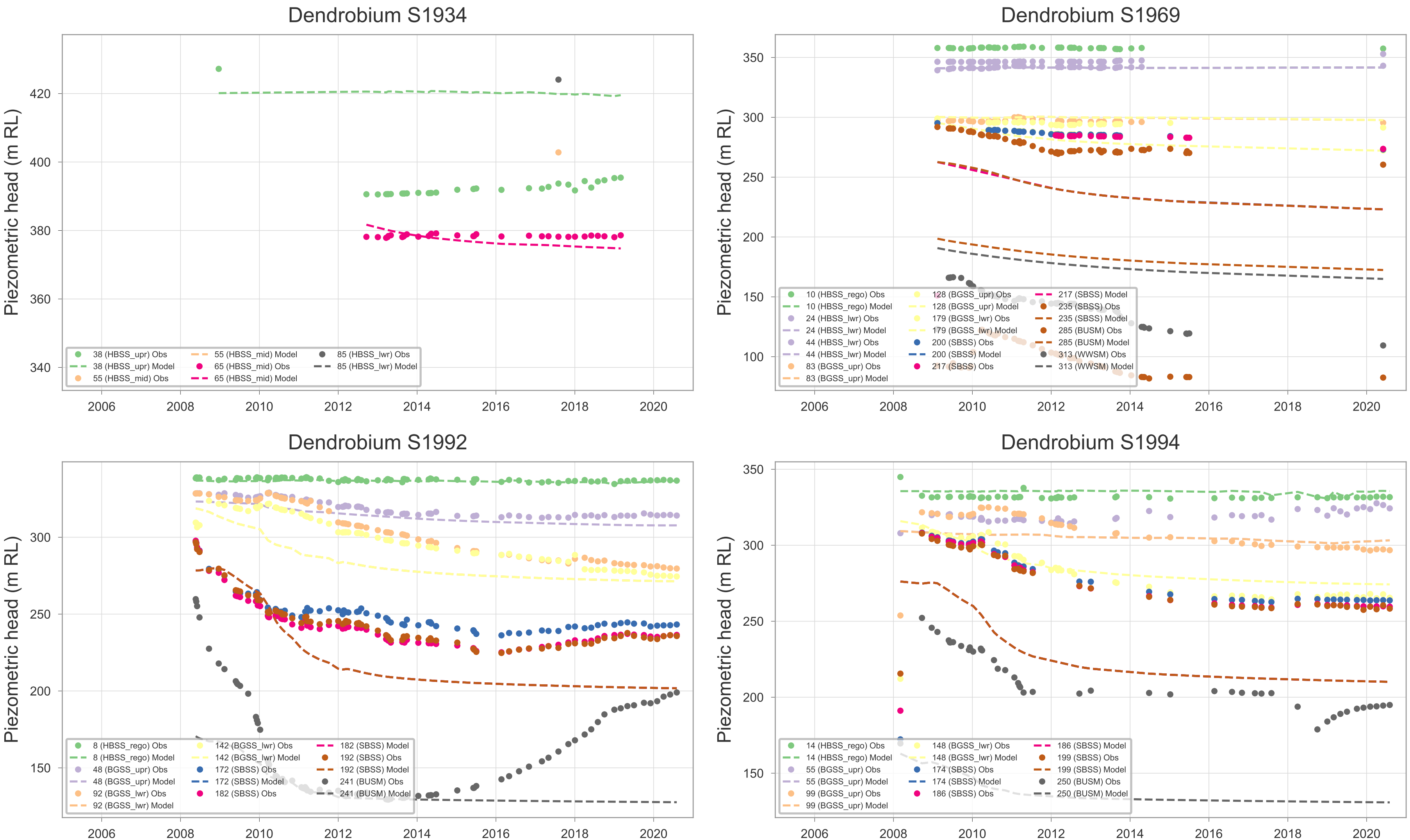


Dendrobium S1907
Dendrobium S1908
Dendrobium S1910
Dendrobium S1911
Piezometric head (m RL)
11 (HBSS_rego) Obs
11 (HBSS_rego) Model
21 (HBSS_lwr) Obs
21 (HBSS_lwr) Model
65 (BGSS_upr) Obs
65 (BGSS_upr) Model
169 (BGSS_lwr) Obs
169 (BGSS_lwr) Model
204 (SBSS) Obs
204 (SBSS) Model
209 (SBSS) Obs
209 (SBSS) Model
256 (BUSM) Obs
256 (BUSM) Model
290 (WWSM) Obs
290 (WWSM) Model
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
154 (HBSS_lwr) Obs
154 (HBSS_lwr) Model
201 (BGSS_upr) Obs
201 (BGSS_upr) Model
276 (BGSS_lwr) Obs
276 (BGSS_lwr) Model
304 (BGSS_lwr) Obs
304 (BGSS_lwr) Model
337 (SBSS) Obs
337 (SBSS) Model
379 (BUSM) Obs
379 (BUSM) Model
412 (WWSM) Obs
412 (WWSM) Model
9 (HBSS_rego) Obs
9 (HBSS_rego) Model
125 (HBSS_lwr) Obs
125 (HBSS_lwr) Model
169 (BGSS_upr) Obs
169 (BGSS_upr) Model
247 (BGSS_lwr) Obs
247 (BGSS_lwr) Model
273 (BGSS_lwr) Obs
273 (BGSS_lwr) Model
313 (SBSS) Obs
313 (SBSS) Model
362 (BUSM) Obs
362 (BUSM) Model
391 (WWSM) Obs
391 (WWSM) Model
68 (HBSS_mid) Obs
68 (HBSS_mid) Model
135 (HBSS_lwr) Obs
135 (HBSS_lwr) Model
187 (BGSS_upr) Obs
187 (BGSS_upr) Model
229 (BGSS_lwr) Obs
229 (BGSS_lwr) Model
277 (BGSS_lwr) Obs
277 (BGSS_lwr) Model
301 (SBSS) Obs
301 (SBSS) Model
318 (SBSS) Obs
318 (SBSS) Model
331 (WBCS) Obs
331 (WBCS) Model
349 (CCSS) Obs
349 (CCSS) Model
359 (CCSS) Obs
359 (CCSS) Model
387 (WWSM) Obs
387 (WWSM) Model
2006
2008
2010
2012
2014
2016
2018
2020

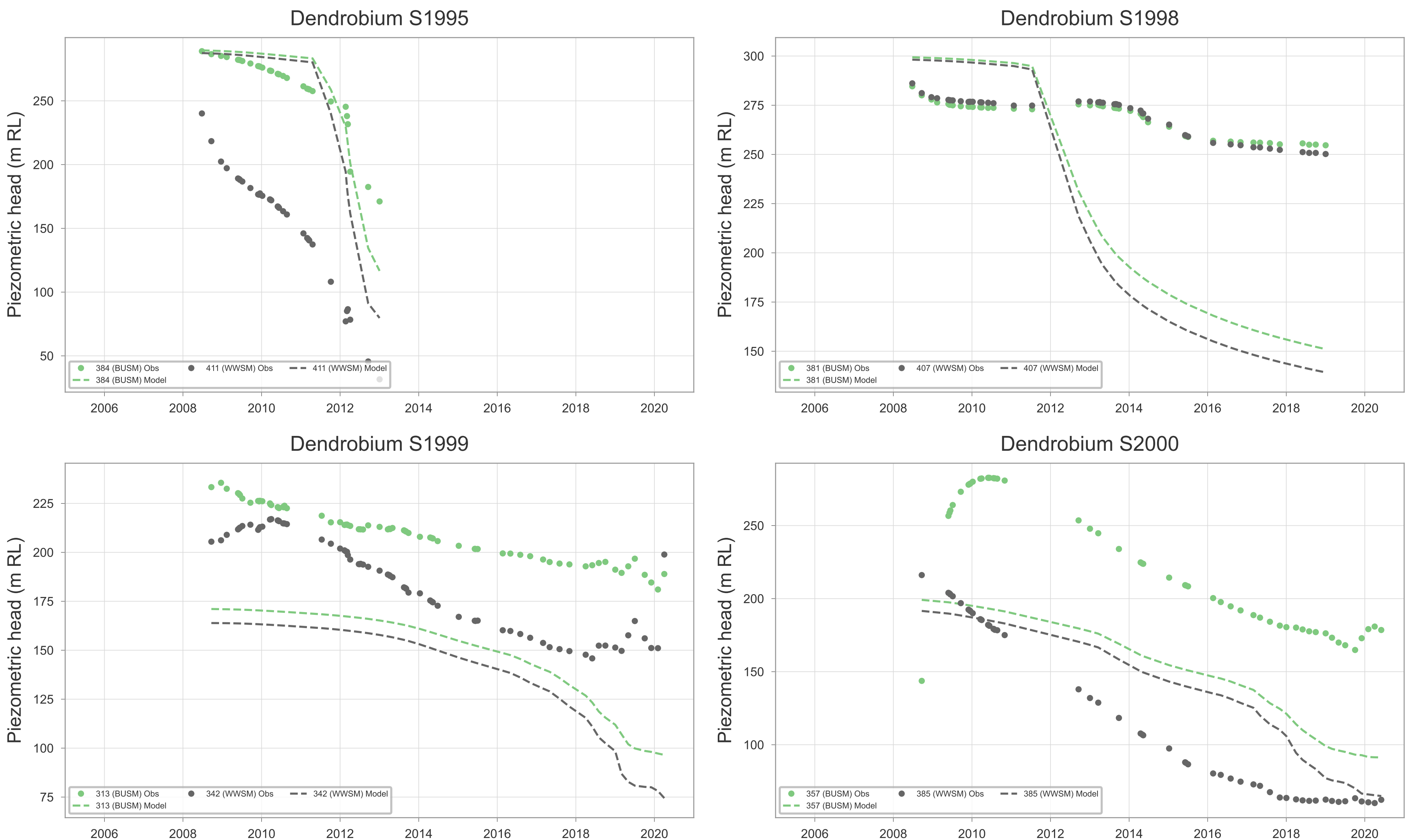

Dendrobium S1914
Piezometric head (m RL)
147 (HBSS) Obs
147 (HBSS) Model
187 (BGSS) Obs
187 (BGSS) Model
300 (SBSS) Obs
300 (SBSS) Model
330 (SBSS) Obs
330 (SBSS) Model
371 (BUSM) Obs
371 (BUSM) Model
400 (WWSM) Obs
400 (WWSM) Model
Dendrobium S1925
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
144 (HBSS_lwr) Obs
144 (HBSS_lwr) Model
202 (BGSS_upr) Obs
202 (BGSS_upr) Model
295 (BGSS_lwr) Obs
295 (BGSS_lwr) Model
320 (SBSS) Obs
320 (SBSS) Model
342 (SBSS) Obs
342 (SBSS) Model
383 (BUSM) Obs
383 (BUSM) Model
413 (WWSM) Obs
413 (WWSM) Model
Dendrobium S1926
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
139 (HBSS_lwr) Obs
139 (HBSS_lwr) Model
192 (BGSS_upr) Obs
192 (BGSS_upr) Model
289 (BGSS_lwr) Obs
289 (BGSS_lwr) Model
313 (SBSS) Obs
313 (SBSS) Model
337 (SBSS) Obs
337 (SBSS) Model
378 (BUSM) Obs
378 (BUSM) Model
408 (WWSM) Obs
408 (WWSM) Model
Dendrobium S1927
Piezometric head (m RL)
9 (HBSS_rego) Obs
9 (HBSS_rego) Model
133 (HBSS_lwr) Obs
133 (HBSS_lwr) Model
176 (BGSS_upr) Obs
176 (BGSS_upr) Model
254 (BGSS_lwr) Obs
254 (BGSS_lwr) Model
270 (SBSS) Obs
270 (SBSS) Model
316 (SBSS) Obs
316 (SBSS) Model
360 (BUSM) Obs
360 (BUSM) Model
388 (WWSM) Obs
388 (WWSM) Model



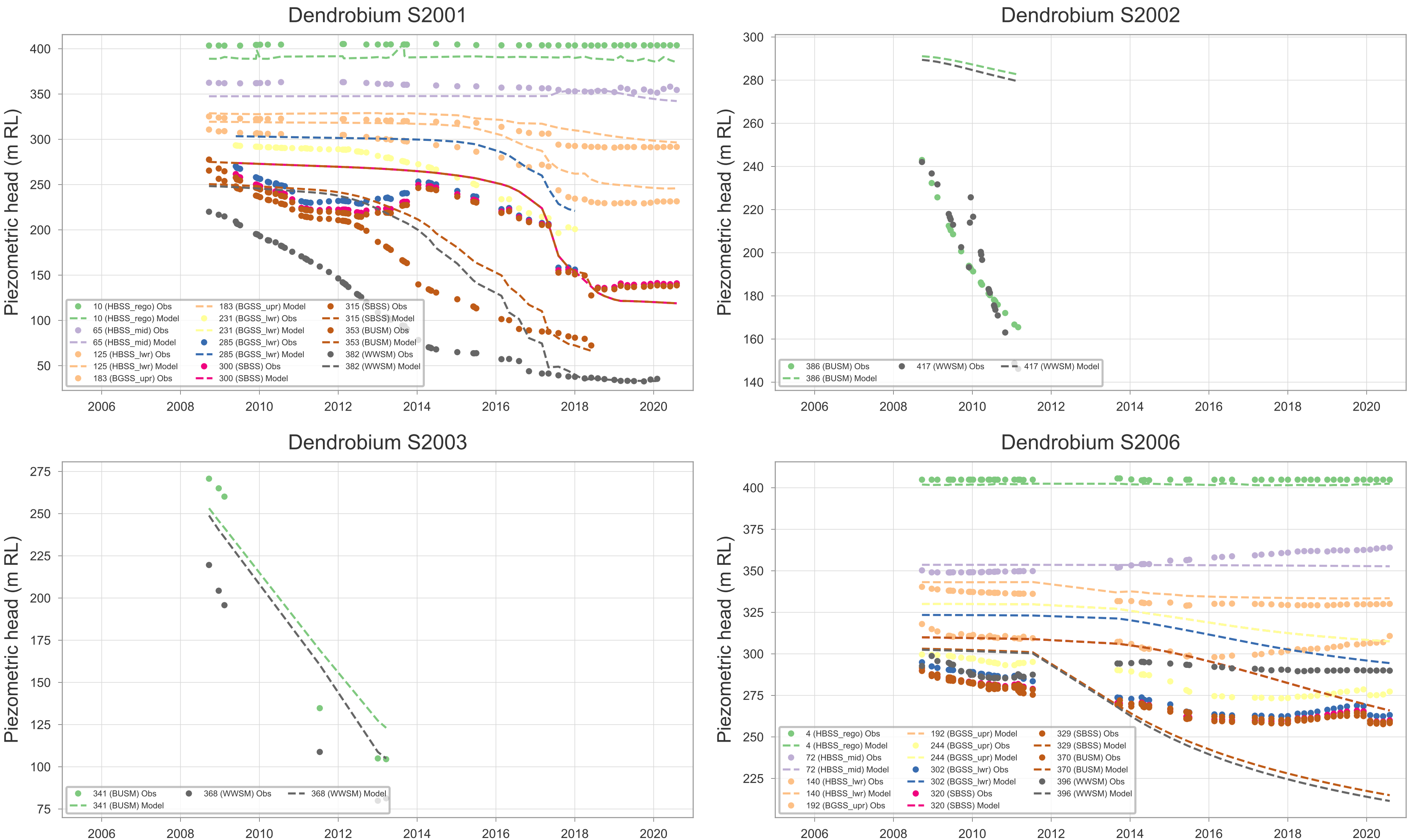
Dendrobium S1929
Dendrobium S1930
Dendrobium S1931
Dendrobium S1932
Piezometric head (m RL)
2006
2008
2010
2012
2014
2016
2018
2020
8 (HBSS_rego) Obs
8 (HBSS_rego) Model
76 (HBSS_lwr) Obs
76 (HBSS_lwr) Model
114 (BGSS_upr) Obs
114 (BGSS_upr) Model
207 (BGSS_lwr) Obs
207 (BGSS_lwr) Model
236 (SBSS) Obs
236 (SBSS) Model
260 (SBSS) Obs
260 (SBSS) Model
302 (BUSM) Obs
302 (BUSM) Model
333 (WWSM) Obs
333 (WWSM) Model
9 (HBSS_rego) Obs
9 (HBSS_rego) Model
45 (HBSS_mid) Obs
45 (HBSS_mid) Model
87 (HBSS_lwr) Obs
87 (HBSS_lwr) Model
123 (BGSS_upr) Obs
123 (BGSS_upr) Model
168 (BGSS_lwr) Obs
168 (BGSS_lwr) Model
219 (BGSS_lwr) Obs
219 (BGSS_lwr) Model
248 (SBSS) Obs
248 (SBSS) Model
260 (SBSS) Obs
260 (SBSS) Model
273 (SBSS) Obs
273 (SBSS) Model
294 (WBCS) Obs
294 (WBCS) Model
317 (BUSM) Obs
317 (BUSM) Model
346 (WWSM) Obs
346 (WWSM) Model
120 (NPFM) Obs
120 (NPFM) Model
136 (BHCS) Obs
136 (BHCS) Model
151 (BGSS_upr) Obs
151 (BGSS_upr) Model
157 (BGSS_upr) Obs
157 (BGSS_upr) Model
245 (BGSS_lwr) Obs
245 (BGSS_lwr) Model
279 (SBSS) Obs
279 (SBSS) Model
301 (SBSS) Obs
301 (SBSS) Model
345 (BUSM) Obs
345 (BUSM) Model
373 (WWSM) Obs
373 (WWSM) Model
9 (HBSS_mid) Obs
9 (HBSS_mid) Model
48 (HBSS_mid) Obs
48 (HBSS_mid) Model
96 (HBSS_lwr) Obs
96 (HBSS_lwr) Model
148 (BGSS_upr) Obs
148 (BGSS_upr) Model
194 (BGSS_lwr) Obs
194 (BGSS_lwr) Model
234 (BGSS) Obs
234 (BGSS) Model
264 (SBSS) Obs
264 (SBSS) Model
272 (SBSS) Obs
272 (SBSS) Model
281 (SBSS) Obs
281 (SBSS) Model
318 (CCSS) Obs
318 (CCSS) Model
346 (WWSM) Obs
346 (WWSM) Model



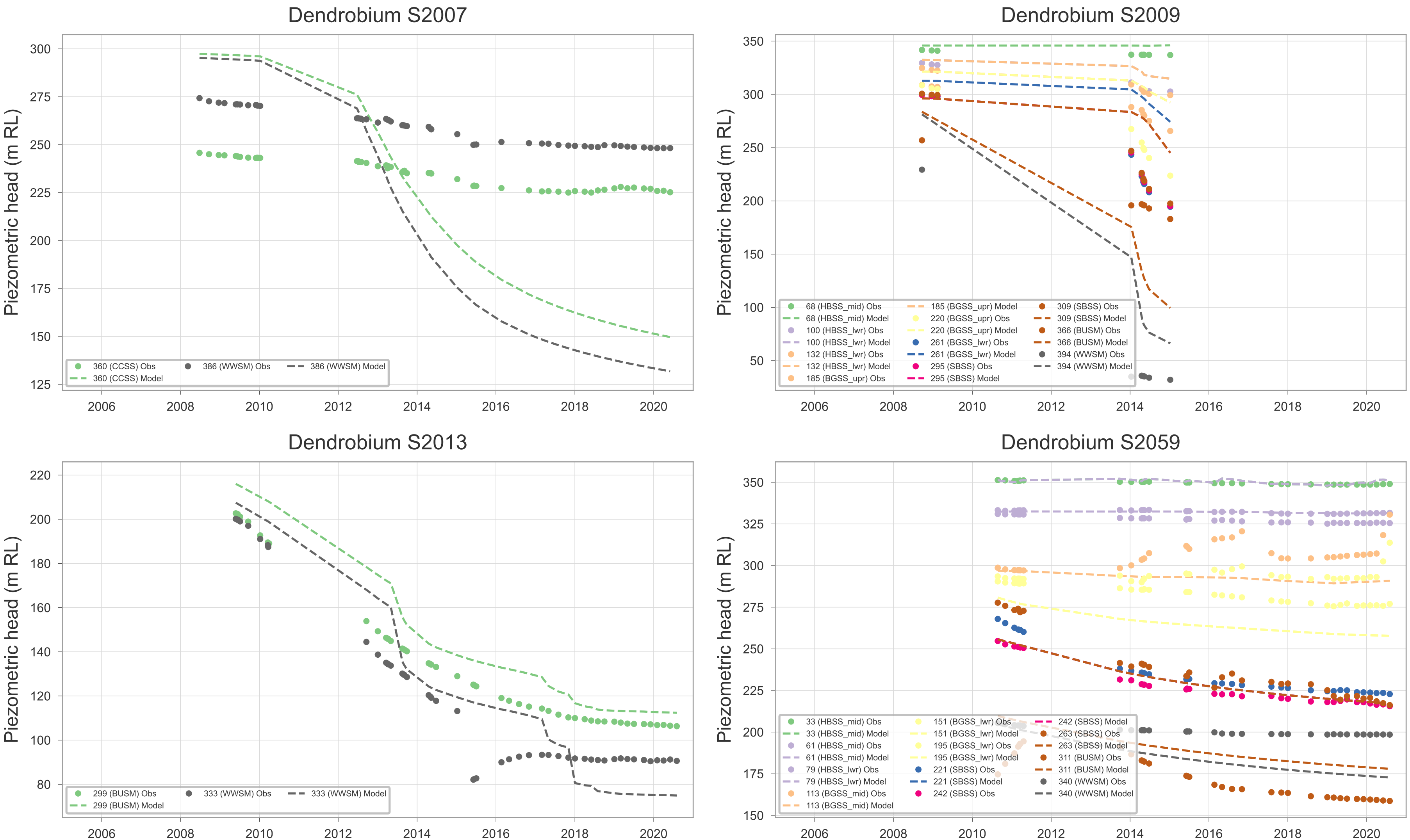
Dendrobium S1934
Piezometric head (m RL)
340
360
380
400
420
2006
2008
2010
2012
2014
2016
2018
2020
38 (HBSS_upr) Obs
38 (HBSS_upr) Model
55 (HBSS_mid) Obs
55 (HBSS_mid) Model
65 (HBSS_mid) Obs
65 (HBSS_mid) Model
85 (HBSS_lwr) Obs
85 (HBSS_lwr) Model
Dendrobium S1969
Piezometric head (m RL)
100
150
200
250
300
350
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
24 (HBSS_lwr) Obs
24 (HBSS_lwr) Model
44 (HBSS_lwr) Obs
44 (HBSS_lwr) Model
83 (BGSS_upr) Obs
83 (BGSS_upr) Model
128 (BGSS_upr) Obs
128 (BGSS_upr) Model
179 (BGSS_lwr) Obs
179 (BGSS_lwr) Model
200 (SBSS) Obs
200 (SBSS) Model
217 (SBSS) Obs
217 (SBSS) Model
235 (SBSS) Obs
235 (SBSS) Model
285 (BUSM) Obs
285 (BUSM) Model
313 (WWSM) Obs
313 (WWSM) Model
Dendrobium S1992
Piezometric head (m RL)
150
200
250
300
2006
2008
2010
2012
2014
2016
2018
2020
8 (HBSS_rego) Obs
8 (HBSS_rego) Model
48 (BGSS_upr) Obs
48 (BGSS_upr) Model
92 (BGSS_lwr) Obs
92 (BGSS_lwr) Model
142 (BGSS_lwr) Obs
142 (BGSS_lwr) Model
172 (SBSS) Obs
172 (SBSS) Model
182 (SBSS) Obs
182 (SBSS) Model
192 (SBSS) Obs
192 (SBSS) Model
241 (BUSM) Obs
241 (BUSM) Model
Dendrobium S1994
Piezometric head (m RL)
150
200
250
300
350
2006
2008
2010
2012
2014
2016
2018
2020
14 (HBSS_rego) Obs
14 (HBSS_rego) Model
55 (BGSS_upr) Obs
55 (BGSS_upr) Model
99 (BGSS_upr) Obs
99 (BGSS_upr) Model
148 (BGSS_lwr) Obs
148 (BGSS_lwr) Model
174 (SBSS) Obs
174 (SBSS) Model
186 (SBSS) Obs
186 (SBSS) Model
199 (SBSS) Obs
199 (SBSS) Model
250 (BUSM) Obs
250 (BUSM) Model



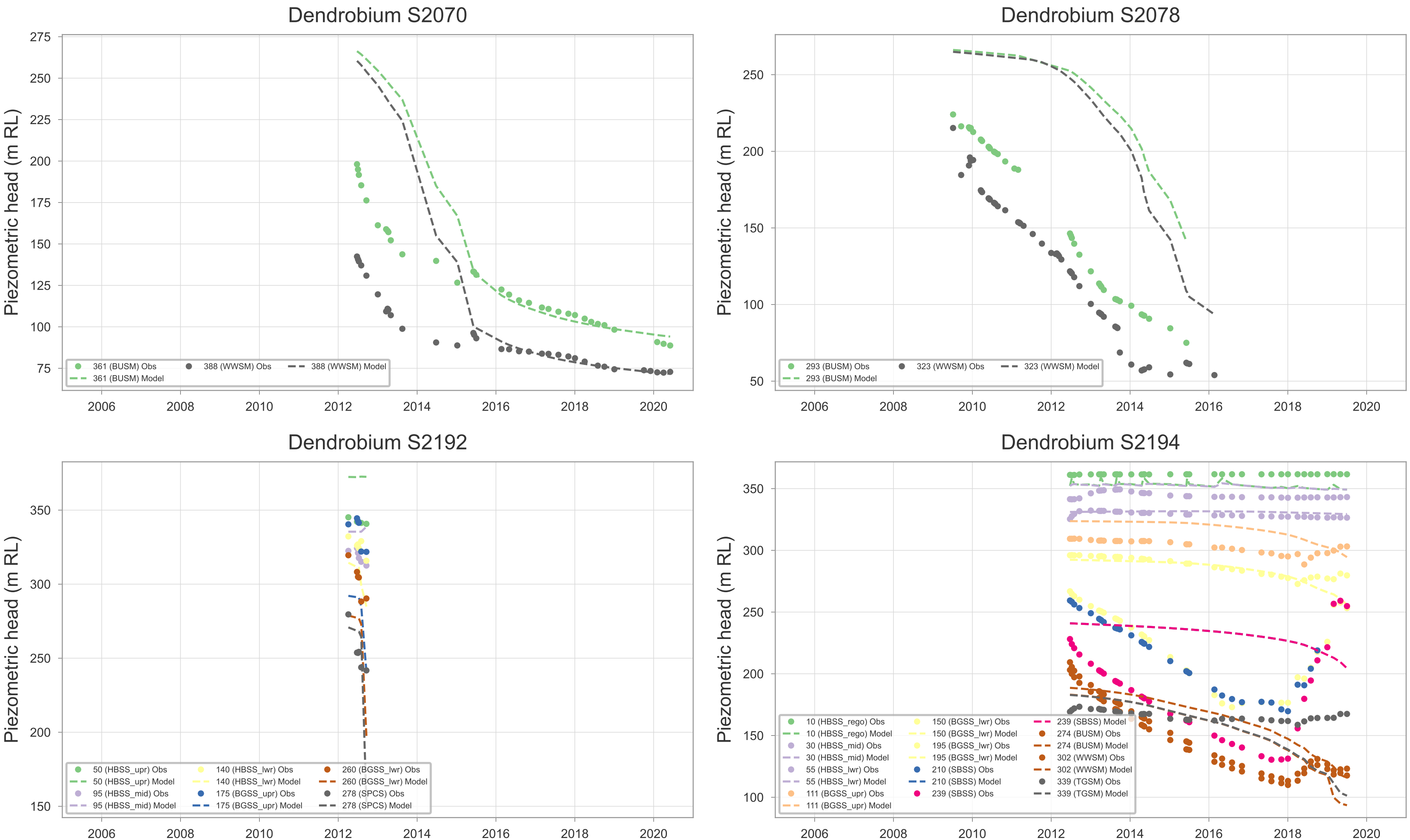
Dendrobium S1995
Dendrobium S1998
Dendrobium S1999
Dendrobium S2000
Piezometric head (m RL)
384 (BUSM) Obs
384 (BUSM) Model
411 (WWSM) Obs
411 (WWSM) Model
381 (BUSM) Obs
381 (BUSM) Model
407 (WWSM) Obs
407 (WWSM) Model
313 (BUSM) Obs
313 (BUSM) Model
342 (WWSM) Obs
342 (WWSM) Model
357 (BUSM) Obs
357 (BUSM) Model
385 (WWSM) Obs
385 (WWSM) Model
2006
2008
2010
2012
2014
2016
2018
2020

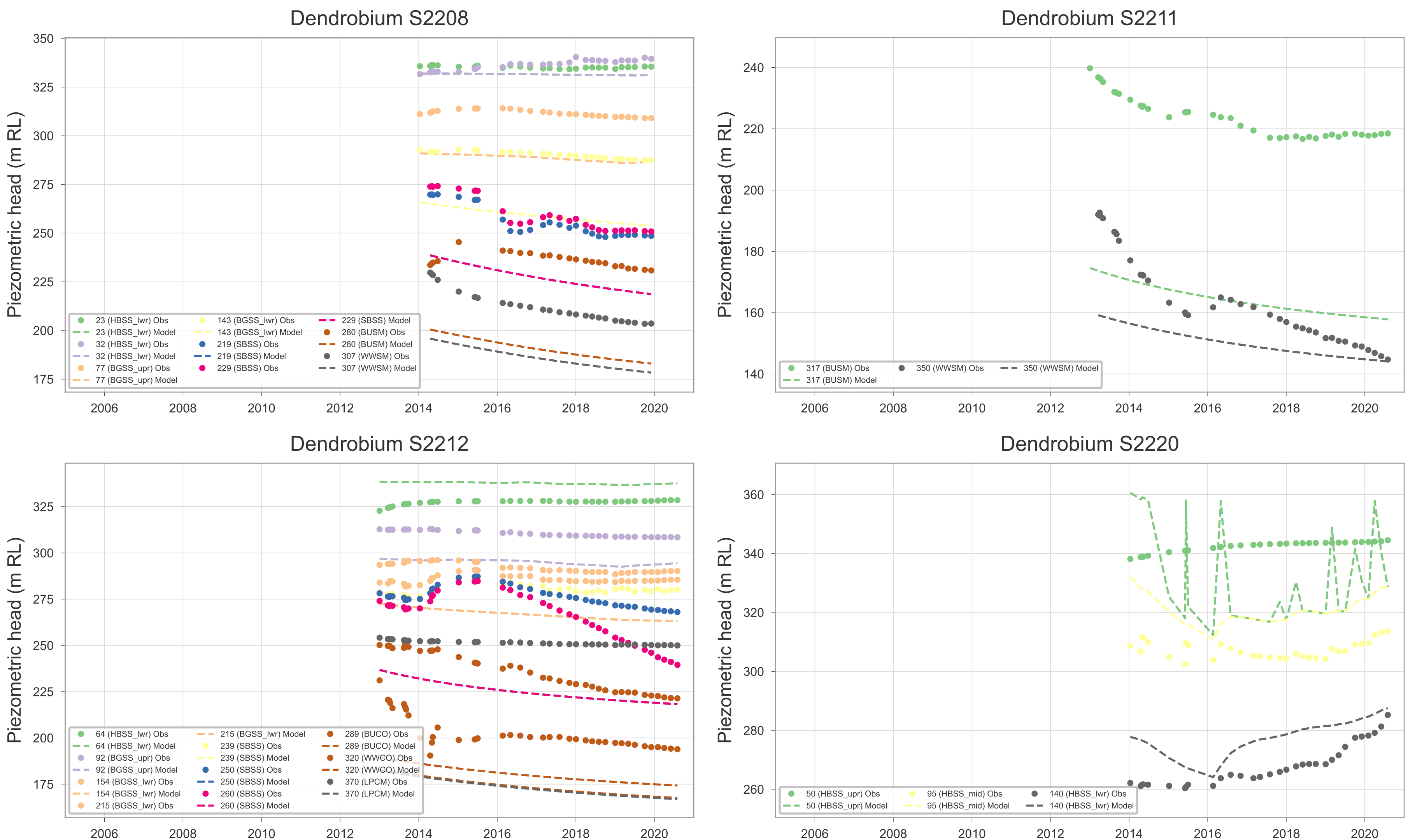


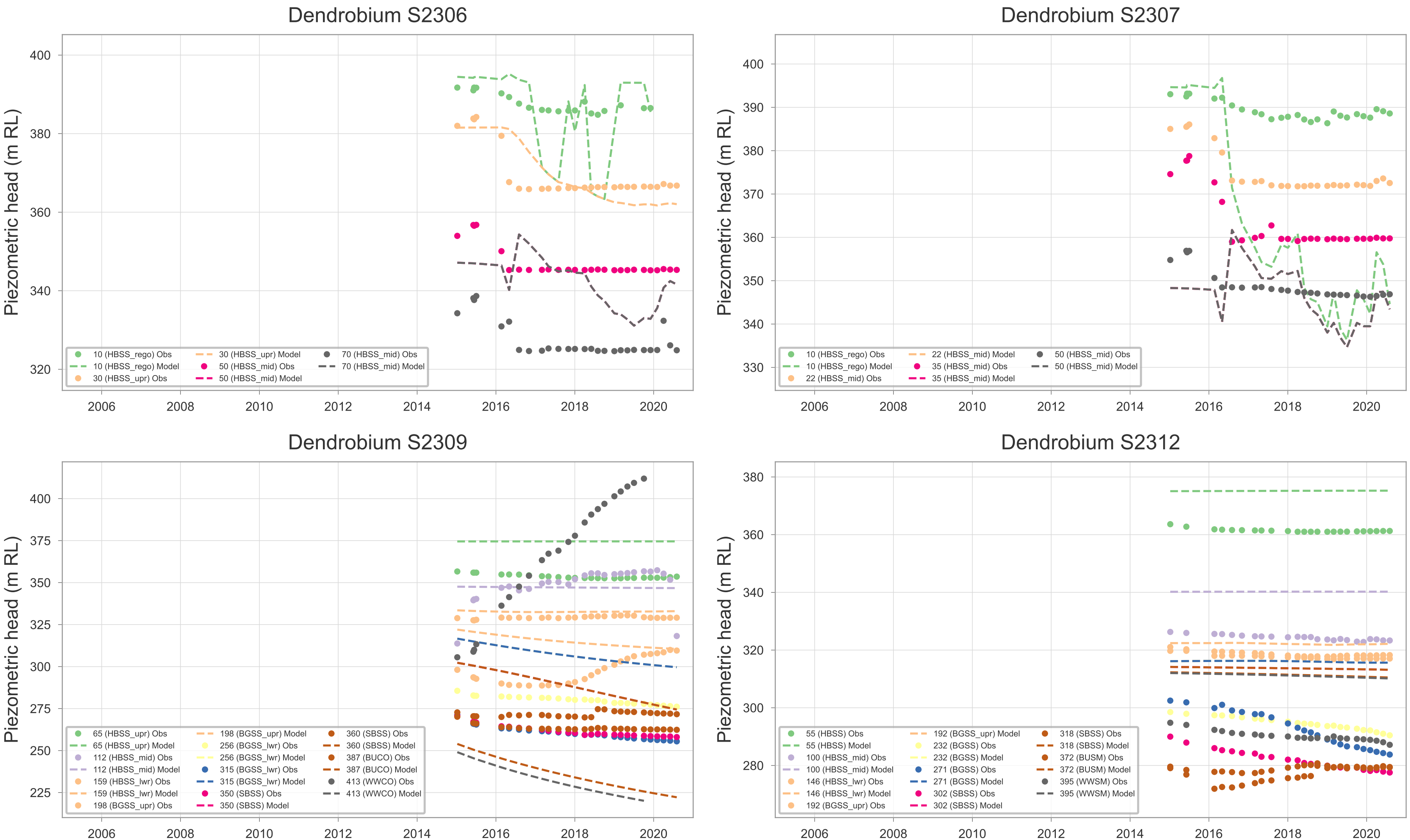
Dendrobium S2001
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
65 (HBSS_mid) Obs
65 (HBSS_mid) Model
125 (HBSS_lwr) Obs
125 (HBSS_lwr) Model
183 (BGSS_upr) Obs
183 (BGSS_upr) Model
231 (BGSS_lwr) Obs
231 (BGSS_lwr) Model
285 (BGSS_lwr) Obs
285 (BGSS_lwr) Model
300 (SBSS) Obs
300 (SBSS) Model
315 (SBSS) Obs
315 (SBSS) Model
353 (BUSM) Obs
353 (BUSM) Model
382 (WWSM) Obs
382 (WWSM) Model
Dendrobium S2002
Piezometric head (m RL)
386 (BUSM) Obs
386 (BUSM) Model
417 (WWSM) Obs
417 (WWSM) Model
Dendrobium S2003
Piezometric head (m RL)
341 (BUSM) Obs
341 (BUSM) Model
368 (WWSM) Obs
368 (WWSM) Model
Dendrobium S2006
Piezometric head (m RL)
4 (HBSS_rego) Obs
4 (HBSS_rego) Model
72 (HBSS_mid) Obs
72 (HBSS_mid) Model
140 (HBSS_lwr) Obs
140 (HBSS_lwr) Model
192 (BGSS_upr) Obs
192 (BGSS_upr) Model
244 (BGSS_upr) Obs
244 (BGSS_upr) Model
302 (BGSS_lwr) Obs
302 (BGSS_lwr) Model
320 (SBSS) Obs
320 (SBSS) Model
329 (SBSS) Obs
329 (SBSS) Model
370 (BUSM) Obs
370 (BUSM) Model
396 (WWSM) Obs
396 (WWSM) Model



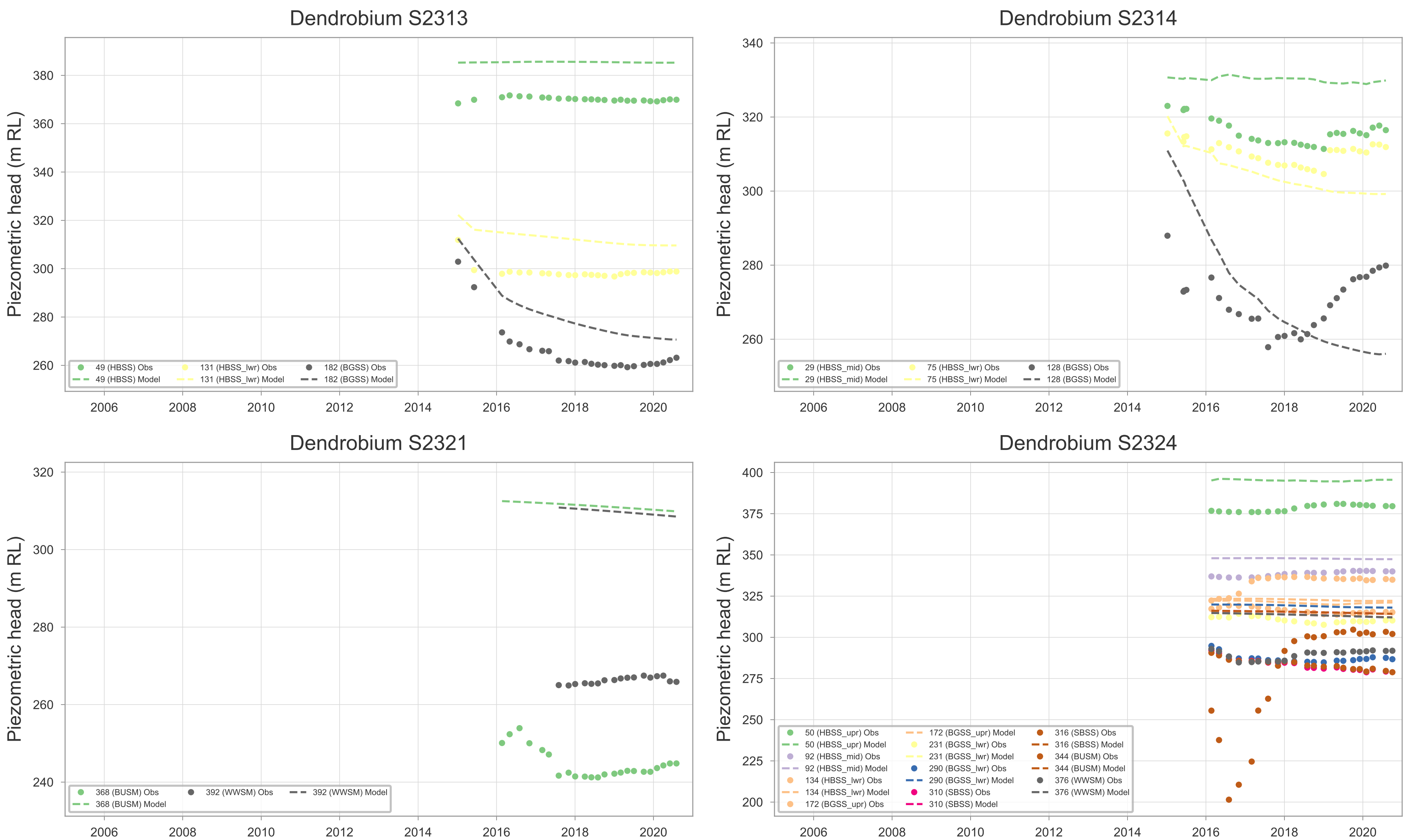
Dendrobium S2007
Piezometric head (m RL)
300
275
250
225
200
175
150
125
2006
2008
2010
2012
2014
2016
2018
2020
360 (CCSS) Obs
360 (CCSS) Model
386 (WWSM) Obs
386 (WWSM) Model
Dendrobium S2009
Piezometric head (m RL)
350
300
250
200
150
100
50
2006
2008
2010
2012
2014
2016
2018
2020
68 (HBSS_mid) Obs
68 (HBSS_mid) Model
100 (HBSS_lwr) Obs
100 (HBSS_lwr) Model
132 (HBSS_lwr) Obs
132 (HBSS_lwr) Model
185 (BGSS_upr) Obs
185 (BGSS_upr) Model
220 (BGSS_upr) Obs
220 (BGSS_upr) Model
261 (BGSS_lwr) Obs
261 (BGSS_lwr) Model
295 (SBSS) Obs
295 (SBSS) Model
309 (SBSS) Obs
309 (SBSS) Model
366 (BUSM) Obs
366 (BUSM) Model
394 (WWSM) Obs
394 (WWSM) Model
Dendrobium S2013
Piezometric head (m RL)
220
200
180
160
140
120
100
80
2006
2008
2010
2012
2014
2016
2018
2020
299 (BUSM) Obs
299 (BUSM) Model
333 (WWSM) Obs
333 (WWSM) Model
Dendrobium S2059
Piezometric head (m RL)
350
325
300
275
250
225
200
175
150
2006
2008
2010
2012
2014
2016
2018
2020
33 (HBSS_mid) Obs
33 (HBSS_mid) Model
61 (HBSS_mid) Obs
61 (HBSS_mid) Model
79 (HBSS_lwr) Obs
79 (HBSS_lwr) Model
113 (BGSS_mid) Obs
113 (BGSS_mid) Model
151 (BGSS_lwr) Obs
151 (BGSS_lwr) Model
195 (BGSS_lwr) Obs
195 (BGSS_lwr) Model
221 (SBSS) Obs
221 (SBSS) Model
242 (SBSS) Obs
242 (SBSS) Model
263 (SBSS) Obs
263 (SBSS) Model
311 (BUSM) Obs
311 (BUSM) Model
340 (WWSM) Obs
340 (WWSM) Model


Dendrobium S2070
Piezometric head (m RL)
361 (BUSM) Obs
361 (BUSM) Model
388 (WWSM) Obs
388 (WWSM) Model
Dendrobium S2078
Piezometric head (m RL)
293 (BUSM) Obs
293 (BUSM) Model
323 (WWSM) Obs
323 (WWSM) Model
Dendrobium S2192
Piezometric head (m RL)
50 (HBSS_upr) Obs
50 (HBSS_upr) Model
95 (HBSS_mid) Obs
95 (HBSS_mid) Model
140 (HBSS_lwr) Obs
140 (HBSS_lwr) Model
175 (BGSS_upr) Obs
175 (BGSS_upr) Model
260 (BGSS_lwr) Obs
260 (BGSS_lwr) Model
278 (SPCS) Obs
278 (SPCS) Model
Dendrobium S2194
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
30 (HBSS_mid) Obs
30 (HBSS_mid) Model
55 (HBSS_lwr) Obs
55 (HBSS_lwr) Model
111 (BGSS_upr) Obs
111 (BGSS_upr) Model
150 (BGSS_lwr) Obs
150 (BGSS_lwr) Model
195 (BGSS_lwr) Obs
195 (BGSS_lwr) Model
210 (SBSS) Obs
210 (SBSS) Model
239 (SBSS) Obs
239 (SBSS) Model
274 (BUSM) Obs
274 (BUSM) Model
302 (WWSM) Obs
302 (WWSM) Model
339 (TGSM) Obs
339 (TGSM) Model

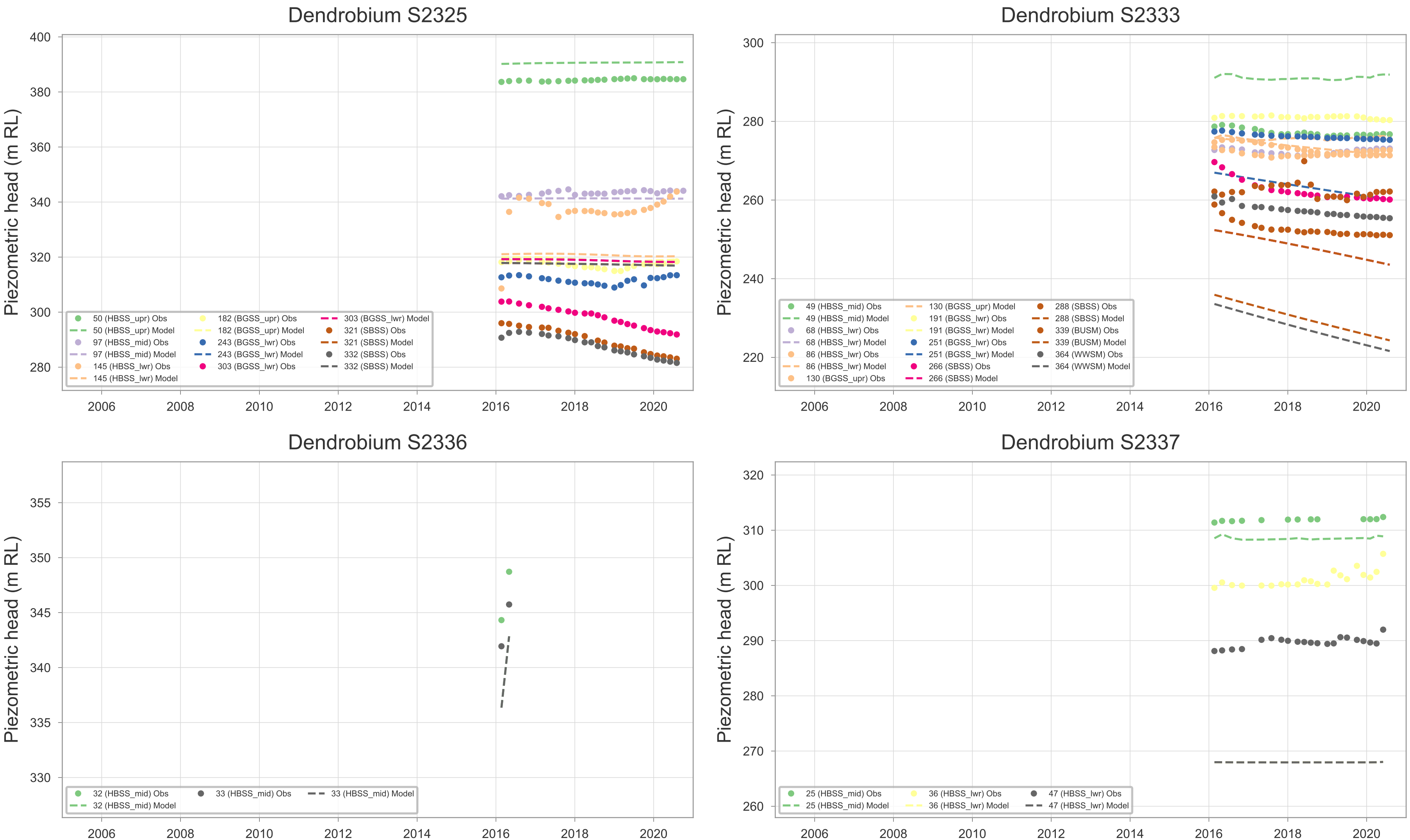

Dendrobium S2208
Piezometric head (m RL)
23 (HBSS_lwr) Obs
23 (HBSS_lwr) Model
32 (HBSS_lwr) Obs
32 (HBSS_lwr) Model
77 (BGSS_upr) Obs
77 (BGSS_upr) Model
143 (BGSS_lwr) Obs
143 (BGSS_lwr) Model
219 (SBSS) Obs
219 (SBSS) Model
229 (SBSS) Obs
229 (SBSS) Model
280 (BUSM) Obs
280 (BUSM) Model
307 (WWSM) Obs
307 (WWSM) Model
Dendrobium S2211
Piezometric head (m RL)
317 (BUSM) Obs
317 (BUSM) Model
350 (WWSM) Obs
350 (WWSM) Model
Dendrobium S2212
Piezometric head (m RL)
64 (HBSS_lwr) Obs
64 (HBSS_lwr) Model
92 (BGSS_upr) Obs
92 (BGSS_upr) Model
154 (BGSS_lwr) Obs
154 (BGSS_lwr) Model
215 (BGSS_lwr) Obs
215 (BGSS_lwr) Model
239 (SBSS) Obs
239 (SBSS) Model
250 (SBSS) Obs
250 (SBSS) Model
260 (SBSS) Obs
260 (SBSS) Model
289 (BUCO) Obs
289 (BUCO) Model
320 (WWCO) Obs
320 (WWCO) Model
370 (LPCM) Obs
370 (LPCM) Model
Dendrobium S2220
Piezometric head (m RL)
50 (HBSS_upr) Obs
50 (HBSS_upr) Model
95 (HBSS_mid) Obs
95 (HBSS_mid) Model
140 (HBSS_lwr) Obs
140 (HBSS_lwr) Model

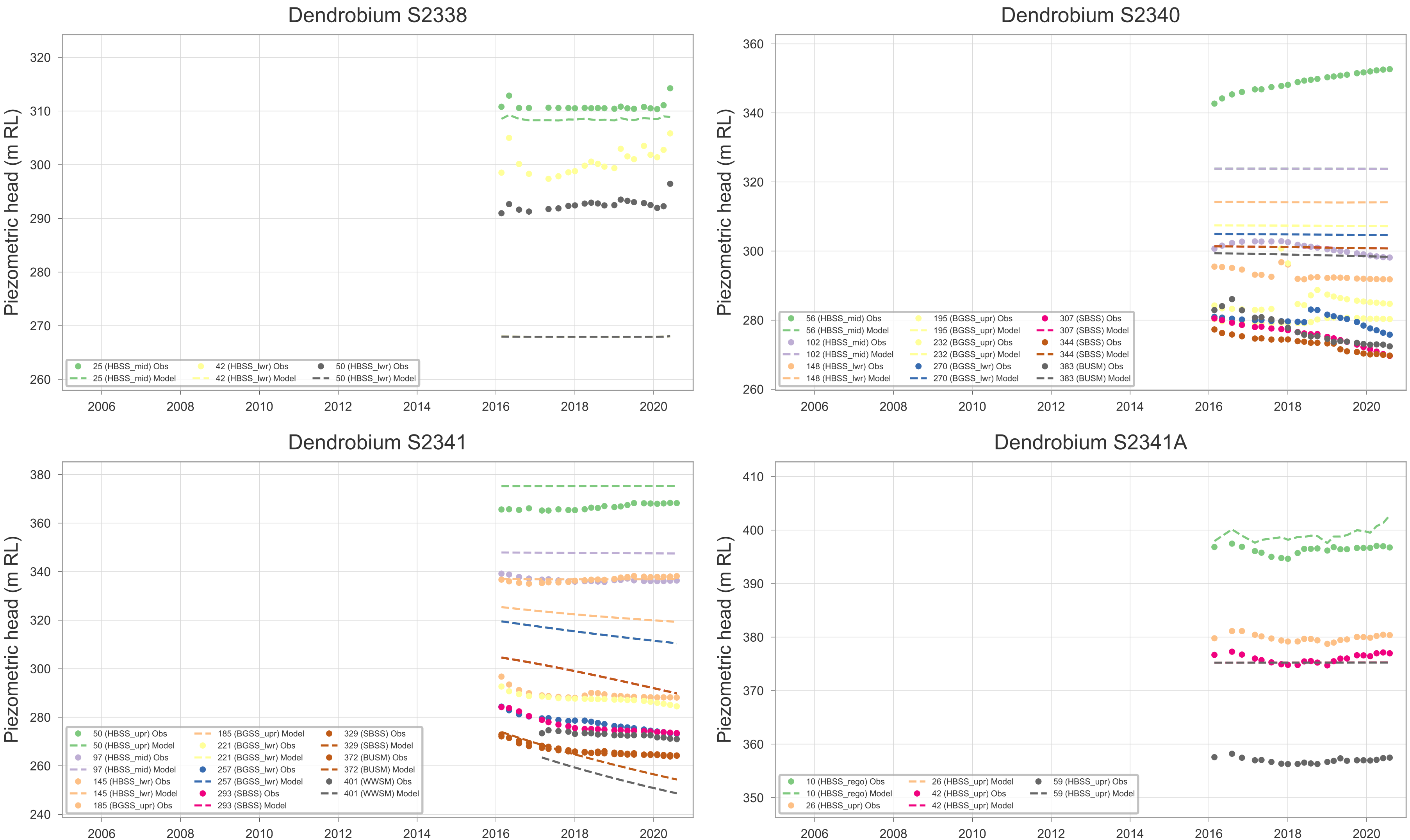


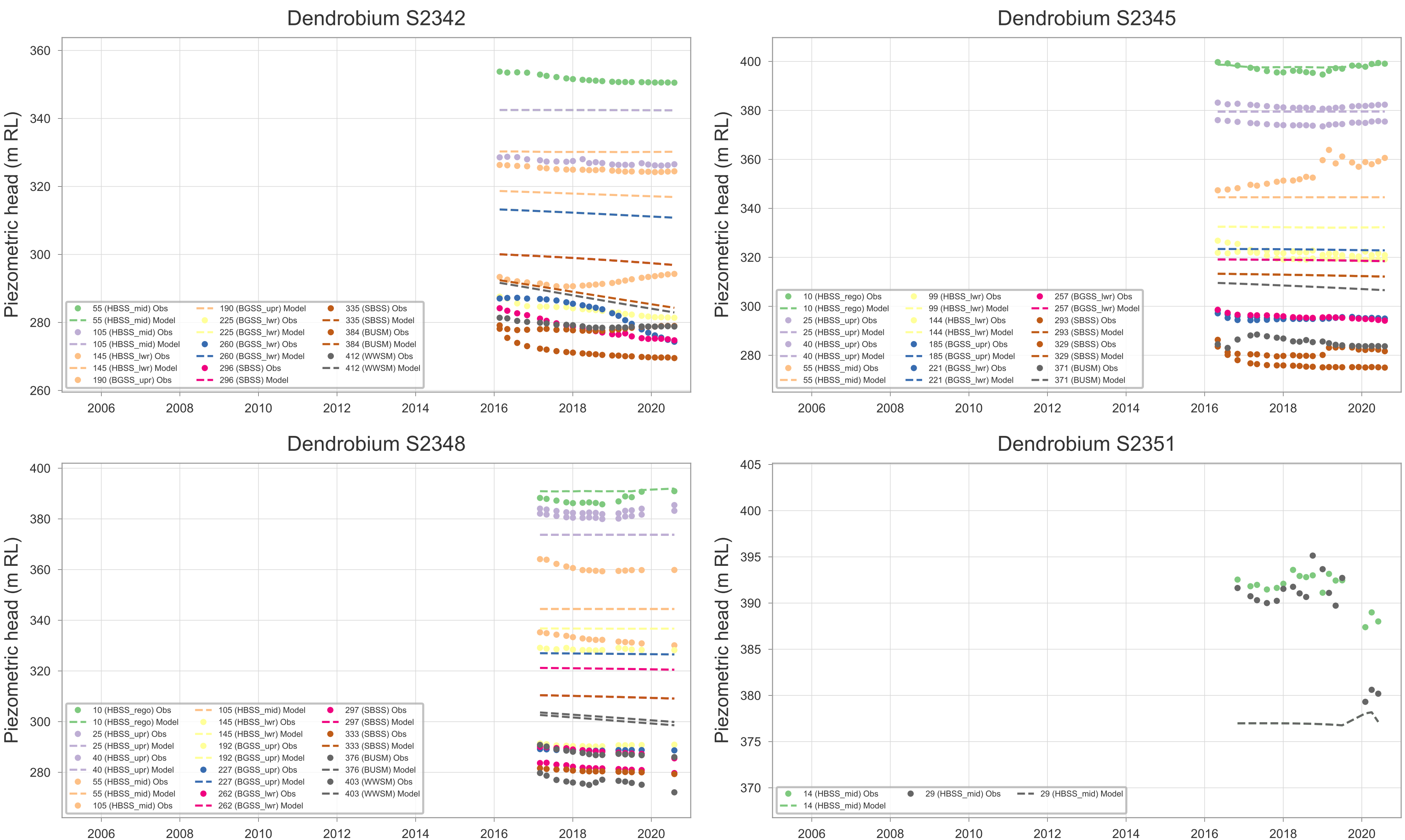
Dendrobium S2306
Piezometric head (m RL)
400
380
360
340
320
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
30 (HBSS_upr) Obs
30 (HBSS_upr) Model
50 (HBSS_mid) Obs
50 (HBSS_mid) Model
70 (HBSS_mid) Obs
70 (HBSS_mid) Model
Dendrobium S2307
Piezometric head (m RL)
400
390
380
370
360
350
340
330
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
22 (HBSS_mid) Obs
22 (HBSS_mid) Model
35 (HBSS_mid) Obs
35 (HBSS_mid) Model
50 (HBSS_mid) Obs
50 (HBSS_mid) Model
Dendrobium S2309
Piezometric head (m RL)
400
375
350
325
300
275
250
225
2006
2008
2010
2012
2014
2016
2018
2020
65 (HBSS_upr) Obs
65 (HBSS_upr) Model
112 (HBSS_mid) Obs
112 (HBSS_mid) Model
159 (HBSS_lwr) Obs
159 (HBSS_lwr) Model
198 (BGSS_upr) Obs
198 (BGSS_upr) Model
256 (BGSS_lwr) Obs
256 (BGSS_lwr) Model
315 (BGSS_lwr) Obs
315 (BGSS_lwr) Model
350 (SBSS) Obs
350 (SBSS) Model
360 (SBSS) Obs
360 (SBSS) Model
387 (BUCO) Obs
387 (BUCO) Model
413 (WWCO) Obs
413 (WWCO) Model
Dendrobium S2312
Piezometric head (m RL)
380
360
340
320
300
280
2006
2008
2010
2012
2014
2016
2018
2020
55 (HBSS) Obs
55 (HBSS) Model
100 (HBSS_mid) Obs
100 (HBSS_mid) Model
146 (HBSS_lwr) Obs
146 (HBSS_lwr) Model
192 (BGSS_upr) Obs
192 (BGSS_upr) Model
232 (BGSS) Obs
232 (BGSS) Model
271 (BGSS) Obs
271 (BGSS) Model
302 (SBSS) Obs
302 (SBSS) Model
318 (SBSS) Obs
318 (SBSS) Model
372 (BUSM) Obs
372 (BUSM) Model
395 (WWSM) Obs
395 (WWSM) Model



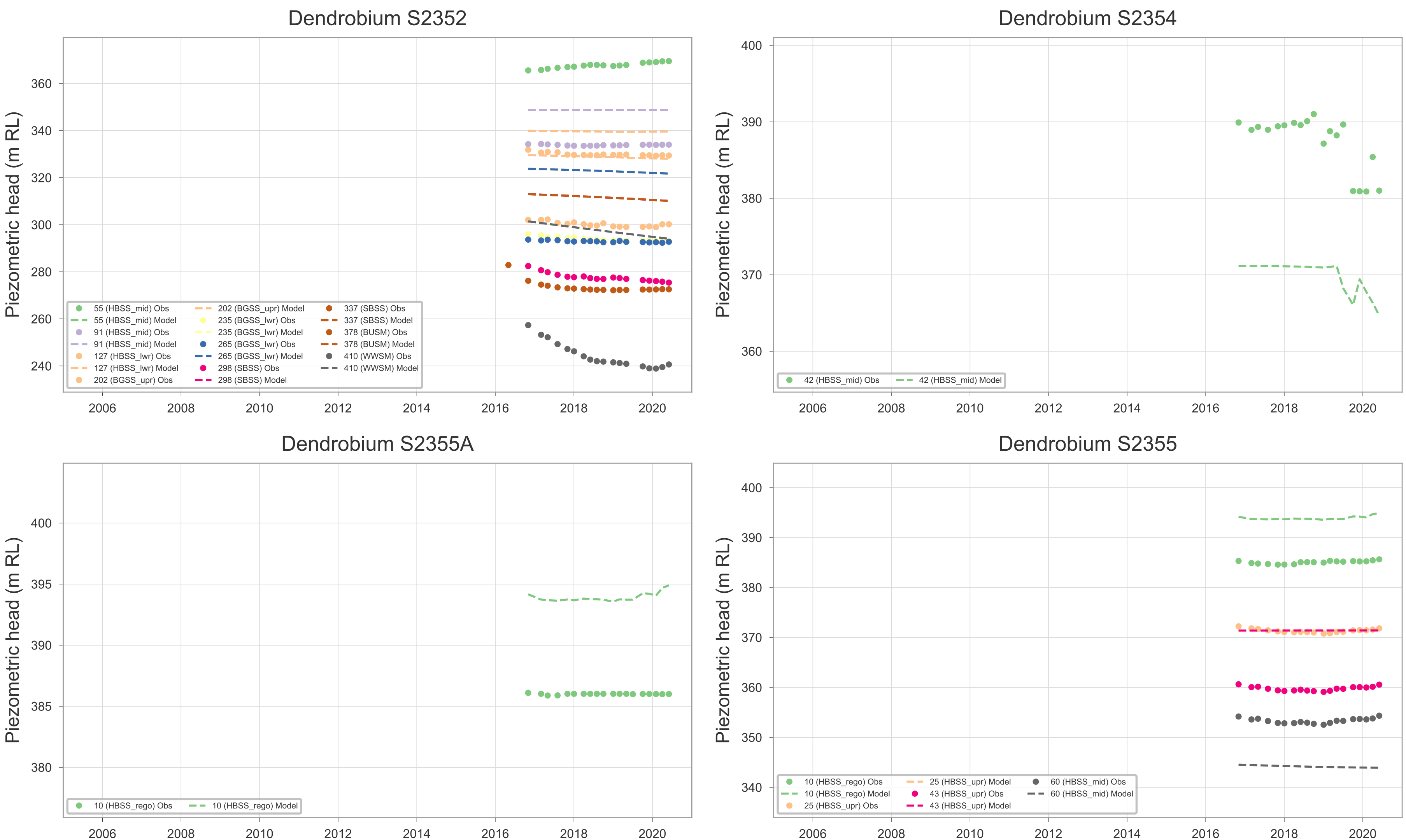
Dendrobium S2313
Piezometric head (m RL)
260
280
300
320
340
360
380
2006
2008
2010
2012
2014
2016
2018
2020
49 (HBSS) Obs
49 (HBSS) Model
131 (HBSS_lwr) Obs
131 (HBSS_lwr) Model
182 (BGSS) Obs
182 (BGSS) Model
Dendrobium S2314
Piezometric head (m RL)
260
280
300
320
340
29 (HBSS_mid) Obs
29 (HBSS_mid) Model
75 (HBSS_lwr) Obs
75 (HBSS_lwr) Model
128 (BGSS) Obs
128 (BGSS) Model
Dendrobium S2321
Piezometric head (m RL)
240
260
280
300
320
368 (BUSM) Obs
368 (BUSM) Model
392 (WWSM) Obs
392 (WWSM) Model
Dendrobium S2324
Piezometric head (m RL)
200
225
250
275
300
325
350
375
400
50 (HBSS_upr) Obs
50 (HBSS_upr) Model
92 (HBSS_mid) Obs
92 (HBSS_mid) Model
134 (HBSS_lwr) Obs
134 (HBSS_lwr) Model
172 (BGSS_upr) Obs
172 (BGSS_upr) Model
231 (BGSS_lwr) Obs
231 (BGSS_lwr) Model
290 (BGSS_lwr) Obs
290 (BGSS_lwr) Model
310 (SBSS) Obs
310 (SBSS) Model
316 (SBSS) Obs
316 (SBSS) Model
344 (BUSM) Obs
344 (BUSM) Model
376 (WWSM) Obs
376 (WWSM) Model

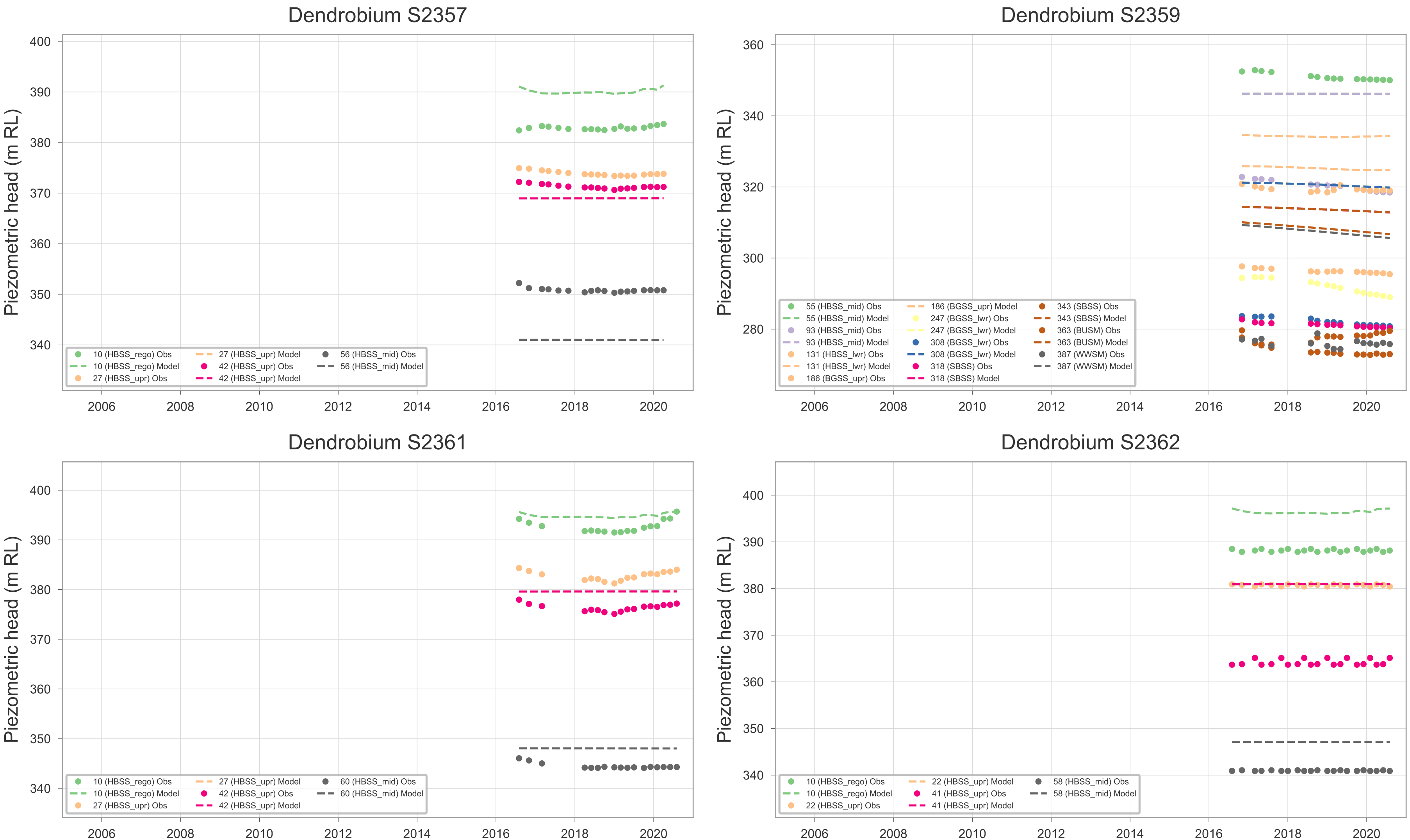

Dendrobium S2325
Piezometric head (m RL)
400
380
360
340
320
300
280
2006
2008
2010
2012
2014
2016
2018
2020
50 (HBSS_upr) Obs
50 (HBSS_upr) Model
97 (HBSS_mid) Obs
97 (HBSS_mid) Model
145 (HBSS_lwr) Obs
145 (HBSS_lwr) Model
182 (BGSS_upr) Obs
182 (BGSS_upr) Model
243 (BGSS_lwr) Obs
243 (BGSS_lwr) Model
303 (BGSS_lwr) Obs
303 (BGSS_lwr) Model
321 (SBSS) Obs
321 (SBSS) Model
332 (SBSS) Obs
332 (SBSS) Model
Dendrobium S2333
Piezometric head (m RL)
300
280
260
240
220
2006
2008
2010
2012
2014
2016
2018
2020
49 (HBSS_mid) Obs
49 (HBSS_mid) Model
68 (HBSS_lwr) Obs
68 (HBSS_lwr) Model
86 (HBSS_lwr) Obs
86 (HBSS_lwr) Model
130 (BGSS_upr) Obs
130 (BGSS_upr) Model
191 (BGSS_lwr) Obs
191 (BGSS_lwr) Model
251 (BGSS_lwr) Obs
251 (BGSS_lwr) Model
266 (SBSS) Obs
266 (SBSS) Model
288 (SBSS) Obs
288 (SBSS) Model
339 (BUSM) Obs
339 (BUSM) Model
364 (WWSM) Obs
364 (WWSM) Model
Dendrobium S2336
Piezometric head (m RL)
355
350
345
340
335
330
2006
2008
2010
2012
2014
2016
2018
2020
32 (HBSS_mid) Obs
32 (HBSS_mid) Model
33 (HBSS_mid) Obs
33 (HBSS_mid) Model
Dendrobium S2337
Piezometric head (m RL)
320
310
300
290
280
270
260
2006
2008
2010
2012
2014
2016
2018
2020
25 (HBSS_mid) Obs
25 (HBSS_mid) Model
36 (HBSS_lwr) Obs
36 (HBSS_lwr) Model
47 (HBSS_lwr) Obs
47 (HBSS_lwr) Model

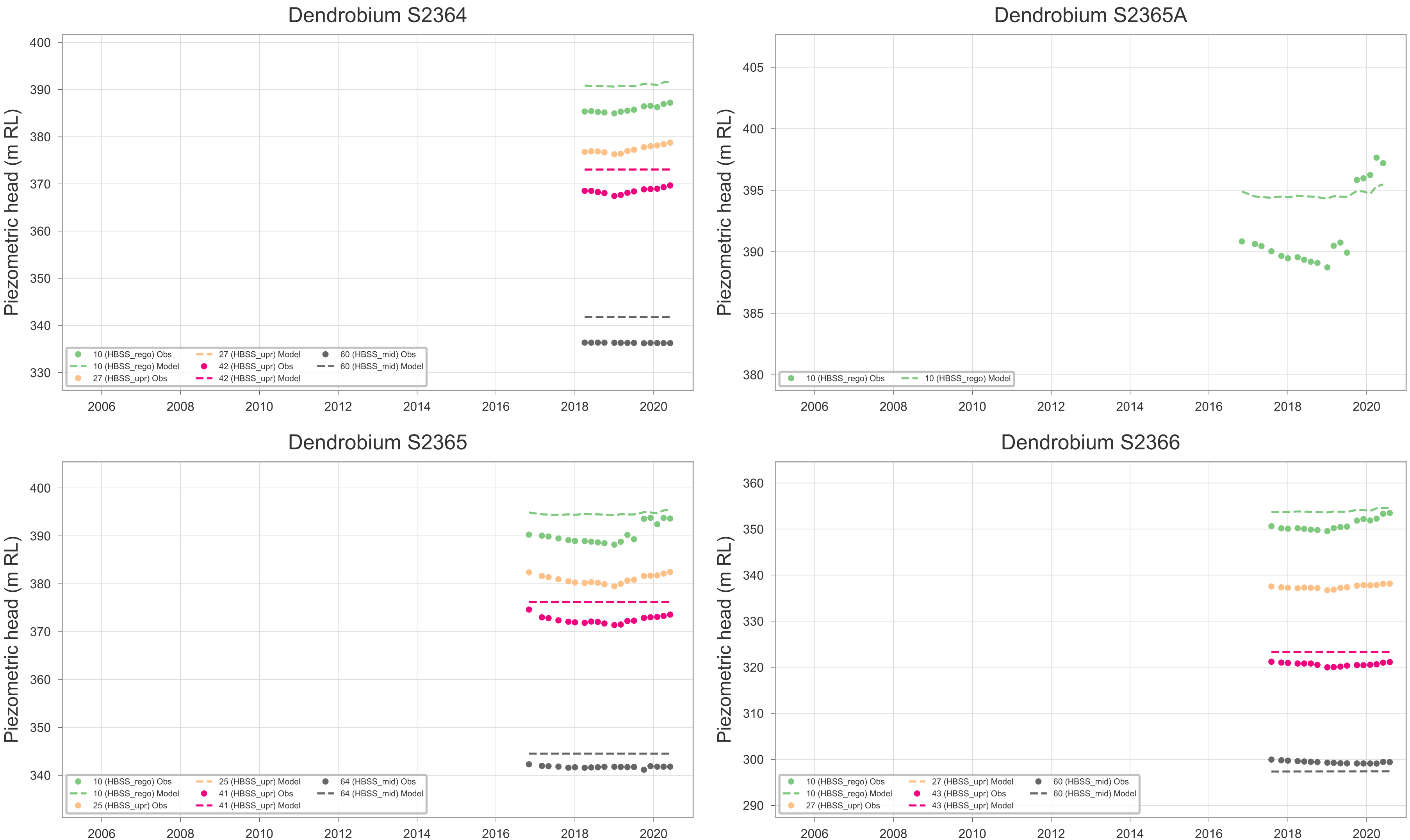

Dendrobium S2338
Piezometric head (m RL)
320
310
300
290
280
270
260
2006
2008
2010
2012
2014
2016
2018
2020
25 (HBSS_mid) Obs
25 (HBSS_mid) Model
42 (HBSS_lwr) Obs
42 (HBSS_lwr) Model
50 (HBSS_lwr) Obs
50 (HBSS_lwr) Model
Dendrobium S2340
Piezometric head (m RL)
360
340
320
300
280
260
2006
2008
2010
2012
2014
2016
2018
2020
56 (HBSS_mid) Obs
56 (HBSS_mid) Model
102 (HBSS_mid) Obs
102 (HBSS_mid) Model
148 (HBSS_lwr) Obs
148 (HBSS_lwr) Model
195 (BGSS_upr) Obs
195 (BGSS_upr) Model
232 (BGSS_upr) Obs
232 (BGSS_upr) Model
270 (BGSS_lwr) Obs
270 (BGSS_lwr) Model
307 (SBSS) Obs
307 (SBSS) Model
344 (SBSS) Obs
344 (SBSS) Model
383 (BUSM) Obs
383 (BUSM) Model
Dendrobium S2341
Piezometric head (m RL)
380
360
340
320
300
280
260
240
2006
2008
2010
2012
2014
2016
2018
2020
50 (HBSS_upr) Obs
50 (HBSS_upr) Model
97 (HBSS_mid) Obs
97 (HBSS_mid) Model
145 (HBSS_lwr) Obs
145 (HBSS_lwr) Model
185 (BGSS_upr) Obs
185 (BGSS_upr) Model
221 (BGSS_lwr) Obs
221 (BGSS_lwr) Model
257 (BGSS_lwr) Obs
257 (BGSS_lwr) Model
293 (SBSS) Obs
293 (SBSS) Model
329 (SBSS) Obs
329 (SBSS) Model
372 (BUSM) Obs
372 (BUSM) Model
401 (WWSM) Obs
401 (WWSM) Model
Dendrobium S2341A
Piezometric head (m RL)
410
400
390
380
370
360
350
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
26 (HBSS_upr) Obs
26 (HBSS_upr) Model
42 (HBSS_upr) Obs
42 (HBSS_upr) Model
59 (HBSS_upr) Obs
59 (HBSS_upr) Model



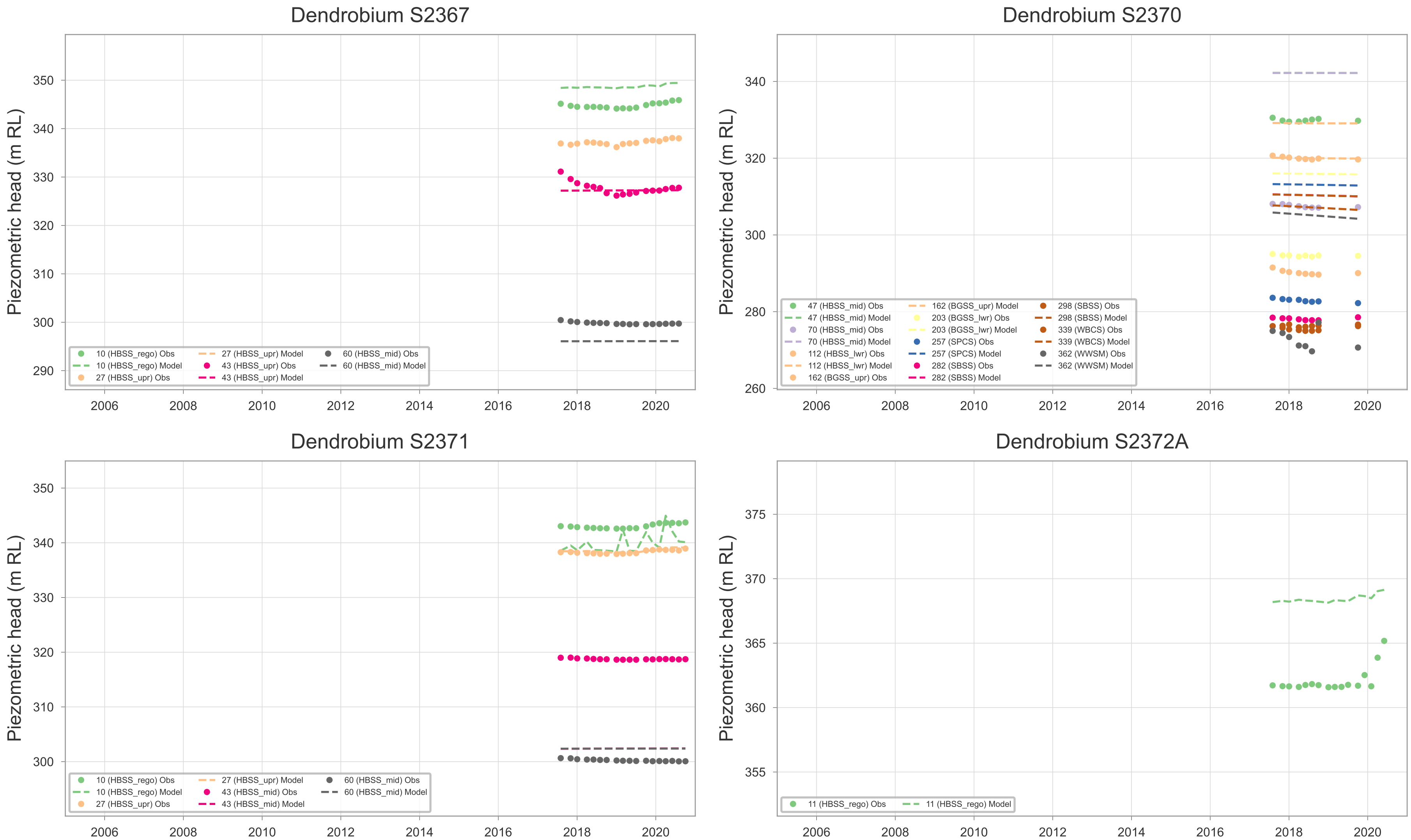
Dendrobium S2342
Piezometric head (m RL)
260
280
300
320
340
360
2006
2008
2010
2012
2014
2016
2018
2020
55 (HBSS_mid) Obs
55 (HBSS_mid) Model
105 (HBSS_mid) Obs
105 (HBSS_mid) Model
145 (HBSS_lwr) Obs
145 (HBSS_lwr) Model
190 (BGSS_upr) Obs
190 (BGSS_upr) Model
225 (BGSS_lwr) Obs
225 (BGSS_lwr) Model
260 (BGSS_lwr) Obs
260 (BGSS_lwr) Model
296 (SBSS) Obs
296 (SBSS) Model
335 (SBSS) Obs
335 (SBSS) Model
384 (BUSM) Obs
384 (BUSM) Model
412 (WWSM) Obs
412 (WWSM) Model
Dendrobium S2345
Piezometric head (m RL)
280
300
320
340
360
380
400
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
25 (HBSS_upr) Obs
25 (HBSS_upr) Model
40 (HBSS_upr) Obs
40 (HBSS_upr) Model
55 (HBSS_mid) Obs
55 (HBSS_mid) Model
99 (HBSS_lwr) Obs
99 (HBSS_lwr) Model
144 (HBSS_lwr) Obs
144 (HBSS_lwr) Model
185 (BGSS_upr) Obs
185 (BGSS_upr) Model
221 (BGSS_lwr) Obs
221 (BGSS_lwr) Model
257 (BGSS_lwr) Obs
257 (BGSS_lwr) Model
293 (SBSS) Obs
293 (SBSS) Model
329 (SBSS) Obs
329 (SBSS) Model
371 (BUSM) Obs
371 (BUSM) Model
Dendrobium S2348
Piezometric head (m RL)
280
300
320
340
360
380
400
2006
2008
2010
2012
2014
2016
2018
2020
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
25 (HBSS_upr) Obs
25 (HBSS_upr) Model
40 (HBSS_upr) Obs
40 (HBSS_upr) Model
55 (HBSS_mid) Obs
55 (HBSS_mid) Model
105 (HBSS_mid) Obs
105 (HBSS_mid) Model
145 (HBSS_lwr) Obs
145 (HBSS_lwr) Model
192 (BGSS_upr) Obs
192 (BGSS_upr) Model
227 (BGSS_upr) Obs
227 (BGSS_upr) Model
262 (BGSS_lwr) Obs
262 (BGSS_lwr) Model
297 (SBSS) Obs
297 (SBSS) Model
333 (SBSS) Obs
333 (SBSS) Model
376 (BUSM) Obs
376 (BUSM) Model
403 (WWSM) Obs
403 (WWSM) Model
Dendrobium S2351
Piezometric head (m RL)
370
375
380
385
390
395
400
405
2006
2008
2010
2012
2014
2016
2018
2020
14 (HBSS_mid) Obs
14 (HBSS_mid) Model
29 (HBSS_mid) Obs
29 (HBSS_mid) Model


Dendrobium S2352
Piezometric head (m RL)
55 (HBSS_mid) Obs
55 (HBSS_mid) Model
91 (HBSS_mid) Obs
91 (HBSS_mid) Model
127 (HBSS_lwr) Obs
127 (HBSS_lwr) Model
202 (BGSS_upr) Obs
202 (BGSS_upr) Model
235 (BGSS_lwr) Obs
235 (BGSS_lwr) Model
265 (BGSS_lwr) Obs
265 (BGSS_lwr) Model
298 (SBSS) Obs
298 (SBSS) Model
337 (SBSS) Obs
337 (SBSS) Model
378 (BUSM) Obs
378 (BUSM) Model
410 (WWSM) Obs
410 (WWSM) Model
Dendrobium S2354
Piezometric head (m RL)
42 (HBSS_mid) Obs
42 (HBSS_mid) Model
Dendrobium S2355A
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
Dendrobium S2355
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
25 (HBSS_upr) Obs
25 (HBSS_upr) Model
43 (HBSS_upr) Obs
43 (HBSS_upr) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model

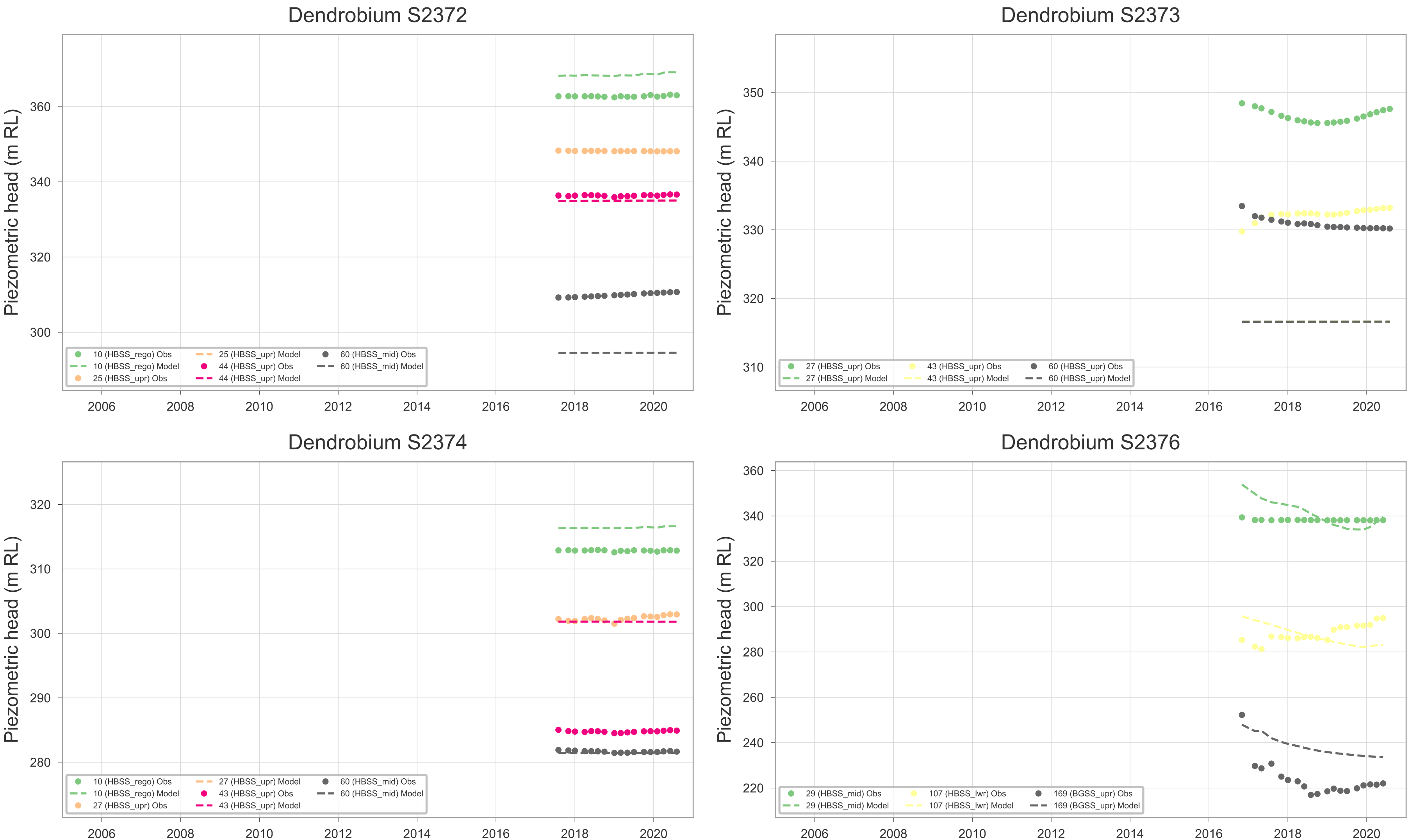

Dendrobium S2357
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
42 (HBSS_upr) Obs
42 (HBSS_upr) Model
56 (HBSS_mid) Obs
56 (HBSS_mid) Model
Dendrobium S2359
Piezometric head (m RL)
55 (HBSS_mid) Obs
55 (HBSS_mid) Model
93 (HBSS_mid) Obs
93 (HBSS_mid) Model
131 (HBSS_lwr) Obs
131 (HBSS_lwr) Model
186 (BGSS_upr) Obs
186 (BGSS_upr) Model
247 (BGSS_lwr) Obs
247 (BGSS_lwr) Model
308 (BGSS_lwr) Obs
308 (BGSS_lwr) Model
318 (SBSS) Obs
318 (SBSS) Model
343 (SBSS) Obs
343 (SBSS) Model
363 (BUSM) Obs
363 (BUSM) Model
387 (WWSM) Obs
387 (WWSM) Model
Dendrobium S2361
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
42 (HBSS_upr) Obs
42 (HBSS_upr) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model
Dendrobium S2362
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
22 (HBSS_upr) Obs
22 (HBSS_upr) Model
41 (HBSS_upr) Obs
41 (HBSS_upr) Model
58 (HBSS_mid) Obs
58 (HBSS_mid) Model



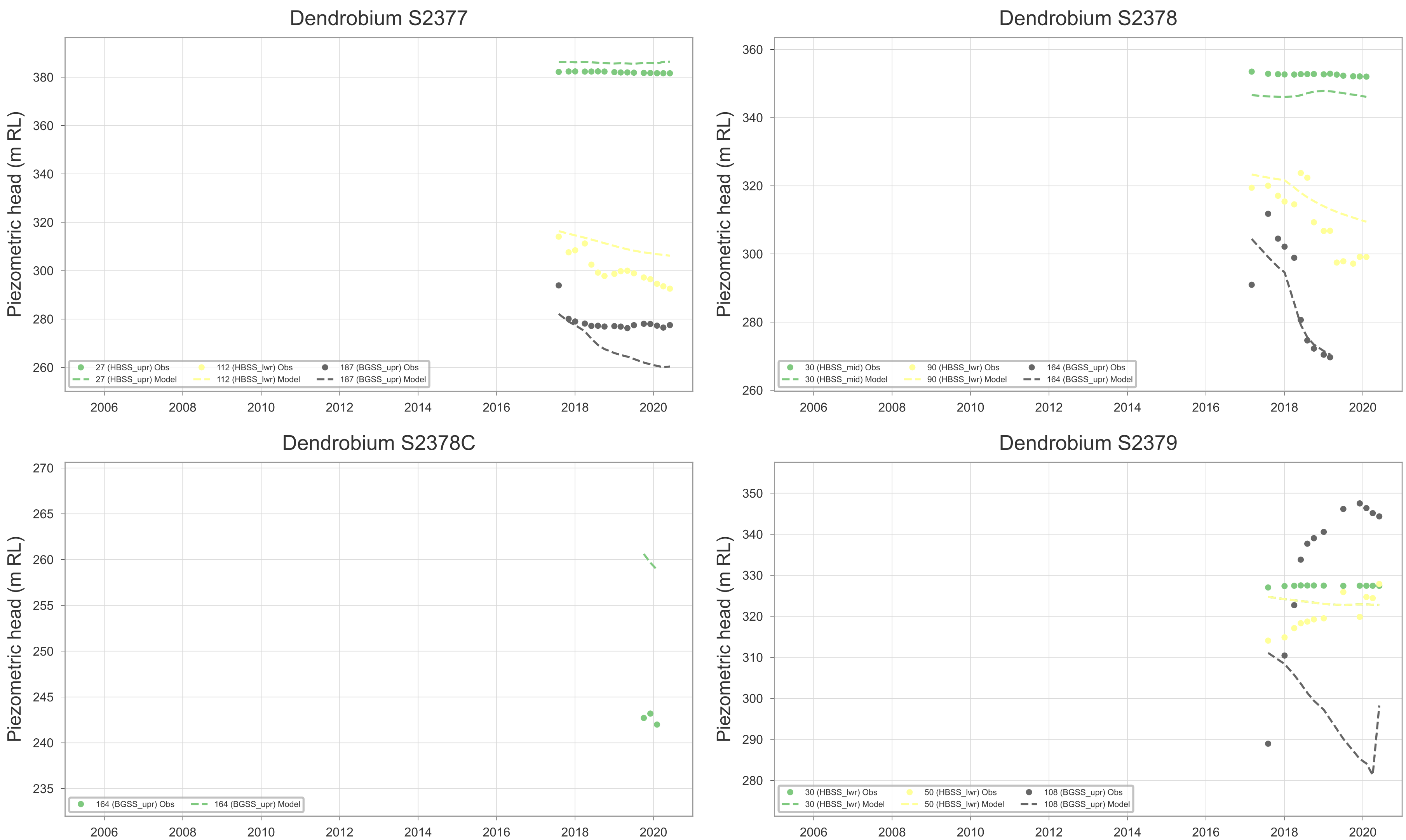
Dendrobium S2364
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
42 (HBSS_upr) Obs
42 (HBSS_upr) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model
Dendrobium S2365A
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
Dendrobium S2365
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
25 (HBSS_upr) Obs
25 (HBSS_upr) Model
41 (HBSS_upr) Obs
41 (HBSS_upr) Model
64 (HBSS_mid) Obs
64 (HBSS_mid) Model
Dendrobium S2366
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
43 (HBSS_upr) Obs
43 (HBSS_upr) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model



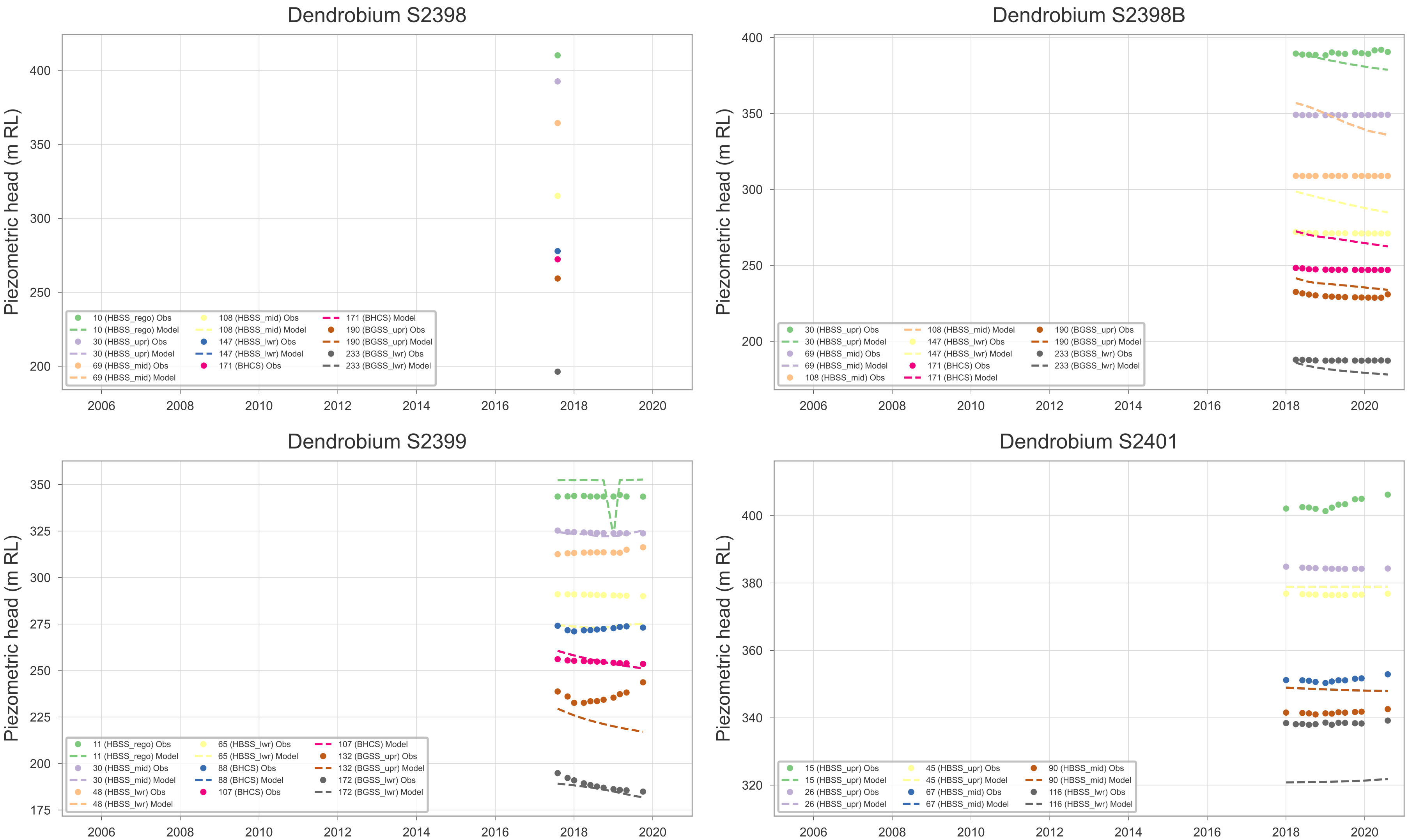
Dendrobium S2367
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
43 (HBSS_upr) Obs
43 (HBSS_upr) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model
Dendrobium S2370
Piezometric head (m RL)
47 (HBSS_mid) Obs
47 (HBSS_mid) Model
70 (HBSS_mid) Obs
70 (HBSS_mid) Model
112 (HBSS_lwr) Obs
112 (HBSS_lwr) Model
162 (BGSS_upr) Obs
162 (BGSS_upr) Model
203 (BGSS_lwr) Obs
203 (BGSS_lwr) Model
257 (SPCS) Obs
257 (SPCS) Model
282 (SBSS) Obs
282 (SBSS) Model
298 (SBSS) Obs
298 (SBSS) Model
339 (WBCS) Obs
339 (WBCS) Model
362 (WWSM) Obs
362 (WWSM) Model
Dendrobium S2371
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
43 (HBSS_mid) Obs
43 (HBSS_mid) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model
Dendrobium S2372A
Piezometric head (m RL)
11 (HBSS_rego) Obs
11 (HBSS_rego) Model



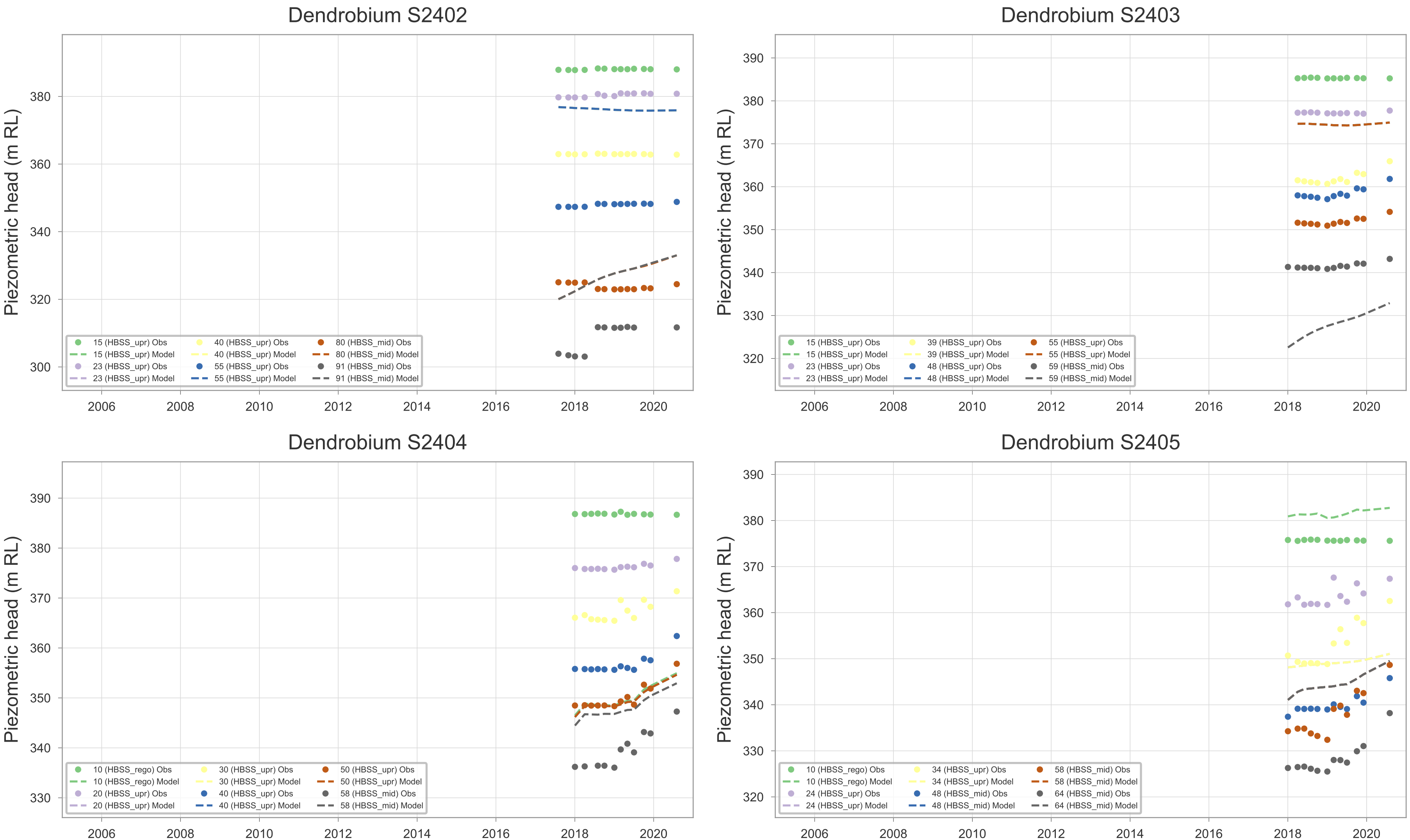
Dendrobium S2372
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
25 (HBSS_upr) Obs
25 (HBSS_upr) Model
44 (HBSS_upr) Obs
44 (HBSS_upr) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model
Dendrobium S2373
Piezometric head (m RL)
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
43 (HBSS_upr) Obs
43 (HBSS_upr) Model
60 (HBSS_upr) Obs
60 (HBSS_upr) Model
Dendrobium S2374
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
43 (HBSS_upr) Obs
43 (HBSS_upr) Model
60 (HBSS_mid) Obs
60 (HBSS_mid) Model
Dendrobium S2376
Piezometric head (m RL)
29 (HBSS_mid) Obs
29 (HBSS_mid) Model
107 (HBSS_lwr) Obs
107 (HBSS_lwr) Model
169 (BGSS_upr) Obs
169 (BGSS_upr) Model

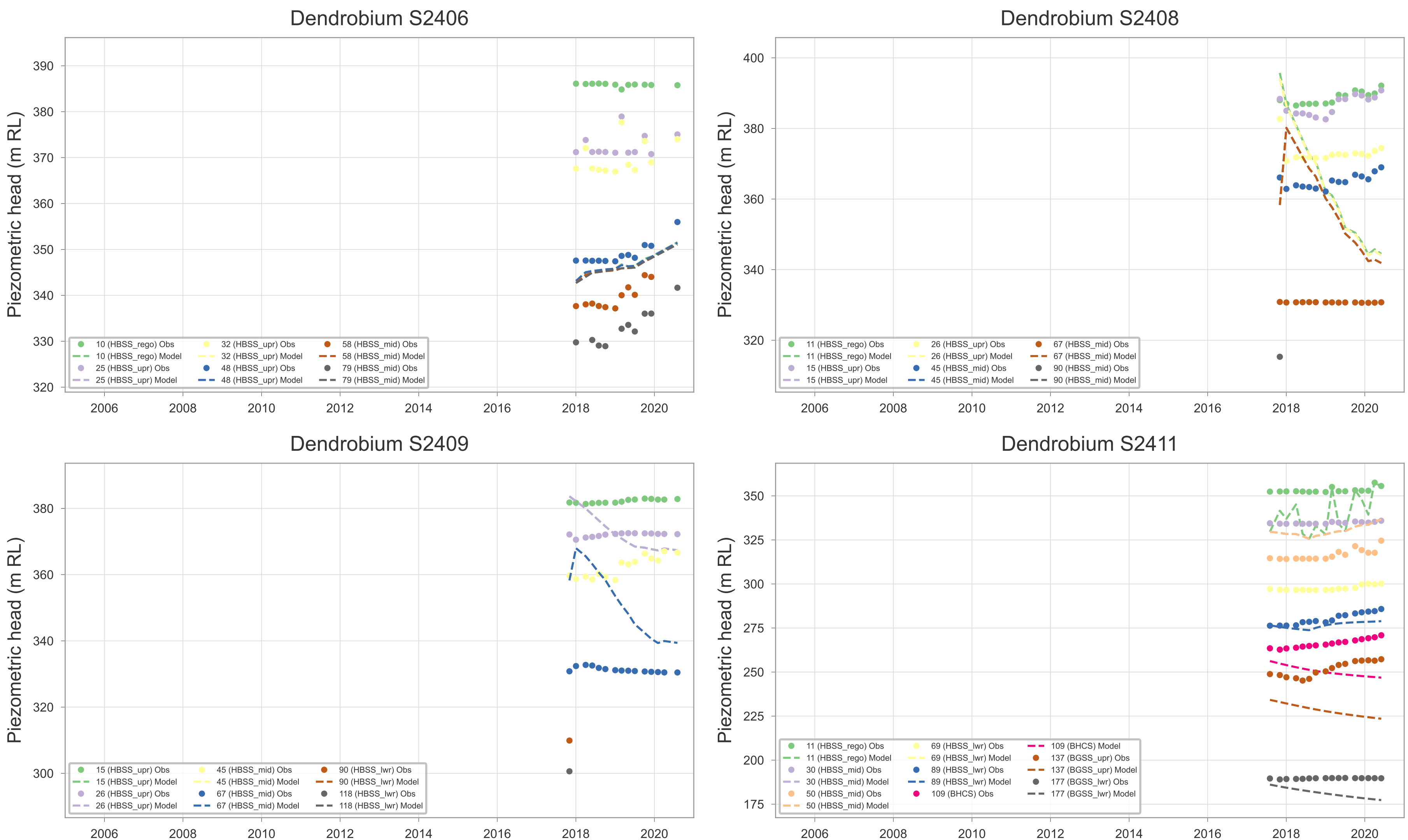


Dendrobium S2377
Dendrobium S2378
Dendrobium S2378C
Dendrobium S2379
Piezometric head (m RL)
27 (HBSS_upr) Obs
27 (HBSS_upr) Model
112 (HBSS_lwr) Obs
112 (HBSS_lwr) Model
187 (BGSS_upr) Obs
187 (BGSS_upr) Model
30 (HBSS_mid) Obs
30 (HBSS_mid) Model
90 (HBSS_lwr) Obs
90 (HBSS_lwr) Model
164 (BGSS_upr) Obs
164 (BGSS_upr) Model
30 (HBSS_lwr) Obs
30 (HBSS_lwr) Model
50 (HBSS_lwr) Obs
50 (HBSS_lwr) Model
108 (BGSS_upr) Obs
108 (BGSS_upr) Model
2006
2008
2010
2012
2014
2016
2018
2020



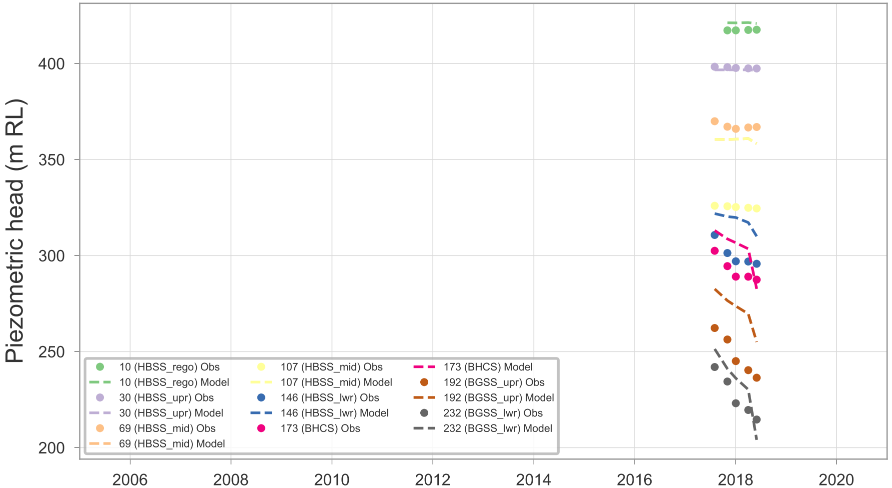
Dendrobium S2398
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
30 (HBSS_upr) Obs
30 (HBSS_upr) Model
69 (HBSS_mid) Obs
69 (HBSS_mid) Model
108 (HBSS_mid) Obs
108 (HBSS_mid) Model
147 (HBSS_lwr) Obs
147 (HBSS_lwr) Model
171 (BHCS) Obs
171 (BHCS) Model
190 (BGSS_upr) Obs
190 (BGSS_upr) Model
233 (BGSS_lwr) Obs
233 (BGSS_lwr) Model
Dendrobium S2398B
Piezometric head (m RL)
30 (HBSS_upr) Obs
30 (HBSS_upr) Model
69 (HBSS_mid) Obs
69 (HBSS_mid) Model
108 (HBSS_mid) Obs
108 (HBSS_mid) Model
147 (HBSS_lwr) Obs
147 (HBSS_lwr) Model
171 (BHCS) Obs
171 (BHCS) Model
190 (BGSS_upr) Obs
190 (BGSS_upr) Model
233 (BGSS_lwr) Obs
233 (BGSS_lwr) Model
Dendrobium S2399
Piezometric head (m RL)
11 (HBSS_rego) Obs
11 (HBSS_rego) Model
30 (HBSS_mid) Obs
30 (HBSS_mid) Model
48 (HBSS_lwr) Obs
48 (HBSS_lwr) Model
65 (HBSS_lwr) Obs
65 (HBSS_lwr) Model
88 (BHCS) Obs
88 (BHCS) Model
107 (BHCS) Obs
107 (BHCS) Model
132 (BGSS_upr) Obs
132 (BGSS_upr) Model
172 (BGSS_lwr) Obs
172 (BGSS_lwr) Model
Dendrobium S2401
Piezometric head (m RL)
15 (HBSS_upr) Obs
15 (HBSS_upr) Model
26 (HBSS_upr) Obs
26 (HBSS_upr) Model
45 (HBSS_upr) Obs
45 (HBSS_upr) Model
67 (HBSS_mid) Obs
67 (HBSS_mid) Model
90 (HBSS_mid) Obs
90 (HBSS_mid) Model
116 (HBSS_lwr) Obs
116 (HBSS_lwr) Model


Dendrobium S2402
Piezometric head (m RL)
15 (HBSS_upr) Obs
15 (HBSS_upr) Model
23 (HBSS_upr) Obs
23 (HBSS_upr) Model
40 (HBSS_upr) Obs
40 (HBSS_upr) Model
55 (HBSS_upr) Obs
55 (HBSS_upr) Model
80 (HBSS_mid) Obs
80 (HBSS_mid) Model
91 (HBSS_mid) Obs
91 (HBSS_mid) Model
Dendrobium S2403
Piezometric head (m RL)
15 (HBSS_upr) Obs
15 (HBSS_upr) Model
23 (HBSS_upr) Obs
23 (HBSS_upr) Model
39 (HBSS_upr) Obs
39 (HBSS_upr) Model
48 (HBSS_upr) Obs
48 (HBSS_upr) Model
55 (HBSS_upr) Obs
55 (HBSS_upr) Model
59 (HBSS_mid) Obs
59 (HBSS_mid) Model
Dendrobium S2404
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
20 (HBSS_upr) Obs
20 (HBSS_upr) Model
30 (HBSS_upr) Obs
30 (HBSS_upr) Model
40 (HBSS_upr) Obs
40 (HBSS_upr) Model
50 (HBSS_upr) Obs
50 (HBSS_upr) Model
58 (HBSS_mid) Obs
58 (HBSS_mid) Model
Dendrobium S2405
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
24 (HBSS_upr) Obs
24 (HBSS_upr) Model
34 (HBSS_upr) Obs
34 (HBSS_upr) Model
48 (HBSS_mid) Obs
48 (HBSS_mid) Model
58 (HBSS_mid) Obs
58 (HBSS_mid) Model
64 (HBSS_mid) Obs
64 (HBSS_mid) Model

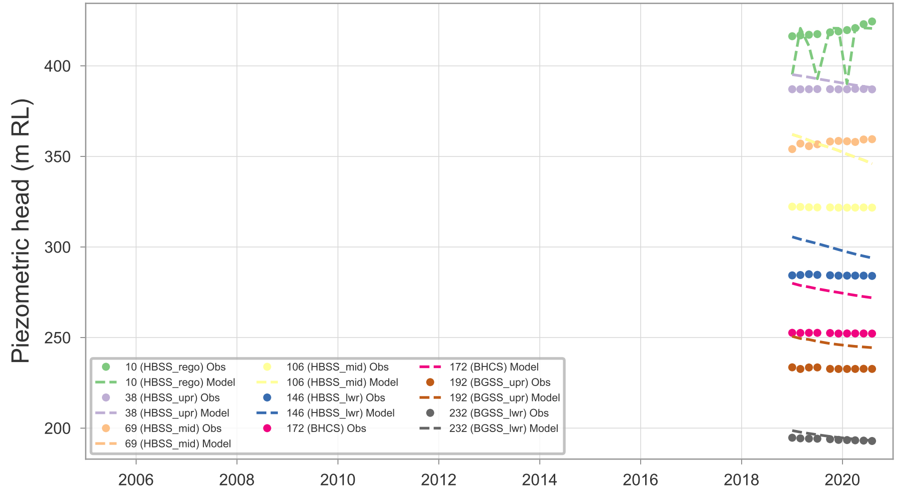


Dendrobium S2406
Dendrobium S2408
Dendrobium S2409
Dendrobium S2411
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
25 (HBSS_upr) Obs
25 (HBSS_upr) Model
32 (HBSS_upr) Obs
32 (HBSS_upr) Model
48 (HBSS_upr) Obs
48 (HBSS_upr) Model
58 (HBSS_mid) Obs
58 (HBSS_mid) Model
79 (HBSS_mid) Obs
79 (HBSS_mid) Model
11 (HBSS_rego) Obs
11 (HBSS_rego) Model
15 (HBSS_upr) Obs
15 (HBSS_upr) Model
26 (HBSS_upr) Obs
26 (HBSS_upr) Model
45 (HBSS_mid) Obs
45 (HBSS_mid) Model
67 (HBSS_mid) Obs
67 (HBSS_mid) Model
90 (HBSS_mid) Obs
90 (HBSS_mid) Model
15 (HBSS_upr) Obs
15 (HBSS_upr) Model
26 (HBSS_upr) Obs
26 (HBSS_upr) Model
45 (HBSS_mid) Obs
45 (HBSS_mid) Model
67 (HBSS_mid) Obs
67 (HBSS_mid) Model
90 (HBSS_lwr) Obs
90 (HBSS_lwr) Model
118 (HBSS_lwr) Obs
118 (HBSS_lwr) Model
11 (HBSS_rego) Obs
11 (HBSS_rego) Model
30 (HBSS_mid) Obs
30 (HBSS_mid) Model
50 (HBSS_mid) Obs
50 (HBSS_mid) Model
69 (HBSS_lwr) Obs
69 (HBSS_lwr) Model
89 (HBSS_lwr) Obs
89 (HBSS_lwr) Model
109 (BHCS) Obs
109 (BHCS) Model
137 (BGSS_upr) Obs
137 (BGSS_upr) Model
177 (BGSS_lwr) Obs
177 (BGSS_lwr) Model
2006
2008
2010
2012
2014
2016
2018
2020

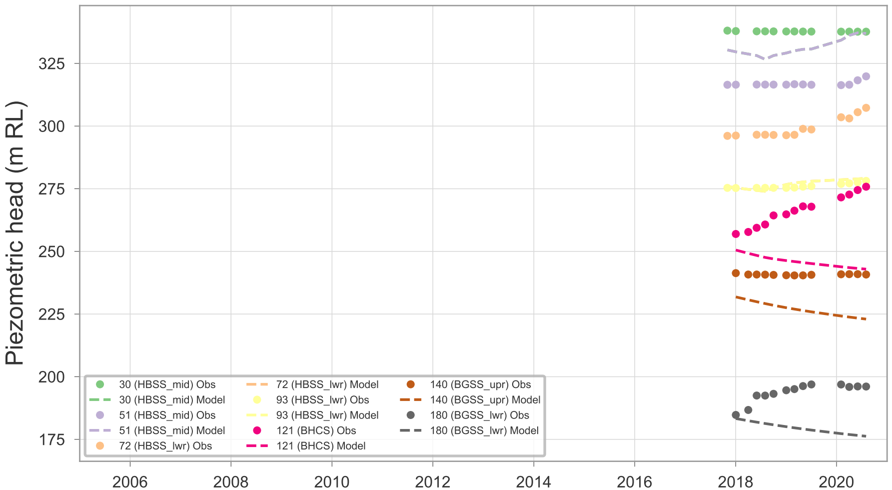
Dendrobium S2412



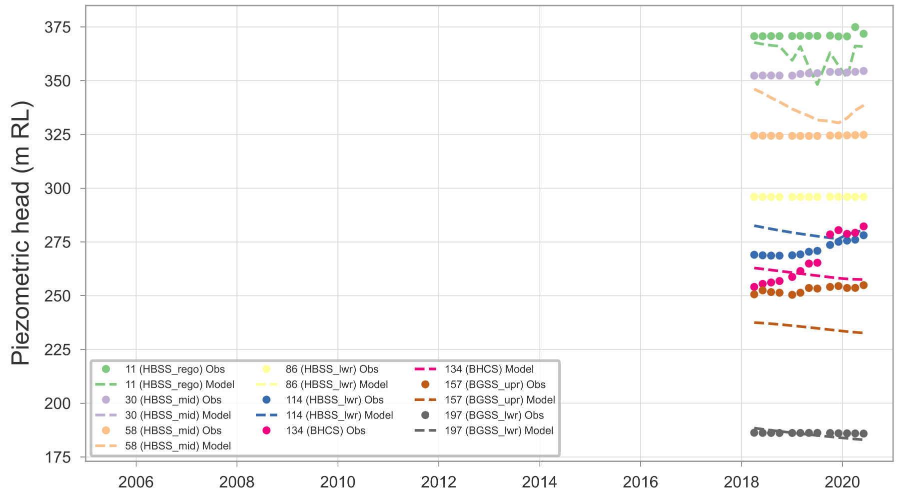
Dendrobium S2412B

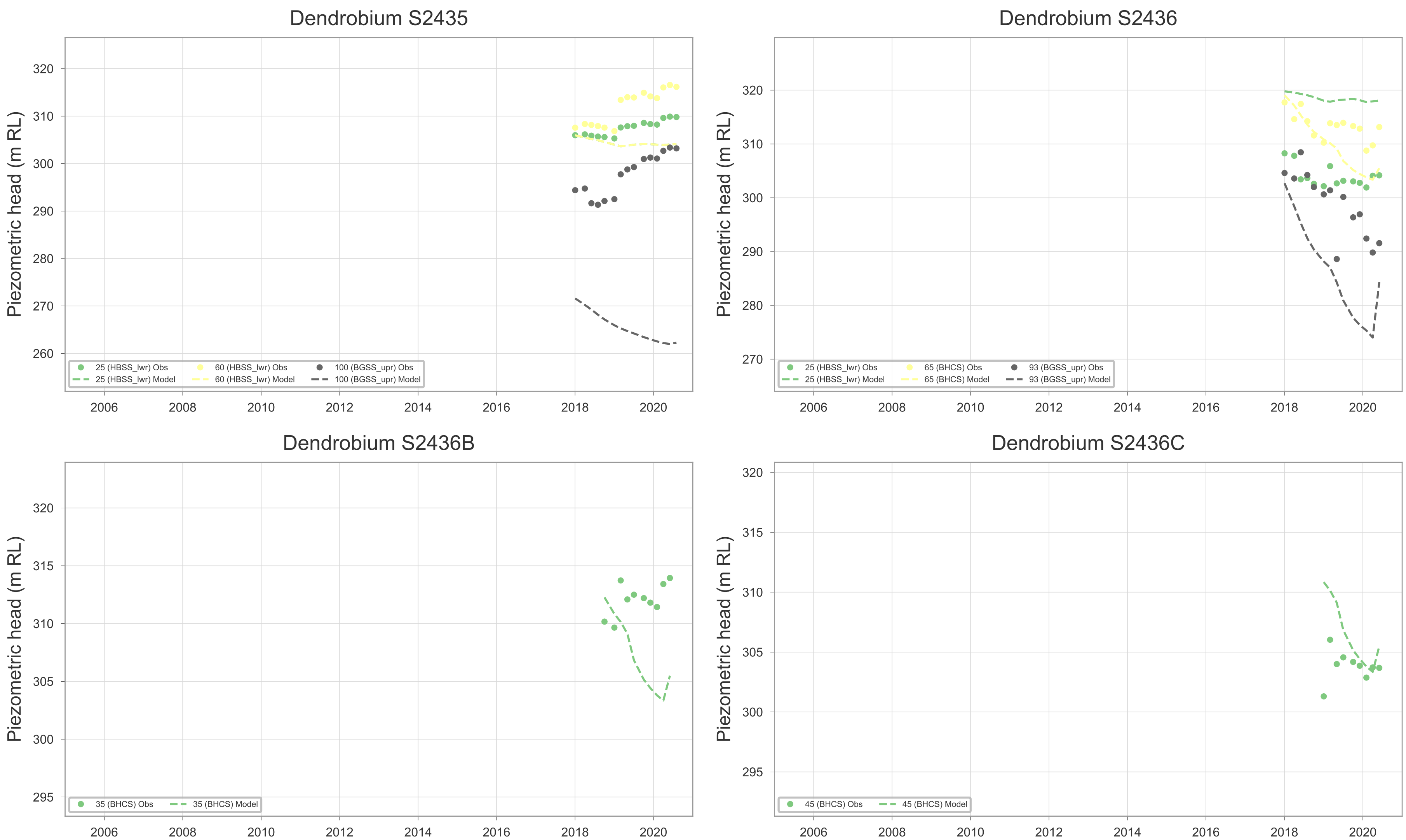


Dendrobium S2420

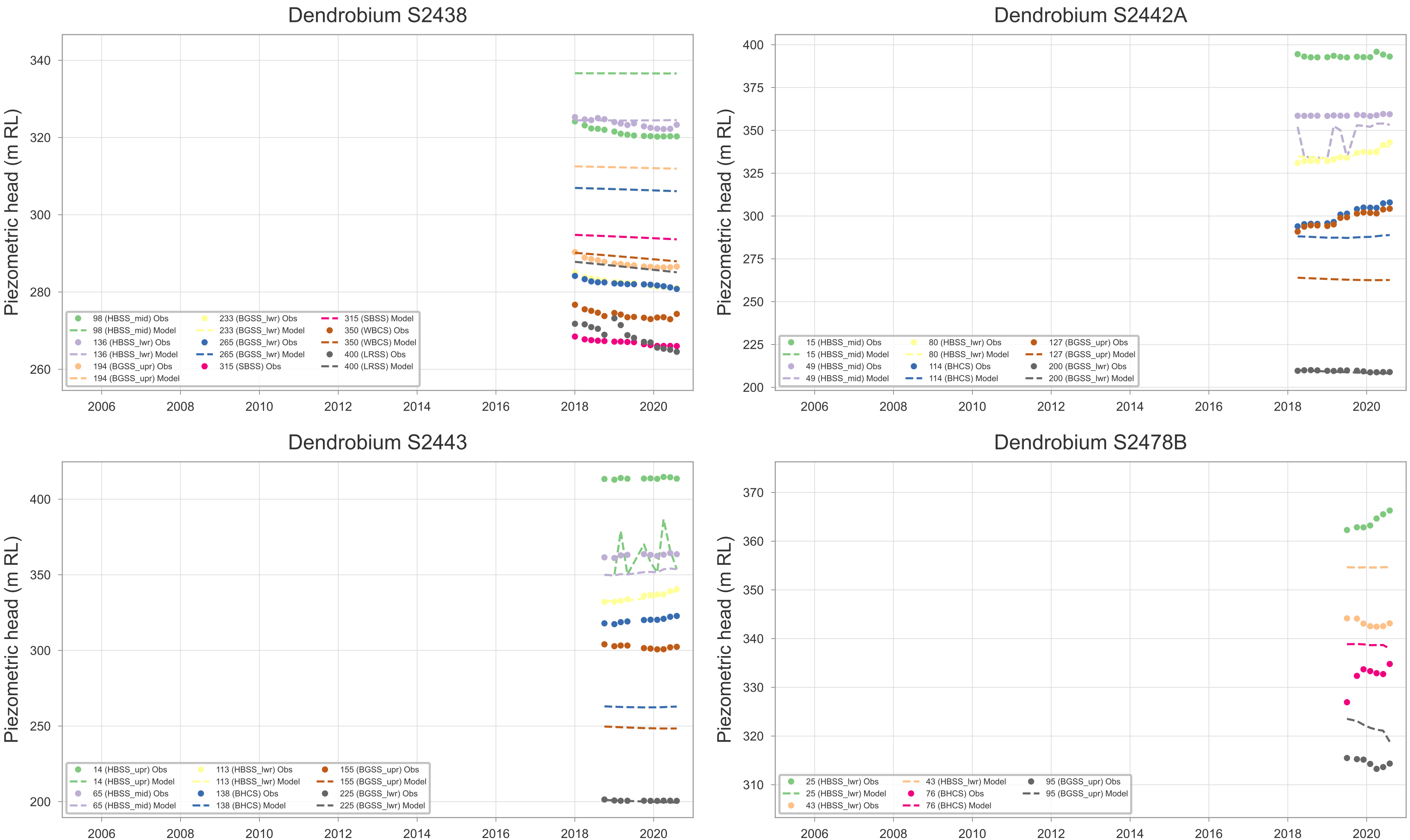


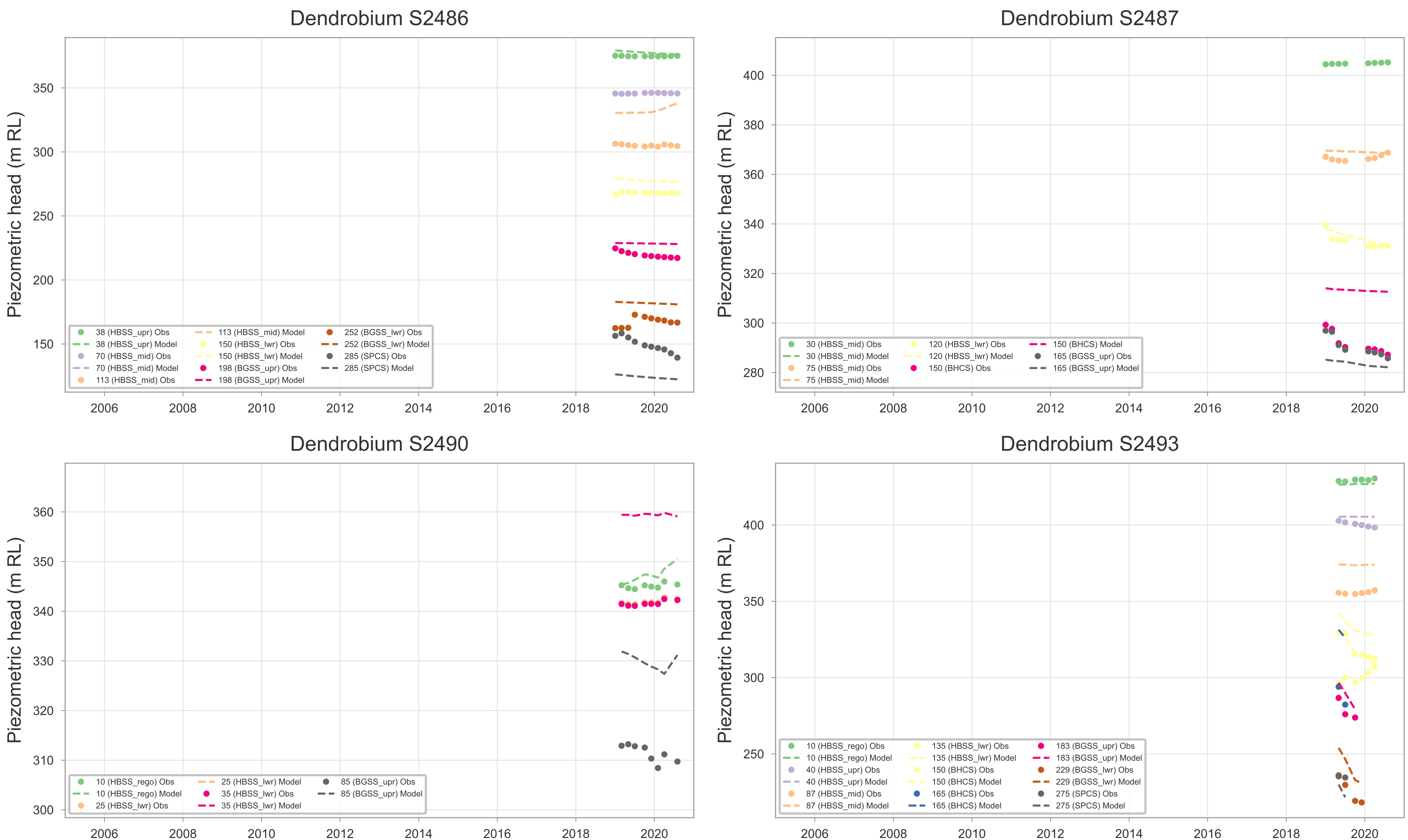
Dendrobium S2421



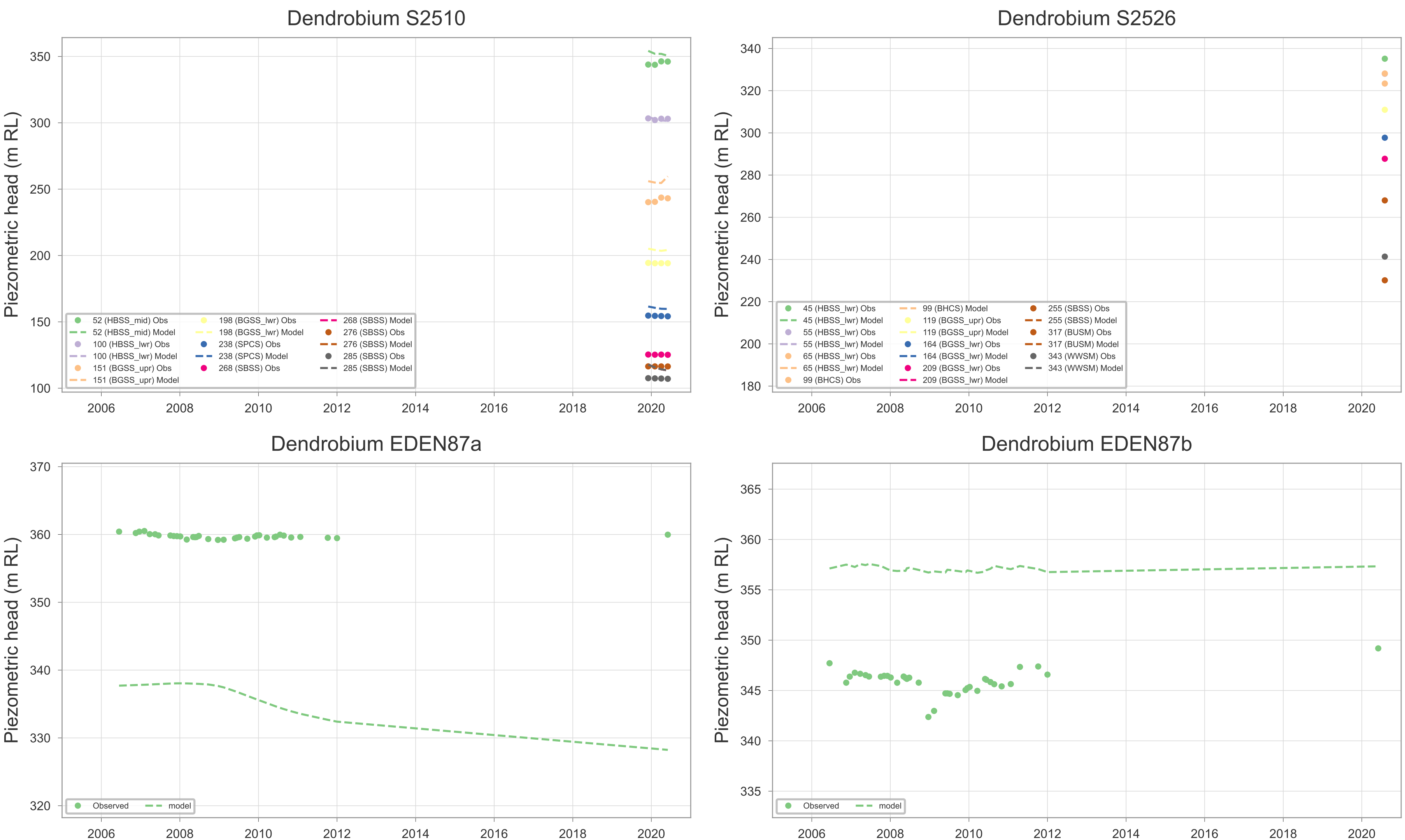


Dendrobium S2435
Dendrobium S2436
Dendrobium S2436B
Dendrobium S2436C
Piezometric head (m RL)
25 (HBSS_lwr) Obs
25 (HBSS_lwr) Model
60 (HBSS_lwr) Obs
60 (HBSS_lwr) Model
100 (BGSS_upr) Obs
100 (BGSS_upr) Model
65 (BHCS) Obs
65 (BHCS) Model
93 (BGSS_upr) Obs
93 (BGSS_upr) Model
35 (BHCS) Obs
35 (BHCS) Model
45 (BHCS) Obs
45 (BHCS) Model
2006
2008
2010
2012
2014
2016
2018
2020

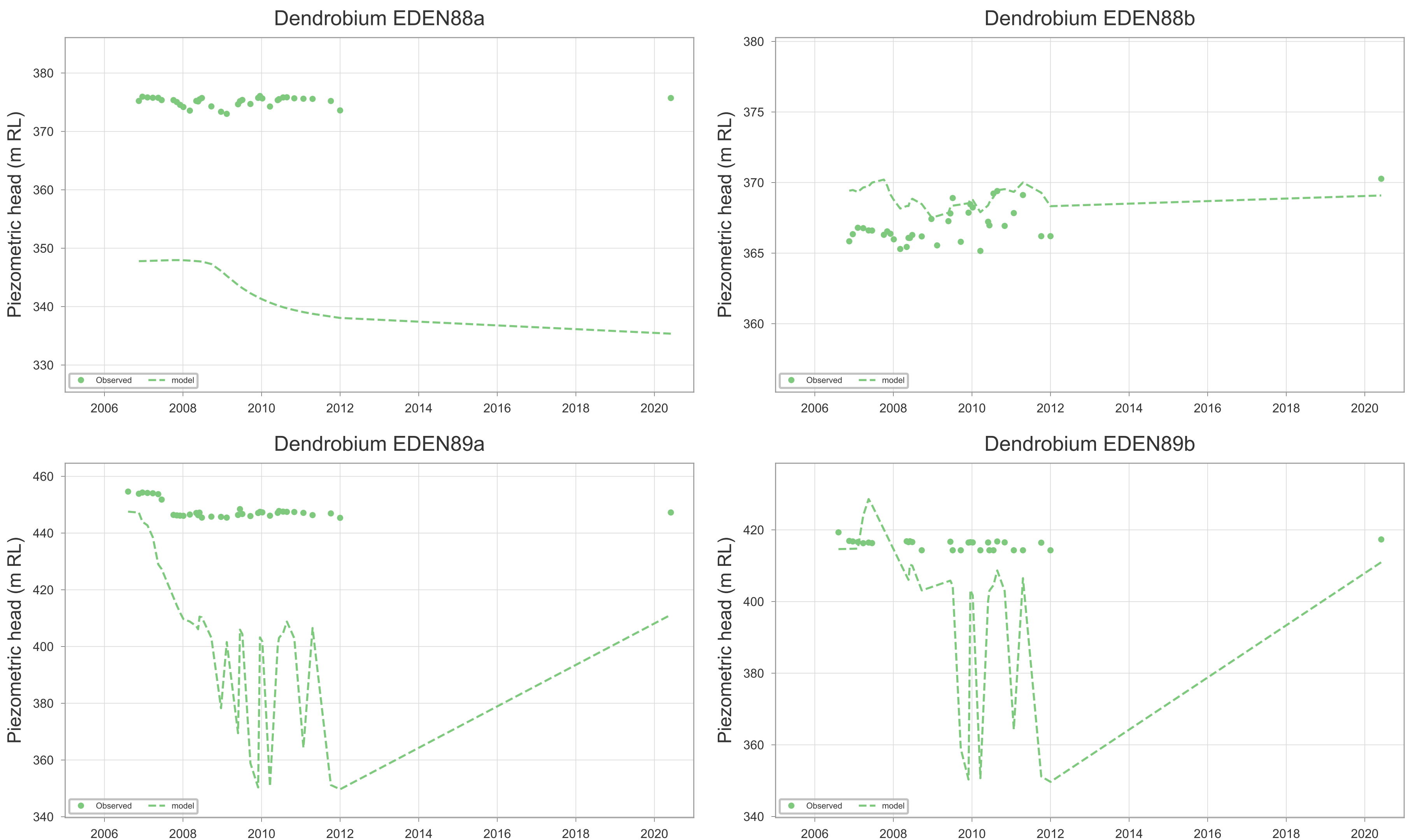

Dendrobium S2438
Piezometric head (m RL)
98 (HBSS_mid) Obs
98 (HBSS_mid) Model
136 (HBSS_lwr) Obs
136 (HBSS_lwr) Model
194 (BGSS_upr) Obs
194 (BGSS_upr) Model
233 (BGSS_lwr) Obs
233 (BGSS_lwr) Model
265 (BGSS_lwr) Obs
265 (BGSS_lwr) Model
315 (SBSS) Obs
315 (SBSS) Model
350 (WBCS) Obs
350 (WBCS) Model
400 (LRSS) Obs
400 (LRSS) Model
Dendrobium S2442A
Piezometric head (m RL)
15 (HBSS_mid) Obs
15 (HBSS_mid) Model
49 (HBSS_mid) Obs
49 (HBSS_mid) Model
80 (HBSS_lwr) Obs
80 (HBSS_lwr) Model
114 (BHCS) Obs
114 (BHCS) Model
127 (BGSS_upr) Obs
127 (BGSS_upr) Model
200 (BGSS_lwr) Obs
200 (BGSS_lwr) Model
Dendrobium S2443
Piezometric head (m RL)
14 (HBSS_upr) Obs
14 (HBSS_upr) Model
65 (HBSS_mid) Obs
65 (HBSS_mid) Model
113 (HBSS_lwr) Obs
113 (HBSS_lwr) Model
138 (BHCS) Obs
138 (BHCS) Model
155 (BGSS_upr) Obs
155 (BGSS_upr) Model
225 (BGSS_lwr) Obs
225 (BGSS_lwr) Model
Dendrobium S2478B
Piezometric head (m RL)
25 (HBSS_lwr) Obs
25 (HBSS_lwr) Model
43 (HBSS_lwr) Obs
43 (HBSS_lwr) Model
76 (BHCS) Obs
76 (BHCS) Model
95 (BGSS_upr) Obs
95 (BGSS_upr) Model

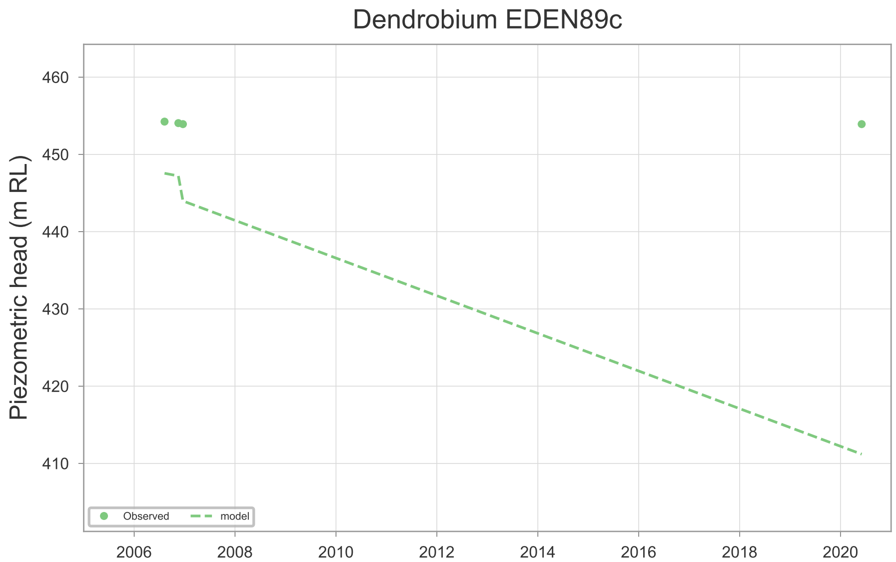


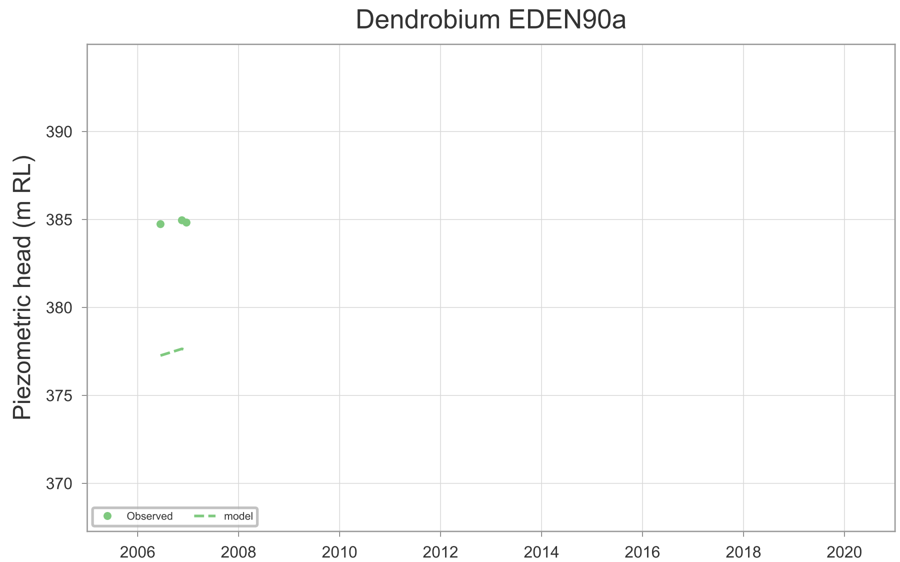
Dendrobium S2486
Piezometric head (m RL)
38 (HBSS_upr) Obs
38 (HBSS_upr) Model
70 (HBSS_mid) Obs
70 (HBSS_mid) Model
113 (HBSS_mid) Obs
113 (HBSS_mid) Model
150 (HBSS_lwr) Obs
150 (HBSS_lwr) Model
198 (BGSS_upr) Obs
198 (BGSS_upr) Model
252 (BGSS_lwr) Obs
252 (BGSS_lwr) Model
285 (SPCS) Obs
285 (SPCS) Model
Dendrobium S2487
Piezometric head (m RL)
30 (HBSS_mid) Obs
30 (HBSS_mid) Model
75 (HBSS_mid) Obs
75 (HBSS_mid) Model
120 (HBSS_lwr) Obs
120 (HBSS_lwr) Model
150 (BHCS) Obs
150 (BHCS) Model
165 (BGSS_upr) Obs
165 (BGSS_upr) Model
Dendrobium S2490
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
25 (HBSS_lwr) Obs
25 (HBSS_lwr) Model
35 (HBSS_lwr) Obs
35 (HBSS_lwr) Model
85 (BGSS_upr) Obs
85 (BGSS_upr) Model
Dendrobium S2493
Piezometric head (m RL)
10 (HBSS_rego) Obs
10 (HBSS_rego) Model
40 (HBSS_upr) Obs
40 (HBSS_upr) Model
87 (HBSS_mid) Obs
87 (HBSS_mid) Model
135 (HBSS_lwr) Obs
135 (HBSS_lwr) Model
150 (BHCS) Obs
150 (BHCS) Model
165 (BHCS) Obs
165 (BHCS) Model
183 (BGSS_upr) Obs
183 (BGSS_upr) Model
229 (BGSS_lwr) Obs
229 (BGSS_lwr) Model
275 (SPCS) Obs
275 (SPCS) Model
2006 2008 2010 2012 2014 2016 2018 2020



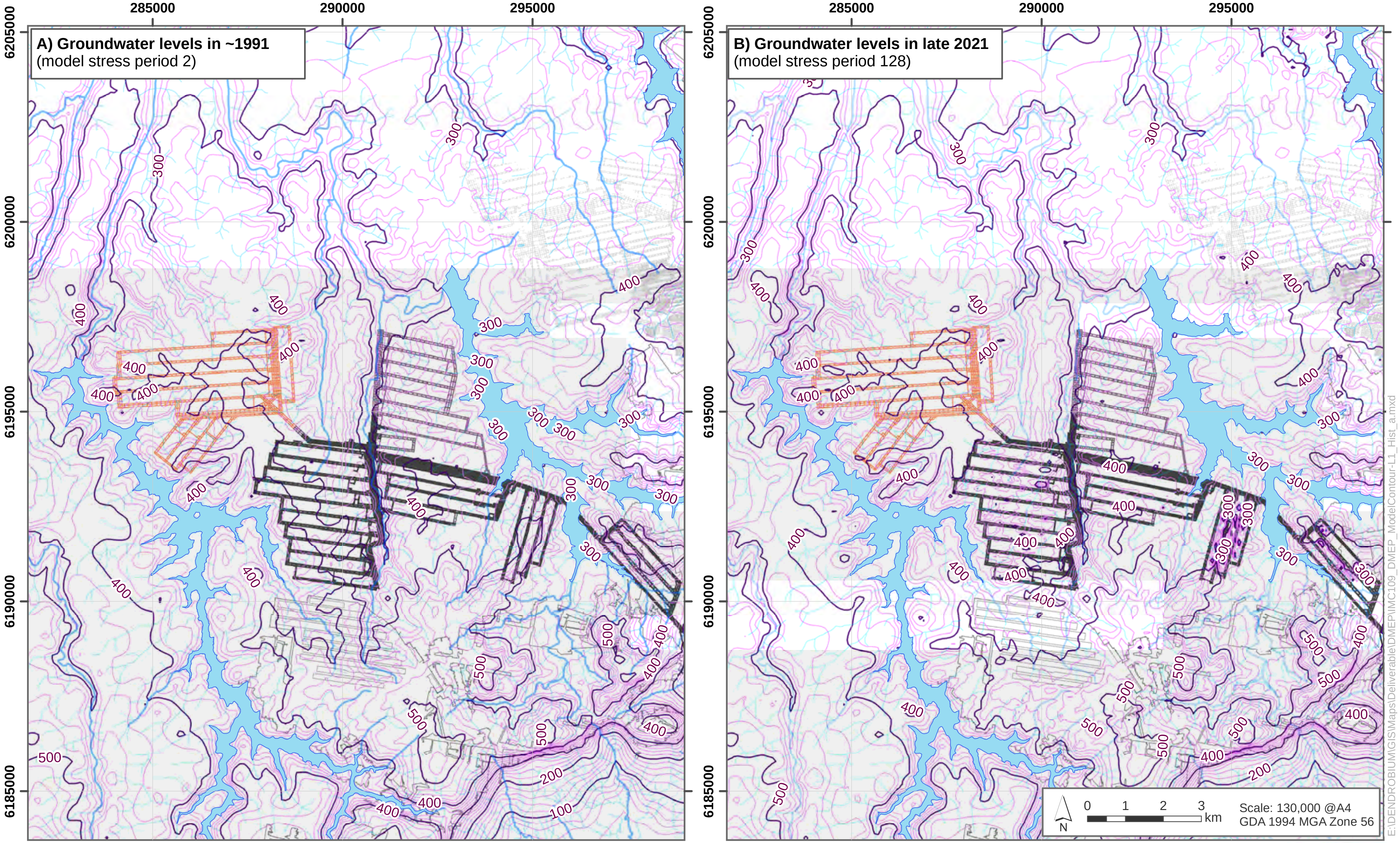
Dendrobium S2510
Piezometric head (m RL)
52 (HBSS_mid) Obs
52 (HBSS_mid) Model
100 (HBSS_lwr) Obs
100 (HBSS_lwr) Model
151 (BGSS_upr) Obs
151 (BGSS_upr) Model
198 (BGSS_lwr) Obs
198 (BGSS_lwr) Model
238 (SPCS) Obs
238 (SPCS) Model
268 (SBSS) Obs
268 (SBSS) Model
276 (SBSS) Obs
276 (SBSS) Model
285 (SBSS) Obs
285 (SBSS) Model
Dendrobium S2526
Piezometric head (m RL)
45 (HBSS_lwr) Obs
45 (HBSS_lwr) Model
55 (HBSS_lwr) Obs
55 (HBSS_lwr) Model
65 (HBSS_lwr) Obs
65 (HBSS_lwr) Model
99 (BHCS) Obs
99 (BHCS) Model
119 (BGSS_upr) Obs
119 (BGSS_upr) Model
164 (BGSS_lwr) Obs
164 (BGSS_lwr) Model
209 (BGSS_lwr) Obs
209 (BGSS_lwr) Model
255 (SBSS) Obs
255 (SBSS) Model
317 (BUSM) Obs
317 (BUSM) Model
343 (WWSM) Obs
343 (WWSM) Model
Dendrobium EDEN87a
Piezometric head (m RL)
Observed
model
Dendrobium EDEN87b
Piezometric head (m RL)
Observed
model


Dendrobium EDEN88a
Dendrobium EDEN88b
Dendrobium EDEN89a
Dendrobium EDEN89b
Piezometric head (m RL)
Observed
model
2006
2008
2010
2012
2014
2016
2018
2020


Dendrobium EDEN89c
Piezometric head (m RL)
460
450
440
430
420
410
2006
2008
2010
2012
2014
2016
2018
2020
Observed
model


Dendrobium EDEN90a
Piezometric head (m RL)
390
385
380
375
370
2006
2008
2010
2012
2014
2016
2018
2020
Observed
model

Appendix J: Modelled groundwater level maps



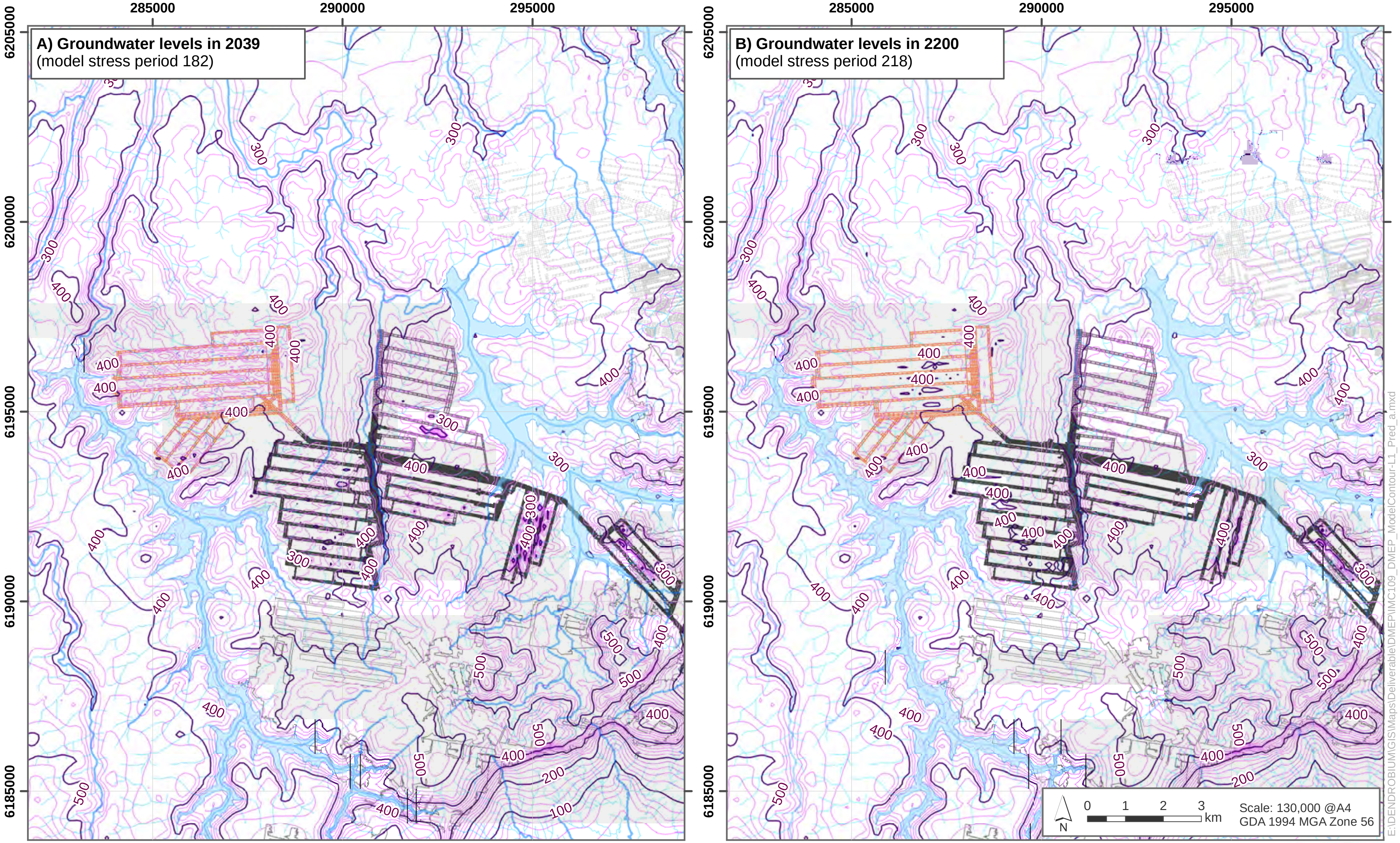
Rev: A | W Minchin | 17/02/2021

Lake
Watercourse
Tribs
Mine workings
DMEP - proposed workings
Modelled groundwater level (100m interval)
Modelled groundwater level (20m interval)
Groundwater Model extent
Inactive area

IMC | Dendrobium Mine

Modelled groundwater levels:
water table in a) 1991 and b) 2021

Figure J1



Rev: A | W Minchin | 17/02/2021

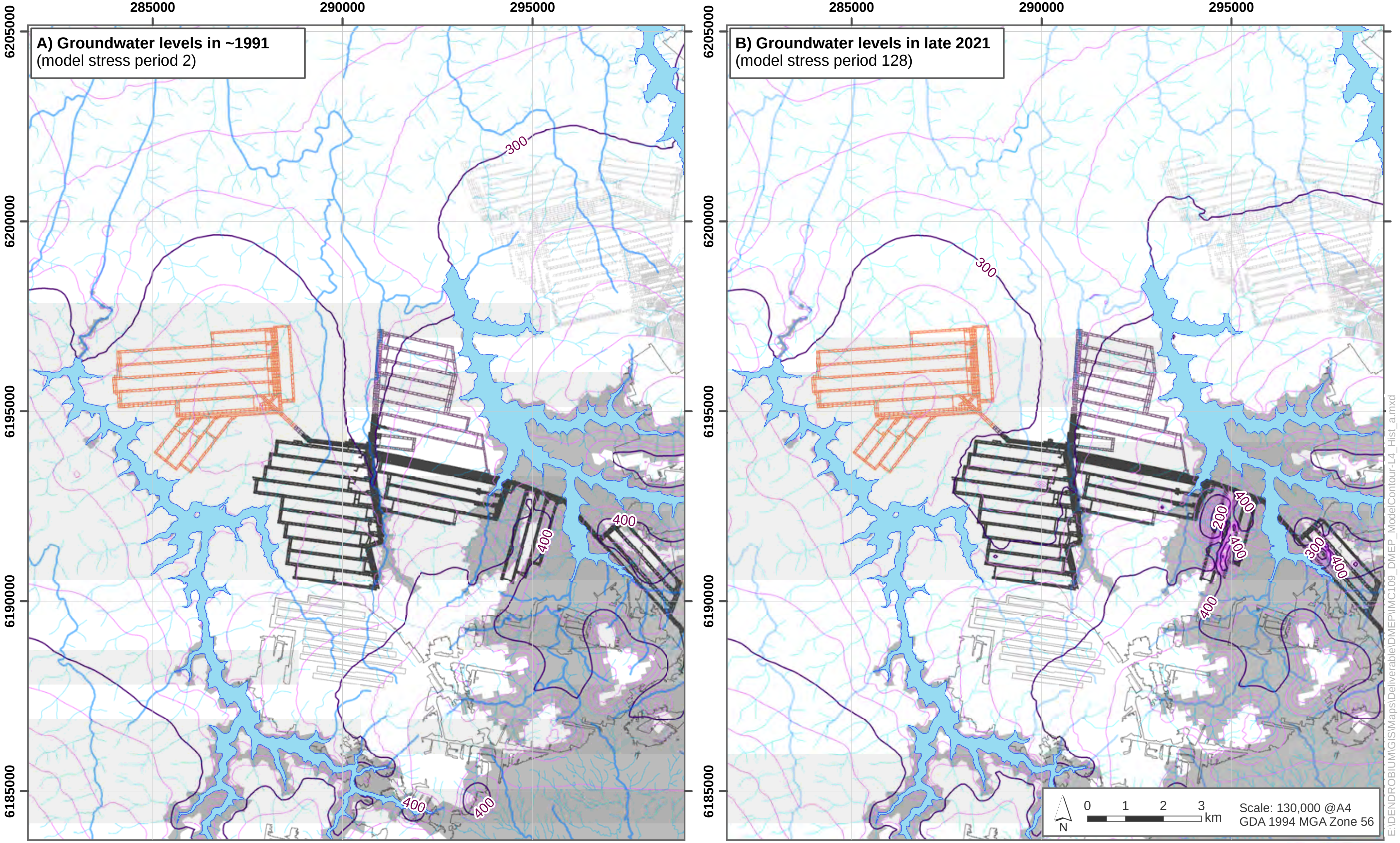
- Lake
- Watercourse
- Tribs
- Mine workings
- DMEP - proposed workings
- Modelled groundwater level (100m interval)
- Modelled groundwater level (20m interval)
- Groundwater Model extent
- Inactive area (lwr HBSS, L4)

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels:
water table in a) 2039 [end of mine]
and b) ~2200 [long-term post-closure]

Figure J2



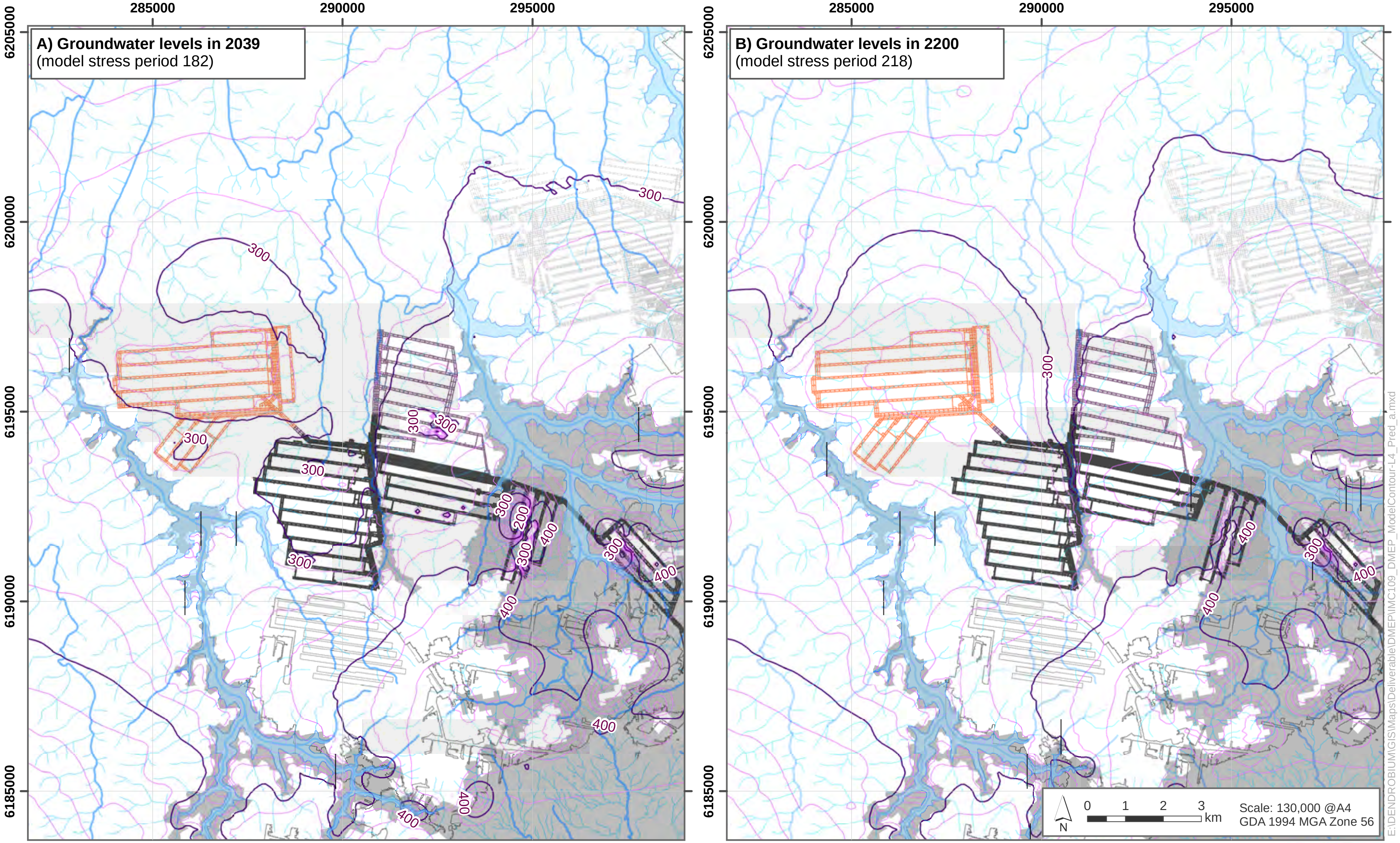
Rev: A | W Minchin | 17/02/2021

Lake
Watercourse
Tribs
Mine workings
DMEP - proposed workings
Modelled groundwater level (100m interval)
Modelled groundwater level (20m interval)
Groundwater Model extent
Inactive area (lwr HBSS, L4)

IMC | Dendrobium Mine

Modelled groundwater levels:
lwr Hawkesbury Sst in a) 1991 and b) 2021

Figure J3



Rev: A | W Minchin | 17/02/2021

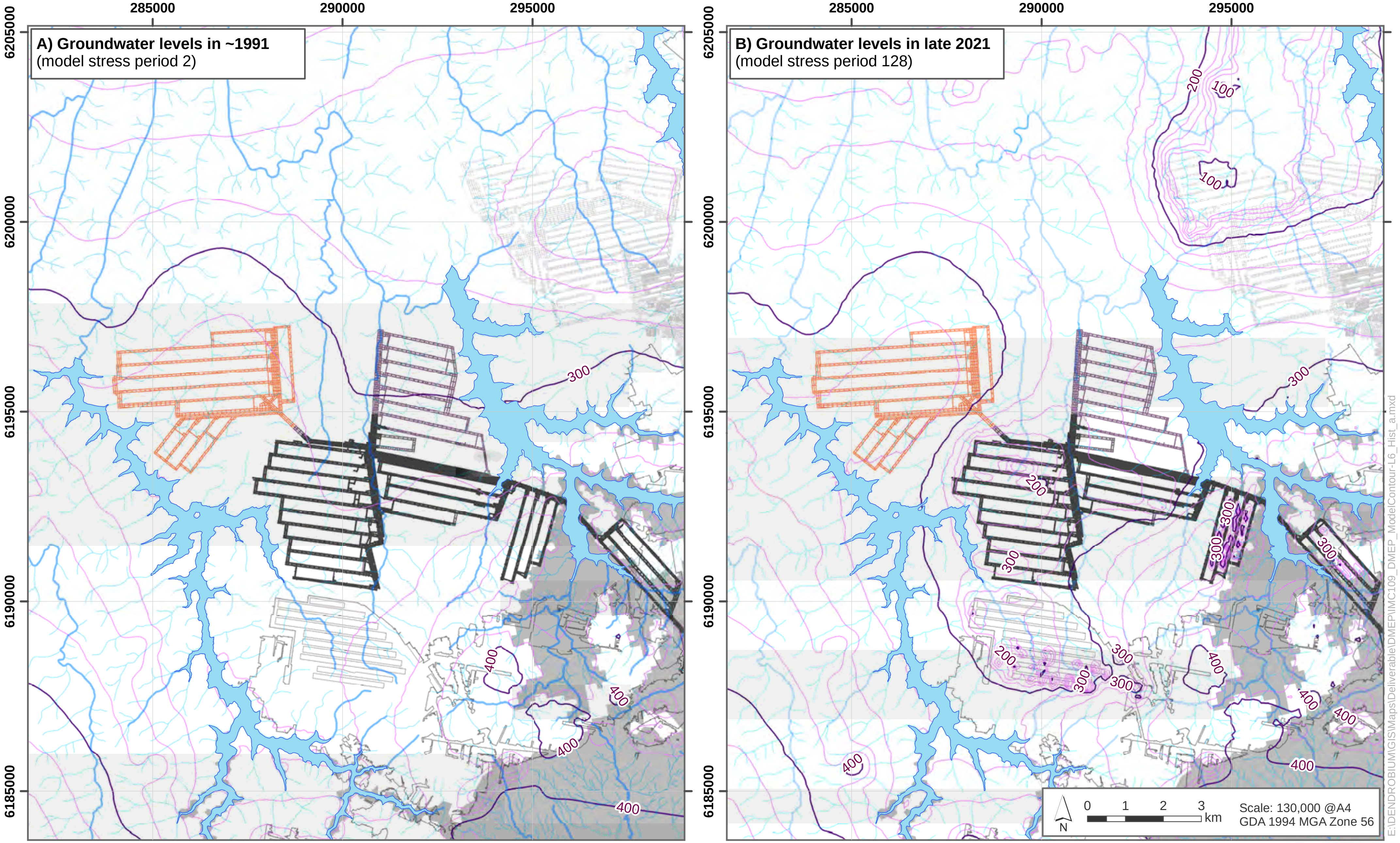
- Lake
- Watercourse
- Tribs
- Mine workings
- DMEP - proposed workings
- Modelled groundwater level (100m interval)
- Modelled groundwater level (20m interval)
- Groundwater Model extent
- Inactive area (lwr HBSS, L4)

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels:
lower Hawkesbury Sst in a) 2039 [end of mine]
and b) ~2200 [long-term post-closure]

Figure J4



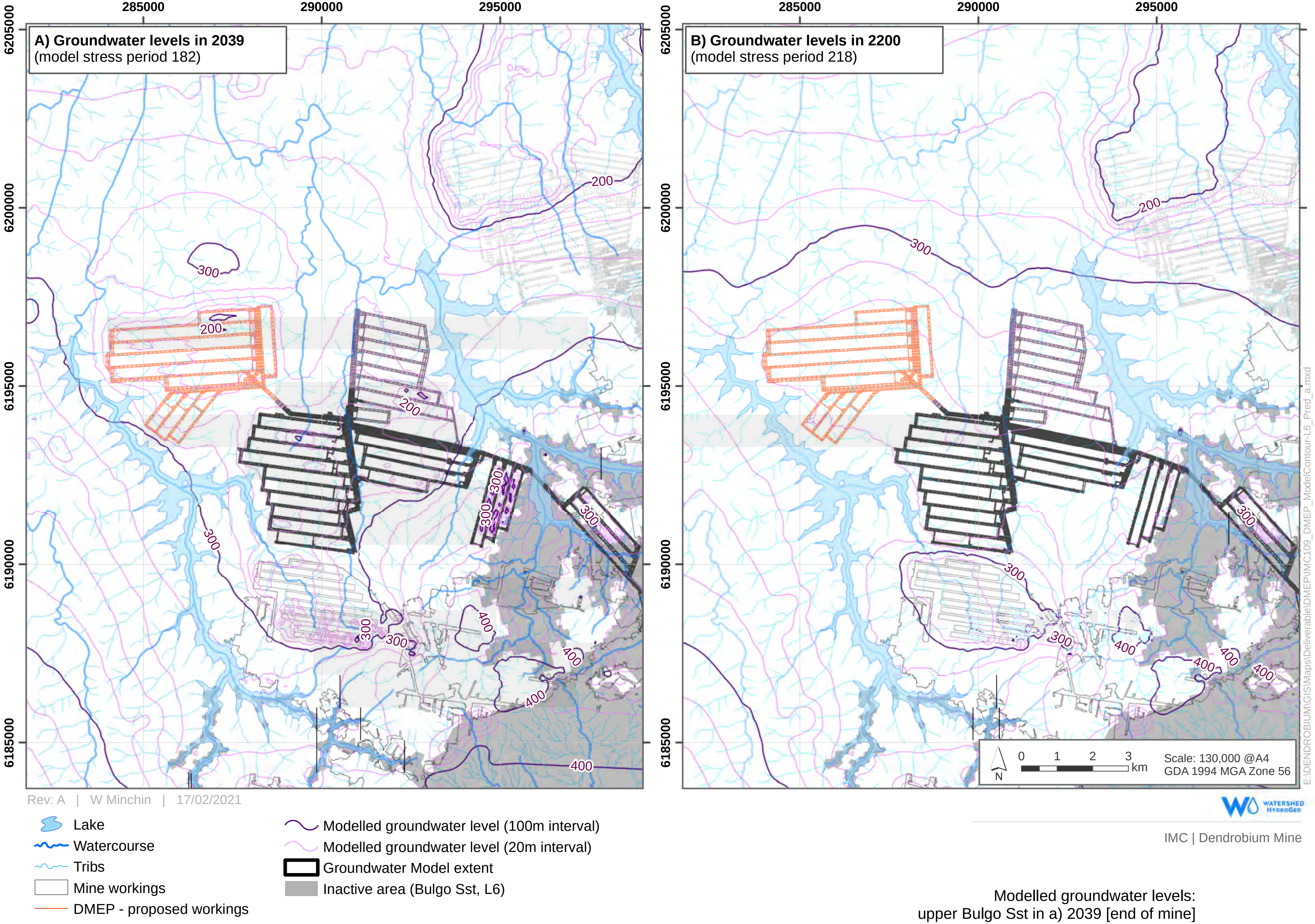
Rev: A | W Minchin | 17/02/2021

- Lake
- Watercourse
- Tribs
- Mine workings
- DMEP - proposed workings
- Modelled groundwater level (100m interval)
- Modelled groundwater level (20m interval)
- Groundwater Model extent
- Inactive area (upper Bulgo, L6)

IMC | Dendrobium Mine

Modelled groundwater levels:
upper Bulgo Sst in a) 1991 and b) 2021

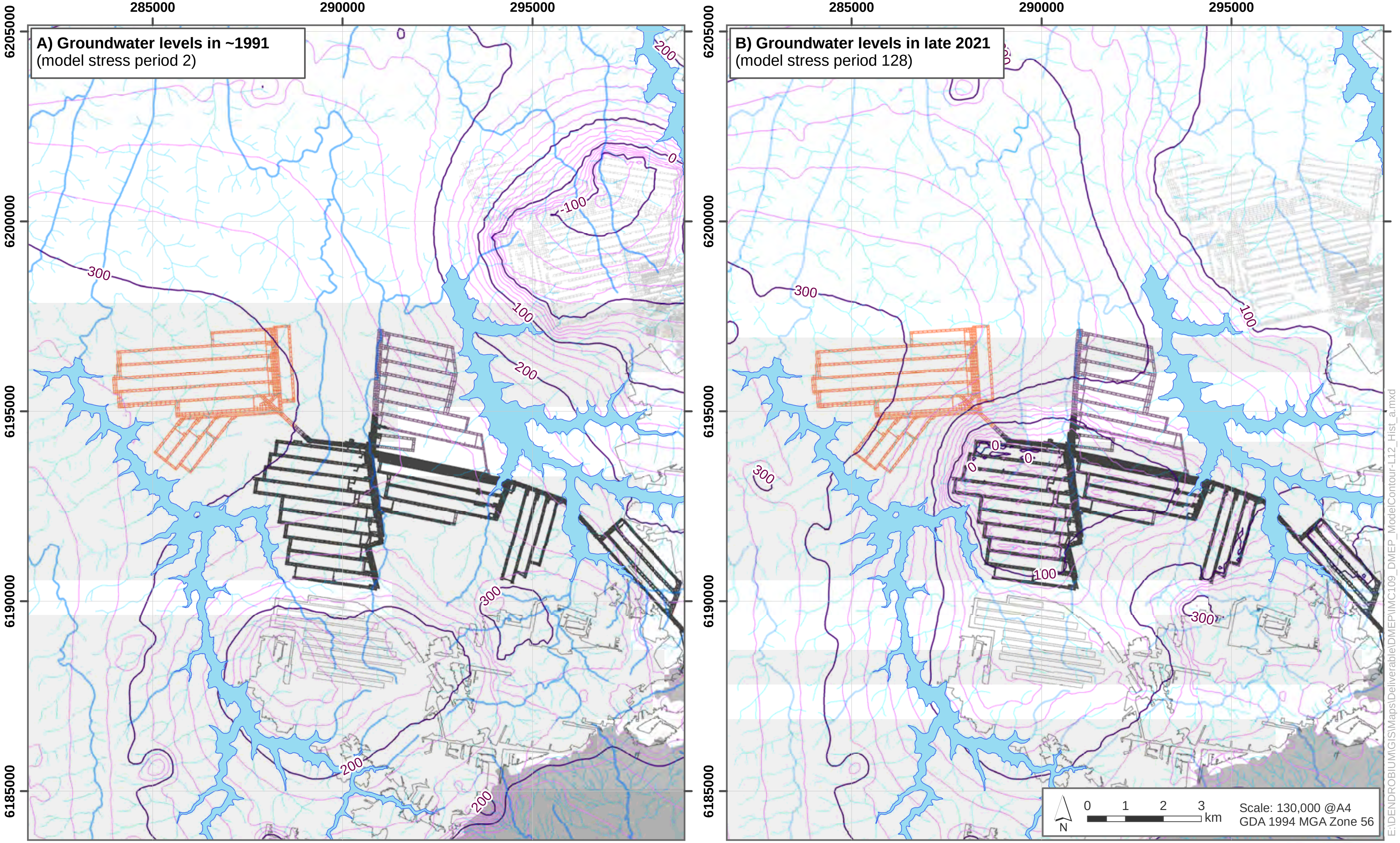
Figure J5



IMC | Dendrobium Mine

Modelled groundwater levels:
upper Bulgo Sst in a) 2039 [end of mine]
and b) ~2200 [long-term post-closure]

Figure J6



Rev: A | W Minchin | 17/02/2021

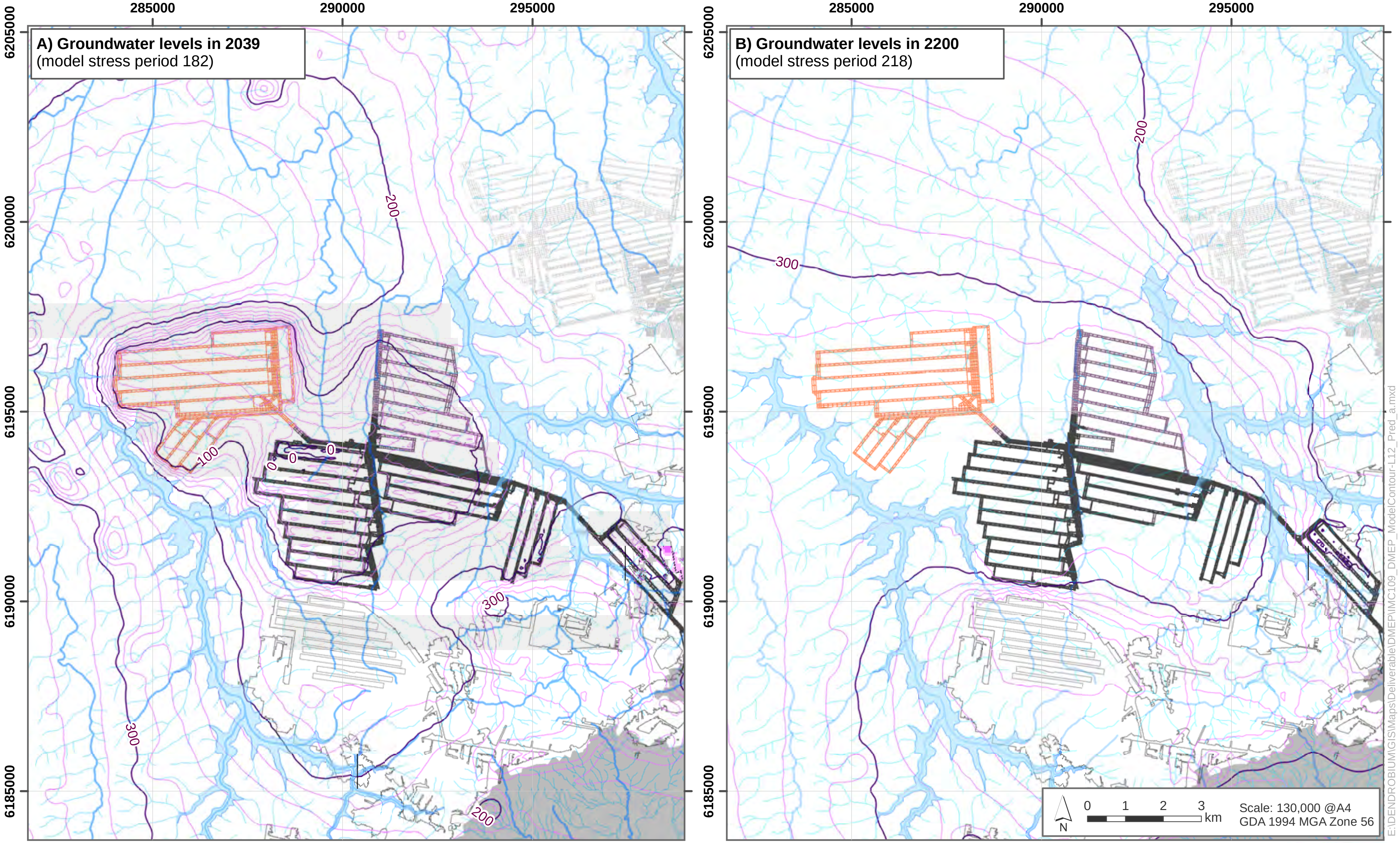
- Lake
- Watercourse
- Tribs
- Mine workings
- DMEP - proposed workings
- Modelled groundwater level (100m interval)
- Modelled groundwater level (20m interval)
- Groundwater Model extent
- Inactive area (Bulli Seam, L12)

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels:
Bulli Seam in a) 1991 and b) 2021

Figure J7



Rev: A | W Minchin | 17/02/2021

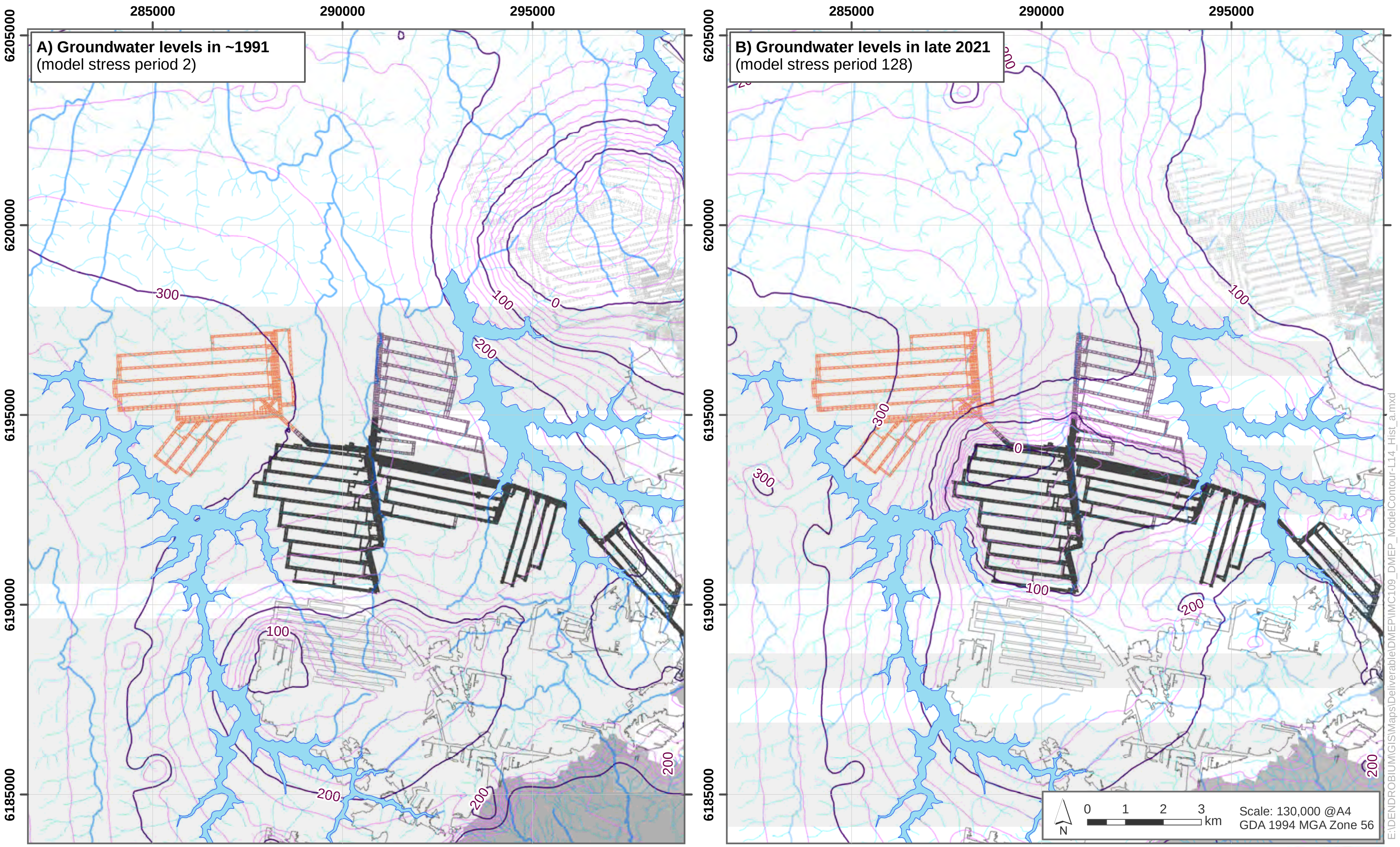
- Lake
- Watercourse
- Tribs
- Mine workings
- DMEP - proposed workings
- Modelled groundwater level (100m interval)
- Modelled groundwater level (20m interval)
- Groundwater Model extent
- Inactive area (Bulli Seam, L12)

WATERSHED HYDROGEO

IMC | Dendrobium Mine

Modelled groundwater levels:
Bulli Seam in a) 2039 [end of mine]
and b) ~2200 [long-term post-closure]

Figure J8



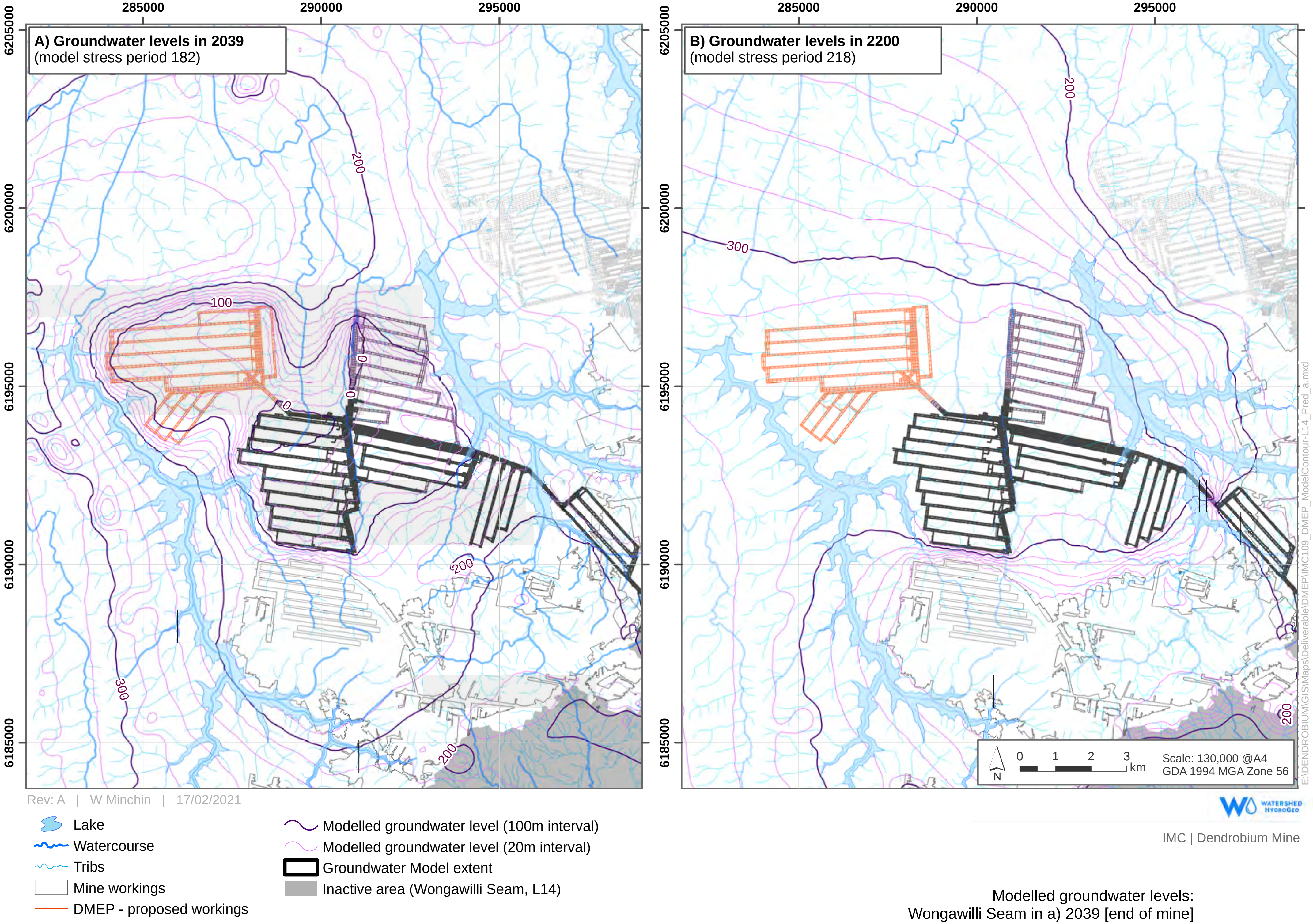
Rev: A | W Minchin | 17/02/2021

- Lake
- Watercourse
- Tribs
- Mine workings
- DMEP - proposed workings
- Modelled groundwater level (100m interval)
- Modelled groundwater level (20m interval)
- Groundwater Model extent
- Inactive area (Wongawilli Seam, L14)

IMC | Dendrobium Mine

Modelled groundwater levels:
Wongawilli Seam in a) 1991 and b) 2021

Figure J9



IMC | Dendrobium Mine

Modelled groundwater levels:
Wongawilli Seam in a) 2039 [end of mine]
and b) ~2200 [long-term post-closure]

Figure J10

Appendix K: Model Confidence Classification

Appendix K: Groundwater model confidence level classification table

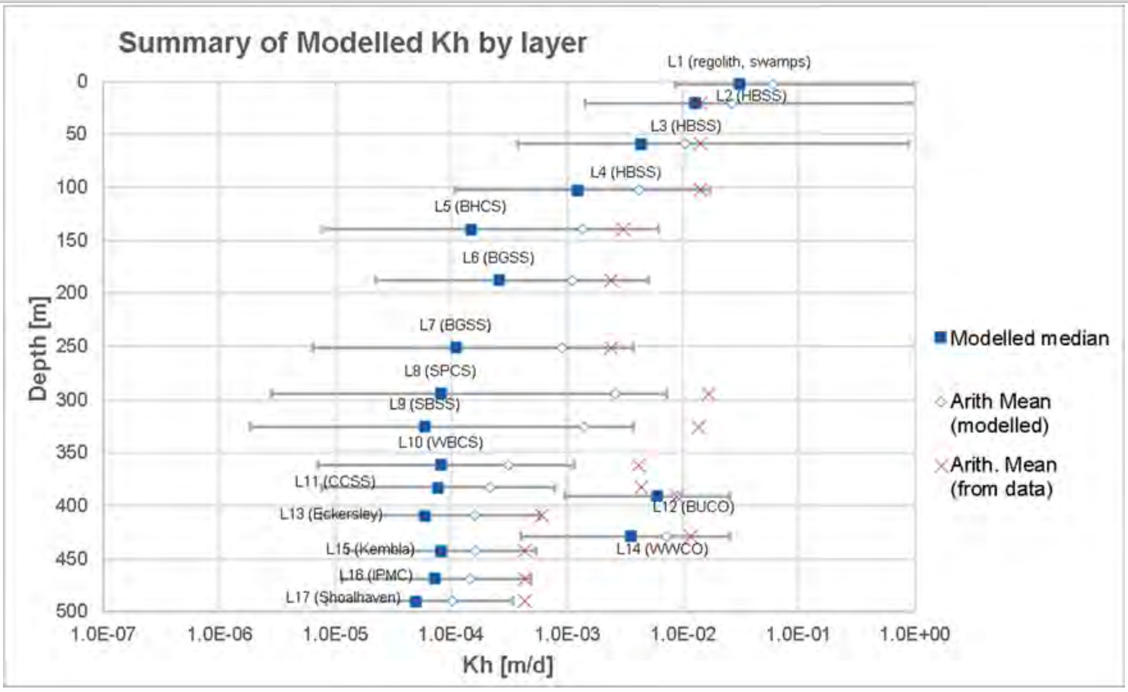
Australian Groundwater Modelling Guidelines (Barnett *et al*., 2012)

	Data		Calibration		Prediction		Key indicator	
Class 3	Spatial and temporal distribution of groundwater head observations adequately define groundwater behaviour, especially in areas of greatest interest and where outcomes are to be reported.		Adequate validation is demonstrated. **Noting that it is not widely agreed that setting aside data for verification is the best use of that information.*		Length of predictive model is not excessive compared to length of calibration period.		Key calibration statistics are acceptable and meet agreed targets.	✓
	Spatial distribution of bore logs and associated stratigraphic interpretations clearly define aquifer geometry.	✓	Scaled RMS error (refer Chapter 5) or other calibration statistics are acceptable.	✓	Temporal discretisation used in the predictive model is consistent with the transient calibration.	✓	Model predictive time frame is less than 3 times the duration of transient calibration. *(for operational mine life)*	✓
	Reliable metered groundwater extraction and injection data is available. *(for Dendrobium Mine)*	✓	Long-term trends are adequately replicated where these are important.	✓	Level and type of stresses included in the predictive model are within the range of those used in the transient calibration.	✓	Stresses are not more than 2 times greater than those included in calibration.	✓
	Rainfall and evaporation data is available.	✓	Seasonal fluctuations are adequately replicated where these are important.		Model validation* suggests calibration is appropriate for locations and/or times outside the calibration model.		Temporal discretisation in predictive model is the same as that used in calibration.	✓
	Aquifer-testing data to define key parameters.	✓	Transient calibration is current, i.e. uses recent data.	✓	Steady-state predictions used when the model is calibrated in steady- state only.		Mass balance closure error is less than 0.5% of total.	✓
	Streamflow and stage measurements are available with reliable baseflow estimates at a number of points.	✓	Model is calibrated to heads and fluxes.	✓			Model parameters consistent with conceptualisation.	✓
	Reliable land-use and soil- mapping data available.		Observations of the key modelling outcomes dataset is used in calibration:				Appropriate computational methods used with appropriate spatial discretisation to model the problem.	✓
			* Mine inflow	✓				
			* Groundwater levels	✓				
			* Watercourse impacts	✓				
			* Reservoir leakage	X				
	Good quality and adequate spatial coverage of digital elevation model to define ground surface elevation.	✓					The model has been reviewed and deemed fit for purpose by an experienced, independent hydrogeologist with modelling experience.	✓
Class 2	Groundwater head observations and bore logs are available but may not provide adequate coverage throughout the model domain.	✓	Validation* is either not undertaken or is not demonstrated for the full model domain.	✓	Transient calibration over a short time frame compared to that of prediction.		Key calibration statistics suggest poor calibration in parts of the model domain.	
	Metered groundwater- extraction data may be available but spatial and temporal coverage may not be extensive.		Calibration statistics are generally reasonable but may suggest significant errors in parts of the model domains).		Temporal discretisation used in the predictive model is different from that used in transient calibration.		Model predictive time frame is between 3 and 10 times the duration of transient calibration. *(for long-term post-closure estimates)*	✓
	Streamflow data and baseflow estimates available at a few points.		Long-term trends not replicated in all parts of the model domain.		Level and type of stresses included in the predictive model are outside the range of those used in the transient calibration.		Stresses are between 2 and 5 times greater than those included in calibration.	
	Reliable irrigation-application data available in part of the area or for part of the model duration.		Transient calibration to historic data but not extending to the present day.		Validation* suggests relatively poor match to observations when calibration data is extended in time and/or space.		Temporal discretisation in predictive model is not the same as that used in calibration.	
			Seasonal fluctuations not adequately replicated in all parts of the model domain.	✓			Mass balance closure error is less than 1% of total.	
			Observations of the key modelling outcome data set are not used in calibration.				Not all model parameters consistent with conceptualisation.	
			(see above for those that are used) > cannot directly observe reservoir losses > cannot infer losses from water balance with any reliability	X			Spatial refinement too coarse in key parts of the model domain.	
							The model has been reviewed and deemed fit for purpose by an independent hydrogeologist.	
Class 1	Few or poorly distributed existing wells from which to obtain reliable groundwater and geological information.		No calibration is possible.		Predictive model time frame far exceeds that of calibration.		Model is uncalibrated or key calibration statistics do not meet agreed targets.	
	Observations and measurements unavailable or sparsely distributed in areas of greatest interest.		Calibration illustrates unacceptable levels of error especially in key areas.		Temporal discretisation is different to that of calibration.		Model predictive time frame is more than 10 times longer than transient calibration period.	
	No available records of metered groundwater extraction or injection.		Calibration is based on an inadequate distribution of data.		Transient predictions are made when calibration is in steady state only.		Stresses in predictions are more than 5 times higher than those in calibration.	
	Climate data only available from relatively remote locations.		Calibration only to datasets other than that required for prediction.		Model validation* suggests unacceptable errors when calibration dataset is extended in time and/or space.		Stress period or calculation interval is different from that used in calibration.	
	Little or no useful data on land-use, soils or river flows and stage elevations.						Transient predictions made but calibration in steady state only.	
							Cumulative mass-balance closure error exceeds 1% or exceeds 5% at any given calculation time.	
							Model parameters outside the range expected by the conceptualisation with no further justification.	
							Unsuitable spatial or temporal discretisation.	
							The model has not been reviewed.	

Appendix L: Model parameters for deterministic scenario analysis

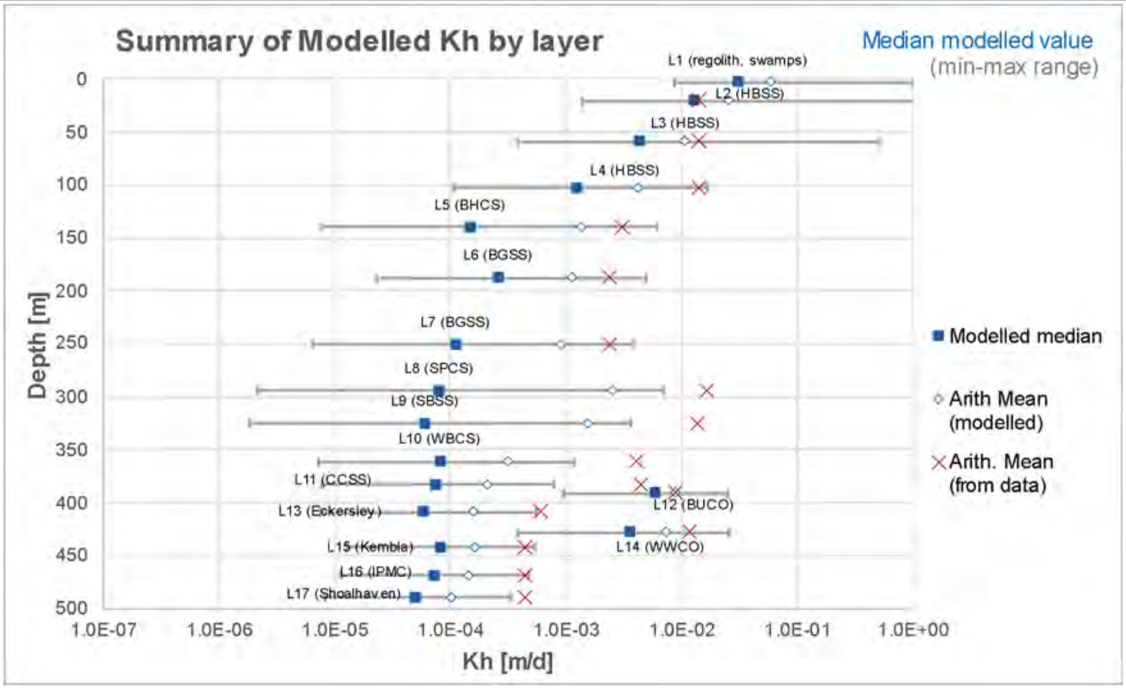
Summary of modelled Kh

Base case Kh



E:\DENDROBIUM\ModelGW\modelConstruction\Properties\DND5_mesh_Kwdepth_5v25.xlsx

Kh real#1



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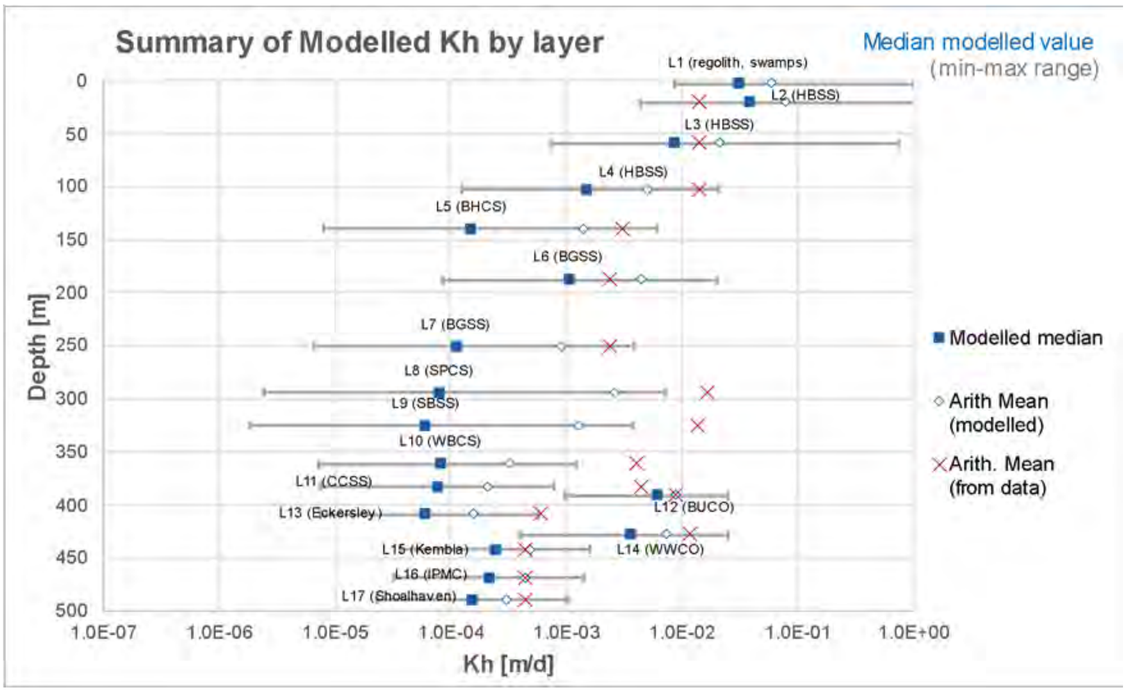
Kh real#2



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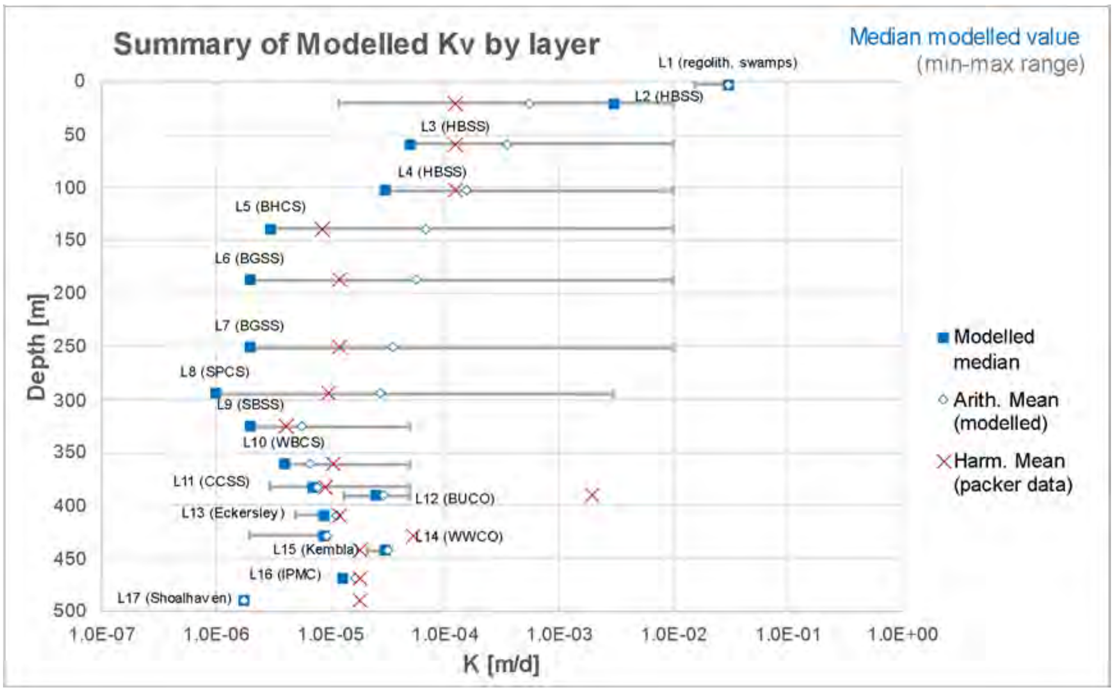
Summary of modelled Kv

Base case Kv



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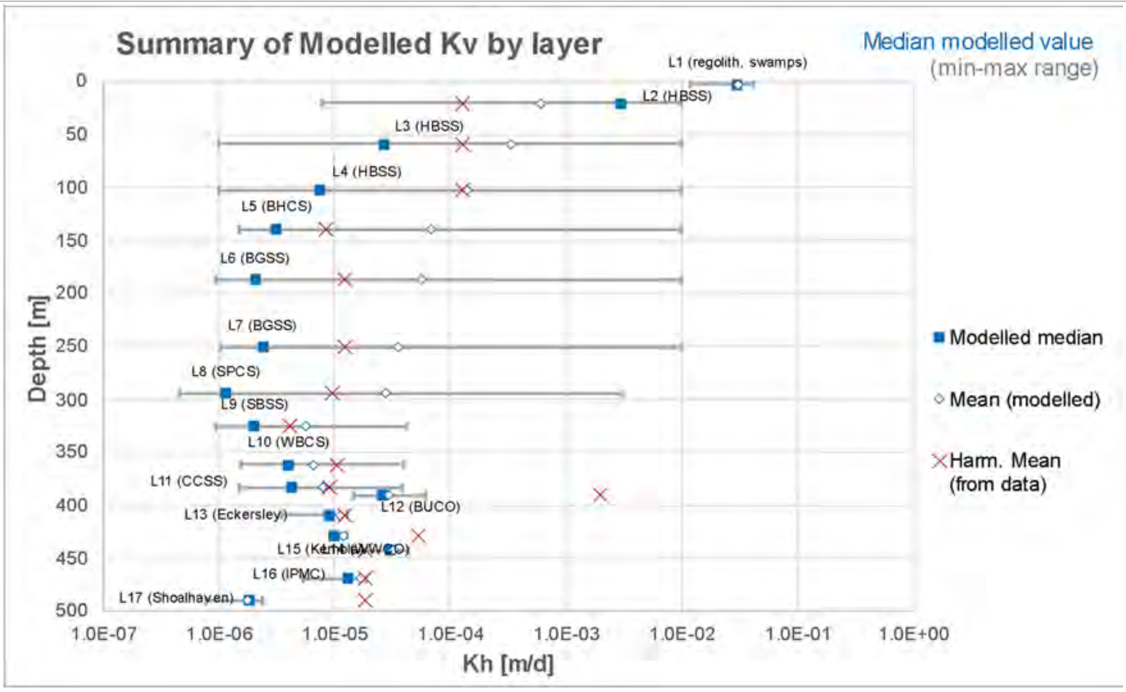
Kh real#1



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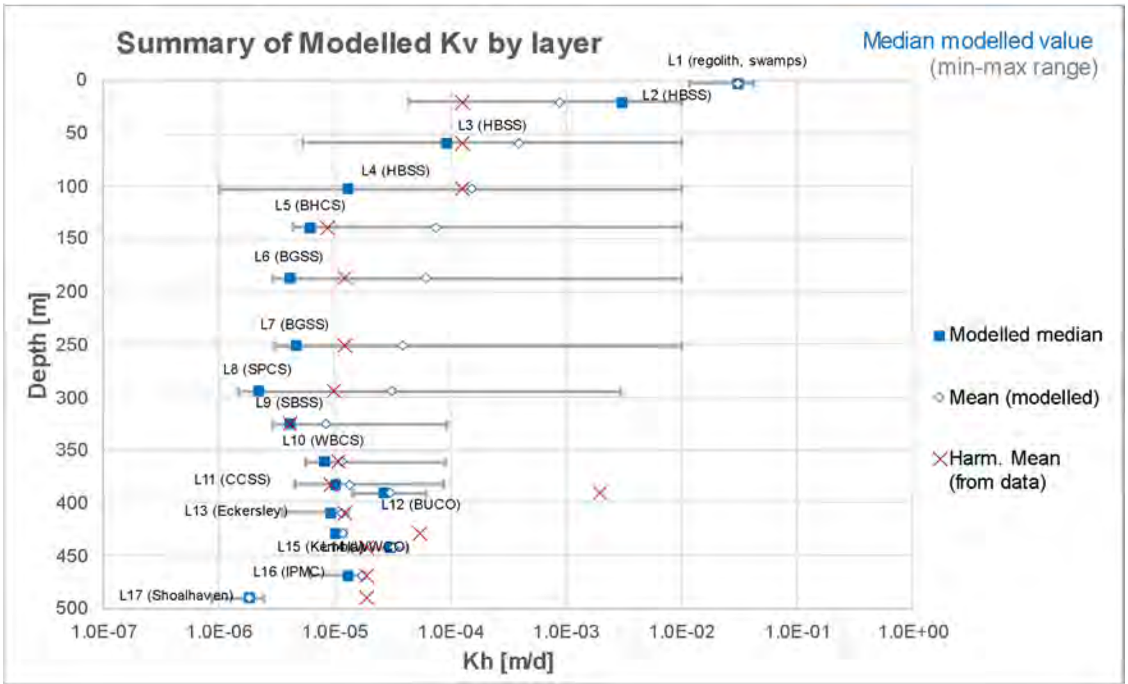
Kh real#2



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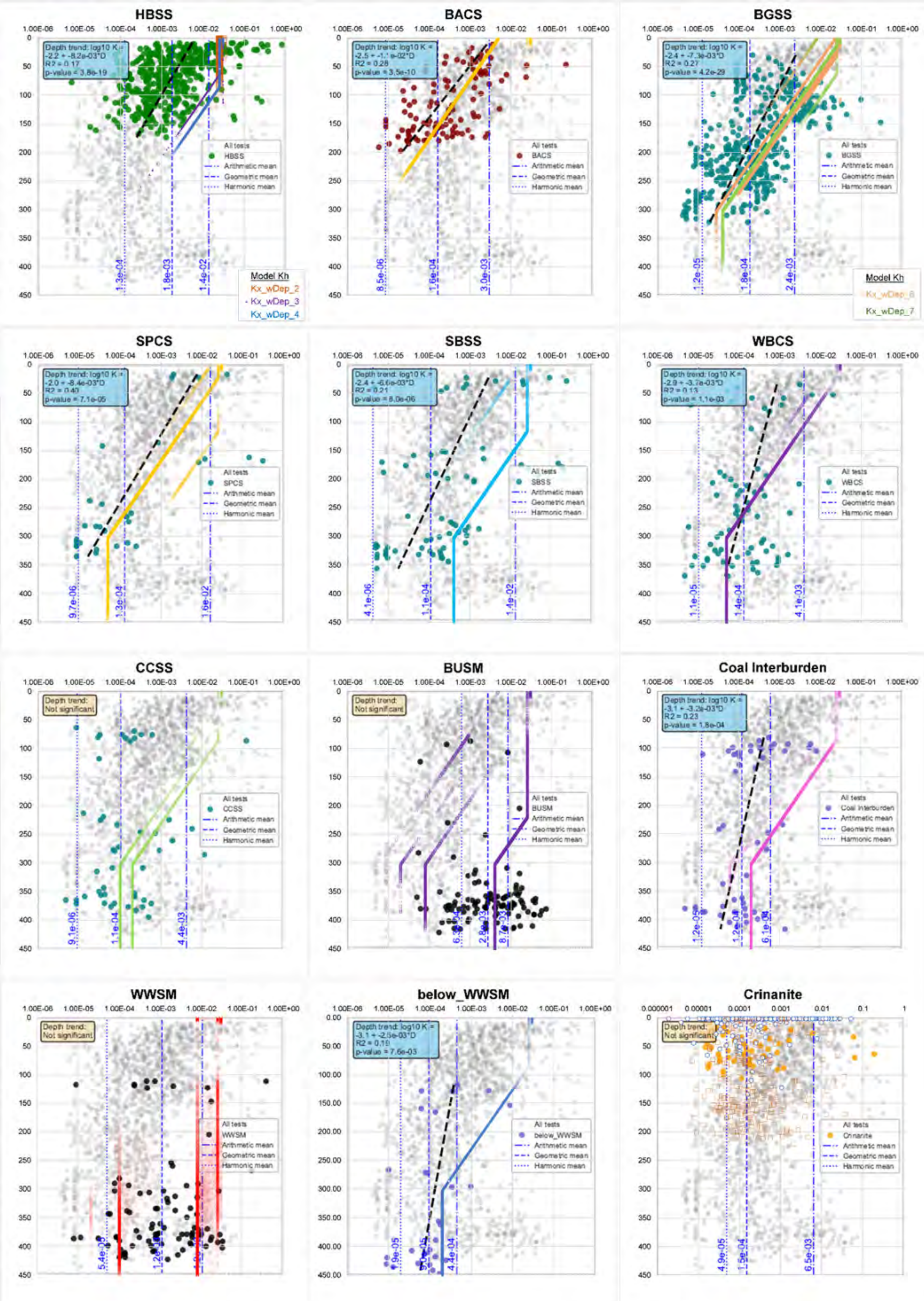
Modelled Kh – detail

Kh base case

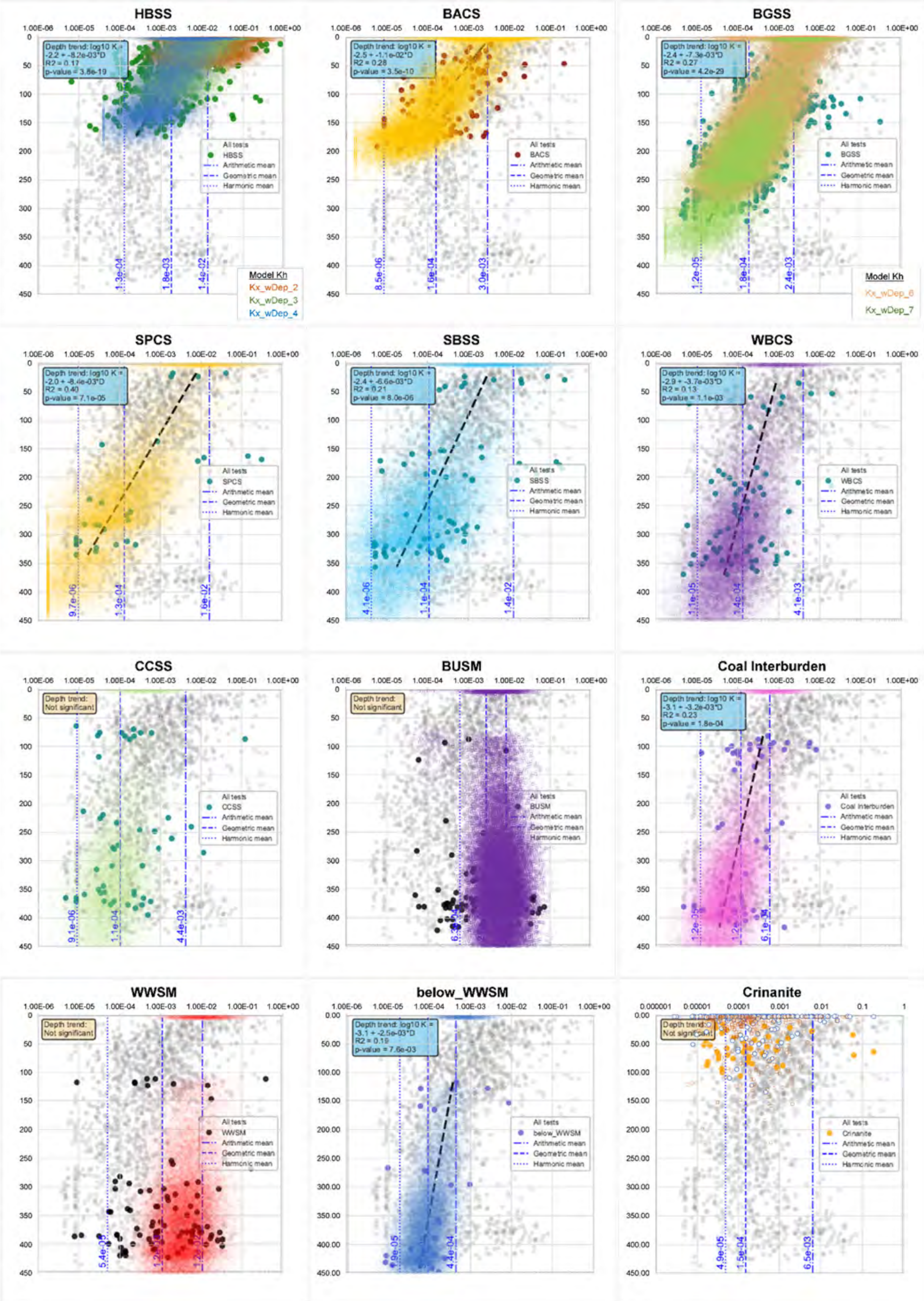
Refer to Appendix C – packer test results.



Modelled Kh – detail

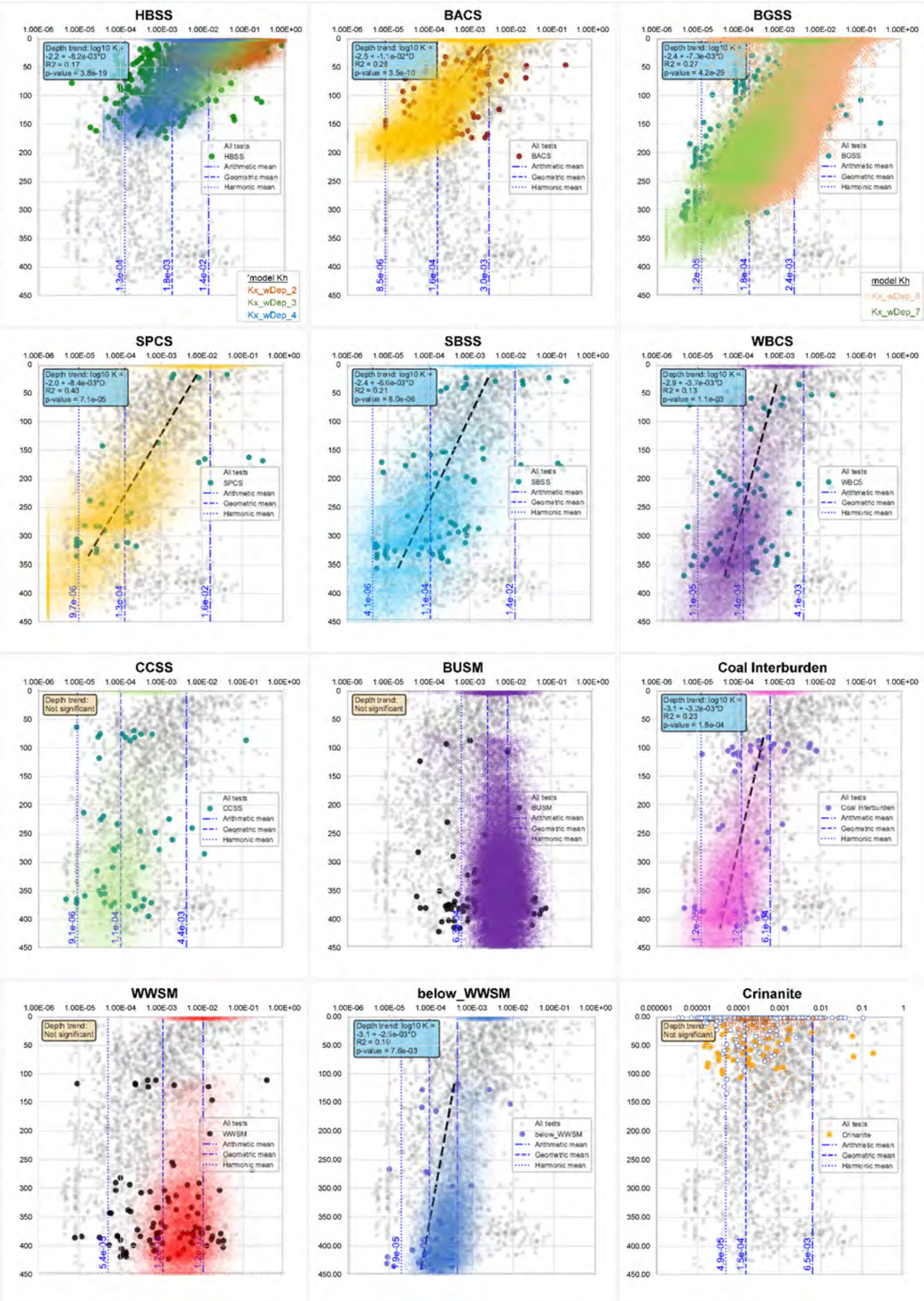
Kh real#1

Refer to Appendix C – packer test results.



Modelled Kh – detail

Kh real#2 *Refer to Appendix C – packer test results.*



Appendix M: Water supply works with predicted >2 m drawdown

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

GW_Work	Purpose	'Water supply' work?	Aquifer unit	Modelled Maximum Drawdown (at any time); [m] based on the simulation of the following mine development scenarios						
				Project (Area 5)	Dendrobium Mine - base case	Range: Dend. Total Dendrobium - uncert. MIN	Dendrobium - uncert. MAX	Cumulative (all mines)	Range: cumul. mining Cumul mining - uncert. MIN	Cumul mining - uncert. MAX
GW007445	Irrigation	Yes	HBSS	0.2	0.2	0.2	1.9	96.1	51.3	140.8
GW008537	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	4	0	8
GW008548	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0	0	0
GW010459	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.3
GW010460	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.1	0	0.2
GW010496	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	16.5	10.9	22
GW010584	Unknown	Yes	HBSS (WMFM)	0	0	0	0	4.7	1.2	8.2
GW010604	Stock and Domestic	Yes	HBSS	0.1	0.1	0.1	0.3	23.5	11.2	35.8
GW010654	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.8	0.5	1.1
GW010779	Water Supply	Yes	Shoalhaven	0	0	0	0	4.2	2.3	6
GW010968	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.2	0.3
GW011042	Stock and Domestic	Yes	HBSS (WMFM)	0	0	0	0	1.1	0.8	1.3
GW011200	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	5.5	1	10
GW011234	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	2.4	0	4.7
GW011299	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	7.1	2.3	11.9
GW011738	Water Supply	Yes	KBSS	0	0	0	0	2	0	4
GW011918	Water Supply	Yes	Shoalhaven	0	0	0	0	2.5	0.7	4.2
GW012581	Stock and Domestic	Yes	Shoalhaven	0	0	0	0	4.7	3.4	6
GW012611	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	3.7	0	7.3
GW012612	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	7.5	2.4	12.6
GW013023	Water Supply	Yes	Shoalhaven	0	0	0	0	2.1	1.8	2.3
GW013282	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0	0	0
GW013401	Stock and Domestic	Yes	Shoalhaven	0	0	0	0	7.9	4	11.8
GW013626	Water Supply	Yes	Shoalhaven	0	0	0	0	3.4	1.5	5.3
GW013668	Water Supply	Yes	Shoalhaven	0	0	0	0	3.2	1.3	5
GW013965	Water Supply	Yes	Shoalhaven	0	0.1	0.1	0.1	7.2	2.2	12.1
GW014262	Stock and Domestic	Yes	HBSS (WMFM)	0	0	0	0	6.8	6.1	7.4
GW015069	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW015090	Stock and Domestic	Yes	HBSS (WMFM)	0	0	0	0	6.5	6.1	6.8
GW015266	Water Supply	Yes	Shoalhaven	0	0	0	0	5.2	3.1	7.2
GW015549	Water Supply	Yes	HBSS	0	0	0	0	0	0	0
GW015789	Water Supply	Yes	HBSS	0	0	0	0	0	0	0
GW016480	Stock and Domestic	Yes	Shoalhaven	0	0	0	0	1.7	0.9	2.4
GW016553	Water Supply	Yes	HBSS	0	0	0	0	0.1	0.1	0.1
GW017381	Irrigation	Yes	Shoalhaven	0	0	0	0	2.2	1.7	2.7
GW017768	Water Supply	Yes	Shoalhaven	0	0	0	0	4.7	3.4	5.9
GW018568	Irrigation	Yes	HBSS	0	0	0	0.2	28.8	21.1	36.4
GW018800	Water Supply	Yes	HBSS	0	0	0	0	0.8	0.3	1.3
GW019590	Water Supply	Yes	HBSS	0	0	0	0.1	3.3	1.5	5
GW022245	Water Supply	Yes	HBSS	0	0	0	0.8	28.4	18.7	38.1
GW024238	Commercial and Ind	Yes	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW024417	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0	0.3
GW024565	Stock and Domestic	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW024623	Stock and Domestic	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.2	0.4
GW024644	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW025598	Water Supply	Yes	HBSS	0	0	0	0	0.4	0.3	0.5
GW028270	Stock and Domestic	Yes	HBSS (WMFM)	0	0	0	0	0.1	0.1	0.1
GW028786	Stock and Domestic	Yes	Shoalhaven	0	0	0	0	3.9	2	5.8
GW028859	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	1.3	0.8	1.8
GW029143	Water Supply	Yes	HBSS	0	0	0	0.2	24.1	15.5	32.7
GW031294	Irrigation	Yes	HBSS	0.1	0	0	0.2	14.7	5.1	24.2
GW032443	Irrigation	Yes	HBSS	0.2	0.2	0.2	0.2	165.3	46.5	284
GW033916	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	1.4	1.2	1.6
GW034425	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.5	0.1	0.8
GW034518	Irrigation	Yes	HBSS	0	0	0	0.2	31.7	22.4	40.9
GW034687	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0.3	0	0.6
GW035033	Stock and Domestic	Yes	HBSS	0	0	0	0	2.6	1.2	4
GW035753	Irrigation	Yes	HBSS	0.1	0.1	0.1	0.2	56.1	30	82.2
GW035844	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.2	0.4
GW037283	Water Supply	Yes	Shoalhaven	0	0	0	0	2.3	0.6	4
GW037289	Irrigation	Yes	HBSS	0.1	0	0	0.2	77.9	49.8	106
GW037294	Commercial and Ind	Yes	HBSS	0	0	0	0.2	4	1.7	6.3
GW037742	Irrigation	Yes	HBSS	0	0	0	0.2	22.1	13.9	30.3
GW037747	Irrigation	Yes	HBSS	0	0	0	0	2.1	0.8	3.4
GW037860	Irrigation	Yes	HBSS	0.1	0	0	0.2	73.6	49.8	97.4
GW037932	Irrigation	Yes	HBSS	0	0	0	0	5.3	1.4	9.2
GW038059	Exploration	No	BGSS	0	0	0	0	0	0	0
GW038060	Irrigation	Yes	HBSS	0.1	0	0	0.1	54.9	42.6	67.1
GW038074	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.6	0.1	1
GW038451	Water Supply	Yes	HBSS	0	0	0	0	0.3	0.2	0.4
GW040945	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW040946	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW040952	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW042537	Irrigation	Yes	HBSS	0	0	0	0.1	51.2	41	61.4
GW042788	Irrigation	Yes	HBSS	0	0	0	0	8.1	3	13.2
GW042825	Irrigation	Yes	HBSS	0	0	0	0.1	11.5	3.9	19
GW043154	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	3.5	2.7	4.2
GW043690	Water Supply	Yes	HBSS	0	0	0	0	19.7	14.6	24.7
GW043728	Water Supply	Yes	HBSS	0	0	0	0	0	0	0
GW043863	Water Supply	Yes	HBSS	0	0	0	0	16	9.1	22.9
GW045404	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW047037	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.1	0	0.1
GW047217	Irrigation	Yes	HBSS	0	0	0	0	1.1	0.7	1.4

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

				Modelled Maximum Drawdown (at any time); [m] based on the simulation of the following mine development scenarios						
GW_Work	Purpose	'Water supply' work?	Aquifer unit	Project (Area 5)	Dendrobium Mine - base case	Range: Dend. Total		Cumulative (all mines)	Range: cumul. mining	
						Dendrobium - uncert. MIN	Dendrobium - uncert. MAX		Cumul mining - uncert. MIN	Cumul mining - uncert. MAX
GW047416	Water Supply	Yes	HBSS	0	0	0	0.1	16	6.8	25.2
GW047817	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.1	0	0.1
GW047903	Water Supply	Yes	HBSS	0.1	0	0	0.1	18.2	6.2	30.1
GW048563	Unknown	Yes	Shoalhaven	0	0	0	0	2.4	1.1	3.6
GW048564	Unknown	Yes	Shoalhaven	0	0	0	0	2.4	1.1	3.6
GW049292	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0	0.3
GW049516	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW049796	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	9.7	5	14.3
GW050408	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW051877	Stock and Domestic	Yes	HBSS	0	0	0	0.1	5.7	2.3	9
GW052016	Stock and Domestic	Yes	HBSS	0.1	0.1	0.1	0.2	14.3	4.3	24.3
GW052540	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW052628	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW053288	Irrigation	Yes	HBSS	0	0	0	0	3.4	0.6	6.1
GW053294	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.1	0.4
GW053306	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW053449	Irrigation	Yes	HBSS	0.1	0	0	0.2	11.9	4.4	19.4
GW053450	Irrigation	Yes	HBSS	0	0	0	0.1	4	1.5	6.4
GW054146	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.3	17.5	4.6	30.3
GW055146	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0	0.3
GW055147	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0	0.3
GW055149	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0	0.3
GW055154	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.1	0.1	0.1
GW055918	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW056095	Water Supply	Yes	Shoalhaven	0	0	0	0	4.1	1.3	6.9
GW056632	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.1	0.5
GW056750	Stock and Domestic	Yes	HBSS (WMFM)	0	0	0	0	0.1	0.1	0.1
GW057274	Stock and Domestic	Yes	HBSS	0	0	0	0	2.1	0.4	3.7
GW057797	Irrigation	Yes	HBSS	0	0	0	0	1.6	0.7	2.5
GW057829	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.3
GW057969	Irrigation	Yes	HBSS	0	0	0	0.1	6.4	2.7	10
GW058634	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.5	26.6	12.6	40.5
GW058644	Water Supply	Yes	HBSS	0	0	0	0	0.5	0.2	0.7
GW058832	Stock and Domestic	Yes	HBSS	0	0	0	0	4.5	3	5.9
GW059106	Irrigation	Yes	HBSS	0	0	0	0	2.3	1	3.6
GW059311	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.1	0.4
GW059446	Commercial and Ind	Yes	HBSS (WMFM)	0	0	0	0	0.7	0	1.3
GW059618	Water Supply	Yes	HBSS	0	0	0	0.1	6.7	2.3	11.1
GW060205	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.9	0.4	1.3
GW060238	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	3.5	2.8	4.2
GW060886	Dewatering	No	SBSS	0	0	0	0	0	0	0
GW060887	Dewatering	No	SPCS	0	0	0	0	0	0	0
GW060888	Dewatering	No	SPCS	0	0	0	0	0	0	0
GW060889	Dewatering	No	SBSS	0	0	0	0	0	0	0
GW062068	Water Supply	Yes	HBSS	0.1	0	0	1.7	58.4	31.8	85
GW062169	Exploration	No	HBSS	0	0	0	0	0	0	0
GW062251	Irrigation	Yes	Shoalhaven	0	0	0	0	0.6	0.2	0.9
GW062644	Unknown	Yes	Shoalhaven	0	0	0	0	6.9	3.9	9.9
GW062644	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW062645	Unknown	Yes	Shoalhaven	0	0	0	0	6	3.7	8.3
GW062645	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW062646	Unknown	Yes	Shoalhaven	0	0	0	0	7.3	3.9	10.6
GW062646	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW062647	Unknown	Yes	Shoalhaven	0	0	0	0	9	4.1	13.8
GW062647	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW062648	Unknown	Yes	Shoalhaven	0	0	0	0	6.7	3.9	9.5
GW062648	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW062649	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW062661	Water Supply	Yes	HBSS	0	0	0	0	2.2	0.9	3.5
GW063525	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	1.4	0.8	1.9
GW063641	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063641	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063642	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063642	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063643	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW063643	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW063644	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063644	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063645	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063645	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063646	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063646	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063647	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063647	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063648	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063648	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063649	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW063649	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW063650	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063650	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063651	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063651	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063652	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

				Modelled Maximum Drawdown (at any time); [m]						
				based on the simulation of the following mine development scenarios						
						Range: Dend. Total			Range: cumul. mining	
GW_Work	Purpose	'Water supply' work?	Aquifer unit	Project (Area 5)	Dendrobium Mine - base case	Dendrobium - uncert. MIN	Dendrobium - uncert. MAX	Cumulative (all mines)	Cumul mining - uncert. MIN	Cumul mining - uncert. MAX
GW063652	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW063653	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063653	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW063732	Water Supply	Yes	HBSS	0	0	0	0.2	4.6	2.9	6.2
GW064080	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.6	0.4	0.7
GW064081	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.1	0.5
GW064083	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.2	0.3
GW064084	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.2	0.3
GW064358	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW064359	Exploration	No	Shoalhaven	0	0	0	0	0	0	0
GW064469	Water Supply	Yes	HBSS	0.1	0	0	0.2	16.2	4.9	27.4
GW064932	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.1	0.5
GW067309	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW067310	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW067570	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	10	5.5	14.5
GW067606	Irrigation	Yes	HBSS	0	0	0	0	2.5	0.9	4.1
GW068118	Water Supply	Yes	Shoalhaven	0	0	0	0	0.5	0	0.9
GW068119	Irrigation	Yes	Shoalhaven	0	0.1	0.1	0.1	10.3	4.1	16.5
GW070245	Water Supply	Yes	HBSS	0.1	0	0	0.2	14.7	5.1	24.2
GW070979	Unknown	Yes	HBSS (WMFM)	0	0	0	0	2.1	1.4	2.8
GW072168	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.1	0.1	0.1
GW072226	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.7	0	1.3
GW072249	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0	0.3
GW072298	Water Supply	Yes	Shoalhaven	0	0.1	0.1	0.2	3.7	1	6.4
GW072391	Water Supply	Yes	BGSS	0	0	0	0.1	2	1.4	2.5
GW072410	Water Supply	Yes	Shoalhaven	0	0	0	0	4.8	2.4	7.1
GW072432	Water Supply	Yes	HBSS	0	0	0	0.1	6.2	1.9	10.4
GW072482	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW072623	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW072887	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.3
GW073018	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	5.4	2.7	8.1
GW073406	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	7.1	2.3	11.9
GW075139	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW075408	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW075409	Unknown	Yes	Shallow (rego., alluv)	0	0	0	0	0.2	0.1	0.2
GW075409	Unknown	Yes	Shallow (rego., alluv)	0	0	0	0	0.2	0.1	0.2
GW075409	Unknown	Yes	Shallow (rego., alluv)	0	0	0	0	0.2	0.1	0.2
GW075409	Unknown	Yes	Shallow (rego., alluv)	0	0	0	0	0.2	0.1	0.2
GW075409	Unknown	Yes	Shallow (rego., alluv)	0	0	0	0	0.2	0.1	0.2
GW075409	Unknown	Yes	Shallow (rego., alluv)	0	0	0	0	0.2	0.1	0.2
GW075409	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW075410	Unknown	Yes	HBSS	0	0	0	0	5.2	1.5	8.8
GW075410	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW075410	Unknown	Yes	HBSS	0	0	0	0	5.2	1.5	8.8
GW075411	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW075411	Unknown	Yes	HBSS (WMFM)	0	0	0	0	2.8	2.6	3
GW075411	Unknown	Yes	HBSS (WMFM)	0	0	0	0	2.8	2.6	3
GW099002	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW099003	Monitoring	No	SBSS	0	0	0	0	0	0	0
GW099004	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW099005	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW099006	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW099007	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW099008	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW100018	Other	Yes	Shoalhaven	0	0	0	0	0.8	0.3	1.3
GW100089	Irrigation	Yes	BGSS	0.2	0.3	0	0.3	2.3	2	2.6
GW100198	Water Supply	Yes	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW100433	Water Supply	Yes	HBSS	0.2	0.2	0.1	0.2	82.9	57.2	108.6
GW100455	Stock and Domestic	Yes	HBSS	0	0	0	0.1	3.9	1.8	5.9
GW100480	Water Supply	Yes	HBSS	0	0	0	0	6	4	8
GW100519	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW100524	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW100525	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW100526	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW100562	Irrigation	Yes	HBSS	0.1	0.1	0.1	0.2	14.8	3.6	25.9
GW100678	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW100688	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW100689	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW100690	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW100691	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW100692	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW100693	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW100694	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW100721	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW100802	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW101026	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0	0	0
GW101133	Water Supply	Yes	HBSS	0	0	0	0	8.2	4.9	11.5
GW101174	Unknown	Yes	HBSS	0	0	0	0	0	0	0
GW101247	Water Supply	Yes	HBSS	0	0	0	0.1	3.5	1.2	5.8
GW101363	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101364	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101365	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101366	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

				Modelled Maximum Drawdown (at any time); [m]						
				based on the simulation of the following mine development scenarios						
GW_Work	Purpose	'Water supply' work?	Aquifer unit	Project (Area 5)	Dendrobium Mine - base case	Range: Dend. Total		Cumulative (all mines)	Range: cumul. mining	
						Dendrobium - uncert. MIN	Dendrobium - uncert. MAX		Cumul mining - uncert. MIN	Cumul mining - uncert. MAX
GW101367	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101368	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101369	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101370	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101371	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101372	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101373	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101374	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101375	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101376	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101377	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101378	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101379	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101380	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101381	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101382	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101383	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101384	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101385	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101386	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101387	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101388	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101389	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101390	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101391	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101392	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101394	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101395	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101396	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101397	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101398	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101399	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101400	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101401	Unknown	Yes	Shoalhaven	0	0.1	0.1	0.1	10.3	4.1	16.5
GW101402	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101403	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101404	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101405	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW101406	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101407	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101408	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW101520	Water Supply	Yes	HBSS	0	0	0	0	0.1	0.1	0.1
GW101551	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW101554	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW101936	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.8	21.5	14.4	28.5
GW101942	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW102043	Water Supply	Yes	HBSS	0	0	0	0	54.2	43.4	65
GW102045	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.6	13	8.3	17.7
GW102084	Water Supply	Yes	HBSS	0.1	0.1	0	0.1	0.5	0.4	0.6
GW102179	Irrigation	Yes	HBSS	0.1	0.1	0.1	0.7	16.7	10.8	22.5
GW102223	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW102289	Commercial and Ind	Yes	Shoalhaven	0	0	0	0	0.7	0.1	1.3
GW102344	Irrigation	Yes	HBSS	0	0	0	0.2	10.2	6.6	13.7
GW102355	Unknown	Yes	HBSS	0	0	0	0	0.1	0.1	0.1
GW102390	Water Supply	Yes	HBSS	0	0	0	0.1	8.2	2.6	13.7
GW102418	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.2	14	4.2	23.7
GW102439	Water Supply	Yes	HBSS	0	0	0	0.1	24.3	15.8	32.8
GW102452	Stock and Domestic	Yes	HBSS	0	0	0	0.1	7	1.9	12.1
GW102468	Commercial and Ind	Yes	HBSS	0	0	0	0	1	0.5	1.5
GW102478	Water Supply	Yes	HBSS	0	0	0	0	3.2	1.1	5.2
GW102481	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW102482	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW102483	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW102523	Water Supply	Yes	Shoalhaven	0	0	0	0	7.3	3.8	10.7
GW102528	Water Supply	Yes	HBSS	0	0.1	0.1	0.1	2	1.5	2.5
GW102630	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.4	0.2	0.6
GW102704	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.1	0.4
GW102706	Commercial and Ind	Yes	BGSS	0	0	0	0.2	6.3	5.6	7
GW102794	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW102796	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW102798	Irrigation	Yes	HBSS	0	0	0	0	4.6	2.2	6.9
GW103023	Stock and Domestic	Yes	HBSS	0.1	0.1	0.1	0.3	10.2	5.9	14.5
GW103036	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.3	10.2	5.9	14.5
GW103235	Water Supply	Yes	HBSS	0	0	0	0.4	5.9	3	8.8
GW103320	Water Supply	Yes	HBSS	0	0	0	0.2	7.8	5.5	10
GW103457	Water Supply	Yes	HBSS	0	0	0	0	3.4	1.1	5.7
GW103535	Water Supply	Yes	HBSS	0	0	0	0.1	2.3	1.3	3.2
GW103559	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.4	0.2	0.5
GW103615	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.5	21.4	5.8	37
GW103624	Water Supply	Yes	Shoalhaven	0	0	0	0	4.7	3.4	5.9
GW103627	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103628	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103629	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

GW_Work	Purpose	'Water supply' work?	Aquifer unit	Modelled Maximum Drawdown (at any time); [m] based on the simulation of the following mine development scenarios: Project (Area 5)	Dendrobium Mine - base case	Range: Dend. Total: Dendrobium - uncert. MIN	Range: Dend. Total: Dendrobium - uncert. MAX	Cumulative (all mines)	Range: cumul. mining: Cumul mining - uncert. MIN	Range: cumul. mining: Cumul mining - uncert. MAX
GW103630	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103631	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103632	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103633	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103634	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103635	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103636	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103637	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW103638	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103639	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103640	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW103641	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103642	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103643	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103648	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103649	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103650	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103651	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103652	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103653	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103654	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103655	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW103656	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW104008	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.9	16.9	11.4	22.3
GW104024	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0	0	0
GW104068	Water Supply	Yes	HBSS	0	0	0	0	16.3	14.3	18.3
GW104077	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	1.7	0.9	2.5
GW104183	Commercial and Ind	Yes	HBSS	0	0.1	0	0.1	1.9	1.1	2.6
GW104323	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.5	28.5	14.3	42.6
GW104326	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.3
GW104454	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.2	0.2
GW104499	Water Supply	Yes	HBSS	0	0	0	0	2.9	0.9	4.8
GW104531	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW104546	Water Supply	Yes	HBSS	0	0	0	0.1	2.5	1.4	3.5
GW104558	Water Supply	Yes	HBSS	0	0	0	0.3	4.5	2	7
GW104565	Water Supply	Yes	HBSS	0	0	0	0.1	2.8	1.5	4
GW104577	Water Supply	Yes	HBSS	0	0	0	0.1	8.9	2.4	15.4
GW104590	Irrigation	Yes	HBSS (WMFM)	0	0	0	0	0.1	0	0.1
GW104633	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	10.5	8.9	12.1
GW104659	Irrigation	Yes	HBSS	0.1	0.1	0.1	1.8	57.7	28.4	86.9
GW104689	Water Supply	Yes	HBSS	0	0	0	0.1	7.5	2.2	12.8
GW104690	Irrigation	Yes	HBSS	0	0	0	0.1	12.7	3.3	22.1
GW104720	Water Supply	Yes	HBSS	0	0	0	0.1	11.7	3.8	19.5
GW104776	Water Supply	Yes	Shoalhaven	0	0.6	0.1	0.6	16.6	4.5	28.7
GW104860	Commercial and Ind	Yes	HBSS	0	0	0	0.2	4.3	3.1	5.5
GW105145	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	3.2	0	6.3
GW105148	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.3	28.2	8.7	47.7
GW105236	Water Supply	Yes	HBSS	0	0	0	0.2	22.6	14.3	30.8
GW105246	Water Supply	Yes	HBSS	0	0	0	1.2	33.2	21.3	45.1
GW105254	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.3	25.1	5.1	45
GW105262	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.2	9.4	2.4	16.4
GW105351	Water Supply	Yes	Shoalhaven	0	0	0	0	6	3.7	8.3
GW105356	Water Supply	Yes	HBSS	0	0	0	0.1	7	1.9	12.1
GW105395	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.5	32.4	16.1	48.7
GW105467	Water Supply	Yes	HBSS	0.1	0	0	0.2	16.5	4.5	28.4
GW105494	Water Supply	Yes	Shoalhaven	0	0	0	0.2	3.1	0.8	5.4
GW105546	Irrigation	Yes	HBSS	0.1	0	0	1.1	20.7	10.4	31
GW105563	Water Supply	Yes	HBSS	0	0	0	0	0	0	0
GW105577	Irrigation	Yes	HBSS	0.1	0	0	1	16.1	11.6	20.5
GW105679	Water Supply	Yes	HBSS	0	0	0	0	0	0	0
GW105699	Water Supply	Yes	Shoalhaven	0	0	0	0	8	3.8	12.2
GW105735	Water Supply	Yes	HBSS	0	0	0	0	2.6	0.9	4.2
GW105787	Water Supply	Yes	HBSS	0	0	0	0	1.1	0.5	1.6
GW105802	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0	0.6
GW105803	Water Supply	Yes	HBSS	0.1	0	0	0.4	6.7	3.9	9.5
GW105813	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.3	11.2	0	22.3
GW105821	Water Supply	Yes	HBSS	0	0	0	0.8	18.7	9.8	27.5
GW105827	Irrigation	Yes	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW105847	Unknown	Yes	HBSS (WMFM)	0	0	0	0	10.7	8.3	13
GW105860	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0.1	0	0.1
GW105863	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0.1	0	0.1
GW105876	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0	0	0
GW105883	Unknown	Yes	HBSS (WMFM)	0	0	0	0	8	6.6	9.3
GW105884	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0.1	0	0.1
GW105944	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0	0	0
GW106250	Water Supply	Yes	HBSS	0	0	0	0	4.1	2.8	5.3
GW106281	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW106292	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW106546	Water Supply	Yes	HBSS	0	0	0	0	2.4	1.1	3.7
GW106566	Water Supply	Yes	HBSS	0	0	0	0	4.2	1	7.4
GW106590	Water Supply	Yes	HBSS	0.1	0.1	0.1	1.1	20.8	16.9	24.6
GW106613	Irrigation	Yes	HBSS	0.1	0	0	0.3	7.2	4.1	10.3
GW106628	Water Supply	Yes	CCSS	0	0.5	0.2	0.5	14.2	14	14.3

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

GW_Work	Purpose	'Water supply' work?	Aquifer unit	Modelled Maximum Drawdown (at any time); [m] based on the simulation of the following mine development scenarios: Project (Area 5)	Dendrobium Mine - base case	Range: Dend. Total: Dendrobium - uncert. MIN	Dendrobium - uncert. MAX	Cumulative (all mines)	Range: cumul. mining: Cumul mining - uncert. MIN	Cumul mining - uncert. MAX
GW107011	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.1	0.4
GW107116	Unknown	Yes	HBSS (WMFM)	0	0	0	0	1.6	0	3.1
GW107117	Unknown	Yes	HBSS (WMFM)	0	0	0	0	2.2	0	4.3
GW107191	Water Supply	Yes	Shoalhaven	0	0	0	0	0.8	0.1	1.4
GW107470	Water Supply	Yes	HBSS	0	0	0	0.3	5.6	3.4	7.7
GW107525	Water Supply	Yes	HBSS	0.1	0	0	1.7	46.2	34	58.3
GW107546	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW107547	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW107654	Other	Yes	Shoalhaven	0	0	0	0	2.3	0.7	3.8
GW107675	Water Supply	Yes	Shoalhaven	0	0	0	0	11	4.3	17.7
GW107692	Unknown	Yes	HBSS (WMFM)	0	0	0	0	0.1	0.1	0.1
GW107727	Water Supply	Yes	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW107786	Water Supply	Yes	HBSS	0	0	0	0	0.5	0.2	0.7
GW107886	Water Supply	Yes	HBSS	0	0	0	0.1	4.1	1.5	6.6
GW107918	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0	0	0
GW107925	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW108033	Water Supply	Yes	Shoalhaven	0	0	0	0	0.9	0.2	1.5
GW108065	Water Supply	Yes	WBCS	0	0	0	0	3.5	0.6	6.4
GW108186	Commercial and Ind	Yes	BGSS	0.2	0.2	0.1	0.2	3.8	3.2	4.4
GW108333	Water Supply	Yes	KBSS	0	0.4	0.1	0.4	7.9	1.3	14.4
GW108391	Unknown	Yes	Shoalhaven	0	0	0	0	0.9	0.2	1.5
GW108392	Unknown	Yes	Shoalhaven	0	0	0	0	0.9	0.2	1.5
GW108415	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW108524	Water Supply	Yes	BGSS	0.2	0.2	0	0.2	0.7	0.2	1.2
GW108538	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.3	0.2	0.4
GW108629	Water Supply	Yes	HBSS	0	0	0	0.1	5.7	1.9	9.4
GW108842	Irrigation	Yes	HBSS	0	0	0	0.3	6.3	3.5	9
GW108854	Other	Yes	Shoalhaven	0	0	0	0	1	0.3	1.7
GW108922	Commercial and Ind	Yes	Shoalhaven	0	0	0	0	0.5	0	0.9
GW108981	Other	Yes	HBSS	0.1	0.1	0.1	0.2	59.4	40.2	78.6
GW109010	Water Supply	Yes	HBSS	0.2	0.2	0.2	0.2	90.2	48.6	131.7
GW109032	Water Supply	Yes	HBSS	0	0	0	0.2	6	4.6	7.4
GW109038	Water Supply	Yes	Shoalhaven	0	0.1	0.1	0.3	8.8	2.4	15.2
GW109153	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.5	0.3	0.6
GW109159	Water Supply	Yes	HBSS	0	0	0	0.1	3.9	0	7.8
GW109203	Water Supply	Yes	HBSS	0	0	0	0.1	14	3.9	24.1
GW109224	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.3	11.5	0	23
GW109257	Water Supply	Yes	HBSS	0.2	0.2	0.2	0.2	95.8	50.2	141.4
GW109278	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW109279	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW109630	Irrigation	Yes	HBSS	0	0	0	0.2	17.6	6.6	28.6
GW109772	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW109778	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW109779	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW109780	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW109781	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW109782	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW109950	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.2
GW110073	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW110074	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW110075	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW110076	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW110077	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW110215	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0	0.3
GW110435	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW110436	Monitoring	No	HBSS	0	0	0	0	0	0	0
GW110516	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW110517	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW110518	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW110523	Water Supply	Yes	HBSS	0	0	0	0.1	17.2	5.9	28.5
GW110613	Water Supply	Yes	HBSS	0	0	0	0	0	0	0
GW110626	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW110627	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW110628	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW110669	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.2	74.5	48.2	100.8
GW110697	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW110698	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW110699	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW111039	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW111044	Dewatering	No	WWCO	0	0	0	0	0	0	0
GW111045	Dewatering	No	LRSS	0	0	0	0	0	0	0
GW111046	Dewatering	No	LRSS	0	0	0	0	0	0	0
GW111047	Water Supply	Yes	HBSS	0.1	0	0	0.2	13.3	5.2	21.3
GW111109	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW111110	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW111306	Water Supply	Yes	HBSS	0	0	0	0	2	0.8	3.1
GW111357	Other	Yes	HBSS	0.1	0.1	0.1	0.3	10.2	5.9	14.5
GW111415	Irrigation	Yes	HBSS	0	0	0	0	0.4	0.3	0.5
GW111416	Irrigation	Yes	HBSS	0.1	0.1	0	0.1	1.2	0.7	1.6
GW111417	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW111494	Water Supply	Yes	HBSS	0	0	0	0	0.5	0.2	0.7
GW111518	Water Supply	Yes	HBSS	0.1	0.1	0.1	0.3	10.2	5.9	14.5
GW111519	Water Supply	Yes	HBSS (WMFM)	0	0	0	0	0.2	0.1	0.3

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

GW_Work	Purpose	'Water supply' work?	Aquifer unit	Modelled Maximum Drawdown (at any time); [m] based on the simulation of the following mine development scenarios						
				Project (Area 5)	Dendrobium Mine - base case	Range: Dend. Total		Cumulative (all mines)	Range: cumul. mining	
						Dendrobium - uncert. MIN	Dendrobium - uncert. MAX		Cumul mining - uncert. MIN	Cumul mining - uncert. MAX
GW111520	Water Supply	Yes	HBSS (WMFM)	**0**	**0**	0	0	**0.2**	0.1	0.2
GW111521	Water Supply	Yes	HBSS (WMFM)	**0**	**0**	0	0	**0.2**	0.1	0.3
GW111637	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW111669	Water Supply	Yes	HBSS	**0.2**	**0.2**	0.2	0.2	**118.5**	47.9	189.1
GW111810	Water Supply	Yes	HBSS	**0.2**	**0.2**	0.2	0.2	**91.8**	49.2	134.3
GW111828	Irrigation	Yes	HBSS	**0.1**	**0.1**	0.1	0.1	**17.2**	9.5	24.9
GW111841	Irrigation	Yes	HBSS	**0**	**0**	0	0.2	**16**	6.2	25.8
GW111842	Irrigation	Yes	BGSS	**0.3**	**0.2**	0.2	0.3	**29.8**	27.5	32
GW111913	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW111914	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW111915	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW111916	Monitoring	No	BGSS	0	0	0	0	0	0	0
GW111917	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW111955	Water Supply	Yes	Shallow (rego., alluv)	**0**	**0**	0	0	**0**	0	0
GW112057	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112058	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112059	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112060	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112061	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112062	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112063	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112064	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112065	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112066	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112386	Monitoring	No	SBSS	0	0	0	0	0	0	0
GW112415	Water Supply	Yes	HBSS	**0.1**	**0.1**	0.1	0.5	**11.1**	7	15.2
GW112437	Water Supply	Yes	HBSS	**0**	**0**	0	0	**0**	0	0
GW112473	Irrigation	Yes	HBSS	**0.1**	**0**	0	0.6	**15.6**	9.2	21.9
GW112556	Dewatering	No	Shoalhaven	0	0	0	0	0	0	0
GW112557	Dewatering	No	Shoalhaven	0	0	0	0	0	0	0
GW112558	Dewatering	No	Shoalhaven	0	0	0	0	0	0	0
GW112559	Dewatering	No	Shoalhaven	0	0	0	0	0	0	0
GW112561	Dewatering	No	Shoalhaven	0	0	0	0	0	0	0
GW112723	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112724	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112725	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112726	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112727	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112825	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112826	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112827	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112828	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW112991	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112992	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112993	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112994	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112995	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW112996	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW112997	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW112998	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW112999	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW113000	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW113138	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113139	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113140	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113141	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113142	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113143	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113150	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW113151	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW113152	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW113681	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113682	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113683	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113684	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113685	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113686	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113687	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113688	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113689	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113690	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113691	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113692	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW113693	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113694	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113695	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113696	Monitoring	No	HBSS (WMFM)	0	0	0	0	0	0	0
GW113697	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113698	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113717	Monitoring	No	Shallow (rego., alluv)	0	0	0	0	0	0	0
GW113718	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113719	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113720	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0

Registered bores (including "Water supply works") predicted to be affected >2 m drawdown

				Modelled Maximum Drawdown (at any time); [m]						
				based on the simulation of the following mine development scenarios						
GW_Work	Purpose	'Water supply' work?	Aquifer unit	Project (Area 5)	Dendrobium Mine - base case	Range: Dend. Total		Cumulative (all mines)	Range: cumul. mining	
						Dendrobium - uncert. MIN	Dendrobium - uncert. MAX		Cumul mining - uncert. MIN	Cumul mining - uncert. MAX
GW113721	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113722	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113723	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113724	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113725	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113726	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113727	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113728	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113729	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113730	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113731	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113732	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113733	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113734	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0
GW113735	Monitoring	No	Shoalhaven	0	0	0	0	0	0	0